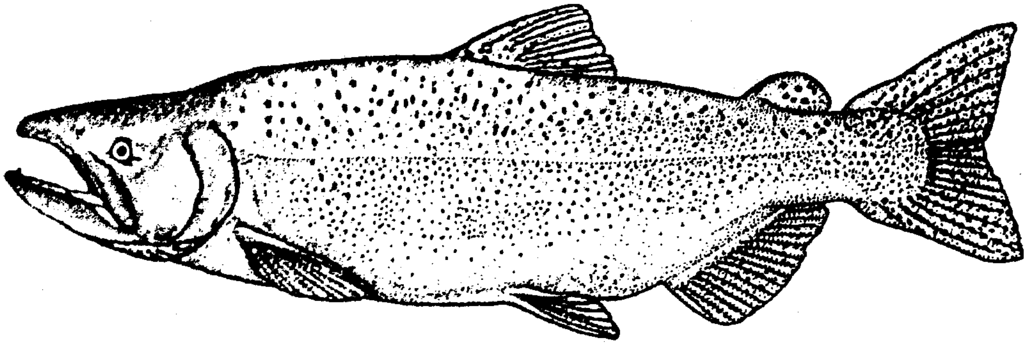
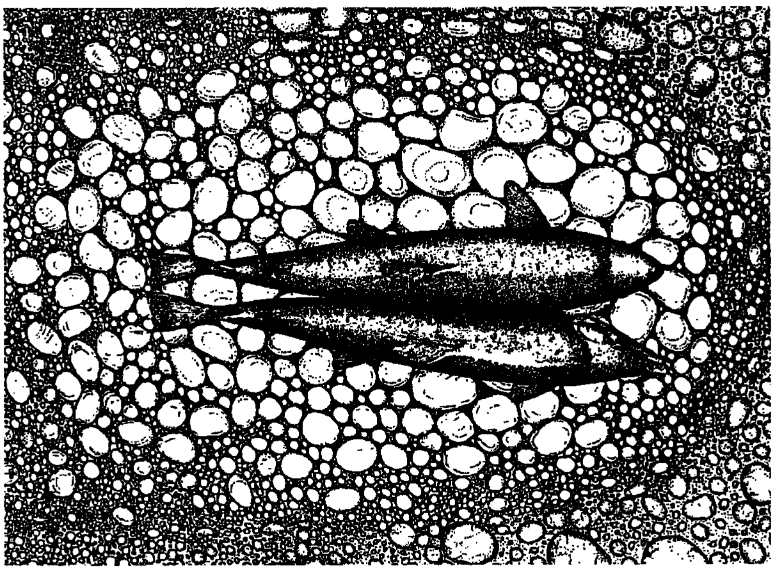
FLOW-HABITAT RELATIONSHIPS FOR SPRING-RUN CHINOOK SALMON SPAWNING IN BUTTE CREEK





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CVPIA INSTREAM FLOW INVESTIGATIONS
BUTTE CREEK SPRING-RUN CHINOOK SPAWNING

PREFACE

The following is the final report for the U.S. Fish and Wildlife Service's investigations on Butte Creek, part of the Central Valley Project Improvement Act (CVPIA) Instream Flow Investigations, a 7-year effort which began in February, 1995. 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 are to provide scientific information to the U.S. Fish and Wildlife Service's Central Valley Project Improvement Act implementation program to be used to develop such recommendations for Central Valley rivers.

To those who are interested, comments and information regarding this report are welcomed. Written comments or information can be submitted to:

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INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act requires the doubling of the natural production of anadromous fish stocks, including the four races of chinook salmon (fall, late-fall, winter, and spring runs), steelhead, and white and green sturgeon. The focus of the Butte Creek study were the reaches between Centerville Head Dam and Parrot-Phelan Diversion Dam where spring-run chinook salmon spawning occurs. For Butte Creek downstream of Centerville Head Dam, the Central Valley Project Improvement Act Anadromous Doubling Plan calls for minimum flows of 40 cfs (U. S. Fish and Wildlife Service 1995). In December 1994, the U. S. Fish and Wildlife Service prepared a study proposal to identify the instream flow requirements for anadromous fish in certain streams within the Central Valley of California, including Butte Creek. The purpose of this study was to produce models predicting the availability of physical habitat in Butte Creek for spring-run chinook salmon spawning over a range of stream flows.

A 2-dimensional hydraulic and habitat model (RIVER2D, Steffler and Blackburn 2001) was used for this modeling, instead of the Physical Habitat Simulation (PHABSIM[1]) component of the Instream Flow Incremental Methodology (IFIM). Similar to one-dimensional PHABSIM, the 2-D model uses as inputs the bed topography and substrate of a site, and the water surface elevation at the bottom of the site, and HSC, to predict the amount of habitat present in the site. However, the 2-D model avoids problems of transect placement, since the entire site can be modeled. The 2-D model also has the potential to model depths and velocities over a range of flows more accurately than PHABSIM because it takes into account upstream and downstream bed topography and bed roughness, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's n values and an empirical velocity adjustment factor. Other advantages of 2-D modeling are that it can explicitly handle complex habitats, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions. The model scale of resolution can be adjusted to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. The 2-D model does a better job of representing patchy microhabitat features, such as gravel patches. The data can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate. Bed topography and substrate mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the top and bottom of the site and flow and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

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[1] 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.

Data collection began in September 1999. Data collection for this effort was completed by March 2002, with data analysis from that work resulting in this report. The results of this study are intended to support or revise the flow recommendations mentioned above.

METHODS

Study Reach Selection

Study reaches were delineated based on differences in flow. Flow data are available for three USGS gages within the study area: Butte Creek between Little Butte Creek and Parrot-Phelan Diversion Dam (USGS gage # 11390000), Little Butte Creek (USGS gage # 11389950) and Centerville Powerhouse (USGS gage # 11389775). Flow data were available for all three gages for the period October 1, 1979 to September 30, 1985. Flows for Butte Creek upstream of Little Butte Creek were calculated by subtracting Little Butte Creek flows from Butte Creek flows below Little Butte Creek, while Butte Creek flows upstream of the Centerville Powerhouse were calculated by subtracting Centerville Powerhouse flows from Butte Creek flows upstream of Little Butte Creek. Average flows for the period of October 1, 1979 to September 30, 1985 were 345 cfs between Centerville Head Dam and Centerville Powerhouse, 492 cfs between Centerville Powerhouse and Little Butte Creek, and 514 cfs between Little Butte Creek and Parrot-Phelan Diversion Dam. Flows downstream of the Centerville Powerhouse typically are higher than above due to the addition of Feather River water which is diverted from Butte Creek at Centerville Head Dam and returns to Butte Creek via a flume at the Centerville Powerhouse. Bovee (1995) recommends that the cumulative change in flow within a reach be less than 10%. We established one reach between Centerville Head Dam and Centerville Powerhouse, based on the 43% increase in flow at Centerville Powerhouse, but only one additional reach between Centerville Powerhouse and Parrot-Phelan Diversion Dam, based on the 4.5% increase in Butte Creek flows associated with Little Butte Creek. These reaches encompassed the portion of Butte Creek where spring-run chinook salmon are known to spawn.

Field Reconnaissance and Study Site Selection

The two study reaches of Butte Creek were surveyed for spring-run chinook salmon spawning September 27-30, 1999 and October 5-7, 1999. The reconnaissance work consisted of wading Butte Creek and recording with GPS the locations and approximate numbers of redds observed. We counted in excess of 468 spring-run redds between Centerville Head Dam and Centerville Powerhouse and 459 spring-run redds between Centerville Powerhouse and Parrot-Phelan Dam. This data was collected in order to facilitate the selection of study sites based on heaviest spawning use.

Considering time and manpower constraints, seven study sites were selected for modeling spring-run chinook salmon (Figure 1, Table 1). The study sites selected were among those that received heaviest use by spawning spring-run chinook salmon. Four sites were located between

Figure 1
Butte Creek Stream Reaches and Study Site Locations

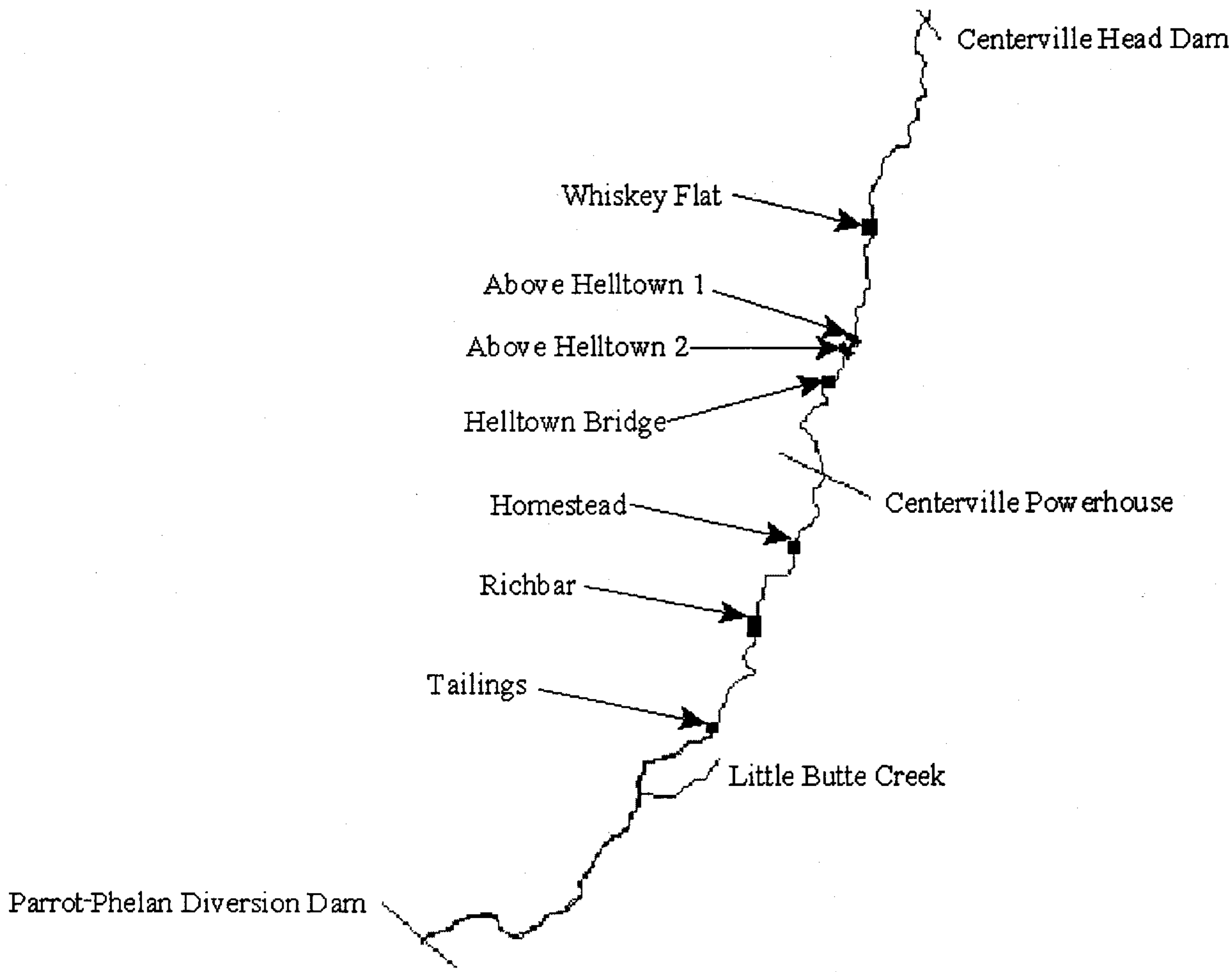

Table 1
Sites Selected for Modeling Spring-run Chinook Salmon Spawning

Site Name	Reach	Number of Redds in 1999
Whiskey Flat	Centerville Head Dam - Centerville Powerhouse	13
Above Helltown 1	Centerville Head Dam - Centerville Powerhouse	30
Above Helltown 2	Centerville Head Dam - Centerville Powerhouse	>80
Helltown Bridge	Centerville Head Dam - Centerville Powerhouse	39
Homestead	Centerville Powerhouse - Parrot-Phelan Dam	18
Richbar	Centerville Powerhouse - Parrot-Phelan Dam	58
Tailings	Centerville Powerhouse - Parrot-Phelan Dam	28

Centerville Head Dam and Centerville Powerhouse and the remaining three sites were located between Centerville Powerhouse and Parrot-Phelan Diversion Dam. For the sites selected for modeling, the landowners along both riverbanks were identified and temporary entry permits were sent, accompanied by a cover letter, to acquire permission for entry onto their property during the course of the study.

Transect Placement (study site set-up)

Study sites were established in May and June 2000. The study site boundaries (top and bottom) were generally selected to coincide with the top and bottom of the boundaries of the heavy spawning use areas[2]. The location of these boundaries was established during site set-up by navigating to the points marked with the GPS unit during our redd counts in September and October 1999.

For each study site, a transect was placed at the top and bottom of the site. The bottom 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 800 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 reference elevations to which all elevations (streambed and water surface) were tied. Vertical benchmarks consisted of lag bolts driven into trees. In addition, horizontal benchmarks (rebar driven into the ground) were established at each site for total station placement to serve as reference locations to which all horizontal locations (northings and eastings) were tied when collecting bed topography data.

Hydraulic and structural data collection began in May 2000 and was completed in March 2002 for the seven sites that were established in 2000. The data collected at the inflow and outflow transects include: 1) WSEL's, measured to the nearest .01 foot at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were

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[2]In some cases, the top of the site was moved upstream or the bottom of the site was moved downstream to a location that was better suited to being a boundary for the 2-D model (a relatively unvarying WSEL and parallel flow across the channel).

taken; and 5) substrate and cover classification at these same locations and also where dry ground elevations were surveyed. Data collected between the transects include: 1) bed elevation; 2) northing and easting (horizontal location); 3) cover[3]; and 4) substrate. These parameters are collected at enough points to characterize the bed topography, substrate and cover of the site. Table 2 gives the substrate codes and size classes used in this study.

Table 2
Substrate Descriptors and Codes

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

Water surface elevations were measured at high (225-283 cfs), medium (107 cfs) and low (47 cfs) flows for the four sites between Centerville Head Dam and Centerville Powerhouse, and at high (325-414 cfs), medium (241-260 cfs), and low (89-153 cfs) flows for the three sites between Centerville Powerhouse and Parrot-Phelan Dam. In all cases, water surface elevations were measured along both banks and in the middle of each transect. The water surface elevations at each transect were then derived by averaging the three values. The stage of zero flow value was measured for all sites by

[3] Cover data was collected to compute bed roughness values and to provide the option to use the spawning sites in the future for modeling juvenile chinook salmon habitat. Cover codes are given in Appendix A.

determining, using differential leveling, the highest bed elevation on the thalweg downstream of the bottom transect of each site. This was done to accurately measure the highest low point that acts as the true stage of zero flow for the bottom transect. The gradual gradient change that existed in the vicinity of the downstream cross section of many of the sites often resulted in a highest low point in the thalweg downstream of the bottom transect that was higher than that measured at the bottom transect. We collected the data between the top and bottom transects by obtaining the bed elevation and horizontal location of individual points with a total station, while the cover and substrate were visually assessed at each point. Substrate and cover along the transects were also determined visually. The number and density of points collected for each site is given in Table 3.

Table 3
Number and Density of Data points Collected for Each Site

Site Name	Number of Points on Transects	Number of Points Between Transects	Density of Points (points/m^2)
Whiskey Flat	46	227	0.35
Above Helltown 1	51	143	0.09
Above Helltown 2	64	232	0.044
Helltown Bridge	58	466	0.11
Homestead	64	91	0.075
Richbar	46	268	0.043
Tailings	64	248	0.13

To validate the velocities predicted by the 2-D model, depth, velocities, substrate and cover measurements were collected by wading with a wading rod equipped with a Marsh-McBirney^R model 2000 or a Price AA velocity meter at the high flow. 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.

Habitat Suitability Criteria (HSC) Data Collection

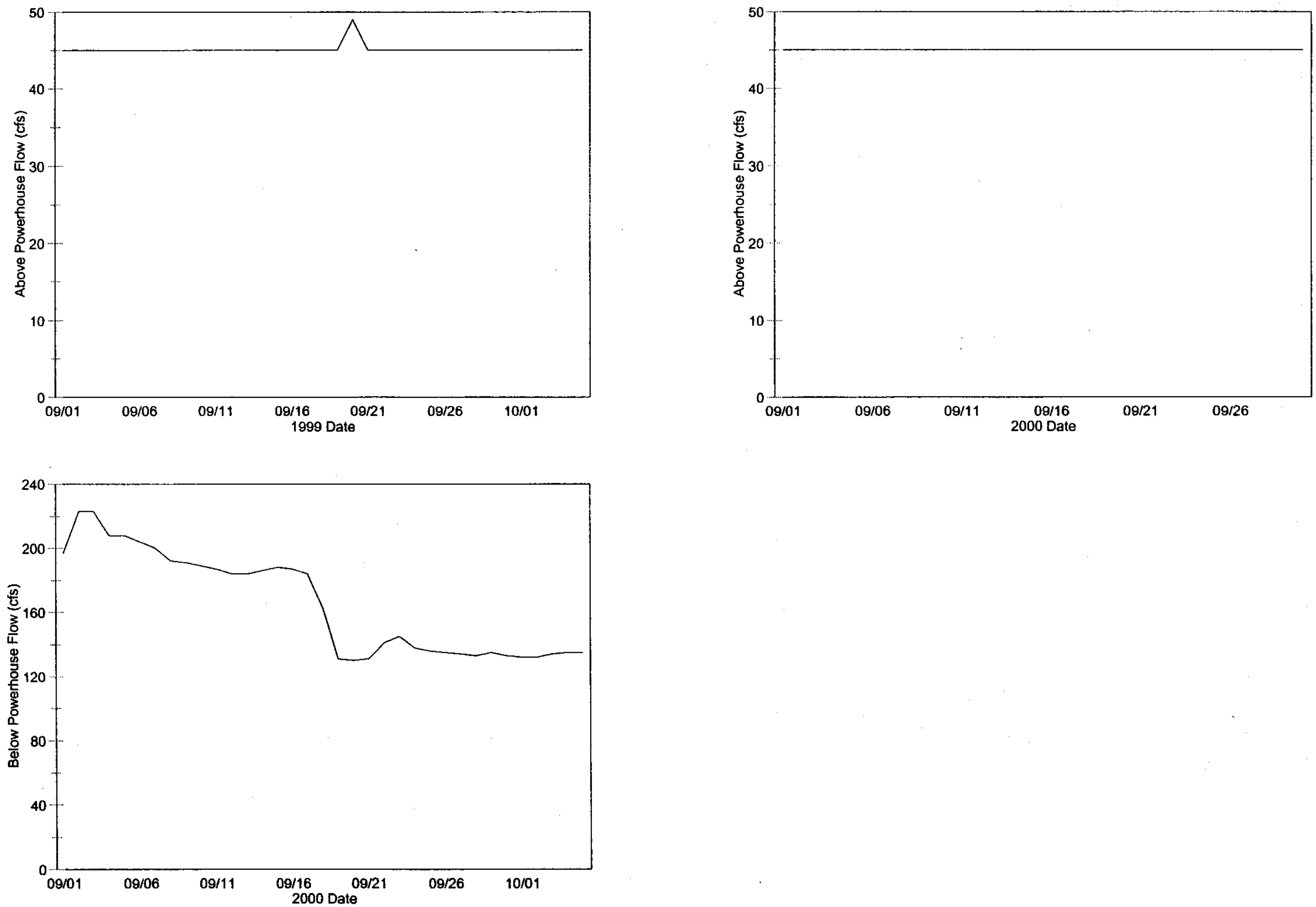
Habitat suitability curves (HSC or HSI Curves) are used within 2-D habitat modeling to translate hydraulic and structural elements of rivers into indices of habitat quality (Bovee 1994). One HSC set for spring-run chinook salmon was used in this study. The spring-run chinook salmon criteria were based on data we collected on spring-run chinook salmon redds in Butte Creek in 1999 and 2000.

The primary habitat variables which are used to assess physical habitat suitability for spawning chinook salmon are water depth, velocity, and substrate composition. Data relative to these variables were collected for a total of 792 spring-run chinook salmon redds in Butte Creek on September 27-30, 1999, October 5, 1999, September 26-27, 2000 and October 2-5, 2000, between Centerville Head Dam and Parrot-Phelan Diversion Dam. During the 1999 data collection, we sampled Butte Creek from Centerville Head Dam to Centerville Powerhouse, collecting habitat suitability data (depth, velocity and substrate) on 392 spring-run redds. Flows in this portion of Butte Creek were stable at 45 cfs from the beginning of spring-run spawning (September 1) through the end of habitat suitability data collection (Figure 2). These steady flow conditions ensured that the measured depths and velocities were likely the same as those present at the time of redd construction. Flows below the Centerville Powerhouse dropped from around 170 cfs to around 120 cfs on September 21, 1999. As a result, we were unable to collect habitat suitability criteria from the Centerville Powerhouse to Parrot-Phelan Diversion Dam in the fall of 1999.

The 2000 data were collected in segments of Butte Creek between Centerville Powerhouse and Parrot-Phelan Diversion Dam where substantial spawning was found in 1999. Habitat suitability criteria data were also collected in the seven study sites established in 2000. We collected habitat suitability criteria for 193 spring-run chinook salmon redds between Centerville Head Dam and Centerville Powerhouse, and 207 spring-run chinook salmon redds between Centerville Powerhouse and Parrot-Phelan Diversion Dam in 2000. Flows in the portion of Butte Creek between Centerville Head Dam and Centerville Powerhouse were stable at 45 cfs from the beginning of spring-run spawning (September 1) until the end of habitat suitability data collection. These steady flow conditions ensured that the measured depths and velocities were likely the same as those present at the time of redd construction. However, flows below Centerville Powerhouse increased from 197 cfs on September 1 to 223 cfs on September 2-3 and thereafter gradually decreased to 184 cfs on September 17. Flows were decreased further to 131 cfs on September 19 and remained at approximately 135 cfs for the remainder of the period during which habitat suitability criteria data were collected (Figure 2). The unstable nature of the flows downstream of Centerville Powerhouse from the beginning of the spring-run spawning resulted in some uncertainty that the measured depths and velocities in the section from Centerville Powerhouse to Parrot-Phelan Dam were the same as those present at the time of redd construction. However, CDFG personnel conducting weekly carcass counts on Butte Creek noted that there was little spawning activity downstream of Centerville Powerhouse prior to September 19. Accordingly, it is likely that most of the redds that we measured below Centerville Powerhouse were constructed at a flow close to that at the time the HSC data were collected, and thus that the measured depths and velocities were likely similar to those present at the time of redd construction.

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. This location was generally about two to four feet

Figure 2
1999 and 2000 Butte Creek Flows Above and Below Centerville Powerhouse During Spring-run Spawning



upstream of the pit of the redd; however it was sometimes necessary to make measurements at a 45 degree angle upstream, to the side, or behind the pit. The data were usually collected within six feet of the pit of the redd. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. Measurements were taken with a wading rod and a Marsh-McBirney[R] model 2000 velocity meter or a Price-AA velocity meter equipped with a current meter digitizer. Substrate was visually assessed for the dominant particle size range (i.e., range of 1-2") at three locations: 1) in front of the pit; 2) on the sides of the pit; and 3) in the tailspill. Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded. The substrate coding system used is shown in Table 2.

All data were entered into spreadsheets for analysis and development of Suitability Indices (HSC). The HSC data had depths ranging from 0.3 to 3.3 feet deep, velocities ranging from 0.06 to 3.80 ft/s, and substrate sizes ranging from 1-2 inches to 4-6 inches.

Biological Validation Data Collection

The horizontal location of the redds found in the seven study sites during the surveys for spring-run chinook salmon redds conducted September 26-27, 2000 and October 2-5, 2000 was recorded by sighting from the total station to a stadia rod and prism. Depth, velocity, and substrate size as described in the previous section on habitat suitability criteria data collection were also measured. We measured 29 redds at Whiskey Flat, 40 redds at Above Helltown 1, 90 redds at Above Helltown 2, 34 redds at Helltown Bridge, 16 redds at Homestead, 72 redds at Richbar, and 22 redds at Tailings, for a total of 303 redds for the seven study sites. All data were entered into spreadsheets. These 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. This hypothesis was statistically tested with a Mann-Whitney U test.

