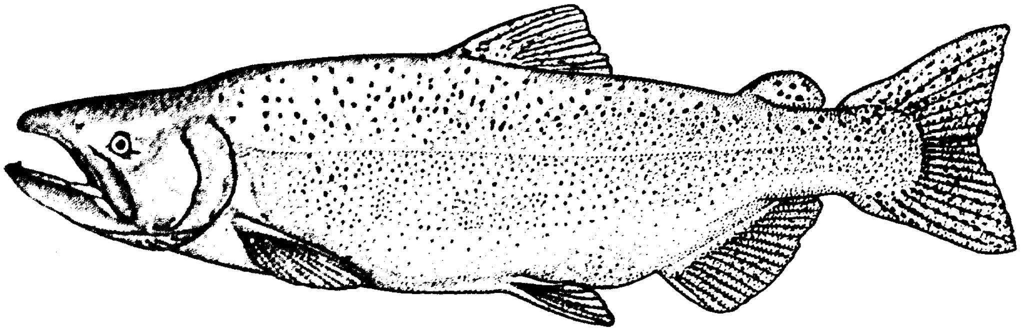
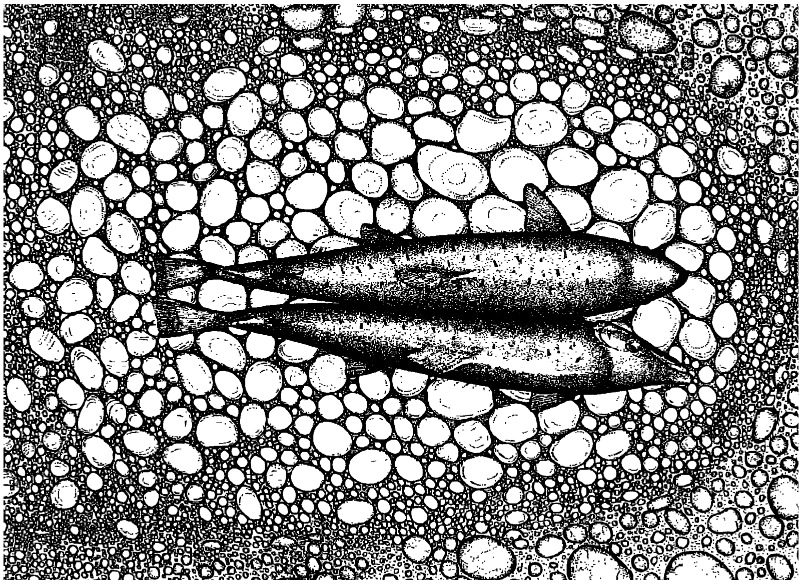
# FLOW-HABITAT RELATIONSHIPS FOR SPRING AND FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING IN THE YUBA RIVER





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# CVPIA INSTREAM FLOW INVESTIGATIONS
# YUBA RIVER SPRING AND FALL-RUN CHINOOK SALMON AND STEELHEAD/RAINBOW TROUT SPAWNING HABITAT

## PREFACE

The following is the final report for the U.S. Fish and Wildlife Service's investigations on anadromous salmonid spawning habitat in the Yuba River between Englebright Dam and the Feather River, part of the Central Valley Project Improvement Act (CVPIA) Instream Flow Investigations, a 6-year effort which began in October, 2001.[1] Title 34, Section 3406(b)(1)(B) of the CVPIA, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U.S. Fish and Wildlife Service after consultation with the California Department of Fish and Game. The purpose of these investigations is to provide scientific information to the U.S. Fish and Wildlife Service Central Valley Project Improvement Act Program to assist in developing such recommendations for Central Valley rivers.

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

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

# ACKNOWLEDGMENTS

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# ABSTRACT

Flow-habitat relationships were derived for spring and fall-run Chinook salmon and steelhead/rainbow trout spawning in the Yuba River between Englebright Dam and the Feather River. A 2-dimensional hydraulic and habitat model (RIVER2D) was used for this study to model available habitat. Habitat was modeled for sites upstream and downstream of Daguerre Point Dam which were among those which received the heaviest use by spawning spring-run and fall-run Chinook salmon and steelhead/rainbow trout. Model inputs included bed topography and additional data to develop stage-discharge relationships at the upstream and downstream end of the sites. Velocities measured in the sites were used to validate the velocity predictions of RIVER2D. Habitat suitability criteria (HSC) were developed from depth, velocity and substrate measurements collected on 168 spring-run Chinook salmon redds, 870 fall-run Chinook salmon redds, and 184 steelhead/rainbow trout redds. The horizontal location of a subset of these redds, located in the study sites, was measured with a total station to use in biological verification of the habitat models. Logistic regression, along with a technique to adjust spawning depth habitat utilization curves to account for low availability of deep waters with suitable velocities and substrates (Gard 1998), was used to develop the depth and velocity HSC. The HSC had optimal velocities ranging from 1.5 to 1.7 feet/sec (0.457 to 0.518 m/s) for fall-run Chinook salmon to 2.6 to 2.9 feet/sec (0.792 to 0.884 m/s) for steelhead/rainbow trout, optimal depths ranging from 1.4 feet (0.43 m) for fall-run Chinook salmon to 7.0 to 16.9 feet (2.13 to 5.15 m) for steelhead/rainbow trout, and optimal substrate sizes of 1-2 inches (2.5-5 cm) for steelhead/rainbow trout to 2-4 inches (5-10 cm) for spring and fall-run Chinook salmon. Flows with the most amount of spawning habitat ranged from 900 cfs for spring-run Chinook salmon downstream of Daguerre Point Dam to 3,700 cfs for steelhead/rainbow trout downstream of Daguerre Point Dam. Differences between the HSC from this study and other studies are likely primarily due to the methods used in the other studies underestimating the suitability of deeper and faster conditions because they did not take availability into account. The flow-habitat relationships from this study, predicting greater amounts of habitat at all flows and a peak amount of habitat at higher flows than an earlier instream flow study in the mid-1980's on the Yuba River, likely reflect the differences in the criteria between the two studies, the use of River2D in this study and modeling only high-use spawning areas in this study. The improvement of the techniques for performing instream flow studies since the 1980's have increased the accuracy of habitat predictions and better reflect the hydraulic complexities of river channels.

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# INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act provided for enactment of all reasonable efforts to double sustainable natural production of anadromous fish stocks including the four races of Chinook salmon (fall, late-fall, winter, and spring-runs), steelhead, white and green sturgeon, American shad and striped bass in the Central Valley of California. The Yuba River is a major tributary of the Feather River, located in the Sacramento River basin portion of the Central Valley of California. The focus of the Yuba River study was the reach between Englebright Dam and the Feather River, the only portion of the Yuba River accessible for spring and fall-run Chinook salmon and steelhead spawning. For the Yuba River downstream of Englebright Dam, the Central Valley Project Improvement Act Anadromous Doubling Plan calls for improved flows for all life history stages of Chinook salmon and steelhead (U.S. Fish and Wildlife Service 1995) as a high priority action to restore anadromous fish populations in the Yuba River. Subsequently, Yuba County Water Agency, collaboratively with the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, the California Department of Fish and Game and Non-Governmental Organizations, diligently worked to develop a comprehensive set of improved flow regimes, which now are the Flow Schedules of the Lower Yuba River Accord (HDR/SWRI 2007).

In June 2001, 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 the Yuba River. The Yuba River was selected for study because of a number of factors, including the presence of listed threatened or endangered species, the number of target species or races, whether current instream flows were inadequate and if there was an upcoming hydroelectric project relicensing. The goal of this study was to produce models predicting habitat-discharge relationships in the Yuba River for spring and fall-run Chinook salmon and steelhead/rainbow trout spawning that meet, to the extent feasible, the levels of accuracy specified in the methods section. The tasks and their associated objectives are given in Table 1.

To develop a flow regime which will accommodate the habitat needs of anadromous species inhabiting streams, it is necessary to determine the relationship between streamflow and habitat availability for each life stage of those species. We are using the models and techniques contained within the Instream Flow Incremental Methodology (IFIM) to establish these relationships. The IFIM is a habitat-based tool developed by the U.S. Fish and Wildlife Service to assess instream flow problems (Bovee 1996). The decision variable generated by the IFIM is total habitat, in units of Weighted Useable Area (WUA), for each life stage (fry, juvenile and spawning) of each evaluation species (or race as applied to Chinook salmon). Habitat incorporates both macro- and microhabitat features. Macrohabitat features, with a spatial scale of 10 to 100 km, include longitudinal changes in channel characteristics, base flow, water quality, and water temperature. Microhabitat features, with a spatial scale of 1 to 5 m, include the

Table 1. Study tasks and associated objectives.

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

hydraulic and structural conditions (depth, velocity, substrate or cover) which define the actual living space of the organisms. The total habitat available to a species/life stage at any streamflow is the area of overlap between available microhabitat and suitable macrohabitat conditions.

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

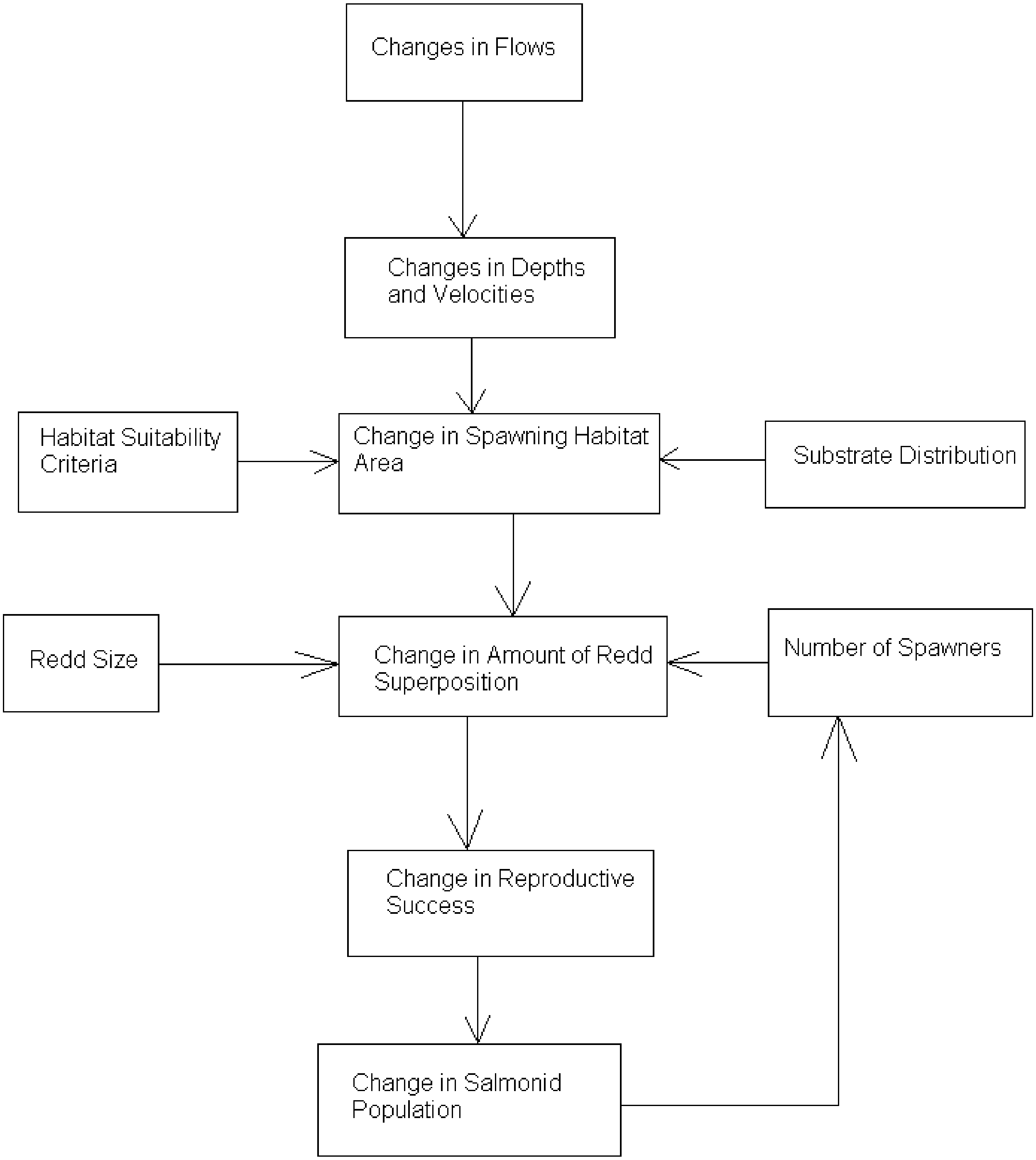

Figure 1. Conceptual model of the linkage between flow and salmonid populations.

reproductive success through the use of habitat of different suitability or alterations in the amount of redd superimposition. These alterations in reproductive success could ultimately result in changes in salmonid populations.

There are a variety of alternative techniques available to quantify the functional relationship between flow and spawning habitat availability, but they can be broken down into three general categories: 1) biological response correlations; 2) demonstration flow assessment; and 3) habitat modeling (Annear et al. 2002). Biological response correlations can be used to evaluate spawning habitat by directly examining the degree of redd superimposition at different flows in a stream of interest (Snider et al. 1996). However, this method requires many years of data collected at intermediate levels of spawning – at low spawning levels, there will not be any redd superimposition even at low habitat levels, while at high spawning levels, the amount of superimposition cannot be determined because individual redds can no longer be identified. Redd surveys presently are being conducted for the second year as part of the Lower Yuba River Accord. Although these data are expected to provide insight into salmonid spawning habitat use, they are too limited to use for determining instream flow needs. Demonstration flow assessments (CIFGS 2003) likewise use direct observation of river habitat conditions at several flows; at each flow, polygons of habitat are delineated in the field. Because the flow regime in the lower Yuba River is set by Federal Energy Regulatory Commission license requirements and water delivery demands made on the Yuba County Water Agency, demonstration flows cannot be conducted. Therefore, we chose to conduct habitat modeling for the lower Yuba River under a range of flows using data collected from representative study sites in the river. Modeling approaches are widely used to assess the effects of instream flows on fish habitat availability despite potential assumption, sampling, and measurement errors that, as in the other methods described above, can contribute to the uncertainty of results.

The range of Yuba River flows to be evaluated for management generally is 150 cubic feet per second (cfs) downstream of Daguerre Point Dam (the lowest flow in the Yuba River Accord) and 400 cfs upstream of Daguerre Point Dam (the current State Water Resources Control Board minimum flow) to 4,170 cfs (the combined capacity of Narrows I and II). Accordingly, the range of study flows encompasses the range of flows to be evaluated for management. The assumptions of this study are: 1) that physical habitat is the limiting factor for salmonid populations in the Yuba River; 2) that spawning habitat quality can be characterized by depth, velocity and substrate; 3) that the depths and velocities present during Habitat Suitability Index (HSI) data collection were the same as when the redds were constructed; 4) any steelhead/rainbow trout redds that we measured in our surveys were constructed during the 30 days prior to the survey dates based on the assumption that redds would not appear fresh after that time period; 5) that the ten study sites are representative of anadromous salmonid spawning habitat in the Yuba River; 6) that theoretical equations of physical processes along with a description of stream bathymetry provide sufficient input to simulate velocity distributions through a study site; and 7) that the Yuba River is in dynamic equilibrium.

## METHODS

### *Approach*

RIVER2D (Steffler and Blackburn 2002), a two-dimensional (2-D) hydraulic and habitat model, was used for predicting Weighted Useable Area (WUA), instead of the Physical Habitat Simulation (PHABSIM[2]) used in some of our earlier studies (e.g., USFWS 2000). Two-dimensional model inputs include the bed topography (i.e., representing channel volume and directionality) and bed roughness (i.e., representing the frictional effect of the streambed substrate and cover on flow), and the water surface elevation at the downstream end of the site. The amount of habitat present in the site is computed using the depths and velocities predicted by the 2-D model, and the substrate present in the site. The 2-D model avoids problems of transect placement, since data are collected uniformly across the entire site (Gard 2009). 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 Equation and a velocity adjustment factor (Leclerc et al. 1995). Other advantages of 2-D compared to 1-D modeling are that it can explicitly handle complex hydraulics, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions (Ghanem et al. 1996, Crowder and Diplas 2000, Pasternack et al. 2004). With appropriate bathymetry data, the model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. The 2-D model, with compact cells, should be more accurate than PHABSIM, with long rectangular cells, in capturing longitudinal variation in depth, velocity and substrate. The 2-D model should do 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 up- and downstream ends of the site and flow, and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

We did use PHABSIM to model transects at the upstream and downstream ends of the study sites to provide water surface elevations as an input to RIVER2D (Figure 2). By calibrating the upstream and downstream transects with PHABSIM using the collected calibration water surface elevations (WSELs), we could then predict the WSELs for the various simulation flows that were

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

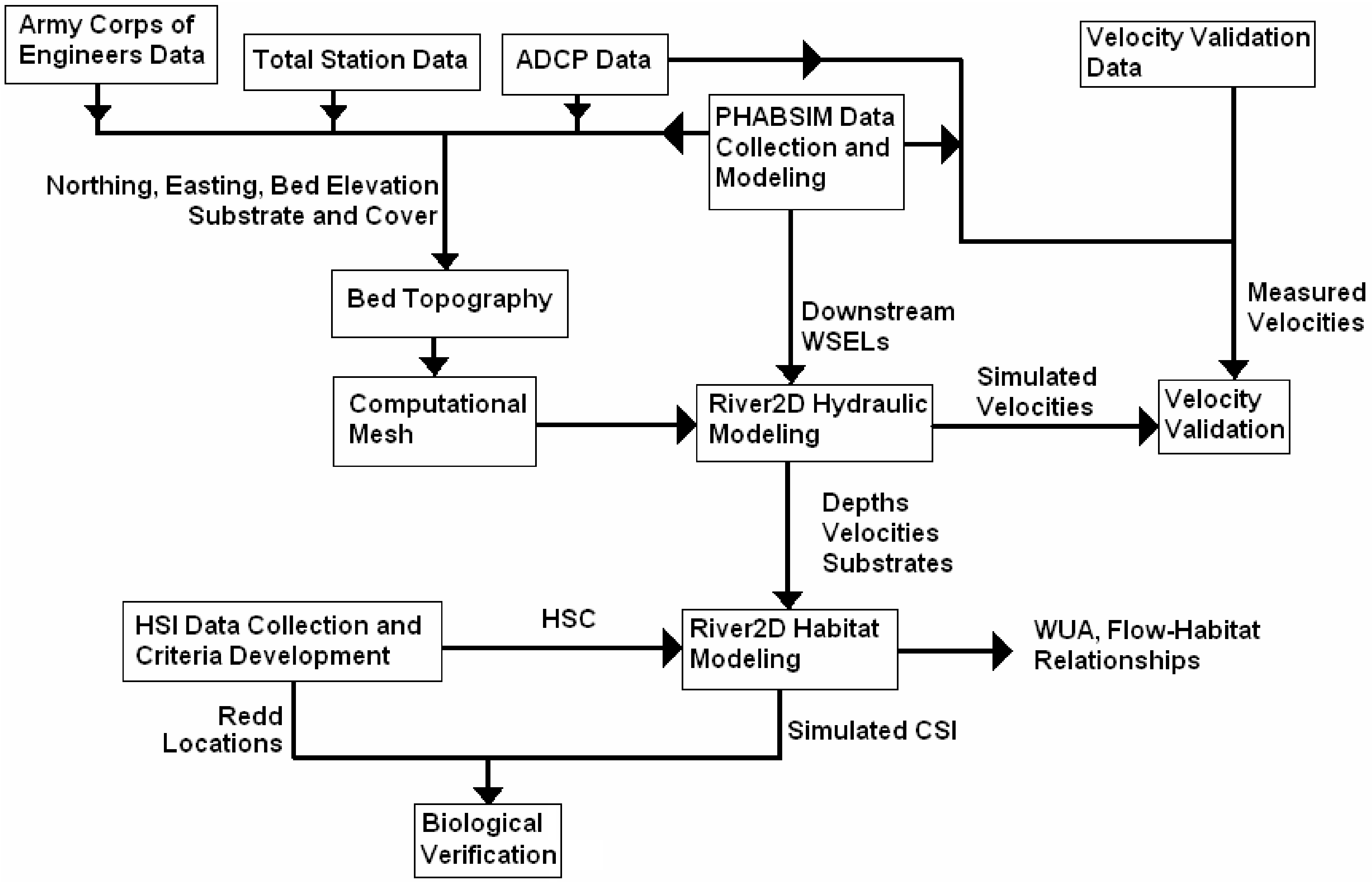

Figure 2. Flow diagram of data collection and modeling.

to be modeled using RIVER2D. We then calibrated the RIVER2D models using the highest simulation flow. The highest simulation WSELs predicted by PHABSIM for the upstream and downstream transects could be used for the upstream boundary condition (in addition to flow) and the downstream boundary condition. The PHABSIM-predicted WSEL for the upstream transect at the highest simulation flow was used to ascertain calibration of the RIVER2D model at the highest simulation flow. After the RIVER2D model was calibrated at the highest simulation flow, the WSELs predicted by PHABSIM for the downstream transect for each simulation flow were used for the downstream boundary conditions for RIVER2D simulation flows.

Traditionally, habitat suitability 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 actively selecting areas without that substrate size. Guay et al. (2000) proposed a modification of the above technique where depth, velocity, and substrate data are collected both in locations where redds are present and in locations where redds are absent, and a logistic regression is used to develop the criteria.

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

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

### *Study Segment Delineation*

Study segments were delineated within the study reach of the Yuba River between Englebright Dam and the Feather River (Figure 3) based on differences in flow. Flow data are available for six United States Geological Survey (USGS) gages within the study reach: Yuba River at Smartville (USGS gage # 11418000), Deer Creek (USGS gage # 11418500), Browns Valley Diversion (USGS gage # 11420750), Brophy Diversion (USGS gage # 11420760), Hallwood-Cordua Diversion (USGS gage # 11420770) and Yuba River at Marysville (USGS gage # 11421000). Flow data are available for all six gages for the period January 1971 to November

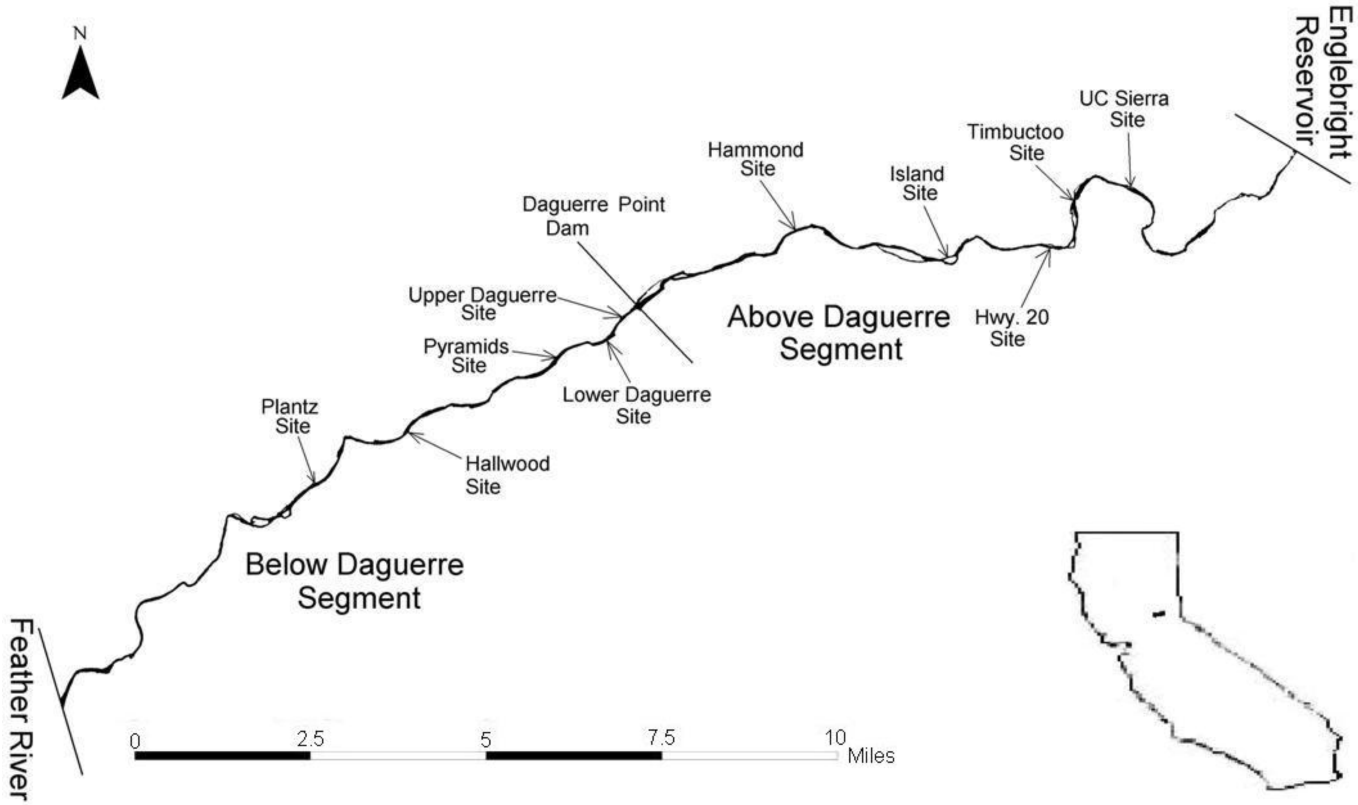

Figure 3. Yuba River stream segments and spawning study sites. See Appendix A for the spatial extent of each study site.

2000. Flows for the Yuba River downstream of Deer Creek were calculated by adding Deer Creek gage flows to Smartville gage flows. Flows for the Yuba River downstream of Browns Valley Diversion were calculated by subtracting Browns Valley gage diversion flows from Yuba River flows below Deer Creek. Flows for the Yuba River downstream of Daguerre Point Dam were calculated by subtracting gage flows for Brophy and Hallwood-Cordua Diversions from the Yuba River flow downstream of the Browns Valley Diversion.

### *Field Reconnaissance and Study Site Selection*

We began preliminary work of determining spring-run Chinook salmon spawning locations on September 21, 2001. This work consisted of floating downstream from U.C. Sierra Research Station to Daguerre Point Dam and recording with a Global Positioning System (GPS) unit the locations and approximate numbers of spring-run Chinook salmon redds observed. These data were collected in order to select study sites based on heaviest spawning use. We collected the same data in November and December 2001 for fall-run Chinook salmon redds between the downstream end of the Narrows (river mile 21.9) and Simpson Lane Bridge (river mile 1.8 - downstream extent of Chinook salmon spawning habitat). For fall-run Chinook salmon redds, we also visually estimated redd superimposition and periodically recorded water temperature.

The observations made in 2001 for spawning spring-run and fall-run Chinook salmon were combined in a Geographic Information System (GIS) analysis with data collected in 2000 on fall-run Chinook salmon and steelhead/rainbow trout spawning by Jones and Stokes Associates, Inc. biologists. Study sites selected correspond to those areas which received the heaviest use by spring-run and fall-run Chinook salmon and steelhead/rainbow trout. 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 request permission for entry onto their property during the course of the study.

### *Transect Placement (study site set-up)*

Ten study sites (Figure 3) were established March-June 2002. The study site boundaries (upstream and downstream ends) were selected to coincide with the upstream and downstream boundaries of the heavy spawning use areas[3]. The location of these boundaries was established during site setup by navigating to the points marked with the GPS unit during our redd counts in September and November-December 2001 and the mapped locations of fall-run Chinook salmon and steelhead/rainbow trout redds recorded by Jones and Stokes Associates, Inc. biologists.

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[3] In some cases, the top of the site was moved upstream and/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 transect).

For each study site, a transect was placed at the upstream and downstream end of the site. The downstream transect was modeled with PHABSIM to provide WSELs as an input to the 2-D model. The upstream transect was used in calibrating the 2-D model - bed roughnesses are adjusted until the WSEL at the top of the site matches the WSEL predicted by PHABSIM. Transect pins (headpins and tailpins) were installed on each river bank above the 7,000 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Survey flagging was used to mark the locations of each pin.

*Hydraulic and Structural Habitat Data Collection*

The precision and accuracy of the field equipment used for the hydraulic and structural data collection is given in Table 2. 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 were tied together, using differential leveling, to achieve a level loop accuracy (ft) of at least 0.05 x (level loop distance [mi]) $^{0.5}$. Vertical benchmarks consisted of lag bolts driven into trees or painted bedrock points. In addition, horizontal benchmarks (rebar driven into the ground) were established at each site for total station placement to serve as the reference locations to which all horizontal locations (northings and eastings) were tied when collecting bed topography data. The precise northing and easting coordinates and vertical elevations of two horizontal benchmarks were established for each site by the U.S. Bureau of Reclamation using dual frequency survey-grade differential GPS. The elevations of these benchmarks were tied into the vertical benchmarks on our sites using differential leveling. Collection of site bed topography data relative to these values were used primarily to enable the incorporation of bed topography data collected for the Yuba River by the U.S. Army Corps of Engineers (Corps) using photogrammetry and hydro-acoustic mapping.

Hydraulic and structural data collection began in March 2002 and was completed in November 2003 for the 10 sites that were established in 2002. The data collected at the inflow and outflow transects included: 1) WSELs measured to the nearest 0.01 foot (0.003 m) at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot (0.031 m); 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate and cover[4] classification at these same locations (Tables 3 and 4) and also where dry ground elevations were surveyed.

When conditions allowed, WSELs were measured along both banks and in the middle of each transect. Otherwise, the WSELs were measured along both banks. If the WSELs measured for a transect were within 0.1 foot (0.031 m) of each other, the WSELs at each transect were then

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[4] Cover types were only used to calculate bed roughness.

Table 2. Precision and accuracy of field equipment (+- 1 SD). The precision of the ADCP (Acoustic Doppler Current Profiler) is the statistical uncertainty (1 σ) of the horizontal velocities, and varies depending on the depth cell size, number of pings and mode. The low end of the precision range is for a depth cell size of 0.2 m with 4 pings, while the upper end of the range is for a depth cell size of 0.1 m with 4 pings. A blank means that that information is not available.

| Equipment | Parameter | Precision | Accuracy |
|---|---|---|---|
| ADCP | Velocity | 15.5 – 37 cm/s | 0.2% ± 0.2 cm/s |
| ADCP | Depth | | 4% |
| Marsh-McBirney | Velocity | | ± 2% + 1.5 cm/s |
| Price AA | Velocity | | ± 6% at 7.6 cm/s to<br>± 1.5% at vel > 46 cm/s |
| Total Station | Slope Distance | ± (5ppm + 5) mm | |
| Total Station | Angle | | 4 sec |
| Electronic Distance Meter | Slope Distance | | 1.5 cm |
| Autolevel | Elevation | | 0.3 cm |
| GPS | Horizontal Location | | 3 – 7 m |

derived by averaging the two to three values. If the WSEL differed by greater than 0.1 foot (0.031 m), the WSEL for the transect was selected based on which side of the transect was considered most representative of the flow conditions.

Depth and velocity measurements in portions of the transects with depths greater than 3 feet (0.9 m) were made with a RD Instruments$^R$ Broad-Band Acoustic Doppler Current Profiler (ADCP) mounted on a boat, whereas depth and velocity measurements in shallower areas were made by wading with a wading rod equipped with a Marsh-McBirney$^R$ model 2000 or Price AA velocity meter until the water became sufficiently deep to operate the ADCP (approximately 3 feet [0.9 m]). The ADCP settings used are shown in Table 5. The distance intervals of each depth and velocity measurement from the headpin or tailpin were measured using a hand held laser range finder[5]. At the location of the last depth and velocity measurement made while wading, a buoy was placed to serve as a starting point for the ADCP. The boat was then positioned so that the ADCP started operation at the buoy, and water depth and velocity data were collected across the transect up to the location near the opposite bank where water depths of approximately 3 feet (0.9 m) were reached. A buoy was placed at the location where ADCP operation ceased and the procedure used for measuring depths and velocities in shallow water was repeated until the far

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

Table 3. Substrate codes, descriptors and particle sizes.

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

bank water's edge was reached. Additional details on the ADCP operation are given in Gard and Ballard (2003). All substrate and cover data on the transects were assessed by one observer based on the visually-estimated average of multiple grains.

Data collected between the transects included: 1) bed elevation; 2) northing and easting (horizontal location); 3) substrate; and 4) cover. These parameters were collected at enough points to characterize the bed topography, substrate and cover of the sites. We used two techniques to collect the data between the upstream and downstream transects: 1) for areas that were dry or shallow (less than three feet [0.9 m]), bed elevation and horizontal location of individual points were obtained with a total station, whereas the substrate and cover values were assessed by one observer based on the visually-estimated average of multiple grains at each point; and 2) in portions of the site with depths greater than three feet (0.9 m), the ADCP was used in concert with the total station to obtain bed elevation and horizontal location. Specifically, the ADCP was driven by boat across the channel at 50 to 150-foot (15 to 45 m) intervals, with the initial and final horizontal location of each traverse[6] measured by the total

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[6] A traverse refers to a set of data collected each time the ADCP is driven across the channel.

Table 4. Cover coding system.

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

Table 5. CFG[7] files used for ADCP data. The first four characters of the ADCP traverse designates which CFG file (containing the ADCP settings) was used for the traverses. WT is the water track transmit length.

| CFG File | Mode | Depth Cell Size (cm) | Depth Cell Number | Max Bottom Track (m) | Pings | WT | First Depth Cell (m) | Blanking Dist. (cm) |
|---|---|---|---|---|---|---|---|---|
| MD8A | 8 | 20 | 15 | 7.9 | 4 | 5 | 0.49 | 10 |
| MD4C | 4 | 10 | 30 | 7.9 | 4 | 5 | 0.46 | 10 |
| MD4A | 4 | 20 | 15 | 7.9 | 4 | 5 | 0.56 | 10 |
| MD1D | 1 | 10 | 60 | 7.9 | 10 | 5 | 1.87 | 10 |

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[7] CFG is an acronym for Configuration File.

station. The WSEL of each ADCP traverse was measured with the level before starting the traverse. The WSEL of each traverse was then used together with the depths from the ADCP to determine the bed elevation of each point along the traverse. For the collection of the substrate and cover data on the ADCP traverses for the sites, the initial and final locations of each deep bed elevation traverse were marked with buoys prior to the ACDP traverses. The substrate and cover values were assessed by one observer based on the visually-estimated average of multiple grains, and a laser range finder was used to measure the points along the ADCP traverses where transitions in substrate and cover occurred so that values could be assigned to each point of the traverse.

Velocities at each point measured by the ADCP were used to validate the 2-D model by comparison with predicted velocities for deep areas within a site. To validate the velocities predicted by the 2-D model for shallow areas within a site, depth, velocity, substrate, and cover measurements were collected along the right and left banks within each site by wading with a wading rod equipped with a Marsh-McBirney$^R$ model 2000 or a Price AA velocity meter. These validation velocities and the velocities measured on the transects described previously were collected using the standard practice of measurement 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 25 representative points were measured along the length of each side of the river per site, for a total of 50 points per site. Velocity data collected on the PHABSIM transects in depths of approximately 3 feet (0.9 m) or less where the ADCP could not be utilized were also used to validate the velocities predicted for shallow areas within the site.

For sites where there was a gradual gradient change in the vicinity of the downstream transect, there could be a point in the thalweg a short way downstream of the site that was higher than that measured at the downstream transect thalweg simply due to natural variation in topography (Figure 4). This stage of zero flow downstream of the site acts as a control on the water surface elevations at the downstream transect, and could cause errors in the WSELs. Because the true stage of zero flow is needed to accurately calibrate the water surface elevations on the downstream transect, this stage of zero flow in the thalweg downstream of the downstream transect was surveyed in using differential leveling. If the true stage of zero flow was not measured as described above, the default stage of zero flow would be the thalweg elevation at the transect.

Under some flow conditions, water from the Yuba River diverts just upstream of Daguerre Point Dam into an adjacent area of land that has undergone extensive mining, known as the Goldfields. This water then returns to the Yuba River at RM 9.75. Flows for sites located between Daguerre Point Dam and the location where flows return from the Goldfields are equal to the flow at the Marysville gage minus the flow returning from the Goldfields. Accordingly, we measured the flow coming out of the Goldfields under four different flow conditions to use in developing a relationship between the flow coming out of the Goldfields and gage flows.

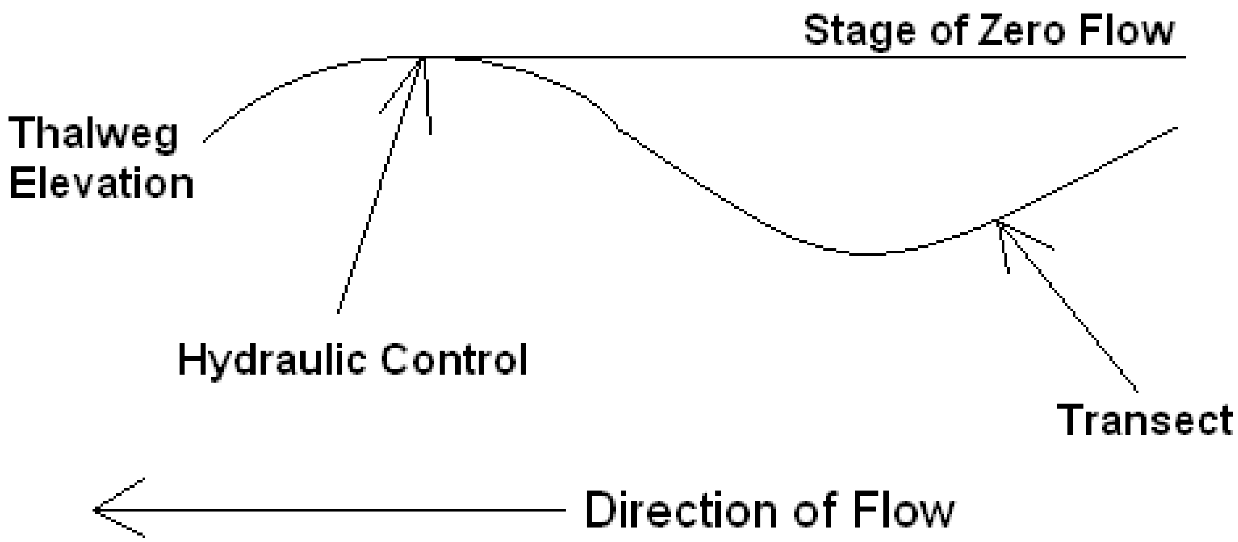

Figure 4. Stage of zero flow diagram.

*Hydraulic Model Construction and Calibration*

**PHABSIM WSEL Calibration**

All data were compiled and checked before entry into PHABSIM files for the upstream and downstream transects. American Standard Code for Information Interchange (ASCII) files of each ADCP traverse were produced using the Playback feature of the Transect program[8]. Each ASCII file was then imported into RHABSIM Version 2.0[9] to produce the bed elevations, average water column velocities, and stations (relative to the start of the ADCP traverse). RHABSIM was then used to output a second ASCII file containing this data. The second ASCII file was input into an Excel spreadsheet and combined with the velocity, depth, and station data collected in shallow water. Gard and Ballard (2003) defined a statistic (R) to provide a quality control check of the velocity measured by the ADCP at a given station n, where $R = Vel_n/(Vel_{n-1} + Vel_{n+1})/2$ at station n[10]. R was calculated for each velocity where $Vel_n$, $Vel_{n-1}$ and $Vel_{n+1}$ were all greater than 1.00 ft/s (0.305 m/s) for each ADCP data set. Based on data collected using a Price AA velocity meter on the Lower American River, the acceptable range of R was set at 0.5-

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[8] The Transect program is the software used to receive, record and process data from the ADCP.

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

[10] n - 1 refers to the station immediately before station n and n + 1 refers to the station immediately after station n.

1.6 (Gard and Ballard 2003). All velocities with R values less than 0.5 or greater than 1.6 were deleted from each ADCP data set. We also deleted velocities where $Vel_n$ was less than 1.00 ft/s (0.305 m/s) and $Vel_{n-1}$ and $Vel_{n+1}$ were greater than 2.00 ft/s (0.610 m/s), and where $Vel_n$ had one sign (negative or positive) and $Vel_{n-1}$ and $Vel_{n+1}$ had the opposite sign (when the absolute value of all three velocities were greater than 1.00 ft/s [0.305 m/s]); these criteria were also based on the acceptability indicated by the Lower American River data set. The ADCP traverse for each transect which had the flow closest to the gaged flow, determined from U.S. Geological Survey gage readings, was selected for use in the PHABSIM files. Flows were calculated for these ADCP traverses, including the data collected in shallow water.

A table of substrate and cover ranges/values was created to determine the substrate and cover for each vertical[11]/cell (e.g., if the substrate size class was 2-4 inches (5-10 cm) on a transect from station 50 to 70, all of the verticals with station values between 50 and 70 were given a substrate coding of 2.4). Dry bed elevation data in field notebooks were entered into the spreadsheet to extend the bed profile up the banks above the WSEL of the highest flow to be modeled. An 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. A separate PHABSIM file was constructed for each study site. A total of five or six sets of measured WSELs were used, all being checked to ensure that there was no uphill movement of water. The slope for each transect was computed for each WSEL 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. If WSELs were available for several closely spaced flows, the WSEL that corresponded with the velocity set or the WSEL collected at the lowest flow was used in the PHABSIM files. Calibration flows in the PHABSIM files were the flows calculated from gage readings with the exception of sites located between Daguerre Point Dam and the location where flows return from the Goldfields. A multiple linear regression was conducted to predict the Goldfields flows from gage flows. This regression was conducted using the four measurements of the flow coming out of the Goldfields and the gage flows on those days. Calibration flows for the sites between Daguerre Point Dam and the location where flows return from the Goldfields were calculated using flows from the Marysville gage reading minus the flows returning from the Goldfields.

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

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[11] A vertical is each point on a transect.

the upstream transect. For downstream transects in habitat types with a backwater effect, we used the Corps hydro-acoustic mapping data downstream of the study site to determine the SZF for the downstream transect (the highest point on the thalweg downstream of the study site).

The first step in the calibration procedure was to determine the best approach for WSEL simulation. Initially, the *IFG4* hydraulic model (Milhous *et al*., 1989) was run on the PHABSIM file to compare predicted and measured WSELs. This model produces a stage-discharge relationship using a log-log linear rating curve calculated from at least three sets of measurements taken at different flows. Besides *IFG4*, two other hydraulic models are available in PHABSIM to predict stage-discharge relationships. These models are: 1) *MANSQ*, which operates under the assumption that the geometry of the channel and the nature of the streambed control WSELs; and 2) *WSP*, the water surface profile model, which calculates the energy loss between transects to determine WSELs. *MANSQ*, like *IFG4*, evaluates each transect independently. *WSP* must, by nature, link at least two adjacent transects. *IFG4*, the most versatile of these models, is considered to have worked well if the following criteria are met: 1) the beta value (a measure of the change in channel roughness with changes in streamflow) is between 2.0 and 4.5; 2) the mean error in calculated versus given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs[12]. *MANSQ* is considered to have worked well if the second through fourth of the above criteria are met, and if the beta value parameter used by *MANSQ* is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier and flow; and 3) there is no more than a 0.1 foot (0.031 m) difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*.

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

## RIVER2D Model Construction

After completing the PHABSIM calibration process to arrive at the simulation WSELs that will be used as inputs to the RIVER2D model, the next step is to construct the RIVER2D model using the collected bed topography data. The data from the ADCP traverses made to characterize the bed topography of the sites between the transects for input to the 2-D model were processed for input into an Excel spreadsheet in the same manner described above for the ADCP data on the

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

transects. We applied the same quality criteria to the velocities from these ADCP traverses as described above for the velocity data collected on the transects, with the velocities not meeting the quality control criteria deleted from each ADCP data set.

The bed elevation of each point along the ADCP traverse was calculated as the difference between the WSEL shot at the location of the traverse and the depth at each point. The distance along each ADCP traverse, in concert with initial and final horizontal locations, was used to compute the horizontal location of each point along the traverse. The station along each PHABSIM transect, in concert with the horizontal locations of the headpins and tailpins of the transects, was used to compute the horizontal location of each vertical of the PHABSIM transects. Substrate and cover were assigned to each point along each ADCP traverse in the same manner as described above for the transects.

The data from the ADCP traverses were combined in Excel with the total station data and the PHABSIM transect data to create the input files (bed and substrate) for the 2-D modeling program. We also incorporated bed topography data collected for the Yuba River by the Corps using hydroacoustic mapping and photogrammetry. The accuracy of the hydroacoustic data was 1 foot (0.3 m) horizontal and 0.1 foot (0.031 m) vertical, whereas the accuracy of the photogrammetry data was 3 feet (0.9 m) horizontal and 1 foot (0.3 m) vertical (Scott Stonestreet, Corps, personal communication). We used the raw hydroacoustic data and the 2-foot (0.6 m) contour photogrammetry data to develop the bed topography upstream of the study sites and improve the accuracy of the flow distribution at the upstream end of the sites. Using this data, we extended the bed topography at least one and a half channel widths upstream of the upstream transect. For sites where there was a split channel at lower flows at the downstream transect, we also extended the bed topography downstream of the downstream transect approximately five channel widths. The Corps data were used to develop the bed topography in the downstream extension. The bed files contain the horizontal location (northing and easting), bed elevation, and initial bed roughness value for each point, whereas the substrate files contain the horizontal location, bed elevation, and the substrate for each point. The initial bed roughness value for each point was determined from the substrate and cover codes for that point and the corresponding bed roughness values in Table 6, with the bed roughness value computed as the sum of the substrate bed roughness value and the cover bed roughness value. The bed roughness values for substrate in Table 6 were computed as five times the average particle size[13]. The bed roughness values for cover in Table 6 were computed as five times the average cover size, where the cover size was measured on the Sacramento River on a representative sample of cover elements of each cover-type. The bed and substrate files were exported from Excel as ASCII files.

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

Table 6. Initial bed roughness values.

| Substrate Code | Bed Roughness (m) | Cover Code | Bed Roughness (m) |
|---|---|---|---|
| 0.1 | 0.05 | 0.1 | 0 |
| 1 | 0.1 | 1 | 0 |
| 1.2 | 0.2 | 2 | 0 |
| 1.3 | 0.25 | 3 | 0.11 |
| 2.3 | 0.3 | 3.7 | 0.2 |
| 2.4 | 0.4 | 4 | 0.62 |
| 3.4 | 0.45 | 4.7 | 0.96 |
| 3.5 | 0.5 | 5 | 1.93 |
| 4.6 | 0.65 | 5.7 | 2.59 |
| 6.8 | 0.9 | 7 | 0.28 |
| 8 | 1.25 | 8 | 2.97 |
| 9 | 0.05, 0.71, 1.95[14] | 9 | 0.29 |
| 10 | 1.4 | 9.7 | 0.57 |
| | | 10 | 3.05 |

A utility program, R2D_BED (Steffler 2002), was used to define the study area boundary and to refine the raw topographical data triangulated irregular network (TIN) by defining breaklines[15] going up the channel along features such as thalwegs, tops of bars and bottoms of banks. Breaklines were also added along lines of constant elevation.

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

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

An additional utility program, R2D_MESH (Waddle and Steffler 2002), was used to define the inflow and outflow boundaries and create the finite element computational mesh for the RIVER2D model. R2D_MESH uses the final bed file as an input. The first stage in creating the computational mesh was to define mesh breaklines[16] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and then additional nodes were added as needed to improve the fit between the mesh and the final bed file and to improve the quality of the mesh, as measured by the Quality Index (QI) value. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Waddle and Steffler 2002). The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. The final step with the R2D_MESH software was to generate the computational file.

## RIVER2D Model Calibration

Once a RIVER2D model has been constructed, calibration is then required to determine that the model is reliably simulating the flow-WSEL relationship that was determined through the PHABSIM calibration process using the measured WSELs. The computational files were opened in the RIVER2D software, where the computational bed topography mesh was used together with the WSEL at the bottom of the site, the flow entering the site, and the bed roughnesses of the computational mesh elements to compute the depths, velocities and WSELs throughout the site. The basis for the current form of RIVER2D is given in Ghanem et al. (1995). The computational mesh was run to steady state at the highest flow to be simulated, and the WSELs predicted by RIVER2D at the upstream end of the site were compared to the WSELs predicted by PHABSIM at the upstream transect. Calibration was considered to have been achieved when the WSELs predicted by RIVER2D at the upstream transect were within 0.1 foot (0.031 m) of the WSEL predicted by PHABSIM. In cases where the simulated WSELs at the highest simulation flow varied across the channel by more than 0.1 foot (0.031 m), we used the highest measured flow within the range of simulated flows for RIVER2D calibration. The bed roughnesses of the computational mesh elements were then modified by multiplying them by a constant bed roughness multiplier (BR Mult) until the WSELs predicted by RIVER2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the top transect. The minimum groundwater depth was adjusted to a value of 0.05 to increase the stability of the model. The values of all other RIVER2D hydraulic parameters were left at their default values (upwinding coefficient = 0.5, groundwater transmissivity = 0.1, groundwater storativity = 1, and eddy viscosity parameters $\varepsilon_1 = 0.01$, $\varepsilon_2 = 0.5$ and $\varepsilon_3 = 0.1$).

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

An additional step was needed for sites with a downstream extension to develop a relationship between the WSEL at the downstream boundary and the WSEL predicted by PHABSIM at the downstream transect for the simulation flows. For such sites, we tried different WSELs for the downstream boundary at the highest simulation flow until we found a WSEL for the downstream boundary that resulted in a WSEL predicted by RIVER2D at the downstream transect which matched the WSEL predicted by PHABSIM for the downstream transect. The same process was repeated at the lowest simulation flow and an intermediate simulation flow, with the WSEL predicted by RIVER2D at the downstream transect compared to the WSEL predicted by PHABSIM at the downstream transect for these two flows. We then developed a linear relationship between flow and the difference between the WSEL specified at the downstream boundary and the WSEL at the downstream transect, using the data from these three flows. This relationship was then used to determine what to subtract from the WSEL predicted by PHABSIM at the downstream transect for each simulation flow to generate the WSEL to be used for the downstream boundary for each simulation flow.

A stable solution will generally have a solution change (Sol Δ) of less than 0.00001 and a net flow (Net Q) of less than 1% (Steffler and Blackburn 2002). In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than one[17]. Finally, the WSEL predicted by the 2-D model should be within 0.1 foot (0.031 m) of the WSEL measured at the upstream transects[18].

## RIVER2D Model Velocity Validation

Velocity validation is the final step in the preparation of the hydraulic models for use in habitat simulation. Velocities predicted by RIVER2D were compared with measured velocities to determine the accuracy of the model's predictions of mean water column velocities. The measured velocities used were those measured at the upstream and downstream transects, the velocities measured during collection of the deep bed topography with the ADCP, and the 50 measurements taken between the transects. The criterion used to determine whether the model was validated was whether the correlation between measured and simulated velocities was greater than 0.6. A correlation of 0.5 to 1.0 is considered to have a large effect (Cohen 1992). The model would not be validated if the simulated velocities deviated from the measured velocities to the extent that the correlation between measured and simulated velocities fell below 0.6.

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[17] This criterion 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).

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

## RIVER2D Model Simulation Flow Runs

After the RIVER2D model was calibrated, the flow and downstream WSEL in the calibrated cdg file were changed to simulate the hydraulics of the site at the simulation flows. The data file for each flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow, or for sites with a downstream extension, the WSEL for the downstream boundary developed during the calibration process. Each cdg file was run in RIVER2D to steady state. Again, a stable solution will generally have a Sol Δ of less than 0.00001 and a Net Q of less than 1%. In addition, solutions should usually have a Max F of less than one.

### *Habitat Suitability Criteria (HSC) Data Collection*

Habitat suitability criteria (HSC) are used within 2-D habitat modeling to translate hydraulic and structural elements of rivers into indices (HSIs) of habitat quality (Bovee 1986). HSC refer to the overall functional relationships that are used to convert depth, velocity and substrate suitability into habitat quality (HSI). HSI refers to the independent variable in the HSC relationships. The primary habitat variables which are used to assess physical habitat suitability for spawning Chinook salmon and steelhead/rainbow trout are water depth, velocity, and substrate composition. One HSC set for spring-run Chinook salmon, one HSC set for fall-run Chinook salmon and one HSC set for steelhead/rainbow trout were used in this study. The spring-run Chinook salmon criteria were based on data we collected on spring-run Chinook salmon redds in the Yuba River in 2002, fall-run Chinook salmon criteria on data we collected on fall-run Chinook salmon redds in the Yuba River in 2001, 2002, and 2003, and steelhead/rainbow trout criteria on data we collected on steelhead/rainbow trout redds in the Yuba River in 2002, 2003, and 2004. All habitat data were entered into spreadsheets for analysis and development of Suitability Indices (HSC). We attempted to locate spring and fall-run Chinook salmon and steelhead/rainbow trout redds in shallow and deep water. We searched for shallow redds on foot and by boat. For both races of Chinook salmon and steelhead/rainbow trout, all of the active redds (those not covered with periphyton growth) within a given mesohabitat unit were measured. The location of most redds (both in shallow and deep water) was recorded with a GPS unit, so that we could ensure that redds were not measured twice[19]. The horizontal location of shallow redds in our study sites was recorded using a total station and prism during some surveys to validate the models and determine unoccupied locations for developing HSC.

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[19] We concluded that redds had been measured twice if all of the following criteria were met: 1) the distance between the redds was less than 13 feet (4.0 m); 2) the depths differed by less than 0.3 foot (0.09 m); 3) the velocities differed by less than 0.5 ft/s (0.15 m/s); and 4) the substrate was the same.

Data for shallow redds 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 (Gard 1998). Depth was recorded to the nearest 0.1 foot (0.031 m) and average water column velocity was recorded to the nearest 0.01 ft/s (0.003 m/s). Measurements were taken with a wading rod and a Marsh-McBirney$^R$ model 2000 velocity meter 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 inches [2.5-5 cm]) at three locations: 1) in front of the pit; 2) on the sides of the pit; and 3) in the tailspill. The substrate coding system used is shown in Table 3.

Location of redds in deep water was accomplished by boat, from the surface visually and using underwater video equipment. The underwater video equipment consists of two cameras mounted on a 75 pound (34 kg) bomb at angles of 45 and 90 degrees. The main feature used to identify redds was the clean substrate present in the redd, compared with the algal-covered substrate surrounding the redd. The camera mounted at a 45 degree angle was used to look for topographic features (such as the rise of the tailspill or the depression at the pit), while the camera mounted at 90 degrees was used to look for differences in algal growth on the substrate and the cut at the head of the pit. The 75 (34 kg) pound bomb is raised and lowered from the boat using a winch. Two monitors on the boat provide the views from the cameras. A calibrated[20] grid on the 90 degree camera monitor is used to measure the substrate. When searching for redds in deep water using underwater video, a series of parallel traverses spaced approximately 50 feet (15 m) apart in an upstream direction were made within a mesohabitat unit with the boat. After locating a redd in deep water, substrate size was measured using underwater video directly over the redds. Depth and water velocity were measured over the redds with the ADCP. The average water column velocity was calculated for each ADCP ensemble and then the average of these for all of the ensembles was calculated to arrive at the water column velocity for the redd. The depth for each redd was computed as the average of the depths for all of the ensembles. Additional information on the deep redd measurement techniques is given in Gard and Ballard (2003).

For steelhead/rainbow trout, we also measured the width and length of each shallow redd; such data could not be collected for deep redds. Based on data collected by CDFG on fall-run chinook salmon and steelhead redds in the Lower American River, we have developed the following criteria to distinguish steelhead/rainbow trout redds from chinook salmon redds: Steelhead/rainbow trout redds have a length less than 5.1 feet (1.55 m) and a width less than 4.5 feet (1.37 m), whereas Chinook salmon redds have a length greater than 5.1 feet (1.55 m) or a width greater than 4.5 feet (1.37 m). These criteria correctly classified 96% of 129 Chinook salmon redds and 53% of 28 steelhead redds from the Lower American River. We used these

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[20] The grid was calibrated so that, when the camera frame was 1 foot (0.3 m) off the bottom, the smallest grid corresponded to a 2-inch (5 cm) substrate, the next largest grid corresponded to a 4-inch (10 cm) substrate, etc.

criteria for redds measured prior to April. We classified all redds measured in April as steelhead/rainbow trout redds, because April is after the end of late-fall-run chinook salmon spawning season.