Hydraulic Model Construction and Calibration

All data were compiled and checked before entry into PHABSIM data decks. 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" on a transect from station 50 to 70, all of the verticals with station values between 50 and 70 were given a substrate coding of 2.4). Dry bed elevation data in field notebooks were entered into the spreadsheet to extend the bed profile up the banks above the WSEL of the highest flow to be modeled. An ASCII file produced from the spreadsheet was run through the FLOMANN program (written by Andy Hamilton) to get the PHABSIM input file and then translated into RHABSIM files.

All of the measured WSELs were checked to make sure that water was not flowing uphill. A total of three WSEL sets at low, medium, and high flows were used, except for Homestead, where four sets of WSELs were used (Appendix B).

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 separate deck was constructed for each study site.

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 the upstream transect contains a lower bed elevation than the downstream transect, the SZF for the downstream transect applies to both. The SZF for downstream transects with backwater effects was the SZF measured by differential surveying below the downstream transect. For sites where the hydraulic control for the upstream transect was located within the site, the SZF (the thalweg elevation at the hydraulic control) was determined from the bed topography data collected for the 2-D model.

Calibration flows in the data decks (Appendix B) were the flows calculated from gage readings. For the sites above Centerville Powerhouse, the calibration flow was set equal to the flow for USGS gage # 11389780, located downstream of the Centerville Head Dam. For the sites below Centerville Powerhouse, the calibration flow was computed by subtracting a discharge we measured for Little Butte Creek from the flow for USGS gage # 11390000.

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 difference between measured and simulated WSELs[4]. *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

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

MANSQ is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier and flow; and 3) there is no more than a 0.1 foot difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*.

For a majority of the transects, *IFG4* met the above criteria for *IFG4* (Appendix B). The only exception where IFG4 was used but did not meet the above criteria was Above Helltown 1 XS 2, where the beta value equaled 4.88. We still used *IFG4* for this transect because the slightly high beta value was preferable to using *WSP* because we were unable to calibrate *WSP* starting at Above Helltown 2 XS 2 through Above Helltown 1 XS1 continuing all the way to Above Helltown 1 XS 2, and because *WSP* was the only model that could successfully be used to simulate water surface elevations at Above Helltown 1 XS 1. *IFG4* was also preferable to *MANSQ* for Above Helltown 1 XS 2 because *MANSQ* gave much greater errors. *MANSQ* worked successfully for three other transects, meeting the above criteria for *MANSQ*, with the exception of Tailings XS 1 (Appendix B). For the Tailings XS1 transect, *MANSQ* did not meet the mean error and the calculated-given discharge criteria and did not meet the measured-simulated WSEL criterion for the 153 cfs calibration flow with a simulated WSEL value that differed from the measured by 0.11. We still used *MANSQ* for this transect because *IFG4* gave much greater errors and *WSP* could not be used because it was the downstream-most transect in the site. *WSP* worked successfully for the remaining transect, with the above *WSP* criteria being met.

The final step in simulating WSELs was to check whether water was going uphill at any of the simulated WSELs. This did not occur for any of the study sites.

VAFs were examined for all of the simulated flows (Appendix C). None of the transects deviated significantly from the expected pattern of VAFs. In addition, VAF values (ranging from 0.13 to 2.05) were all within an acceptable range except for the lowest two flows at Helltown site upper transect.[5] The low VAF values for the above site are due to strong backwater effects caused by a bridge downstream in the site, and is acceptable in this case since RHABSIM was only used to simulate the WSEL at the highest calibration flow, to use in calibrating River2D.

The dry/shallow 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. 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. An artificial extension one channel-width-long was added upstream of the top of the site to enable the flow to be distributed by the model when it reached the study area, thus minimizing boundary conditions

[5] VAFs are considered acceptable if they fall within the range of 0.2 to 5.0.

influencing the flow distribution at the upsteam transect and within the study site. 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 computed as the sum of the substrate bed roughness value and the cover bed roughness value. The bed roughness values for substrate in Table 4 were computed as five times the average particle size[6]. 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 2001b), was used to define the study area boundary and to refine the raw topographical data TIN (triangulated irregular network) by defining breaklines[7] following longitudinal features such as thalwegs, tops of bars and bottoms of banks. Breaklines were also added along lines of constant elevation. The bed topography of the sites is shown in Appendix D.

An additional utility program, R2D_MESH (Steffler 2001a), was used to define the inflow and outflow boundaries and create the finite element computational mesh for the River2D model. R2D_MESH uses the final bed files as an input. The first stage in creating the computational mesh was to define mesh breaklines[8] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and additional nodes were added as needed to improve the fit between the mesh and the final bed file and to improve the quality of the mesh, as measured by the Quality Index (QI) value. The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Steffler 2001a). As shown in Appendix E, the meshes for all sites, with the exception of Whiskey Flat, had QI values of at least 0.3. Whiskey Flat had a QI value of 0.25, still considered well within the acceptable range. In addition, the difference in bed elevation between the mesh and final bed file was less than 0.1 feet (0.03 m) for most of the area

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[6] Five times the average particle size is approximately the same as 2 to 3 times the d85 particle size, which was suggested by Peter Steffler (personal communication) for the initial bed roughness values.

[7] 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 2001b).

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

Table 4
Initial Bed Roughness Values[9]

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

of all sites. The percentage of the original bed nodes for which the mesh differed by less than 0.1 feet (0.03 m) from the elevation of the original bed nodes ranged from 80% to 95% (Appendix E). In most cases, the areas of the mesh where there was greater than a 0.1 (0.03 m) feet difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 feet (0.03 m) vertically of the bed file within one foot (0.3 m) horizontally of the bed file location. Given that we had a one-foot (0.3 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file. The final step with the R2D_MESH software was to generate the computational (cdg) files.

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

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 top transect. In this study, where the highest simulated flow was much greater than the highest flow at which WSELs were measured, we calibrated using the WSELs simulated by PHABSIM, since we felt that any inaccuracies in the PHABSIM simulated WSELs were more than countered by the increased accuracy of calibrating the 2-D model at the highest flow to be simulated. The bed roughnesses of the computational mesh elements were then modified by multiplying them by a constant bed roughness multiplier (BR Mult) until the WSELs predicted by RIVER2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the top transect.

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 one percent (Steffler and Blackburn 2001). In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than one[10]. Finally, the WSEL predicted by the 2-D model should be within 0.10 feet (0.031 m) of the WSEL measured at the upstream transect[11]. The calibrated cdg files all had a solution change of less than 0.00001, with the net Q for all sites, with the exception of Above Helltown 1, less than 1% (Appendix E). We considered Above Helltown 1 to have a stable solution since the net Q was not changing and the net Q was still less than 2%. The calibrated cdg file for the Whiskey Flat, Helltown Bridge, Richbar, and Tailings sites had a maximum Froude Number of greater than one (Appendix E). Both the Whiskey Flat and Helltown Bridge sites were higher gradient sites with limited areas of supercritical flow, where a Max Froude value of greater than one would be expected. In addition, we considered the solutions for all four sites to be acceptable since the Froude Number was only greater than 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 water's edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water's edge or in very shallow depths would be expected to have an insignificant effect on the model results.

With the exception of Tailings site, the calibrated cdg files had WSELs that were within 0.1 feet (0.031

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

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

m) of the measured WSELs (Appendix E). Due to problems with the bed profile in the upper portion of Tailings site that can likely be attributed to some aspect of the bed topography that we did not capture in our data collection, we were unable to calibrate the model at the upper cross section within 0.1 feet (0.031 m) of the measured WSELs. However, we were able to calibrate the model to within 0.1 feet (0.031 m) of measured water surface elevations for approximately the lower two-thirds of the site. Consequently, the upper portion of the site that did not calibrate was excluded when calculating the Weighted Useable Area (WUA) values for Tailings site. The upper portion of the site was also excluded for other data analyses (e.g., 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 both the velocities measured on the upper and lower transects, and the 50 velocities per site measured in between the upper and lower transects. See Appendix F for velocity validation statistics. Although there was a strong correlation between predicted and measured velocities, there were significant differences between individual measured and predicted velocities. In general, the simulated and measured velocities profiles at the upper and lower transects (Appendix F[12]) were relatively similar in shape. Differences in magnitude in most cases are likely due to (1) operator error during data collection, i.e., the probe was not facing precisely into the direction of current, (2) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the velocity range averaged in the model simulations, (3) aspects of the bed topography of the site that were not captured in our data collection, (4) the effect of the velocity distribution at the upstream boundary of the site. River2D distributes velocities across the upstream boundary in proportion to depth, so that the fastest velocities are at the thalweg. In contrast, the bed topography of a site may be such that the fastest measured velocities may be located in a different part of the channel. Since we did not measure the bed topography above a site, this may result in River2D improperly distributing the flow across the top of the site. As discussed above, we added artificial upstream extensions to the sites to try to address this issue.

The 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.

Overall, the simulated velocities for the Whiskey Flat site were relatively similar to the measured velocities for both cross sections, with some differences in magnitude that fall within the expected

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

amount of natural variation in velocity. Measured velocities on the right side of cross section two that were lower than the simulated velocities can be attributed to a bed feature that likely existed upstream of the study site that slowed the water velocity. The simulated velocities accordingly reflected the absence of this feature.

In Above Helltown 1, the simulated and measured velocities for the most part matched relatively well for cross section two. The lower simulated velocities on the left side of the channel were likely an artifact of the flow distribution from the upstream extension. The River2D model acts to increase velocities with depth. At the location of the higher simulated velocities on cross section two, the depths were shallow. The use of the upstream extension longitudinally extended the shallow area upstream of cross section two. The increased length of this shallow area above cross section two likely acted to slow the water velocities more than actually occurred at cross section two. In reality, upstream of the site on the left side of the channel there was a deep, long pool which likely resulted in the higher measured velocities on the left side of the channel. Because this feature was outside of the site and thus not included in the model, the velocities on the left side of the site reflected only the shallow depths that were present on the transect.

The Above Helltown 1 simulated velocities on cross section one were quite different from the measured velocities, being higher on the left and right sides of the channel and lower in the middle. Again, features that were present outside of the site likely caused some of the differences in magnitude. A bedrock outcropping downstream of the right side of the cross section one likely slowed the measured velocities. Because this feature was outside of the site and not included in the model, the simulated velocities reflect a lack of any slowing influences in this deepest part of the channel. Similarly, on the left side of the channel a feature in the bed topography either downstream of the site or missed when collecting data in the vicinity of this portion of cross section one likely slowed the measured velocities, but was not reflected in the simulated velocities due to its absence in the model. An analysis of the River2D file showed that there is a boulder feature in the bed topography in the middle of the channel that appears to have slowed the simulated velocities, although in reality the boulder did not appear to have significantly slowed the measured velocities. Furthermore, this area of shallow depths and higher bed elevations may have resulted in velocities being slowed in the model more than actually occurred.

Cross section two of the Above Helltown 2 site, like that of the Above Helltown 1 site, had shallow depths along one side of the transect. The upstream extension resulted in a long shallow bed profile on the right side of the channel that acted through the model to create slower velocities at cross section two on the right side of the channel. Consequently, this resulted in higher velocities on the left side of the channel than existed when the measured velocities were collected. The cross section one simulated and measured velocities were relatively similar, the differences in magnitude considered to be within the expected range of variation.

Both cross sections in the Helltown Bridge site had simulated and measured velocities that were similar, the differences in magnitude being within the range of expected variation.

In the Homestead site, the simulated velocities on cross section two appear to be an artifact of the upstream extension. The thalweg began a rapid transition diagonally across the channel from the right side to the left side starting at cross section two. The upstream extension started this transition above cross section two, causing the flow to shift toward mid-channel by the time it reached cross section two. This resulted in simulated velocities being more evenly distributed at cross section two, with highest velocities at mid-channel. This is a situation where it perhaps would have been better to run the model without an upstream extension. At cross section one, the simulated and measured velocities were similar, the differences in magnitude within the expected range of variation.

The Richbar site was deepest along the left and right banks, particularly at the upstream transect. The River2D model's tendency to make velocities highest in the deepest areas, due to the distribution of flow at the upstream boundary, likely resulted in the higher than measured simulated velocities along the right and left side of the transect. Alternatively, there may have been bed features upstream of cross section two outside the site that reduced the velocities measured at these locations on the transect. However, this is strictly conjecture and the actual cause of the higher simulated velocities on the left and right sides of cross section two is uncertain. The simulated and measured velocities for the rest of cross section two were relatively similar, reflecting the range of expected natural velocity variation. This was also true for all of cross section one.

Cross section one of the Tailings site had simulated and measured velocities that were similar, the differences in magnitude within the range of expected variation. The inability to calibrate the water surface elevations for cross section two prevented a comparison of the simulated and measured velocities for that transect.

The flow and downstream WSEL in the calibrated cdg file were changed to simulate the hydrodynamics of the sites at the simulation flows (20 cfs to 50 cfs by 5 cfs increments, 50 cfs to 110 cfs by 10 cfs increments, and 110 cfs to 450 cfs by 20 cfs increments for the four sites upstream of the Centerville Power House and 60 cfs to 150 cfs by 10 cfs increments, 150 to 310 cfs by 20 cfs increments, and 310 cfs to 790 cfs by 40 cfs increments for the three sites downstream of the Centerville Power House). 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 one percent. In addition, solutions will usually have a Max F of less than one. The production cdg files all had a solution change of less than 0.00001, but the Net Q was greater than 1% for twenty flows for Above Helltown 1, thirteen flows for Above Helltown 2, one flow for Helltown Bridge, one flow for Homestead, sixteen flows for Richbar, and two flows for Tailings (Appendix G). We still considered these sites to have a stable solution since the net Q was not changing and the net Q in all cases was less than 5%, with the exception of one flow for Above Helltown 1 (5.5%). 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. The maximum Froude Number was greater than one for 26 out of 30 simulated flows for Whiskey Flat, 1 out of 30 simulated flows for Above Helltown 1, 0 out of 30 simulated flows for Above Helltown 2, 24 out of 30 simulated flows for Helltown Bridge, 1 out of 30 simulated flows for Homestead, 26 out of 30 simulated flows for Richbar, and 24 out of 30 simulated flows for Tailings (Appendix G); however, we considered these production runs to be acceptable since the Froude Number was only greater than one at a few nodes, with the vast majority of the area within the site having Froude Numbers less than one. Also, as described previously, these nodes were located either at water's edge or where water depth was extremely shallow, typically approaching zero and would be expected to have an insignificant effect on the model results, and the Whiskey Flat and Helltown Bridge sites were higher gradient sites with limited areas of supercritical flow, where a Max Froude value of greater than one would be expected.

Habitat Suitability Criteria (HSC) Development

Using the spring-run chinook salmon spawning HSC data that we collected in 1999 and 2000, we applied a method presented in Rubin et al (1991) to explicitly take into account habitat availability in developing HSC criteria, without using preference ratios (use divided by availability). Traditionally criteria are created from observations of fish use by fitting a nonlinear function to the frequency of habitat use for each variable (depth, velocity, and substrate). One concern with this technique is the effect of availability of habitat on the observed frequency of habitat use. For example, if a substrate size is relatively rare in a stream, fish will be found primarily not using that substrate size simply because of the rarity of that substrate size, rather than because they are selecting areas without that substrate size. Rubin et al (1991) proposed a modification of the above technique where depth, velocity, and substrate data are collected both in locations where redds are present and in locations where redds are absent. Criteria are then developed by using a logistic regression procedure, with presence or absence of redds as the dependent variable and depth, velocity, and substrate as the independent variables, with all of the data (in both occupied and unoccupied locations) used in the regression. Velocity, depth, and substrate 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 flow at which spawning data was collected for the reach in which the site was located. The velocity, depth, and substrate data at each node within the file were then downloaded. Using a random numbers generator, 200 points, with the exception of Whiskey Flat site with 193, were selected that had the following characteristics: 1) were inundated; 2) were more than three feet from a redd recorded during the 2000 survey; 3) were more than three feet from any other point that was selected; and 4) were located in the site, rather than in the upstream extension of the file. We ended up with less than 200 points for Whiskey Flat site because its small size limited the number of available points.

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

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

where Exp is the exponential function; I, J, K, L, and M are coefficients calculated by the logistic regression; and V is velocity or depth. The logistic regressions were conducted in a sequential fashion, where the first regression tried included all of the terms. If any of the coefficients or the constant were not statistically significant at $p = 0.05$, the associated terms were dropped from the regression equation, and the regression was repeated. The coefficients for the final logistic regressions for depth and velocity for each run and for juveniles are shown in Table 5. The p

Table 5
Logistic Regression Coefficients

race	parameter	I	J	K	L	M
spring-run	depth	-6.211825	17.00699	-15.281341	5.351263	-0.663025
spring-run	velocity	-4.109489	5.741906	-2.101293	0.199181	---

values for all of the non-zero coefficients in Table 5 were less than 0.05, as were the p values for the overall regressions. The results of the regression equations were rescaled so that the highest value was 1.0. The resulting HSC were modified by truncating at the slowest/shallowest and deepest/fastest ends, so that the next shallower depth or slower velocity value below the shallowest observed depth or the slowest observed velocity had a SI value of zero, and so that the next larger depth or faster velocity value above the deepest observed depth or the fastest observed velocity had an SI value of zero; and eliminating points not needed to capture the basic shape of the curves.

The initial HSC showed suitability rapidly decreasing for depths greater than 1.0 feet. This effect was likely due to the low availability of deeper water in Butte Creek with suitable velocities and substrates rather than a selection by spring-run salmon of only shallow depths for spawning. 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 spring-run chinook salmon.

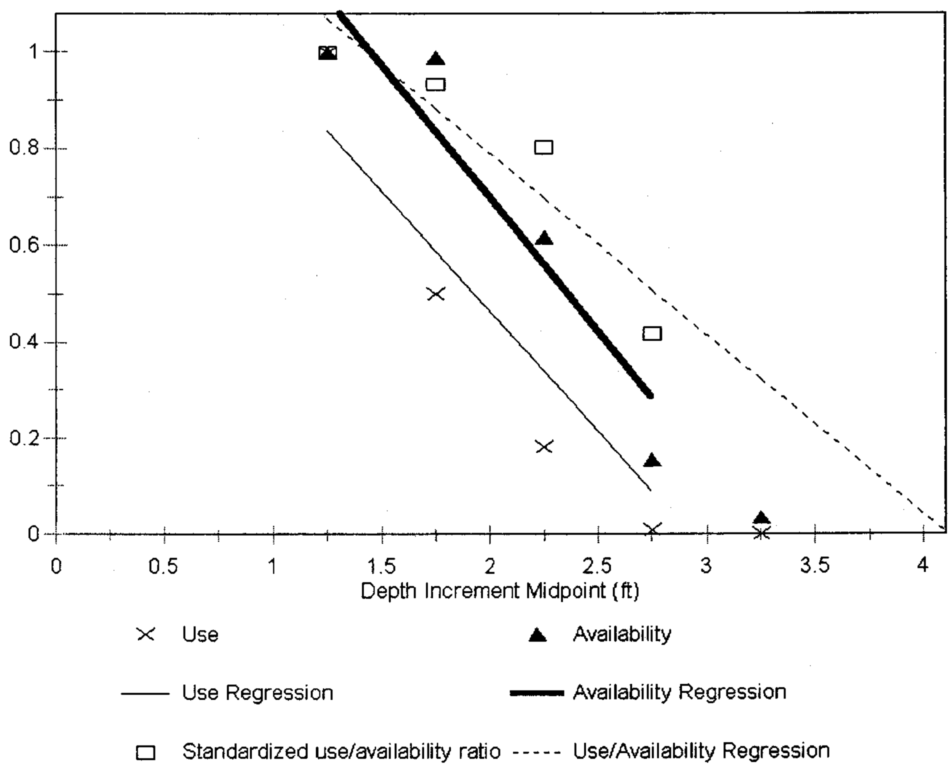
The technique begins with the construction of multiple sets of HSC, differing only in the suitabilities assigned for optimum depth increments, to determine how the available river area with suitable velocities and substrates varies with depth. Ranges of suitable velocities and substrates are determined from the velocity and substrate HSC curves, with suitable velocities and substrates defined as those with HSC values greater than 0.5. For spring-run chinook salmon, suitable velocities were between 0.8 and 3.22 ft/s, while suitable substrates were 1-3 to 3-5 inches in diameter (i.e., substrate codes 1.3, 2.4, and 3.5). A range of depths is selected, starting at the depth at which the initial depth of HSC reached 1.0, through the greatest depth at which there were redds or available habitat. A series of HSC sets are constructed where: (1) all of the sets have the same velocity and substrate HSC curves, with values of 1.0 for the suitable velocity and substrate range with all other velocities and substrates assigned a value of 0.0; and (2) each set has a different depth HSC curve. To develop the depth HSC curves, each HSC set is assigned a different half-foot depth increment within the selected depth range to have an HSC value of 1.0, and the other half-foot depth increments and depths outside of the depth range a value of 0.0 (e.g., 2-2.5' depth HSC value equal 1.0, < 2' and >2.5' depths HSC value equals 0.0 for a depth increment of 2-2.5'). Each HSC set is used in RIVER2D with the calibrated RIVER2D file for each study site at which HSC data were collected for that run. The resulting habitat output is used to determine the available river area with suitable velocities and substrates for all half-foot depth increments.

To modify the HSC depth curves 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 chinook salmon is defined as the number of redds observed in each depth increment for each run. Availability data were determined using the output of the calibrated hydraulic decks for the seven spawning habitat modeling sites at which HSC data were collected, while redd data from these seven sites were used to assess use. Availability and use are normalized by computing relative availability and use, so that both measures would 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., 2.25' for the 2-2.5' depth increment), we used linear regressions of relative availability and use versus the midpoints of the depth increments. The results of the initial regressions showed that availability dropped with increasing depth, but not as quickly as use (Figure 3). 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. The result of the final regression was that the scaled ratio reached zero at 4.1 feet; thus, the spring-run chinook salmon depth criteria were modified to have a linear decrease in suitability from 1.0 for the greatest depth in the original criteria which had a suitability of 1.0, to a suitability of 0.0 at 4.1 feet.

The final depth and velocity criteria, along with the frequency distributions of occupied and unoccupied locations, are shown in Figures 4 and 5 and Appendix H. It should be noted that the regressions were fit to the raw occupied and unoccupied data, rather than to the frequency histograms shown in Figures 4 and 5. In general, the criteria track the occupied data, but drop off slower than the occupied data due to the frequency of the unoccupied data also dropping over the same range of depths and velocities.

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 final substrate criteria are shown in Figure 6 and Appendix H.

Figure 3
Relations Between Relative Availability and Use and Depth for Spring-run[13]



[13] Points are relative use, relative availability, or the standardized ratio of the 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.