### *Biological Verification Data Collection*

Biological verification data were collected to test the hypothesis that the compound suitability predicted by the RIVER2D model is higher at locations where redds were present versus locations where redds were absent. The compound suitability is the product of the depth suitability, the velocity suitability, and the substrate suitability. The collected biological verification data were the horizontal locations of redds. Depth, velocity, and substrate size as described in the previous section on habitat suitability criteria data collection were also measured. The hypothesis that the compound suitability predicted by the RIVER2D model is higher at locations where redds were present versus locations where redds were absent was statistically tested with a one-tailed Mann-Whitney U test (Gard 2006, Gard 2009, McHugh and Budy 2004).

The horizontal locations of spring-run Chinook salmon redds found during surveys on September 23-26, 2002 in six study sites was recorded by sighting from the total station to a stadia rod and prism. The horizontal location of the fall-run Chinook salmon redds found during surveys on November 4-6, 2002 and November 18-21, 2002 in eight study sites was recorded by sighting from the total station to a stadia rod and prism. The horizontal location of steelhead/rainbow trout redds found during surveys on April 8-10, 2003 in six study sites was recorded by sighting from the total station to a stadia rod and prism for shallow redds and using GPS for deep water steelhead/rainbow trout redds. GPS was not used for recording the horizontal location of the spring and fall-run Chinook salmon redds for biological verification purposes since none of the redds located within the study sites were found in deep water.

### *Habitat Suitability Criteria (HSC) Development*

Substrate criteria were developed by: 1) determining the number of redds with each substrate code (Table 3); 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 collected redd depth and velocity data must be processed through a series of steps to arrive at the HSC that will be used in the RIVER2D model to predict habitat suitability. Using the spring-run Chinook salmon spawning HSC data collected in 2002, fall-run Chinook salmon spawning HSC data collected in 2001-2003, and steelhead/rainbow trout spawning HSC data that were collected in 2002-2004, we applied a logistic regression method presented in Guay et al. (2000) to explicitly take into account habitat availability in developing HSC criteria, without using preference ratios (use divided by availability). Criteria are developed by using a logistic regression procedure, with presence or absence of redds as the dependent variable and depth and velocity as the independent variables, with all of the data (in both occupied and unoccupied locations) used in the regression.

Velocity and depth data were obtained for locations within each site where redds were not found (unoccupied). These data were obtained by running a final RIVER2D cdg file for each site where the location of extant redds were recorded using a total station and the depth and velocity data were collected. The flows for these files were the average flows: (1) from September 1 through the date of data collection for spring-run Chinook salmon; (2) from October 1 through the date of data collection for fall-run Chinook salmon; and (3) for the month preceding the date of data collection for steelhead/rainbow trout. After running the final RIVER2D models for each study site, velocity and depth data at each node within the file were then downloaded. Using a random number generator, 300 points were selected that had the following characteristics: 1) were inundated; 2) were more than three feet (0.9 m) from any other point that was selected; and 3) were located between the upstream and downstream transects of the site. We then selected the first 200 of these points from each site which were more than three feet (0.9 m) from a redd location.

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

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

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

For steelhead/rainbow trout, we originally developed the criteria using all of the steelhead/rainbow trout redd observations (occupied data) and unoccupied data from all sites in which we found steelhead/rainbow trout redds. Subsequently, we performed a sensitivity analysis calculating criteria using only occupied and unoccupied data collected upstream of Highway 20 (Appendix M). Since the sensitivity analysis indicated that the criteria calculated using only occupied and unoccupied data collected upstream of Highway 20 outperformed the criteria using all occupied and unoccupied data, we selected the criteria calculated using only occupied and unoccupied data collected upstream of Highway 20 to use in this report.

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 and fall-run Chinook salmon HSC data. The technique begins with the construction of multiple sets of HSC, differing only in the suitabilities assigned for optimum depth increments, to determine how the available 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. A range of depths is selected, starting at the depth at which the initial depth HSC reached 1.0, through the greatest depth at which there were redds or available habitat. A series of HSC sets are constructed where: (1) all of the sets have the same velocity and substrate HSC curves, with values of 1.0 for the suitable velocity and substrate range with all other velocities and substrates assigned a value of 0.0; and (2) each set has a different depth HSC curve. To develop the depth HSC curves, each HSC set is assigned a different half-foot depth increment within the selected depth range to have an HSC value of 1.0, and the other half-foot depth increments and depths outside of the depth range a value of 0.0 (e.g., 2.0-2.47 foot [0.61-0.75 m] depth HSC value equal 1.0, < 2.0 feet [0.61 m] and >2.47 feet [0.75 m] depths HSC value equals 0.0 for a depth increment of 2.0-2.47 feet [0.61-0.75 m]). Each HSC set is used in RIVER2D with the calibrated RIVER2D file for each study site at which HSC data were collected for that run. The resulting habitat output is used to determine the available river area with suitable velocities and substrates for all half-foot depth increments.

To modify the spring and fall-run Chinook salmon HSC depth curve to account for the low availability of deep water having suitable velocities and substrates, a sequence of linear regressions (Gard 1998) was used to determine the relative rate of decline of use versus availability with increasing depth. We defined habitat use by spawning spring and fall-run Chinook salmon as the number of redds observed in each depth increment. For spring-run Chinook salmon, availability data were determined using the output of the calibrated hydraulic files for the six spawning habitat modeling sites at which HSC data were collected, whereas redd data from these six sites were used to assess use. For fall-run Chinook salmon, availability data were determined using the output of the calibrated hydraulic files for the eight spawning habitat modeling sites where HSC data were collected in 2002 and four of these sites where HSC data were collected in 2001, whereas redd data from these eight sites in 2002 and four sites in 2001 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 feet [0.68 m] for a 2.0-2.47 foot [0.61-0.75 m] depth increment), we used linear regressions of relative availability and use versus the midpoints of the depth increments. Linearized use is divided by linearized availability for the range of depths where the regression equations predict positive relative use and availability. The resulting use-availability ratio is standardized so that the maximum ratio is 1.0. To determine the depth at which the depth HSC would reach zero (the depth at which the scaled ratios reach zero), we used a linear regression with the scaled ratios versus the midpoint of the depth increments.

### *Biological Verification*

We computed the combined habitat suitability predicted by RIVER2D at each redd location in the six sites where spring-run Chinook salmon redds locations were recorded with total station and prism. We also did the same for the eight study sites where fall-run Chinook salmon redds locations were recorded and the six study sites where steelhead/rainbow trout redds locations were recorded. We ran the RIVER2D cdg files at the averaged flows for the period from the start of the spawning season up to the date of redd location data collection for spring and fall-run Chinook salmon (spring-run Chinook Salmon: September 1 – 26, 2002; fall-run Chinook salmon: October 1 – November 21, 2002) and for the month preceding the date of redd location data collection for steelhead/rainbow trout (March 9-April 8, 2003) as described previously in the Habitat Suitability Criteria Development section to determine the combined habitat suitability at individual points for RIVER2D. We used the horizontal location measured for each redd to determine the location of each redd in the RIVER2D sites. We used a random number generator to select locations without redds in each site. Locations were eliminated that: 1) were less than 3 feet (0.9 m) from a previously-selected location; 2) were less than 3 feet (0.9 m) from a redd location; 3) were located in the unwetted part of the site; and 4) were located outside of the site (upstream of the upstream transect or downstream of the downstream transect). We used one-tailed Mann-Whitney U tests (Zar 1984) to determine whether the combined suitability predicted by RIVER2D was higher at redd locations versus locations where redds were absent.

### *Habitat Simulation*

The final step was to simulate available habitat for each site. Preference curve files were created containing the digitized HSC developed for the Yuba River spring and fall-run Chinook salmon and steelhead/rainbow trout. RIVER2D was used with the final cdg production files, the substrate files and the preference curve files to compute WUA for each site over the desired range of 30 flows for all 10 sites. The WUA values for the sites in each segment were added together and multiplied by the ratio of total redds counted in the segment to number of redds in the modeling sites for that segment to produce the total WUA per reach. For spring-run Chinook salmon, we used the fall-run Chinook salmon multipliers because we did not do a synoptic survey to count spring-run Chinook salmon redds in the entire river. The fall-run Chinook salmon multipliers were calculated using redd counts from 2001. The steelhead/rainbow trout multipliers were calculated using redd counts from 2002-2004.

### *Evaluation of Polygon Substrate Data Collection Methods*

In an effort to more accurately characterize the spatial distribution of substrates within our study sites, we tested out a polygon method of delineating the substrates for Highway 20 and Upper Daguerre study sites, in addition to the standard (transect) method described previously in the Hydraulic and Structural Habitat Data Collection methods section. Prior to collecting the data for a study site, we enlarged color photocopies of orthorectified photos of the study site. A 10 meter grid labeled with northing and easting coordinates was printed onto a clear film. We attached cardboard backing to these photocopies and placed the clear film over the photocopies. Polygons delineating the dominant substrate characteristics for the study site were then drawn onto the photocopy. The grid was used together with a GPS receiver to determine the placement of the polygons on the photocopy. GPS waypoints were recorded for the corner locations of the polygons. These data were then digitized in GIS using the aerial photos and GPS waypoints to define a shape file in GIS of the substrate polygons. The shape file was then mapped onto a grid of points with a two feet (0.6 m) spacing with the substrate assigned to each point based on what polygon it was in. The grid of points was then imported into Excel to produce the polygon RIVER2D substrate input files for these two sites.

## Biological Verification

We compared the biological verification for these two sites using study site substrates as characterized using the polygon method with those using the standard method. Mann-Whitney tests were applied for this comparison. The data for the Highway 20 and Upper Daguerre study sites were combined when doing this biological verification comparison (Upper Daguerre was excluded for the steelhead/rainbow trout because the criteria for this species were not developed using data from downstream of Highway 20). Second, we compared the percent of redds where the substrate was correctly characterized using the polygon method versus the standard method, for the two study sites. To compare the percentage of redds where the substrate was correctly characterized by the 2-D model using the standard method versus the polygon method, we combined: 1) the spring- and fall-run Chinook salmon and steelhead/rainbow trout redd data; and 2) the data for Highway 20 and Upper Daguerre sites (in the case of steelhead/rainbow trout, only data for Highway 20 were used). The data were combined for both sites in the two comparisons to provide a larger sample size for the comparisons.

## Habitat Simulation

For both study sites, we compared the WUA values generated for each flow using the polygon substrate input file with those generated using the standard substrate input file. When comparing the WUA values, the data for the two study sites were kept separate because the WUA for each site is independent. For steelhead/rainbow trout, we only compared WUA values for Highway 20 site.

## RESULTS

### *Study Segment Delineation*

Average flows for the period January 1971 to November 2000 were 2,476 cfs at the Smartville gage, 2,601 cfs downstream of Deer Creek confluence, 2,583 cfs downstream of the Browns Valley Diversion, 2,285 cfs downstream of Daguerre Point Dam (downstream of both Brophy and Hallwood-Cordua Diversions), and 2,488 cfs at the Marysville gage. Bovee (1995) recommends that the cumulative change in flow within a study segment be less than 10%. Therefore, we established one segment between Englebright Dam (river mile 24.1) and Daguerre Point Dam (river mile 11.4) (Above Daguerre Segment) and a second segment between Daguerre Point Dam and the confluence with the Feather River at Marysville (river mile 0) (Below Daguerre Segment) (Figure 3). The two segments were established based on the 12% decrease in average flows from upstream to downstream of Daguerre Point Dam. We did not establish separate segments upstream and downstream of Deer Creek based on only a 5% increase in average flows from the Smartville gage to downstream of Deer Creek confluence. Similarly, we did not establish separate segments upstream and downstream of Browns Valley Diversion based on only a 4% increase from the Smartville gage to downstream of Browns Valley Diversion. Finally, we did not split the Below Daguerre Segment into two separate segments because there was only a 9% increase in flows from below Daguerre Point Dam to the Marysville gage. The Above Daguerre and Below Daguerre Segments encompassed the portions of the Yuba River accessible for spring and fall-run Chinook salmon and steelhead/rainbow trout spawning.

### *Field Reconnaissance and Study Site Selection*

Ten study sites were selected for modeling spring-run and fall-run Chinook salmon and steelhead/rainbow trout habitat (Table 7, Appendix A). Five sites are located between the Narrows and Daguerre Point Dam (Above Daguerre Segment) and the remaining five are located downstream of Daguerre Point Dam between Daguerre Point Dam and Plantz Road (Below Daguerre Segment). As described previously, these 10 sites are among those which received the heaviest use by spawning spring-run and fall-run Chinook salmon and steelhead/rainbow trout.

### *Hydraulic and Structural Habitat Data Collection*

All sites met the standard for level loops (Table 8). Errors for the horizontal benchmarks established by dual frequency survey-grade differential GPS were in all cases less than 0.02 feet (0.006 m, Table 9). Water surface elevations were measured at high (3,049-6,250 cfs), medium (955-2,483 cfs) and low (403-690 cfs) flows for the 10 study sites. The number and density of the points collected for each site is given in Table 10 and shown in Appendix B.

Table 7. Sites selected for modeling spring and fall-run Chinook salmon and steelhead/ rainbow trout spawning. Entries with --- reflect that data was not collected for the race or species in the Below Daguerre segment.

| | | Number of Redds | | | |
|---|---|---|---|---|---|
| **Site Name** | **Reach** | **2000 Fall-Run** | **2001 Fall-Run** | **Spring-Run** | **ST/RBT** |
| U.C. Sierra | Above | 76 | >100 | 108 | >1 |
| Timbuctoo | Above | 50 | 78 | 25 | >8 |
| Highway 20 | Above | 20 | >85 | 15 | >9 |
| Island | Above | 15 | 34 | 30 | >1 |
| Hammond | Above | 40 | 39 | 9 | 0 |
| Upper Daguerre | Below | 41 | >75 | --- | --- |
| Lower Daguerre | Below | 29 | 95 | --- | --- |
| Pyramids | Below | 36 | 51 | --- | --- |
| Hallwood | Below | 16 | 40 | --- | --- |
| Plantz | Below | 10 | 30 | --- | --- |

Table 8. Level loop error results.

| | | Level loop error (ft) | |
|---|---|---|---|
| **Site Name** | **Level Loop Distance** | **Allowable error** | **Actual error** |
| U.C. Sierra | 0.398 (0.636 km) | 0.03 (0.009 m) | 0.01 (0.003 m) |
| Timbuctoo | 1.470 (2.352 km) | 0.06 (0.018 m) | 0.05 (0.015 m) |
| Highway 20 | 0.512 (0.820 km) | 0.03 (0.009 m) | 0.02 (0.006 m) |
| Island | 0.684 (1.094 km) | 0.04 (0.012 m) | 0.02 (0.006 m) |
| Hammond | 0.879 (1.407 km) | 0.05 (0.015 m) | 0.00 (0.00 m) |
| Upper Daguerre | 0.340 (0.544 km) | 0.03 (0.009 m) | 0.03 (0.009 m) |
| Lower Daguerre | 0.777 (1.243 km) | 0.04 (0.012 m) | 0.01 (0.003 m) |
| Pyramids | 0.506 (0.810 km) | 0.03 (0.009 m) | 0.00 (0.00 m) |
| Hallwood | 0.331 (0.530 km) | 0.03 (0.009 m) | 0.01 (0.003 m) |
| Plantz | 0.346 (0.553 km) | 0.03 (0.009 m) | 0.01 (0.003 m) |

Table 9. Horizontal benchmark error results.

| | Coordinate standard deviations (US feet) | | |
|---|---|---|---|
| **Site benchmark** | **Northing** | **Easting** | **Elevation** |
| U.C. Sierra HBM1 | 0.012 (3.6 mm) | 0.012 (3.6 mm) | 0.019 (5.8 mm) |
| U.C. Sierra HBM2 | 0.012 (3.6 mm) | 0.012 (3.6 mm) | 0.019 (5.8 mm) |
| Timbuctoo HBM1 | 0.012 (3.6 mm) | 0.012 (3.6 mm) | 0.014 (4.3 mm) |
| Timbuctoo HBM2 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.012 (3.6 mm) |
| Highway 20 HBM1 | 0.011 (3.3 mm) | 0.011 (3.3 mm) | 0.010 (3.0 mm) |
| Highway 20 HBM2 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.012 (3.6 mm) |
| Island HBM2 | 0.011 (3.3 mm) | 0.011 (3.3 mm) | 0.010 (3.0 mm) |
| Island HBM3 | 0.011 (3.3 mm) | 0.011 (3.3 mm) | 0.009 (2.7 mm) |
| Hammond HBM1 | 0.012 (3.6 mm) | 0.012 (3.6 mm) | 0.015 (4.6 mm) |
| Hammond HBM2 | 0.012 (3.6 mm) | 0.012 (3.6 mm) | 0.017 (5.2 mm) |
| Upper Daguerre HBM1 | 0.012 (3.6 mm) | 0.012 (3.6 mm) | 0.017 (5.2 mm) |
| Upper Daguerre HBM2 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.014 (4.3 mm) |
| Lower Daguerre HBM1 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.014 (4.3 mm) |
| Lower Daguerre HBM3 | 0.012 (3.6 mm) | 0.012 (3.6 mm) | 0.018 (5.5 mm) |
| Pyramids HBM2 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.018 (5.5 mm) |
| Pyramids HBM3 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.015 (4.6 mm) |
| Hallwood HBM1 | 0.011 (3.3 mm) | 0.011 (3.3 mm) | 0.011 (3.3 mm) |
| Hallwood HBM2 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.011 (3.3 mm) |
| Plantz HBM1 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.013 (4.0 mm) |
| Plantz HBM2 | 0.012 (3.6 mm) | 0.011 (3.3 mm) | 0.014 (4.3 mm) |

## *Hydraulic Model Construction and Calibration*

### PHABSIM WSEL Calibration

The gaged flows, determined from USGS gage readings[21], are given in Table 11, and the ADCP traverses selected for use are shown in Table 12. The Goldfield flows were calculated using the following regression equation:

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[21] For the Above Daguerre Segment, we used the sum of the flows from the Smartville (USGS gage number 11418000) and Deer Creek (USGS gage number 11418500) gages. For the Below Daguerre Segment, we used the Marysville gage (USGS gage number 11421000).

Table 10. Number and density of data points collected for each site. The Army Corps of Engineers supplied us with bed topography data derived from photogrammetry and hydro-acoustic mapping.

| | USFWS | USFWS | USFWS | ACE | |
|---|---|---|---|---|---|
| **Site Name** | **Number of Points on Transects** | **Points Between Transects Collected with Total Station** | **Points Between Transects Collected with ADCP** | **Number of Points Between Transects** | **Density of Points (points/100 m$^2$)** |
| U.C. Sierra | 108 | 1,608 | 256 | 602 | 4.17 |
| Timbuctoo | 89 | 2,632 | 731 | 1,665 | 2.31 |
| Highway 20 | 130 | 1,441 | 208 | 623 | 4.06 |
| Island | 103 | 1,459 | 478 | 1,227 | 2.60 |
| Hammond | 106 | 544 | 299 | 411 | 2.21 |
| Upper Daguerre | 116 | 361 | 62 | 70 | 1.53 |
| Lower Daguerre | 95 | 830 | 224 | 248 | 1.75 |
| Pyramids | 132 | 421 | 165 | 221 | 2.23 |
| Hallwood | 100 | 758 | 213 | 172 | 2.78 |
| Plantz | 78 | 540 | 193 | 66 | 3.68 |

Table 11. Gage measured calibration flows for the ten study sites (cfs). For sites downstream of Daguerre Point Dam on 5/6/03, flows were changing during the course of the day, resulting in different flow values for transects 1 (upper row) and 2 (lower row).

| Date | U.C. Sierra | Timbuctoo | Hwy. 20 | Island | Hammond | Upper Daguerre | Lower Daguerre | Pyramids | Hallwood | Plantz |
|---|---|---|---|---|---|---|---|---|---|---|
| 3/27/02 | 2,348 | 2,348 | | | 2,348 | | | | | |
| 3/29/02 | | | | | | 2,483 | 2,483 | | | |
| 6/5/02 | | | | 2,018 | | | | | | |
| 6/6/02 | | | 2,017 | | | | | | | |
| 6/7/02 | | | | | | | | 1,280 | | |
| 7/18/02 | | | | | | 1,460 | 1,460 | | 1,460 | 1,460 |
| 8/26/02 | | | | | | 665 | 665 | 665 | 678 | 678 |
| 8/27/02 | 955 | 955 | 955 | 955 | 955 | | | | | |
| 10/7/02 | 670 | 670 | 670 | | | | | | | |
| 10/8/02 | | | | 690 | 690 | 403 | 403 | 403 | 413 | |
| 10/9/02 | | | | | | | | | | 453 |
| 1/14/03 | | | | | | | | | 1,710 | |
| 1/15/03 | | | | | | | | | | 1,810 |
| 1/29/03 | | | | | | 3,049 | 3,049 | 3,049 | 3,150 | 3,150 |
| 1/30/03 | 3,077 | 3,077 | 3,077 | 3,077 | 3,077 | | | | | |
| 5/5/03 | 4,437 | 4,437 | 4,437 | | | | | | | |
| 5/6/03 | | | | 5,273 | 5,273 | 5,580 | 5,872 | 5,826 | 6,060 | 6,180 |
| | | | | | | 5,450 | 5,801 | 5,756 | 5,920 | 6,250 |

Goldfield Q = 35.5 + 0.13 * Marysville Gage Q – 0.121 * (Smartville Gage Q + Deer Cr Gage Q)

For Upper Daguerre study site, we also had to take into account the operation/non-operation of the Hallwood-Cordua Diversion. This diversion has a fish screen with a fish return pipe that enters the river between the Upper Daguerre upstream and downstream transects. When the Hallwood-Cordua Diversion is operating, the outflow from this pipe back into the river is approximately 20 cfs. Consequently, for days when we collected water surface elevations when the Hallwood-Cordua Diversion was operating, we subtracted an additional 20 cfs to get the flows for the Upper Daguerre upstream transect.

Table 12. ADCP files used in PHABSIM files.

| Date | Site Name | Transect Number | File Name | USFWS Measured Q | % Difference from Gage Measured Q |
|---|---|---|---|---|---|
| 3/27/02 | U. C. Sierra | 1 | MD1D002 | 2,345 | 0.1% |
| 3/27/02 | U. C. Sierra | 2 | MD8A528 | 2,153 | 8.3% |
| 3/27/02 | Timbuctoo | 1 | MD4A073 | 2,494 | 6% |
| 3/27/02 | Timbuctoo | 2 | MD8A527 | 1,947 | 17% |
| 6/6/02 | Highway 20 | 1 | MD1D024 | 1,821 | 10% |
| 6/6/02 | Highway 20 | 2 | MD8A597 | 1,949 | 3% |
| 6/5/02 | Island | 1 | MD8A593 | 2,152 | 7% |
| 6/5/02 | Island | 2 | MD8A589 | 2,032 | 1% |
| 3/27/02 | Hammond | 1 | MD8A517 | 2,239 | 0.4% |
| 3/27/02 | Hammond | 2 | MD8A521 | 2,501 | 7% |
| 3/29/02 | Upper Daguerre | 1 | MD8A536 | 2,484 | 0.4% |
| 3/29/02 | Upper Daguerre | 2 | MD8A533 | 2,579 | 4% |
| 3/29/02 | Lower Daguerre | 1 | MD4C302 | 2,506 | 0.9% |
| 3/29/02 | Lower Daguerre | 2 | MD8A538 | 2,493 | 0.4% |
| 6/7/02 | Pyramids | 1 | MD8A598 | 1,293 | 1% |
| 6/7/02 | Pyramids | 2 | MD8A603 | 1,077 | 16% |
| 1/14/03 | Hallwood | 1 | MD4C338 | 1,915 | 13% |
| 1/14/03 | Hallwood | 2 | MD4C334 | 1,710 | 1% |
| 1/15/03 | Plantz | 1 | MD4C343 | 1,798 | 0.7% |
| 1/15/03 | Plantz | 2 | MD4C346 | 1,794 | 0.9% |

A total of five sets (U.C. Sierra, Timbuctoo, Highway 20, Island, Hammond, Pyramids) or six sets (Upper Daguerre, Lower Daguerre, Hallwood, Plantz) of measured WSELs were used in the WSEL calibration. The SZFs used for each transect are given in Appendix C, Table 1. Calibration flows in the PHABSIM files are given in Appendix C. For all of the transects, *IFG4* met the criteria described in the methods section for *IFG4* (Appendix C). In the cases of Highway 20 downstream transect and Hammond, Upper Daguerre, Lower Daguerre, Hallwood and Plantz upstream and downstream transects, we needed to simulate low and high flows with different sets of calibration WSELs (Appendix C) to meet the *IFG4* criteria. For the Highway 20 downstream transect and the Hammond Grove downstream and upstream transects, where we had measured five sets of WSELS, *IFG4* could be run for the low flows using the three lowest calibration WSELs, and run for high flows using the three highest calibration WSELs. ForUpper Daguerre, Lower Daguerre, Hallwood, and Plantz upstream and downstream transects, where we had six sets of WSELs, *IFG4* could be run for the low flows using the four lowest calibration WSELs, and run for the high flows using the three highest calibration WSELs.

None of the transects deviated significantly from the expected pattern of VAFs (Appendix D). In addition, VAF values (ranging from 0.15 to 2.04) were within an acceptable range of 0.2 to 5.0, with two minor exceptions. The VAFs for the lowest simulation flow of 150 cfs for Upper Daguerre and Hallwood downstream transects were 0.18 and 0.15, respectively.

## RIVER2D Model Construction

For the Pyramid site, we extended the bed topography downstream of the downstream transect approximately five channel widths. We did this since there was a split channel at lower flows at the downstream transect of Pyramids site. The bed topography of the study sites is shown in Appendix E. As shown in Appendix F, the meshes for all sites had QI values of at least 0.30, so all met the acceptability criterion of 0.2 or greater. The percentage of the original bed nodes for which the meshes differed by less than 0.1 foot (0.031 m) from the elevation of the original bed nodes ranged from 75% to 92% (Appendix F). The average mesh resolution was 0.2 nodes/m$^2$. The total number of nodes per segment was 82,803 for the Above Daguerre Segment and 47,093 nodes for the Below Daguerre Segment.

## RIVER2D Model Calibration

Calibration was conducted at the highest simulation flow, 4,500 cfs (127.4 m$^3$/s), for U.C. Sierra, Timbuctoo, Highway 20, Island and Pyramids sites. In the cases of Hammond, Upper Daguerre, Lower Daguerre, Hallwood, and Plantz sites, we used the highest measured flow within the range of simulated flows because the simulated WSELs at the highest simulation flow of 4,500 cfs varied across the channel by more than 0.1 foot (0.031 m), thus resulting in the RIVER2D simulated WSELs differing from the PHABSIM simulated WSELs by more than 0.1 foot (0.031 m). For Pyramids site, the downstream boundary WSEL calibration was conducted at flows of 150, 1,500 cfs and 4,500 cfs. The calibrated cdg files all had a solution change of less than 0.000001, with the net Q for all sites less than 1% (Appendix F), thus these criteria indicating a stable solution were met. The calibrated cdg file for all study sites, with the exception of Upper Daguerre, Lower Daguerre, Pyramids, and Hallwood, had a maximum Froude Number greater than 1 (Appendix F).

Six of the 10 study sites had calibrated cdg files within 0.1 foot (0.031 m) of the PHABSIM or measured WSELs (for those sites using the WSEL for the highest measured flow within the range of simulation flows). Island, Hammond, Upper Daguerre, and Plantz had maximum WSEL values that exceeded the 0.1 foot (0.031 m) criterion but all had average WSELs that were well within that criterion value (Appendix F). The Pyramids downstream transect also had a maximum WSEL value that exceeded the 0.1 foot (0.031 m) criterion.

## RIVER2D Model Velocity Validation

Although there was a moderately strong to very strong correlation between predicted and measured velocities (Appendix G), there were significant differences between individual measured and predicted velocities. The models for all sites were validated, and thus no models were in question, since the correlation between the predicted and measured velocities was greater than 0.6 for all sites. In general, the simulated and measured cross-channel velocity profiles at the upstream and downstream transects (Appendix G[22]) were relatively similar in shape.

Unless noted as follows, the simulated velocities for the ten sites were relatively similar to the measured velocities for the transects and deep bed ADCP traverses, with some differences in magnitude that fall within the amount of variation in the ADCP velocity measurements. Please note that for each study site in Appendix G, below the figures showing the velocity profiles for each transect, there is a figure that displays the locations of the transects and deep bed traverses. RIVER2D over or under-predicted the velocities on one or both sides of the channel for the following deep beds: U.C. Sierra Deep Beds A-R; Timbuctoo Deep Beds B, E-H, T, V, Z, AA, AG, AK, and AM; Highway 20 Deep Beds C, D, F, and J; Island Deep Beds H, I, K, L, P, S, and T; Hammond Deep Beds E, G, H, I, and O; Upper Daguerre Deep Beds E, F, G , H, and I; Lower Daguerre Deep Beds C and K; Pyramids Deep Beds D and E; Hallwood Deep Beds J, K, M, and N; and Plantz Deep Beds A, C, E, F, I, J, and K (Appendix G). RIVER2D over-predicted the simulated velocities for the Timbuctoo downstream (XS1) transect and upstream (XS2) on the east side of the channel. For Island downstream transect, RIVER2D under-predicted the velocities toward the south side of the channel, but over-predicted the velocities on the far south side of the channel and the north side of the channel. For the Island and the Pyramids upstream transects (XS2), RIVER2D for a short distance in the middle of the channel over-predicted and then under-predicted velocities. For Island Deep Beds B-D, and N, O, and R, RIVER2D under-predicted the velocities across most of the channel. RIVER2D over-predicted the simulated velocities for the Hammond Deep Beds A, B and D across most of the channel. The simulated velocities were also over-predicted for Upper Daguerre Deep Beds C and for Lower Daguerre Deep Beds A and M. RIVER2D also over-predicted the simulated velocities for the Pyramids Deep Beds A-C.

## RIVER2D Model Simulation Flow Runs

Example hydraulic model output is given in Appendix H. The simulation flows were 400 cfs to 2,100 cfs by 100 cfs increments and 2,100 cfs to 4,500 cfs by 200 cfs increments for the study sites in the Above Daguerre Segment and 150 cfs to 2,100 cfs by 100 cfs increments, 2,100 cfs to 2,900 cfs by 200 cfs increments and 2,900 cfs to 4,500 cfs by 400 cfs increments for the study

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

sites in the Below Daguerre Segment. The lowest simulated flow for the Above Daguerre Segment was 40% of the lowest measured flow. The lowest simulated flow for the Below Daguerre Segment was the lowest specified flow in the Yuba River Accord.

The production cdg files all had a solution change of less than 0.00001, but the net Q was greater than 1% for 12 flows for Timbuctoo, 3 flows for Island, 5 flows for Upper Daguerre, 1 flow for Lower Daguerre, the 9 lowest flows for Pyramids, and 1 flow for Plantz (Appendix I). The maximum Froude Number was greater than one for all of the simulated flows for U.C. Sierra, Timbuctoo, Island, and Hammond, 28 of the 30 simulated flows for Highway 20, 3 of the simulated flows for Upper Daguerre, 24 of the 30 simulated flows for Lower Daguerre, 26 of the 30 simulated flows for Pyramids, 19 of the 30 simulated flows for Hallwood, and 12 of the 30 simulated flows for Plantz (Appendix I).

### *Habitat Suitability Criteria (HSC) Data Collection*

The location of depth and velocity measurements was generally about 2 to 4 feet (0.6 to 1.2 m) upstream of the pit of the redd; however it was sometimes necessary to make measurements at a 45 degree angle upstream, or to the side. The data were almost always collected within 8 feet (2.4 m) of the pit of the redd. Twenty two percent of spring-run redds, 16 percent of fall-run redds and 11 percent of steelhead/rainbow trout redds had fish on the redds, increasing the likelihood for these redds that the depths and velocities present during redd construction were similar to those present when the HSC data were collected.

Depth, velocity and substrate data were collected for a total of 168 spring-run Chinook salmon redds in the Yuba River on September 16-17, 2002 and September 23-26, 2002. Based on our redd surveys, a majority of the redds were constructed after the September 16-17, 2002 survey, when only 22 redds were measured, despite intensive surveys on both days. The redds were all located in the Above Daguerre Segment from river mile 21.9 to Hammond study site, with the exception of four redds that were measured in the Upper Daguerre study site on September 24, 2002. Flows from the start of spring-run Chinook salmon spawning (September 1, 2002) through the end of HSI data collection (Table 13) are shown in Figure 5. Depth, velocity and substrate data were collected for a total of 870 fall-run Chinook salmon redds in the Yuba River on November 13-16 and 19, 2001; November 4-6 and November 18-21, 2002; and November 18-20, 2003. For the 870 redds measured during the 3 year period, 430 redds were located in the Above Daguerre Segment and 438 redds were located in the Below Daguerre Segment. Flows from the start of fall-run Chinook salmon spawning (October 1) through the end of HSI data collection (Table 13) are shown in Figures 6-7. We found that a sample of 73 out of 213 fall-run Chinook salmon redds in 2002 (or 34%) were superimposed. Superimposition was noted for spring-run Chinook salmon and steelhead/rainbow trout but was not rigorously quantified.

Depth, velocity and substrate data were collected for a total of 184 steelhead/rainbow trout on February 5-6 and 26, 2002; April 9, 11, and 23, 2002; April 8-10, 2003; and April 5-8, 2004. Only four steelhead/rainbow trout redds were located during the surveys (on April 10, 2003) in

Table 13. Average flows prior to HSI data collection.

| Dates | Reach | Species/race | Flows (cfs) |
|---|---|---|---|
| Sep 1-5, 2002 | Above Daguerre | spring-run Chinook salmon | 741 cfs (± 3%) |
| Sep 6-26, 2002 | Above Daguerre | spring-run Chinook salmon | 624 cfs (± 3%) |
| Sep 1-22, 2002 | Below Daguerre | spring-run Chinook salmon | 471 cfs (± 10%) |
| Oct 1 - Nov 19, 2001 | Above Daguerre | fall-run Chinook salmon | 787 cfs (± 27%) |
| Oct 1 - Nov 19, 2001 | Below Daguerre | fall-run Chinook salmon | 436 cfs (± 22%) |
| Oct 1 - Nov 21, 2002 | Above Daguerre | fall-run Chinook salmon | 886 cfs (± 29%) |
| Oct 1 - Nov 21, 2002 | Below Daguerre | fall-run Chinook salmon | 476 cfs (± 39%) |
| Oct 1 - Nov 20, 2003 | Above Daguerre | fall-run Chinook salmon | 911 cfs (± 20%) |
| Oct 1 - Nov 20, 2003 | Below Daguerre | fall-run Chinook salmon | 592 cfs (± 21%) |
| Jan 8-Feb 6, 2002 | Above Daguerre | steelhead/rainbow trout | 1,826 cfs (±14%) |
| Jan 28- Feb 26, 2002 | Above Daguerre | steelhead/rainbow trout | 1,790 cfs (± 31%) |
| Mar 13-Apr 11, 2002 | Above Daguerre | steelhead/rainbow trout | 2,351 cfs (± 22%) |
| Mar 25-Apr 23, 2002 | Above Daguerre | steelhead/rainbow trout | 2,261 cfs (± 16%) |
| Mar 12-Apr 10, 2003 | Above Daguerre | steelhead/rainbow trout | 2,399 cfs (± 58%) |
| Mar 12-Apr 10, 2003 | Below Daguerre | steelhead/rainbow trout | 2,470 cfs (± 123%) |
| Mar 10-Apr 8, 2004 | Above Daguerre | steelhead/rainbow trout | 2,388 cfs (± 16%) |

the Below Daguerre Segment. We assumed that any redds that we measured in our surveys were constructed during the 30 days prior to the survey dates based on the assumption that redds would not appear fresh after that time period. Flows for the 30 days prior to steelhead/rainbow trout HSI data collection (Table 13) are shown in Figure 8. For the 7 redds (all in shallow water) that we measured lengths and widths on in February 2002, the length and width criteria given in the methods section classified 6 as steelhead/rainbow trout redds and 1 as a late-fall run Chinook salmon redd[23].

The spring-run Chinook salmon HSC data had depths ranging from 0.5 to 4.6 feet (0.15 to 1.40 m) deep, velocities ranging from 0.29 to 4.40 ft/s (0.088 to 1.341 m/s), and substrate sizes ranging from 1-3 inches to 4-6 inches (2.5-7.5 cm to 10-15 cm). The fall-run Chinook salmon HSC data had depths ranging from 0.2 to 7.8 feet deep (0.06 to 2.38 m), velocities ranging from 0.23 to 5.31 ft/s (0.070 to 1.618 m/s), and substrate sizes ranging from 1-2 inches to 6-8 inches

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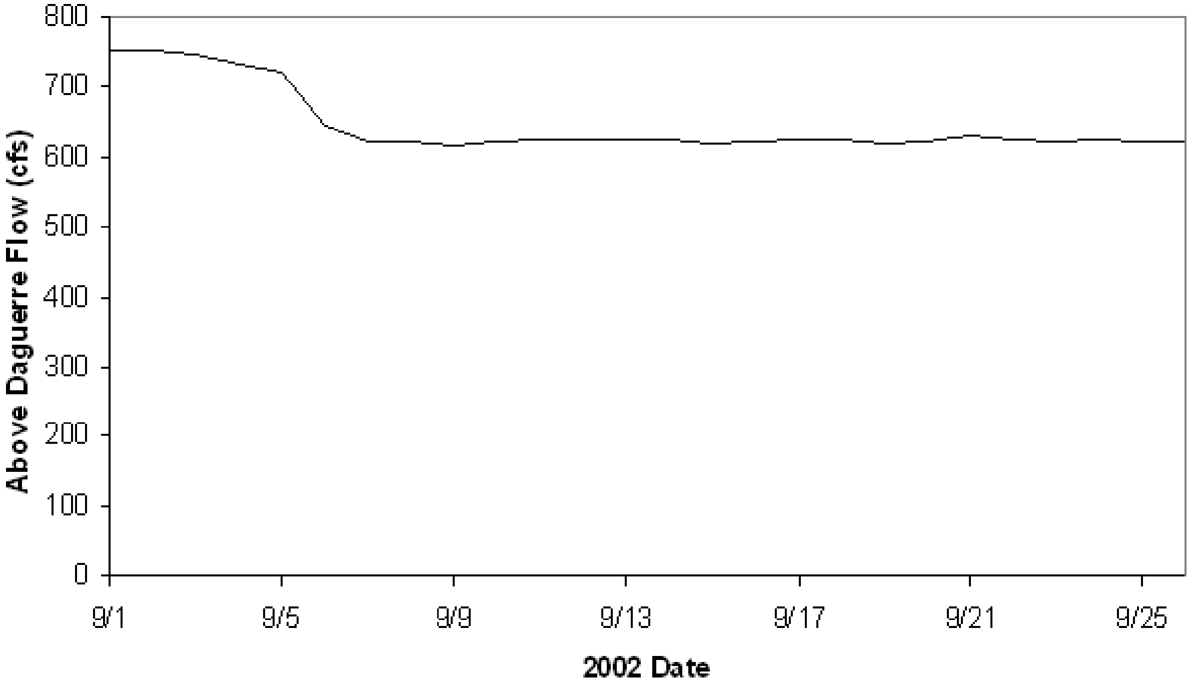
[23] This redd was excluded from further analysis.



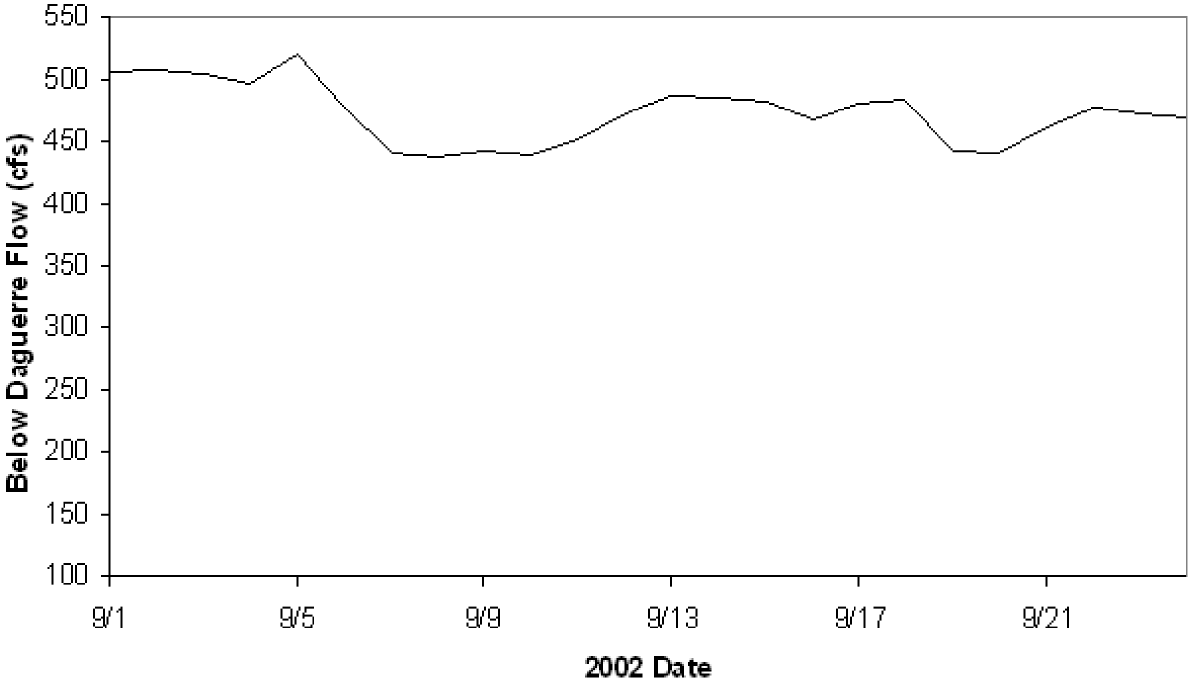


Figure 5. 2002 Yuba River flows in the above Daguerre and below Daguerre segments during spring-run spawning. Flows averaged 624 (± 3.0%) after September 5 above Daguerre and 471 cfs (± 10%) below Daguerre.

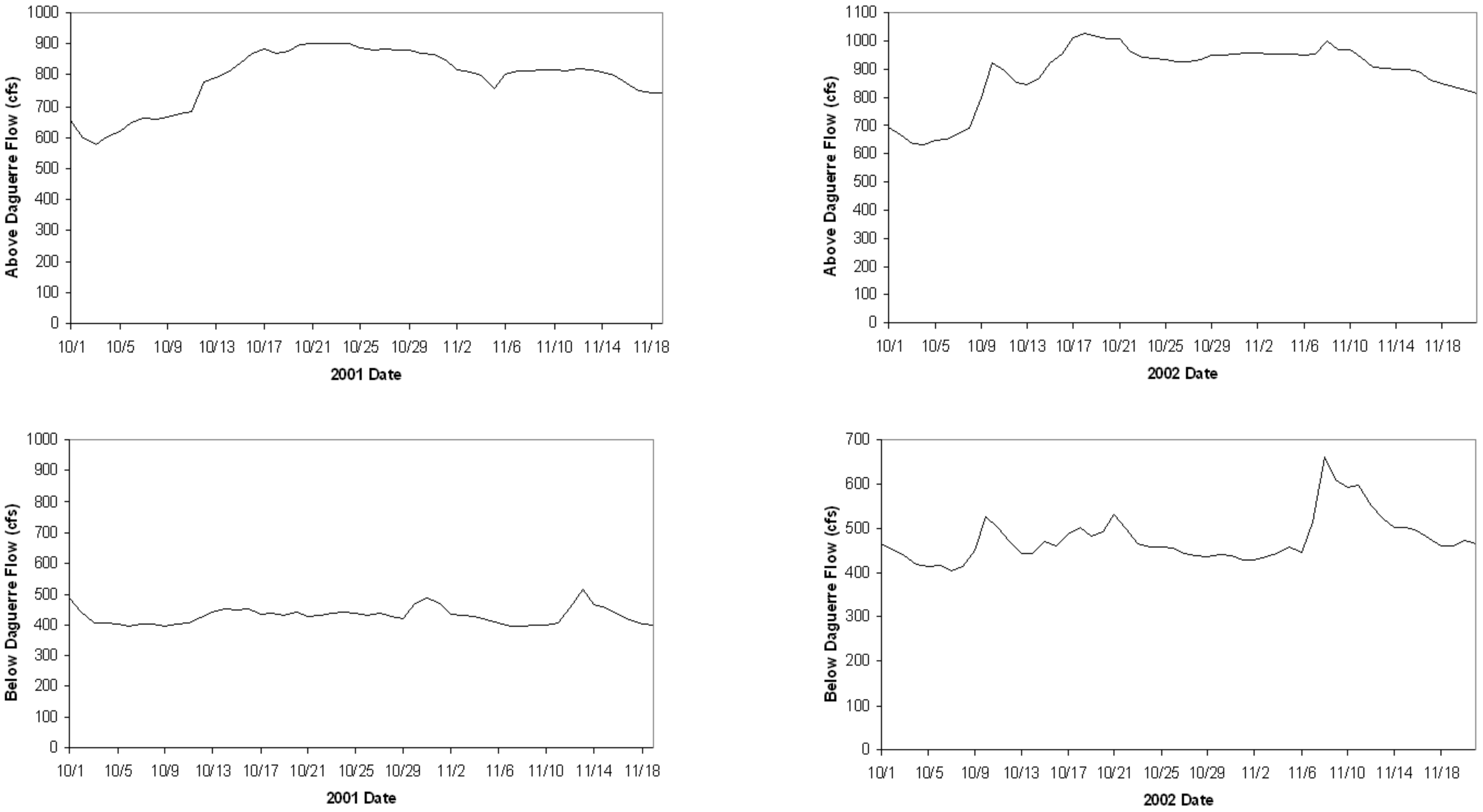
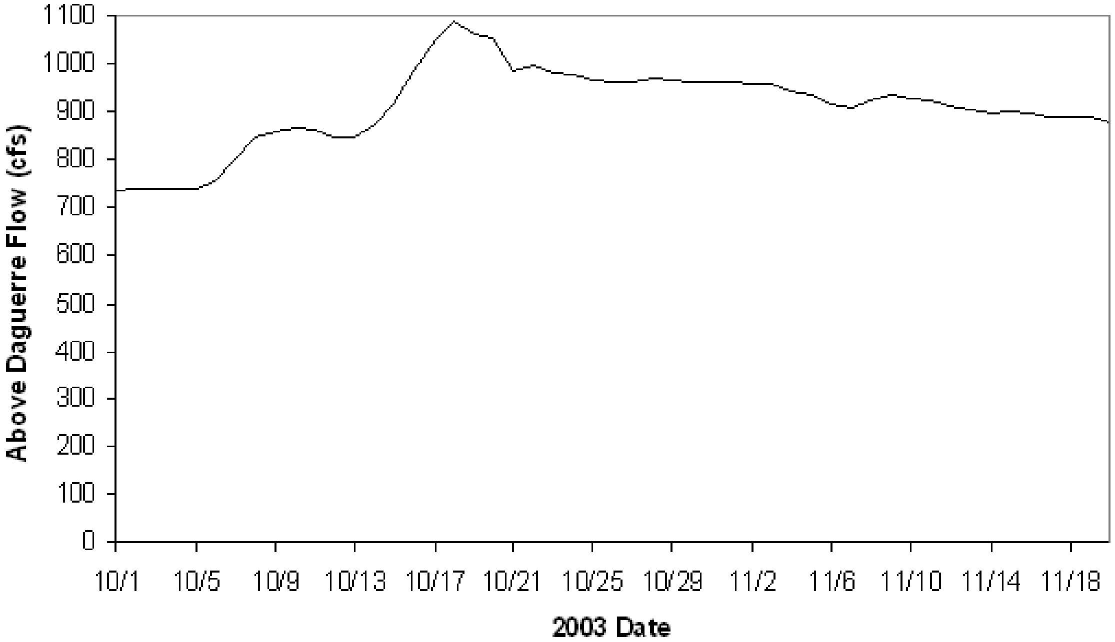


Figure 6. 2001 and 2002 flows in the above and below Daguerre segments during fall-run spawning. In 2001, flows averaged 787 (± 27%) above Daguerre and 436 cfs (± 22%) below Daguerre. In 2002, flows averaged 886 (± 29%) above Daguerre and 476 cfs (± 39%) below Daguerre.



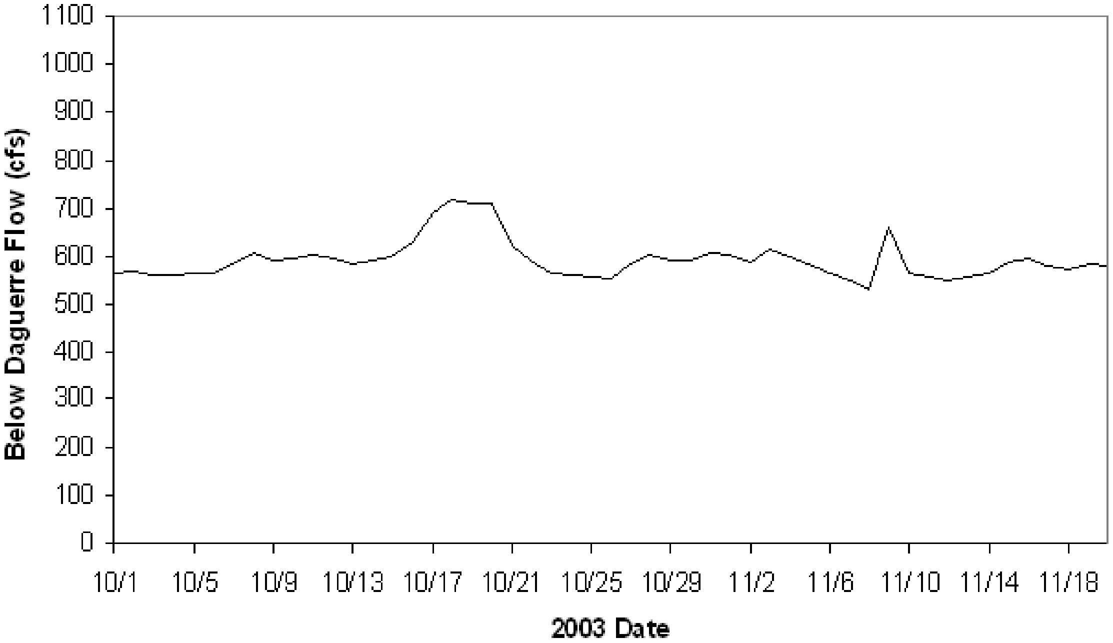


Figure 7. 2003 flows in the above and below Daguerre segments during fall-run spawning. Flows averaged 911 (± 20%) above Daguerre and 592 cfs (± 21%) below Daguerre.

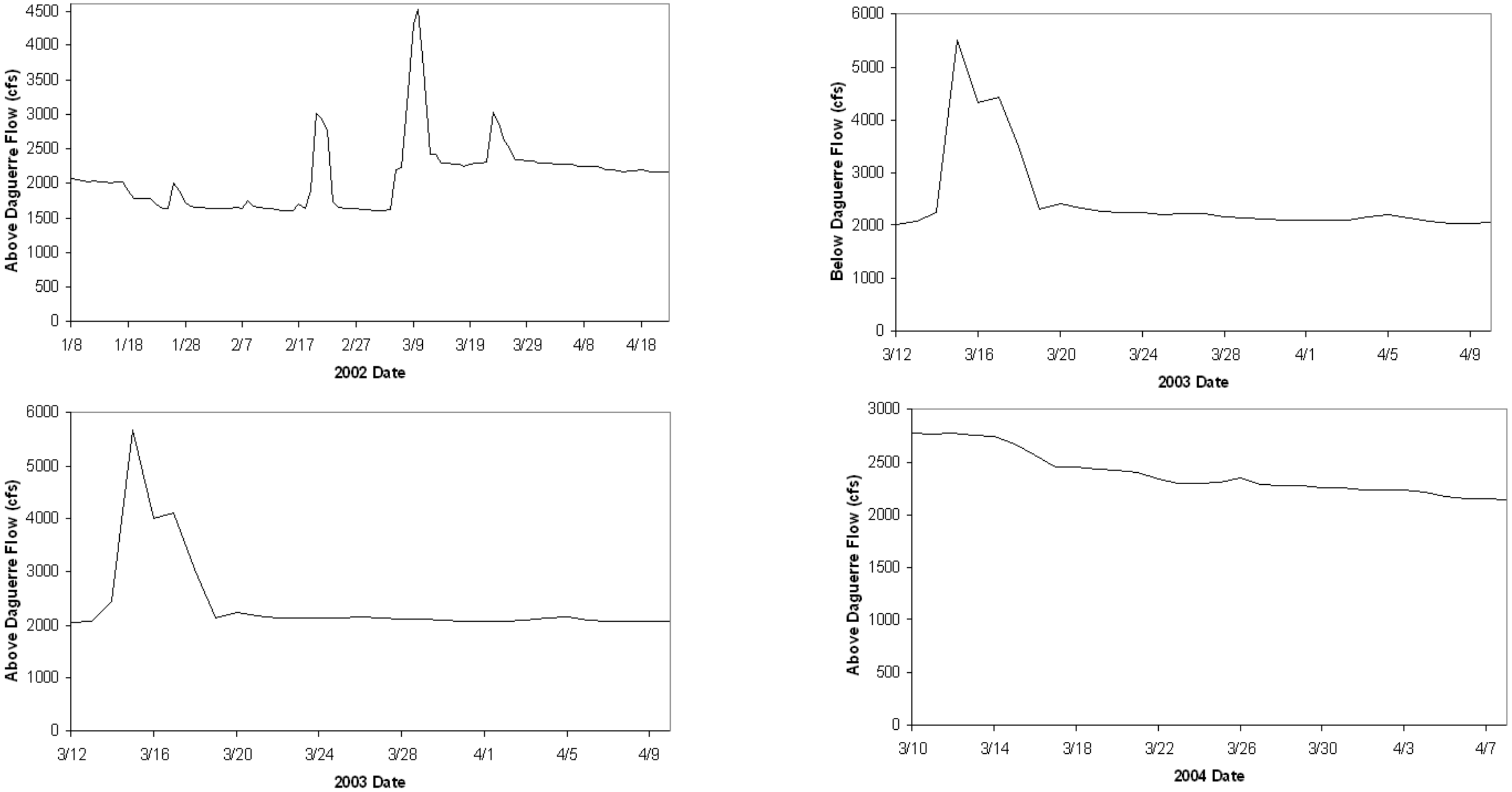


Figure 8. 2002, 2003 and 2004 flows in the above and below Daguerre segments during steelhead/rainbow trout spawning. In 2002 above Daguerre, flows averaged 1826 (± 14%) from January 8 to February 6, 1790 cfs (± 31%) from January 28 to February 26, 2351 cfs (± 22%) from March 13 to April 11, and 2261 cfs (± 16%) from March 25 to April 25. Above Daguerre, flows averaged, respectively, 2399 cfs (± 58%) and 2388 cfs (± 16%), in 2003 and 2004. Flows averaged 2470 (± 123%) below Daguerre in 2003.

(2.5-5 cm to 15-20 cm). The steelhead/rainbow trout HSC data had depths ranging from 0.4 to 19.9 feet deep (0.12 to 6.065 m), velocities ranging from 0.07 to 6.92 ft/s (0.021 to 2.109 m/s), and substrate sizes ranging from 0.1-1 inches to 4-6 inches (0.25-2.5 cm to 10-15 cm).

### *Biological Verification Data Collection*

During the spring-run Chinook salmon redd surveys on September 23-26, 2002, we collected data for 51 redds at U.C. Sierra, 54 redds at Timbuctoo, 13 redds at Highway 20, 16 redds at Island, 8 redds at Hammond, and 4 redds at Upper Daguerre, for a total of 146 redds for the surveys done during that time period. Biological verification data collection was limited to these sites due to time constraints. During the fall-run Chinook salmon redd surveys on November 4-6, 2002 and November 18-21, 2002, we collected data for 70 redds at U.C. Sierra, 112 redds at Timbuctoo, 33 redds at Highway 20, 37 redds at Hammond, 27 redds at Upper Daguerre, 59 redds at Lower Daguerre, 39 redds at Pyramids, and 45 redds at Plantz for a total of 422 redds for the surveys done during those time periods. As for spring-run, biological verification data collection was limited to these sites due to time constraints. During the steelhead/rainbow trout surveys on April 8-10, 2003, we collected data for 6 redds at U.C. Sierra, 19 redds at Timbuctoo, 7 redds at Highway 20, 2 redds at Upper Daguerre, 1 redd at Lower Daguerre, and 1 redd at Hallwood, for a total of 36 redds for the surveys done during that time period.

### *Habitat Suitability Criteria (HSC) Development*

For steelhead/rainbow trout, the logistic regression using only occupied and unoccupied data from upstream of Highway 20 used 159 occupied (86 percent of the total number of steelhead/rainbow trout redds) and 600 unoccupied (200 each from Highway 20, Timbuctoo and UC Sierra sites) observations. The coefficients for the final logistic regressions for depth and velocity for spring-run Chinook salmon, fall-run Chinook salmon and steelhead/rainbow trout are shown in Table 14. The p values for all of the non-zero coefficients in Table 14 were less than 0.05, as were the p values for the overall regressions.

The steelhead/rainbow trout HSC showed suitability reaching 0.9 at a depth of 3.2 feet (0.97 m) and not decreasing with increasing depth. We were not able to apply the depth correction method of Gard (1998) (nor was it necessary) because the final criteria stayed at a suitability of 1.00 up to the depth of the deepest steelhead/rainbow trout redd we observed, and the method requires having data points above the depth where the suitability is 1.00.

The initial spring-run Chinook salmon HSC showed suitability rapidly decreasing for depths greater than 2.0 feet (0.61 m). For spring-run Chinook salmon, suitable velocities were between 1.27 and 3.66 ft/s (0.387 and 1.115 m/s), while the suitable substrate code was 2.4. The results of the initial regressions of the Gard (1998) methodology showed that availability dropped with increasing depth ($R^2 = 0.77$, $p = 0.02$), but not as quickly as use ($R^2 = 0.77$, $p = 0.02$, Figure 9). The final linear regression ($R^2 = 0.73$, $p = 0.06$) to determine the depth at which the scaled ratios

Table 14. Logistic regression coefficients and $R^2$ values. The $R^2$ values are McFadden’s Rho-squared values calculated by the logistic regression. McFadden's rho-squared is conceptually similar to the r-squared used in linear regression, but the values tends to be much lower (Steinberg and Colla 1999). A value of 0 indicates no correlation, whereas values between 0.20 and 0.40 indicate significant correlation.

| race | parameter | I | J | K | L | M | $R^2$ |
|---|---|---|---|---|---|---|---|
| spring-run | depth | -4.992202 | 4.222906 | -1.319801 | 0.075537 | --- | 0.10 |
| spring-run | velocity | -5.757925 | 4.456922 | -1.277759 | 0.093882 | --- | 0.12 |
| fall-run | depth | -4.415397 | 7.717277 | -4.243941 | 0.80188 | -0.049158 | 0.10 |
| fall-run | velocity | -4.626245 | 7.806305 | -4.684532 | 1.155188 | -0.102498 | 0.10 |
| steelhead | depth | -5.2817 | --- | 2.50813 | -0.75673 | 0.059971 | 0.65 |
| steelhead | velocity | -5.5523 | 4.209993 | -1.09807 | 0.081385 | --- | 0.12 |

reach zero found that the scaled ratio reached zero at 5.3 feet (1.61 m). As a result, the spring-run Chinook salmon depth criteria were modified to have a linear decrease in suitability from 2.0 feet (0.61 m), the greatest depth in the original criteria which had a suitability of 1.0, to a suitability of 0.0 at 5.3 feet (1.61 m).

The initial fall-run Chinook salmon HSC showed suitability rapidly decreasing for depths greater than 1.4 feet (0.43 m). For fall-run Chinook salmon, suitable velocities were between 0.68 and 4.52 ft/s (0.207 and 1.378 m/s), while suitable substrate codes were 1.3 to 3.5. The results of the initial regressions for the Gard (1998) methodology showed that availability dropped with increasing depth ($R^2 = 0.94$, $p = 0.006$), but not as quickly as use ($R^2 = 0.88$, $p = 0.02$, Figure 10). The result of the final linear regression ($R^2 = 0.87$, $p = 0.07$) to determine the depth at which the scaled ratios reach zero was that the scaled ratio reached zero at 4.86 feet (1.481 m). However, there were three redds which had depths greater than 4.86 feet (1.481 m) (ranging from 5.0 to 7.8 feet [1.52 to 2.38 m]). As a result, the fall-run Chinook salmon depth criteria were modified to have a linear decrease in suitability from 1.0 at 1.4 feet (0.43 m), the greatest depth in the original criteria which had a suitability of 1.0, to a suitability of 0.02 at 4.8 feet (1.46 m); the suitability of 0.02 was continued through 7.8 feet (2.38 m, the depth of the deepest fall-run Chinook salmon redd) with suitability reaching zero at 7.9 feet (2.41 m).

The final depth and velocity criteria for spring- and fall-run Chinook salmon and steelhead/ rainbow trout, along with the frequency distributions of occupied and unoccupied locations, are shown in Figures 11-16 and Appendix J. The final spring- and fall-run Chinook salmon and steelhead/rainbow trout substrate criteria are shown in Figures 17-19 and Appendix J.

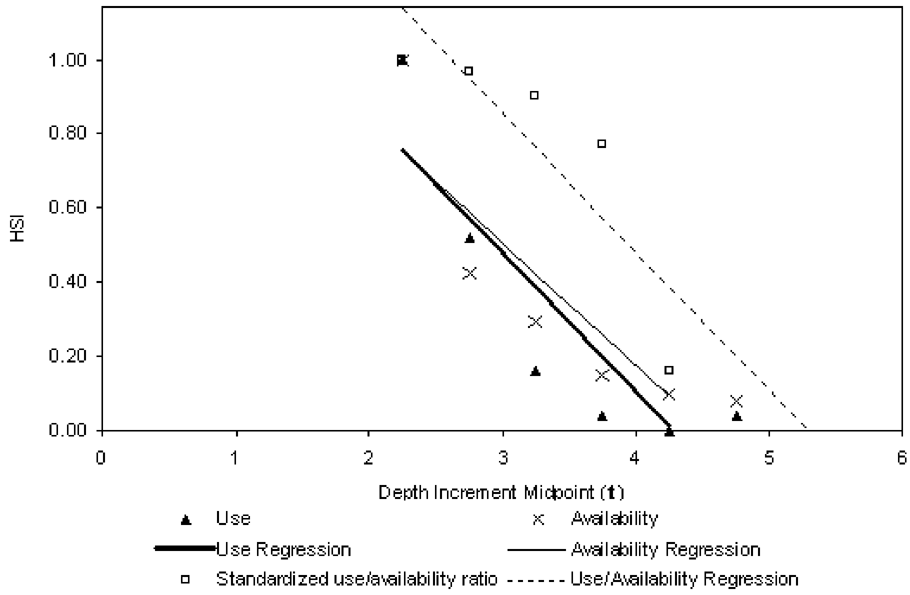


Figure 9. Relations between availability and use and depth for spring-run Chinook salmon. Availability dropped with increasing depth, but not as quickly as use. The use-availability regression reached zero at 5.3 feet (1.61 m).

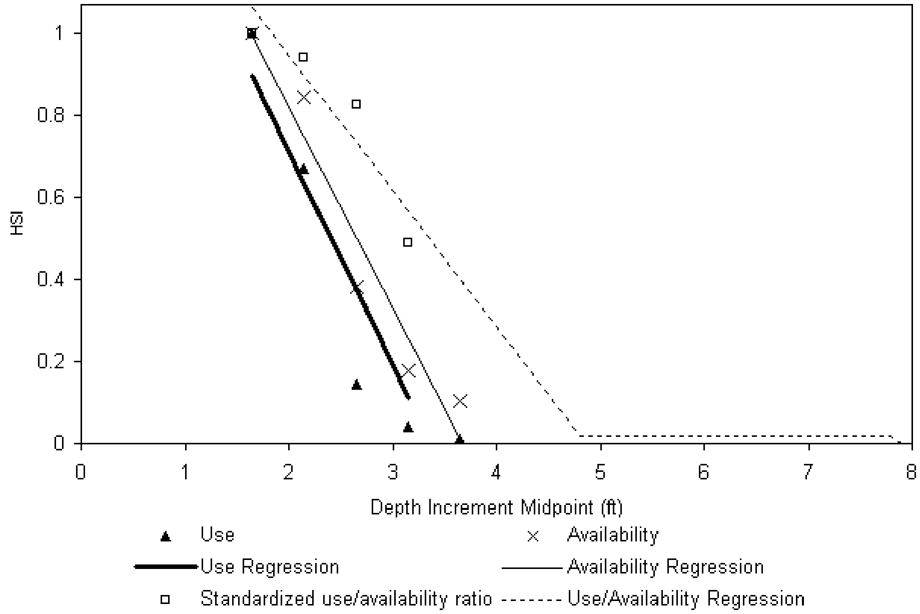


Figure 10. Relations between availability and use and depth for fall-run Chinook salmon. Availability dropped with increasing depth, but not as quickly as use. The use-availability regression reached 0.02 at 4.8 feet (1.46 m). The suitability of 0.02 was continued through 7.8 feet (2.38 m, the depth of the deepest fall-run Chinook salmon redd).

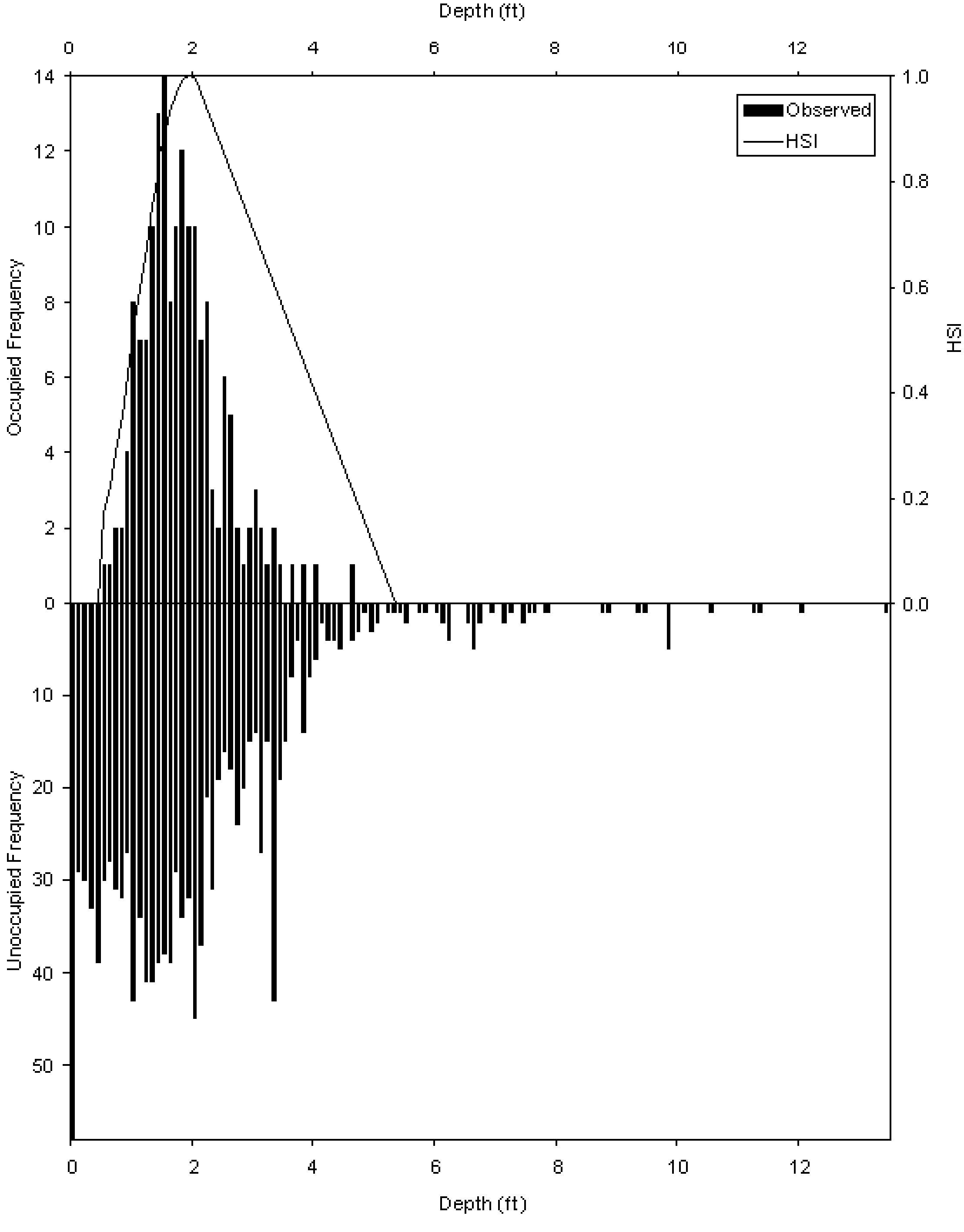


Figure 11. Spring-run Chinook salmon spawning depth HSC. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for depths of 0.5 to 5.2 feet (0.15 to 1.58 m) and an optimum suitability at depths of 1.9 to 2.0 feet (0.58 to 0.61 m).

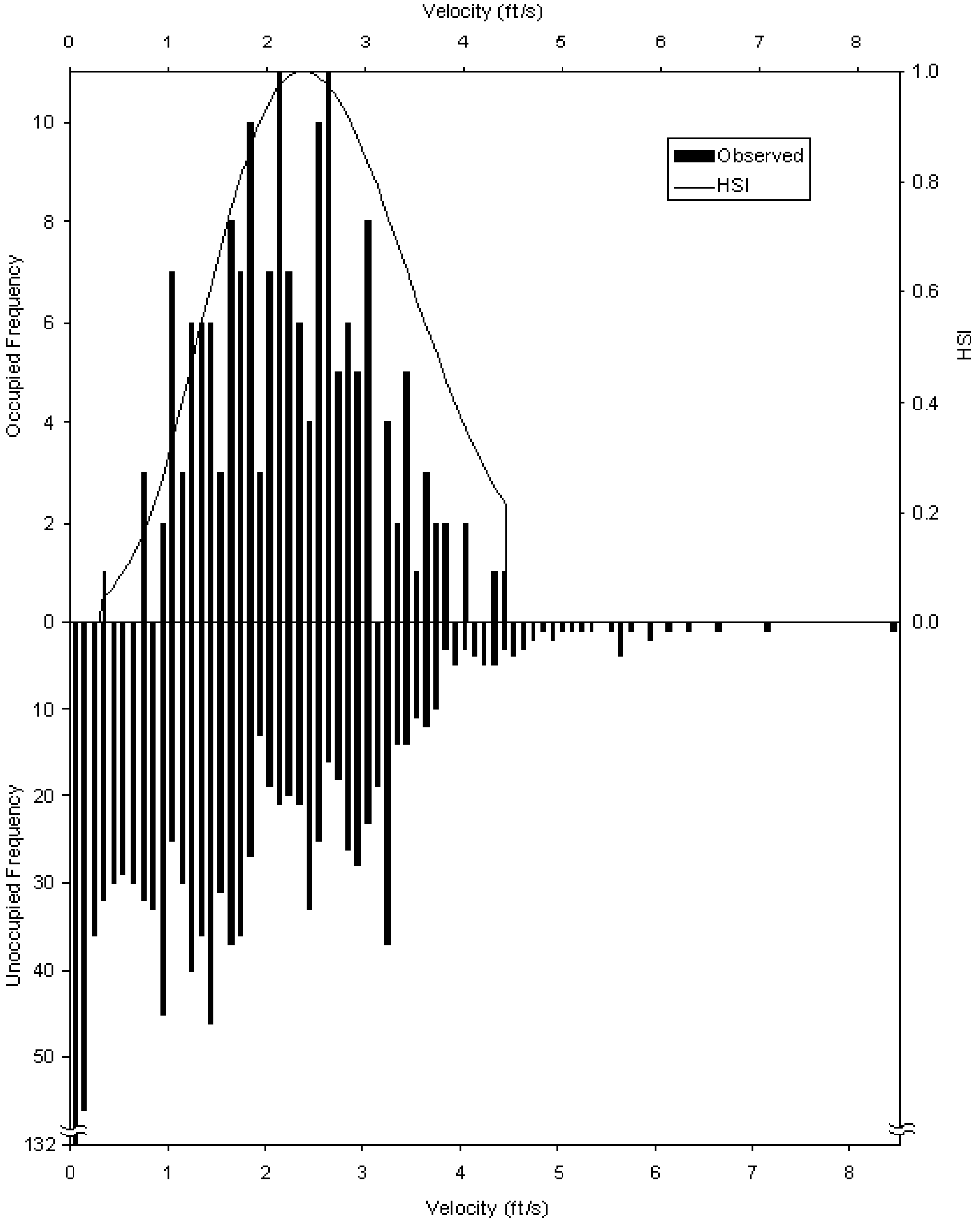


Figure 12. Spring-run Chinook salmon spawning velocity HSC. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for velocities of 0.29 to 4.40 feet/sec (1.341 m/s) and an optimum suitability at velocities of 2.3 to 2.4 feet/sec (0.701 to 0.731 m/s).

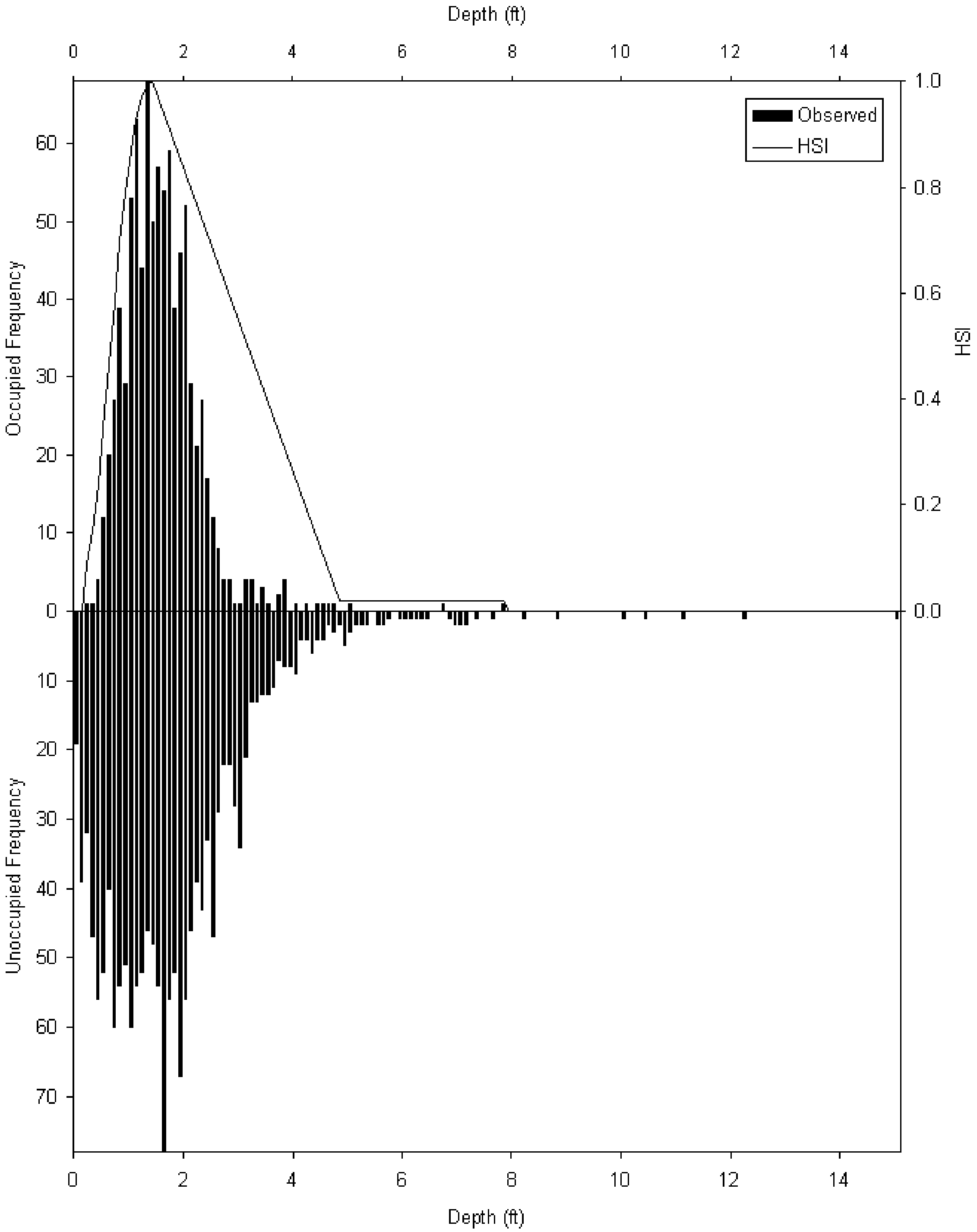


Figure 13. Fall-run Chinook salmon spawning depth HSC. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for depths of 0.2 to 7.8 feet (0.06 to 2.38 m) and an optimum suitability at a depth of 1.4 feet (0.43 m).

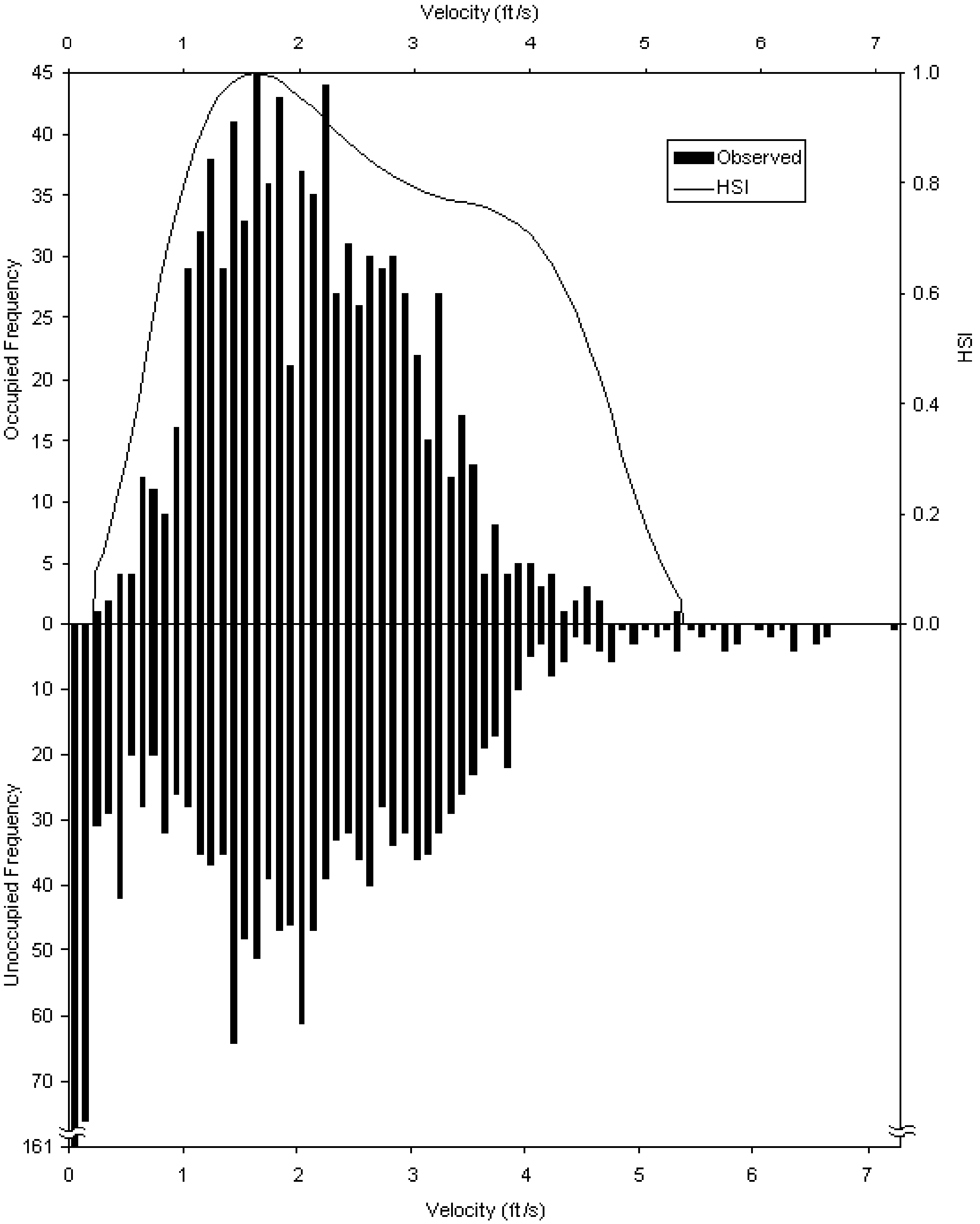


Figure 14. Fall-run Chinook salmon spawning velocity HSC. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for velocities of 0.23 to 5.31 feet/sec (0.070 to 1.618 m/s) and an optimum suitability at velocities of 1.5 to 1.7 feet/sec (0.457 to 0.518 m/s).

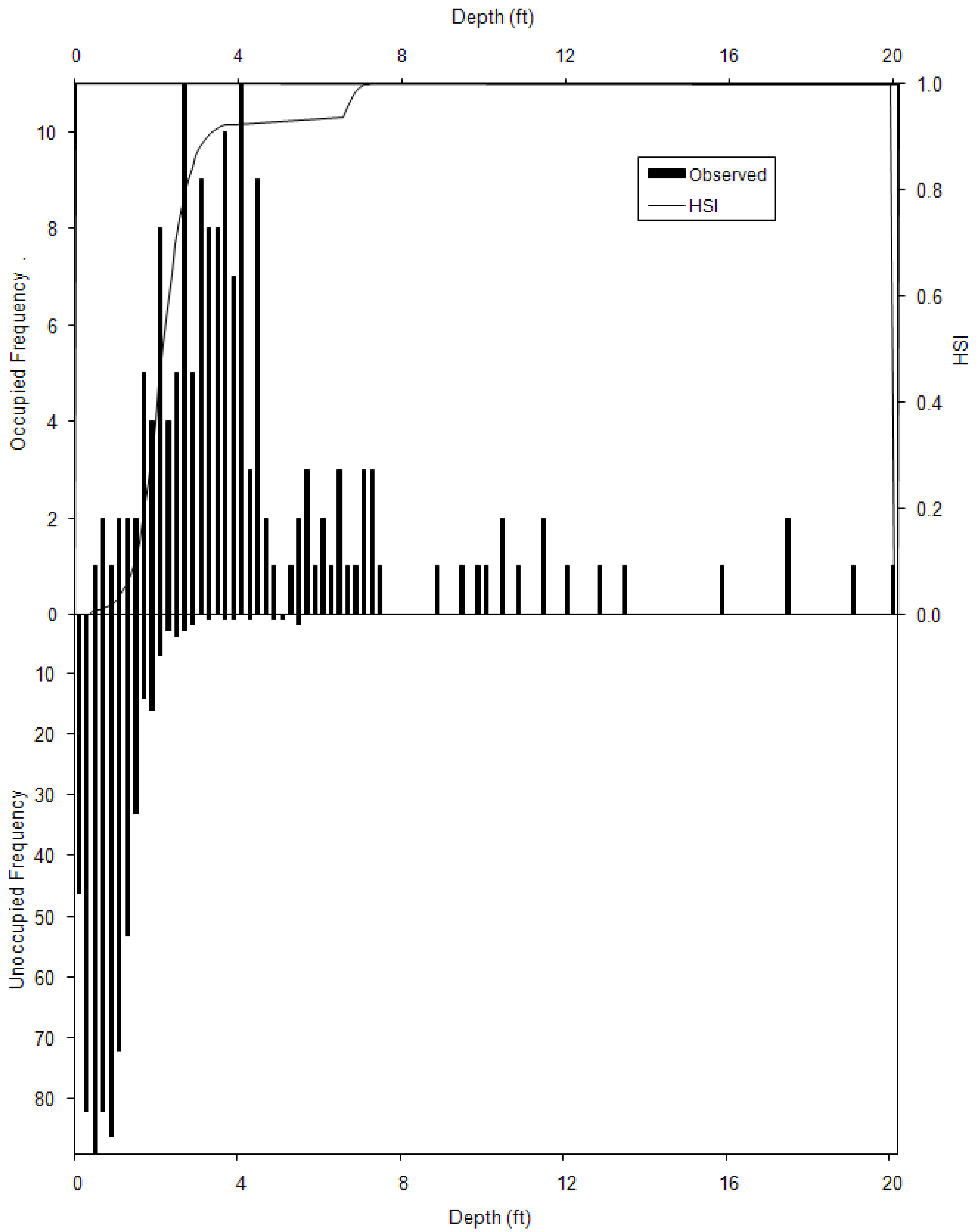


Figure 15. Steelhead/rainbow trout spawning depth HSC. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for depths of 0.4 to 19.9 feet (0.12 to 6.06 m), reaches a suitability of 0.9 at 3.2 feet (0.97 m) and an optimum suitability at depths of 7.0 to 16.9 feet (2.13 to 5.15 m).

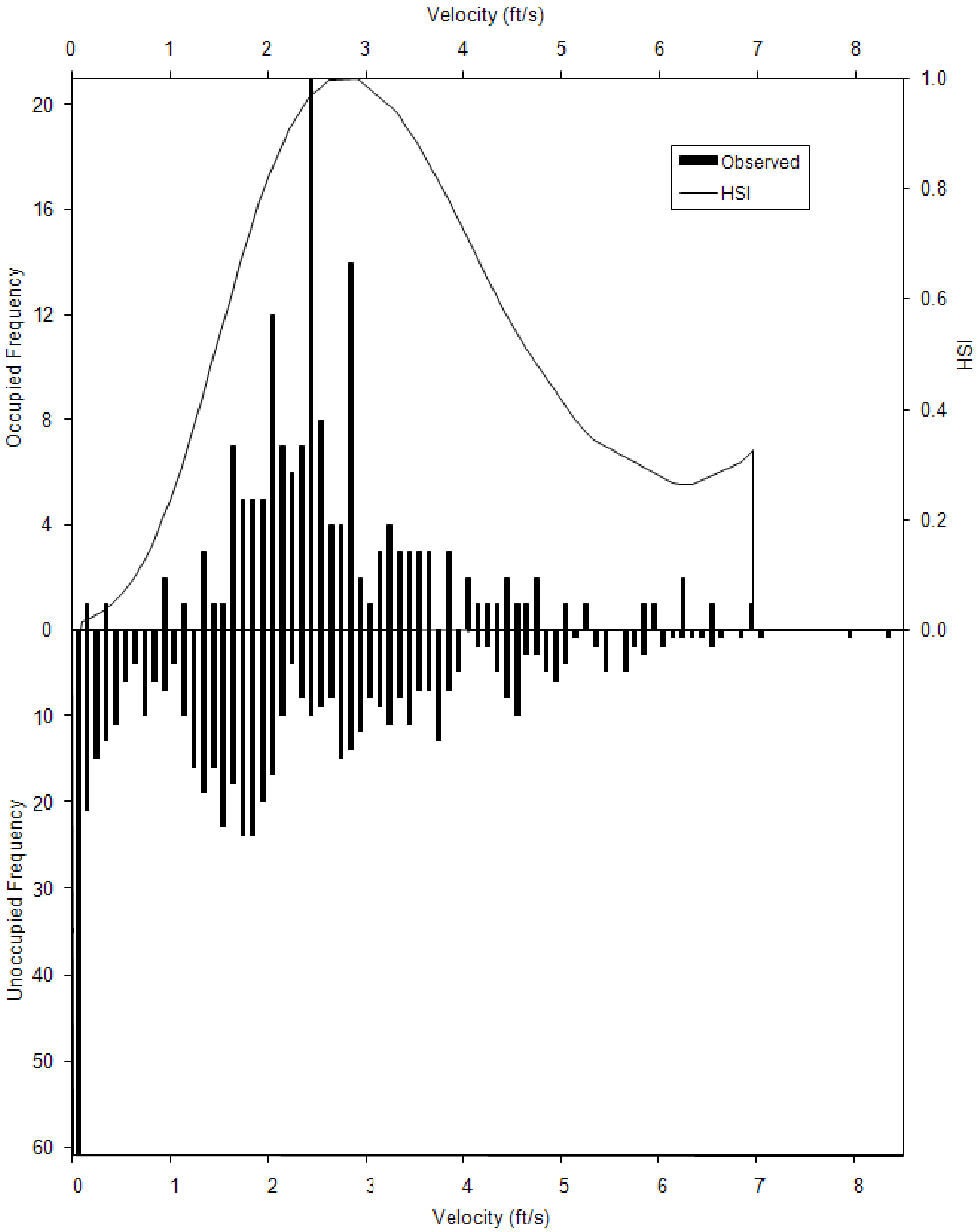


Figure 16. Steelhead/rainbow trout spawning velocity HSC. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for velocities of 0.09 to 6.92 feet/sec (0.027 to 2.109 m/s) and an optimum suitability at velocities of 2.6 to 2.9 feet/sec (0.792 to 0.884 m/s).

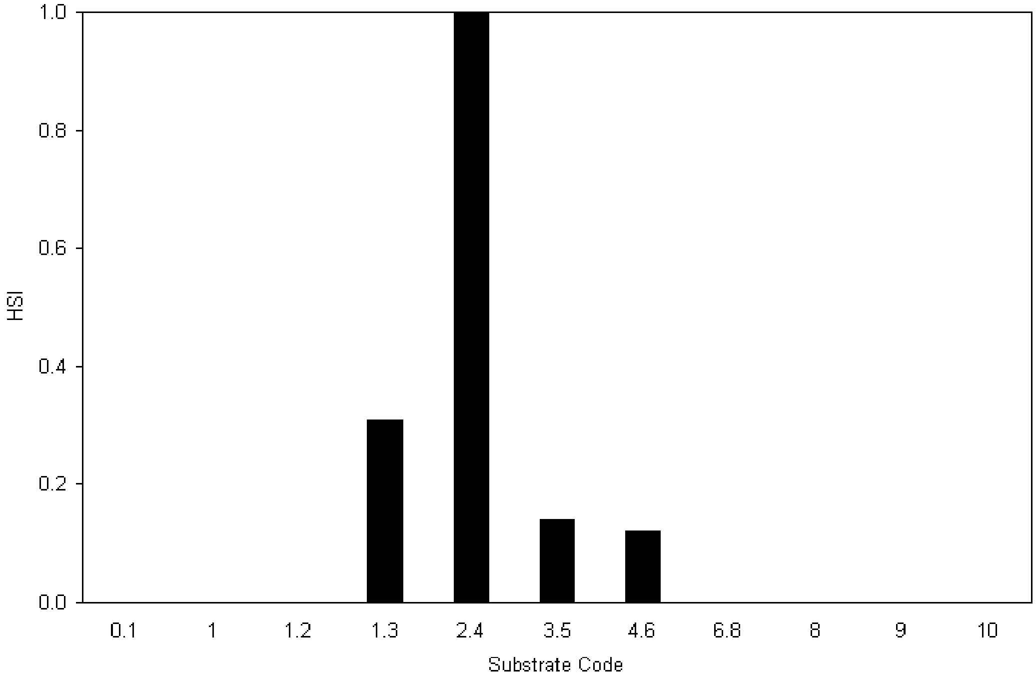


Figure 17. Spring-run Chinook salmon HSC curve for substrate. The HSC show that spring-run Chinook salmon spawning has a non-zero suitability for substrate codes 1.3 to 4.6 and an optimum suitability for substrate code 2.4.

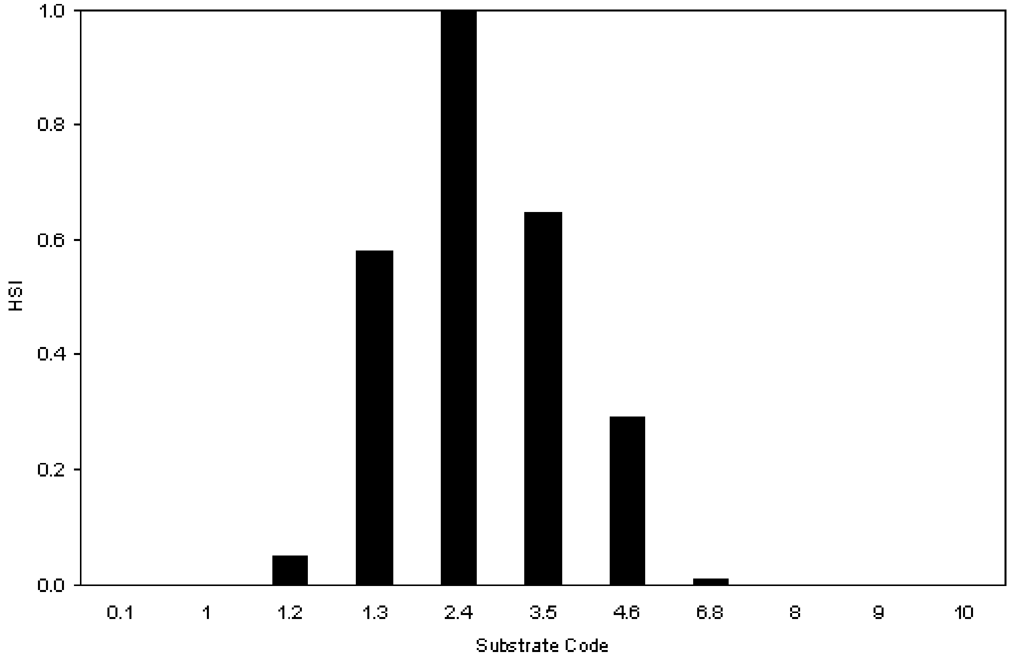


Figure 18. Fall-run Chinook salmon HSC curve for substrate. The HSC show that fall-run Chinook salmon spawning has a non-zero suitability for substrate codes 1.2 to 6.8 and an optimum suitability for substrate code 2.4.

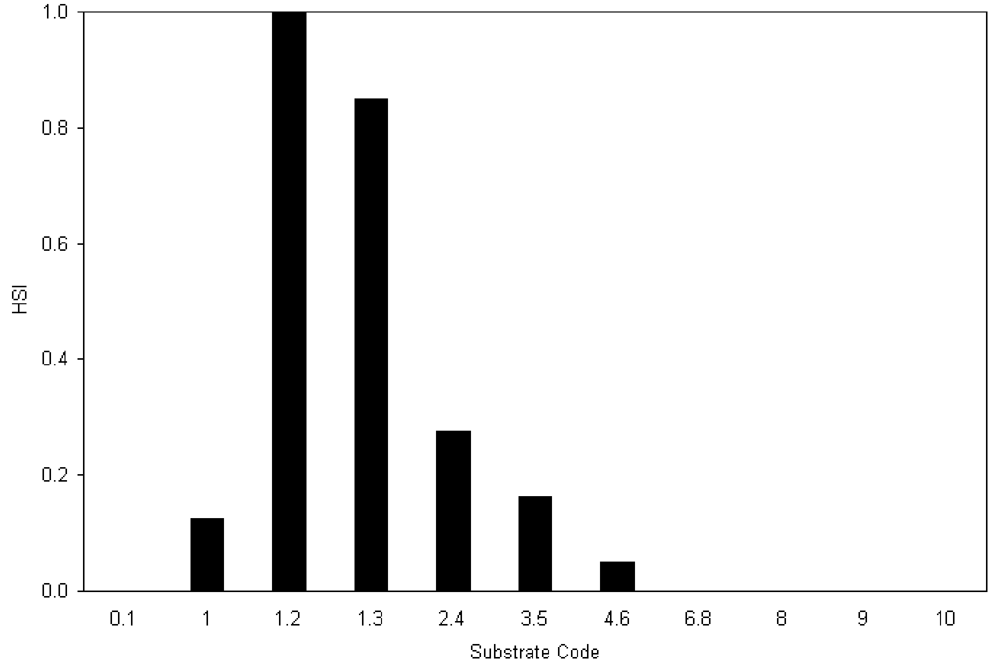


Figure 19. Steelhead/rainbow trout HSC curve for substrate. The HSC show that steelhead/rainbow trout spawning has a non-zero suitability for substrate codes 1 to 4.6 and an optimum suitability for substrate code 1.2.

*Biological Verification*

For spring-run Chinook salmon, the combined habitat suitability predicted by the 2-D model was significantly higher for locations with redds (median = 0.23, n = 146) than for locations without redds (median = 0.01, n = 1200), based on the one-tailed Mann-Whitney U test (U = 48020, $p < 0.000001$). The frequency distribution of combined habitat suitability for locations with spring-run Chinook salmon redds is shown in Figure 20, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 21. A greater number in the suitability index indicates greater suitability.

The location of spring-run Chinook salmon redds relative to the distribution of combined suitability is shown in Appendix L. The 2-D model predicted that 23 of the 146 (16%) redd locations had a combined suitability of zero. Six had a combined suitability of zero due to the predicted substrate being too small (substrate codes of 0.1, 1 and 1.2), 13 had a combined suitability of zero due to the predicted substrate being too large (substrate codes of 6.8, 8, 9 and 10), 1 had a combined suitability of zero due to the predicted velocity being too low (less than 0.29 ft/s [0.088 m/s]), 2 had a combined suitability of zero due to the predicted velocity being too high (greater than 4.40 ft/s [1.341 m/s]), and 1 had a combined suitability of zero due to the predicted depth being too low (depth less than 0.5 foot [0.15 m]).

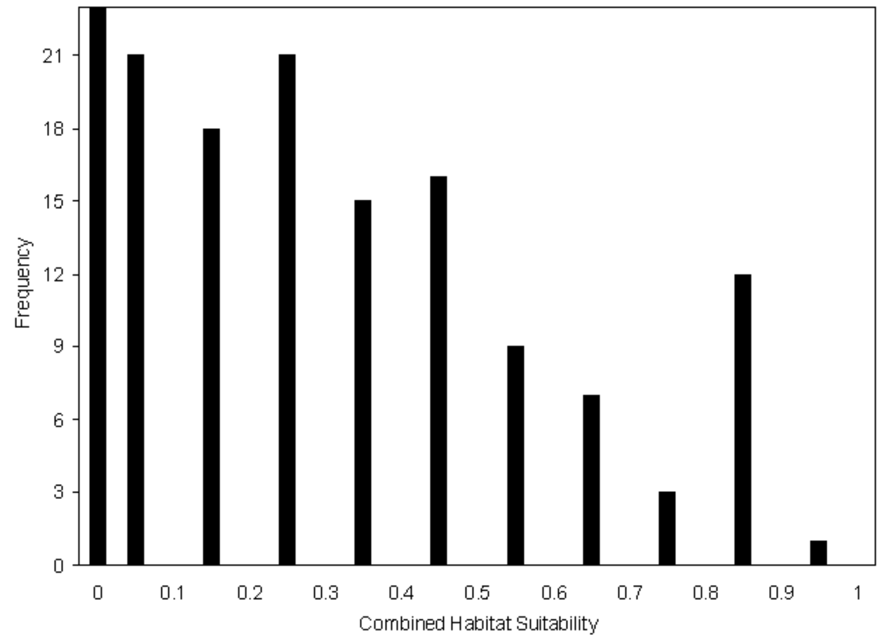


Figure 20. Combined suitability for 2-D model locations with spring-run Chinook salmon redds. The median combined suitability for occupied locations was 0.23.

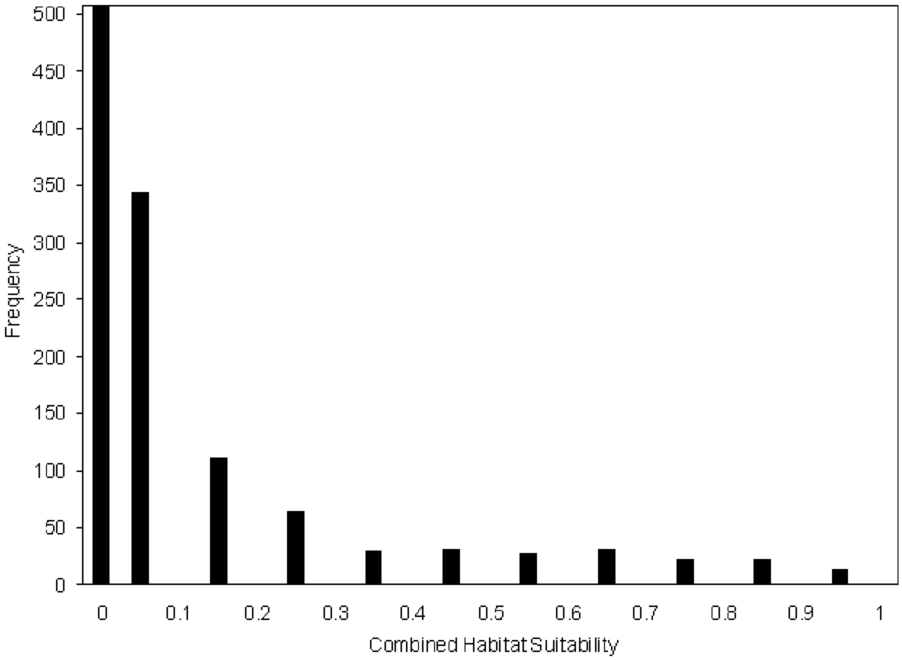


Figure 21. Combined suitability for 2-D model locations without spring-run Chinook salmon redds. The median combined suitability for unoccupied locations was 0.01.

For fall-run Chinook salmon, the combined habitat suitability predicted by the 2-D model was significantly higher for locations with redds (median = 0.39, n = 422) than for locations without redds (median = 0.11, n = 1600), based on the one-tailed Mann-Whitney U test (U = 225858, $p < 0.00001$). The frequency distribution of combined habitat suitability for locations with fall-run Chinook salmon redds is shown in Figure 22, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 23. A greater number in the suitability index indicates greater suitability.

The location of fall-run Chinook salmon redds relative to the distribution of combined suitability is shown in Appendix L. The 2-D model predicted that 33 of the 422 (8%) redd locations had a combined suitability of zero. Three had a combined suitability of zero due to the predicted substrate being too small (substrate codes of 0.1 and 1), 14 had a combined suitability of zero due to the predicted substrate being too large (substrate codes of 8, 9 and 10), 13 had a combined suitability of zero due to the predicted velocity being too low (less than 0.23 ft/s [0.070 m/s]), 1 had a combined suitability of zero because the location was predicted to be dry by the 2-D model, and 2 had a combined suitability of zero due to the predicted depth being too low (depth less than 0.2 ft [0.06 m]).

For steelhead/rainbow trout, the combined habitat suitability predicted by the 2-D model using the criteria determined only from occupied and unoccupied data upstream of Highway 20 was significantly higher for locations with redds (median = 0.245, n =32) than for locations without redds (median = 0.0004, n = 600), based on the one-tailed Mann-Whitney U test (U = 4298, $p < 0.000001$). The frequency distribution of combined habitat suitability using the criteria determined only from occupied and unoccupied data upstream of Highway 20 for locations with steelhead/rainbow trout redds is shown in Figure 24, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 25. A greater number in the suitability index indicates greater suitability.

The location of steelhead/rainbow trout redds relative to the distribution of combined suitability is shown in Appendix L. The 2-D model predicted that 4 of the 36 (11%) redd locations had a combined suitability of zero. Two had a combined suitability of zero due to the predicted substrate being too large (substrate codes of 6.8, 8, 9 and 10), and two had a combined suitability of zero because the location was predicted to be dry by the 2-D model.

### *Habitat Simulation*

The WUA values calculated for each site are contained in Appendix K. The ratios of total redds counted in the segment to number of redds in the modeling sites for that segment were as follows: fall-run Chinook salmon Above Daguerre Segment = 2.20, Below Daguerre Segment = 2.37; steelhead/rainbow trout Above Daguerre Segment = 1.76, Below Daguerre Segment = 1.25.

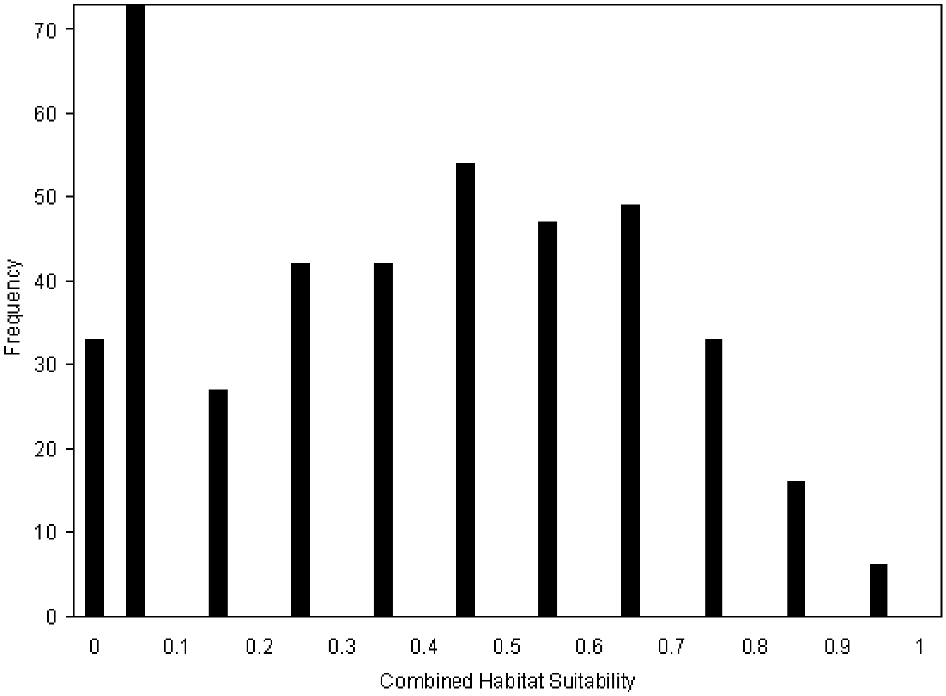


Figure 22. Combined suitability for 2-D model locations with fall-run Chinook salmon redds. The median combined suitability for occupied locations was 0.39.

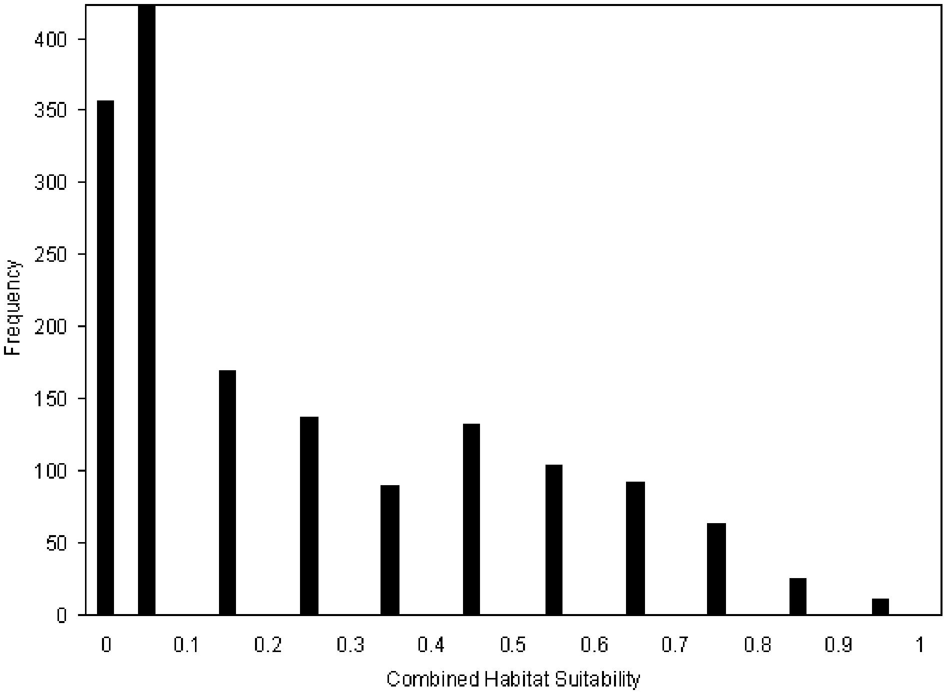


Figure 23. Combined suitability for 2-D model locations without fall-run Chinook salmon redds. The median combined suitability for unoccupied locations was 0.11.

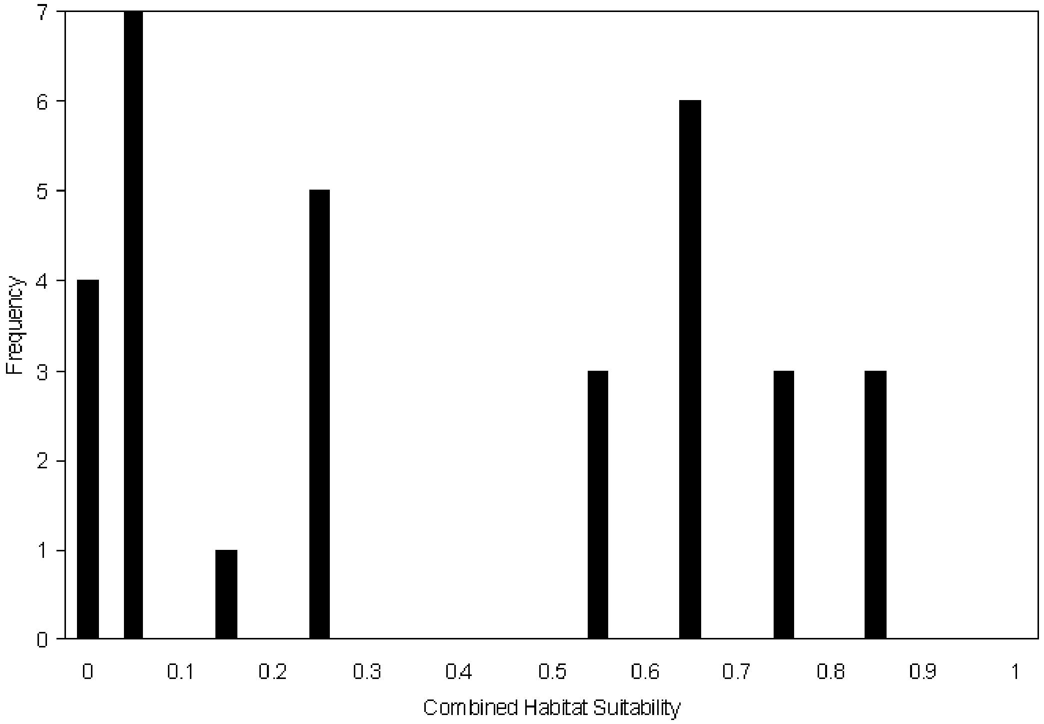


Figure 24. Combined suitability for 2-D model locations with steelhead/rainbow trout redds. The median combined suitability for occupied locations was 0.245.

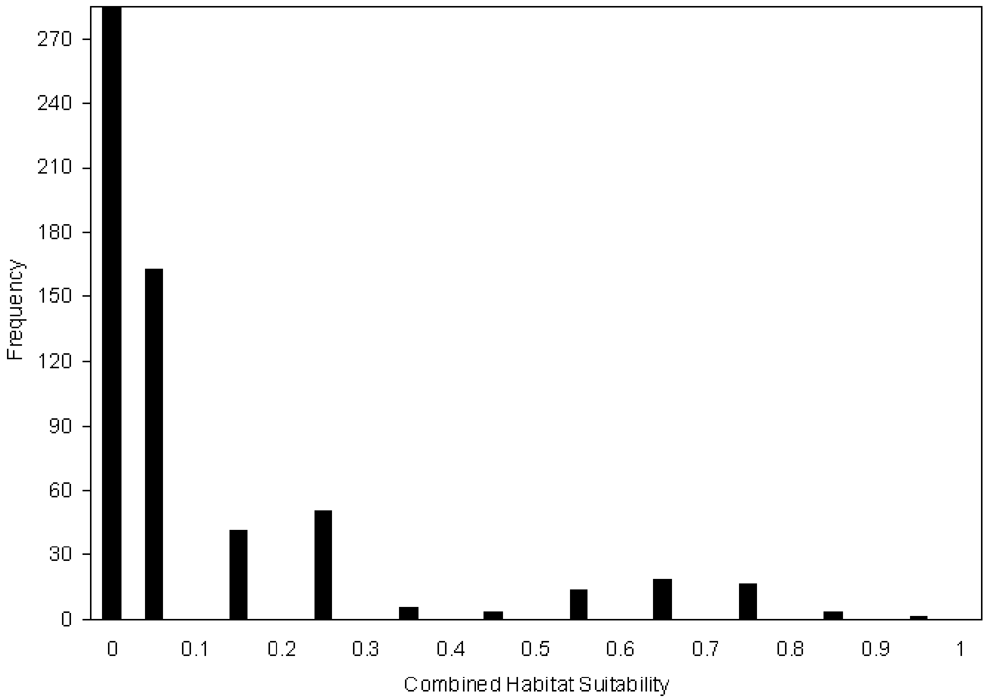


Figure 25. Combined suitability for 2-D model locations without steelhead/rainbow trout redds. The median combined suitability for occupied locations was 0.0004.