Figure 4
Spring-run Chinook Salmon Spawning Depth HSI

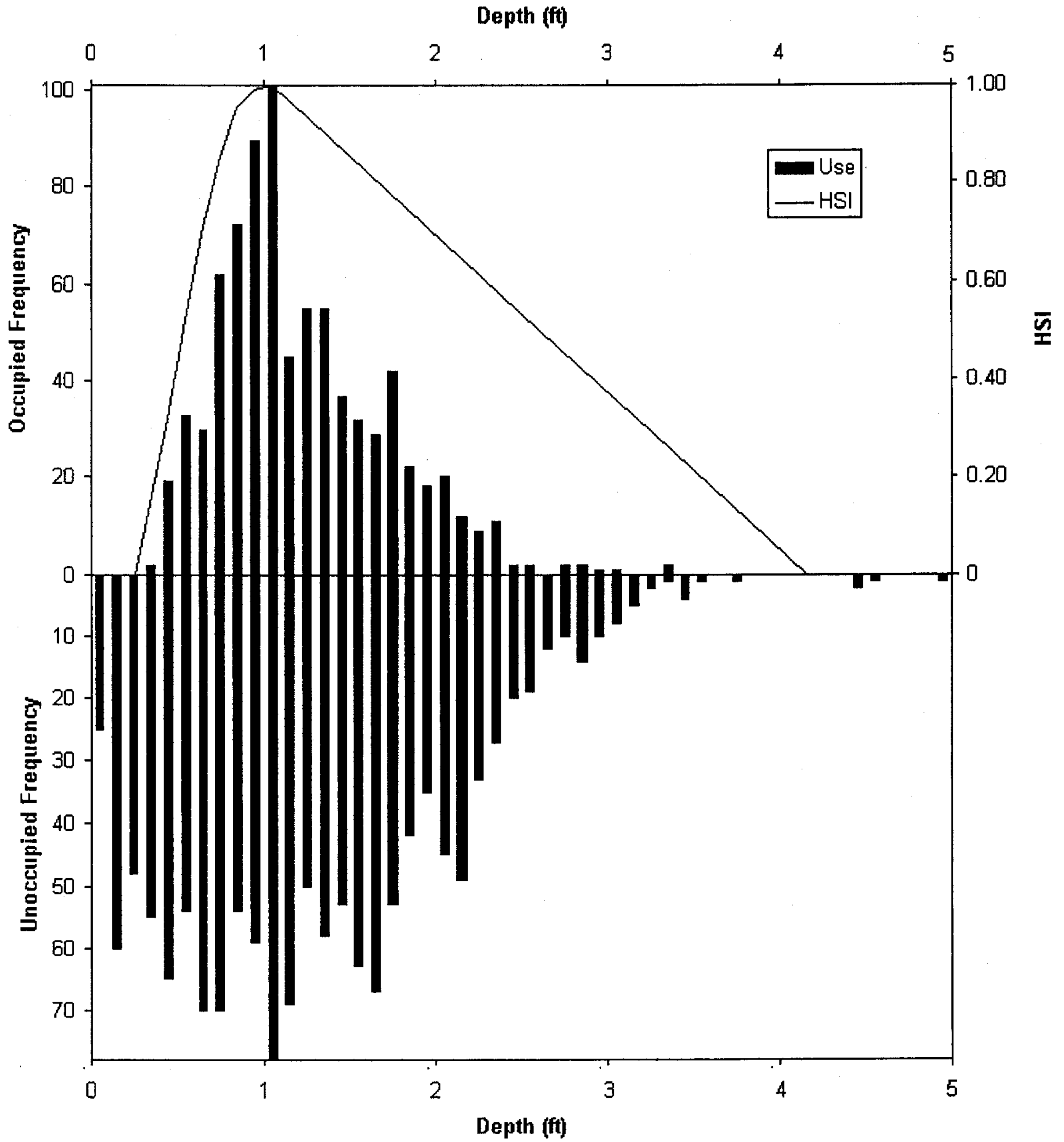


Figure 5
Spring-run Chinook Salmon Spawning Velocity HSI

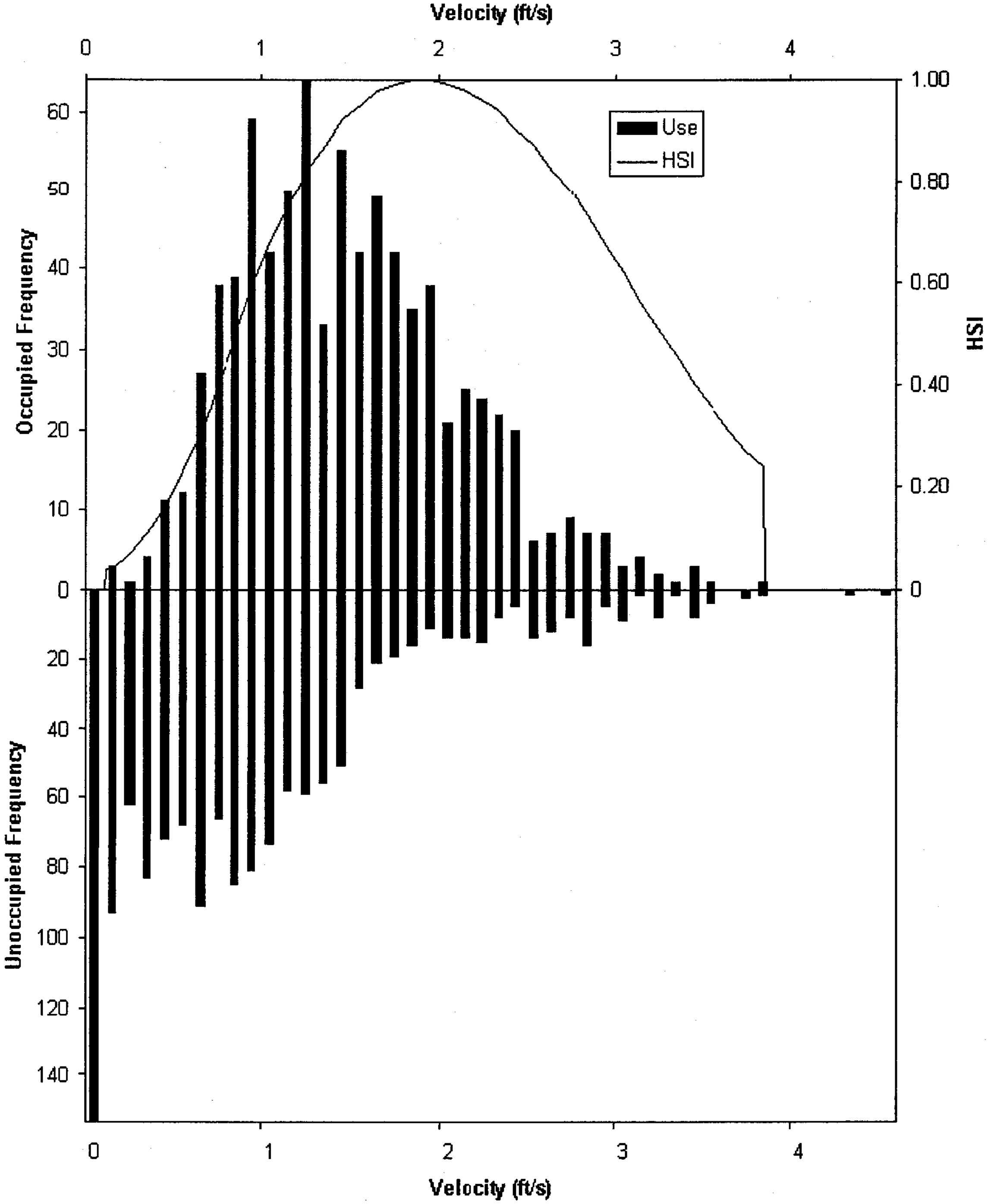
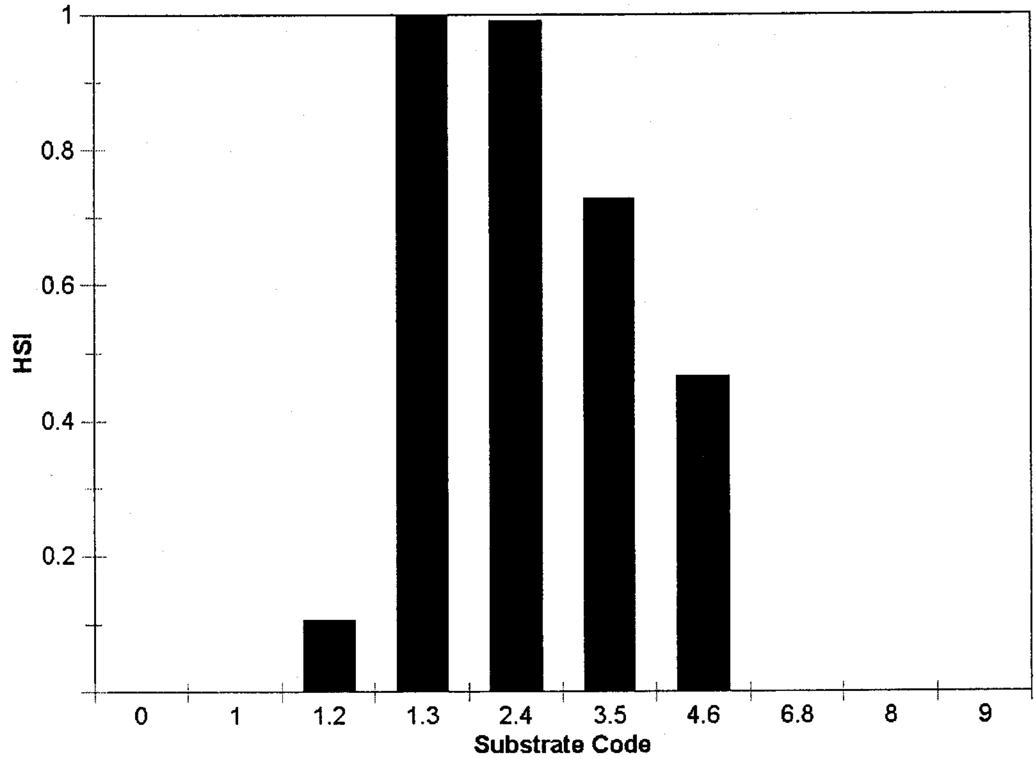


Figure 6
Spring-run Chinook Salmon HSI Curve for Substrate



Biological Validation

We compared the combined habitat suitability predicted by RIVER2D at each redd location in the seven study sites. We ran the RIVER2D cdg files at 45 cfs for the four study sites upstream of Centerville Powerhouse and at 135 cfs for the three study sites downstream (flows at which the biological validation data were collected) to determine the combined habitat suitability at individual points for RIVER2D. We used the horizontal location measured for each redd to determine the location of each redd in the RIVER2D sites. We used a random number generator to select locations without redds in each site. Locations were eliminated that: 1) were less than three feet from a previously-selected location; 2) were less than three feet from a redd location; 3) were not located in the wetted part of the site; and 4) were located in the site, rather than in the upstream extension of the file. We used Mann-Whitney U tests (Zar 1984) to determine whether the compound suitability predicted by RIVER2D was higher at redd locations versus locations where redds were absent.

Habitat Simulation

The final step was to simulate available habitat for each site. A preference curve file was created containing the digitized HSC developed for the Butte Creek spring-run chinook salmon (Appendix H). RIVER2D was used with the final cdg files, the substrate file and the preference curve file to compute WUA for each site over the desired range of flows (20 cfs to 50 cfs by 5 cfs increments, 50 cfs to 110 cfs by 10 cfs increments, and 110 cfs to 450 cfs by 20 cfs increments for the four sites upstream of the Centerville Power House and 60 cfs to 150 cfs by 10 cfs increments, 150 to 310 cfs by 20 cfs increments, and 310 cfs to 790 cfs by 40 cfs increments for the three sites downstream of the Centerville Power House). The WUA values calculated for each site are contained in Appendix I. The WUA values for the sites in each reach were added together and then multiplied by the ratio of total redds in the reach to redds in the modeling sites, from the data we collected in 1999, (Above Centerville Powerhouse Reach = 2.89, Below Centerville Powerhouse Reach = 4.41) to produce the total WUA per reach (Appendix I).

RESULTS

Biological Validation

Of the 303 redds that were measured, eight were located in the upstream portion of the Tailings site that could not be calibrated, and were thus excluded. As a result, we had a total of 295 locations with redds and 1,860 locations without redds for the seven study sites. The combined habitat suitability predicted by the 2-D model was significantly higher for locations with redds (median = 0.18) than for cells without redds (median = 0.0009), based on the Mann-Whitney U test ($p < 0.000001$). The frequency distribution of combined habitat suitability predicted by the 2-D model for locations with redds is shown in Figure 7, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 8. The location of redds relative to the distribution of combined suitability is shown in Appendix J.

Of the 73 redd locations that the 2-D model predicted had a combined suitability of zero (25%), 71 had a combined suitability of zero due to the predicted substrate being too small (substrate codes 0.1 and 1) or too large (substrate codes 6.8, 8, 9 and 10), one had a combined suitability of zero because the location was predicted to be dry by the 2-D model, and one had a combined suitability of zero because the depth was too shallow (less than 0.06 m). An increased density of substrate points would have been required to more accurately represent the substrate and thus the predicted combined suitability of redd locations in the 2D model. However, this would likely had little effect on the resulting flow-habitat relationship. Specifically, flow-habitat relationships are not very sensitive to substrate data, since the substrate does not change with flow. The only effect of substrate data on flow-habitat

Figure 7
Combined Suitability for 2-D Model Locations With Redds

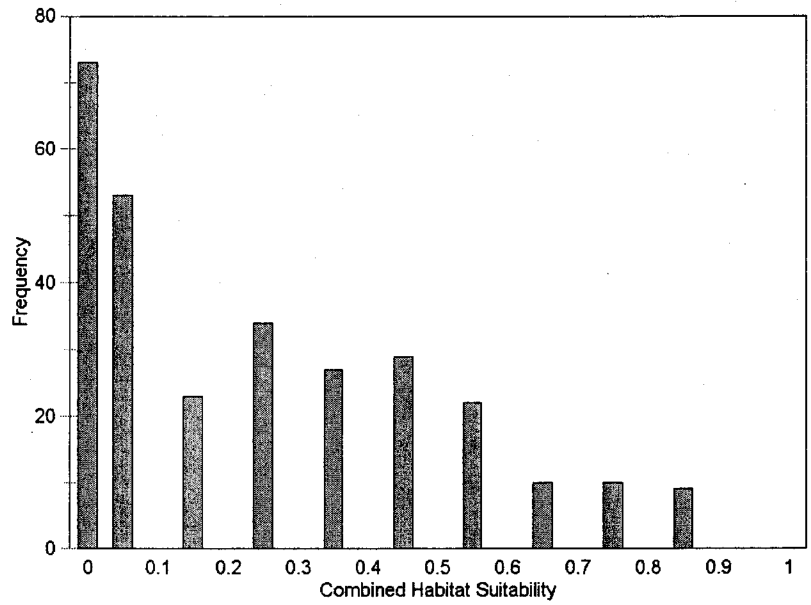
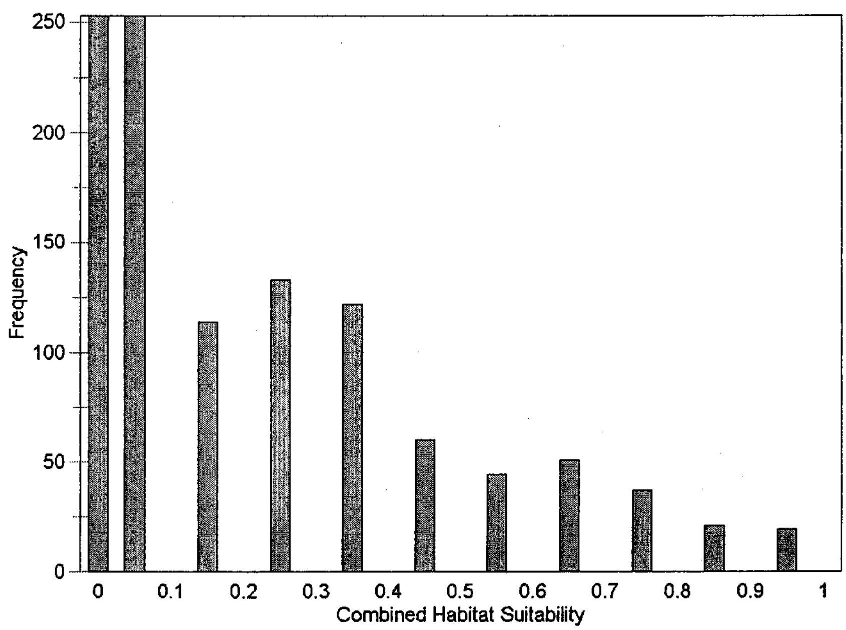


Figure 8
Combined Suitability for 2-D Model Locations Without Redds



relationships is when the depths and velocities in areas with suitable substrates differ from the depths and velocities in areas with unsuitable substrates. For example, if the substrates are suitable in the thalweg (where the highest depths and velocities typically are found) but unsuitable in the remaining portion of the channel, the peak WUA will be at a lower flow than if the substrates are unsuitable in the thalweg but suitable in the remaining portion of the channel.

The 2-D model interpolates substrate at a given location by the substrate at the nearest point in the substrate file. If substrate data varies more laterally (across the channel) than longitudinally (upstream and downstream), adding longitudinal breaklines and/or increasing node density in the substrate file to force the 2-D model to predict substrate at a given location based on the nearest longitudinal point can improve the ability of the 2-D model to predict compound suitability (U.S. Fish and Wildlife Service 2003). In our test of this technique on the Lower American River, the WUA predicted with the modified substrate file differed little from the WUA predicted by the original substrate file (U.S. Fish and Wildlife Service 2003).

The prediction by the 2-D model that redd locations were dry or too shallow can be attributed to either: 1) the model under predicting the WSELs in the site at the flow at which redd data was collected; or 2) to longitudinal curvature in the bed topography which was not captured by the data collection, for redds that were located near the water's edge.

Habitat Simulation

The flow-habitat relationships for spring-run chinook salmon are shown in Figures 9 and 10. In the Above Centerville Powerhouse reach, the 2-D model predicts the highest total WUA at the highest modeled flow of 450 cfs, with the total WUA value still continuing to increase. For the Below the Centerville Powerhouse reach, the total WUA peaks at 190 cfs.

Based on the results of this study, it appears that the current minimum flow requirements during the spawning and incubation period of August-December (40 cfs), particularly in the Above Centerville Powerhouse Reach, are significantly reducing the amount of habitat available to the spawning spring-run chinook salmon. Our data indicates that flows exceeding 200 cfs in the Above Centerville Powerhouse Reach and at least 190 cfs in the Below Centerville Powerhouse Reach are needed throughout September-December to increase the habitat availability and productivity of the spring-run chinook salmon population in Butte Creek. It should be noted that while an increase in flow in the Above Centerville Powerhouse Reach provides a greater percentage increase in spawning habitat (a 66% increase from 40 to 80 cfs) than for the Below Centerville Powerhouse Reach (a 20% increase from 80 to 120 cfs), the increase in the actual square feet of habitat is greater for the Below Centerville Powerhouse Reach (an increase of 20,470 ft^2 from 80 to 120 cfs, versus an increase of 9,983 ft^2 from 40 to 80 cfs for the Above Centerville Powerhouse Reach).

Figure 9
Spring-run Chinook Salmon Flow-Habitat Relationships, Above Centerville Powerhouse Reach

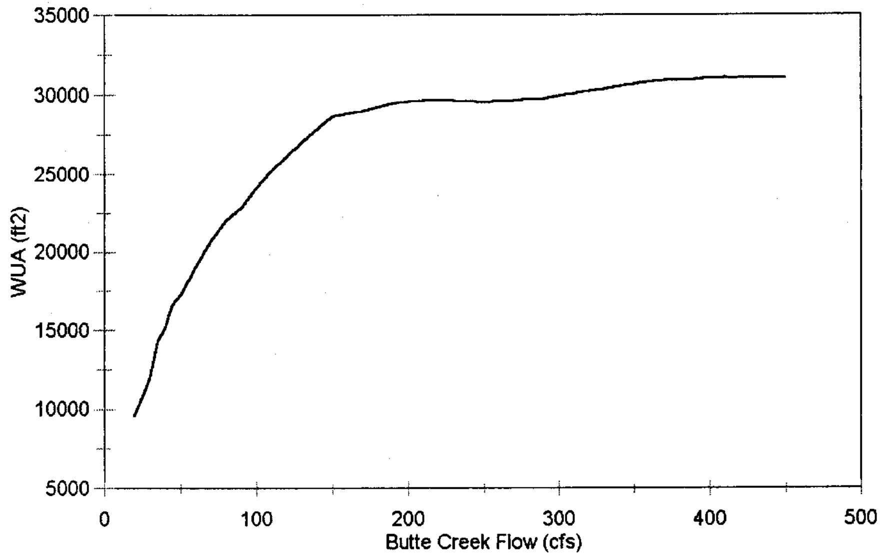
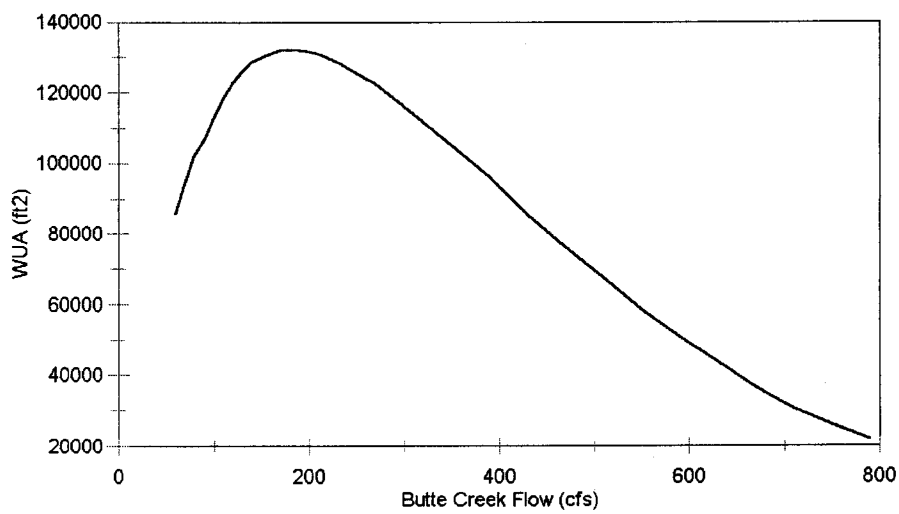


Figure 10
Spring-run Chinook Salmon Flow-Habitat Relationships, Below Centerville Powerhouse Reach



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APPENDIX A
COVER CODES

Cover Category	Cover Code[14]
no cover	0
cobble	1
boulder	2
fine woody vegetation (< 1" diameter)	3
branches	4
log (> 1' diameter)	5
overhead cover (< 2' from water surface)	7
undercut bank	8
aquatic vegetation	9
rip-rap	10

[14] In addition to these cover codes, we have been using composite cover codes (3.7, 4.7, 5.7 and 9.7); for example, 4.7 would be branches plus overhead cover. As noted in the report, the cover codes were used to compute initial bed roughness values and to provide the option to use the spawning sites in the future for modeling juvenile chinook salmon habitat.

APPENDIX B
RHABSIM WSEL CALIBRATION

Calibration Methods and Parameters Used

Study Site	XS #	Flow Range	Calibrations Flows	Method	Parameters
Whiskey Flat	1, 2	20-450	47, 107, 265	IFG4	---
Above Helltown 1	1	20-450	47, 107, 283	WSP[15]	n = 0.04, 47 RM = 1.82, 107 RM = 1.22, 283 RM = 0.76
Above Helltown 1	2	20-450	47, 107, 283	IFG4	---
Above Helltown 2	1, 2	20-450	47, 107, 225	IFG4	---
Helltown	1	20-450	47, 107, 260	IFG4	---
Helltown	2	20-450	47, 107, 228	IFG4	---
Homestead	1	60-790	89, 153, 241, 325	IFG4	---
Homestead	2	60-790	89, 153, 241, 325	MANSQ	$\beta = 0.397$, CALQ = 89
Richbar	1	60-790	153, 241, 325	IFG4	---
Richbar	2	60-790	153, 241, 325	MANSQ	$\beta = 0.5$, CALQ = 153
Tailings	1	60-790	153, 241, 260	MANSQ	$\beta = 0.5$, CALQ = 260
Tailings	2	60-790	153, 260, 414	IFG4	---

[15]Transect two of Above Helltown 2 was used in WSP as the downstream transect for Above Helltown 1 transect one by tying together the vertical benchmarks for Above Helltown 1 and 2. The SZF for Above Helltown 1 transect one was located within the Above Helltown 2 site.