The flow habitat relationships for spring-run Chinook salmon spawning are shown in Figures 26 and 27 and Appendix K. In the Above Daguerre Segment, the 2-D model predicts the highest total WUA at 1,400 cfs. For the Below Daguerre Segment, the total WUA peak is at 900 cfs. The flow habitat relationships for fall-run Chinook salmon spawning are shown in Figures 28 and 29 and Appendix K. In the Above Daguerre Segment, the 2-D model predicts the highest total WUA at 1,000 cfs. For the Below Daguerre Segment, the total WUA peak is at 1,400 cfs. The flow habitat relationships for steelhead/rainbow trout spawning are shown in Figures 30 and 31 and Appendix K. In the Above Daguerre Segment, the 2-D model predicts the highest total WUA at 2,900 cfs. For the Below Daguerre Segment, the total WUA peak is at 3,700 cfs.

### *Evaluation of Polygon Substrate Data Collection Methods*

## Biological Verification

The location of spring-run Chinook salmon redds relative to the distribution of combined suitability is shown in Appendix L. The combined habitat suitability predicted by the 2-D model for the two sites using the standard method was significantly higher for locations with spring-run Chinook salmon redds (median = 0.38) than for locations without redds (median = 0.02) based on the one-tailed Mann-Whitney U test ($U = 1634$, $p < 0.0002$). The combined habitat suitability predicted by the 2-D model for the two sites using the polygon method was also significantly higher for locations with spring-run Chinook salmon redds (median = 0.13) than for locations without redds (median = 0.03) based on the one-tailed Mann-Whitney U test ($U = 1902$, $p < 0.0016$). The location of fall-run Chinook salmon redds relative to the distribution of combined suitability is shown in Appendix L. The combined habitat suitability predicted by the 2-D model for the two sites using the standard method was significantly higher for locations with fall-run Chinook salmon redds (median = 0.38) than for locations without redds (median = 0.08) based on the one-tailed Mann-Whitney U test ($U = 6980$, $p < 0.000001$). The combined habitat suitability predicted by the 2-D model for the two sites using the polygon method was also significantly higher for locations with fall-run Chinook salmon redds (median = 0.63) than for locations without redds (median = 0.13) based on the one-tailed Mann-Whitney U test ($U = 6058$, $p < 0.000001$). The location of steelhead/rainbow trout redds relative to the distribution of combined suitability is shown in Appendix L. The combined habitat suitability predicted by the 2-D model for the Highway 20 site using the standard method was not significantly higher for locations with steelhead/rainbow trout redds (median = 0.17) than for locations without redds (median = 0.014) based on the one-tailed Mann-Whitney U test ($U = 461$, $p = 0.12$). The combined habitat suitability predicted by the 2-D model for the two sites using the polygon method was also not significantly higher for locations with steelhead/rainbow trout redds (median = 0.16) than for locations without redds (median = 0.023) based on the one-tailed Mann-Whitney U test ($U = 560$, $p = 0.37$).

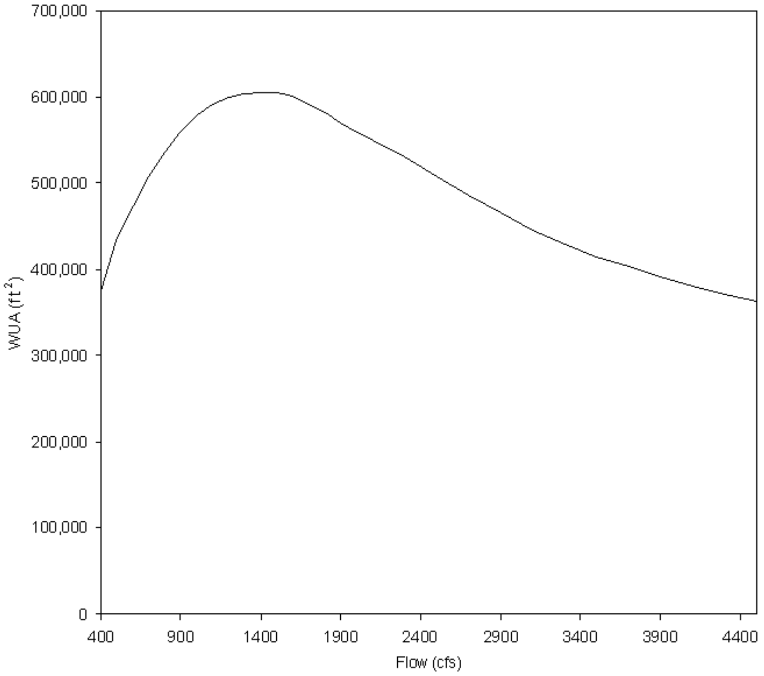


Figure 26. Spring-run Chinook salmon spawning flow-habitat relationship above Daguerre Point Dam. The flow with the maximum spring-run Chinook salmon spawning habitat was 1400 cfs.

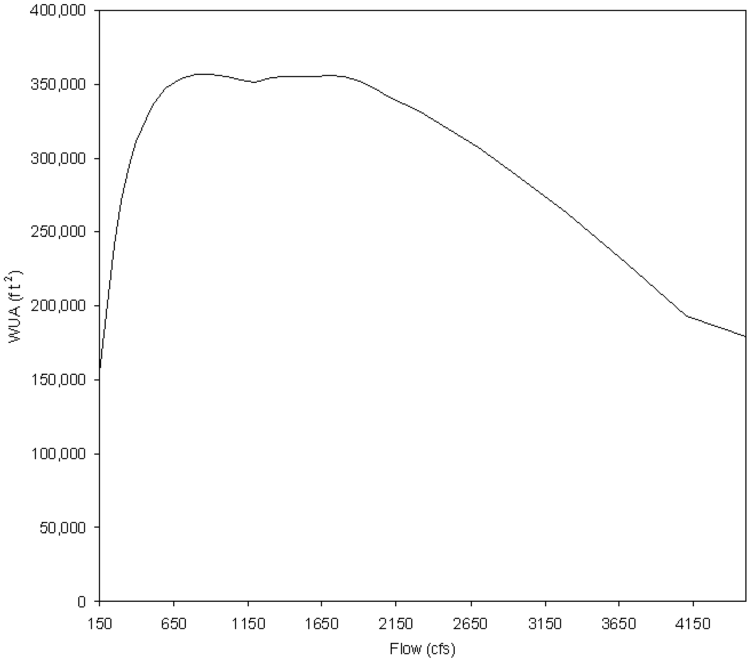


Figure 27. Spring-run Chinook salmon spawning flow-habitat relationship below Daguerre Point Dam. The flow with the maximum spring-run Chinook salmon spawning habitat was 900 cfs.

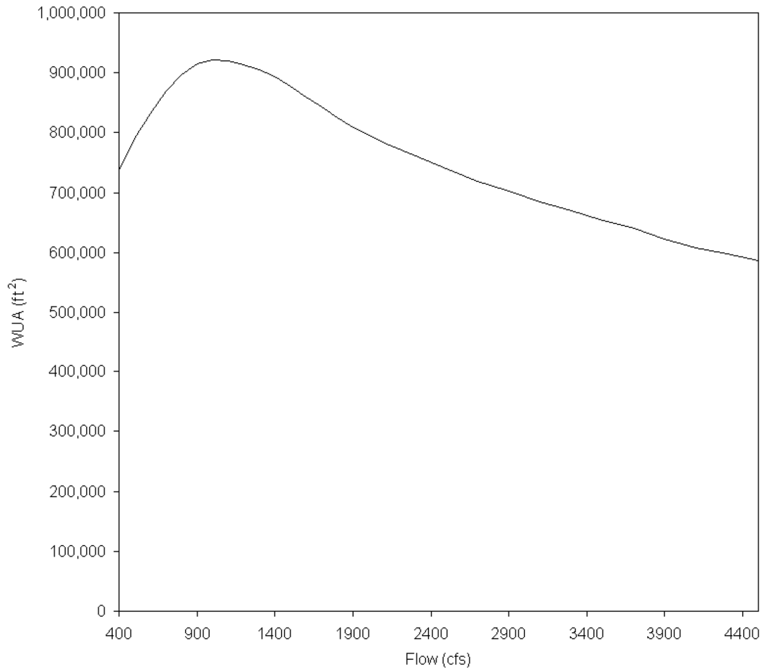


Figure 28. Fall-run Chinook salmon spawning flow-habitat relationship above Daguerre Point Dam. The flow with the maximum fall-run Chinook salmon spawning habitat was 1000 cfs.

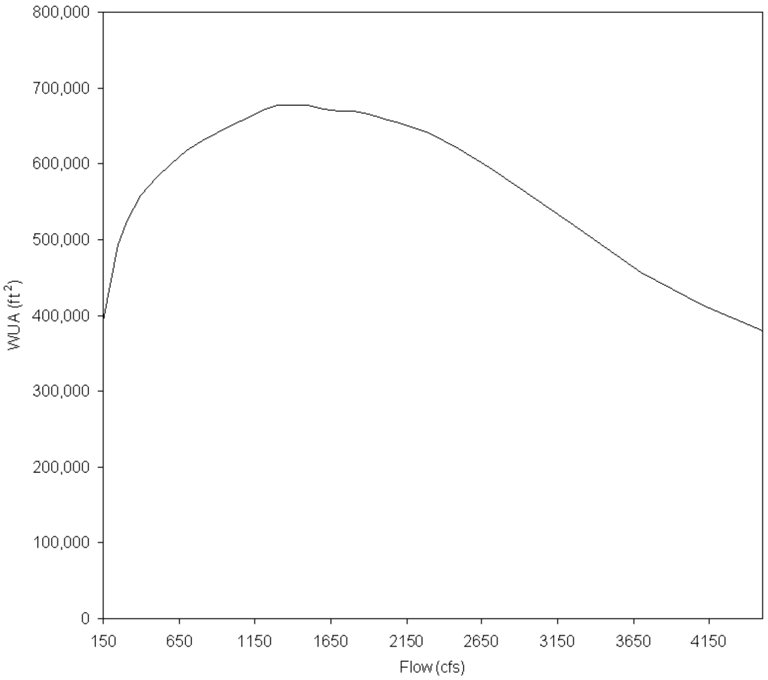


Figure 29. Fall-run Chinook salmon spawning flow-habitat relationship below Daguerre Point Dam. The flow with the maximum fall-run Chinook salmon spawning habitat was 1400 cfs.

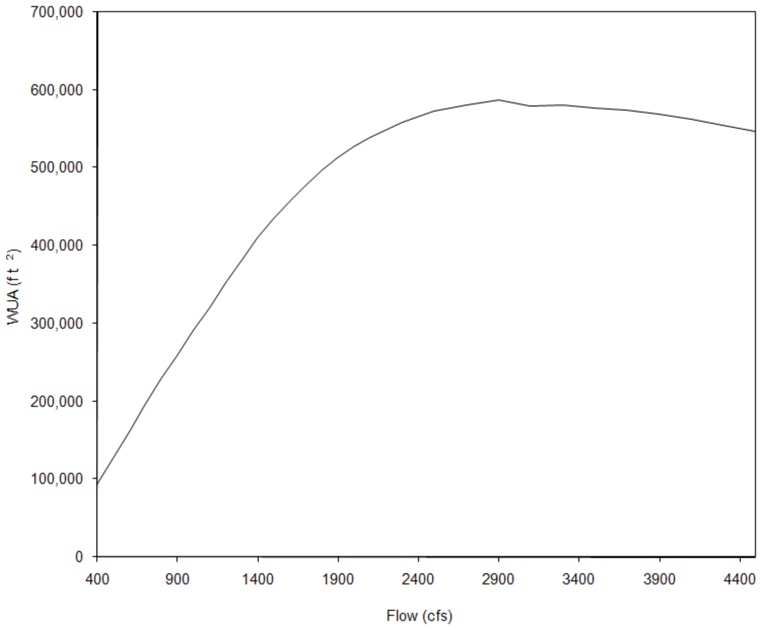


Figure 30. Steelhead/rainbow trout spawning flow-habitat relationship above Daguerre Point Dam. The flow with the maximum steelhead/rainbow trout spawning habitat was 2,900 cfs.

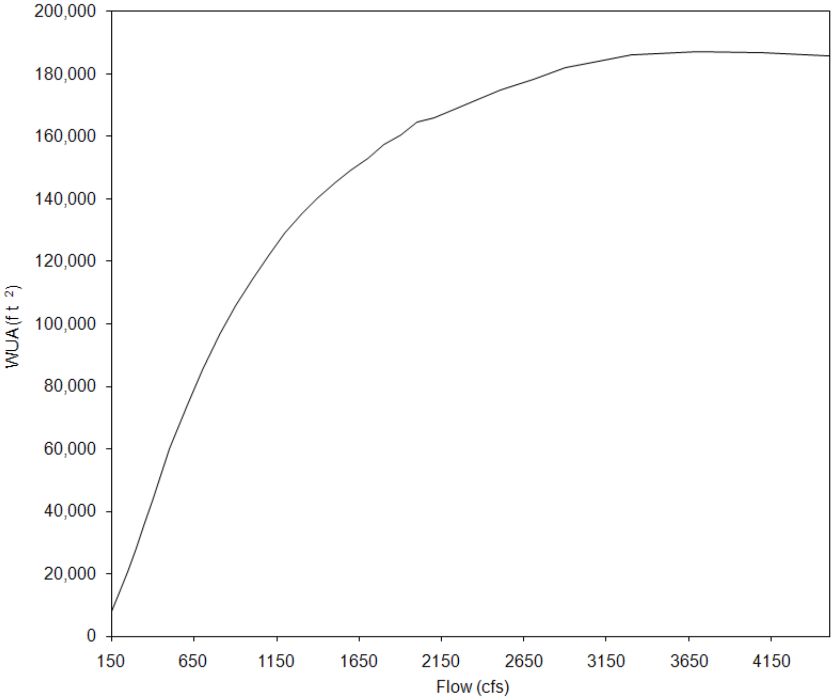


Figure 31. Steelhead/rainbow trout spawning flow-habitat relationship below Daguerre Point Dam. The flow with the maximum steelhead/rainbow trout spawning habitat was 3,700 cfs.

The comparison of the percentage of redds where the substrate was correctly characterized by the 2-D model using the standard method versus the polygon method found that the results for the standard method were nearly identical to those for the polygon method. The 2-D model correctly predicted the substrate for 36% of the redds using the standard method, while the use of the polygon method resulted in the substrate being correctly predicted for 37% of the redds.

### Habitat simulation

The flow habitat relationships for spring-run Chinook salmon spawning predicted by the 2-D model using the standard and polygon methods for Highway 20 site are shown in Figure 32. Using the standard method, the 2-D model predicts the highest WUA at 1,300 cfs. Using the polygon method, the 2-D model predicts the highest WUA at 1,500 cfs. For fall-run Chinook salmon (Figure 33), using the standard method, the 2-D model predicts the highest WUA at 1,000 cfs. Using the polygon method, the 2-D model predicts the highest WUA at 1,400 cfs. For steelhead/rainbow trout, the 2-D model predicts the highest WUA at 3,100 cfs using the standard method, with the WUA still increasing up to that flow. Using the polygon method, the 2-D model predicts the highest WUA at 3,700 cfs (Figure 34). Based on the results for Hwy 20 site, the flow at which WUA peaks is somewhat higher using the polygon method compared to the standard method for spring-run Chinook salmon and more so for fall-run Chinook salmon and steelhead/rainbow trout. Overall, the main notable difference in the results is that the predicted amount of available habitat at each flow is consistently higher using the polygon method compared to the standard method for spring and fall-run Chinook salmon and steelhead/rainbow trout.

The flow habitat relationships for spring-run Chinook salmon spawning predicted by the 2-D model using the standard and polygon methods for Upper Daguerre site are shown in Figure 35. For spring-run Chinook salmon, both methods predict the highest WUA at 800 cfs. For fall-run Chinook salmon, using the standard method, the 2-D model predicts the highest WUA at 500 cfs. Using the polygon method, the 2-D model predicts the highest WUA at 600 cfs (Figure 36). Based on the results for Upper Daguerre site, the flow at which WUA peaks is essentially the same using either method for spring and fall-run Chinook salmon. For spring and fall-run Chinook salmon, the amount of available habitat predicted by the 2-D model for each flow is higher using the polygon method up to about 2,300 cfs for spring-run Chinook salmon and 2,000 cfs for fall-run Chinook salmon. However, beyond these flows, the 2-D model predicts more available habitat using the standard method.

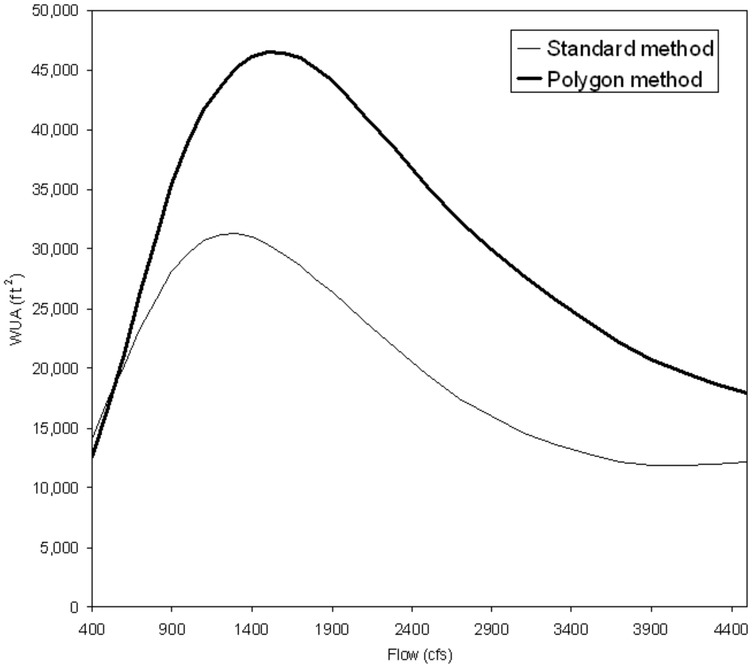


Figure 32. Highway 20 site spring-run Chinook salmon spawning flow-habitat relationships standard and polygon substrate collection methods. The flow with the maximum WUA was higher for the polygon method than for the standard method.

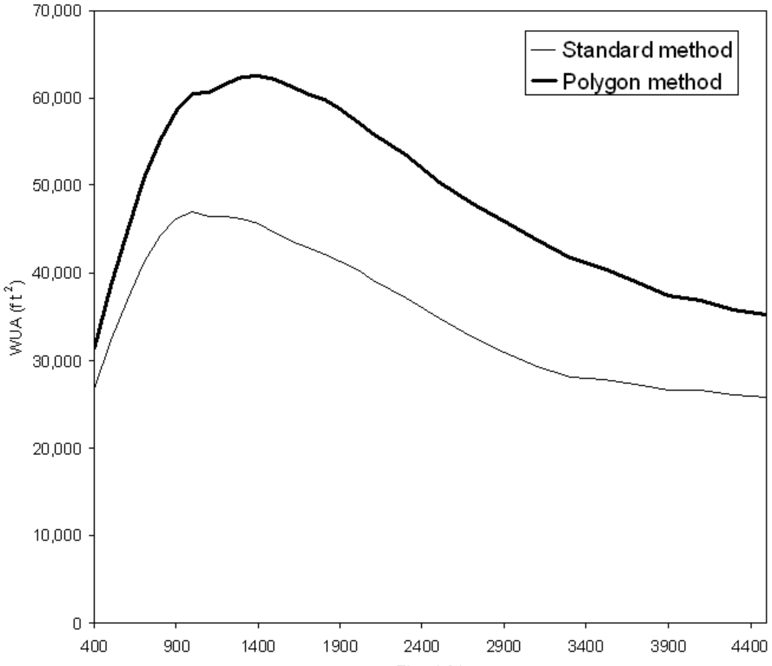


Figure 33. Highway 20 site fall-run Chinook salmon spawning flow-habitat relationships standard and polygon substrate collection methods. The flow with the maximum WUA was higher for the polygon method than for the standard method.

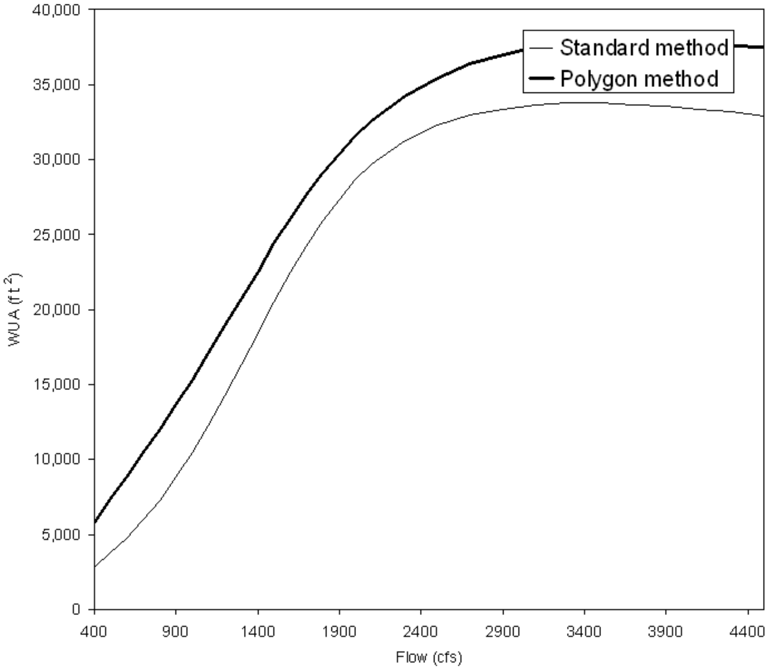


Figure 34. Highway 20 site steelhead/rainbow trout spawning flow-habitat relationships standard and polygon substrate collection methods. The flow with the maximum WUA was higher for the polygon method than for the standard method.

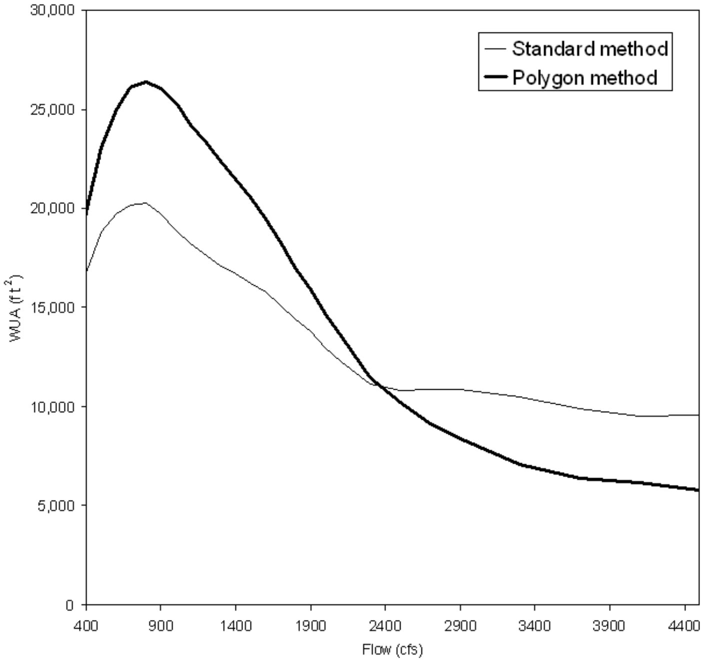


Figure 35. Upper Daguerre site spring-run Chinook salmon spawning flow-habitat relationships standard and polygon substrate collection methods. The flow with the maximum WUA was the same for both methods.

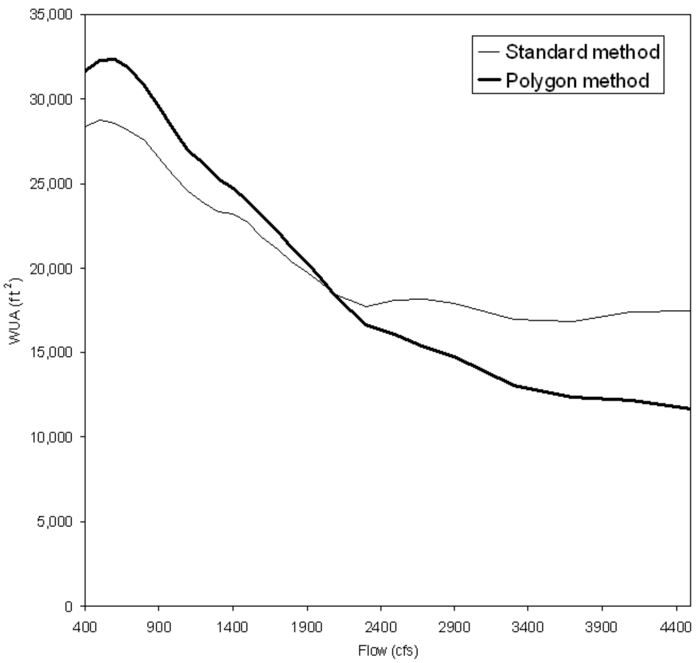


Figure 36. Upper Daguerre site fall-run Chinook salmon spawning flow-habitat relationships standard and polygon substrate collection methods. The flow with the maximum WUA was slightly higher for the polygon method than for the standard method.

## DISCUSSION

### *Hydraulic and Structural Habitat Data Collection*

Incorporating Corps data allowed greater refinement of the bed topography for each study site. Establishing the precise northing and easting coordinates and elevations of our horizontal benchmarks using dual frequency survey-grade differential GPS and tying in our vertical benchmarks to the elevations of the horizontal benchmarks also enabled establishing the location and orientation of the sites and their bed elevations and water surface elevations relative to data that is concurrently being collected by other entities. This will facilitate the sharing and comparison of data for the various studies being conducted on the Yuba River. All of the measurements were accurate to 1 foot (0.3 m) horizontally and 0.1 foot (0.031 m) vertically. We conclude that measurement error would have a minimal effect on the final result. The topographic point densities fall within the range of reported values in published studies. For example, LeClerc et al. (1995) had a point density of 0.25 to 2 points/100 m$^2$, while Jacobson and Galat (2006) had a point density of 6 points/100 m$^2$.

*Hydraulic Model Construction and Calibration*

### PHABSIM WSEL Calibration

We did not regard the slightly low VAF values for the lowest simulation flow of 150 cfs for Upper Daguerre and Hallwood downstream transects as problematic since RHABSIM was only used to simulate WSELs and not velocities.

### RIVER2D Model Construction

The Corps data incorporated into the bed topography allowed greater refinement of the bed topography for each study site. In most cases, the portions of the mesh where there was greater than a 0.1 foot (0.031 m) difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 foot (0.031 m) vertically of the bed file within 1.0 foot (0.3 m) horizontally of the bed file location. Given that we had a 1-foot (0.3 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file.

### RIVER2D Model Calibration

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

We considered the solution to be acceptable for the study site cdg files which had a maximum Froude Number greater than 1, since the Froude Number only exceeded one at a few nodes, with the vast majority of the site having Froude Numbers less than one. Furthermore, these nodes were located either at the water’s edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water’s edge or in very shallow depths would be expected to have an insignificant effect on the model results because these conditions do not coincide with suitable spawning habitat.

Although the maximum WSEL values for the Island, Hammond, Upper Daguerre, and Plantz sites upstream transect and for the Pyramids site downstream transect exceeded the 0.1 foot (0.031 m) criterion, all had average WSELs that were well within that criterion value (Appendix F). In each case, the WSELs next to the locations of the left and right banks within the model were all within the 0.1 foot (0.031 m) criterion value. The PHABSIM simulated WSELs and the measured WSELs used for calibrating the cdg files were based on WSEL measurements taken next to the left and right banks. For higher gradient portions of the Yuba River, the WSEL going across the river will differ by more than 0.1 foot (0.031 m) at some flows, with up to a 0.65 foot (0.198 m) measured difference in WSEL between the two banks in some areas, such as the Highway 20 site. Accordingly, we conclude the calibration for these five sites was acceptable.

## RIVER2D Model Velocity Validation

Differences in magnitude in most cases are likely due to (1) aspects of the bed topography of the site that were not captured in our data collection; (2) operator error during data collection, i.e., the probe was not facing precisely into the direction of current; (3) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the velocity range averaged in the model simulations; and (4) the measured velocities being the component of the velocity in the downstream direction, while the velocities predicted by the 2-D model were the absolute magnitude of velocity (Pasternack et al. 2006)[24]. As shown in the figures in Appendix G, we attribute most of the differences between measured and predicted velocities to noise in the measured velocity measurements; specifically, for the transects, the simulated velocities typically fell within the range of the measured velocities of the three or more ADCP traverses made on each transect. 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. The effects of model errors in predicting velocities on the overall flow-habitat relationships are addressed below in *Factors Causing Uncertainty*.

For those deep beds where RIVER2D over or under-predicted the velocities on one or both sides of the channel for the following deep beds, we attribute this to either errors in the bed topography that did not properly characterize features that resulted in faster/slower velocities, or errors in the ADCP measurements of velocity. Timbuctoo Deep Beds E-H are good examples of where the bed topography was not accurately characterized in the model. The location of these deep beds was in (E and F) and below (G and H) the downstream end of a side channel. Looking at the measured velocities, it is apparent that the water flowing down the main channel reflected off the rock wall that was present at the downstream end of the exit of the side channel, increasing the velocities along the west side of the side channel (with an eddy going up the side channel) and

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

downstream main channel. The RIVER2D predicted velocities do not show any influence from a rock wall. The complexity of the bed topography that existed in the main channel and the exit from the side channel would likely have required a significantly higher density of data points to accurately capture the velocity pattern in this area.

For Timbuctoo downstream (XS1) transect, where RIVER2D over-predicted the simulated velocities, and Island downstream transect, where RIVER2D under-predicted the velocities toward the south side of the channel, but over-predicted the velocities on the far south side of the channel and the north side of the channel, examination of the RIVER2D velocity vectors on the downstream transect showed that there was an eddy that resulted in an upstream direction of flow at the location of the eddy and affected the downstream flow on either side. Comparison with the measured velocities in this area of the downstream transect showed that there was no apparent eddy at that flow. It appears that an inaccurate representation of the bed topography in the vicinity of the downstream transect produced an eddy at that flow with the resulting peaks and troughs in the RIVER2D velocities that do not match with the measured velocities. Another possible explanation is that boundary conditions at the downstream transect may have caused the eddy. Use of a downstream extension might have eliminated the eddy.

In the case of Timbuctoo upstream (XS2) transect, where RIVER2D over-predicted the simulated velocities on the east side of the channel, we attribute this to errors in the ADCP velocity measurements (being too low). For example, the calculated discharge for the upstream transect was 1,901 cfs versus the actual total river discharge of 2,195 cfs.

The over-predicted and the under-predicted velocities for a short distance in the middle of the channel for the Island and the Pyramids upstream transects (XS2) very likely can be attributed to the use of the Corps data to produce the channel topography upstream of the upstream transect. These data were collected at a much lower density than our data and it is very likely that a small-scale feature that was located upstream of the upstream transect that influenced the water velocities in that area was not accurately characterized or is missing from the model bed topography.

Where RIVER2D under-predicted the velocities across most of the channel for Island Deep Beds B-D, we attribute this to errors in the ADCP velocity measurements (being too high). For example, the calculated discharges for Deep Beds B-D were 3,532, 3,230, and 3,254 cfs, respectively, versus the actual total river discharge of 2,373 cfs. RIVER2D also likely under-predicted the velocities for Island Deep Beds N, O, and R due to the ADCP velocity measurements being too high. However, since these Deep Beds were located in a portion of the site where there was a split channel, the calculated discharges represent only a portion of the total flow, preventing a comparison with the actual total river discharge.

In the cases where RIVER2D over-predicted the simulated velocities for the Hammond Deep Beds A, B and D, Upper Daguerre Deep Beds C, Lower Daguerre Deep Beds A and M, and Pyramids Deep Beds A-C, we attribute this to errors in the ADCP measurements (being too low). For example, the calculated discharges for Hammond Deep Beds A, B, and D (which crossed most of the wetted channel) were 552, 498, and 539 cfs, respectively, versus the actual total discharge of 955 cfs. In the case of Upper Daguerre Deep Beds C, the calculated discharge was 417 cfs and the actual total river discharge was 1,640 cfs. The same was true for Lower Daguerre Deep Beds A and M (both of which went across large portions of the wetted channel), where the calculated discharges were 623 and 1,037 cfs, respectively, while the actual total river discharges were 1,640 and 1,620, respectively. For Pyramids Deep Beds A-C, the calculated discharges for Deep Beds A-C (each Deep Bed crossed nearly the entire width of the wetted channel) were 490, 514, and 458 cfs, while the actual total river discharge was 1,620 cfs.

### RIVER2D Model Simulation Flow Runs

The simulation flow run cdg files for Timbuctoo, Island, Upper Daguerre, Lower Daguerre, Pyramids, and Plantz, where the net Q was greater than 1%, had a stable solution since the net Q was not changing and the net Q in all cases was less than 5%. In comparison, the accepted level of accuracy for USGS gages is generally 5%. Thus, the difference between the flows at the upstream and downstream boundary (net Q) is within the same range as the accuracy for USGS gages, and is considered acceptable. In the case of the eight Pyramid production cdg files where the net Q significantly exceeded the 5% level, we consider that a level of uncertainty applies to results for these production files. These higher net Q's resulted from the cross-sectional area at the downstream boundary that was too small at low flows. This was caused by low density of bed topography data collected by the Corps that were used to develop the downstream extension. This affected only the simulated depths and velocities in the downstream extension and thus would not have had an effect on the flow-habitat relationships for this site, since the depths and velocities in the downstream extension are not used to compute habitat. For example, at the lowest simulated flow, the net Q was 3% at the location twenty-five feet (7.6 m) upstream of the downstream boundary.

Although a majority of the simulation flow files had Max Froude values that exceeded 1, we considered these production runs to be acceptable since the Froude Number was only greater than one at a few nodes, with the vast majority of the area within the site having Froude Numbers less than one. Again, as described in RIVER2D Model Calibration discussion, these nodes were located either at the water's edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water's edge or in very shallow depths would be expected to have an insignificant effect on the model results because these conditions do not coincide with suitable spawning habitat.

### *Habitat Suitability Criteria (HSC) Data Collection*

Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded. Since our goal is to avoid classifying Chinook salmon redds as steelhead redds, we feel that the length and width criteria are sufficiently accurate for purposes of collecting steelhead/rainbow trout spawning criteria, particularly since there appear to be relatively few late-fall-run chinook salmon in the Yuba River. Given that a majority of the spring-run Chinook salmon redds were constructed after September 17, 2002 and that flows were steady after September 5, 2002, we are confident that the flows at which the spring-run Chinook salmon redds were measured are representative of the flows at which most were constructed. The unstable nature of the flows in both segments from the beginning of fall-run Chinook salmon and steelhead/rainbow trout spawning resulted in some uncertainty that the measured depths and velocities in both segments were the same as present at the time of redd construction in all three years. Since most spring-run Chinook salmon and steelhead/rainbow trout spawn above Daguerre Point Dam, the main focus for spawning for these species/races should be the segment above Daguerre Point Dam. In contrast, since there was a relatively even split of fall-run spawning above and below Daguerre Point Dam, it will be important to consider both segments in setting flow requirements for fall-run Chinook salmon spawning.

### *Habitat Suitability Criteria (HSC) Development*

The $R^2$ values in Table 14 in general reflect the large degree of overlap in occupied and unoccupied depths and velocities, as shown in Figures 14 to 19. Low $R^2$ values are the norm in logistic regression, particularly in comparison with linear regression models (Hosmer and Lemeshow 2000). The $R^2$ values in this study were significantly lower than those in Knapp and Preisler (1999), Geist et al. (2000) and Guay et al. (2000), which had $R^2$ values ranging from 0.49 to 0.86. We attribute this difference to the fact that the above studies used a multivariate logistic regression which included all of the independent variables. It would be expected that the proportion of variance ($R^2$ value) explained by the habitat suitability variables would be apportioned among depth, velocity and substrate. For example, McHugh and Budy (2004) had much lower $R^2$ values, in the range of 0.13 to 0.31, for logistic regressions with only one independent variable.

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

The rapidly decreasing suitability of the initial spring and fall-run depth criteria for depths greater than, respectively, 2.0 and 1.4 feet (0.61 and 0.43 m), was likely due to the low availability of deeper water with suitable velocities and substrates in the Yuba River at the spawning flows rather than active selection by spring and fall-run Chinook salmon of only shallow depths for spawning. For steelhead/rainbow trout, the logistic regression corrected for the low availability of suitable velocities and substrates in deep water because it incorporates both occupied and unoccupied data into the calculation of the habitat suitability criteria. Specifically in this case the very low number of unoccupied locations in deeper water resulted in the logistic regression HSC having high suitability for deep conditions.

It should be noted that the regressions for depth and velocity were fit to the raw occupied and unoccupied data, rather than to the frequency histograms shown in Figures 14-19. In general, the spring and fall-run Chinook salmon and steelhead/rainbow trout final depth and velocity criteria track the occupied data, but drop off slower than the occupied data due to the frequency of the unoccupied data also dropping over the same range of depths and velocities. The main exception to this trend, as discussed below, was for steelhead/rainbow trout depth HSC. We investigated whether data at the upper tails of the distribution had a substantial effect on the original steelhead/rainbow trout depth HSC (calculated using all of the occupied and unoccupied data) by conducting two alternative logistic regressions: one that eliminated the upper 5% of all occupied and unoccupied observations, and one that included all occupied and unoccupied observations with depths less than 5.8 feet (1.77 m, the value of the 95th percentile unoccupied measurement). This analysis was selected as analogous to what has sometimes been used with Type III HSC (calculated by dividing use by availability), where the upper 5% of the data are eliminated to get rid of the inordinate effect of observations at the extremes of the distribution, so that only the data in the middle 90% of the data are used (Hampton 1988). As shown in Figures 37 and 38, both alternatives still resulted in an optimal suitability at 16 feet (4.88 m), suggesting that the upper tails of the distributions did not have a substantial effect on the steelhead/rainbow trout depth HSC.

Figures 39 to 41 compare the three sets of HSC from this study. The most noticeable difference between the criteria was that steelhead/rainbow trout selected much deeper conditions than either spring-run or fall-run Chinook salmon. As shown in Figure 18, the frequency distribution of all occupied and unoccupied locations for steelhead/rainbow trout is similar for depths up to around 5 feet (1.52 m), whereas the relative frequency for depths greater than 5 feet (1.52 m) is greater for occupied locations than for unoccupied locations. This pattern of data resulted in the logistic regression having lower suitabilities at shallower depths and suitabilities increasing up to 7.0 feet (2.13 m). Even the occupied data showed significant differences between the Chinook salmon and steelhead/rainbow trout redds – there were only two fall-run redds and no spring-run redds

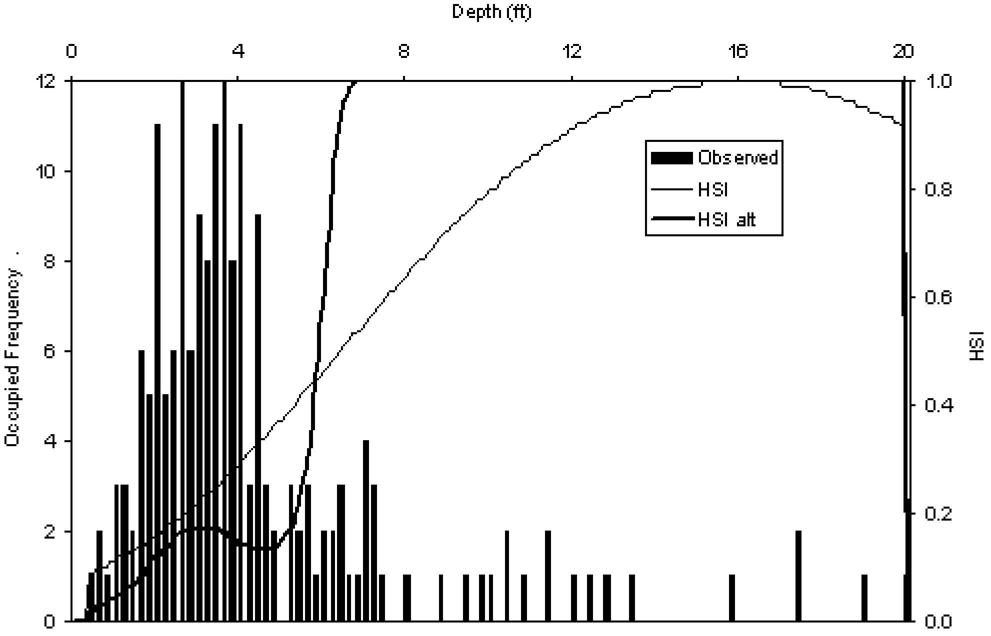

Figure 37. Comparison of steelhead/rainbow trout depth HSC from this study with an alternative depth HSC computed from data that excluded the upper five percent of occupied and unoccupied observations.

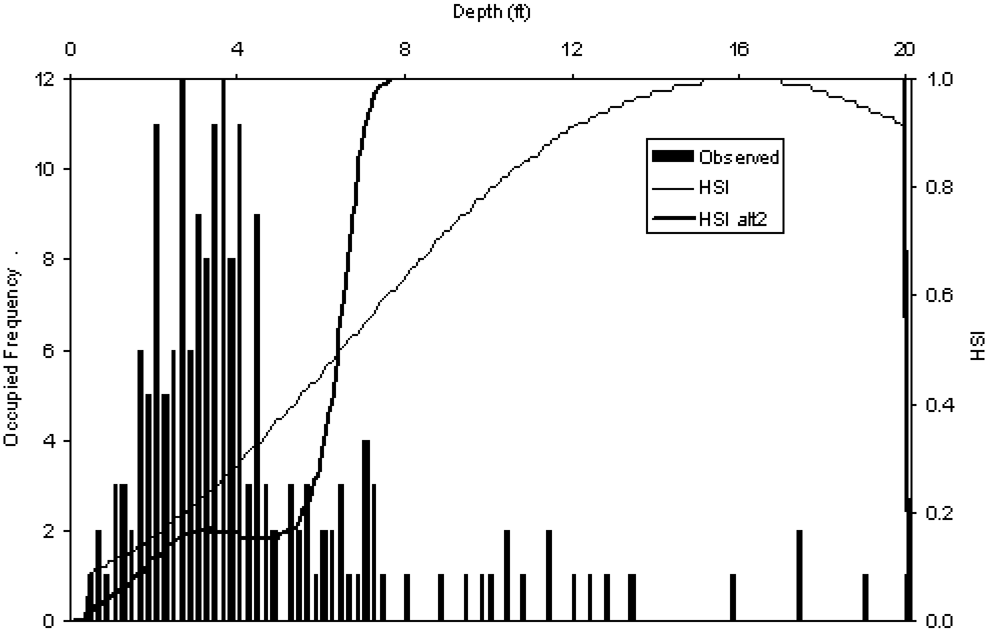

Figure 38. Comparison of steelhead/rainbow trout depth HSC from this study with an alternative depth HSC computed from data that included only occupied and unoccupied observations with depths less than 5.8 feet (1.77m, the value of the 95th percentile unoccupied measurement).

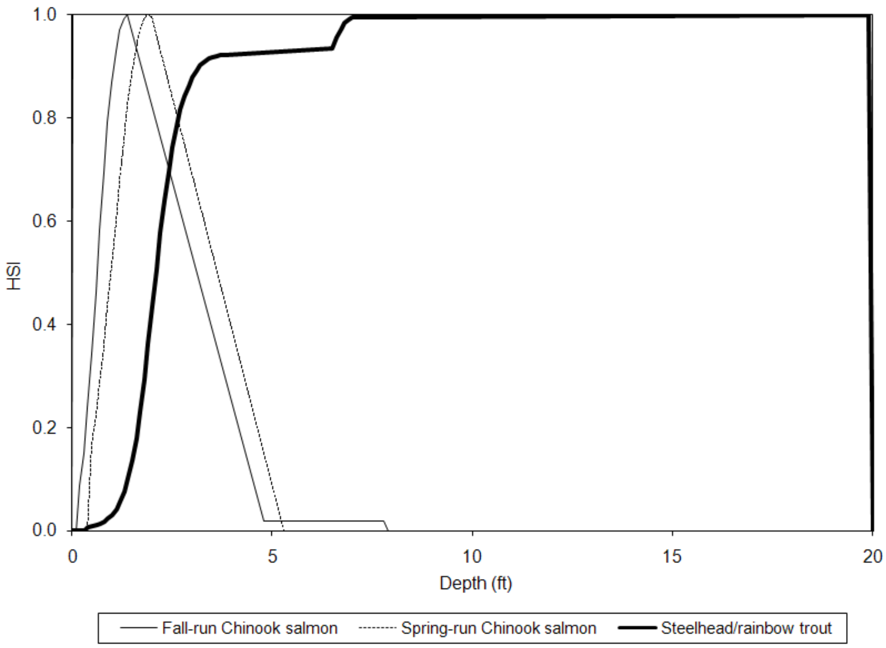

Figure 39. Comparison of depth HSC from this study. These criteria indicate that steelhead/rainbow trout selected much deeper conditions than either spring-run or fall-run Chinook salmon.

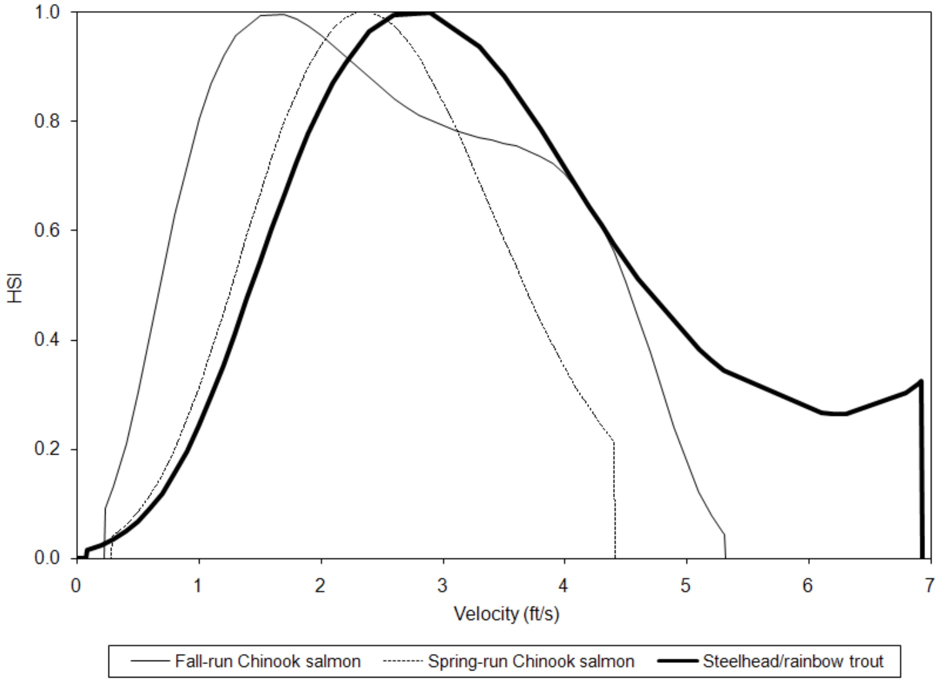

Figure 40. Comparison of velocity HSC from this study. These criteria indicate that fall-run Chinook salmon selected slower velocities than either spring-run Chinook salmon or steelhead/rainbow trout.

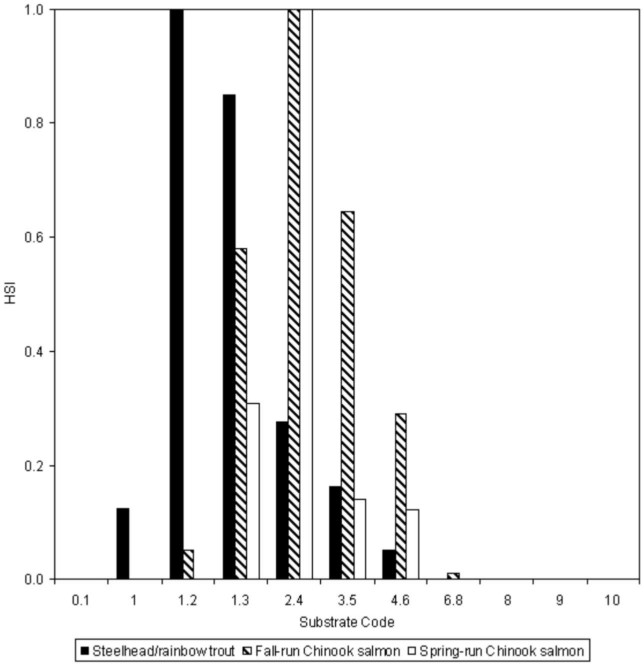

Figure 41. Comparison of substrate HSC from this study. These criteria indicate that steelhead/rainbow trout selected smaller substrates than either spring-run or fall-run Chinook salmon.

with depths of more than 5 feet (1.52 m), whereas 24% of the steelhead/rainbow trout redds had depths greater than 5 feet (1.52 m). The preference of steelhead/rainbow trout for much greater depths than Chinook salmon may be related to steelhead/rainbow trout spawning during the winter, when flows are much more variable – spawning in deeper water may reduce the probability of redds becoming dewatered with decreases in flow or scoured with increases in flow.

Fall-run Chinook salmon selected slower velocities than either spring-run Chinook salmon or steelhead/rainbow trout and used a wider range of substrates than spring-run Chinook salmon. We attribute this to the larger population size of fall-run Chinook salmon, versus spring-run Chinook salmon and steelhead/rainbow trout; with a larger population size, it is likely that some of the fall-run were forced to use less-optimal conditions, while the spring-run and steelhead/rainbow trout were able to use only more optimal conditions since there was less competition for spawning habitat. The upper end of velocities where steelhead/rainbow trout redds were found was greater than for either fall-run or spring-run Chinook salmon; this likely reflects the greater depths at which steelhead/rainbow trout were spawning, where they were able to select lower near-bottom velocities with high mean column velocities. As expected, the smaller-sized steelhead/rainbow trout selected smaller substrates than either spring-run or fall-run Chinook salmon (Figure 41).

Figures 42 to 49 compare the criteria from this study with the criteria from other studies. For fall-run Chinook salmon depth and velocity, we compared the criteria from this study with those used in an earlier study on the Yuba River (Beak 1989) and those used on the Feather River (California Department of Water Resources 2004), since the Yuba River is a tributary of the Feather River. We compared all of the depth and velocity criteria with those from Bovee (1978), since these criteria are commonly used in instream flow studies as reference criteria. For spring-run Chinook salmon spawning, the only two additional criteria we were able to identify, in addition to criteria we developed on Butte Creek, were from the Yakima River in Washington (Stempel 1984) and Panther Creek in Idaho (Reiser 1985). For steelhead/rainbow trout spawning, we compared the criteria from this study with those used on the Feather River and on the Carmel River (Dettman and Kelley 1986), the only other steelhead spawning criteria set from California that we were able to identify.

For substrate, we were limited to comparing the criteria from this study to criteria we had developed on other studies, due to the unique substrate coding system we used. We compared the fall-run Chinook salmon spawning criteria from this study to those we had developed for fall-run Chinook salmon on the Sacramento River (Gard 2006) and on the American River (Gard 1998), and compared the spring-run Chinook salmon spawning criteria from this study to the criteria we developed on Butte Creek (U.S. Fish and Wildlife Service 2003). We have not previously developed criteria for steelhead/rainbow trout spawning.

The fall-run Chinook salmon depth criteria from this study show a slower decline in suitability with increasing depth. We attribute this to the use in this study of the Gard (1998) method to correct for availability, and that the other sets of criteria underestimate the suitability of deeper waters. The fall-run Chinook salmon velocity criteria from this study show a wider range of suitable velocities than the criteria from other studies. We attribute this to the use in this study of a logistic regression to address availability, and that the other criteria, developed using use data, underestimate the suitability of faster conditions (in the range of 4 to 5 feet/sec [1.2 to 1.5 m/s]) because they do not take availability into account. The spring-run Chinook salmon depth criteria from this study show a shift to more suitability at greater depths than the criteria from other studies. We attribute this to the greater availability of deeper-water conditions with suitable velocities and substrates in the Yuba River versus the rivers where the other criteria were developed, the use in this study of the Gard (1998) method to correct for availability, and that the other sets of criteria underestimate the suitability of deeper waters. The spring-run Chinook salmon velocity criteria from this study are similar to the Yakima River criteria, but show greater suitability at higher velocities than the other two criteria. We surmise that the availability of velocities in the Yuba and Yakima Rivers was similar, and that the limited availability of faster conditions in Panther Creek and the streams used for the Bovee (1978) criteria biased these criteria towards slower conditions. The differences between the steelhead/rainbow trout depth and velocity criteria from this study, versus from other studies, can be attributed to the criteria from other studies being likely biased towards shallow depths because of limited availability of deeper water with suitable substrate and velocities, and because the criteria from other studies did

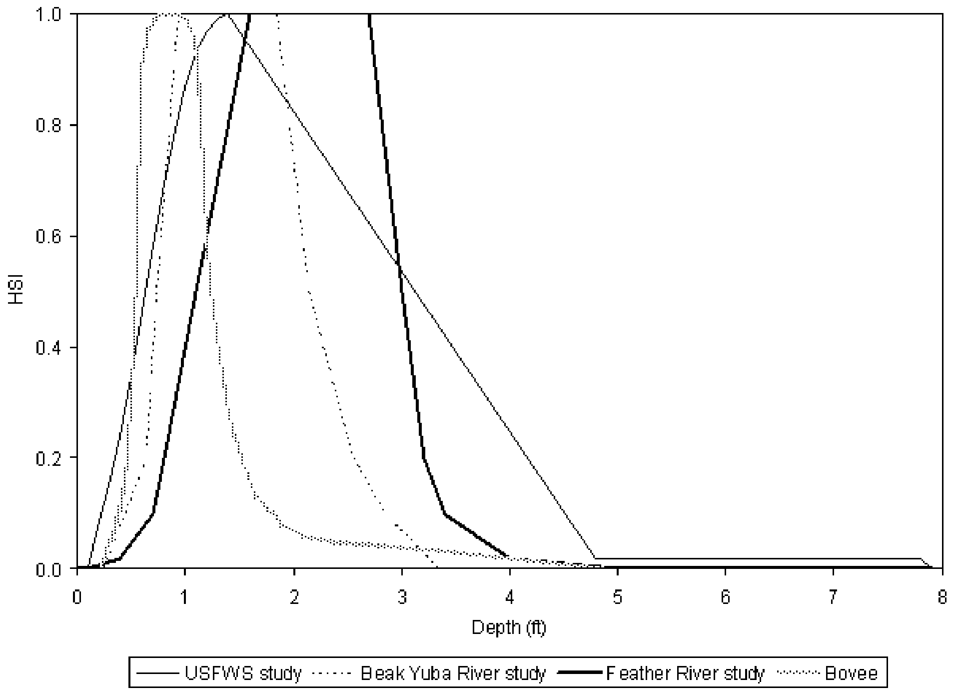

Figure 42. Comparison of fall-run Chinook salmon depth HSC from this study with other fall-run Chinook salmon spawning depth HSC. The criteria from this study show a slower decline in suitability with increasing depth than those from other studies.