Whiskey Flat

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	47 cfs	107 cfs	265 cfs	47 cfs	107 cfs	265 cfs
1	2.87	1.4	1.1	2.1	0.9	0.01	0.02	0.01
2	3.26	2.5	1.8	3.6	1.9	0.01	0.03	0.02

Above Helltown 1

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	47 cfs	107 cfs	283 cfs	47 cfs	107 cfs	283 cfs
1	---	---	---	---	---	0.02	0.1	0.02
2	4.88	0.7	0.5	1.0	0.4	0.00	0.01	0.00

Above Helltown 2

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	47 cfs	107 cfs	225 cfs	47 cfs	107 cfs	225 cfs
1	3.52	3.0	2.3	4.6	2.2	0.01	0.02	0.01
2	3.10	1.7	1.2	2.5	1.4	0.00	0.01	0.01

Helltown

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	47 cfs	107 cfs	228 cfs	47 cfs	107 cfs	228 cfs
1	3.08	1.3	1.2	2.5	1.1	0.01	0.02	0.01
2	3.32	3.6	2.8	5.5	2.5	0.01	0.03	0.02

Homestead

	BETA	%MEAN	Calculated vs Given Disch. (%)				Difference (measured vs. pred. WSELs)			
XSEC	COEFF.	ERROR	89 cfs	153 cfs	241 cfs	325 cfs	89 cfs	153 cfs	241 cfs	325 cfs
1	2.81	3.1	3.7	5.9	2.4	0.4	0.00	0.02	0.04	0.02
2	---	8.7	0.0	4.6	10.8	10.8	0.00	0.04	0.10	0.10

Richbar

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	153 cfs	241 cfs	325 cfs	153 cfs	241 cfs	325 cfs
1	2.91	1.8	1.2	2.8	1.5	0.01	0.02	0.01
2	---	7.4	0.0	8.7	6.1	0.00	0.03	0.03

Tailings

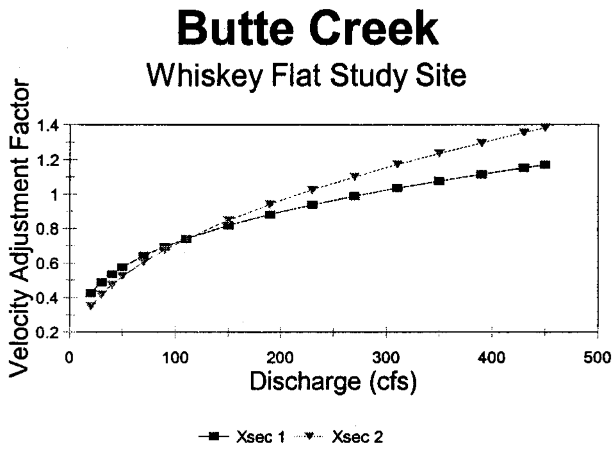
	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	153 cfs	241 cfs	260 cfs	153 cfs	241 cfs	260 cfs
1	---	21.8	30.7	12.9	0.0	0.11	0.06	0.00

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	153 cfs	260 cfs	414 cfs	153 cfs	260 cfs	414 cfs
2	2.91	1.5	0.9	2.2	1.3	0.01	0.01	0.01

APPENDIX C
VELOCITY ADJUSTMENT FACTORS

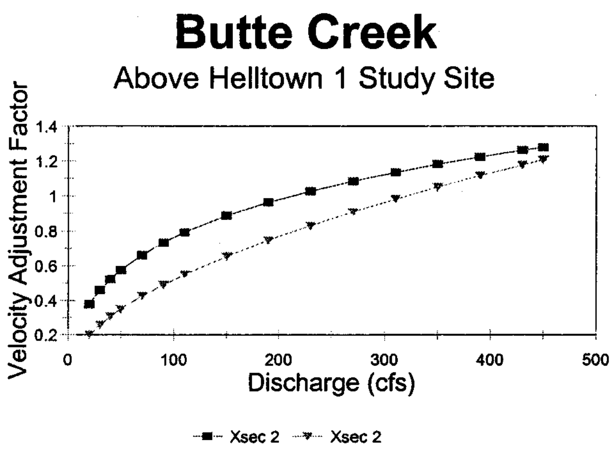
WHISKEY FLAT STUDY SITE

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
20	0.43	0.35
30	0.49	0.42
40	0.54	0.48
50	0.58	0.52
70	0.64	0.61
90	0.70	0.68
110	0.74	0.74
150	0.82	0.85
190	0.88	0.94
230	0.94	1.03
270	0.99	1.10
310	1.04	1.17
350	1.08	1.24
390	1.12	1.30
430	1.15	1.36
450	1.17	1.38



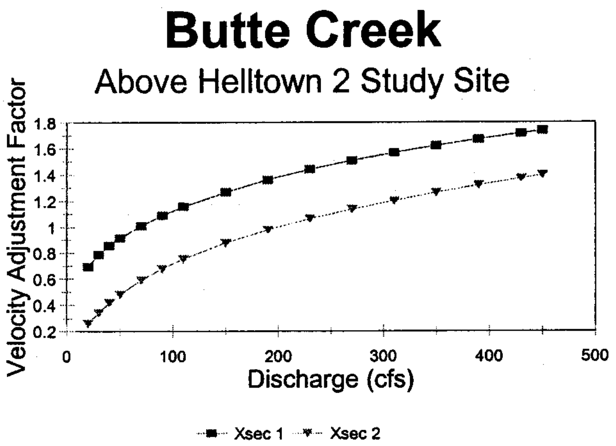
ABOVE HELLTOWN 1 STUDY SITE

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
20	0.38	0.20
30	0.46	0.26
40	0.52	0.31
50	0.58	0.35
70	0.66	0.43
90	0.73	0.49
110	0.79	0.55
150	0.89	0.65
190	0.96	0.75
230	1.03	0.83
270	1.08	0.91
310	1.13	0.98
350	1.18	1.05
390	1.22	1.12
430	1.26	1.18
450	1.28	1.21



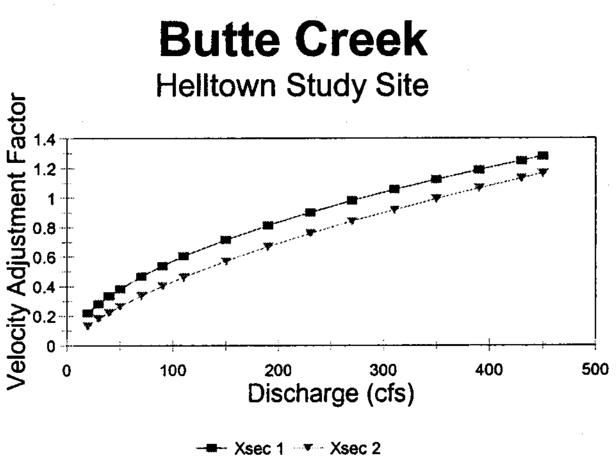
ABOVE HELLTOWN 2 STUDY SITE

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
20	0.69	0.26
30	0.79	0.34
40	0.86	0.42
50	0.92	0.48
70	1.01	0.59
90	1.09	0.68
110	1.16	0.76
150	1.27	0.88
190	1.36	0.98
230	1.44	1.06
270	1.51	1.14
310	1.57	1.21
350	1.62	1.27
390	1.67	1.32
430	1.72	1.37
450	1.74	1.40



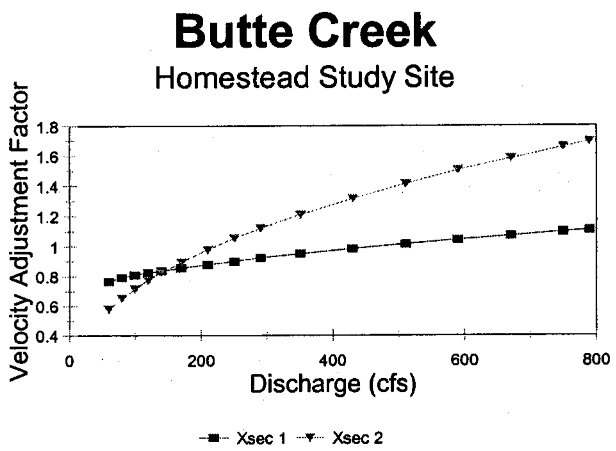
HELLTOWN STUDY SITE

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
20	0.22	0.13
30	0.28	0.18
40	0.34	0.22
50	0.38	0.26
70	0.47	0.34
90	0.54	0.40
110	0.60	0.46
150	0.72	0.57
190	0.82	0.67
230	0.90	0.76
270	0.98	0.84
310	1.06	0.92
350	1.13	1.00
390	1.19	1.07
430	1.25	1.13
450	1.28	1.17



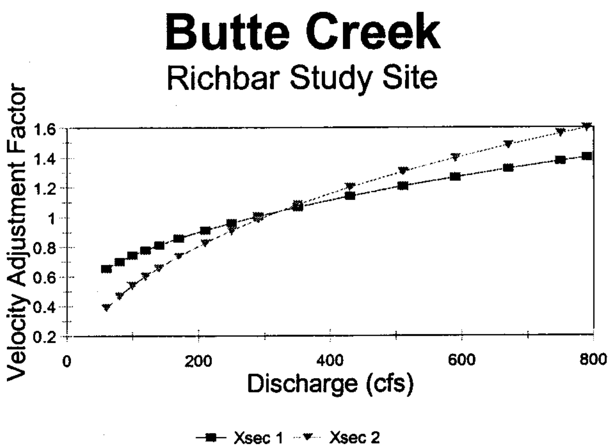
HOMESTEAD STUDY SITE

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
60	0.77	0.58
80	0.79	0.65
100	0.81	0.72
120	0.83	0.77
140	0.84	0.83
170	0.86	0.89
210	0.88	0.98
250	0.90	1.05
290	0.92	1.12
350	0.95	1.21
430	0.99	1.32
510	1.02	1.41
590	1.05	1.51
670	1.07	1.58
750	1.10	1.66
790	1.11	1.70



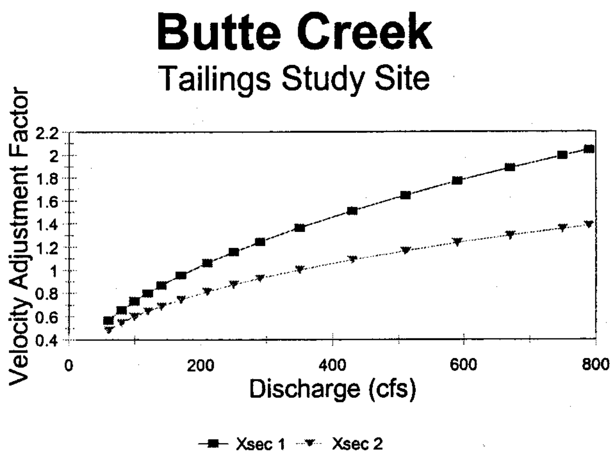
RICHBAR STUDY SITE

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
60	0.66	0.39
80	0.70	0.47
100	0.74	0.54
120	0.78	0.60
140	0.81	0.66
170	0.86	0.74
210	0.91	0.83
250	0.96	0.91
290	1.01	0.99
350	1.07	1.09
430	1.14	1.20
510	1.21	1.30
590	1.27	1.40
670	1.32	1.48
750	1.38	1.56
790	1.40	1.60



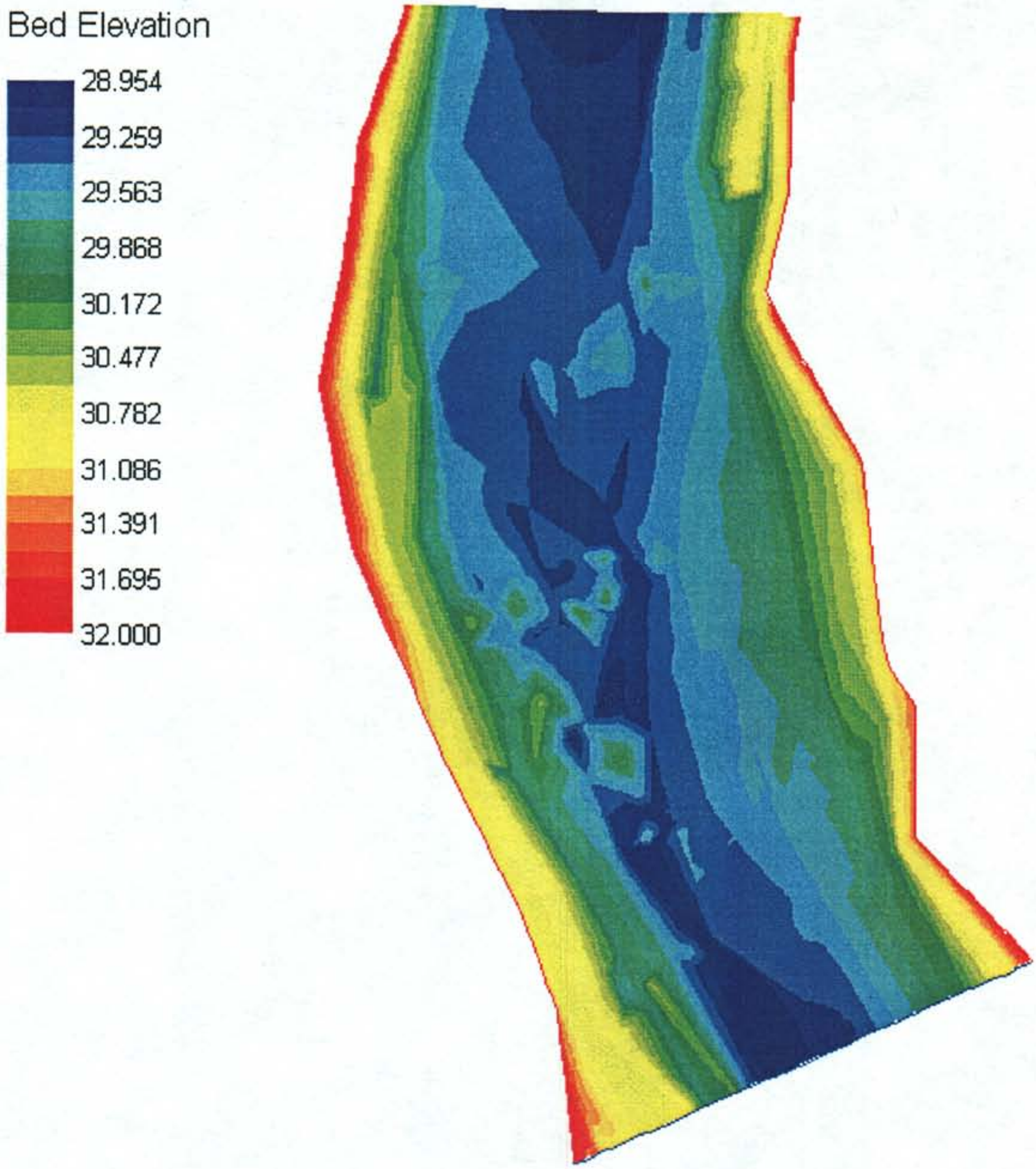
TAILINGS STUDY SITE

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
60	0.57	0.48
80	0.66	0.55
100	0.73	0.60
120	0.80	0.65
140	0.87	0.69
170	0.96	0.75
210	1.06	0.82
250	1.16	0.88
290	1.24	0.93
350	1.36	1.00
430	1.51	1.09
510	1.65	1.17
590	1.77	1.23
670	1.89	1.30
750	1.99	1.36
790	2.05	1.38



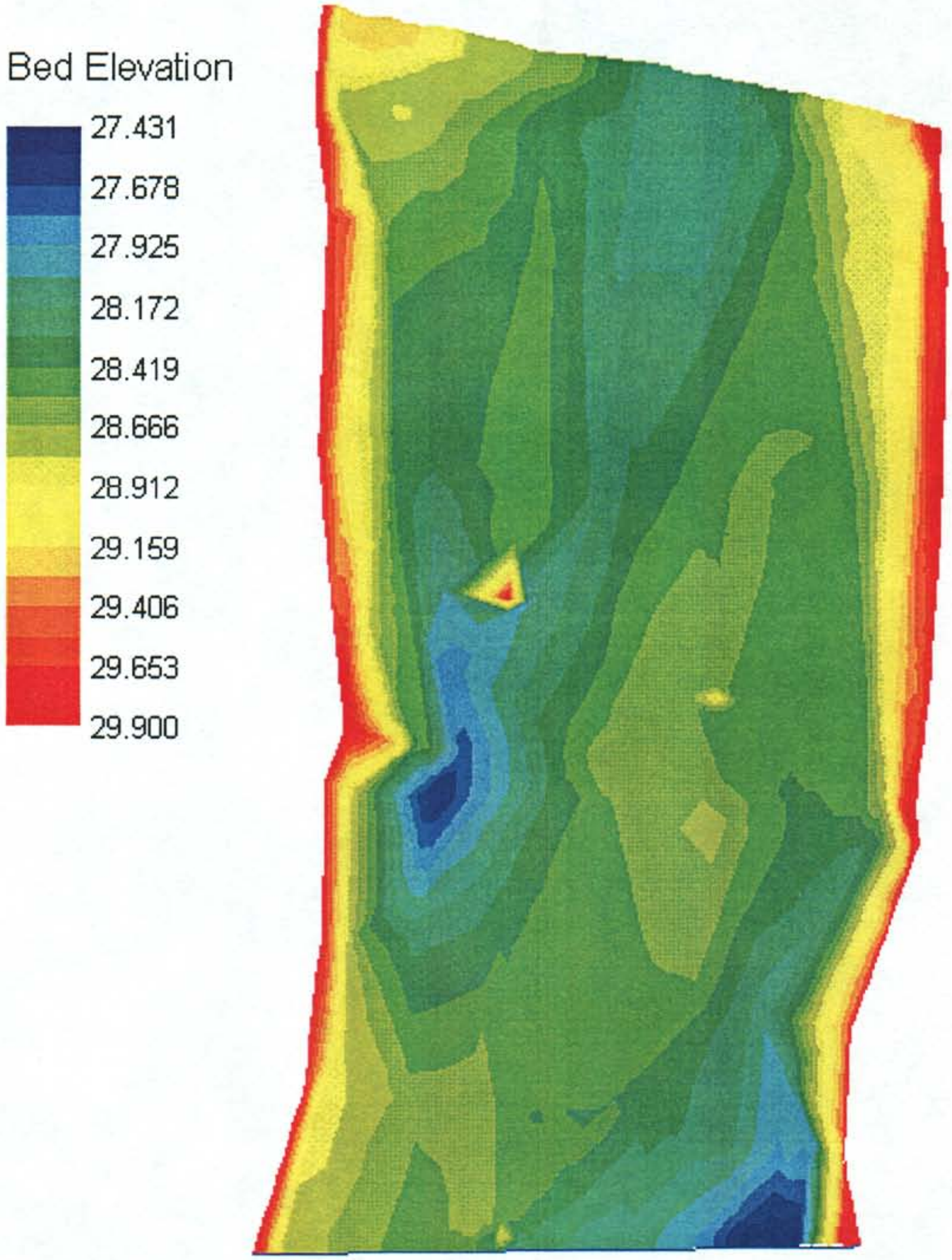
APPENDIX D
BED TOPOGRAPHY OF STUDY SITES

WHISKEY FLAT STUDY SITE



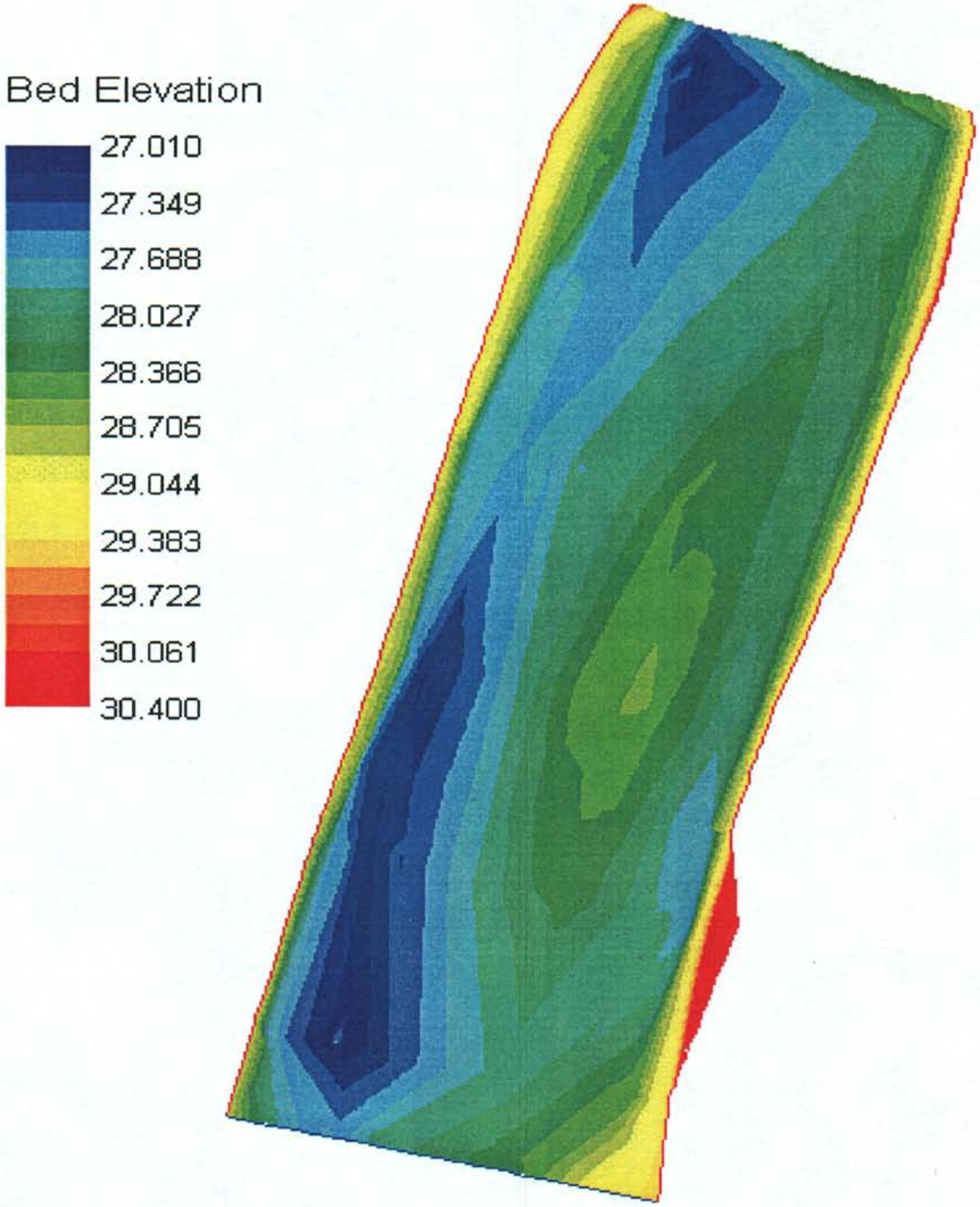
Units of Bed Elevation are meters.

ABOVE HELLTOWN 1 STUDY SITE



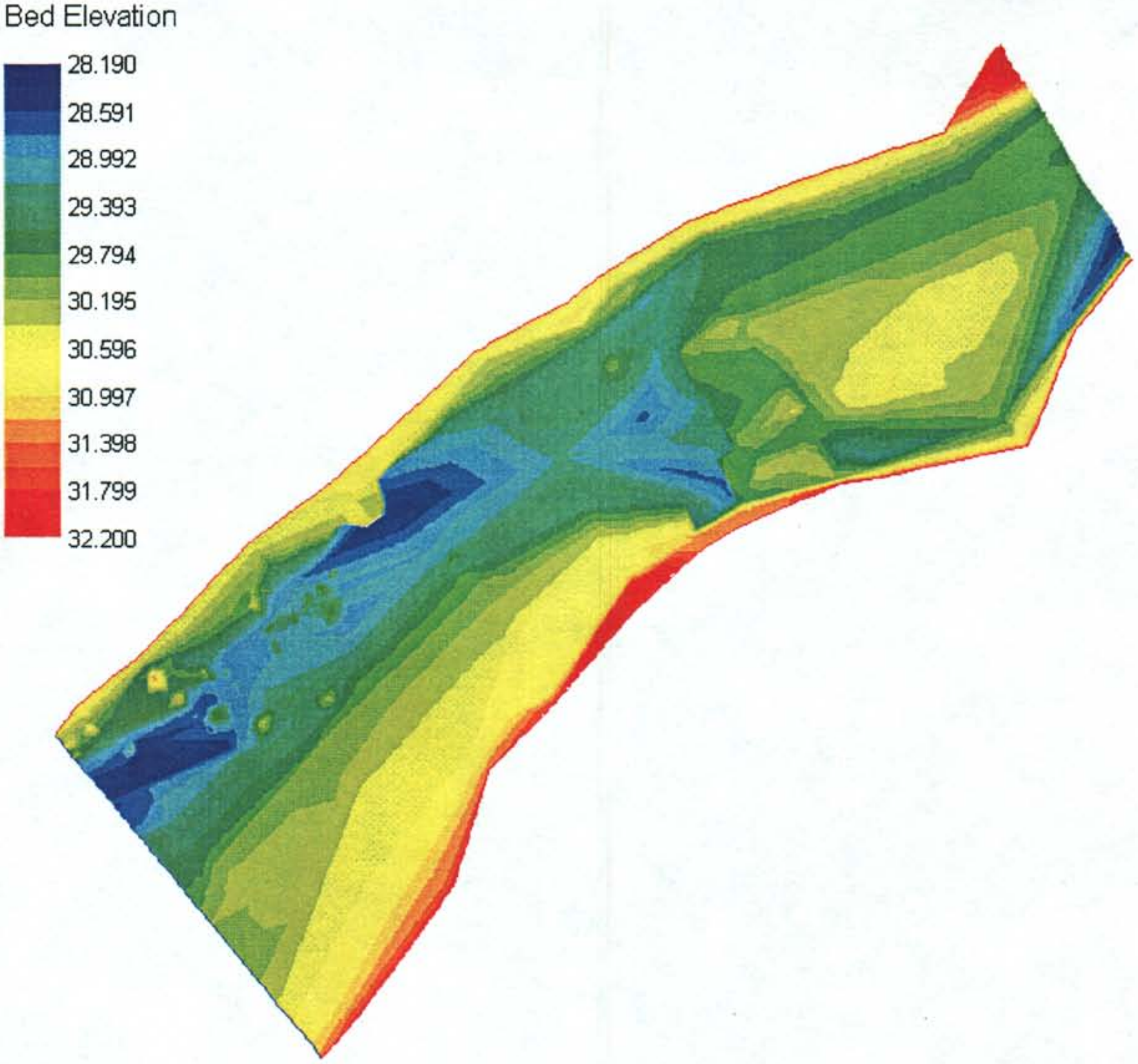
Units of Bed Elevation are meters.

ABOVE HELLTOWN 2 STUDY SITE



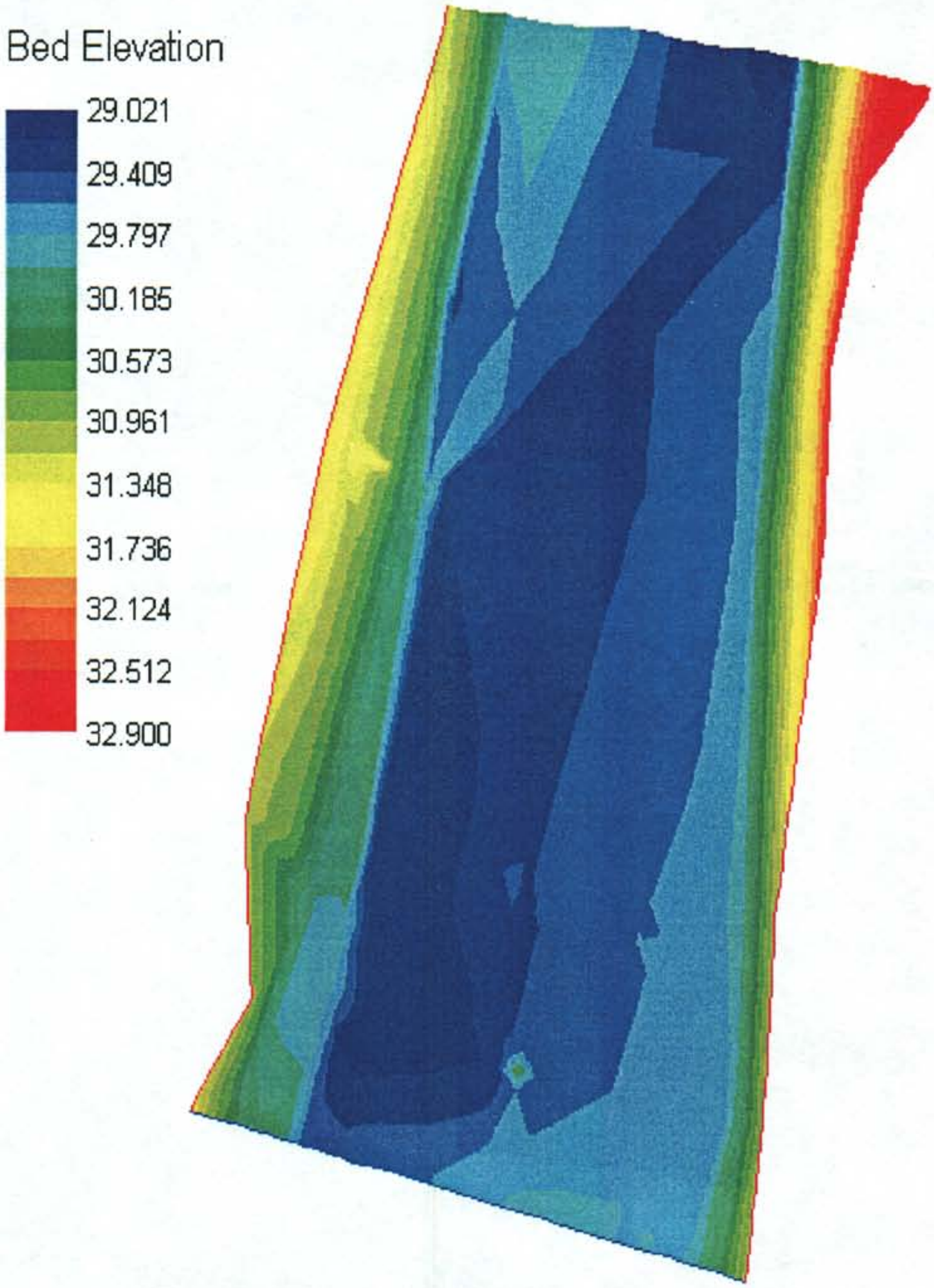
Units of Bed Elevation are meters.

HELLTOWN STUDY SITE



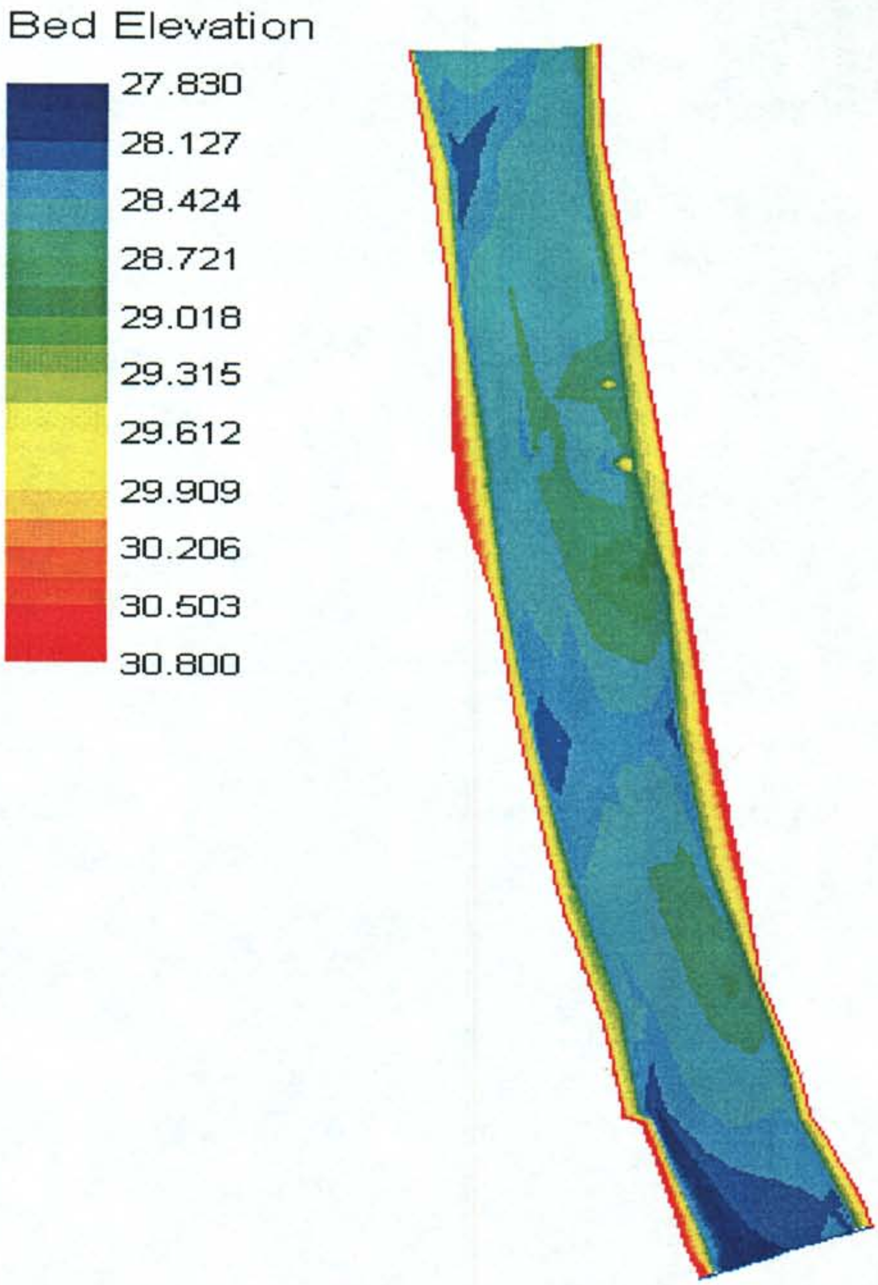
Units of Bed Elevation are meters.

HOMESTEAD STUDY SITE



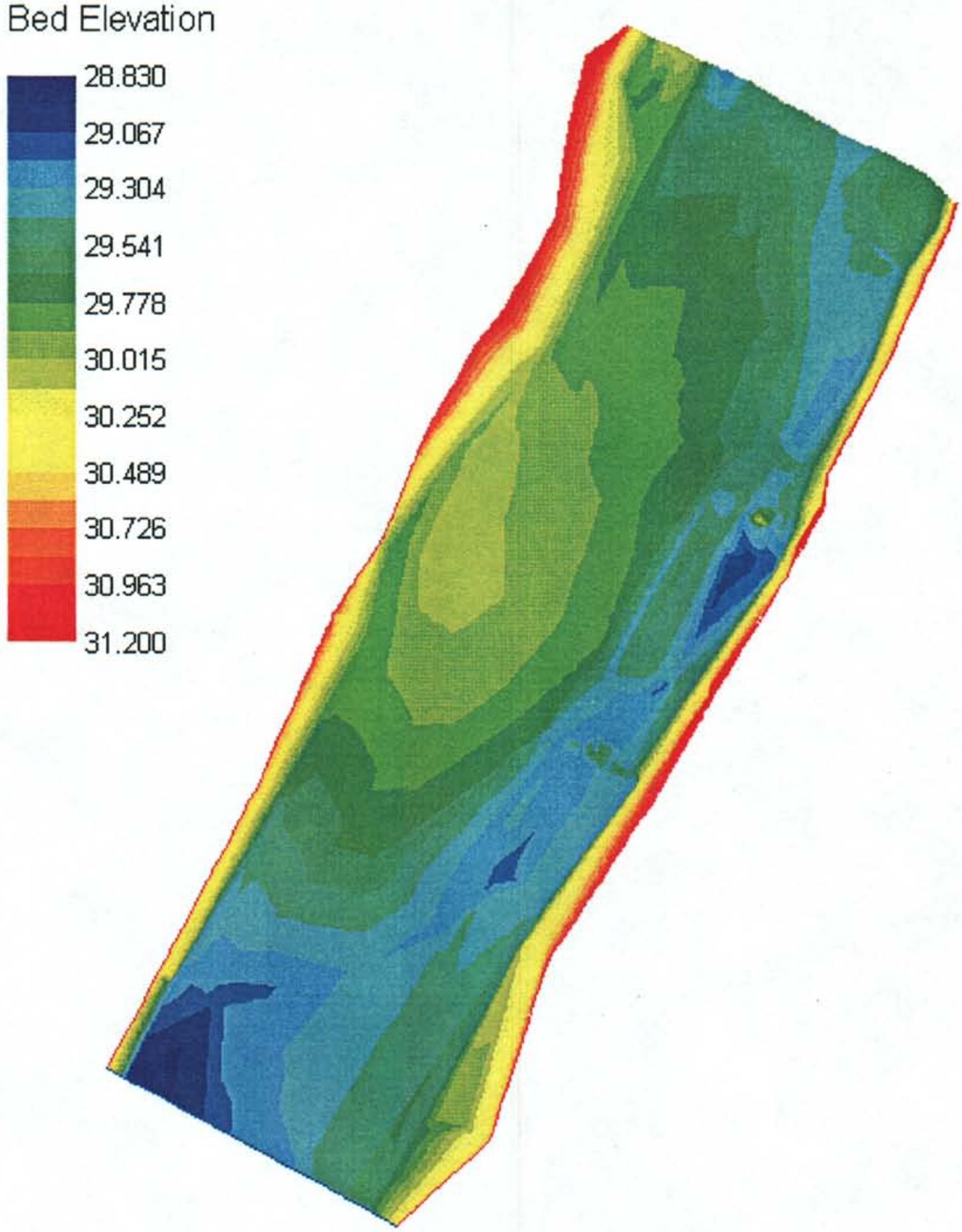
Units of Bed Elevation are meters.

RICHBAR STUDY SITE



Units of Bed Elevation are meters.

TAILINGS STUDY SITE



Units of Bed Elevation are meters.

APPENDIX E
2-D WSEL CALIBRATION

Calibration Statistics

Site Name	% Nodes within 0.1'	Nodes	QI	Net Q	Sol Δ	Max F
Whiskey Flat	86	5164	0.25	0.16%	<.000001	1.87
Above Helltown 1	93	3800	0.30	1.33%	<.000001	0.83
Above Helltown 2	94	6140	0.30	0.86%	.000004	0.71
Helltown	84	9629	0.30	0.41%	.000007	4.52
Homestead	95	3954	0.30	0.17%	.000001	0.78
Richbar	92	9911	0.30	0.89%	.000001	1.09
Tailings	80	7791	0.30	0.16%	<.000001	1.17

Study Sites Cross Section 2

Difference (measured vs. pred. WSELs)

Site Name	Br Multiplier	Average	Standard Deviation	Maximum
Whiskey Flat	0.3	0.04	0.02	0.06
Above Helltown 1	1.0	0.00	0.01	0.02
Above Helltown 2	3.2	0.03	0.01	0.05
Helltown	1.05	0.00	0.02	0.03
Homestead	1.6	0.00	0.03	0.04
Richbar	1.7	0.02	0.06	0.06
Tailings	1.0	N/A	N/A	N/A

The average, standard deviation, and maximum difference between measured and predicted WSELs are not provided for Tailings due to our inability to calibrate cross section 2.

APPENDIX F
VELOCITY VALIDATION STATISTICS

Measured Velocities less than 3 ft/s

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

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Whiskey Flat	76	0.52	0.49	1.81
Above Helltown 1	88	0.73	0.62	3.09
Above Helltown 2	96	0.68	0.50	1.93
Helltown	77	0.42	0.45	2.05
Homestead	86	0.07	0.80	2.49
Richbar	64	0.87	0.78	3.23
Tailings	35	0.68	0.49	1.97

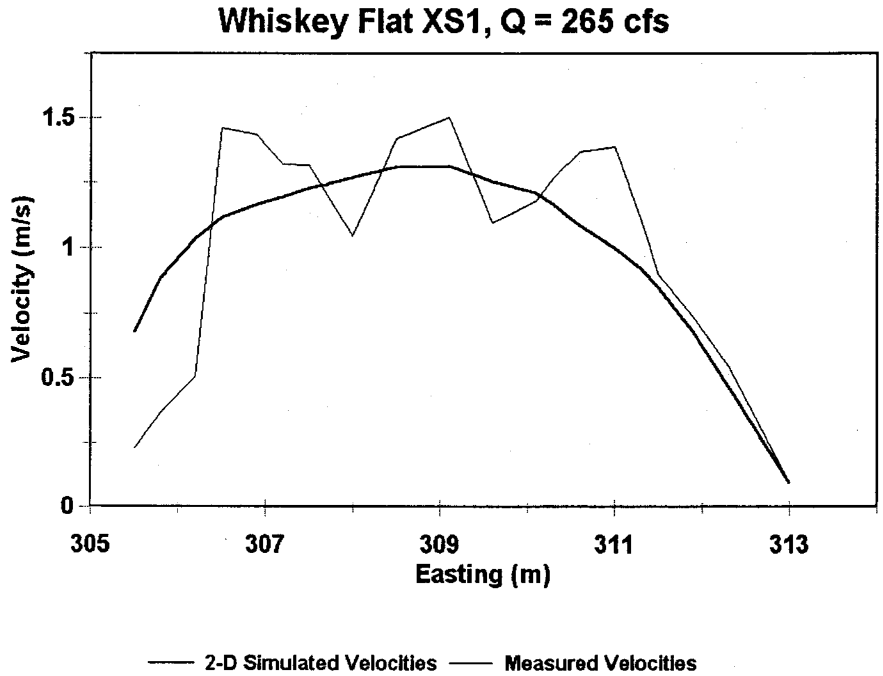
Measured Velocities greater than 3 ft/s

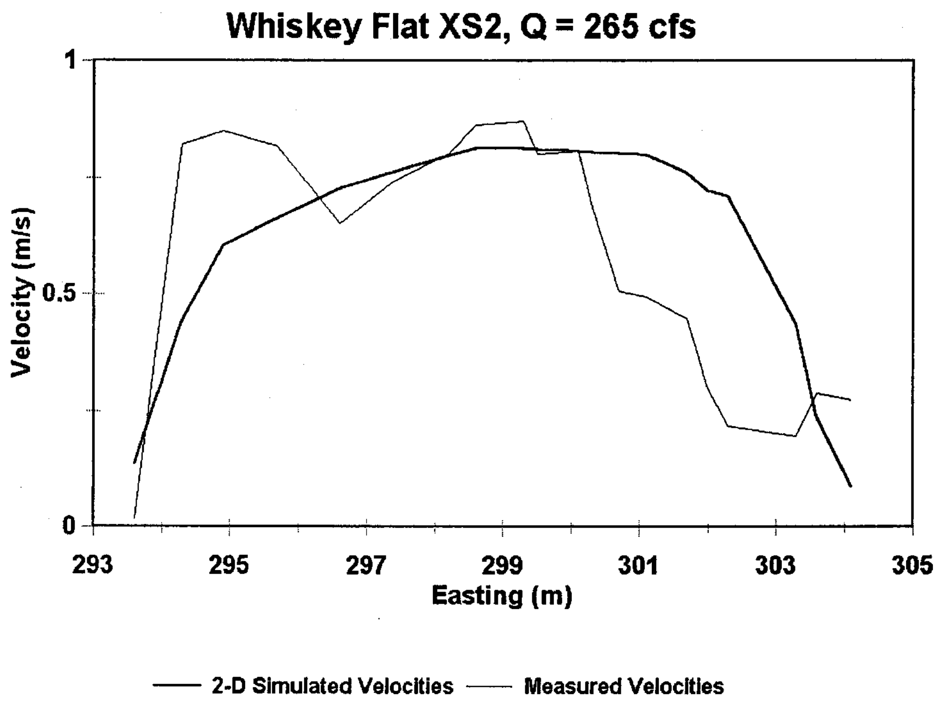
Percent Difference (measured vs. pred. velocities)

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Whiskey Flat	14	14%	8%	28%
Above Helltown 1	2	68%	15%	83%
Above Helltown 2	3	39%	24%	58%
Helltown	8	40%	22%	78%
Homestead	9	25%	15%	51%
Richbar	17	37%	19%	80%
Tailings	21	13%	12%	43%

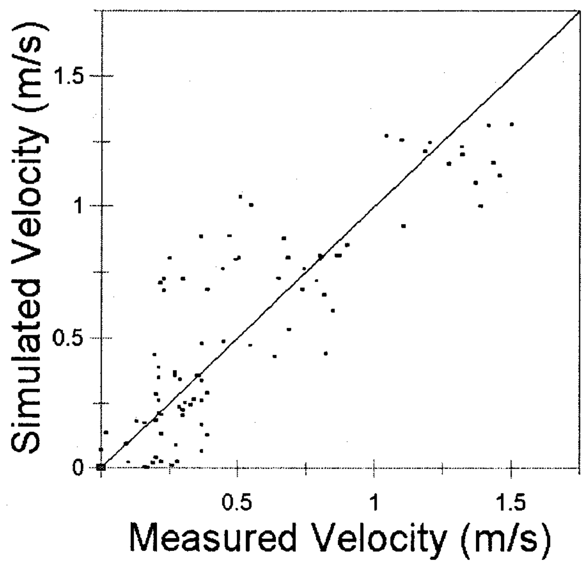
All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