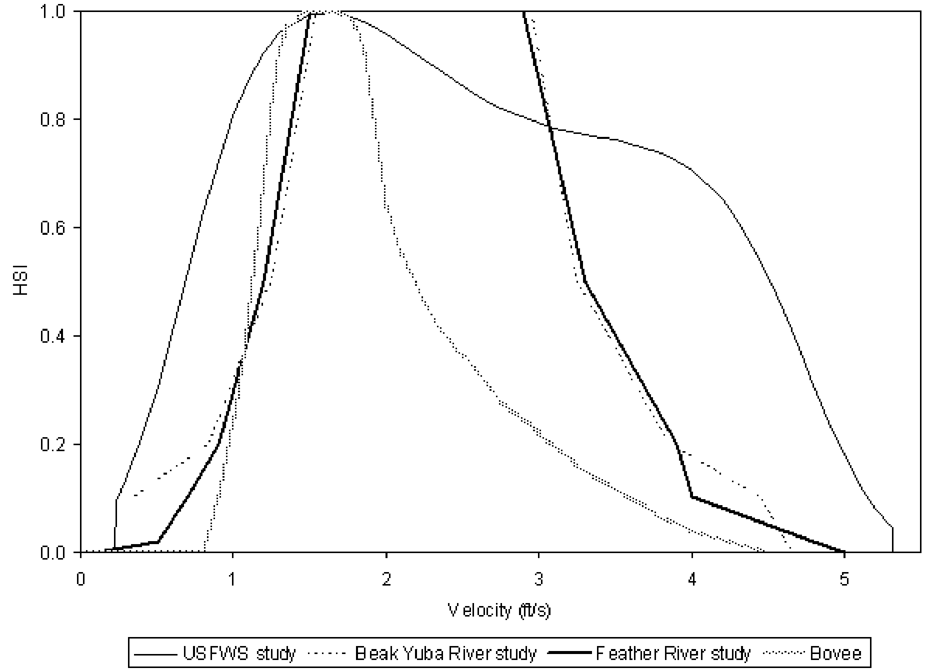

Figure 43. Comparison of fall-run Chinook salmon velocity HSC from this study with other fall-run Chinook salmon spawning velocity HSC. The criteria from this study show a wider range of suitable velocities than the criteria from other studies.

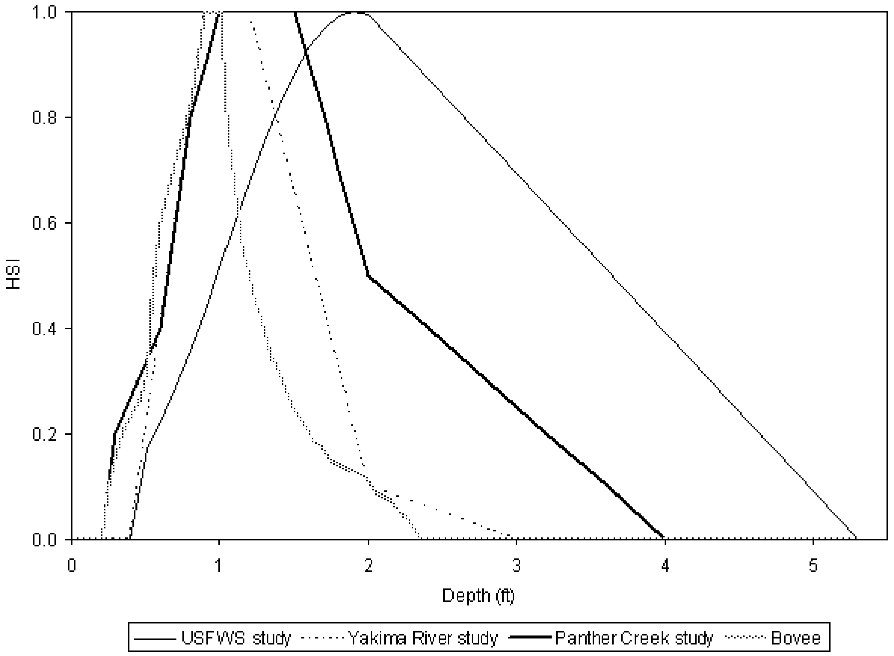

Figure 44. Comparison of spring-run Chinook salmon depth HSC from this study with other spring-run Chinook salmon spawning depth HSC. The criteria from this study show a shift to more suitability at greater depths than the criteria from other studies.

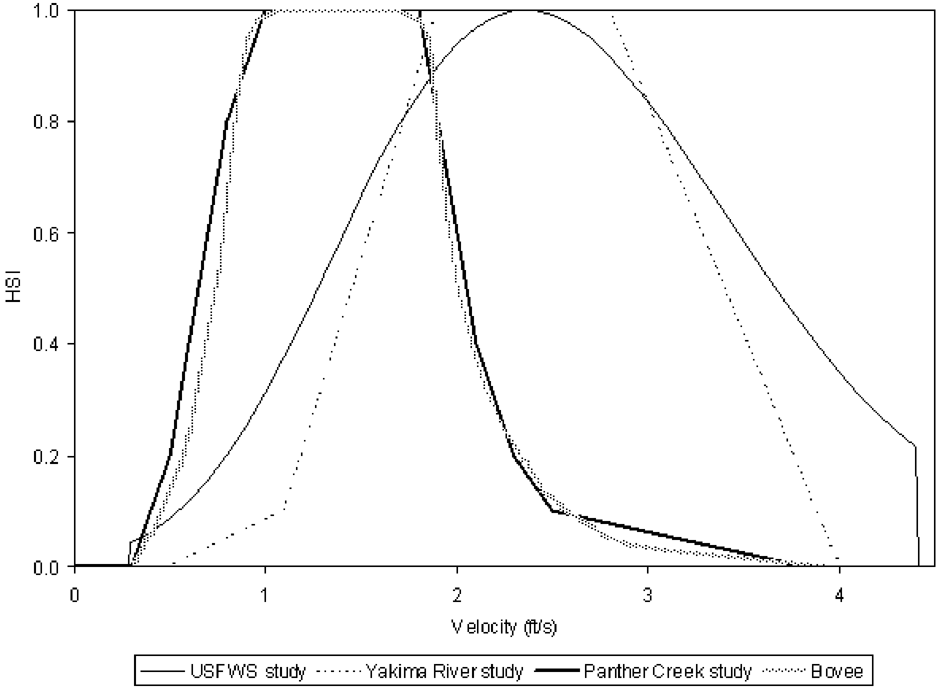

Figure 45. Comparison of spring-run Chinook salmon velocity HSC from this study with other spring-run Chinook salmon spawning velocity HSC. The criteria from this study are most similar to the Yakima River criteria.

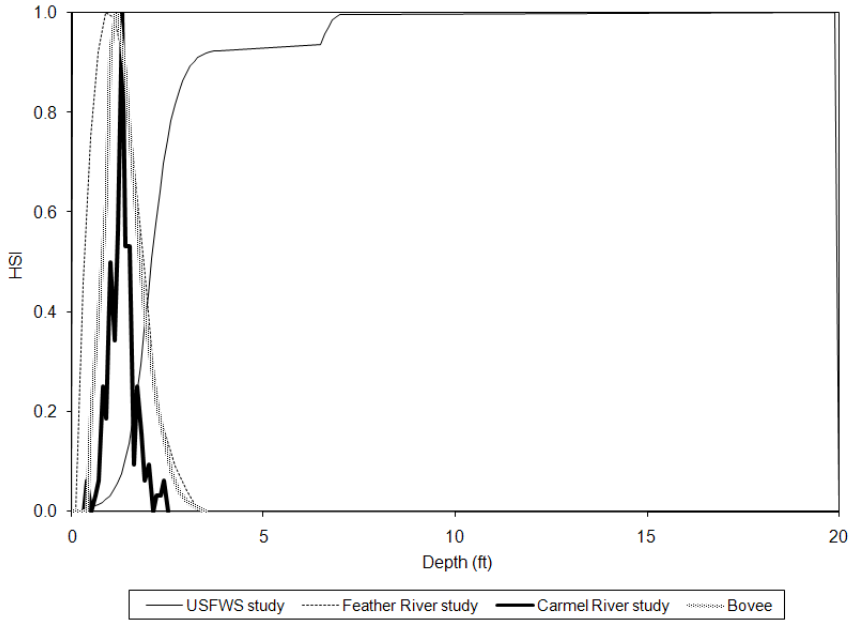

Figure 46. Comparison of steelhead/rainbow trout depth HSC from this study with other steelhead/rainbow trout spawning depth HSC. The criteria from this study show a substantial shift to more suitability at greater depths than the criteria from other studies.

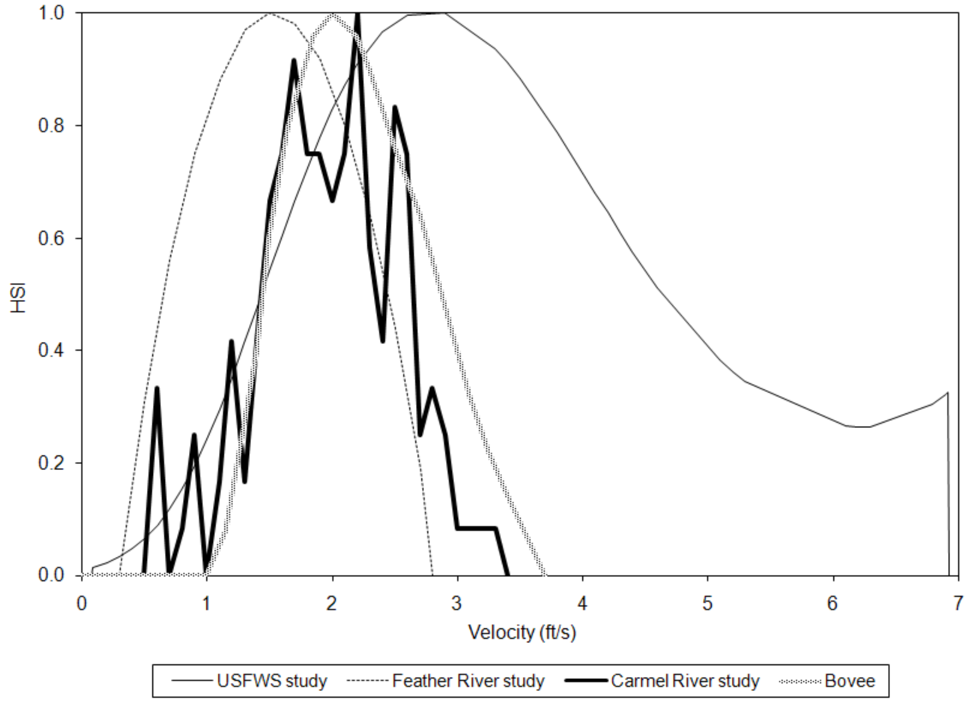

Figure 47. Comparison of steelhead/rainbow trout velocity HSC from this study with other steelhead/rainbow trout spawning velocity HSC. The criteria from this study show suitability extending to higher velocities than for other studies.

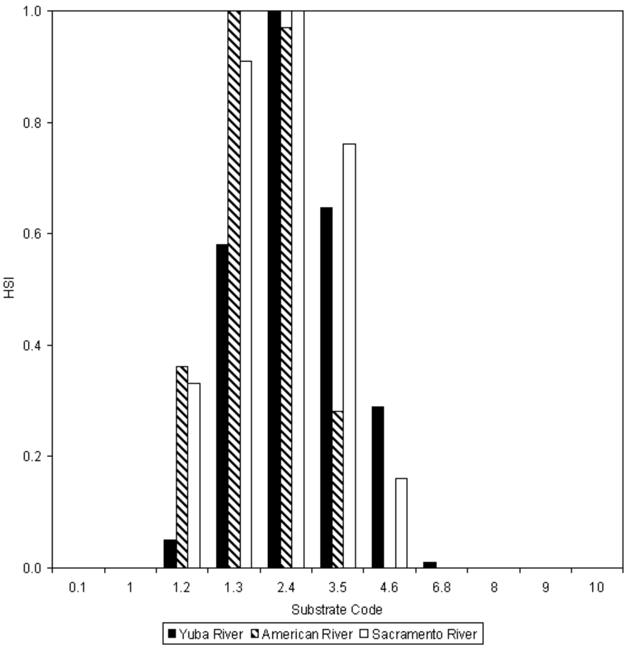

Figure 48. Comparison of fall-run Chinook salmon substrate HSC from this study with other fall-run Chinook salmon spawning substrate HSC.

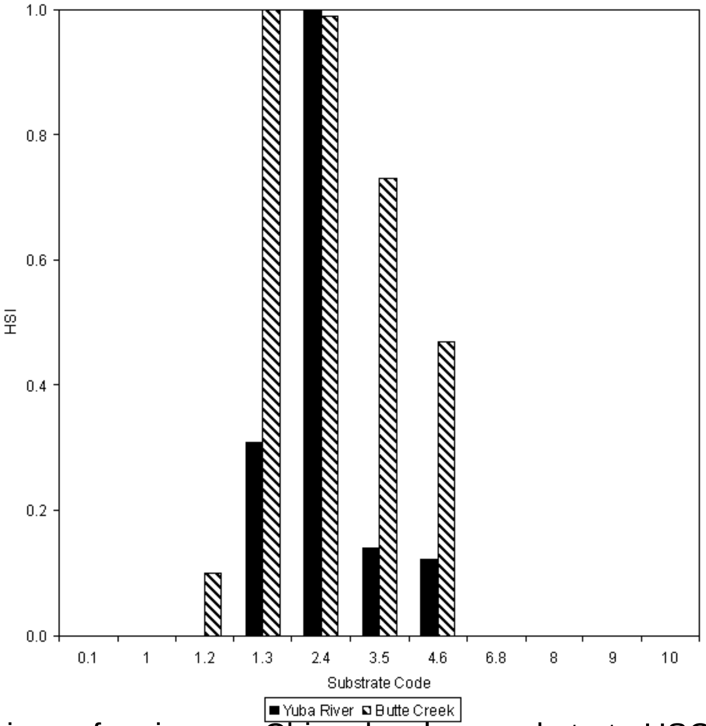

Figure 49. Comparison of spring-run Chinook salmon substrate HSC from this study with other spring-run Chinook salmon spawning substrate HSC.

not apply a logistic regression to correct for availability. We believe that the Yuba River is unique among the rivers studied in that it has some deeper areas with suitable velocities and substrates, allowing 24 percent of the steelhead to spawn in water 5 feet or deeper. In contrast, the criteria from other systems all have zero suitability for depths of 5 feet or greater. Further, the substantial natural flow fluctuations during the steelhead spawning season on the Yuba River would be a strong selective force to shift steelhead spawning behavior towards selecting deeper conditions, since eggs in shallow redds would not survive dewatering or scouring associated with flow fluctuations.

The fall-run Chinook salmon spawning substrate criteria from this study are relatively similar to the criteria from other studies, although the Yuba River fall-run Chinook salmon showed a greater use of cobble-sized substrates (greater than 3 inches [7.5 cm]) than the fall-run Chinook salmon in other streams. We conclude that this pattern is likely due to the same reasons, as discussed above, why the fall-run Chinook salmon spawning substrate criteria differed from the spring-run Chinook salmon spawning criteria in this study. The spring-run Chinook salmon spawning substrate criteria in this study showed a greater selection for 2-4 inch (5-10 cm) sized substrates, versus the Butte Creek criteria. We attribute this to the lower availability of 2-4 inch (5-10 cm) sized substrates and greater densities of spawners in Butte Creek, resulting in the Butte Creek fish being forced to utilize a greater percentage of less-suitable substrate sizes (i.e., all but 2-4 inch (5-10 cm) sized substrates).

### *Biological Verification*

The plots of combined suitability of redd locations in Appendix L are similar to the methods used for biological verification in Hardy and Addley (2001). In general, Hardy and Addley (2001) found a better agreement between redd locations and areas with high suitability than we found in this study. We attribute this difference to Hardy and Addley (2001)'s use of polygons to map substrate. We feel that our results could have had as good an agreement between redd locations and areas with high suitability as Hardy and Addley (2001)'s if we had had a more accurate mapping of the substrate polygons using a total station or RTK GPS during the process of polygon method data collection (see discussion below regarding evaluation of substrate polygon method). The statistical tests used in this report for biological verification differ from those used in Guay et al. (2000). In Guay et al. (2000), biological verification was accomplished by testing for a statistically significant positive relationship between fish densities, calculated as the number of fish per area of habitat with a given range of habitat suitability (i.e. 0 to 0.1), and habitat quality indexes. We were unable to apply this approach in this study because of the low number of redds and low area of habitat with high values of habitat quality. As a result, the ratio of redd numbers to area of habitat for high habitat quality values exhibits significant variation simply due to chance. Both the number of redds and amount of habitat at high values of habitat quality are quite sensitive to the method used to calculate combined suitability. When combined suitability is calculated as the product of depth, velocity and substrate suitability, as is routinely done in instream flow studies, there will be very low amounts of high habitat quality values. For example, if depth, velocity and substrate all have a high suitability of 0.9, the combined suitability would be only 0.7. In contrast, Guay et al. (2000) calculated combined suitability as the geometric mean of the individual suitabilities; for the above example, the combined suitability calculated as a geometric mean would be 0.9.

We did not use a parametric test because the assumption of normality of parametric tests was violated, as shown in Figures 19 to 24, indicating the need to use nonparametric tests. Nonparametric statistical methods were appropriate to use with the large, unbalanced sample size of this study to reduce type II errors, since unoccupied depths, velocities and substrates have a much greater range of values than occupied depths, velocities and substrates. Analogously, Thomas and Bovee (1993) found that a minimum of 55 occupied and 200 unoccupied locations were required to reduce type II errors. We view the biological verification as successful because for all three races/species, there was a greater suitability for occupied versus unoccupied locations, which has the biological significance that fish are preferentially selecting locations with higher suitabilityThe successful biological verification in this study increases the confidence in the use of the flow-habitat relationships from this study for fisheries management in the Yuba River.

### *Habitat Simulation*

There was considerable variation from site to site in the flow-habitat relationships shown in Appendix K. For example, the maximum habitat for spring-run and fall-run Chinook salmon spawning was at lower flows for Upper Daguerre, compared with the other four sites downstream of Daguerre Point Dam, while the maximum habitat for steelhead/rainbow trout spawning was at higher flows for Upper Daguerre, versus three of the other four sites downstream of Daguerre Point Dam. We attribute these differences to the relatively narrow and higher gradient channel at Upper Daguerre, compared to the other sites below Daguerre Point Dam. As a result, velocities at Upper Daguerre reached optimal values for spring-run and fall-run Chinook salmon spawning at lower flows than the other four sites below Daguerre Point Dam, resulting in the maximum habitat at a lower flow. However, Upper Daguerre had significant areas of 1-2 inch (2.5-5 cm) substrate present in areas that were only inundated at high flows, resulting in the observed maximum habitat for steelhead/rainbow trout spawning at 4,500 cfs. The overall flow-habitat relationships for each segment, as shown in Figures 26 to 31, capture the inter-site variability in flow-habitat relationships by summing the amount of habitat for all of the sites within each segment.

An earlier study (Beak 1989) also modeled fall-run Chinook salmon spawning habitat in the Yuba River. As shown in Figures 50 and 51, the results from this study predict greater amounts of habitat at all flows and a peak amount of habitat at higher flows than the Beak (1989) study. However, the difference between studies in the flow with the peak amount of habitat varied by reach. The differences between the results of the two studies can primarily be attributed to the following: 1) the Beak (1989) study used HSC generated only from use data, as opposed to the

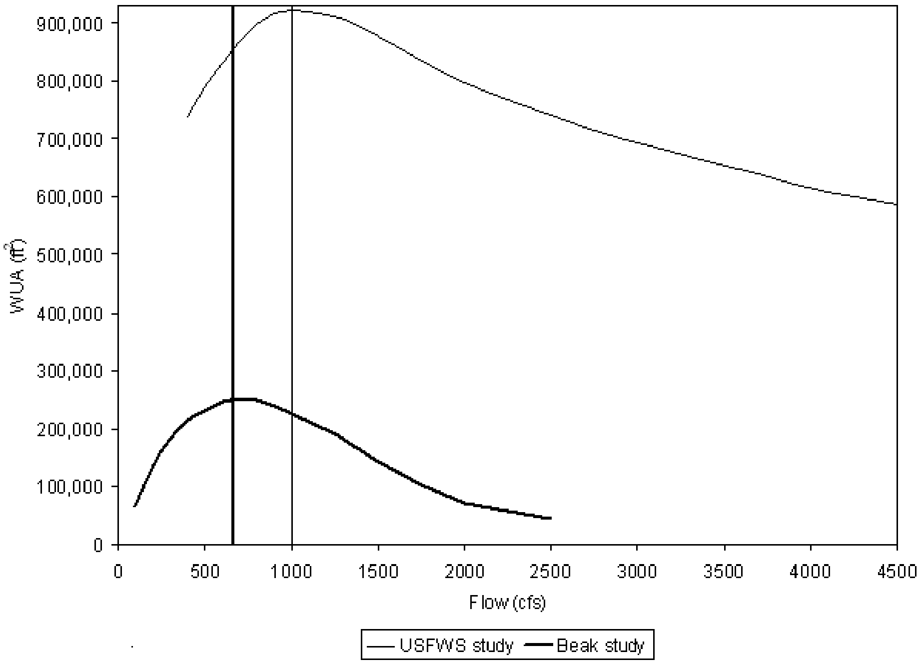

Figure 50. Comparison of fall-run Chinook salmon flow-habitat relationship above Daguerre Point Dam from this study and the Beak (1989) study. This study predicted greater habitat at all flows and the peak habitat at a higher flow than the Beak (1989) study.

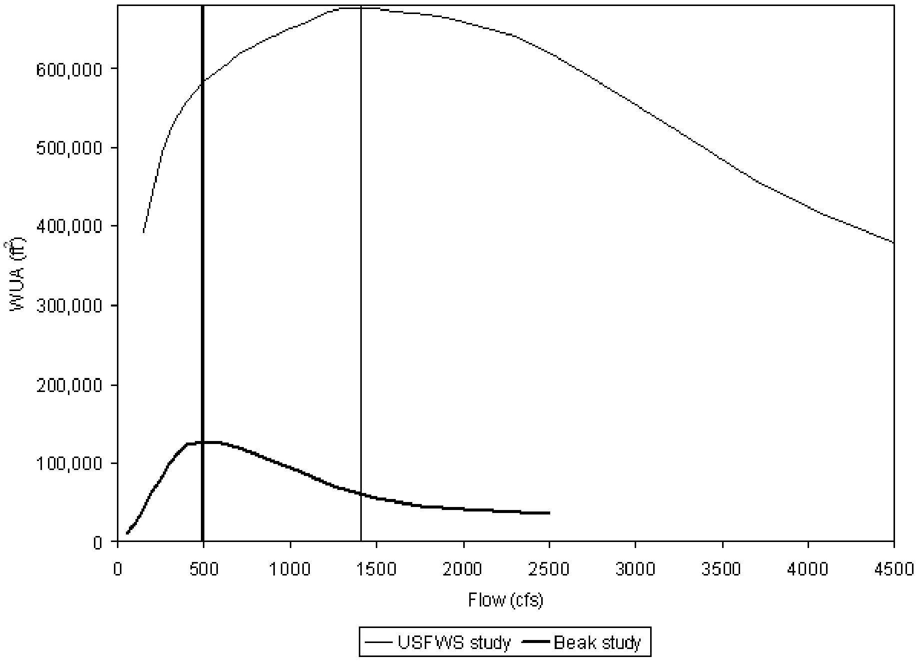

Figure 51. Comparison of fall-run Chinook salmon flow-habitat relationship below Daguerre Point Dam from this study and the Beak (1989) study. This study predicted greater habitat at all flows and the peak habitat at a higher flow than the Beak (1989) study.

criteria generated with logistic regression in this study; 2) the Beak (1989) study did not apply the method used in this report for correcting depth HSC for availability; 3) sites for the Beak (1989) study were placed using a mesohabitat-mapping approach, as opposed to only placing sites in high-spawning-use areas, as was employed in this study; and 4) the use of PHABSIM in the Beak (1989) study, versus 2-D modeling in this study. The flow-habitat results in the Beak (1989) study likely gravitated toward lower flows, since the HSC, generated only from use data and without correcting depth HSC for availability, targeted slower and shallower conditions. However, the difference in criteria are only responsible for a portion of the differences between the two studies, since there was a greater difference between the two studies for the segment below Daguerre Point Dam, versus the segment above Daguerre Point Dam. The remainder of the difference between the two studies for the segment below Daguerre Point Dam may be due to a combination of using 2-D versus PHABSIM and modeling only high-use spawning areas. Using a mesohabitat-based approach for modeling spawning habitat may not to take into account salmonids' preference for spawning in areas with high gravel permeability (Vyverberg et al 1996), whereas having sites only in high-use spawning areas indirectly takes into account preference for high gravel permeability (Gallagher and Gard 1999). A major assumption of this study is that high-use spawning areas have high gravel permeability since salmonids are selecting these areas for spawning. We attribute the much greater predicted amount of WUA at all flows from this study versus Beak (1989) to our extrapolation to the entire segment based on the percentage of the segment's spawning that was in the study sites, versus Beak (1989)'s extrapolation based on habitat mapping. Extrapolation based on the percentage of the segment's spawning that was in the study sites should be more accurate based on considerations of salmonids' preference for high gravel permeability, which is taken into account by the extrapolation approach used in this study, but not with a mesohabitat-based extrapolation approach.

A basic assumption of all instream flow studies is that a stream is in dynamic equilibrium. When a channel is in dynamic equilibrium, there is an approximate balance between sediment supply and transport, so that the channel pattern and cross-sectional profile of the entire stream is consistent (Bovee 1996). For a stream in dynamic equilibrium, it would be expected that large flow events would not result in a significant change in flow-habitat relationships. An unregulated stream would be more likely to be in dynamic equilibrium than a regulated stream. Recent high flows on the Yuba River (Figure 52) have resulted in significant channel changes. While we do not have direct evidence that the Yuba River is in dynamic equilibrium, our findings on the American River that the January 1997 flood did not result in a substantial change in chinook salmon or steelhead spawning flow-habitat relationships (US Fish and Wildlife Service 2000) offer support that the results of this study are still applicable to the Yuba River. The American River has much greater dam-induced changes in hydrology and sediment supply and transport than the Yuba River.

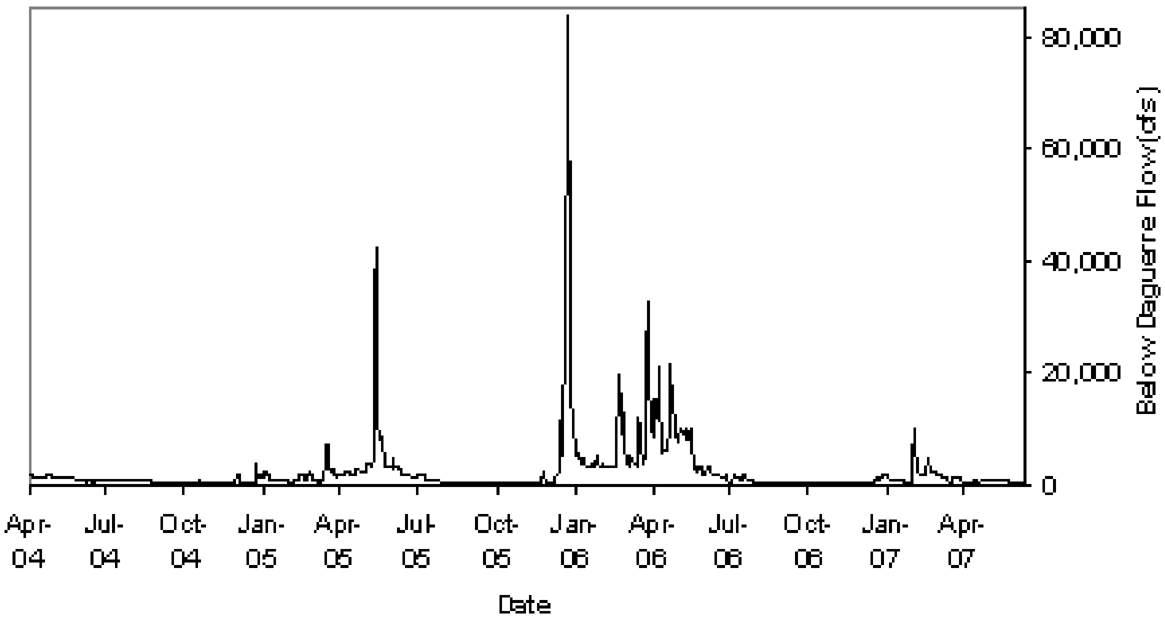

Figure 52. Yuba River flows below Daguerre Point Dam subsequent to the completion of data collection for this study. High flows in May 2005 and January and April 2006 resulted in substantial channel changes in the Yuba River.

The model developed in this study is predictive for flows ranging from 400 to 4,500 cfs above Daguerre Point Dam and from 150 to 4,500 cfs below Daguerre Point Dam. The results of this study are intended to focus on management actions with a temporal scale of one month, and thus do not include an analysis of habitat during peak events (e.g., flows above 4,500 cfs). In the Yuba River, these events are associated with uncontrolled releases from Englebright Dam – anyspawning that would occur in areas that are only inundated at peak events would likely be unsuccessful due to the redds becoming dewatered once flows had dropped back down below 4,500 cfs. However, it should be noted that the data collected in this study could be used to simulate spawning habitat up to 11,000 cfs above Daguerre Point Dam and 13,500 cfs below Daguerre Point Dam. If there was sufficient interest in simulating spawning habitat at flows between 4,500 and 11,000 to 13,500 cfs, an additional report could be prepared presenting such results.

*Evaluation of Polygon Substrate Data Collection Methods*

## Biological Verification

The results of the one-tailed Mann-Whitney U test indicate that the standard method resulted in a better prediction of combined suitability than the polygon method for spring-run Chinook salmon and steelhead/rainbow trout, but that the polygon method resulted in a better prediction of combined suitability than the standard method for fall-run Chinook salmon.

## Habitat simulation

The results of the flow-habitat comparisons (albeit small in sample size) suggest that there is no consistent pattern and no major differences in the flow-habitat relationships for the two methods. It also did not appear that the polygon method was significantly more accurate than the standard method. Use of a total station or RTK GPS during the process of polygon method data collection might have yielded a more accurate mapping of the substrate polygons and perhaps different results. Given that the standard method involves collecting a majority of the substrate data simultaneously with the bed topography data while the polygon method requires an additional step in the data collection process, it is unlikely that we will utilize the polygon method in the future.

### *Factors Causing Uncertainty*

There are a variety of factors causing uncertainty in the flow-habitat relationships given in Appendix K. These include: 1) effects of high flows in May 2005 and January and April 2006; 2) extrapolation from the study sites to the entire Yuba River; 3) transmission losses in the segment upstream of Daguerre Dam in the fall in dry years; 4) errors in velocity simulation; 5) errors in bathymetry data; 6) discretization size and density of bed topography data; 7) errors in velocity measurements used to develop habitat suitability criteria; 8) differences in depths and velocities at the time of redd construction versus at the time habitat suitability criteria data were collected; and 9) differences between sampled versus population habitat suitability criteria data. As discussed above, based on the assumption of dynamic equilibrium, there is likely low uncertainty in the effects of high flows in May 2005 and January and April 2006 on the flow-habitat relationships given in Appendix K. The validity of the assumption of dynamic equilibrium for the Yuba River could be tested by comparing flow-habitat relationships from Professor Greg Pasternack’s topography data for the UC Sierra site, which was collected prior to the May 2005 high flows, between the May 2005 and January 2006 high flows and after the January 2006 high flows – if the flow-habitat relationships from these three datasets had a similar shape, this would support the assumption that the Yuba River is in dynamic equilibrium.

A low level of uncertainty is anticipated to be associated with the extrapolation from the study sites to the entire Yuba River, based on the number of study sites and the high proportion of Yuba River fall-run Chinook salmon (42 to 45 percent) and steelhead/rainbow trout (57 to 80 percent) spawning use found in the study sites. Both data from Professor Greg Pasternack and from this study suggests that there may be transmission losses (on the order of 10 percent) in the fall of dry years in the segment upstream of Daguerre Dam. There are two potential consequences to the transmission losses for the segment upstream of Daguerre Dam: 1) we may have underestimated the stage at the bottom of the sites for lower flows, which would result in an overestimate of velocities and thus an underestimate of the flow with the peak amount of spawning habitat; and 2) additional releases are needed from Englebright Dam in the fall of dry years to get the amount of habitat predicted in this report for spring and fall-run Chinook salmon in the segment upstream of Daguerre Dam.

We anticipate that over or under-predicted velocities would have a minimal effect on the overall flow-habitat relationships, given the high correlation between measured and predicted velocities. Specifically, the effects of over-predicted velocities would be cancelled out by the effect of under-predicted velocities. The overall flow-habitat relationship is driven by the change in the distribution of depths and velocities with flow. The distribution of velocities would not be affected by over or under-predicted velocities because over-predicted velocities would have the opposite effect on the distribution of velocities as under-predicted velocities. Similarly, we conclude that errors in bed bathymetry data, which would cause over-prediction or under-prediction of depths, would have a minimal effect on the overall flow-habitat relationships. Specifically, the effects of over-predicted depths would be cancelled out by the effect of under-predicted depths. The overall flow-habitat relationship is driven by the change in the distribution of depths and velocities with flow. The distribution of depths would not be affected by over or under-predicted depths because over-predicted depths would have the opposite effect on the distribution of depths as under-predicted depths. The uncertainty for this factor could be quantified by performing a sensitivity analysis to look at the influence of topographic uncertainty on hydraulic results and how those propagate into the habitat suitability predictions.

The effects of discretization size and density of bed topography data on the flow-habitat relationships given in Appendix K are unknown but are not expected to be large. The magnitude of these effects could be investigated by comparing the flow-habitat relationships for the UC Sierra Site in Appendix K with flow-habitat relationships that could be generated by hydraulic modeling of Professor Greg Pasternack's bed topography data (with a point density of 0.64 points/m$^2$) for the UC Sierra site collected prior to May 2005.

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

With regards to the effects of differences in depths and velocities at the time of redd construction versus at the time habitat suitability criteria data were collected on the flow-habitat relationships given in Appendix K, in all but one case (fall-run Chinook salmon above Daguerre Dam in 2002), the flows during HSC data collection were less than the average flows during the period of redd construction. Since depths and velocities increase with flow, on average the depth and velocity HSC data are slightly less than the depths and velocities present during redd construction, which would result in an underestimate of the flow with the peak amount of spawning habitat. The degree of uncertainty in the flow-habitat relationships given in Appendix K from differences in depths and velocities at the time of redd construction versus at the time habitat suitability criteria data were collected would be proportional to the percent variation in flow prior to HSI data collection, as shown in Table 13. Accordingly, there would be the most uncertainty in the fall-run Chinook salmon flow-habitat relationships and the least uncertainty in the spring-run Chinook salmon flow-habitat relationships, with regards to differences in depths and velocities at the time of redd construction versus at the time habitat suitability criteria data.

The most likely source of uncertainty in the flow-habitat relationships given in Appendix K probably is the potential for differences between sampled versus population habitat suitability criteria data. The uncertainty from this factor could be quantified by a bootstrap analysis of the sampled HSC data to develop 95 percent confidence limit HSC, which could be applied to the hydraulic models of the ten study sites to determine 95 percent confidence limits for the flow-habitat relationships given in Appendix K.

## CONCLUSION

The results of this study can be used to evaluate 480 different hydrograph management scenarios (each of the 30 simulation flows for each of the two segments[25] in each of the 8 spawning months – September for spring-run, October to December for fall-run, and January to April for steelhead/rainbow trout). For example, increasing flows from 400 cfs to 1,400 cfs upstream of Daguerre Point Dam in September would result in an increase of 61.4% of habitat during this month for spring-run Chinook salmon spawning in this segment. Based on the conceptual model presented in the introduction, this increase in spawning habitat could decrease redd superimposition, increasing reproductive success which could result in an increase in spring-run Chinook salmon populations. Evaluation of alternative hydrograph management scenarios will also require the consideration of flow-habitat relationships for Chinook salmon and steelhead/rainbow trout fry and juvenile rearing, which will be addressed in a future report. We do not feel that there are any significant limitations of the model. This study supported and achieved the objective of producing models predicting the availability of physical habitat in the Yuba River for spring and fall-run Chinook salmon and steelhead/rainbow trout spawning over a range of stream flows. The results of this study are intended to support or revise the flow recommendations in the introduction. The results of this study, showing increasing amounts of spawning habitat with increasing flow up to 900 to 2,100 cfs, are consistent with the flow recommendations in the introduction.

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[25] Flows downstream of Daguerre Point Dam can to some extent be modified independent of flows upstream of Daguerre Point Dam by changes in the amount of flow diverted at Daguerre Point Dam.