Whiskey Flat Study Site

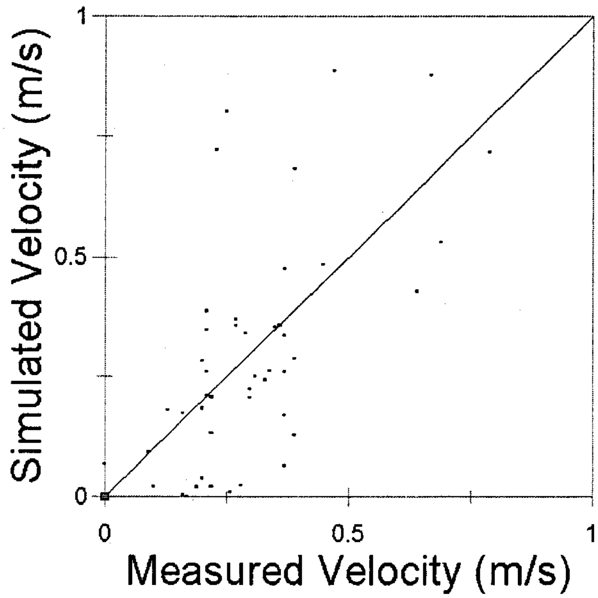




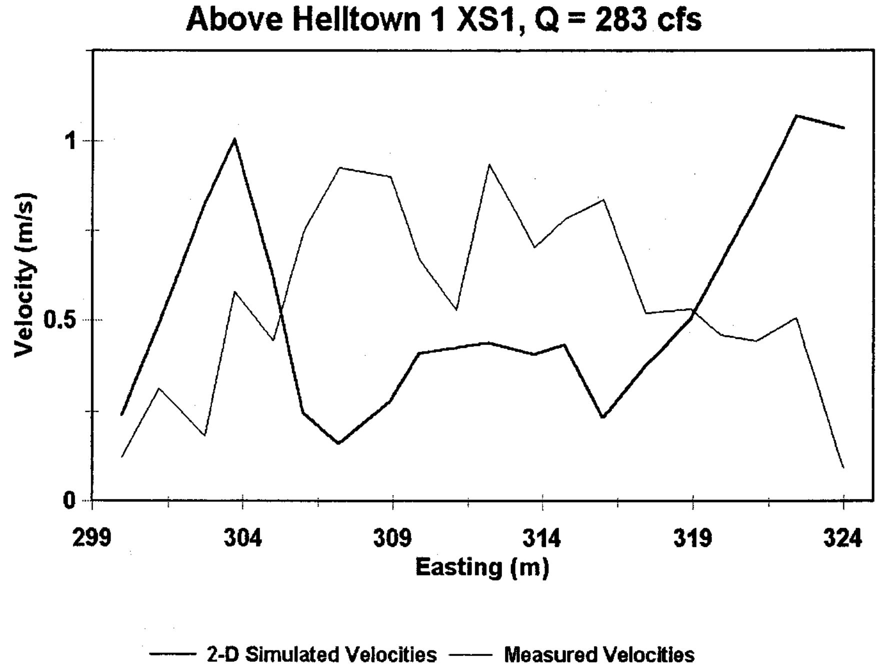
Whiskey Flat
All Validation Velocities

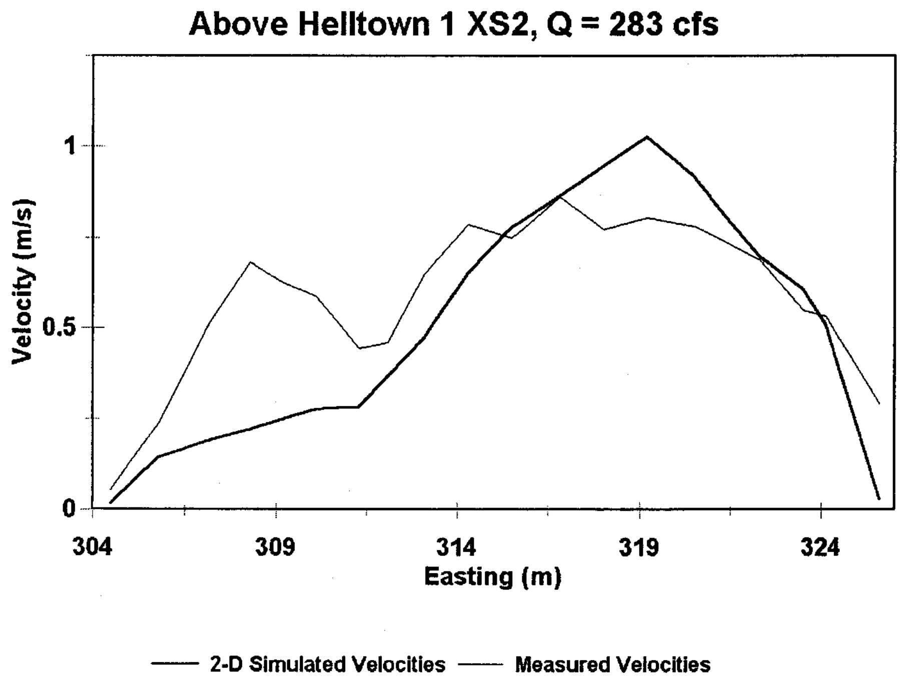


Whiskey Flat
Between Transect Validation Velocities

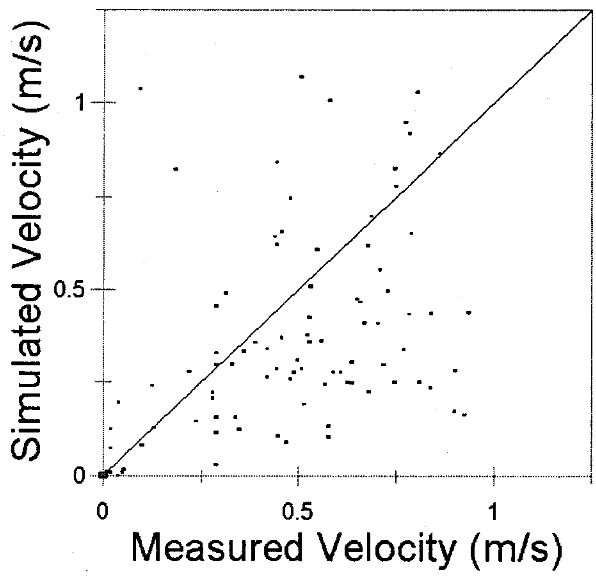


Above Helltown 1 Study Site

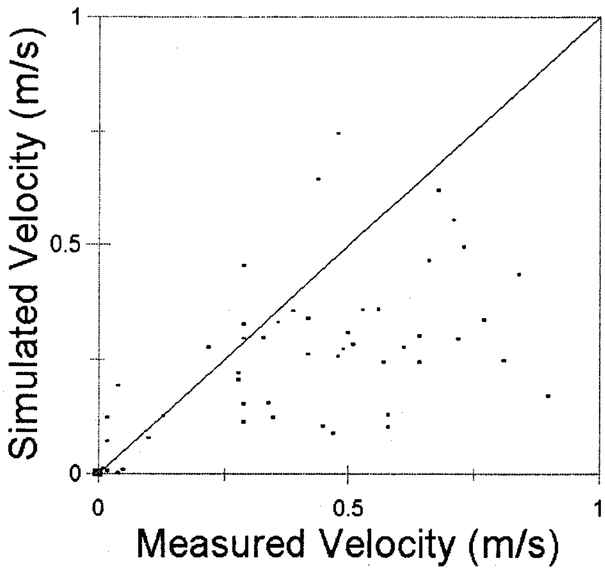




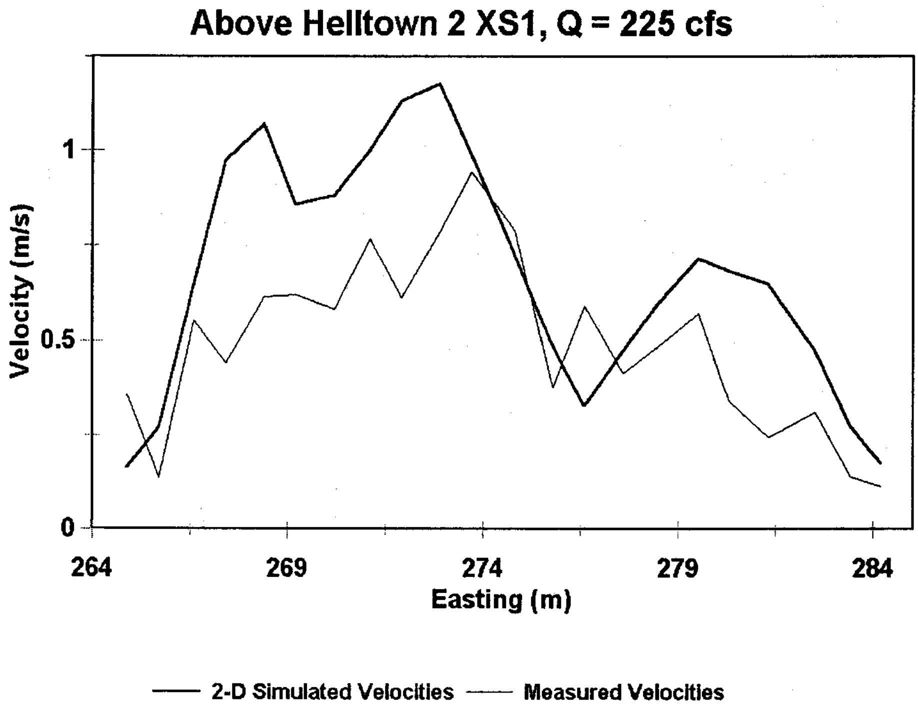
Above Helltown 1
All Validation Velocities

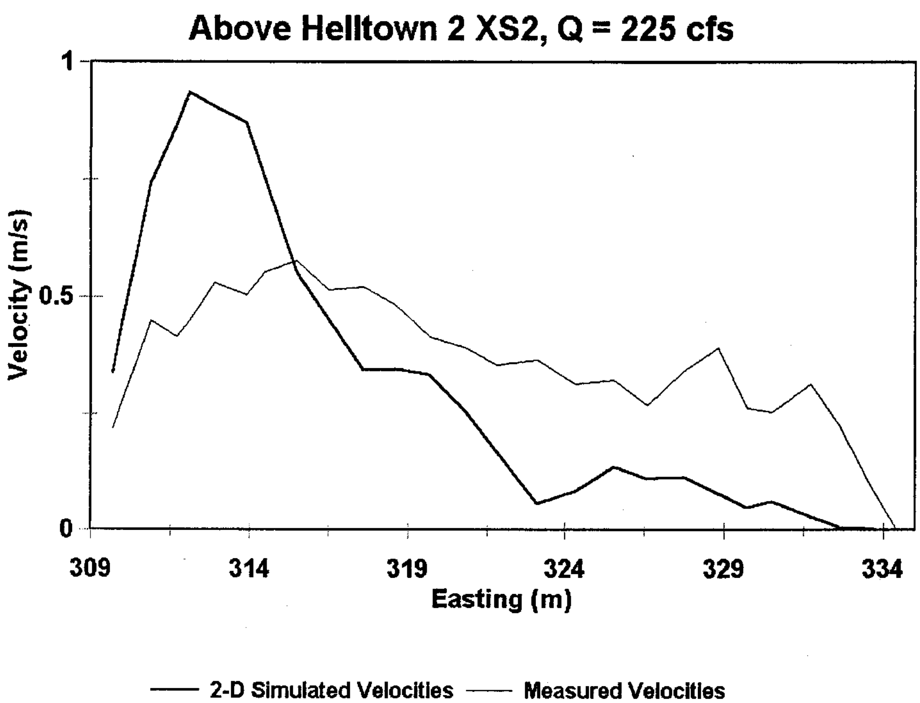


Above Helltown 1
Between Transect Validation Velocities

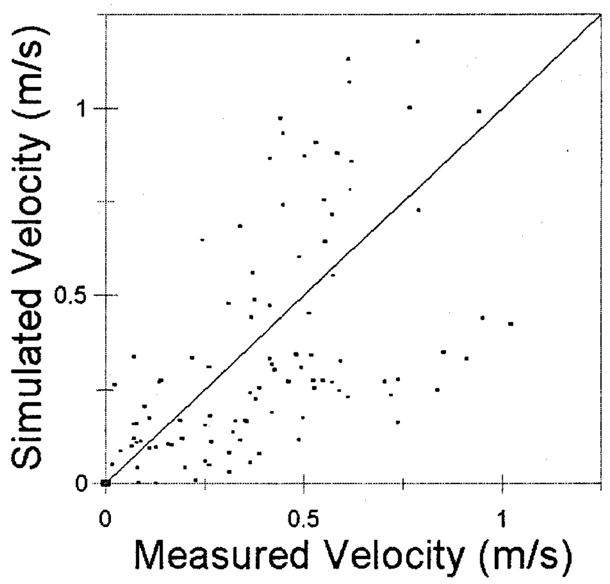


Above Helltown 2 Study Site

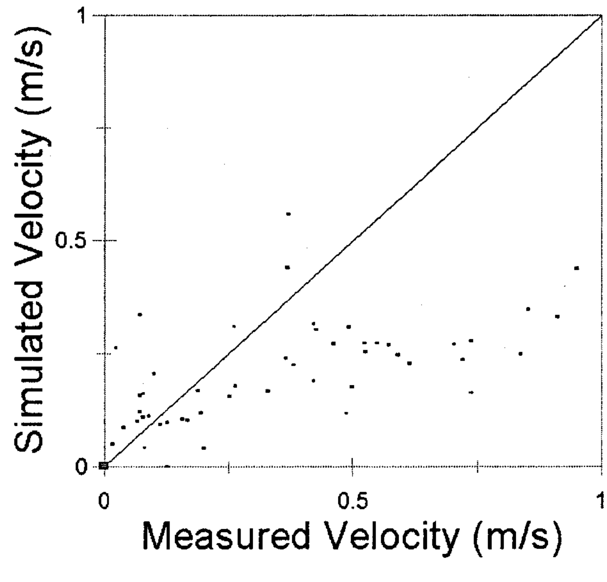




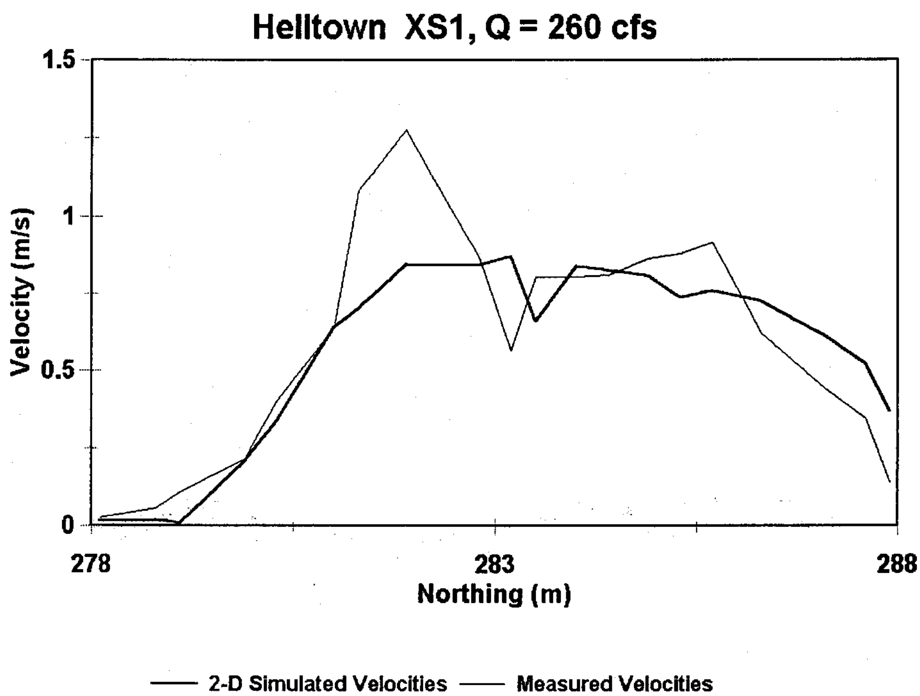
Above Helltown 2
All Validation Velocities

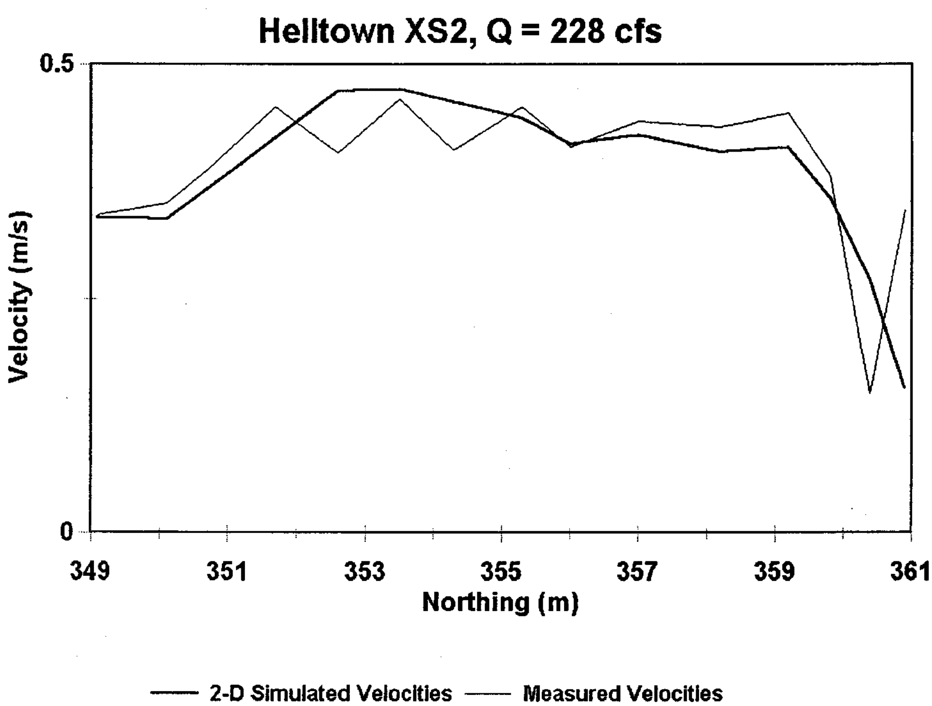


Above Helltown 2
Between Transect Validation Velocities

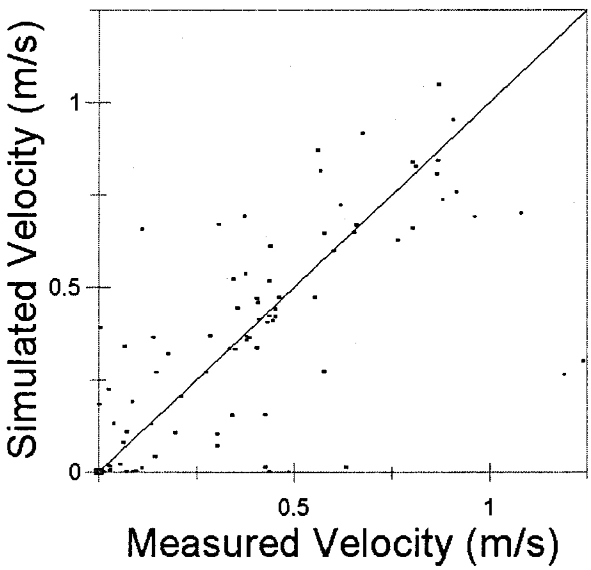


Helltown Study Site

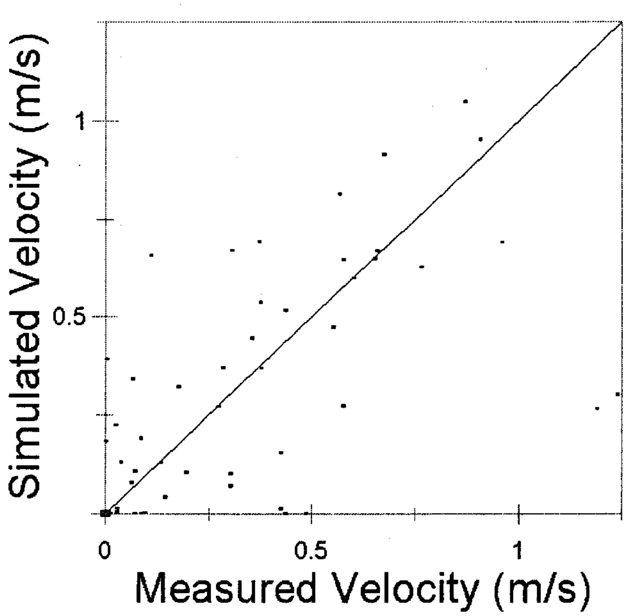




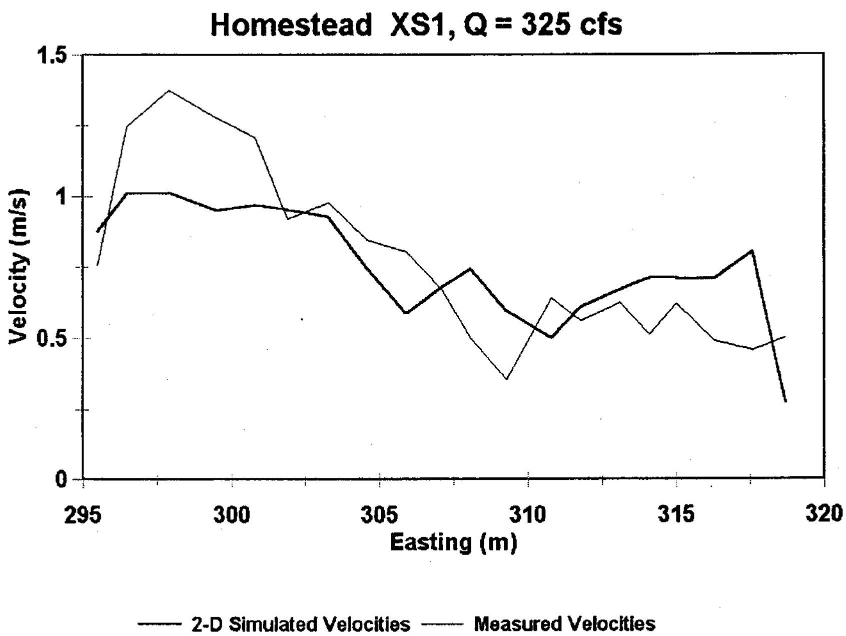
Helltown
All Validation Velocities

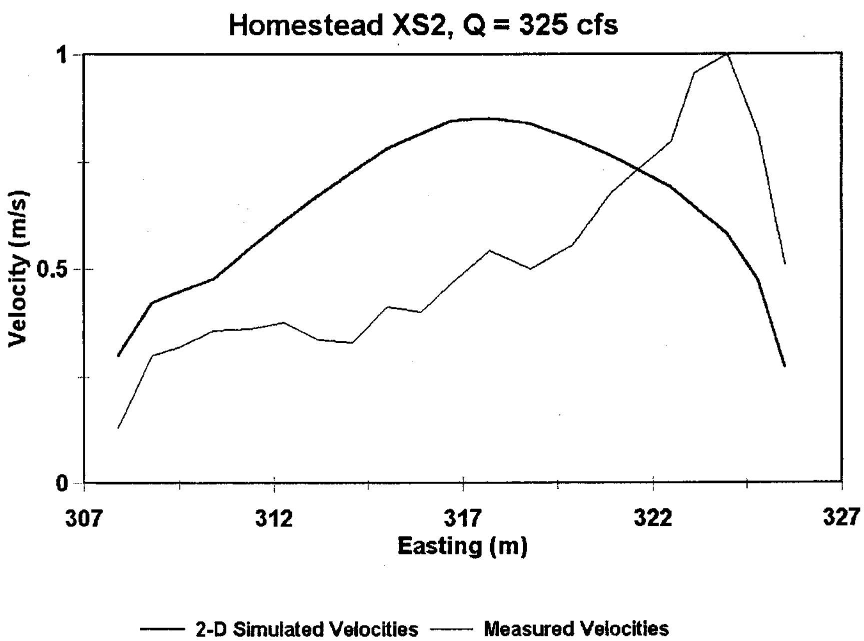


Helltown
Between Transect Validation Velocities

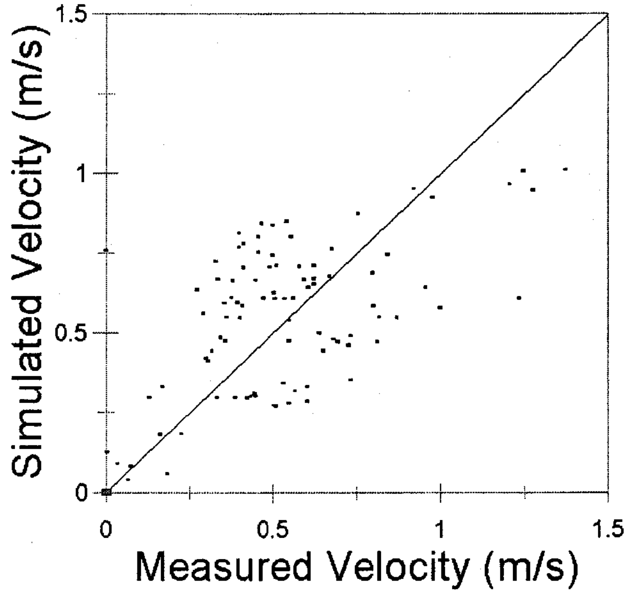


Homestead Study Site

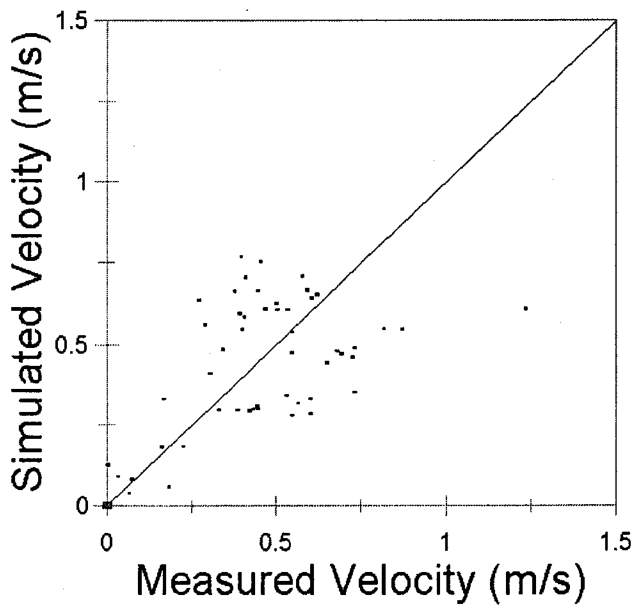




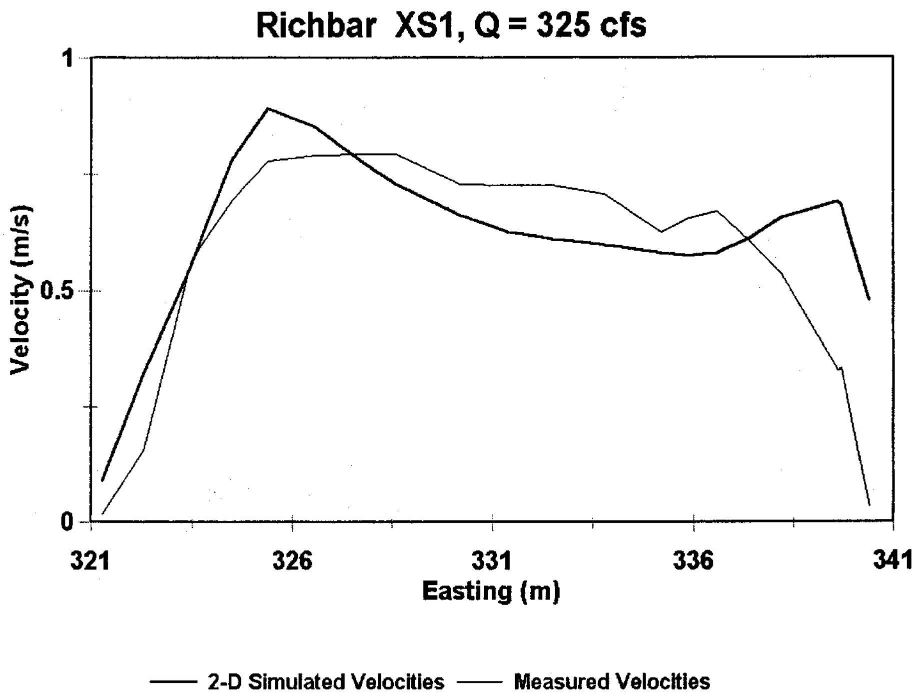
Homestead
All Validation Velocities

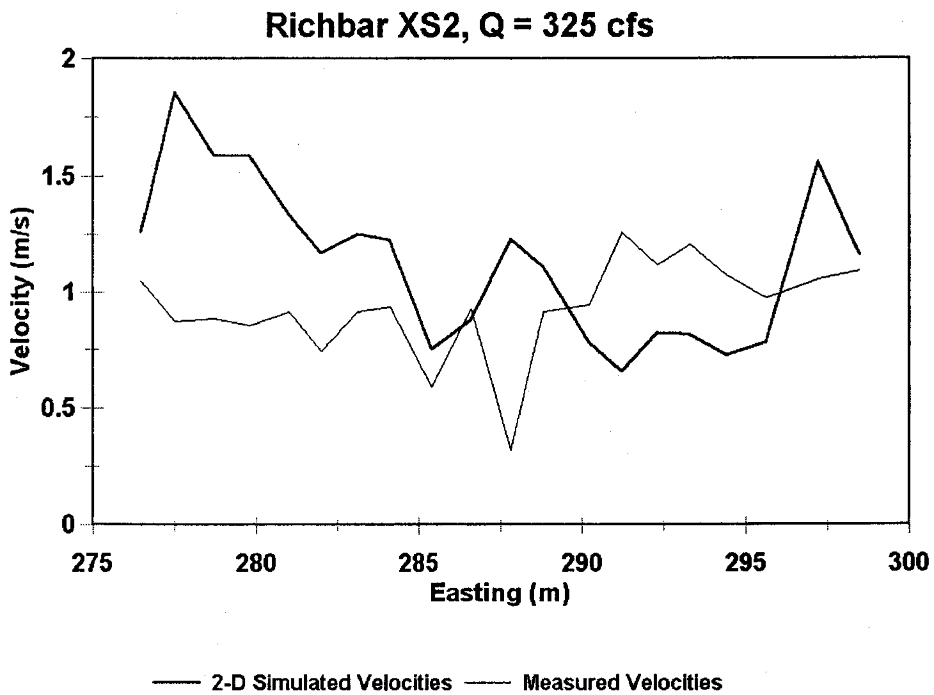


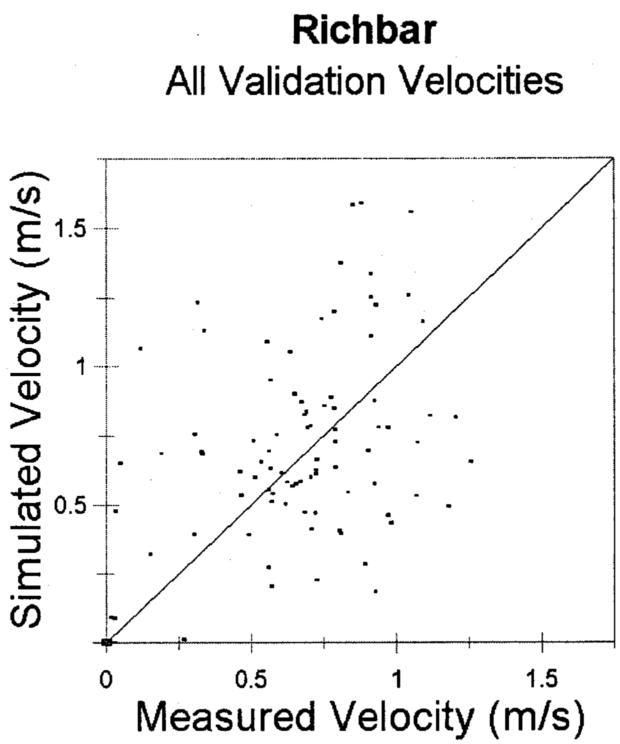
Homestead
Between Transect Validation Velocities

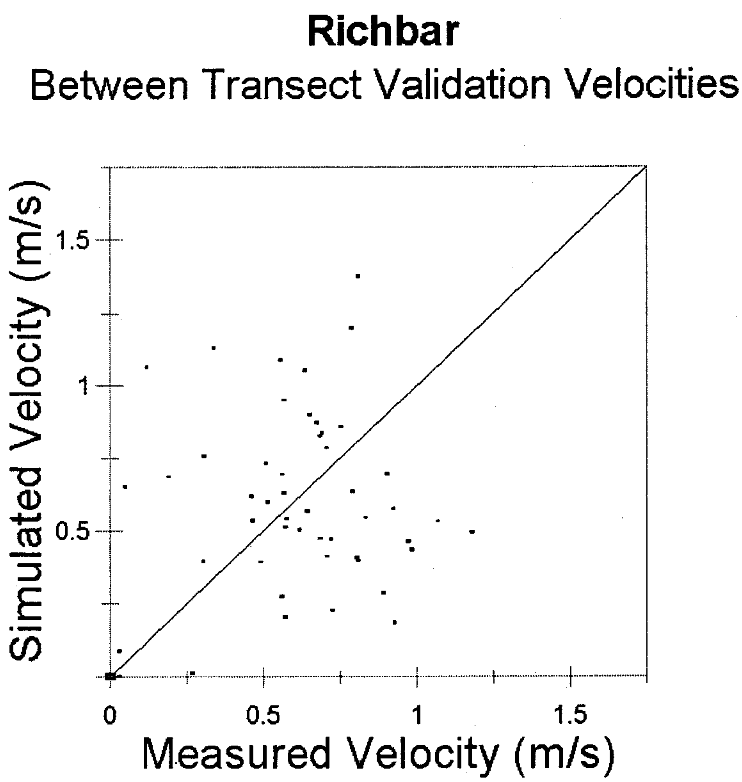


Richbar Study Site

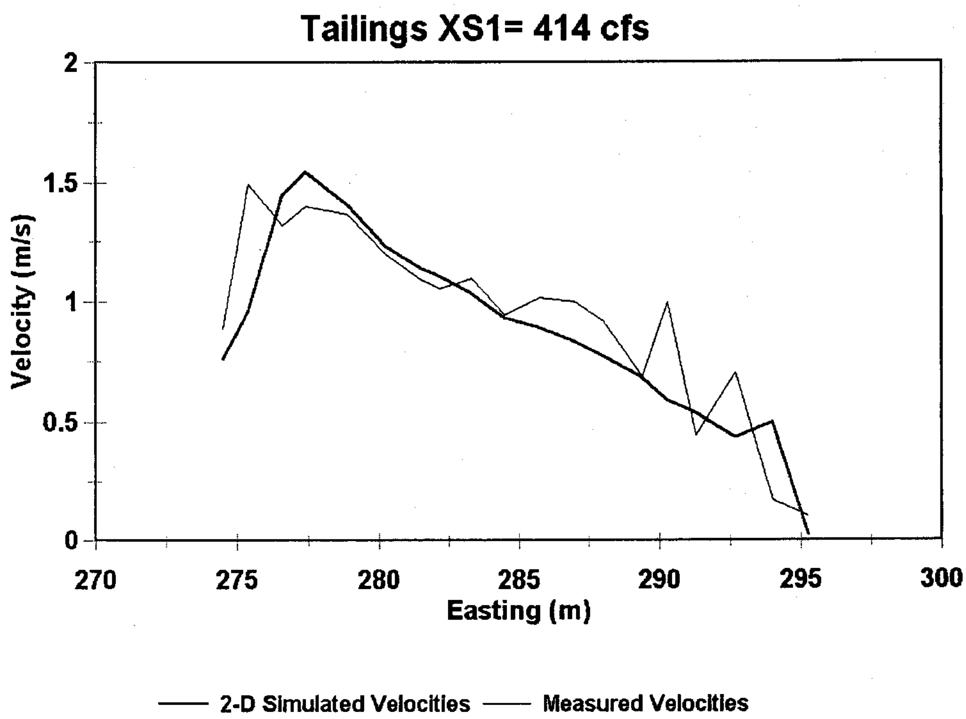




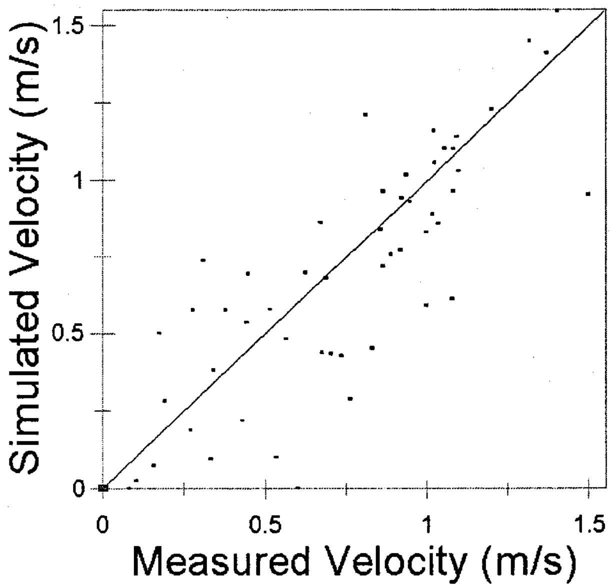

Richbar
All Validation Velocities
Simulated Velocity (m/s)
1.5
1
0.5
0
0.5
1
1.5
Measured Velocity (m/s)


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

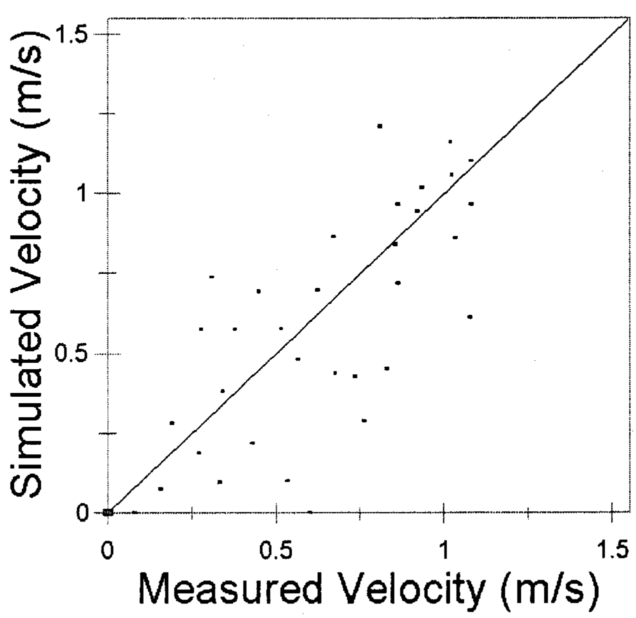
Tailings Study Site



Tailings
All Validation Velocities



Tailings
Between Transect Validation Velocities



APPENDIX G
SIMULATION STATISTICS

Whiskey Flat Site

Flow (cfs)	Net Q	Sol Δ	Max F
20	0.02%	< .000001	0.98
25	0.14%	< .000001	0.84
30	0.50%	< .000001	0.92
35	0.50%	.000002	1.14
40	0.54%	< .000001	1.05
45	0.61%	< .000001	1.04
50	0.64%	< .000001	0.96
60	0.59%	< .000001	1.00
70	0.70%	< .000001	1.18
80	0.60%	< .000001	1.14
90	0.60%	< .000001	1.06
100	0.57%	< .000001	1.57
110	0.52%	< .000001	1.65
130	0.35%	< .000001	2.25
150	0.26%	< .000001	1.70
170	0.29%	< .000001	1.31
190	0.19%	< .000001	1.20
210	0.13%	.000001	1.55
230	0.06%	< .000001	1.68
250	0.01%	< .000001	1.70
270	0.01%	< .000001	1.66
290	0.12%	< .000001	1.64
310	0.10%	< .000001	1.63
330	0.04%	< .000001	3.65
350	0.10%	< .000001	5.17
370	0.10%	< .000001	2.66
390	0.09%	< .000001	2.16
410	0.09%	< .000001	1.77
430	0.08%	< .000001	1.64
450	0.16%	< .000001	1.87

Above Helltown 1 Site

Flow (cfs)	Net Q	Sol Δ	Max F
20	5.50%	< .000001	0.55
25	3.71%	.000008	0.54
30	3.53%	< .000001	0.61
35	2.00%	.000004	0.67
40	4.45%	.000001	0.69
45	3.08%	.000007	0.73
50	2.86%	< .000001	0.74
60	4.12%	.000002	0.78
70	3.50%	.000009	0.79
80	3.91%	< .000001	0.79
90	4.40%	<.000001	0.79
100	4.64%	< .000001	0.76
110	4.83%	< .000001	0.72
130	3.24%	.000001	1.00
150	3.30%	.000002	1.00
170	1.25%	< .000001	1.00
190	0.56%	< .000001	0.72
210	0.34%	.000005	0.71
230	0.31%	.000002	0.70
250	0.28%	< .000001	0.71
270	0.65%	< .000001	0.68
290	0.61%	< .000001	0.69
310	0.68%	< .000001	0.70
330	0.75%	< .000001	0.71
350	0.81%	.000002	0.72
370	1.05%	< .000001	0.73
390	1.00%	.000001	0.74
410	1.12%	< .000001	0.76
430	1.40%	.000002	0.80
450	1.33%	< .000001	0.83

Above Helltown 2 Site

Flow (cfs)	Net Q	Sol Δ	Max F
20	2.30%	.000001	0.27
25	1.55%	.000001	0.31
30	0.94%	.000007	0.41
35	1.51%	< .000001	0.43
40	1.18%	< .000001	0.31
45	1.20%	.000002	0.40
50	0.71%	.000006	0.33
60	0.20%	< .000001	0.36
70	0.00%	< .000001	0.37
80	0.31%	.000002	0.65
90	1.31%	.000001	0.41
100	1.57%	< .000001	0.41
110	0.15%	.000002	0.43
130	0.18%	.000006	0.46
150	1.04%	< .000001	0.51
170	0.09%	.000007	0.49
190	0.84%	< .000001	0.51
210	0.51%	< .000001	0.51
230	1.58%	< .000001	0.53
250	1.01%	< .000001	0.55
270	1.22%	.000002	0.58
290	0.05%	< .000001	0.61
310	0.86%	< .000001	0.63
330	0.86%	.000004	0.67
350	1.31%	.000009	0.68
370	0.03%	< .000001	0.70
390	0.15%	< .000001	0.71
410	1.03%	< .000001	0.70
430	0.90%	.000001	0.71
450	0.86%	.000003	0.72

Helltown Bridge Site

Flow (cfs)	Net Q	Sol Δ	Max F
20	1.24%	< .000001	0.89
25	0.85%	.000007	0.99
30	0.47%	.000003	1.00
35	0.40%	.000002	0.93
40	0.35%	.000001	0.96
45	0.31%	< .000001	0.93
50	0.28%	< .000001	0.90
60	0.24%	< .000001	1.84
70	0.20%	< .000001	2.30
80	0.18%	< .000001	2.44
90	0.20%	.000005	2.51
100	0.21%	< .000001	2.60
110	0.22%	< .000001	2.66
130	0.24%	< .000001	2.64
150	0.26%	.000003	2.78
170	0.31%	.000002	3.65
190	0.33%	.000002	5.75
210	0.34%	.000002	5.82
230	0.35%	.000002	7.41
250	0.41%	< .000001	6.93
270	0.38%	.000003	5.37
290	0.39%	.000005	9.20
310	0.38%	.000001	18.75
330	0.45%	.000002	3.25
350	0.44%	.000005	2.90
370	0.49%	.000003	15.72
390	0.45%	.000001	7.49
410	0.44%	.000001	4.32
430	0.43%	.000001	4.07
450	0.41%	.000007	4.52

Homestead Site

Flow (cfs)	Net Q	Sol Δ	Max F
60	2.53%	< .000001	0.47
70	0.71%	< .000001	0.43
80	0.84%	< .000001	0.45
90	0.94%	< .000001	0.43
100	0.88%	.000003	0.42
110	0.71%	< .000001	0.43
120	0.24%	.000006	0.41
130	0.08%	< .000001	0.42
140	0.08%	< .000001	0.40
150	0.05%	< .000001	0.40
170	0.00%	< .000001	0.42
190	0.07%	< .000001	0.41
210	0.12%	< .000001	0.41
230	0.15%	< .000001	0.41
250	0.18%	< .000001	0.41
270	0.20%	< .000001	0.42
290	0.21%	< .000001	0.41
310	0.21%	< .000001	0.42
350	0.21%	< .000001	0.49
390	0.20%	< .000001	0.59
430	0.12%	< .000001	0.67
470	0.14%	< .000001	1.01
510	0.03%	< .000001	0.76
550	0.08%	< .000001	0.74
590	0.19%	< .000001	0.76
630	0.18%	< .000001	0.77
670	0.16%	< .000001	0.77
710	0.14%	< .000001	0.77
750	0.15%	< .000001	0.91
790	0.17%	.000001	0.78

Richbar Site

Flow (cfs)	Net Q	Sol Δ	Max F
60	1.18%	.000003	0.82
70	1.51%	.000001	0.89
80	1.77%	.000002	0.94
90	1.57%	< .000001	0.97
100	1.77%	< .000001	1.02
110	1.61%	< .000001	1.06
120	1.47%	< .000001	1.10
130	1.63%	< .000001	1.13
140	1.51%	< .000001	1.19
150	1.41%	< .000001	1.18
170	1.25%	< .000001	1.22
190	1.30%	< .000001	1.25
210	1.35%	< .000001	1.26
230	1.23%	< .000001	1.27
250	1.13%	< .000001	1.28
270	1.05%	< .000001	1.40
290	0.97%	< .000001	1.27
310	0.91%	< .000001	1.26
350	0.61%	< .000001	1.22
390	0.36%	< .000001	1.17
430	0.08%	< .000001	1.15
470	0.08%	< .000001	1.16
510	0.35%	< .000001	1.46
550	0.51%	< .000001	1.19
590	0.60%	< .000001	1.20
630	0.73%	< .000001	1.19
670	0.84%	< .000001	1.17
710	0.70%	< .000001	1.14
750	0.89%	.000001	1.12
790	0.89%	.000001	1.09

Tailings Site

Flow (cfs)	Net Q	Sol Δ	Max F
60	1.17%	< .000001	0.78
70	1.01%	< .000001	0.80
80	0.88%	< .000001	0.89
90	0.78%	< .000001	0.88
100	0.71%	< .000001	0.87
110	0.64%	< .000001	0.88
120	0.59%	< .000001	1.06
130	0.54%	< .000001	1.05
140	0.52%	< .000001	1.15
150	0.47%	.000006	1.17
170	0.62%	< .000001	1.20
190	0.56%	.000002	1.20
210	0.67%	.000007	1.20
230	0.31%	< .000001	1.20
250	0.14%	< .000001	1.21
270	0.13%	< .000001	1.25
290	0.24%	.000001	1.28
310	0.23%	.000004	1.31
350	0.40%	.000002	1.34
390	0.54%	< .000001	1.35
430	0.33%	< .000001	1.35
470	0.37%	< .000001	1.34
510	0.41%	< .000001	1.32
550	0.45%	< .000001	1.31
590	0.42%	.000006	1.29
630	0.06%	< .000001	1.27
670	0.03%	< .000001	1.25
710	0.06%	.000005	1.23
750	0.07%	< .000001	1.20
790	0.09%	.000003	1.18

APPENDIX H
FINAL BUTTE CREEK SPRING-RUN CHINOOK SALMON SPAWNING HSC

SPRING-RUN CHINOOK SALMON SPAWNING HSC

Water Depth (ft)	SI Value
0	0
0.2	0
0.3	0.16
0.4	0.32
0.5	0.52
0.6	0.71
0.7	0.85
0.8	0.95
0.9	0.99
1	1
4.1	0
100	0

Water Velocity (ft/s)	SI Value
0	0
0.05	0
0.06	0.04
0.1	0.04
0.2	0.07
0.3	0.11
0.4	0.16
0.5	0.23
0.6	0.31
0.7	0.4
0.8	0.5
0.9	0.59
1	0.68
1.1	0.75
1.2	0.82
1.3	0.87
1.4	0.92
1.5	0.95
1.6	0.98
1.7	0.99
1.8	1
1.9	1
2	0.99
2.1	0.98
2.2	0.96
2.3	0.94
2.4	0.9
2.5	0.87
2.6	0.82
2.7	0.78
2.8	0.73
2.9	0.67
3	0.62
3.1	0.56
3.2	0.51
3.3	0.46
3.4	0.4
3.5	0.36
3.6	0.31
3.7	0.27
3.8	0.24
3.81	0
100	0

Substrate Composition	SI Value
0.1	0
1	0
1.2	0.10
1.3	1.00
2.4	0.99
3.5	0.73
4.6	0.47
6.8	0
100	0

APPENDIX I
HABITAT MODELING RESULTS

Spring-run chinook salmon spawning WUA (ft^2) in Above Centerville Powerhouse Reach

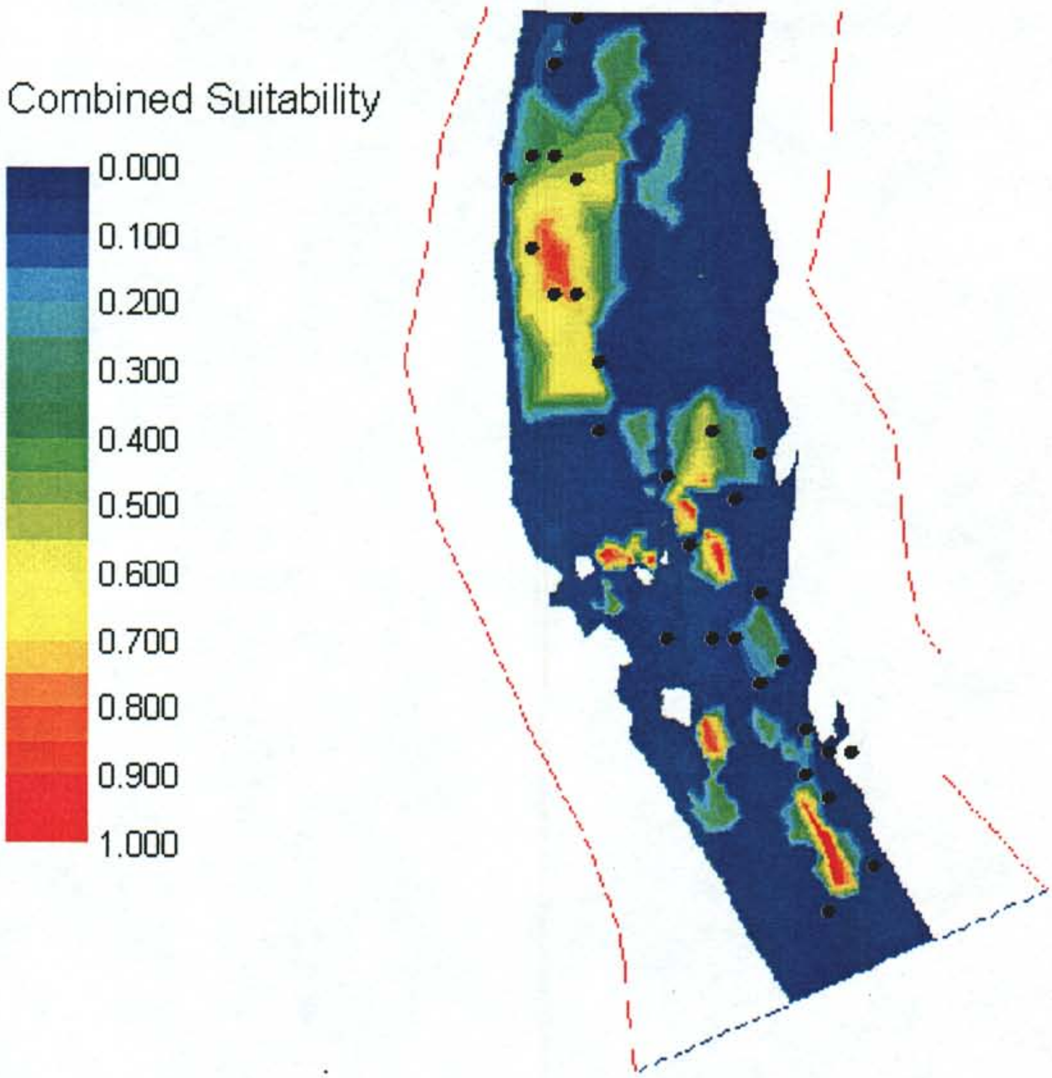
Flow (cfs)	Whiskey Flat	Above Helltown 1	Above Helltown 2	Helltown	Total
20	371	234	951	1751	9560
25	419	287	1076	1963	10822
30	467	341	1188	2164	12021
35	547	446	1415	2540	14300
40	576	503	1518	2644	15145
45	634	613	1711	2791	16615
50	666	669	1805	2847	17303
60	708	848	2093	2965	19112
70	717	982	2371	3082	20668
80	706	1105	2637	4247	25128
90	697	1172	2808	3221	22825
100	688	1258	3071	3327	24114
110	672	1330	3313	3395	25173
130	646	1427	3649	3635	27043
150	603	1490	4042	3771	28630
170	547	1525	4103	3866	29020
190	498	1509	4314	3878	29475
210	460	1504	4455	3845	29665
230	416	1487	4607	3755	29665
250	374	1452	4743	3653	29537
270	339	1434	4863	3619	29635
290	301	1406	5012	3587	29787
310	267	1384	5168	3583	30060
330	240	1365	5290	3613	30369
350	217	1324	5439	3638	30687
370	191	1302	5630	3578	30929
390	168	1279	5755	3518	30981
410	143	1242	5900	3469	31080
430	122	1187	6027	3401	31031
450	106	1158	6131	3336	31012