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# APPENDIX A
# STUDY SITE AND TRANSECT LOCATIONS

**Note: Flow direction for all study sites is from XS 2 to XS 1.**

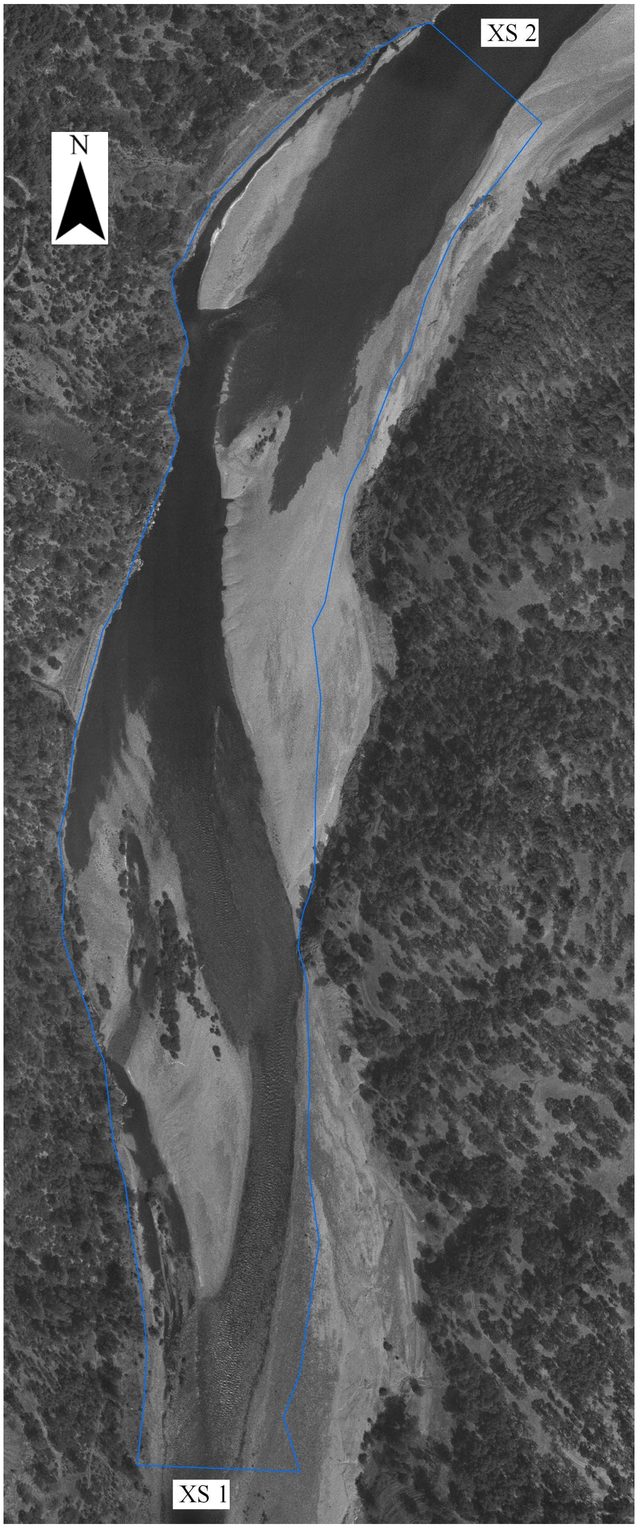
Appendix A

## UC Sierra Study Site

**Scale: 1:1793**

Appendix A

## Timbuctoo Study Site



**Scale: 1:569**

Appendix A

## Highway 20 Study Site

**Scale: 1:1525**

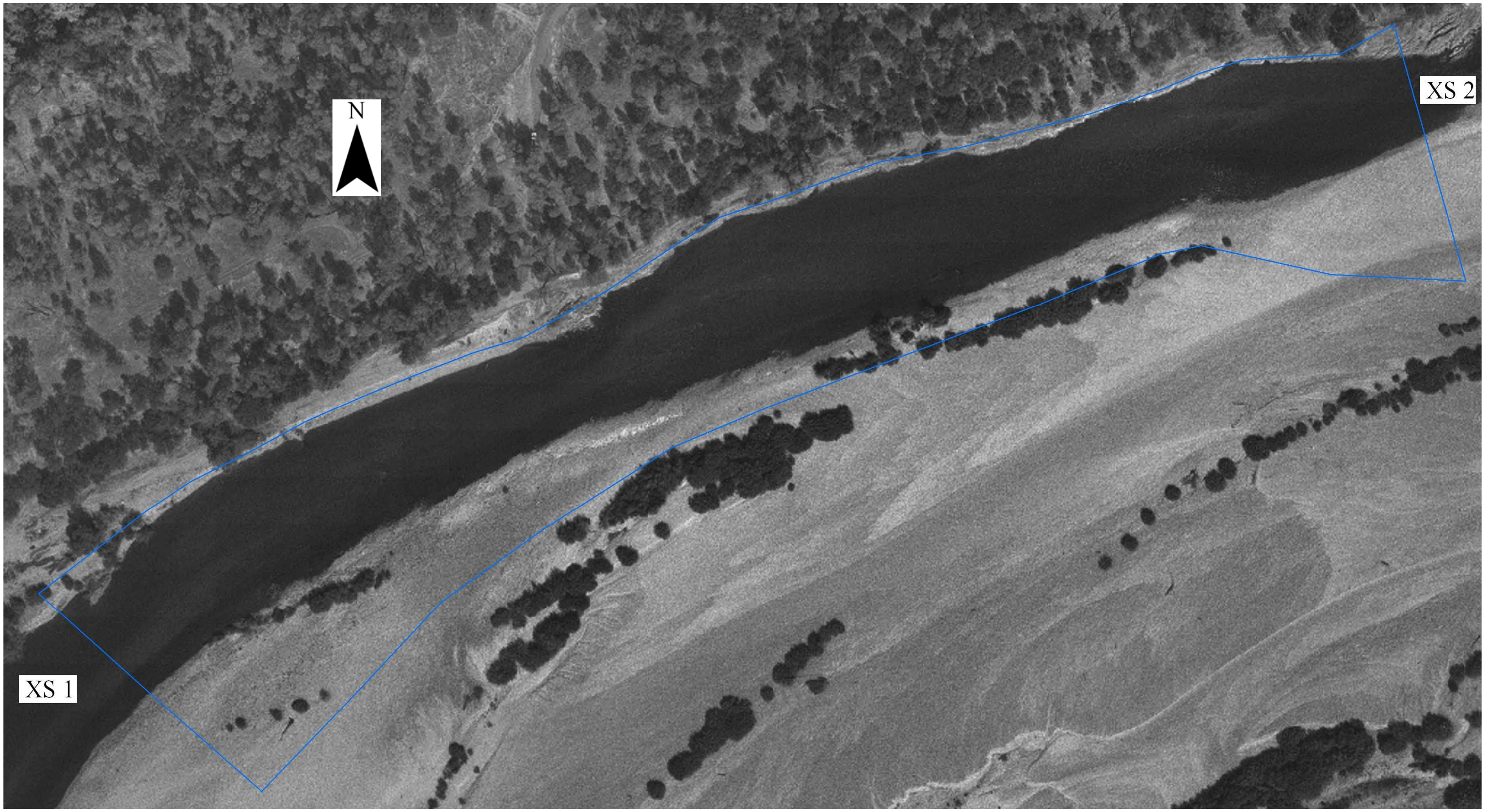
Appendix A

## Island Study Site

**Scale: 1:3275**

Appendix A

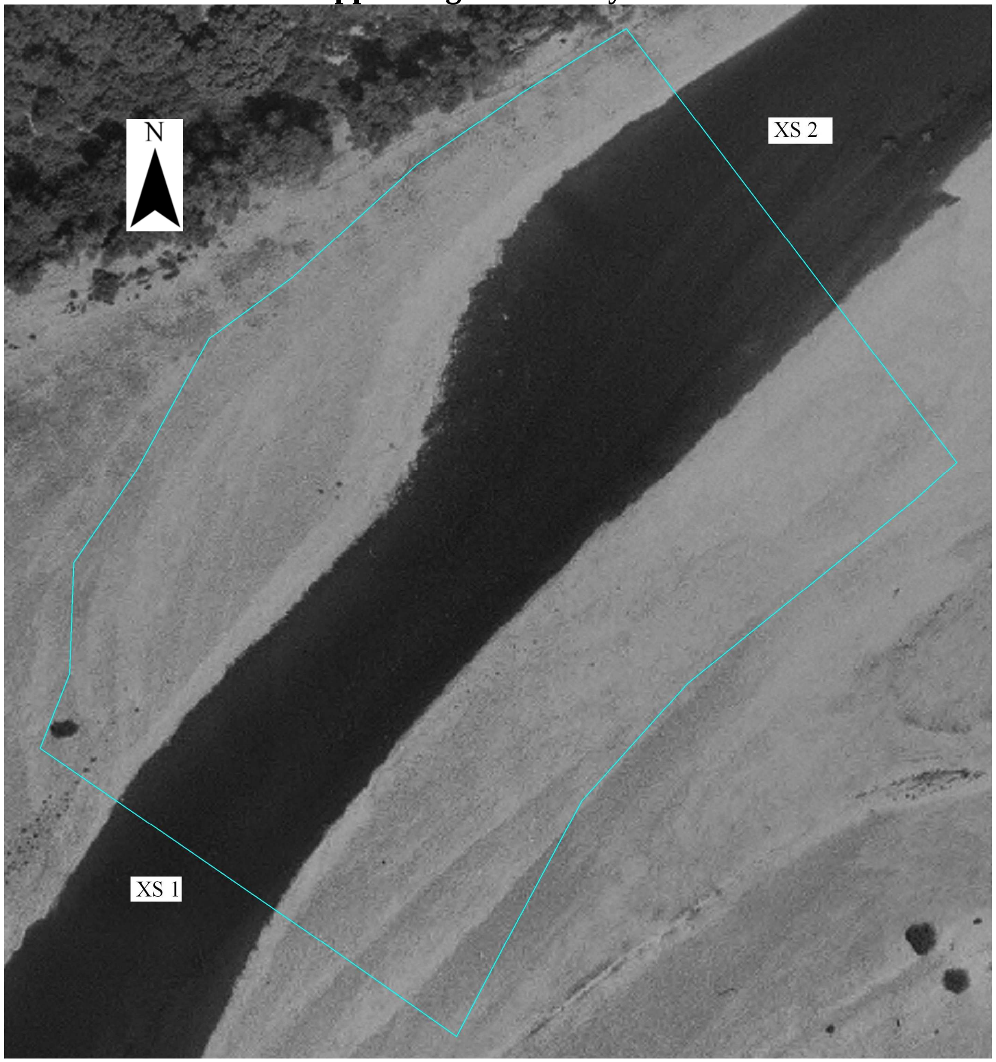
## Hammond Study Site



**Scale: 1:2655**

Appendix A

## Upper Daguerre Study Site



**Scale: 1:2117**

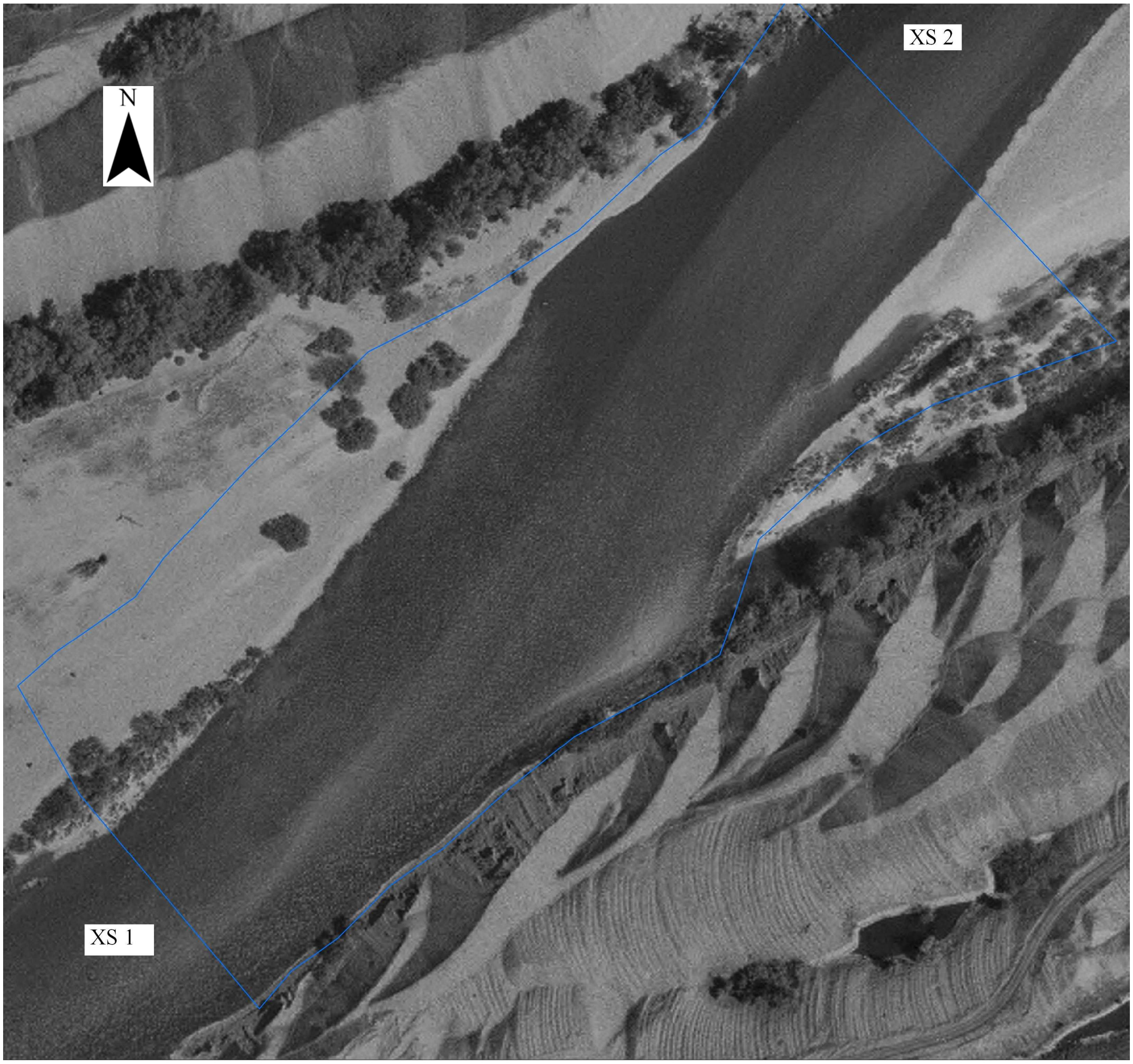
Appendix A

## Lower Daguerre Study Site

**Scale: 1:2959**

Appendix A

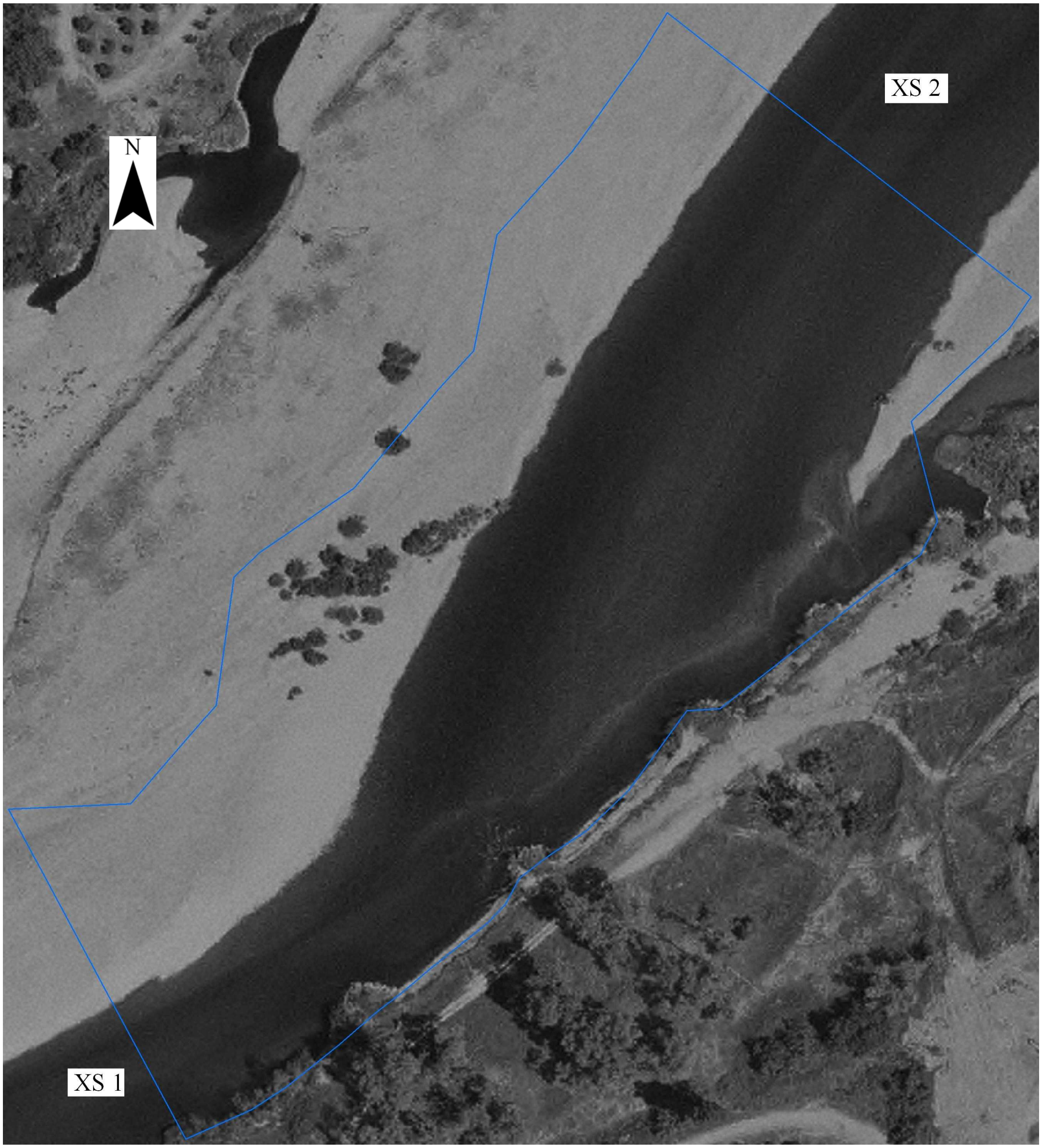
## Pyramids Study Site



**Scale: 1:2344**

Appendix A

## Hallwood Study Site



**Scale: 1:1775**

Appendix A

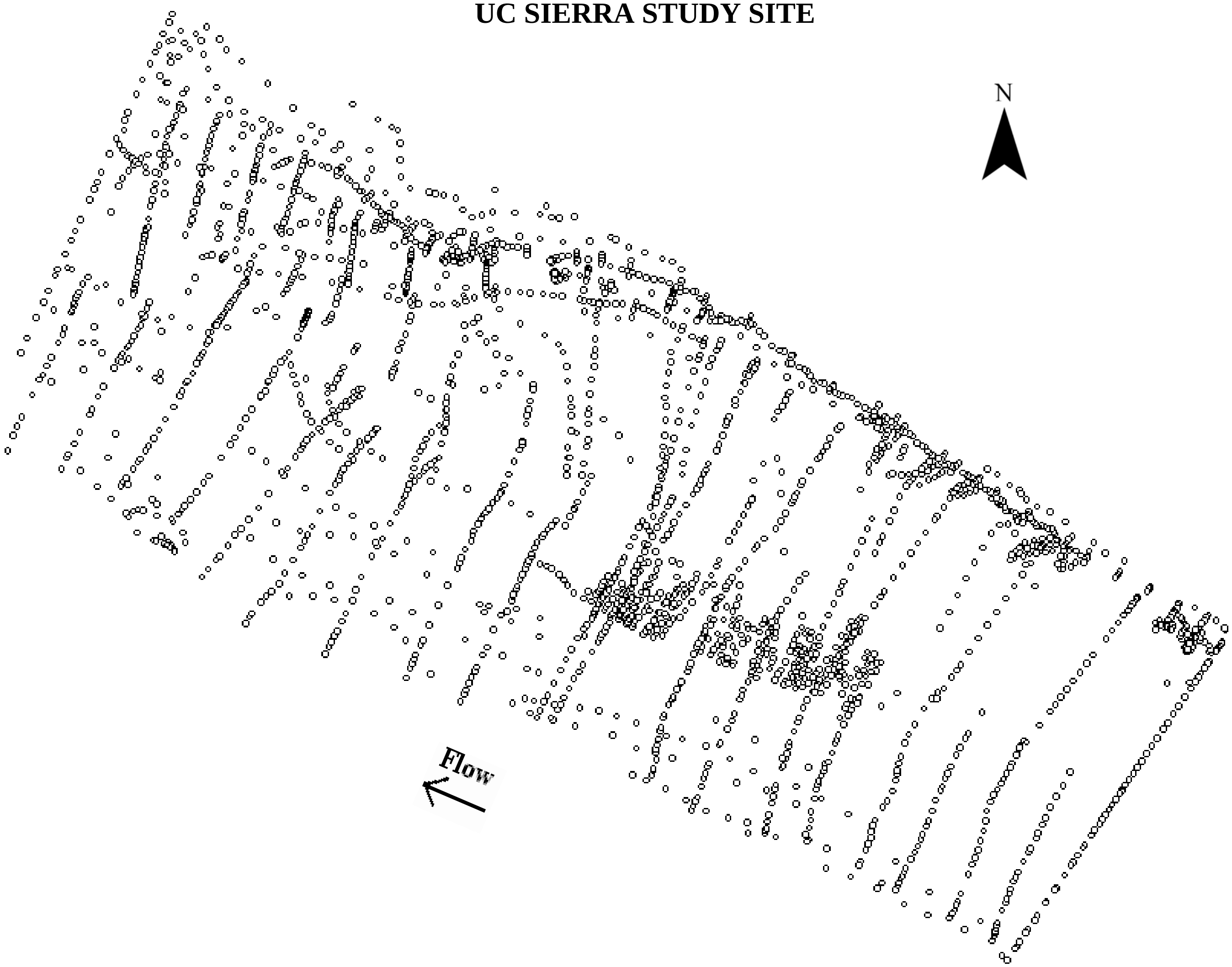
## Plantz Study Site

**Scale: 1:1592**

# APPENDIX B
# BED TOPOGRAPHY POINT LOCATIONS

Appendix B

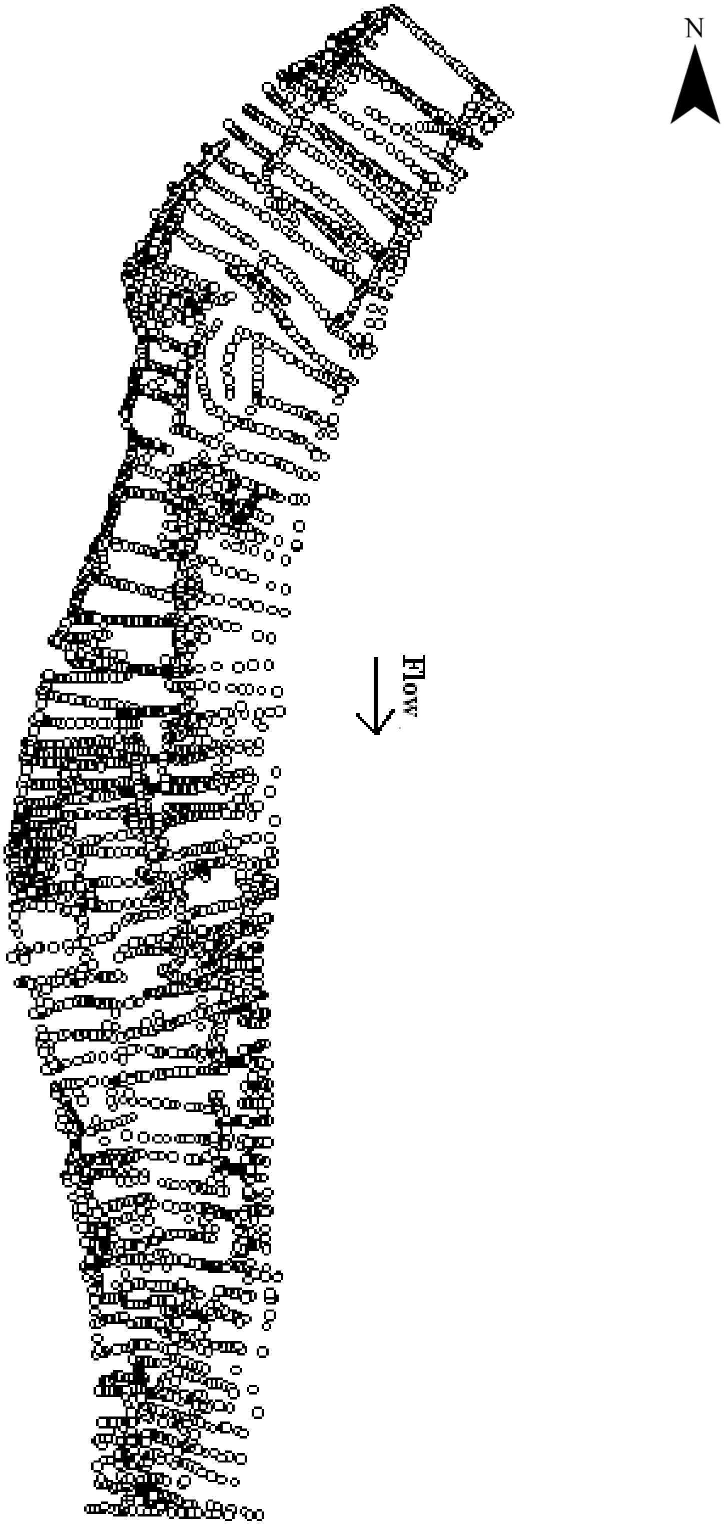
## UC SIERRA STUDY SITE



**Scale: 1:1835**

Appendix B

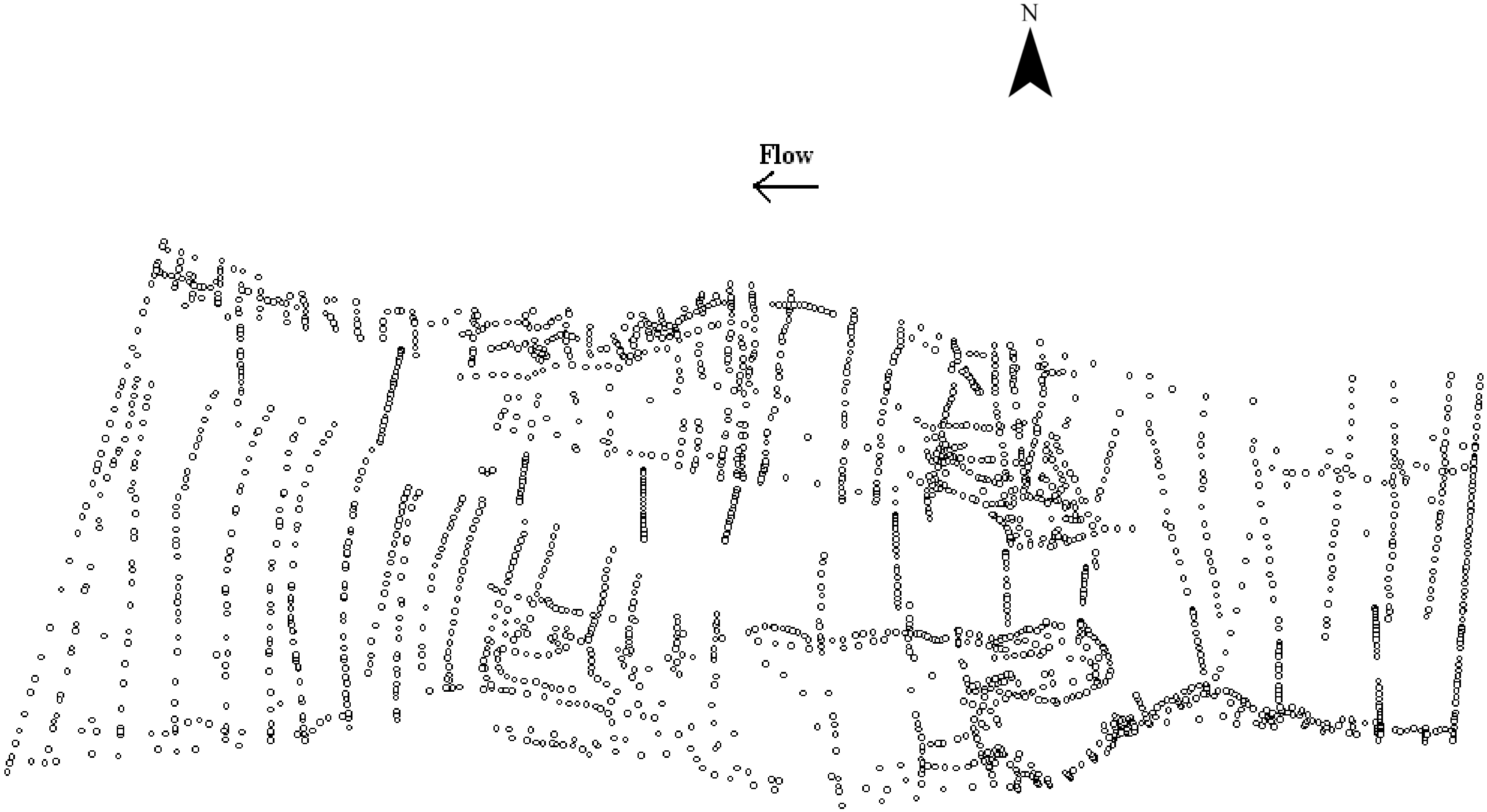
## TIMBUCTOO STUDY SITE



**Scale: 1:7244**

Appendix B

## HIGHWAY 20 STUDY SITE



**Scale: 1:2160**

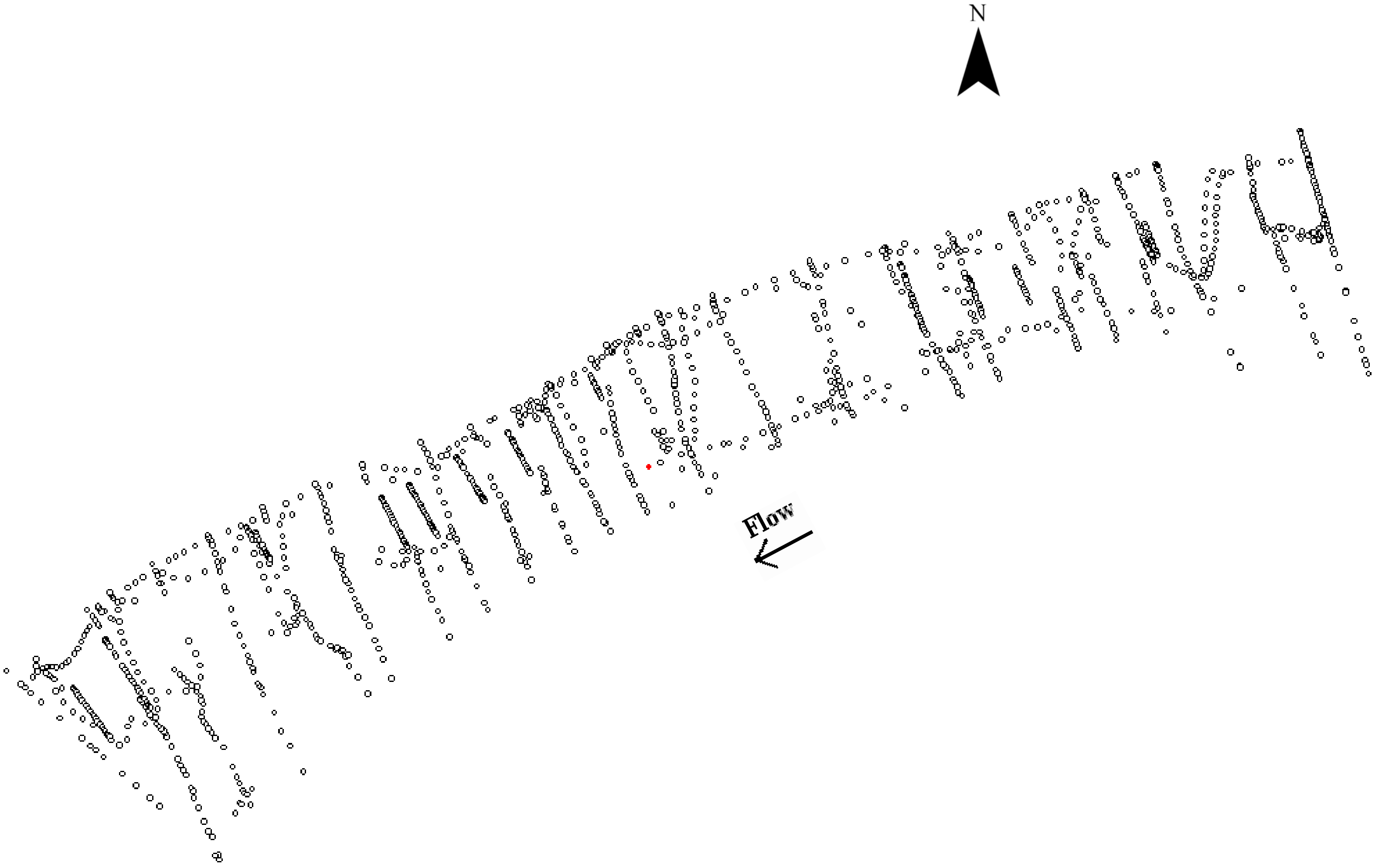
Appendix B

## ISLAND STUDY SITE

**Scale: 1:3684**

Appendix B

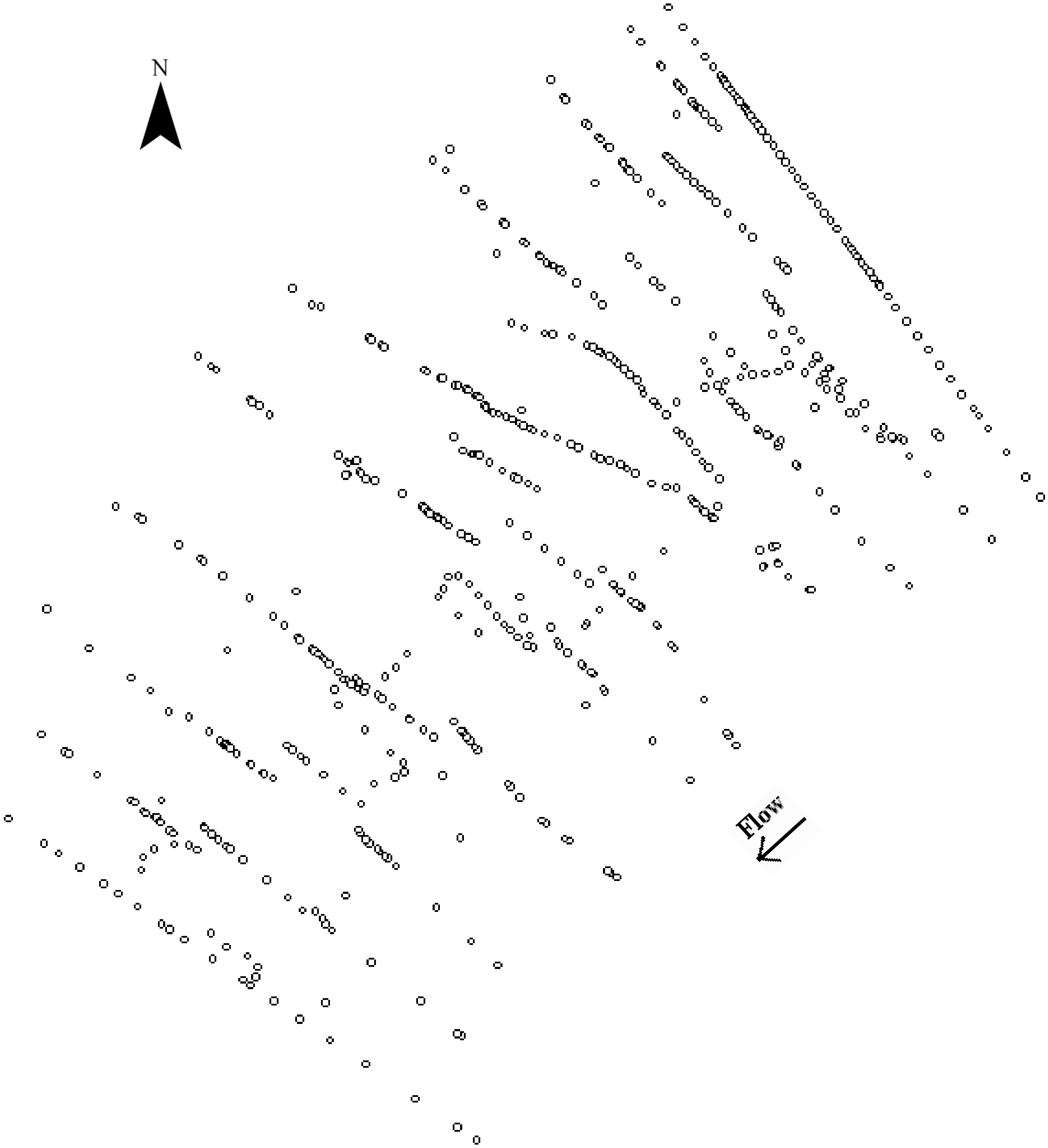
## HAMMOND STUDY SITE



**Scale: 1:2750**

Appendix B

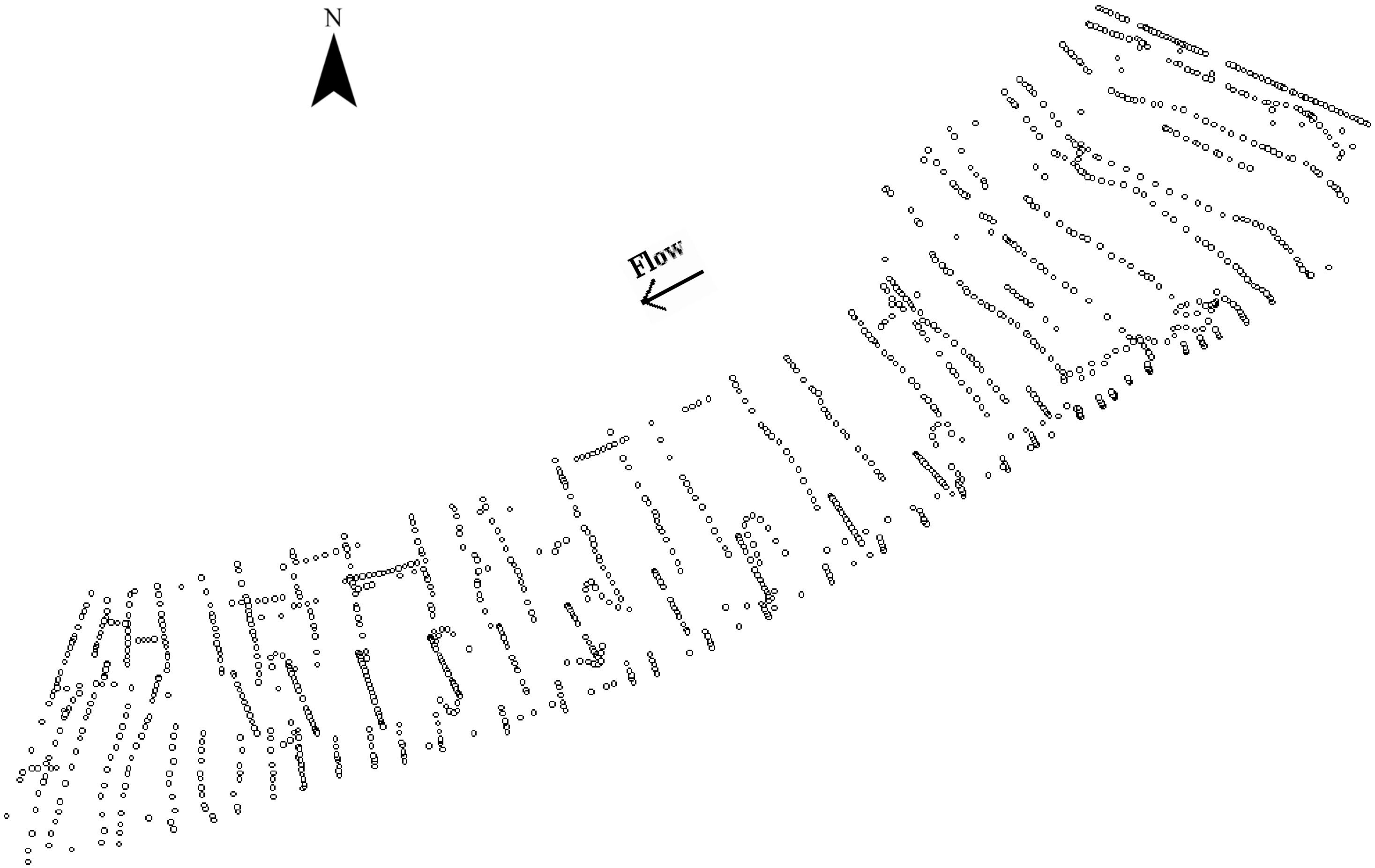
## UPPER DAGUERRE STUDY SITE



**Scale: 1: 1587**

Appendix B

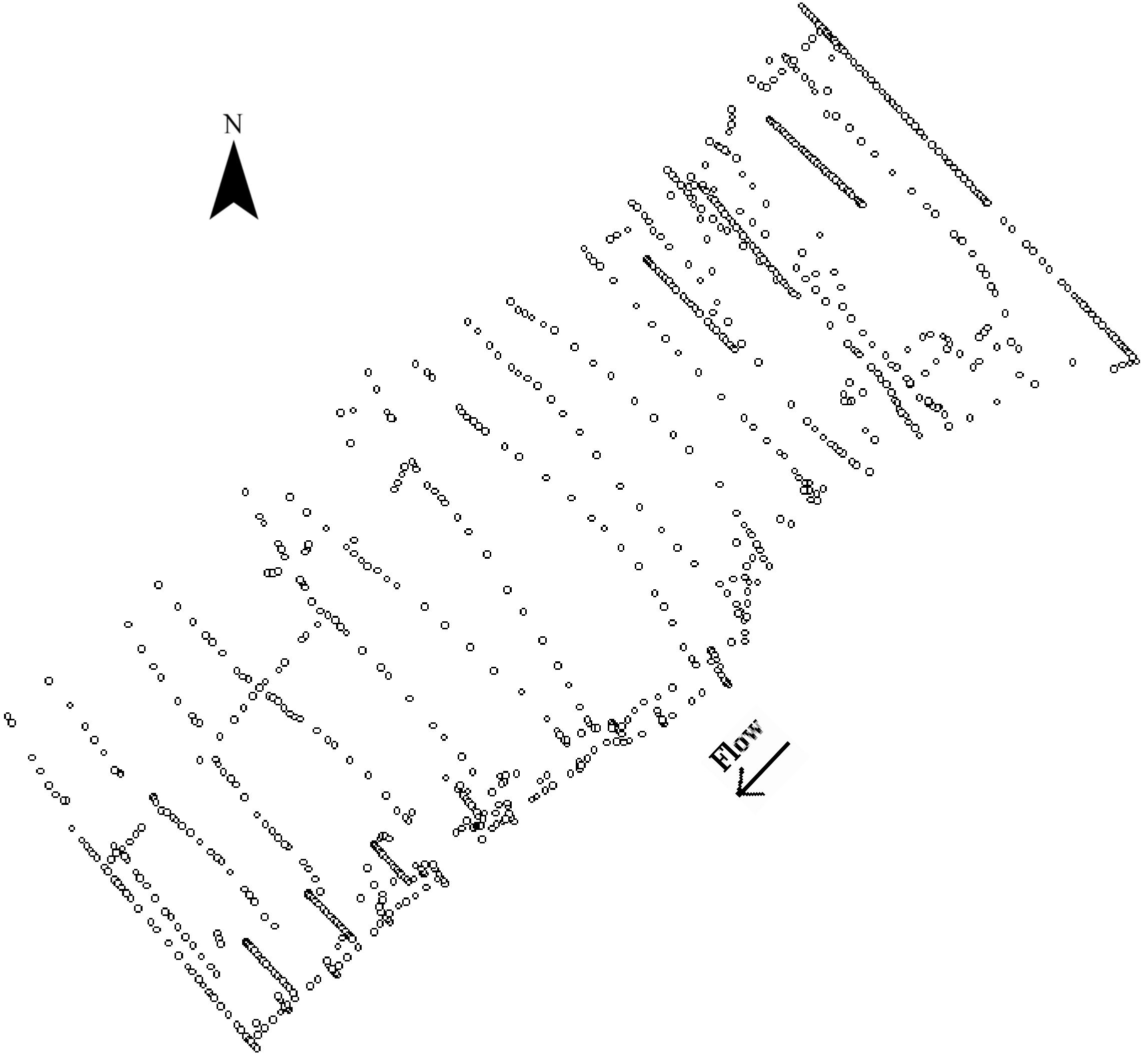
## LOWER DAGUERRE STUDY SITE



**Scale: 1:3099**

Appendix B

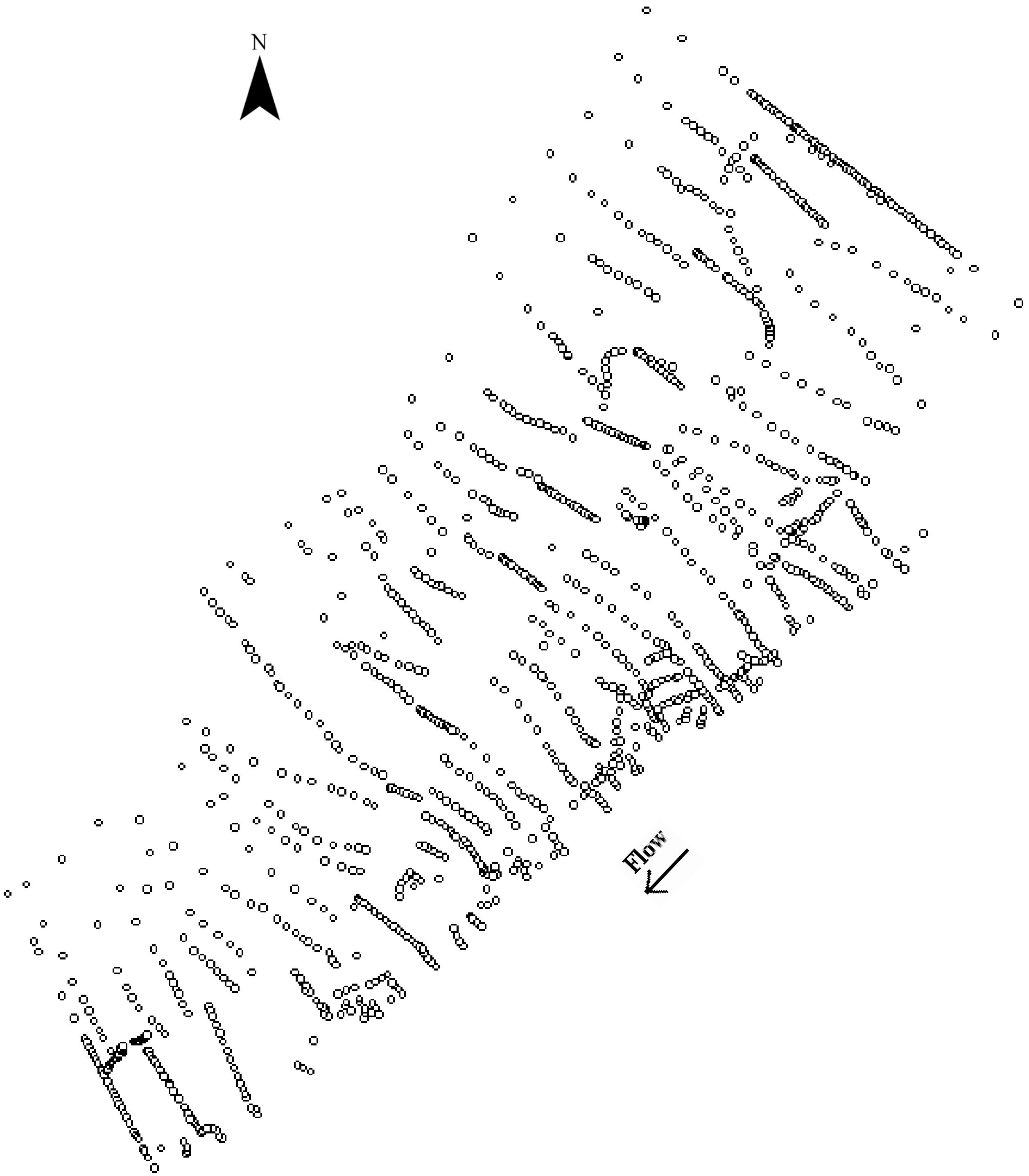
## PYRAMIDS STUDY SITE



**Scale: 1:2344**

Appendix B

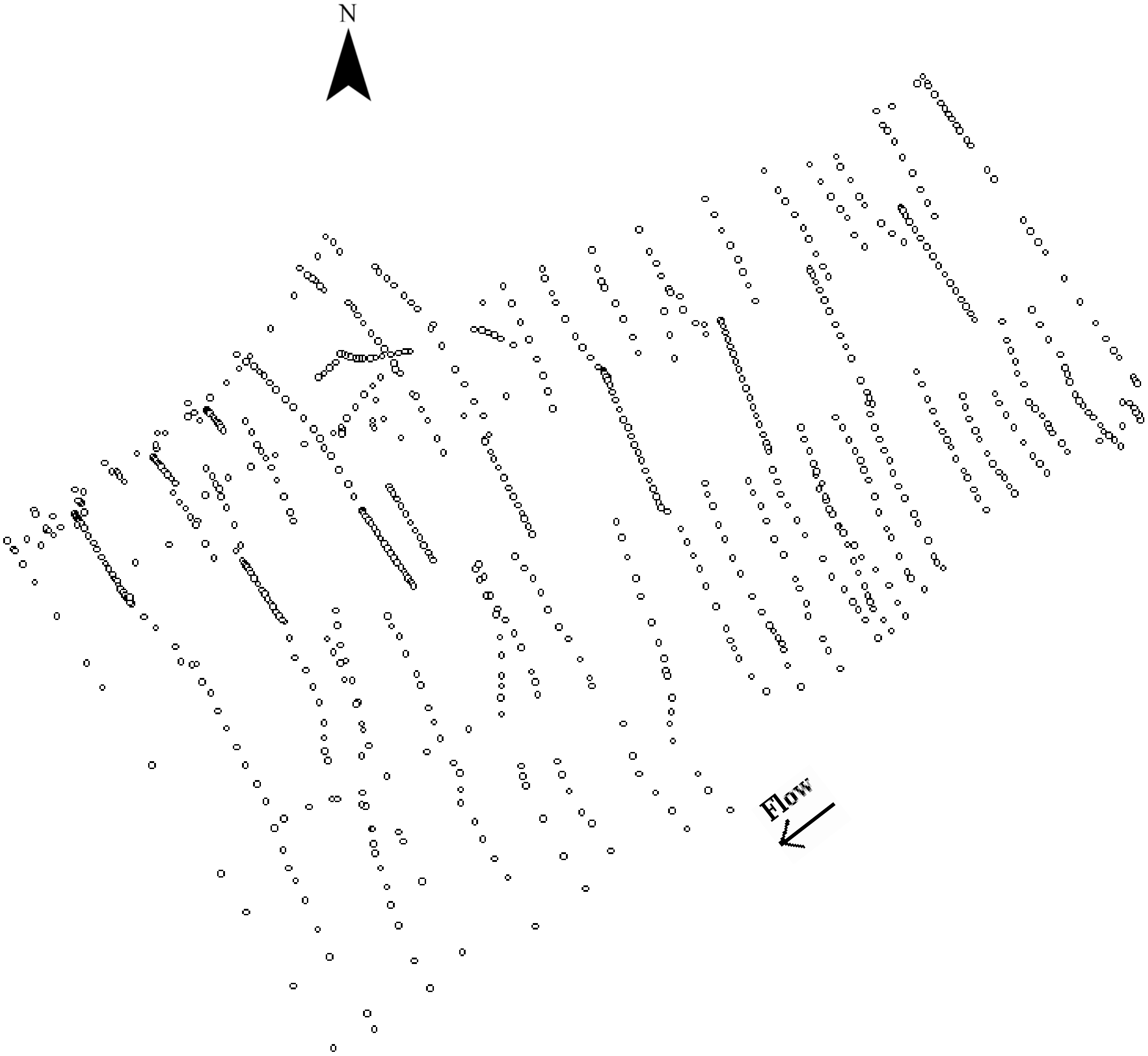
## HALLWOOD STUDY SITE



**Scale: 1:2052**

Appendix B

# PLANTZ STUDY SITE



**Scale: 1:1389**

# APPENDIX C
# RHABSIM WSEL CALIBRATION

Appendix C

## Table 1
## Stage of Zero Flow Values

| Study Site | XS # 1 SZF | XS # 2 SZF |
|---|---|---|
| UC Sierra | 91.0 | 96.8 |
| Timbuctoo | 94.6 | 108.1 |
| Highway 20 | 86.4 | 90.5 |
| Island | 94.9 | 100.5 |
| Hammond | 89.9 | 93.2 |
| Upper Daguerre | 87.9 | 90.3 |
| Lower Daguerre | 92.7 | 100.6 |
| Pyramids | 93.0 | 97.9 |
| Hallwood | 92.2 | 95.1 |
| Plantz | 90.6 | 91.1 |

# Appendix C

## Calibration Methods and Parameters Used

| Study Site | XS # | Flow Range | Calibration Flows | Method | Parameters |
|---|---|---|---|---|---|
| UC Sierra | 1, 2 | 400-4,500 | 670, 955, 2,348, 3,077, 4,437 | IFG4 | - - - |
| Timbuctoo | 1, 2 | 400-4,500 | 670, 955, 2,348, 3,077, 4,437 | IFG4 | - - - |
| Highway 20 | 1 | 400-2,000 | 670, 955, 2,017 | IFG4 | - - - |
| Highway 20 | 1 | 2,100-4,500 | 2,017, 3,077, 4,437 | IFG4 | - - - |
| Highway 20 | 2 | 400-4,500 | 670, 955, 2,017, 3,077, 4,437 | IFG4 | - - - |
| Island | 1, 2 | 400-4,500 | 670, 955, 2,018, 3,077, 5,273 | IFG4 | - - - |
| Hammond | 1, 2 | 400-2,300 | 686, 955, 2,348 | IFG4 | - - - |
| Hammond | 1, 2 | 2,500-4,500 | 2,348, 3,077, 5,273 | IFG4 | - - - |
| Upper Daguerre | 1, 2 | 150-2,300 | 403, 665, 1,460, 2,483 | IFG4 | - - - |
| Upper Daguerre | 1 | 2,500-4,500 | 2,483, 3,049, 5,580 | IFG4 | - - - |
| Upper Daguerre | 2 | 2,500-4,500 | 2,483, 3,049, 5,450 | IFG4 | - - - |
| Lower Daguerre | 1, 2 | 150-2,300 | 403, 665, 1,460, 2,483 | IFG4 | - - - |
| Lower Daguerre | 1, 2 | 2,500-4,500 | 2,483, 3,049, 5,872 | IFG4 | - - - |
| Pyramids | 1 | 150-4,500 | 403, 665, 1,280, 3,049, 5,826 | IFG4 | - - - |
| Pyramids | 2 | 150-4,500 | 403, 665, 1,280, 3,049, 5,756 | IFG4 | - - - |
| Hallwood | 1, 2 | 150-1,700 | 413, 678, 1,460, 1,710 | IFG4 | - - - |
| Hallwood | 1 | 1,800-4,500 | 1,710, 3,150, 6,060 | IFG4 | - - - |
| Hallwood | 2 | 1,800-4,500 | 1,710, 3,150, 5,920 | IFG4 | - - - |
| Plantz | 1, 2 | 150-1,800 | 453, 678, 1,460, 1,810 | IFG4 | - - - |
| Plantz | 1 | 1,900-4,500 | 1,810, 3,150, 6,180 | IFG4 | - - - |
| Plantz | 2 | 1,900-4,500 | 1,810, 3,150, 6,250 | IFG4 | - - - |

Appendix C

## UC Sierra Study Site

|  | BETA | %MEAN | Calculated vs Given Discharge (%) |  |  |  |  | Difference (measured vs. pred. WSELs) |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 670 | 955 | 2,348 | 3,077 | 4,437 | 670 | 955 | 2,348 | 3,077 | 4,437 |
| 1 | 2.33 | 2.7 | 3.1 | 1.4 | 5.2 | 0.4 | 3.6 | 0.03 | 0.02 | 0.08 | 0.01 | 0.07 |
| 2 | 2.83 | 3.1 | 4.0 | 3.7 | 0.7 | 3.3 | 3.5 | 0.03 | 0.03 | 0.01 | 0.04 | 0.05 |

## Timbuctoo Study Site

|  | BETA | %MEAN | Calculated vs Given Discharge (%) |  |  |  |  | Difference (measured vs. pred. WSELs) |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 670 | 955 | 2,348 | 3,077 | 4,437 | 670 | 955 | 2,348 | 3,077 | 4,437 |
| 1 | 2.81 | 3.3 | 3.2 | 5.2 | 0.6 | 5.2 | 2.3 | 0.03 | 0.06 | 0.01 | 0.09 | 0.05 |
| 2 | 3.07 | 3.2 | 4.8 | 6.3 | 2.2 | 1.9 | 0.7 | 0.04 | 0.05 | 0.03 | 0.02 | 0.01 |

## Highway 20 Study Site

|  | BETA | %MEAN | Calculated vs Given Discharge (%) |  |  | Difference (measured vs. pred. WSELs) |  |  |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 670 | 955 | 2,017 | 670 | 955 | 2,017 |
| 1 | 3.23 | 3.7 | 3.3 | 5.3 | 2.2 | 0.03 | 0.05 | 0.03 |

|  | BETA | %MEAN | Calculated vs Given Discharge (%) |  |  | Difference (measured vs. pred. WSELs) |  |  |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 2,017 | 3,077 | 4,437 | 2,017 | 3,077 | 4,437 |
| 1 | 2.27 | 0.6 | 0.4 | 0.9 | 0.5 | 0.01 | 0.02 | 0.01 |

|  | BETA | %MEAN | Calculated vs Given Discharge (%) |  |  |  |  | Difference (measured vs. pred. WSELs) |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 670 | 955 | 2,017 | 3,077 | 4,437 | 670 | 955 | 2,017 | 3,077 | 4,437 |
| 2 | 3.07 | 3.2 | 4.8 | 6.3 | 2.2 | 1.9 | 0.7 | 0.04 | 0.05 | 0.03 | 0.02 | 0.01 |

Appendix C

## Island Study Site

|  | BETA | %MEAN | Calculated vs Given Discharge (%) |  |  |  |  | Difference (measured vs. pred. WSELs) |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 670 | 955 | 2,018 | 3,077 | 5,273 | 670 | 955 | 2,018 | 3,077 | 5,273 |
| 1 | 2.79 | 2.0 | 2.8 | 2.3 | 1.2 | 1.5 | 2.2 | 0.02 | 0.02 | 0.01 | 0.02 | 0.04 |
| 2 | 3.22 | 3.7 | 4.7 | 3.6 | 1.7 | 3.7 | 4.8 | 0.04 | 0.03 | 0.02 | 0.05 | 0.07 |

## Hammond Study Site

|  | BETA | %MEAN | Calculated vs Given Discharge (%) |  |  | Difference (measured vs. pred. WSELs) |  |  |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 686 | 955 | 2,348 | 686 | 955 | 2,348 |
| 1 | 2.49 | 2.2 | 2.3 | 3.3 | 1.0 | 0.02 | 0.04 | 0.02 |
| 2 | 2.94 | 3.0 | 3.0 | 4.3 | 1.4 | 0.03 | 0.05 | 0.02 |

|  | BETA | %MEAN | Calculated vs Given Discharge (%) |  |  | Difference (measured vs. pred. WSELs) |  |  |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 2,348 | 3,077 | 5,373 | 2,348 | 3,077 | 5,373 |
| 1 | 3.12 | 0.8 | 0.8 | 1.2 | 0.4 | 0.01 | 0.02 | 0.01 |
| 2 | 3.84 | 1.0 | 1.0 | 1.5 | 0.6 | 0.01 | 0.02 | 0.01 |

## Appendix C

### Upper Daguerre Study Site

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | | Difference (measured vs. pred. WSELs) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 403 | 665 | 1,460 | 2,483 | 403 | 665 | 1,460 | 2,483 |
| 1 | 3.13 | 3.5 | 5.2 | 7.4 | 0.8 | 0.9 | 0.04 | 0.07 | 0.01 | 0.01 |
| 2 | 3.05 | 4.3 | 6.1 | 7.6 | 1.4 | 2.4 | 0.05 | 0.07 | 0.02 | 0.03 |

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 2,483 | 3,049 | 5,580 | 2,483 | 3,049 | 5,580 |
| 1 | 2.73 | 0.3 | 0.4 | 0.5 | 0.1 | 0.01 | 0.01 | 0.00 |

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 2,483 | 3,049 | 5,450 | 2,483 | 3,049 | 5,450 |
| 2 | 2.33 | 0.8 | 0.9 | 1.2 | 0.3 | 0.02 | 0.02 | 0.01 |

### Lower Daguerre Study Site

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | | Difference (measured vs. pred. WSELs) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 403 | 665 | 1,460 | 2,483 | 403 | 665 | 1,460 | 2,483 |
| 1 | 3.05 | 5.3 | 7.0 | 8.2 | 2.8 | 3.3 | 0.07 | 0.08 | 0.04 | 0.06 |
| 2 | 2.98 | 2.9 | 4.3 | 6.1 | 0.8 | 0.8 | 0.03 | 0.04 | 0.01 | 0.01 |

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 2,483 | 3,049 | 5,872 | 2,483 | 3,049 | 5,872 |
| 1 | 2.17 | 0.1 | 0.1 | 0.2 | 0.05 | 0.00 | 0.01 | 0.00 |
| 2 | 2.40 | 0.1 | 0.1 | 0.2 | 0.05 | 0.00 | 0.00 | 0.00 |

## Appendix C

### Pyramids Study Site

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | | | Difference (measured vs. pred. WSELs) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 403 | 665 | 1,280 | 3,049 | 5,826 | 403 | 665 | 1,280 | 3,049 | 5,826 |
| 1 | 2.50 | 1.9 | 2.6 | 2.8 | 1.5 | 2.1 | 0.5 | 0.02 | 0.03 | 0.02 | 0.04 | 0.01 |

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | | | Difference (measured vs. pred. WSELs) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 403 | 665 | 1,280 | 3,049 | 5,756 | 403 | 665 | 1,280 | 3,049 | 5,756 |
| 2 | 2.65 | 6.2 | 12.2 | 13.1 | 3.1 | 0.0 | 2.3 | 0.08 | 0.09 | 0.03 | 0.00 | 0.04 |

### Hallwood Study Site

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | | Difference (measured vs. pred. WSELs) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 413 | 678 | 1,460 | 1,710 | 413 | 678 | 1,460 | 1,710 |
| 1 | 2.50 | 1.9 | 1.0 | 0.8 | 3.0 | 2.7 | 0.01 | 0.02 | 0.04 | 0.04 |
| 2 | 3.37 | 2.60 | 1.8 | 2.6 | 2.6 | 3.5 | 0.01 | 0.02 | 0.03 | 0.04 |

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 1,710 | 3,150 | 6,060 | 1,710 | 3,150 | 6,060 |
| 1 | 2.23 | 1.1 | 0.9 | 1.7 | 0.8 | 0.01 | 0.04 | 0.02 |

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 1,710 | 3,150 | 5,920 | 1,710 | 3,150 | 5,920 |
| 2 | 2.78 | 0.8 | 0.7 | 1.3 | 0.6 | 0.01 | 0.02 | 0.01 |

## Appendix C

### Plantz Study Site

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | | Difference (measured vs. pred. WSELs) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 453 | 678 | 1,460 | 1,810 | 453 | 678 | 1,460 | 1,810 |
| 1 | 2.79 | 2.8 | 3.1 | 5.2 | 2.5 | 0.2 | 0.02 | 0.05 | 0.03 | 0.00 |
| 2 | 1.64 | 1.6 | 2.1 | 3.0 | 0.2 | 1.2 | 0.02 | 0.03 | 0.00 | 0.02 |

| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 1,810 | 3,150 | 6,180 | 1,810 | 3,150 | 6,180 |
| 1 | 2.36 | 1.9 | 1.6 | 2.9 | 1.2 | 0.02 | 0.05 | 0.03 |

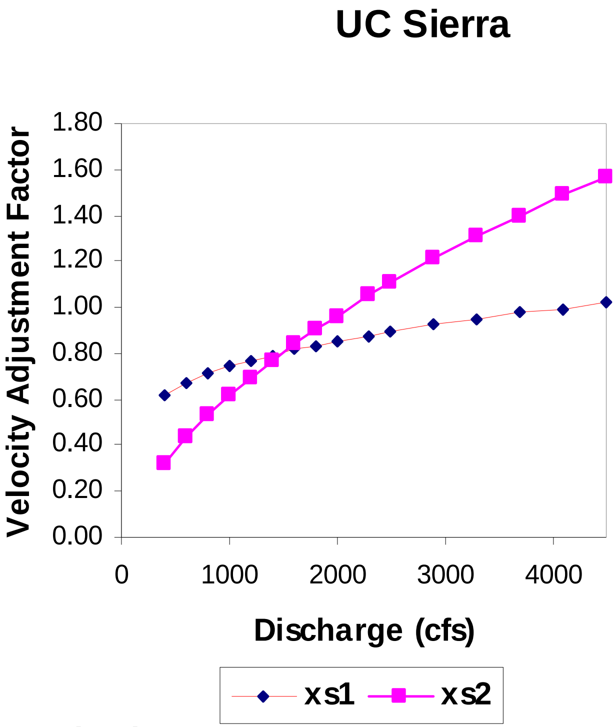
| | BETA | %MEAN | Calculated vs Given Discharge (%) | | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|---|---|---|---|
| XS | COEFF. | ERROR | 1,810 | 3,150 | 6,250 | 1,810 | 3,150 | 6,250 |
| 2 | 2.89 | 1.2 | 1.0 | 2.1 | 0.9 | 0.01 | 0.03 | 0.02 |

# APPENDIX D
# VELOCITY ADJUSTMENT FACTORS

Appendix D

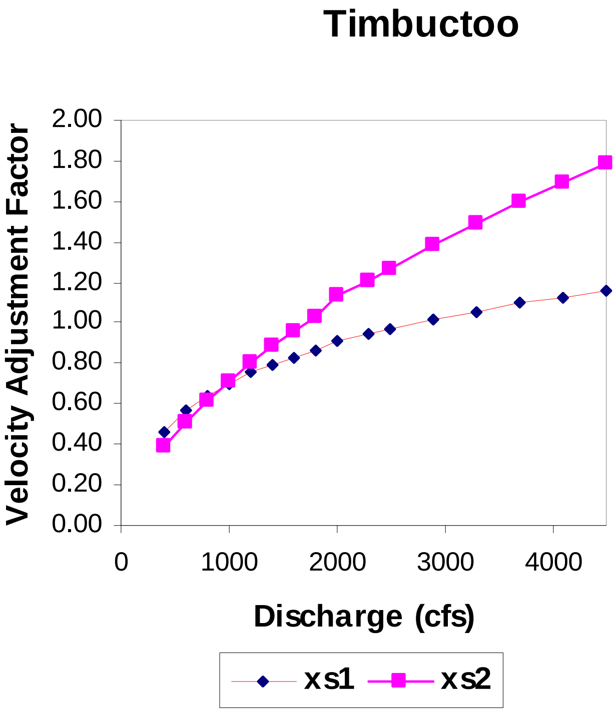
## UC Sierra Study Site

| | Velocity Adjustment Factors | |
|---|---|---|
| Discharge | Xsec 1 | Xsec 2 |
| 400 | 0.62 | 0.32 |
| 600 | 0.68 | 0.43 |
| 800 | 0.71 | 0.53 |
| 1,000 | 0.74 | 0.61 |
| 1,200 | 0.77 | 0.69 |
| 1,400 | 0.79 | 0.77 |
| 1,600 | 0.82 | 0.84 |
| 1,800 | 0.83 | 0.90 |
| 2,000 | 0.85 | 0.96 |
| 2,300 | 0.88 | 1.05 |
| 2,500 | 0.89 | 1.11 |
| 2,900 | 0.92 | 1.21 |
| 3,300 | 0.95 | 1.31 |
| 3,700 | 0.98 | 1.40 |
| 4,100 | 1.00 | 1.49 |
| 4,500 | 1.02 | 1.57 |



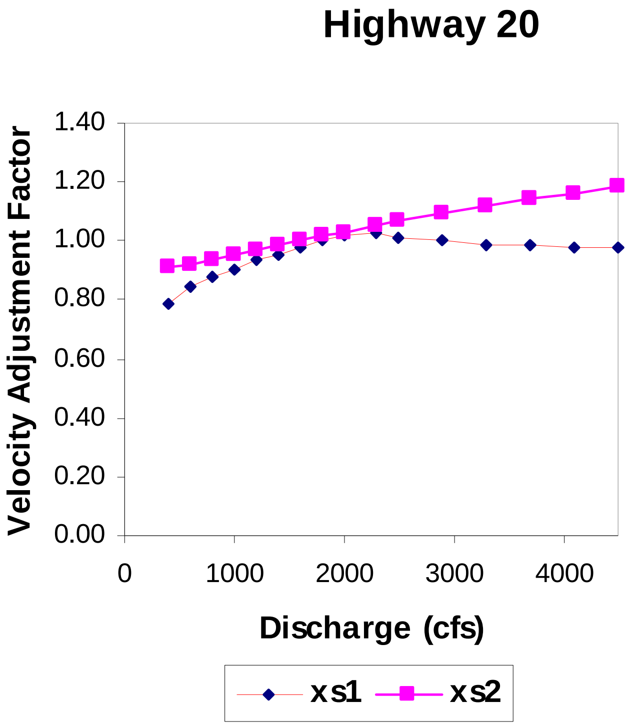
## Timbuctoo Study Site

| | Velocity Adjustment Factors | |
|---|---|---|
| Discharge | Xsec 1 | Xsec 2 |
| 400 | 0.46 | 0.39 |
| 600 | 0.56 | 0.51 |
| 800 | 0.64 | 0.62 |
| 1,000 | 0.70 | 0.71 |
| 1,200 | 0.75 | 0.80 |
| 1,400 | 0.80 | 0.88 |
| 1,600 | 0.83 | 0.96 |
| 1,800 | 0.87 | 1.03 |
| 2,000 | 0.91 | 1.14 |
| 2,300 | 0.94 | 1.20 |
| 2,500 | 0.97 | 1.26 |
| 2,900 | 1.02 | 1.38 |
| 3,300 | 1.06 | 1.49 |
| 3,700 | 1.09 | 1.60 |
| 4,100 | 1.13 | 1.69 |
| 4,500 | 1.16 | 1.79 |



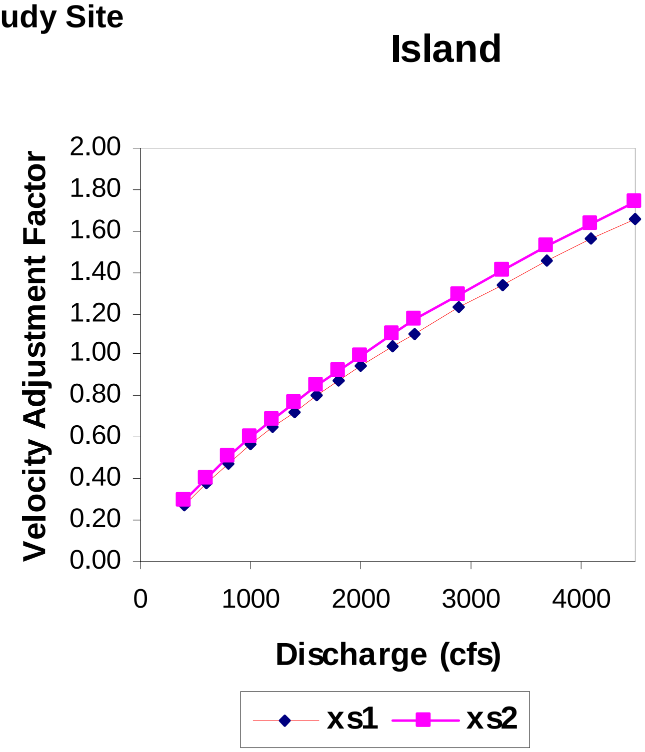
## Highway 20 Study Site

| | Velocity Adjustment Factors | |
|---|---|---|
| Discharge | Xsec 1 | Xsec 2 |
| 400 | 0.79 | 0.91 |
| 600 | 0.84 | 0.92 |
| 800 | 0.88 | 0.94 |
| 1,000 | 0.91 | 0.95 |
| 1,200 | 0.93 | 0.97 |
| 1,400 | 0.96 | 0.98 |
| 1,600 | 0.98 | 1.00 |
| 1,800 | 1.00 | 1.02 |
| 2,000 | 1.02 | 1.03 |
| 2,300 | 1.03 | 1.05 |
| 2,500 | 1.01 | 1.07 |
| 2,900 | 1.00 | 1.09 |
| 3,300 | 0.99 | 1.12 |
| 3,700 | 0.98 | 1.14 |
| 4,100 | 0.98 | 1.16 |
| 4,500 | 0.97 | 1.19 |



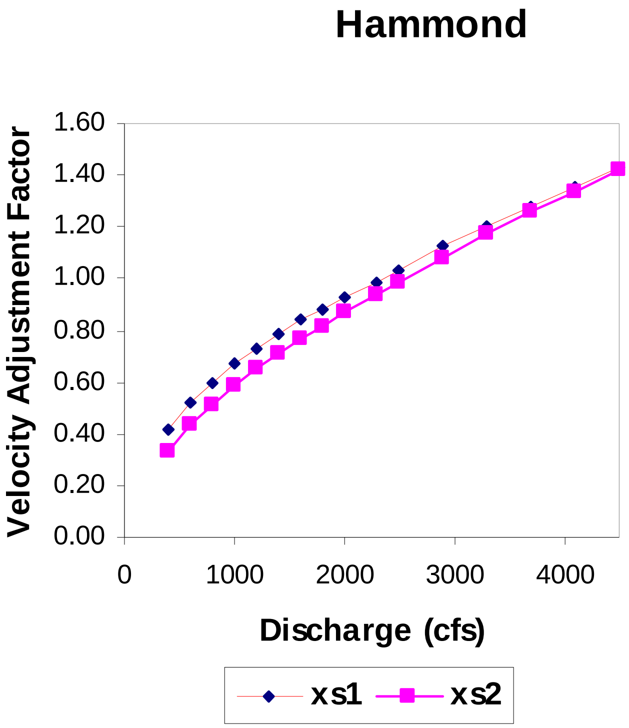
## Island Study Site

| | Velocity Adjustment Factors | |
|---|---|---|
| Discharge | Xsec 1 | Xsec 2 |
| 400 | 0.27 | 0.29 |
| 600 | 0.38 | 0.40 |
| 800 | 0.48 | 0.51 |
| 1,000 | 0.56 | 0.60 |
| 1,200 | 0.65 | 0.69 |
| 1,400 | 0.73 | 0.77 |
| 1,600 | 0.80 | 0.85 |
| 1,800 | 0.87 | 0.92 |
| 2,000 | 0.94 | 1.00 |
| 2,300 | 1.04 | 1.10 |
| 2,500 | 1.11 | 1.17 |
| 2,900 | 1.23 | 1.29 |
| 3,300 | 1.34 | 1.41 |
| 3,700 | 1.45 | 1.53 |
| 4,100 | 1.56 | 1.64 |
| 4,500 | 1.66 | 1.74 |