Spring-run chinook salmon spawning WUA (ft^2) in Below Centerville Powerhouse Reach

Flow (cfs)	Homestead	Richbar	Tailings	Total
60	1569	12895	3299	85615
70	1649	14486	3418	94242
80	1843	15925	3462	102320
90	1922	16804	3462	106937
100	2047	17990	3440	113147
110	2180	19009	3398	118503
120	2271	19848	3357	122790
130	2370	20506	3316	126237
140	2421	20983	3279	128608
150	2469	21218	3264	129897
170	2576	21572	3242	132008
190	2608	21514	3280	132073
210	2622	21186	3346	130876
230	2619	20599	3440	128488
250	2590	19863	3539	125272
270	2567	19189	3641	122409
290	2509	18289	3745	118288
310	2461	17357	3796	113810
350	2319	15547	3903	104919
390	2147	13810	3938	95885
430	1945	11903	3893	85505
470	1759	10217	3804	76057
510	1596	8721	3659	67360
550	1422	7279	3434	58489
590	1285	6072	3176	50764
630	1160	4984	2883	43507
670	1039	3951	3546	36318
710	939	3112	2250	30369
750	841	2524	1979	25756
790	753	2081	1697	21837

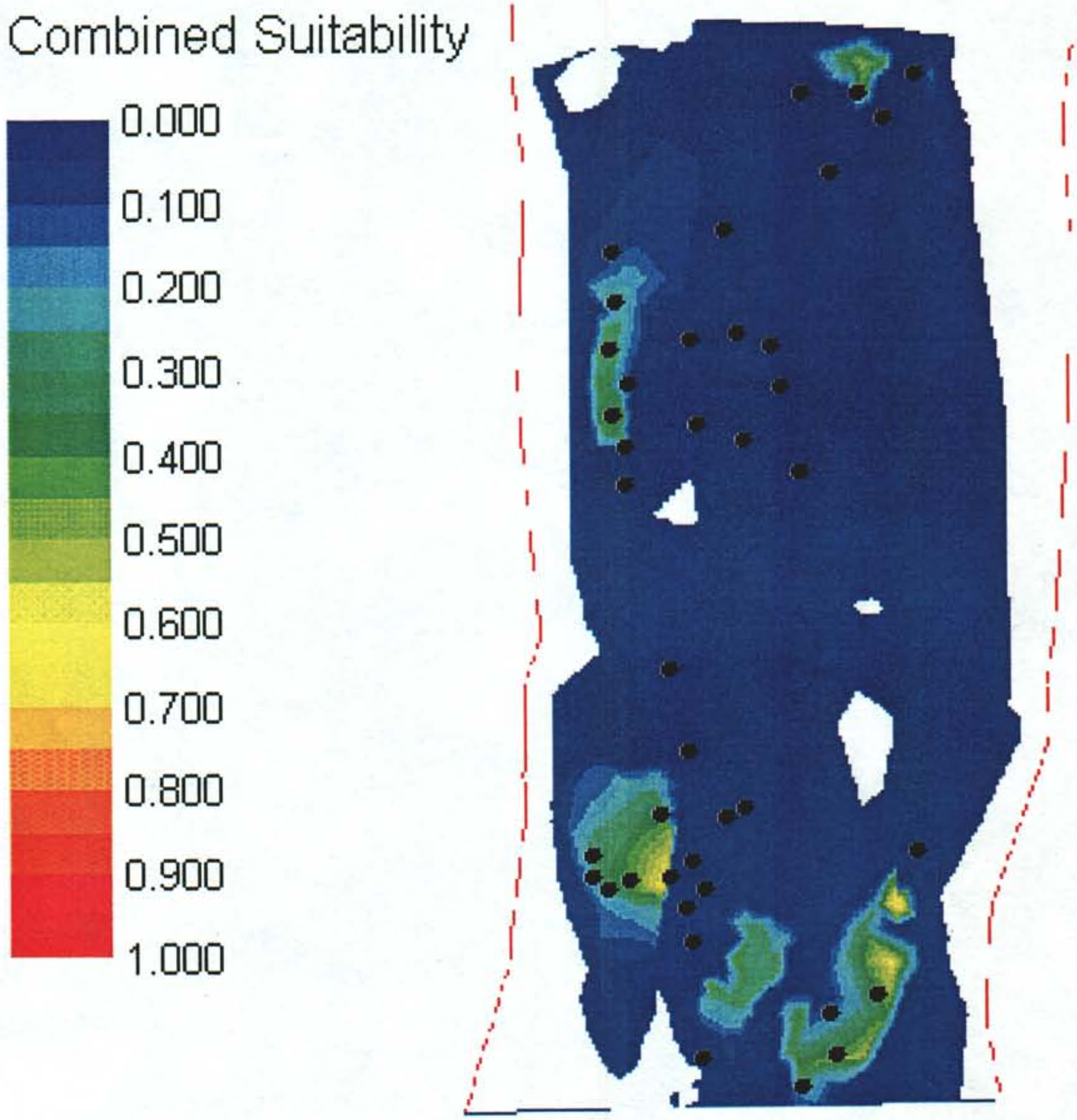
APPENDIX J
RIVER2D COMBINED SUITABILITY OF REDD LOCATIONS

WHISKEY FLAT STUDY SITE



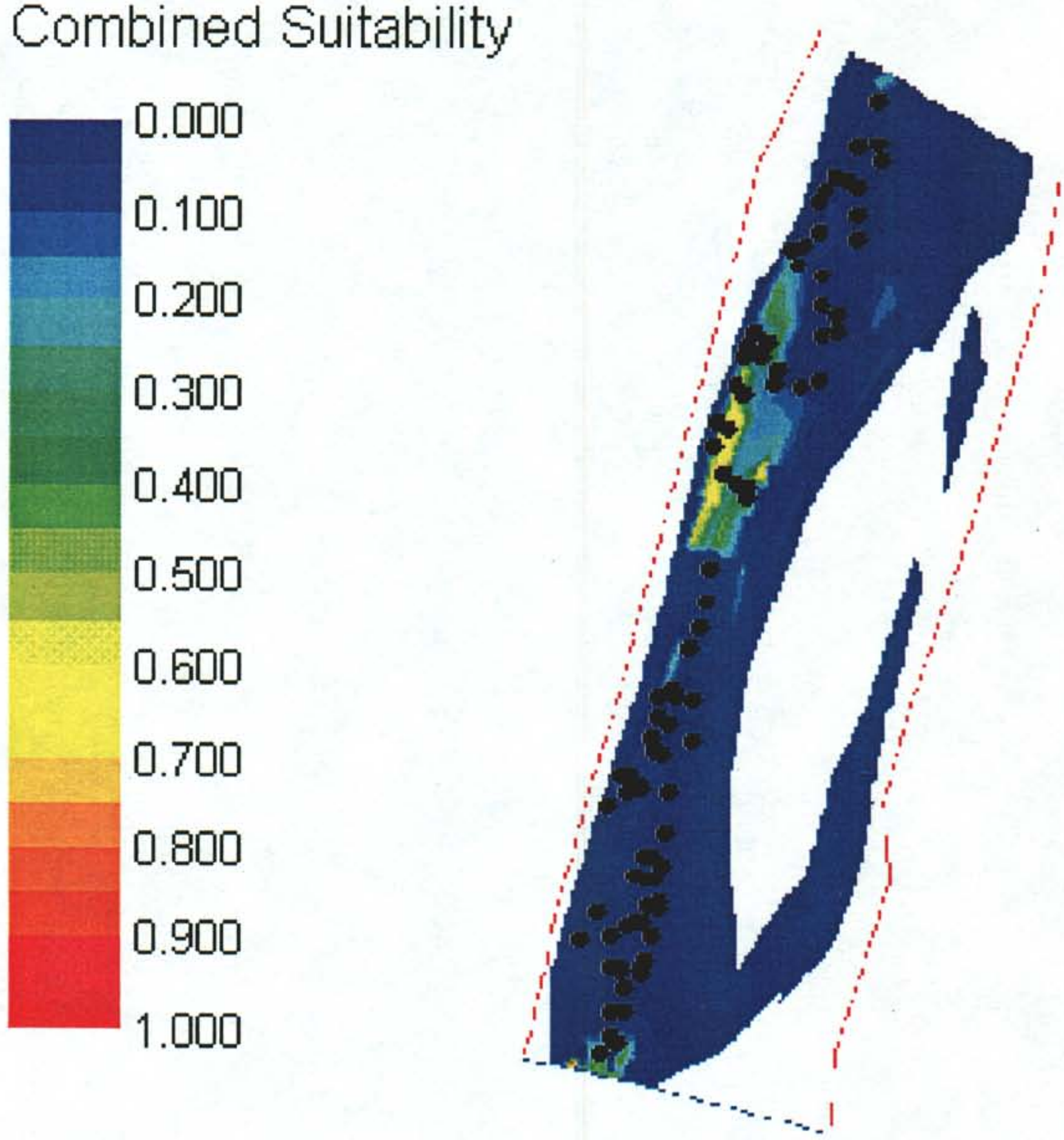
Redd locations: ●

ABOVE HELLTOWN 1 STUDY SITE



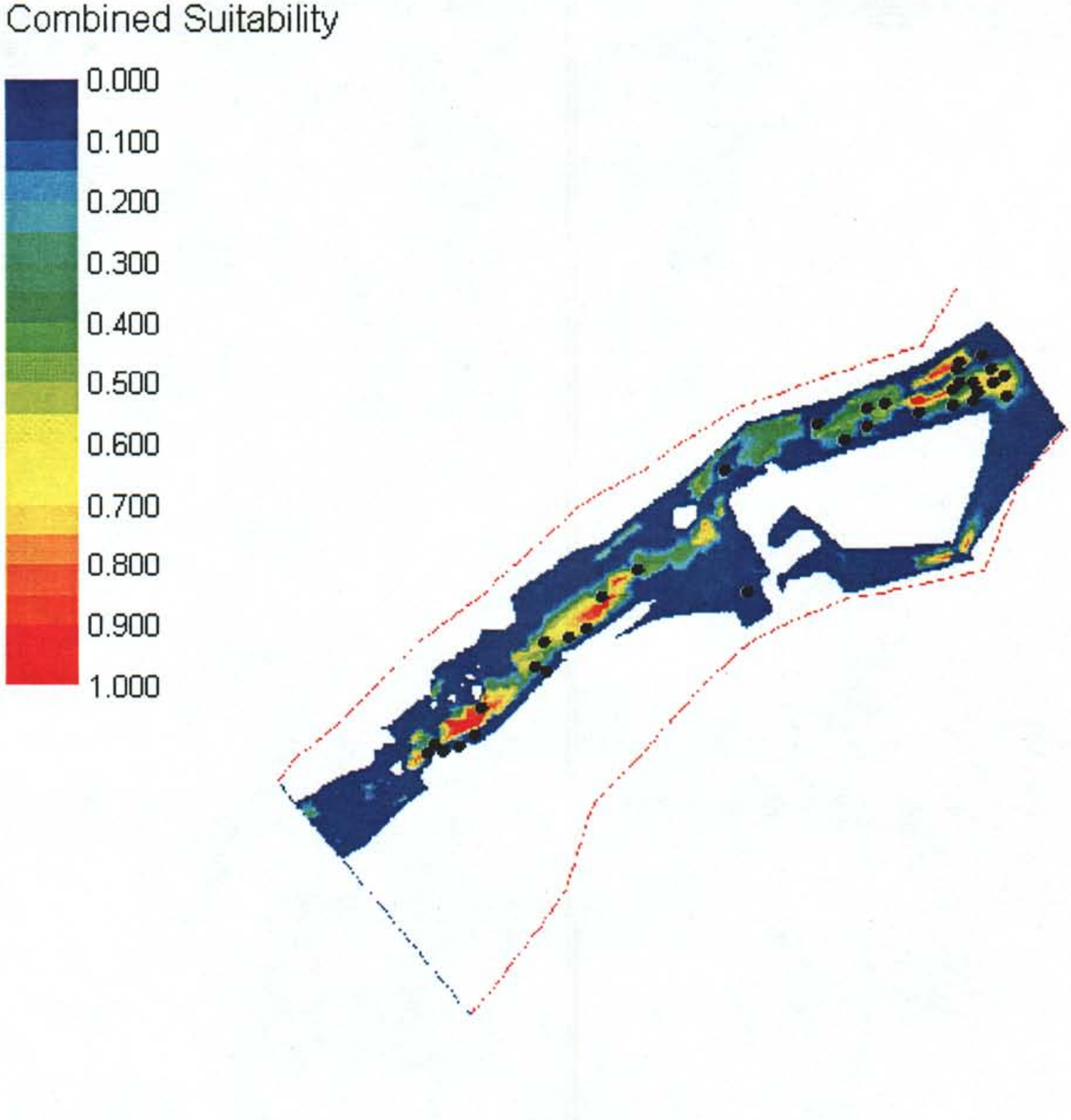
Redd locations: ●

ABOVE HELLTOWN 2 STUDY SITE



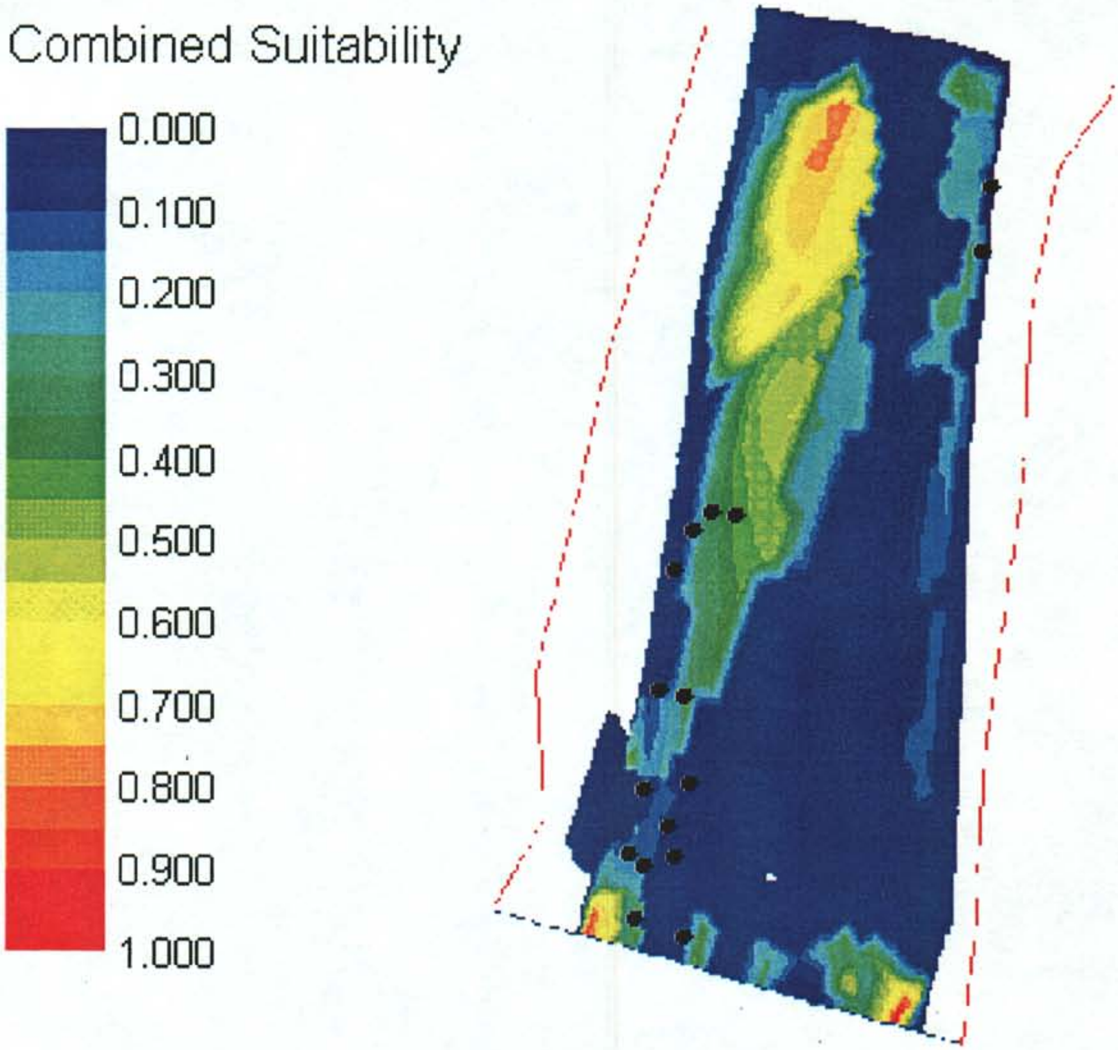
Redd locations: ●

HELLTOWN STUDY SITE



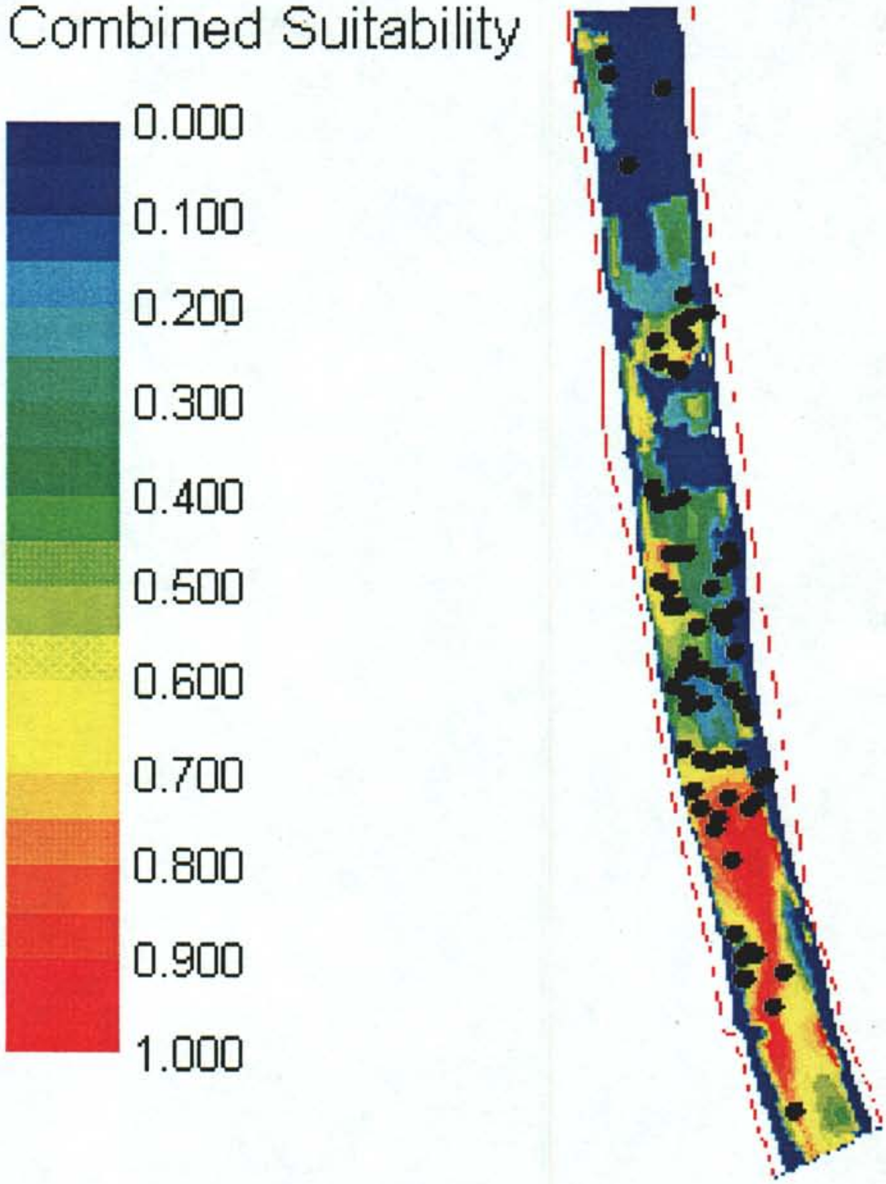
Redd locations: ●

HOMESTEAD STUDY SITE



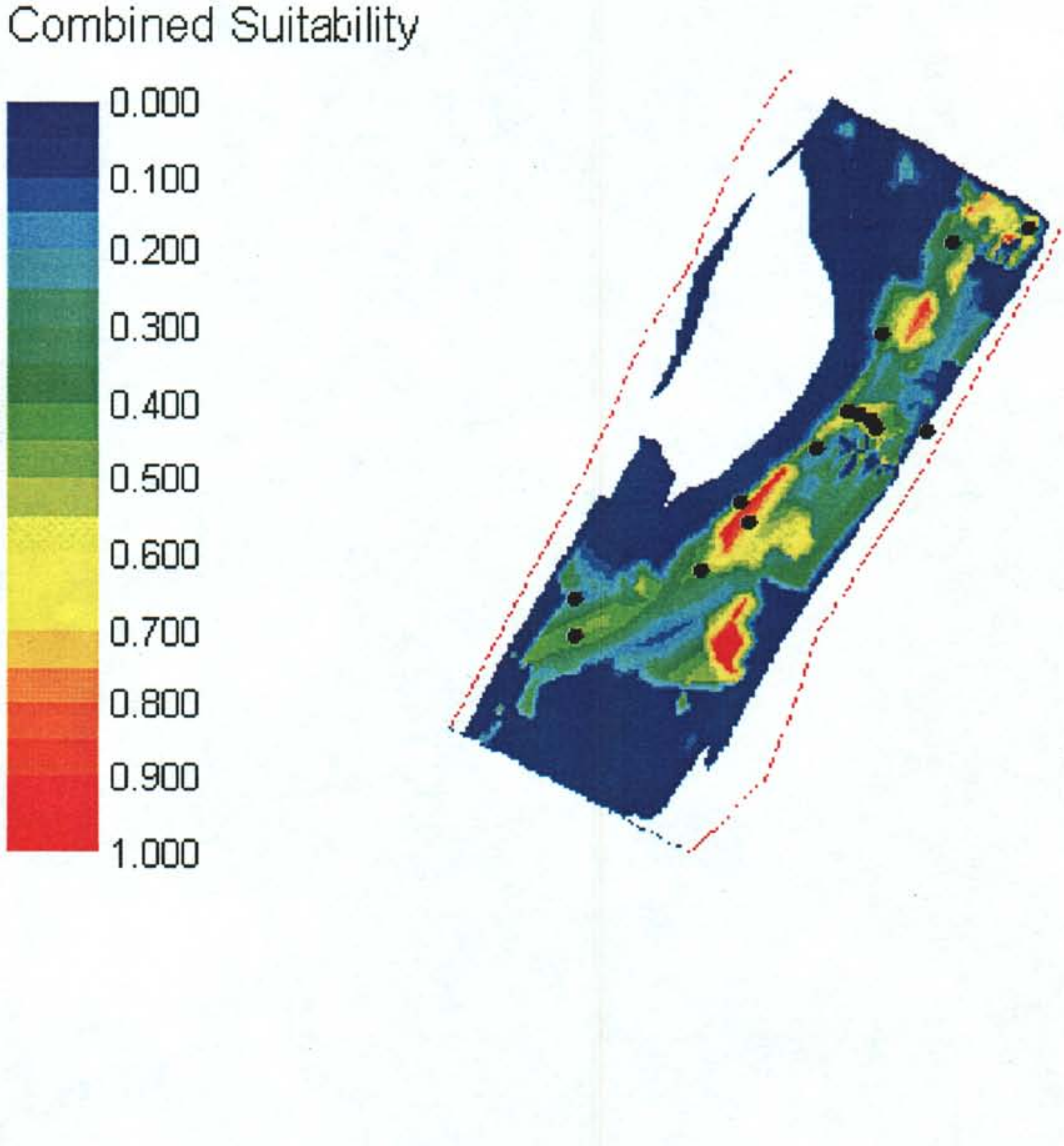
Redd locations: ●

RICHBAR STUDY SITE



Redd locations: ●

TAILINGS STUDY SITE



Redd locations: ●