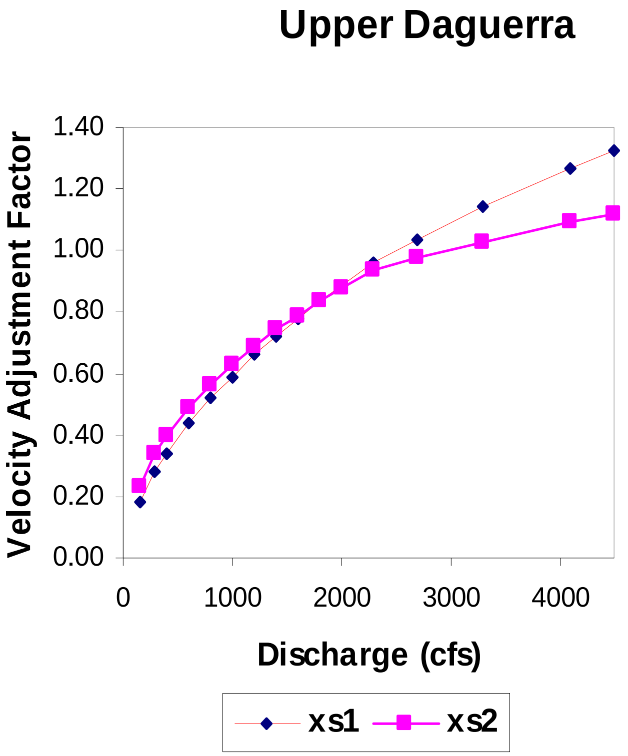
## Hammond Study Site

|  | Velocity Adjustment Factors |  |
|---|---|---|
| Discharge | Xsec 1 | Xsec 2 |
| 400 | 0.42 | 0.33 |
| 600 | 0.52 | 0.43 |
| 800 | 0.60 | 0.51 |
| 1,000 | 0.67 | 0.59 |
| 1,200 | 0.73 | 0.65 |
| 1,400 | 0.79 | 0.71 |
| 1,600 | 0.84 | 0.77 |
| 1,800 | 0.89 | 0.82 |
| 2,000 | 0.93 | 0.87 |
| 2,300 | 0.99 | 0.93 |
| 2,500 | 1.03 | 0.98 |
| 2,900 | 1.12 | 1.08 |
| 3,300 | 1.21 | 1.17 |
| 3,700 | 1.28 | 1.26 |
| 4,100 | 1.36 | 1.34 |
| 4,500 | 1.43 | 1.42 |



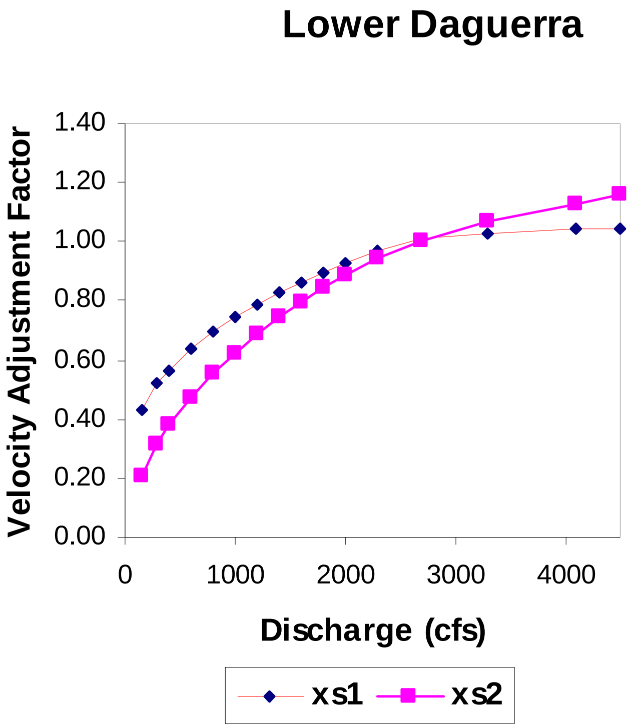
## Upper Daguerre Study Site

|  | Velocity Adjustment Factors |  |
|---|---|---|
| Discharge | Xsec 1 | Xsec 2 |
| 150 | 0.18 | 0.23 |
| 300 | 0.28 | 0.34 |
| 400 | 0.34 | 0.40 |
| 600 | 0.44 | 0.49 |
| 800 | 0.52 | 0.56 |
| 1,000 | 0.59 | 0.63 |
| 1,200 | 0.66 | 0.69 |
| 1,400 | 0.72 | 0.74 |
| 1,600 | 0.78 | 0.79 |
| 1,800 | 0.83 | 0.84 |
| 2,000 | 0.89 | 0.88 |
| 2,300 | 0.96 | 0.94 |
| 2,700 | 1.04 | 0.97 |
| 3,300 | 1.14 | 1.03 |
| 4,100 | 1.27 | 1.09 |
| 4,500 | 1.32 | 1.12 |



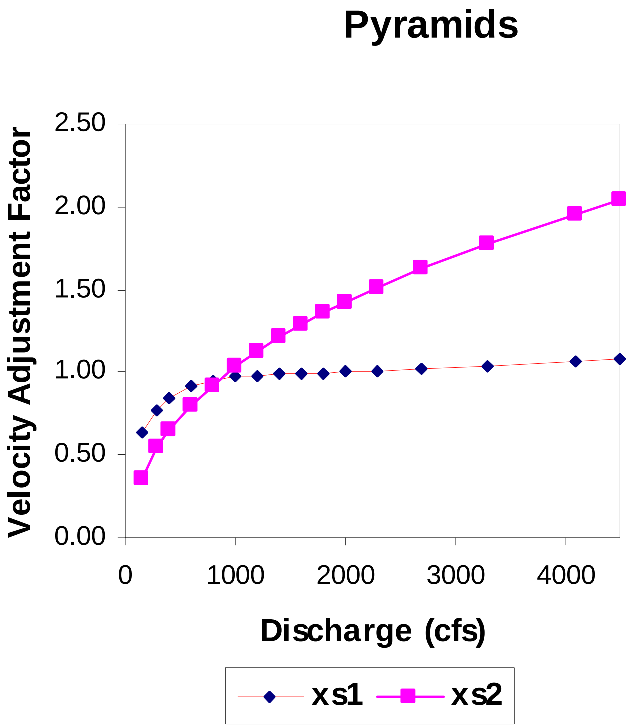
## Lower Daguerre Study Site

| Discharge | Velocity Adjustment Factors<br>Xsec 1 | Xsec 2 |
|---|---|---|
| 150 | 0.43 | 0.21 |
| 300 | 0.52 | 0.32 |
| 400 | 0.57 | 0.38 |
| 600 | 0.64 | 0.47 |
| 800 | 0.70 | 0.55 |
| 1,000 | 0.75 | 0.62 |
| 1,200 | 0.79 | 0.69 |
| 1,400 | 0.83 | 0.74 |
| 1,600 | 0.87 | 0.79 |
| 1,800 | 0.90 | 0.84 |
| 2,000 | 0.93 | 0.89 |
| 2,300 | 0.97 | 0.95 |
| 2,700 | 1.01 | 1.00 |
| 3,300 | 1.03 | 1.06 |
| 4,100 | 1.04 | 1.13 |
| 4,500 | 1.05 | 1.16 |



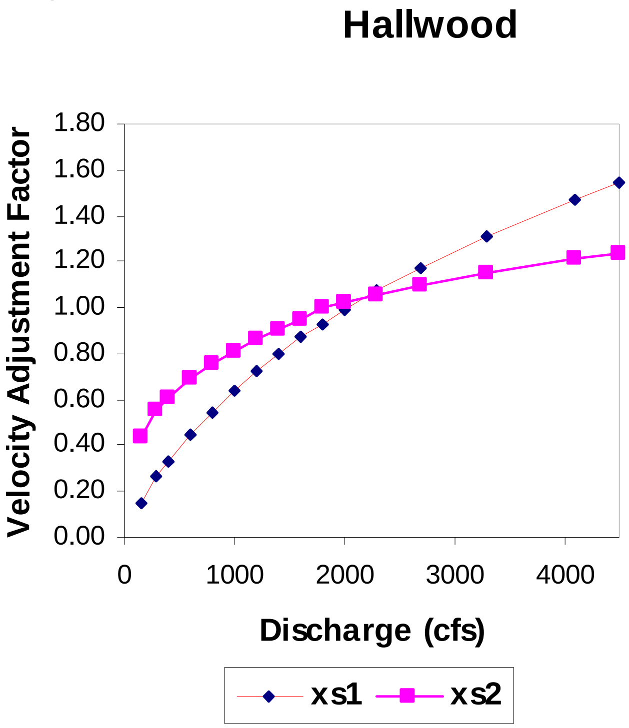
## Pyramids Study Site

| Discharge | Velocity Adjustment Factors<br>Xsec 1 | Xsec 2 |
|---|---|---|
| 150 | 0.63 | 0.36 |
| 300 | 0.77 | 0.55 |
| 400 | 0.84 | 0.64 |
| 600 | 0.92 | 0.80 |
| 800 | 0.95 | 0.92 |
| 1,000 | 0.97 | 1.03 |
| 1,200 | 0.98 | 1.12 |
| 1,400 | 0.99 | 1.21 |
| 1,600 | 0.99 | 1.28 |
| 1,800 | 1.00 | 1.35 |
| 2,000 | 1.00 | 1.42 |
| 2,300 | 1.01 | 1.51 |
| 2,700 | 1.02 | 1.63 |
| 3,300 | 1.04 | 1.78 |
| 4,100 | 1.06 | 1.96 |
| 4,500 | 1.08 | 2.04 |



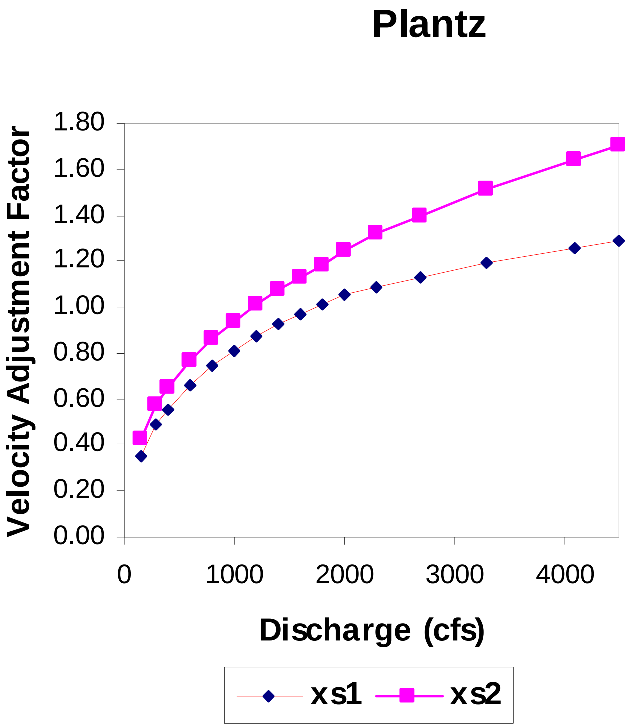
## Hallwood Study Site

| Discharge | Velocity Adjustment Factors<br>Xsec 1 | <br>Xsec 2 |
|---|---|---|
| 150 | 0.15 | 0.44 |
| 300 | 0.26 | 0.55 |
| 400 | 0.33 | 0.61 |
| 600 | 0.44 | 0.69 |
| 800 | 0.54 | 0.75 |
| 1,000 | 0.64 | 0.81 |
| 1,200 | 0.72 | 0.86 |
| 1,400 | 0.80 | 0.90 |
| 1,600 | 0.87 | 0.95 |
| 1,800 | 0.93 | 1.00 |
| 2,000 | 0.99 | 1.03 |
| 2,300 | 1.07 | 1.06 |
| 2,700 | 1.17 | 1.10 |
| 3,300 | 1.31 | 1.15 |
| 4,100 | 1.47 | 1.21 |
| 4,500 | 1.55 | 1.24 |



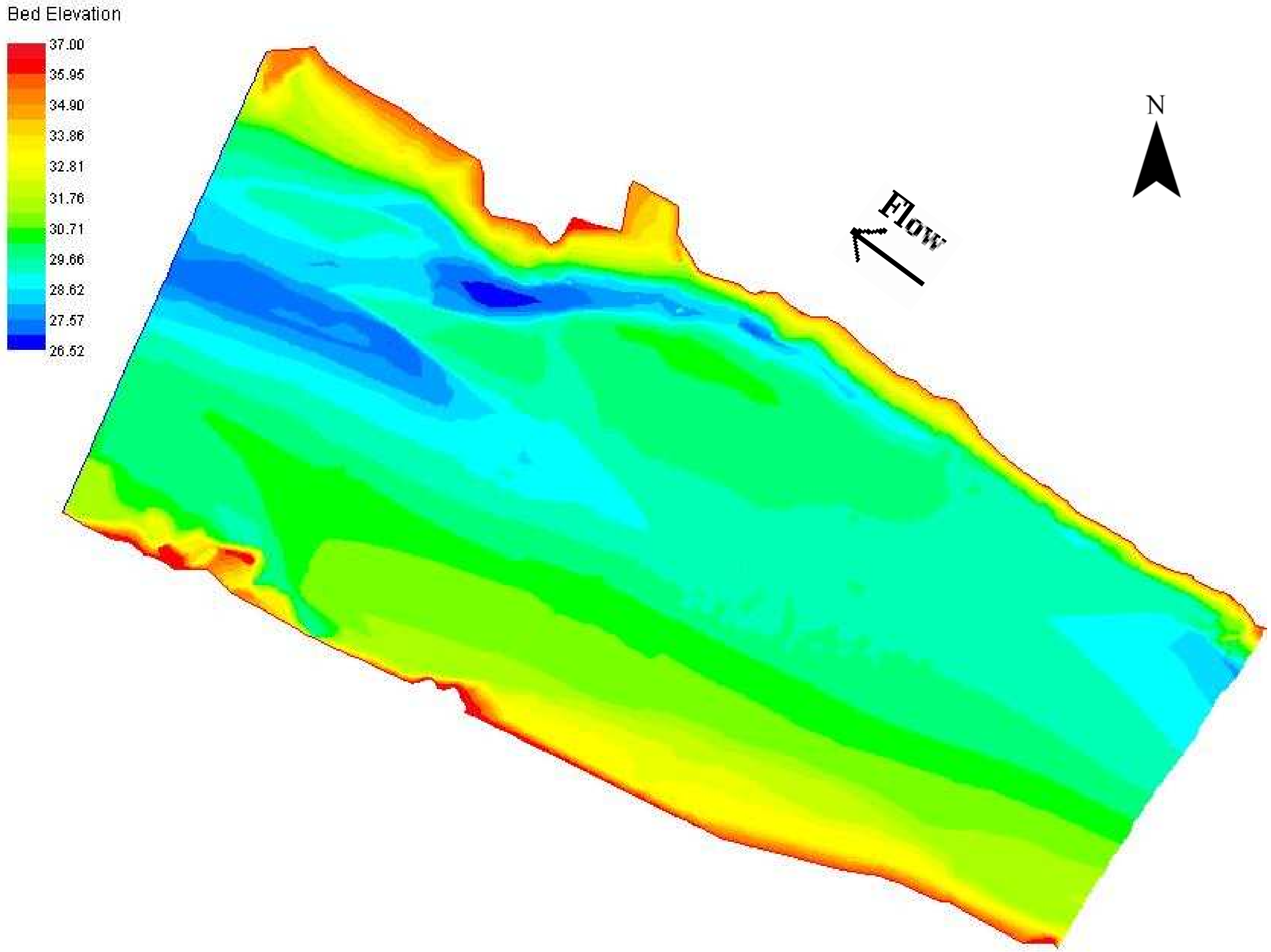
## Plantz Study Site

| Discharge | Velocity Adjustment Factors<br>Xsec 1 | <br>Xsec 2 |
|---|---|---|
| 150 | 0.35 | 0.43 |
| 300 | 0.49 | 0.58 |
| 400 | 0.56 | 0.65 |
| 600 | 0.66 | 0.77 |
| 800 | 0.74 | 0.86 |
| 1,000 | 0.81 | 0.94 |
| 1,200 | 0.87 | 1.01 |
| 1,400 | 0.92 | 1.07 |
| 1,600 | 0.97 | 1.13 |
| 1,800 | 1.01 | 1.18 |
| 2,000 | 1.05 | 1.25 |
| 2,300 | 1.09 | 1.32 |
| 2,700 | 1.13 | 1.40 |
| 3,300 | 1.19 | 1.51 |
| 4,100 | 1.26 | 1.64 |
| 4,500 | 1.29 | 1.71 |



# APPENDIX E
# BED TOPOGRAPHY OF STUDY SITES

## UC SIERRA STUDY SITE

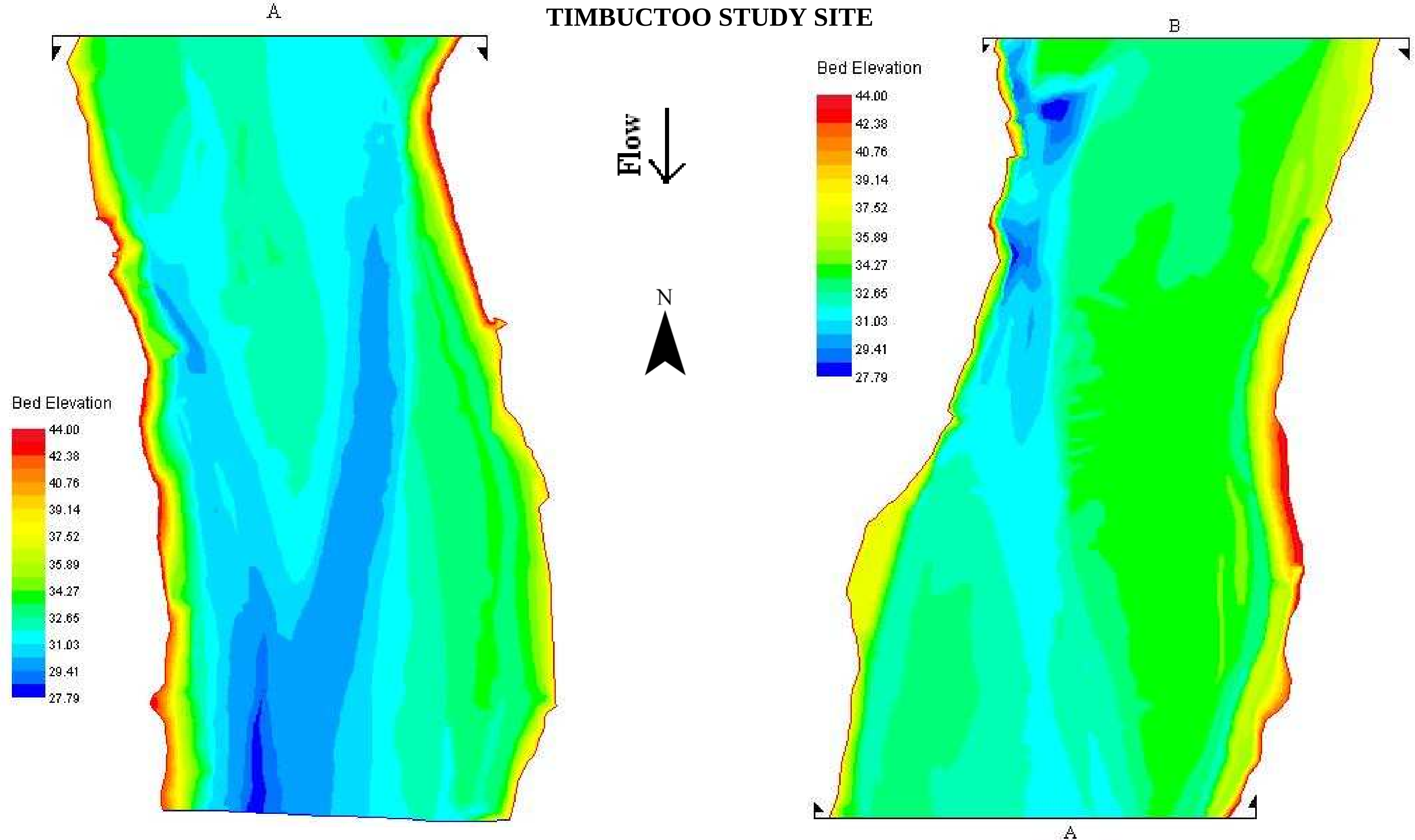


**Scale: 1:1835**

Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

Appendix E

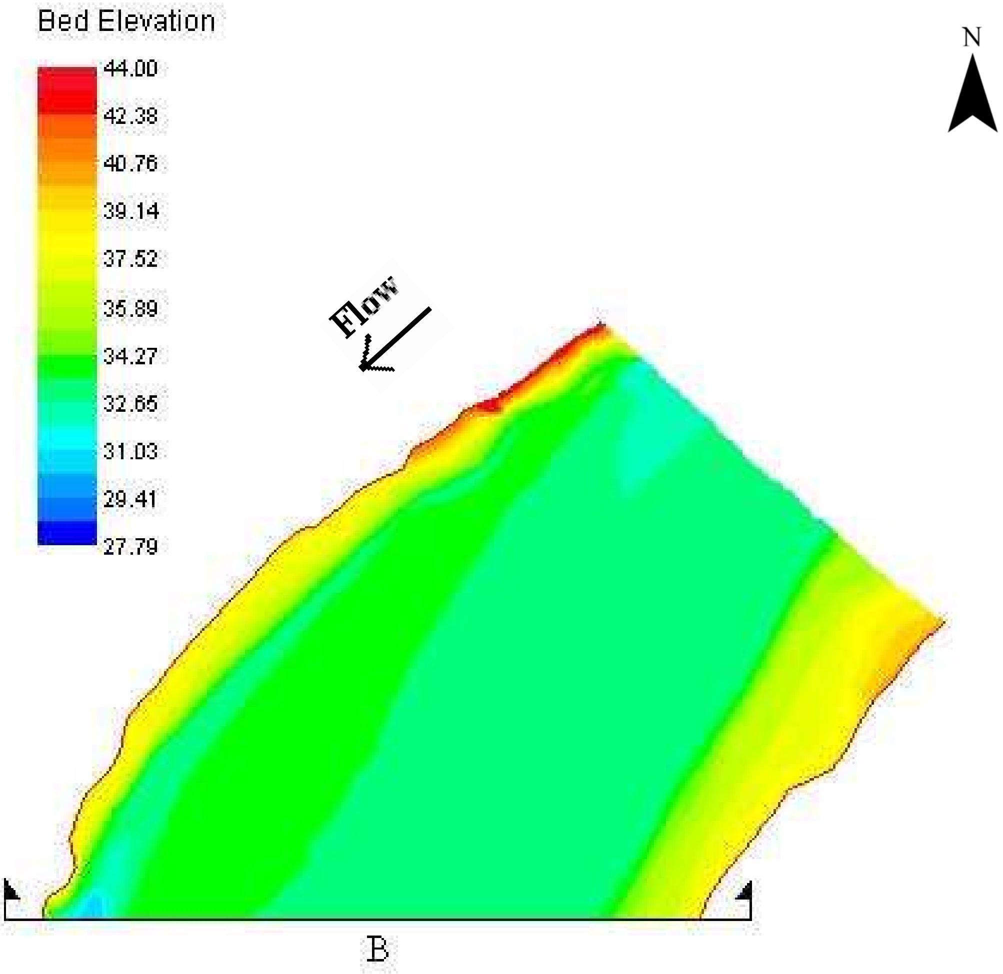
## TIMBUCTOO STUDY SITE



**Scale: 1:2277** **Scale: 1:2163**

Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

## TIMBUCTOO STUDY SITE (CONTINUED)

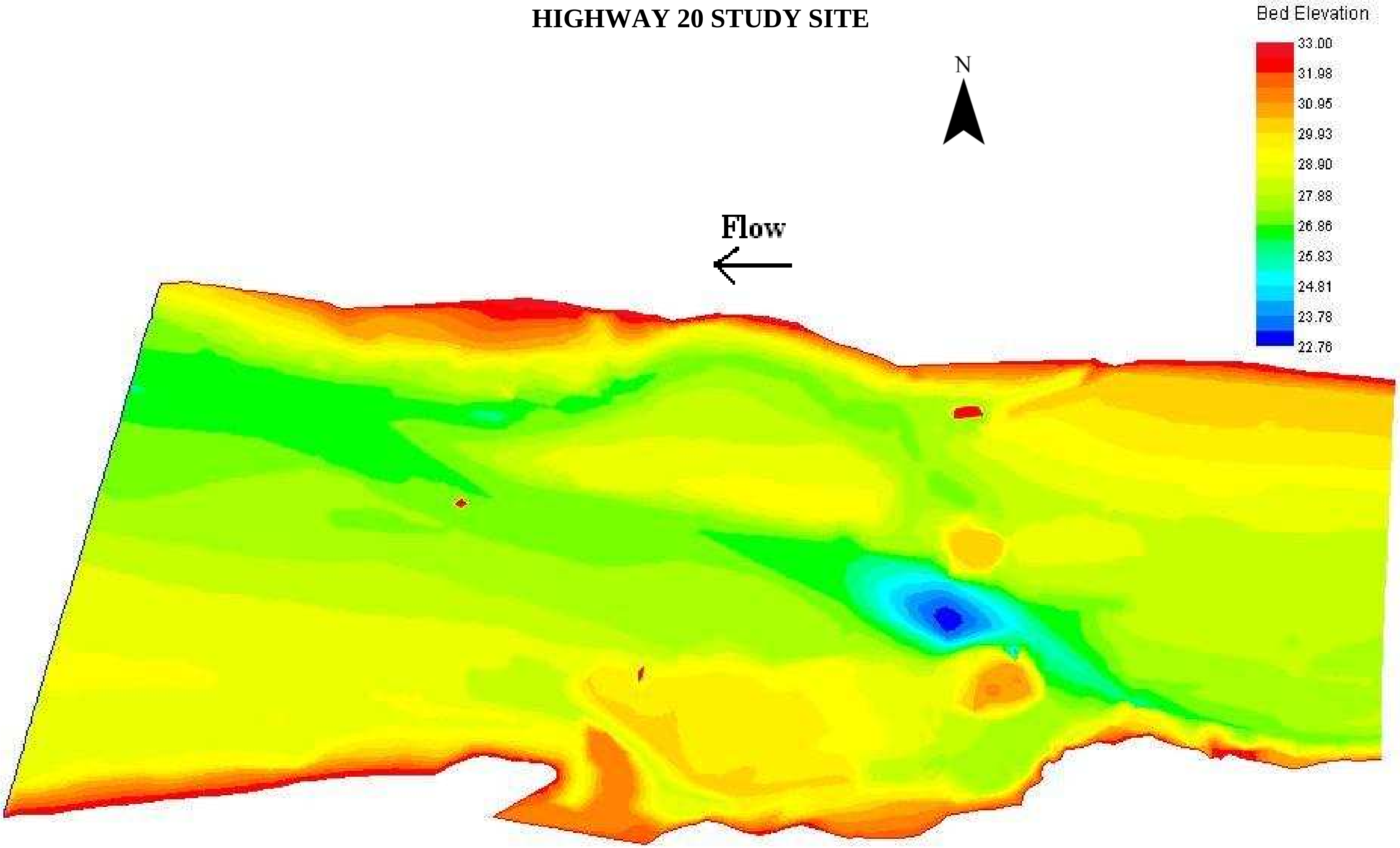


**Scale: 1:1410**

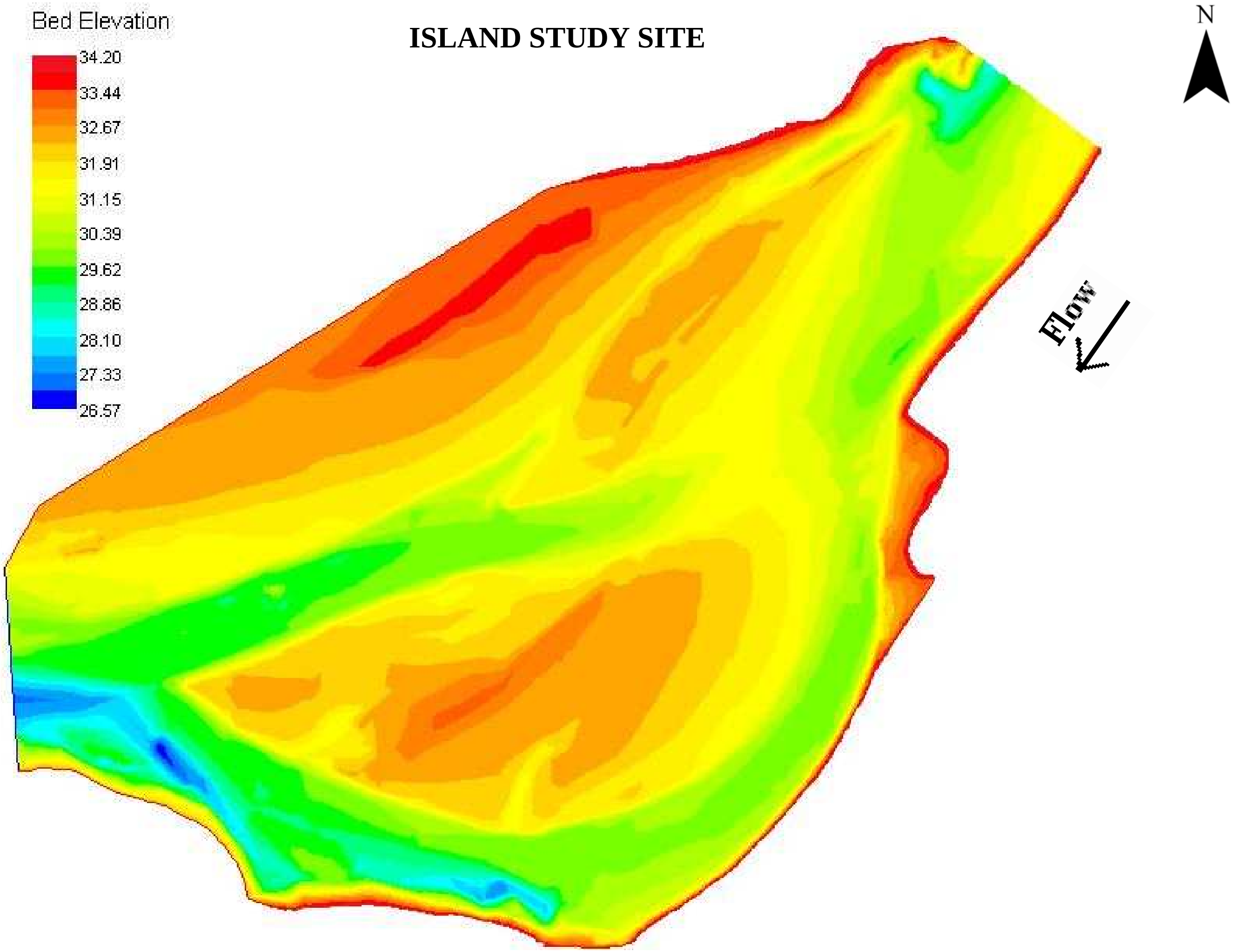
Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

Appendix E

## HIGHWAY 20 STUDY SITE



**Scale: 1:1851**
Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

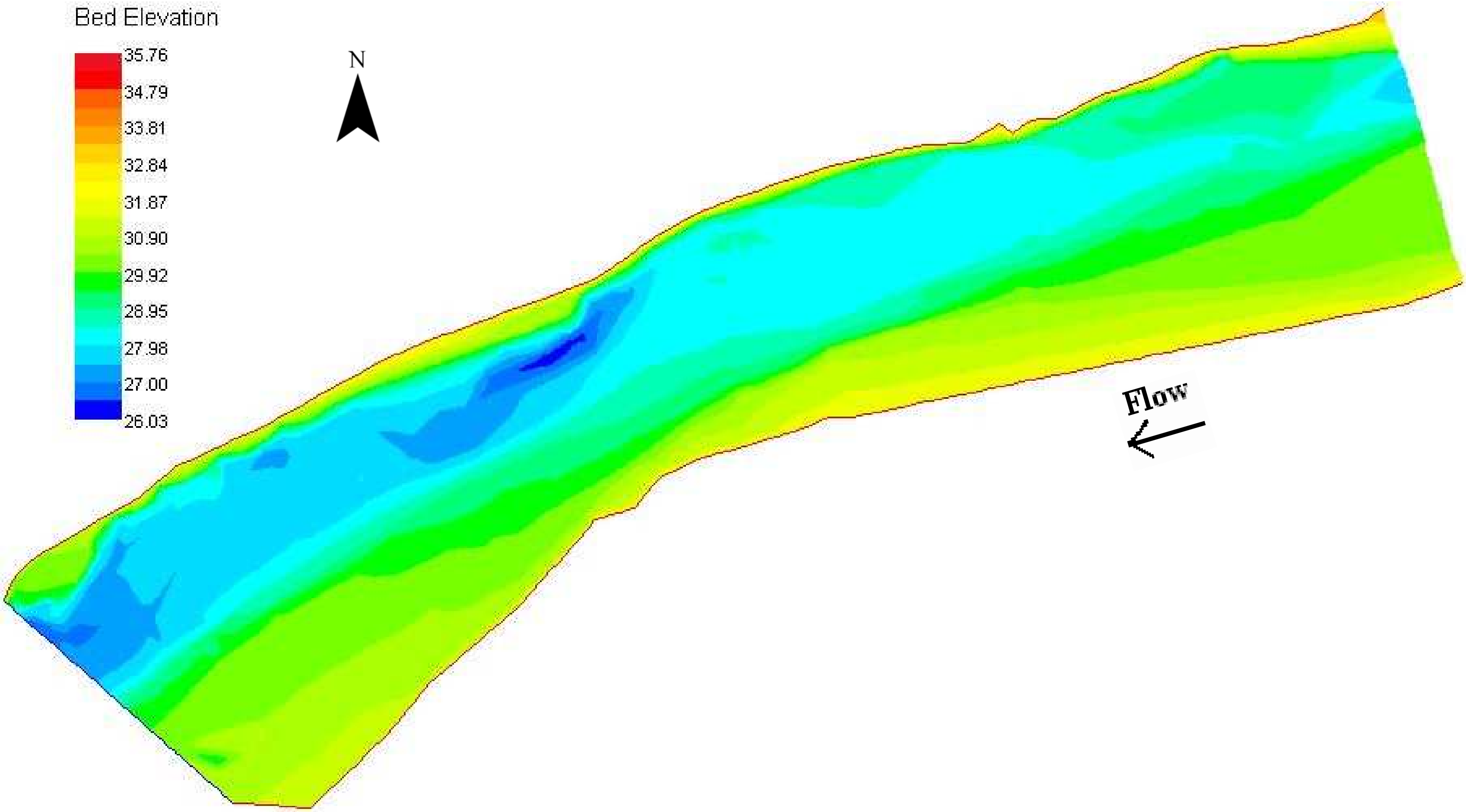


**Scale: 1:3275**

Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

Appendix E

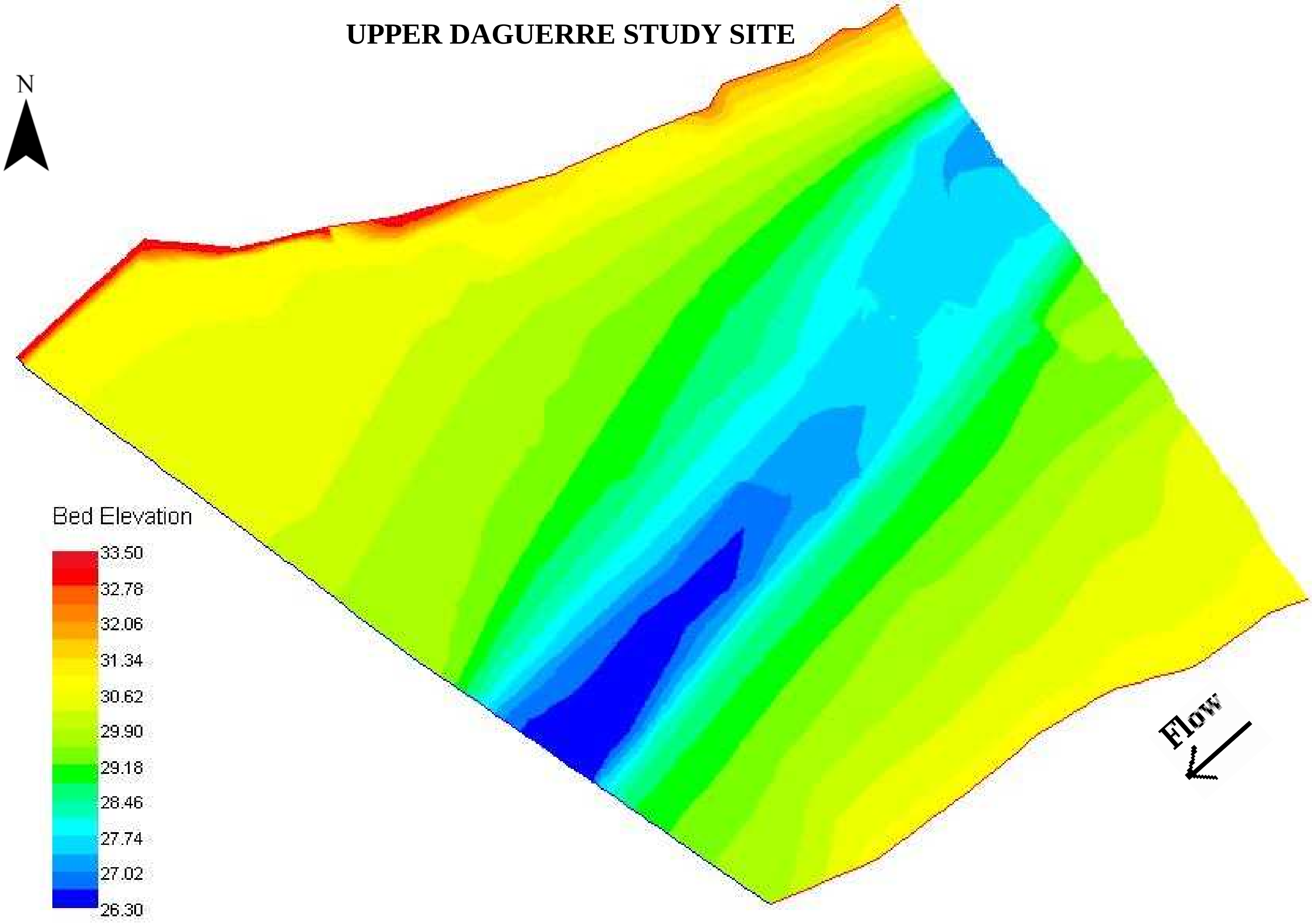
## HAMMOND STUDY SITE



**Scale: 1:2961**

Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

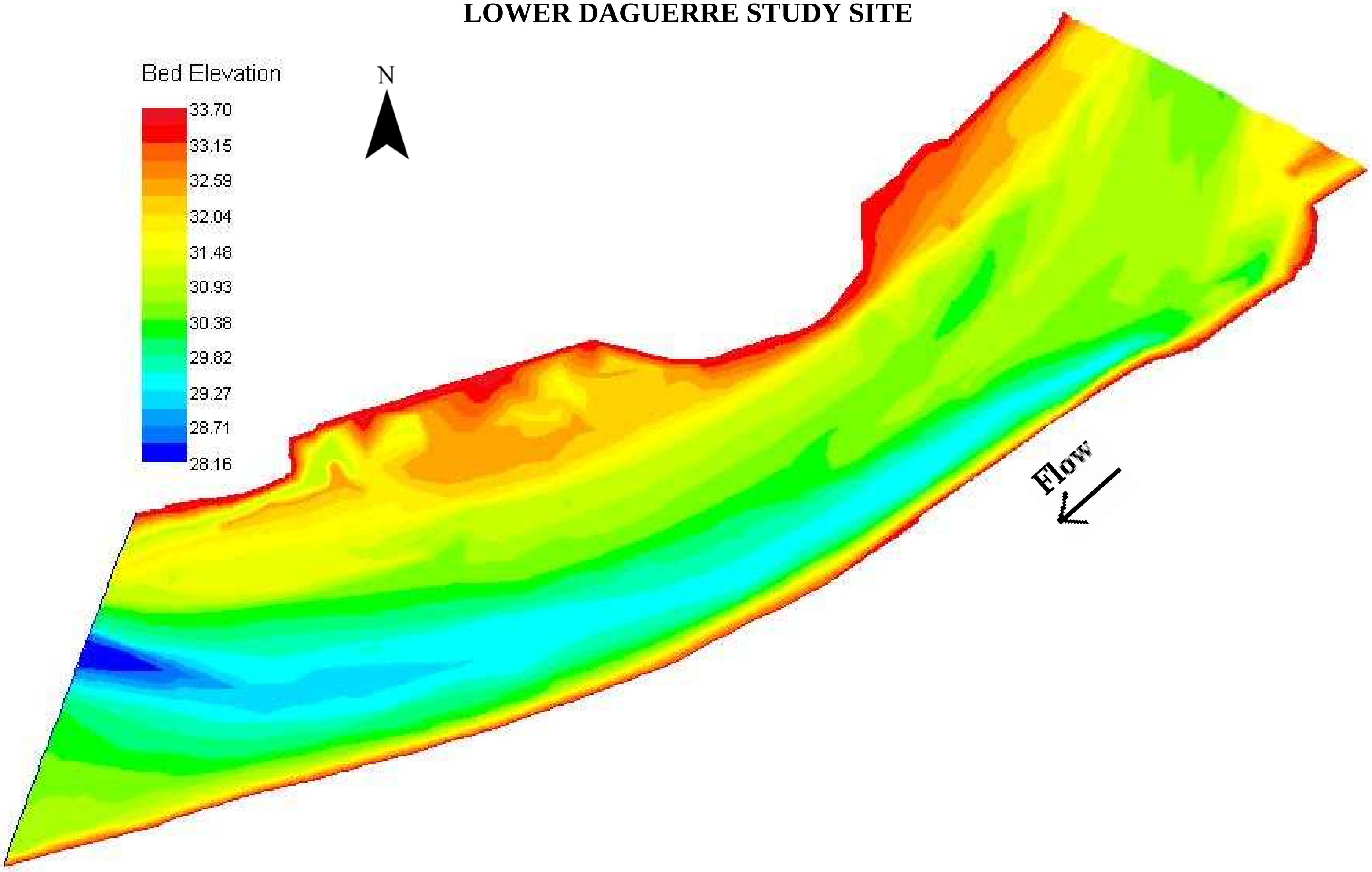
Appendix E



**Scale: 1:1034**

Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

## LOWER DAGUERRE STUDY SITE

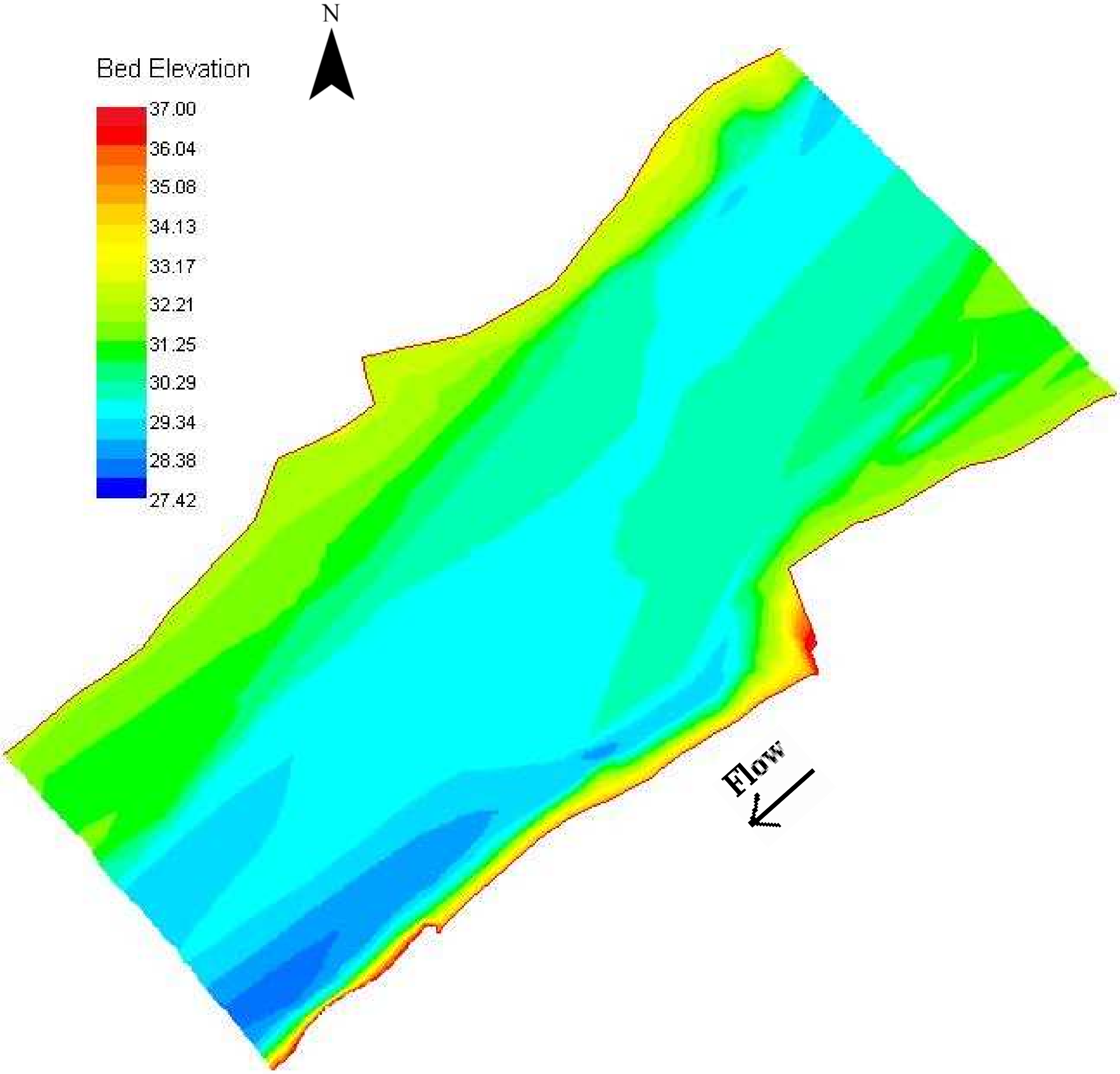


**Scale: 1:1808**

Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

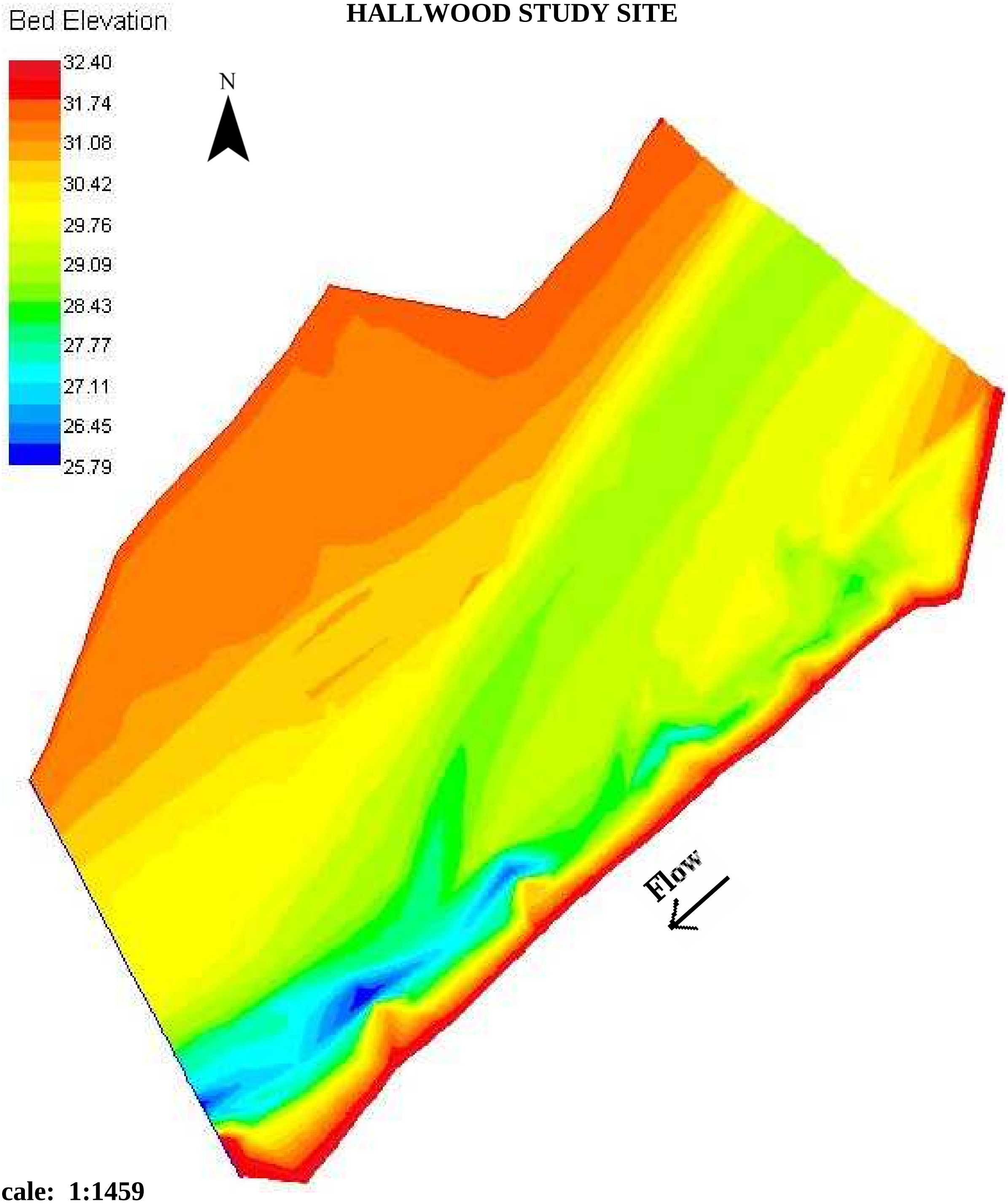
Appendix E

## PYRAMIDS STUDY SITE



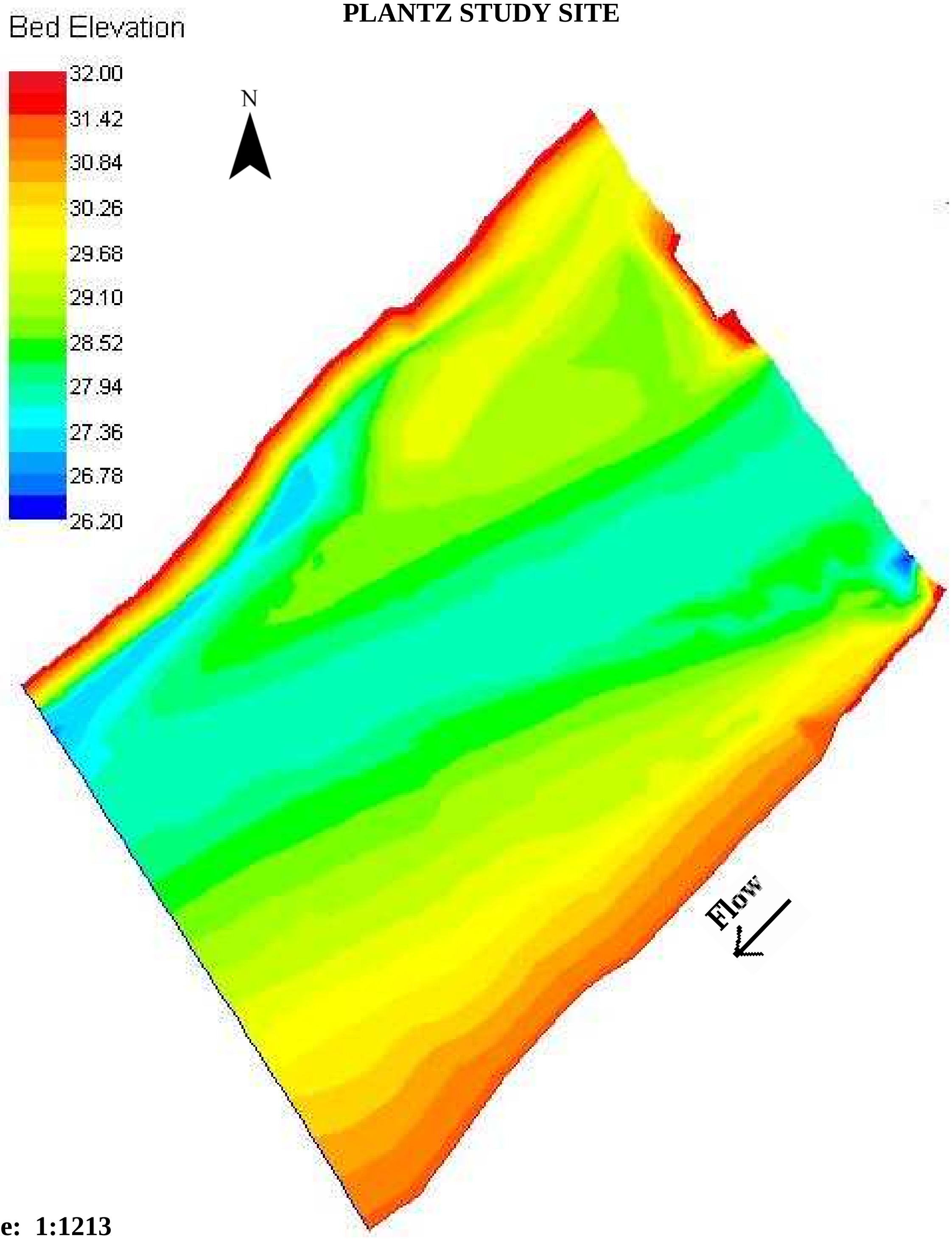
**Scale: 1:2084**
Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

## HALLWOOD STUDY SITE



**Scale: 1:1459**
Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

## PLANTZ STUDY SITE



**Scale: 1:1213**
Units of Bed Elevation are in meters, in 10 equal increments from the lowest to the highest bed elevation in the site.

# APPENDIX F
# 2-D WSEL CALIBRATION

Appendix F

## Calibration Statistics

| Site Name | Cal Q (cfs) | % Nodes within 0.1' | Nodes | QI | Net Q | Sol Δ | Max F |
|---|---|---|---|---|---|---|---|
| UC Sierra | 4,500 | 76% | 12,559 | 0.30 | 0.04% | <.000001 | 5.21 |
| Timbuctoo | 4,500 | 75% | 24,956 | 0.30 | 0.9% | .000003 | 1.31 |
| Highway 20 | 4,500 | 79% | 16,718 | 0.30 | 0.02% | <.000001 | 1.38 |
| Island | 4,500 | 79% | 18,572 | 0.30 | 0.1% | <.000001 | 4.44 |
| Hammond | 3,077 | 79% | 9,998 | 0.31 | 0.1% | .000001 | 3.41 |
| Upper Daguerre | 3,049 | 87% | 7,151 | 0.31 | 0.2% | .000008 | 0.66 |
| Lower Daguerre | 3,049 | 92% | 12,462 | 0.31 | 0.2% | .000009 | 0.93 |
| Pyramids | 4,500 | 87% | 10,576 | 0.30 | 0.1% | .000009 | 0.77 |
| Hallwood | 3,150 | 85% | 8,808 | 0.30 | 0.04% | .000003 | 0.92 |
| Plantz | 3,150 | 90% | 8,096 | 0.30 | 0.03% | .000009 | 2.89 |

Appendix F

## UC Sierra Site

| | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 0.5 | 0.02 | 0.04 | 0.08 |

## Timbuctoo Site

| | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 0.7 | 0.04 | 0.03 | 0.08 |

## Highway 20 Site

| | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 1 | 0.04 | 0.04 | 0.10 |

## Island Site

| | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 0.5 | 0.04 | 0.03 | 0.11 |
| 2 LB | 0.5 | 0.08 | 0.003 | 0.09 |
| 2 RB | 0.5 | 0.01 | 0.004 | 0.02 |

Appendix F

## Hammond Site

| | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 0.3 | 0.05 | 0.05 | 0.12 |
| 2 LB | 0.3 | 0.002 | 0.05 | 0.08 |
| 2 RB | 0.3 | 0.09 | 0.006 | 0.10 |

## Upper Daguerre Site

| | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 0.9 | 0.02 | 0.08 | 0.17 |
| 2 LB | 0.9 | 0.03 | 0.03 | 0.06 |
| 2 RB | 0.9 | 0.001 | 0.05 | 0.08 |

## Lower Daguerre Site

| | | Difference (measured vs. pred. WSELs) | | |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 0.5 | 0.01 | 0.03 | 0.07 |

Appendix F

## Pyramids Site

|  |  | Difference (measured vs. pred. WSELs) |  |  |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 1 | 0.4 | 0.01 | 0.08 | 0.17 |
| 2 | 0.4 | 0.004 | 0.03 | 0.07 |

## Hallwood Site

|  |  | Difference (measured vs. pred. WSELs) |  |  |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 0.8 | 0.05 | 0.06 | 0.17 |
| 2 LB | 0.8 | 0.0002 | 0.03 | 0.06 |
| 2 RB | 0.8 | 0.05 | 0.03 | 0.10 |

## Plantz Site

|  |  | Difference (measured vs. pred. WSELs) |  |  |
|---|---|---|---|---|
| XSEC | Br Multiplier | Average | Standard Deviation | Maximum |
| 2 | 0.3 | 0.04 | 0.04 | 0.11 |
| 2 LB | 0.3 | 0.03 | 0.03 | 0.09 |
| 2 RB | 0.3 | 0.10 | 0 | 0.10 |

# APPENDIX G
# VELOCITY VALIDATION STATISTICS

| Site Name | Number of Observations | Correlation Between Measured and Simulated Velocities |
|---|---|---|
| UC Sierra | 323 | 0.64 |
| Timbuctoo | 763 | 0.79 |
| Highway 20 | 323 | 0.74 |
| Island | 579 | 0.70 |
| Hammond | 377 | 0.75 |
| Upper Daguerre | 173 | 0.64 |
| Lower Daguerre | 302 | 0.82 |
| Pyramids | 288 | 0.71 |
| Hallwood | 316 | 0.78 |
| Plantz | 242 | 0.79 |

Measured Velocities less than 3 ft/s

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

| Site Name | Number of Observations | Average | Standard Deviation | Maximum |
|---|---|---|---|---|
| UC Sierra | 186 | 0.95 | 1.00 | 4.61 |
| Timbuctoo | 432 | 0.77 | 0.76 | 4.95 |
| Highway 20 | 135 | 0.73 | 0.60 | 3.75 |
| Island | 270 | 0.96 | 0.92 | 7.84 |
| Hammond | 227 | 0.70 | 0.82 | 5.44 |
| Upper Daguerre | 99 | 0.96 | 0.74 | 3.40 |
| Lower Daguerre | 125 | 1.09 | 0.81 | 4.24 |
| Pyramids | 183 | 1.14 | 0.93 | 3.45 |
| Hallwood | 129 | 0.91 | 0.80 | 3.70 |
| Plantz | 143 | 0.68 | 0.71 | 3.64 |

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

Appendix G

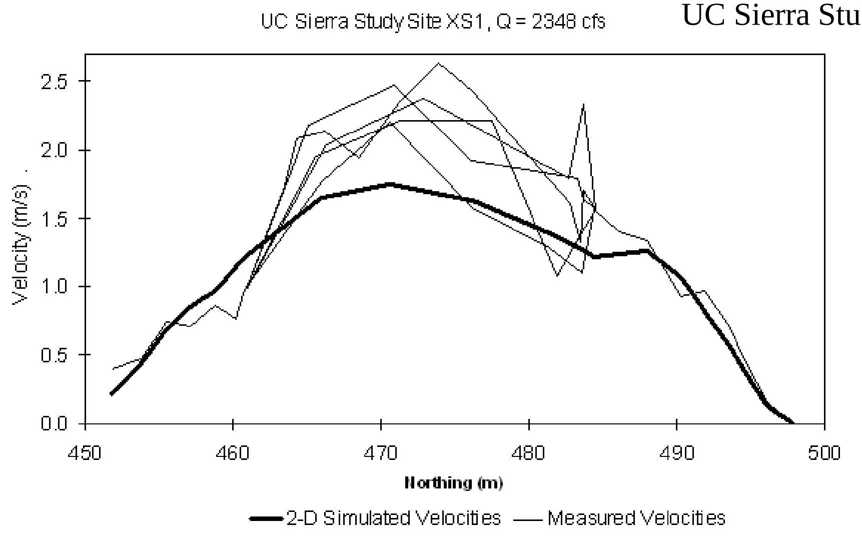
## Measured Velocities greater than 3 ft/s

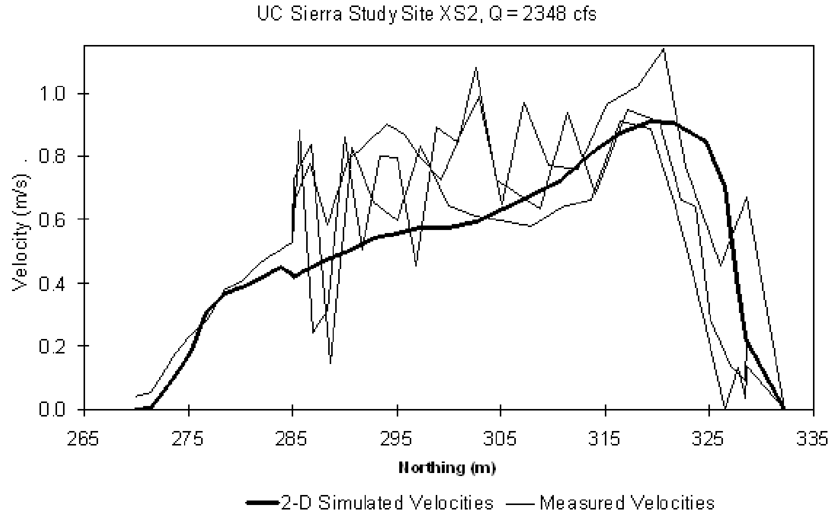
Percent difference (measured vs. pred. velocities)

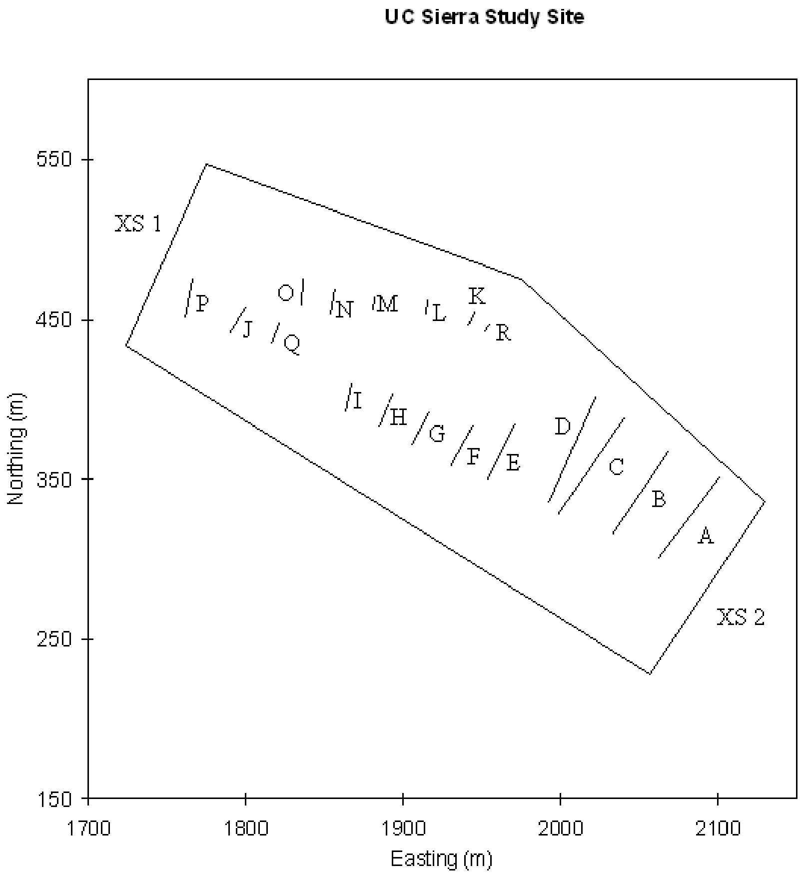
| Site Name | Number of Observations | Average | Standard Deviation | Maximum |
|---|---|---|---|---|
| UC Sierra | 137 | 32% | 21% | 97% |
| Timbuctoo | 331 | 23% | 20% | 154% |
| Highway 20 | 188 | 23% | 19% | 100% |
| Island | 309 | 27% | 16% | 98% |
| Hammond | 150 | 24% | 24% | 125% |
| Upper Daguerre | 74 | 20% | 18% | 76% |
| Lower Daguerre | 177 | 15% | 13% | 59% |
| Pyramids | 105 | 23% | 21% | 97% |
| Hallwood | 187 | 20% | 14% | 70% |
| Plantz | 99 | 22% | 15% | 63% |

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

# UC Sierra Study Site

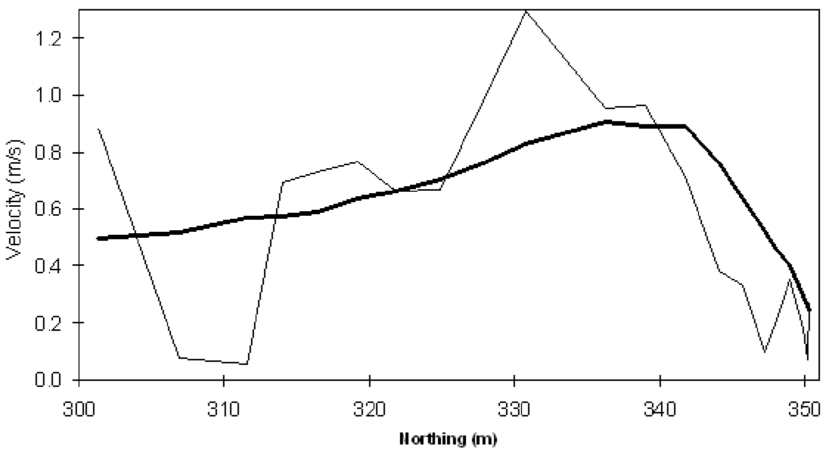




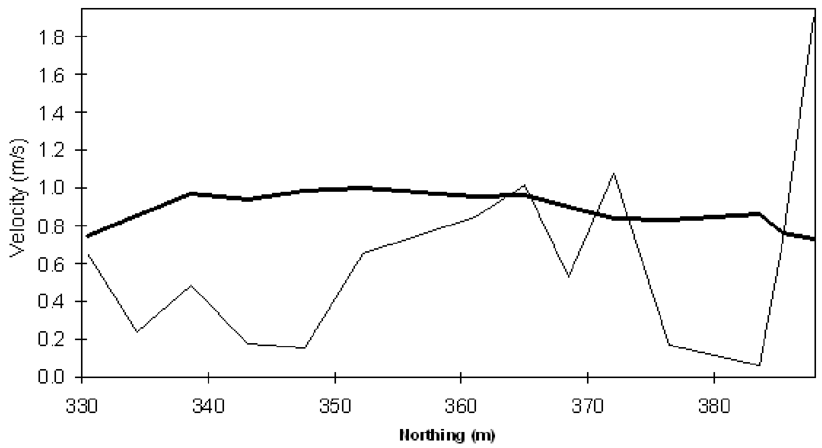


Appendix G

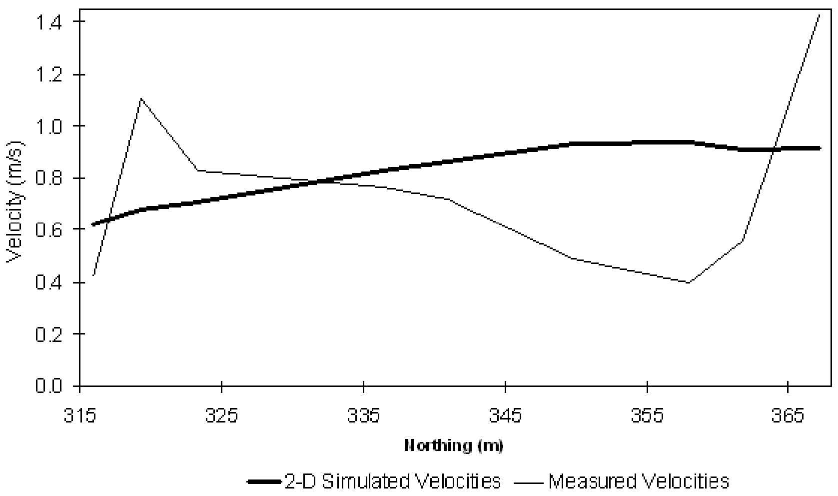
UC Sierra Study Deep Beds A, Q = 2124 cfs



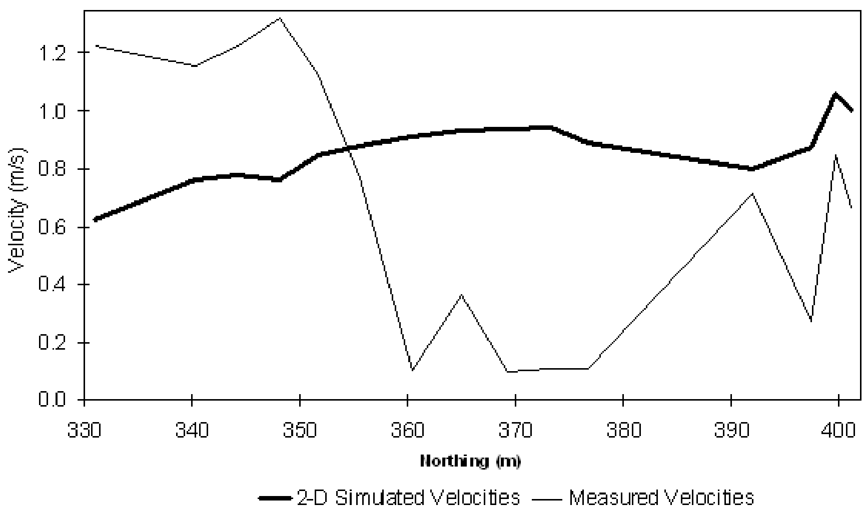
UC Sierra Study Deep Beds C, Q = 2124 cfs



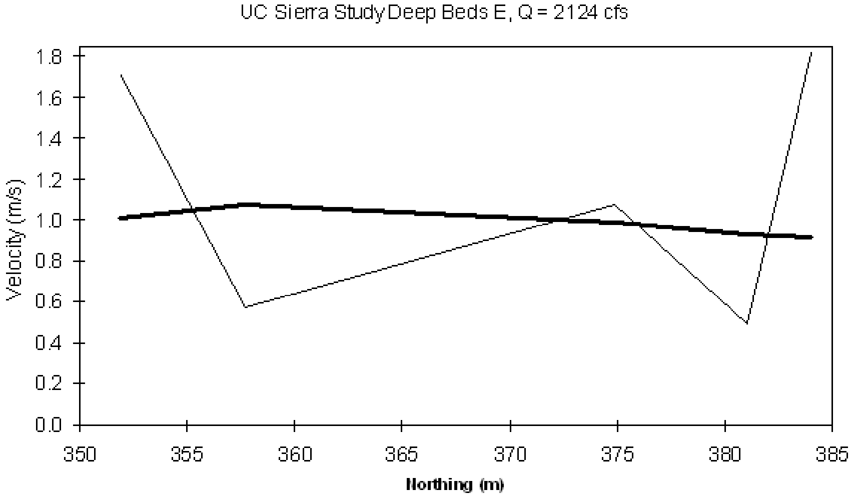
UC Sierra Study Deep Beds B, Q = 2124 cfs

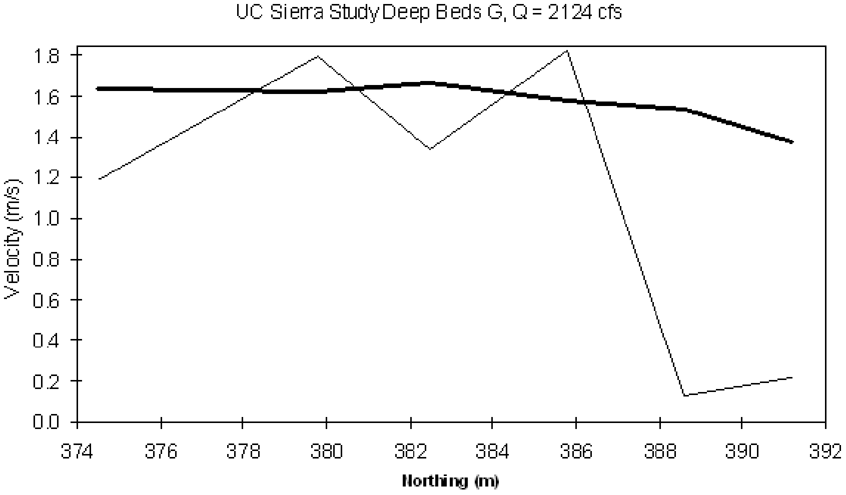


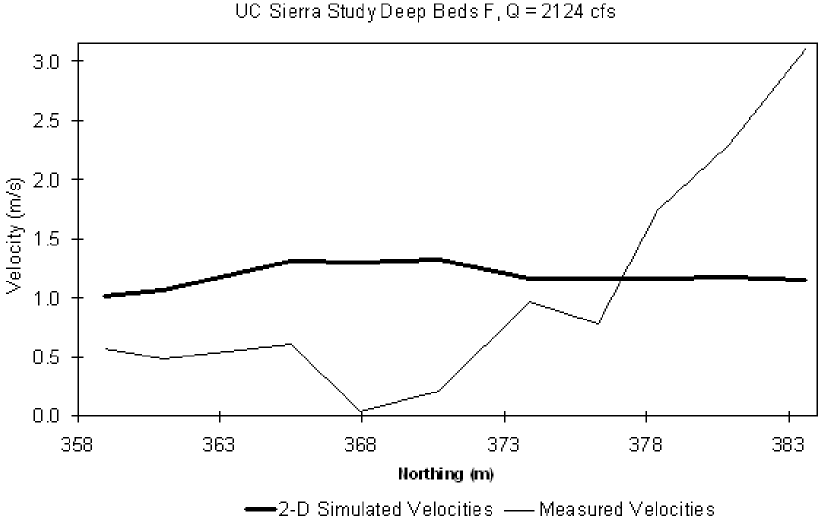
UC Sierra Study Deep Beds D, Q = 2124 cfs

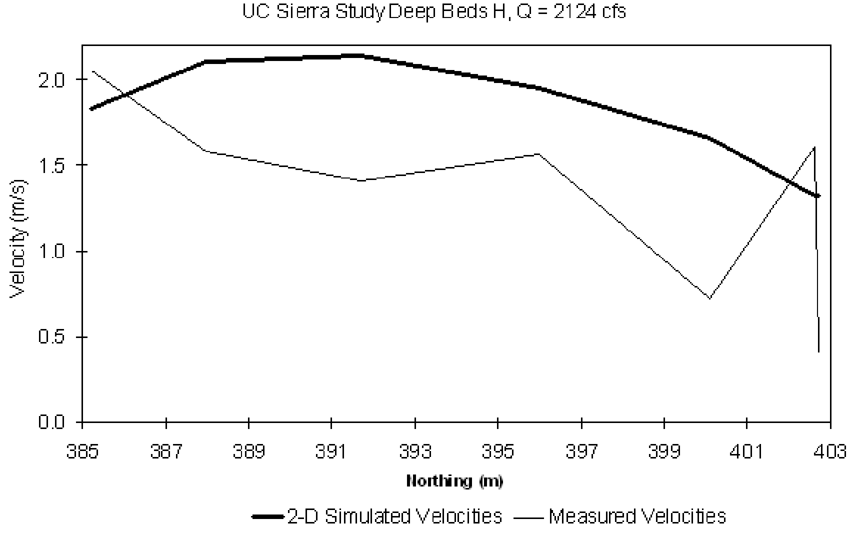


# Appendix G

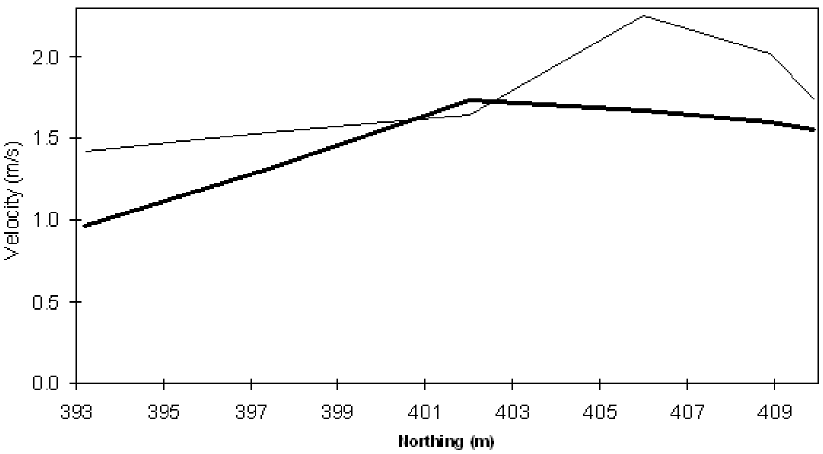

UC Sierra Study Deep Beds E, Q = 2124 cfs
Velocity (m/s)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
350
355
360
365
370
375
380
385
Northing (m)


UC Sierra Study Deep Beds G, Q = 2124 cfs
Velocity (m/s)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
374
376
378
380
382
384
386
388
390
392
Northing (m)


UC Sierra Study Deep Beds F, Q = 2124 cfs
Velocity (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
358
363
368
373
378
383
Northing (m)
2-D Simulated Velocities
Measured Velocities


UC Sierra Study Deep Beds H, Q = 2124 cfs
Velocity (m/s)
2.0
1.5
1.0
0.5
0.0
385
387
389
391
393
395
397
399
401
403
Northing (m)
2-D Simulated Velocities
Measured Velocities

Appendix G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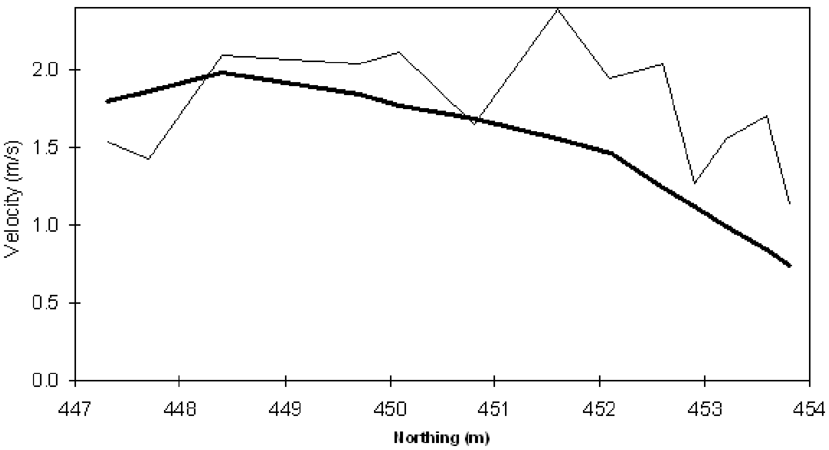
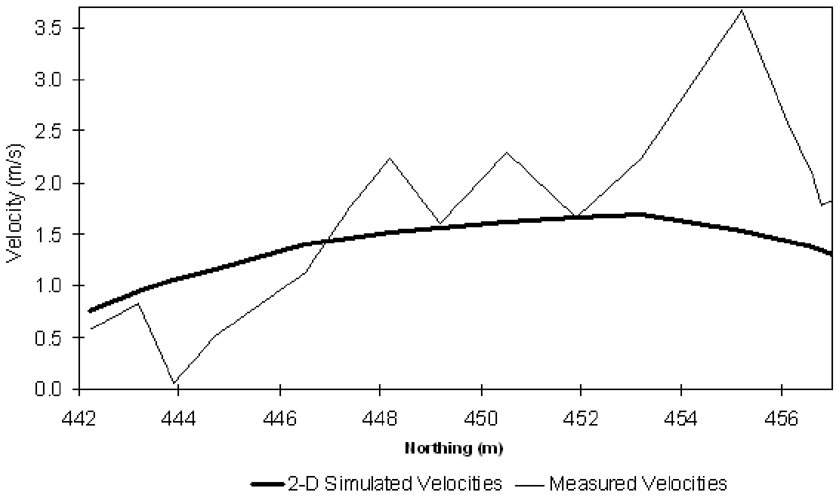
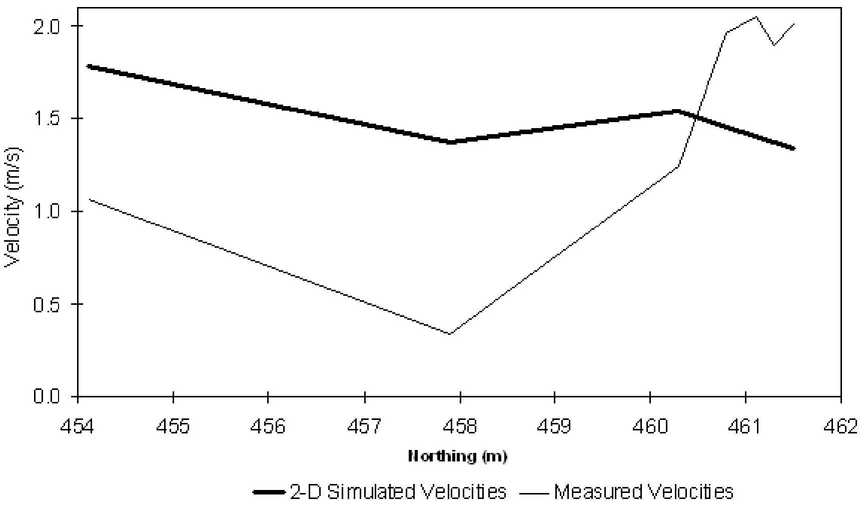
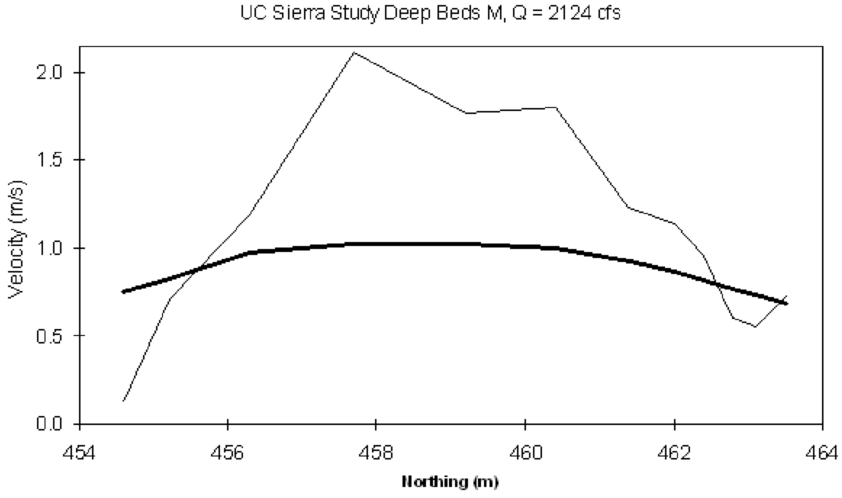
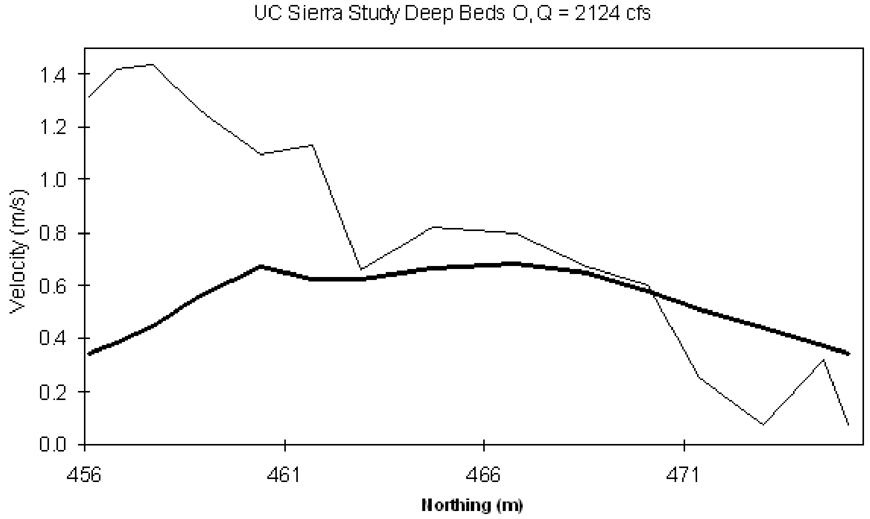

UC Sierra Study Deep Beds K, Q = 2124 cfs

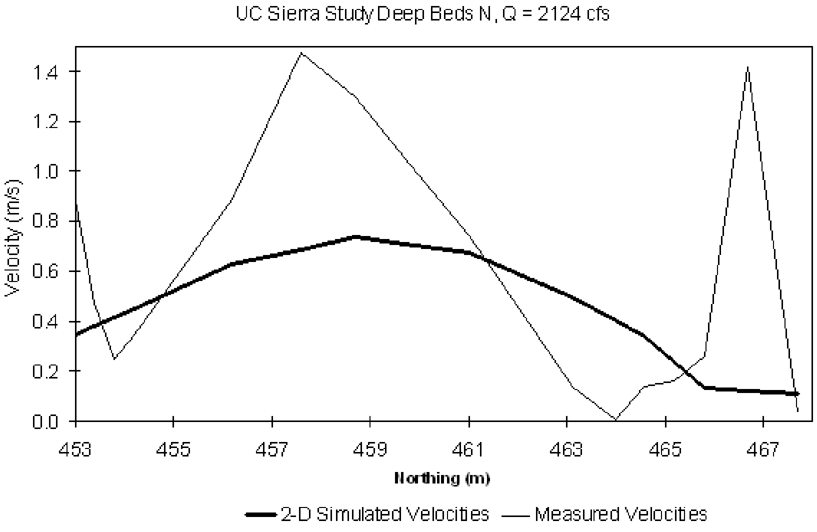

UC Sierra Study Deep Beds J, Q = 2124 cfs

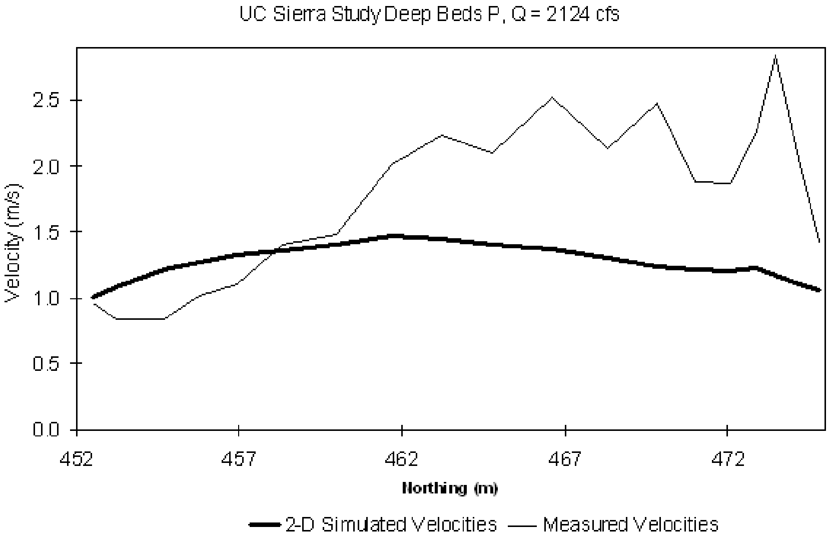

UC Sierra Study Deep Beds L, Q = 2124 cfs

# Appendix G

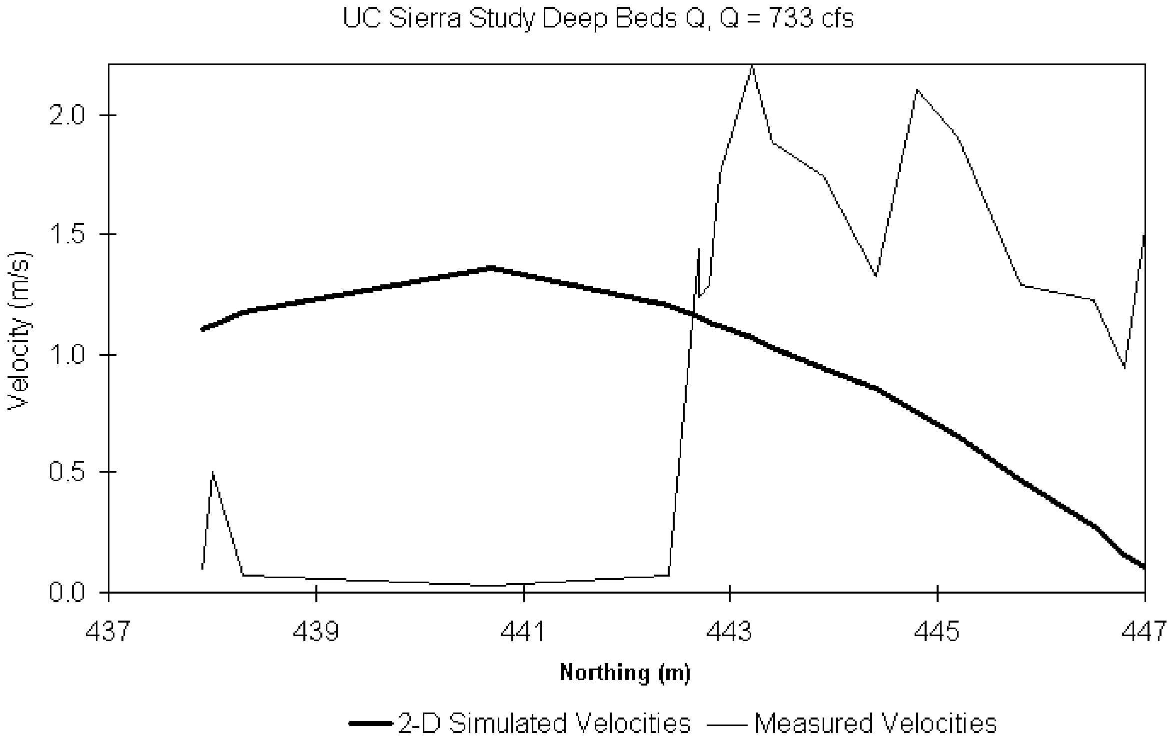

UC Sierra Study Deep Beds M, Q = 2124 cfs

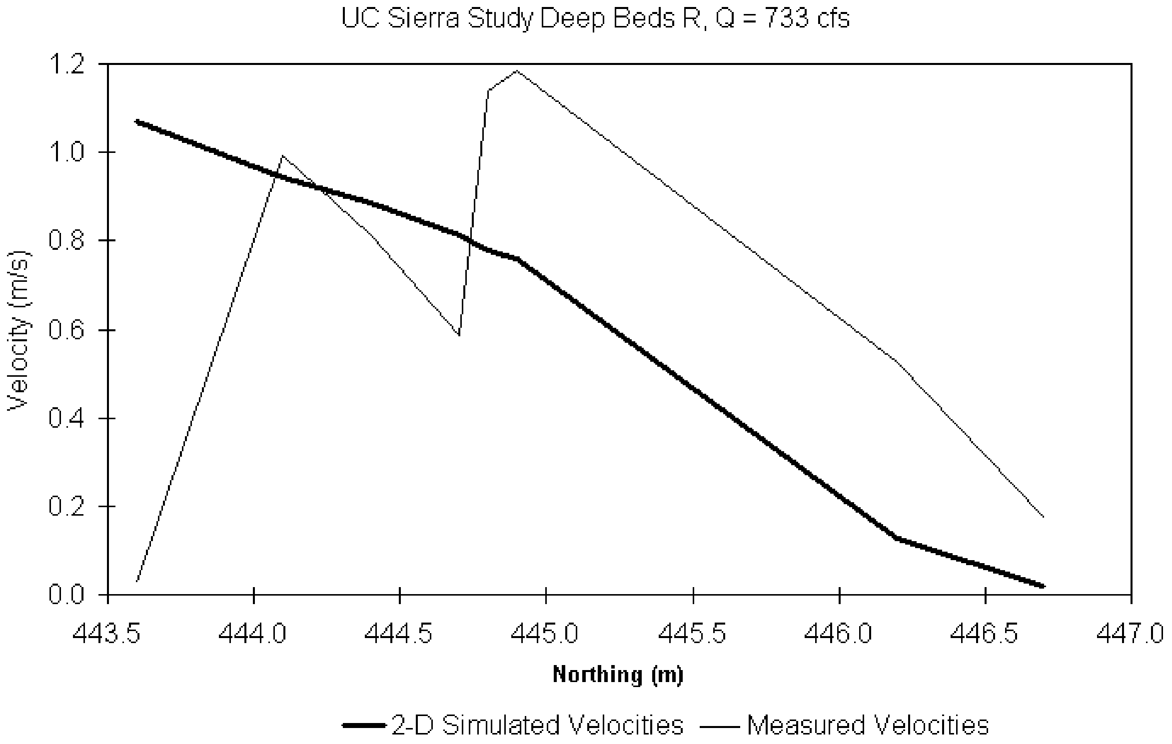

UC Sierra Study Deep Beds O, Q = 2124 cfs

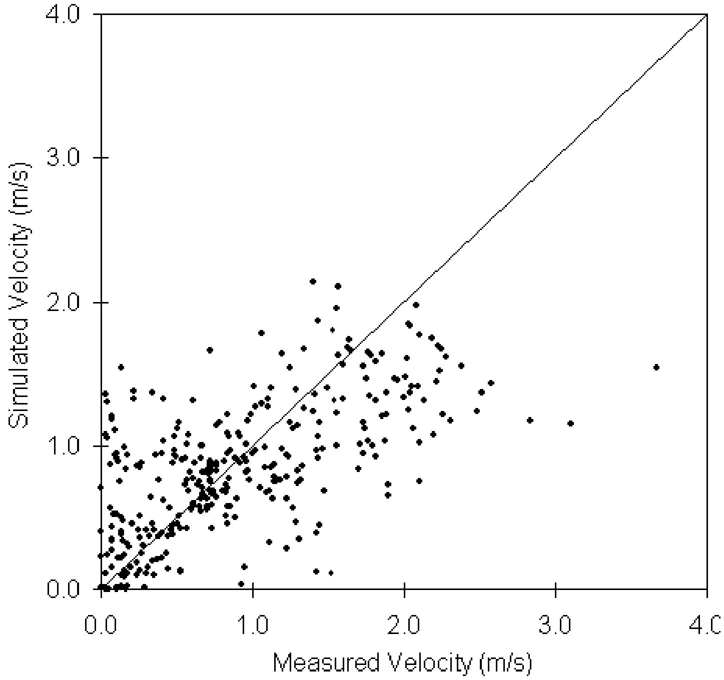

UC Sierra Study Deep Beds N, Q = 2124 cfs


UC Sierra Study Deep Beds P, Q = 2124 cfs

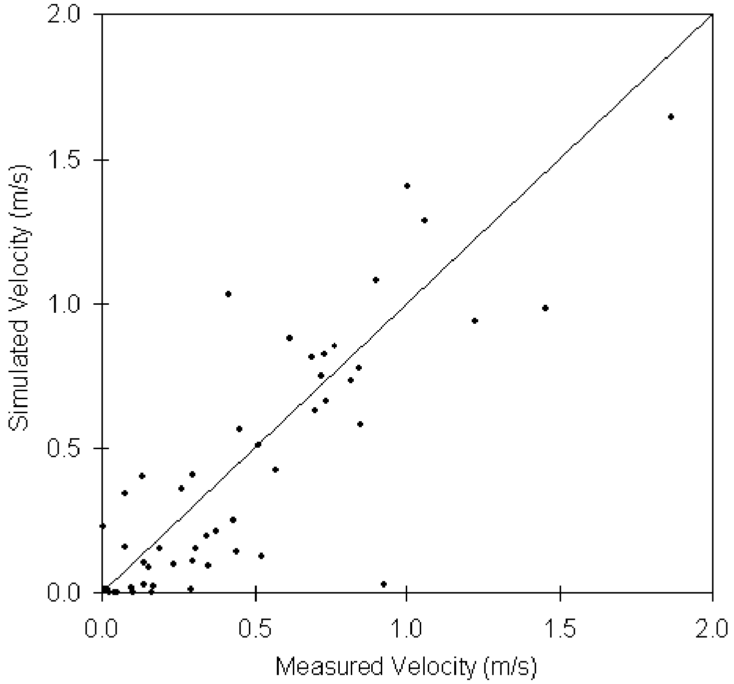
Appendix G


UC Sierra Study Deep Beds Q, Q = 733 cfs
Velocity (m/s)
2.0
1.5
1.0
0.5
0.0
437
439
441
443
445
447
Northing (m)
2-D Simulated Velocities
Measured Velocities


UC Sierra Study Deep Beds R, Q = 733 cfs
Velocity (m/s)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
443.5
444.0
444.5
445.0
445.5
446.0
446.5
447.0
Northing (m)
2-D Simulated Velocities
Measured Velocities



UC Sierra Study Site
All Validation Velocities

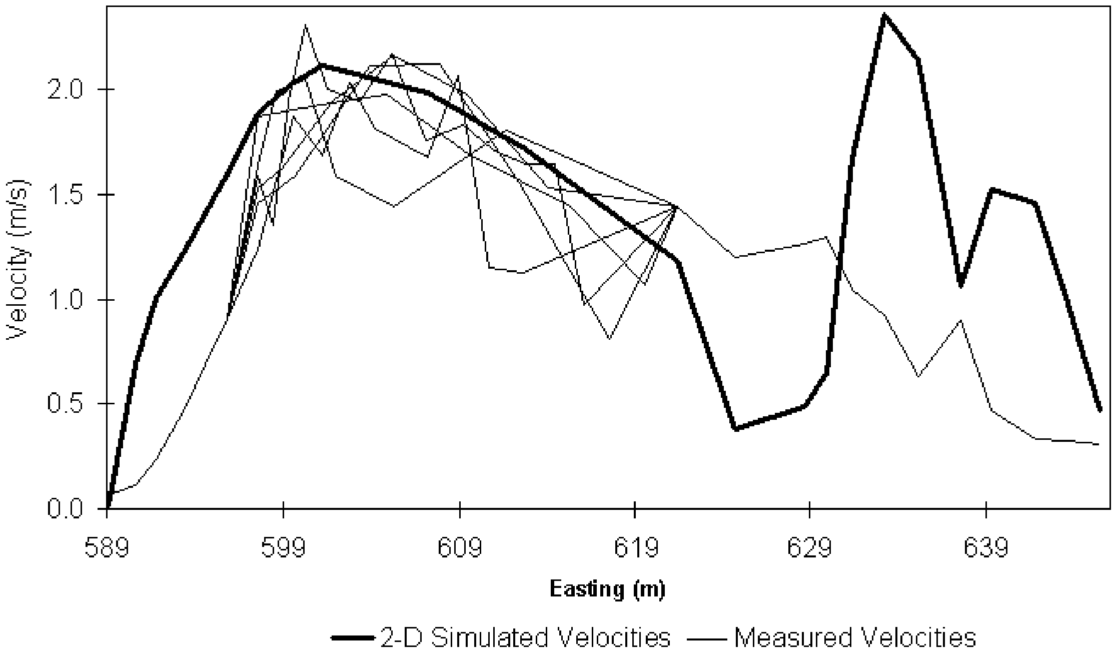


UC Sierra Study Site
Between Transect Non-ADCP Velocities

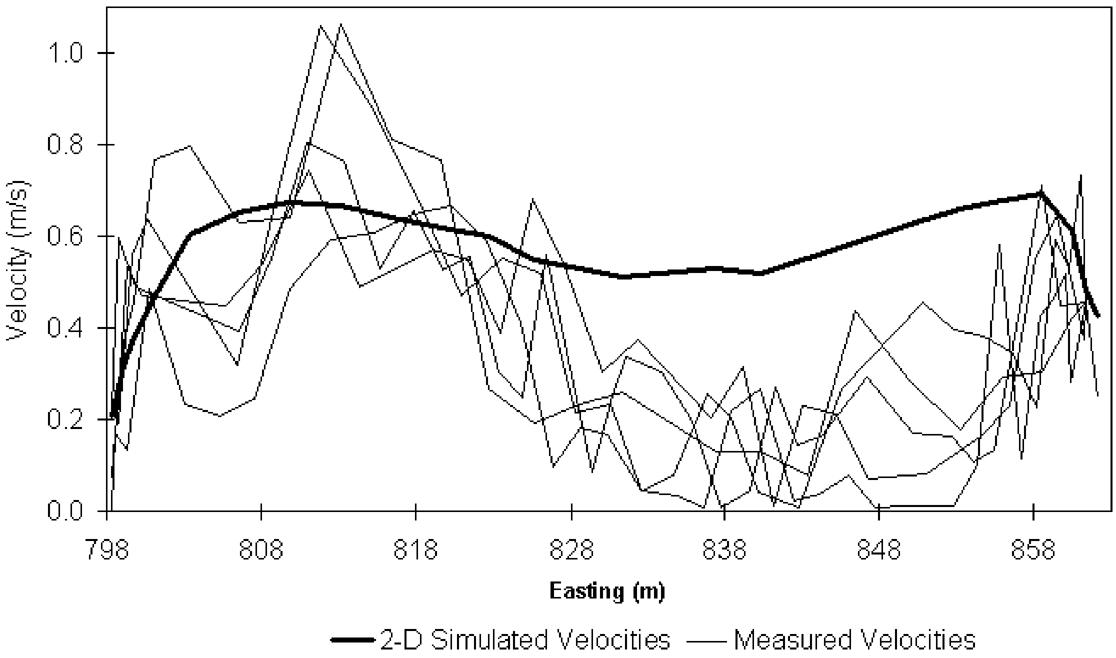
Appendix G

## Timbuctoo Study Site

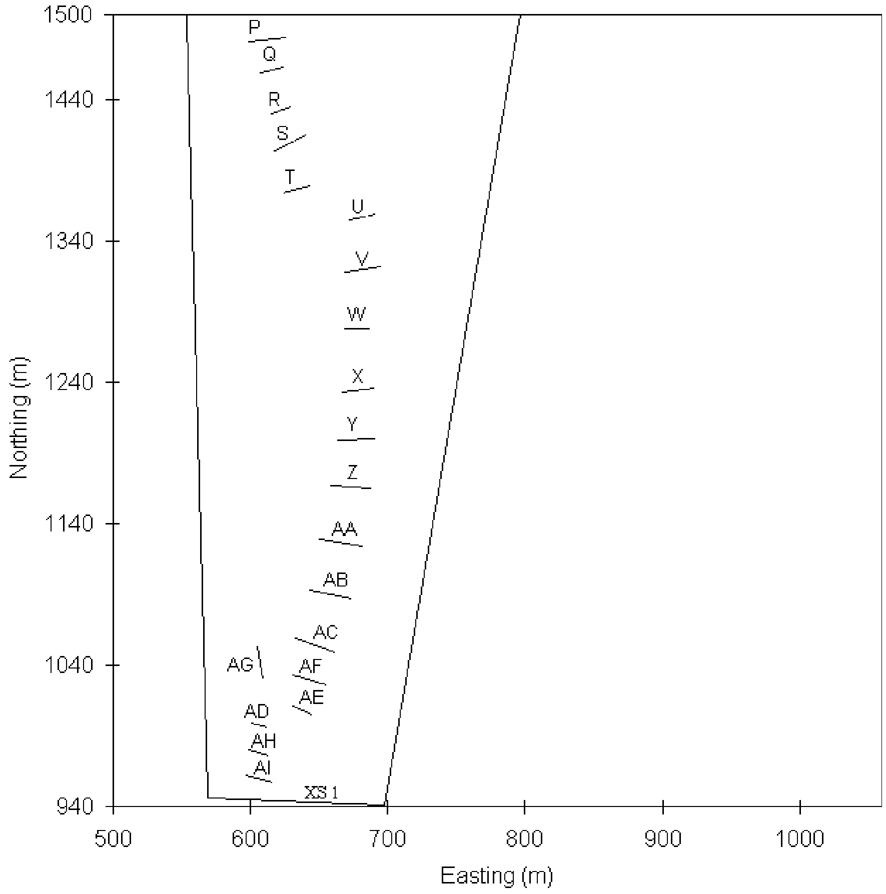
Timbuctoo Study Site XS1, Q = 2348 cfs

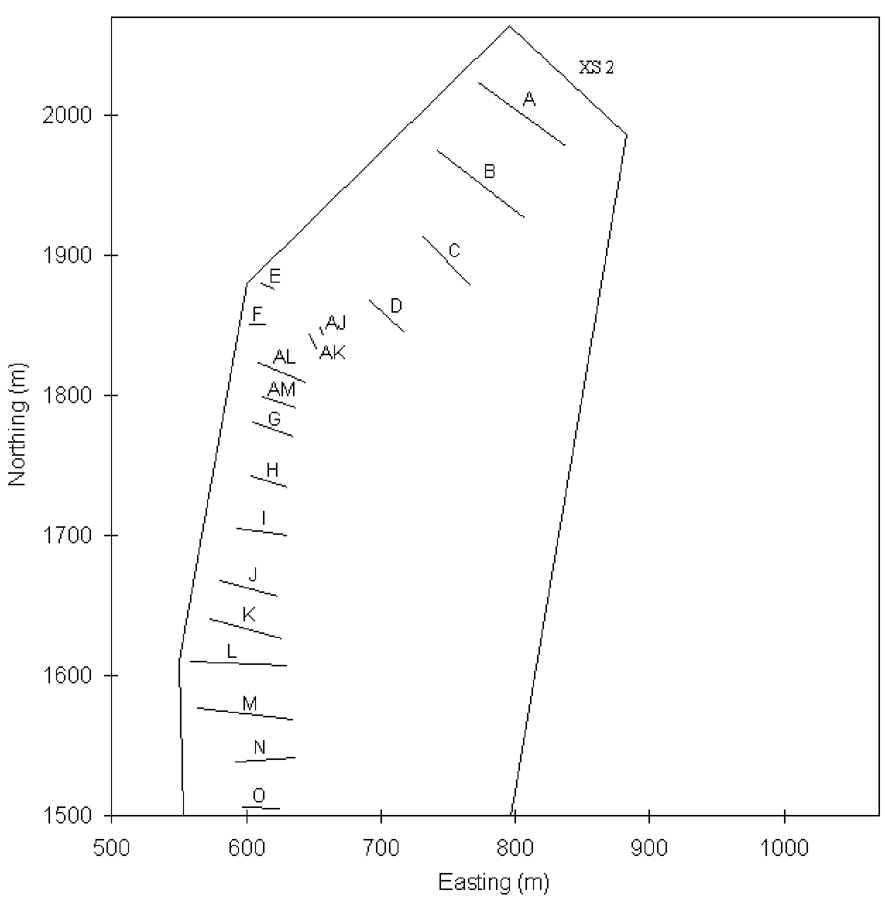


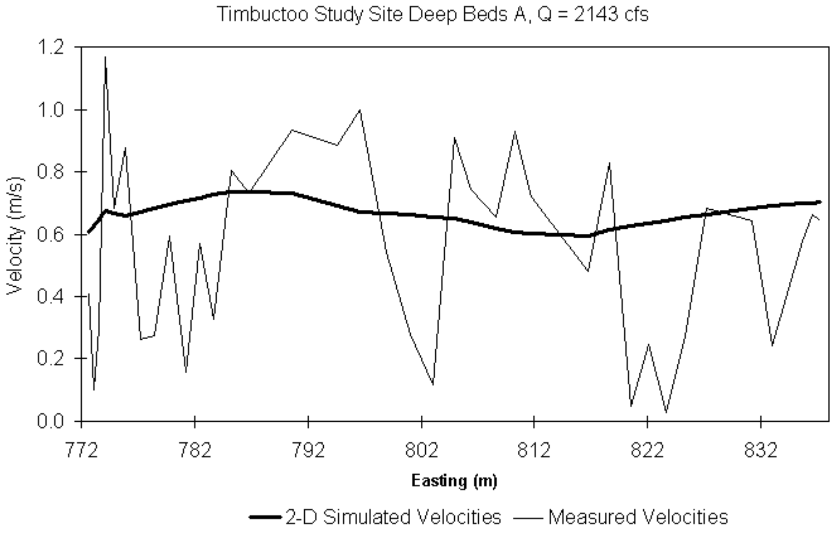
Timbuctoo Study Site XS2, Q = 2348 cfs

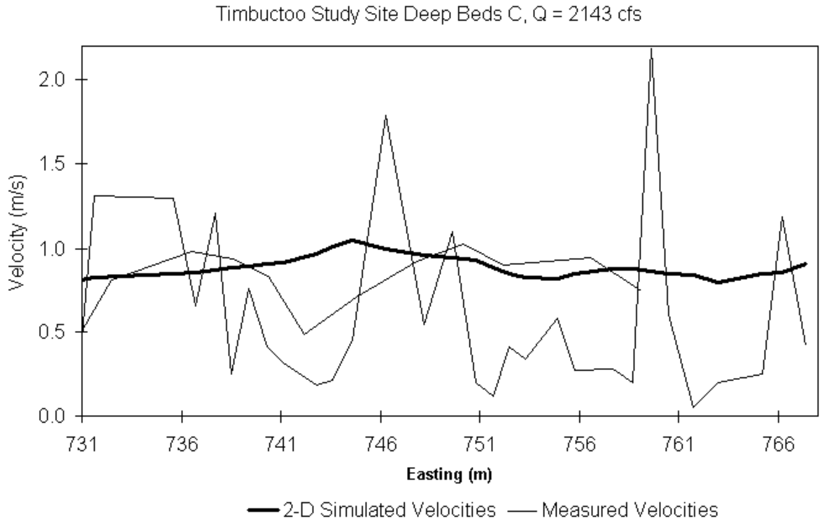


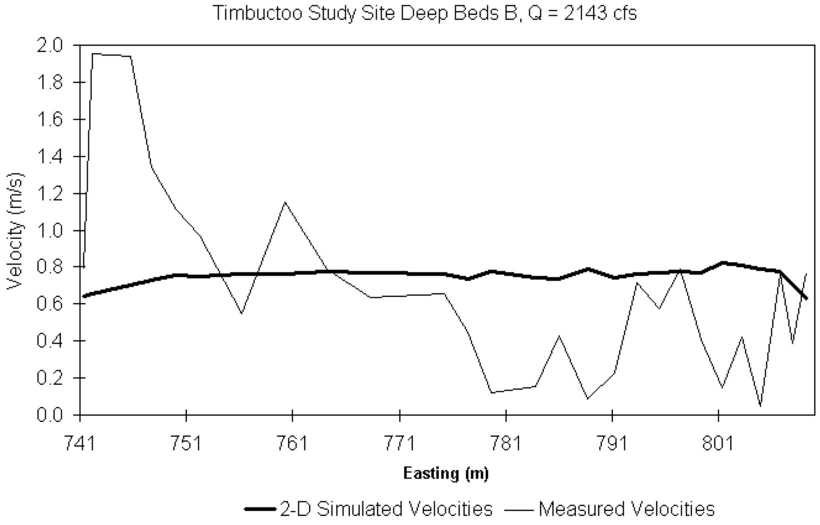
Appendix G


Timbuctoo Study Site


Timbuctoo Study Site


Timbuctoo Study Site Deep Beds A, Q = 2143 cfs


Timbuctoo Study Site Deep Beds C, Q = 2143 cfs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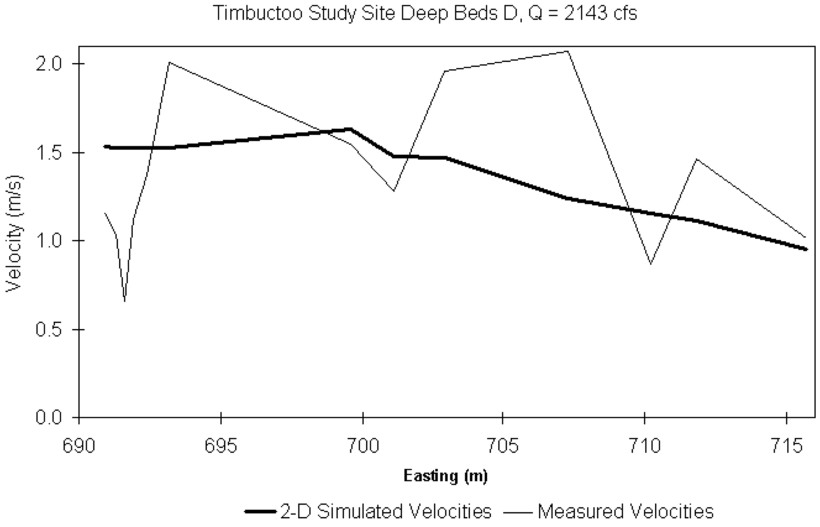
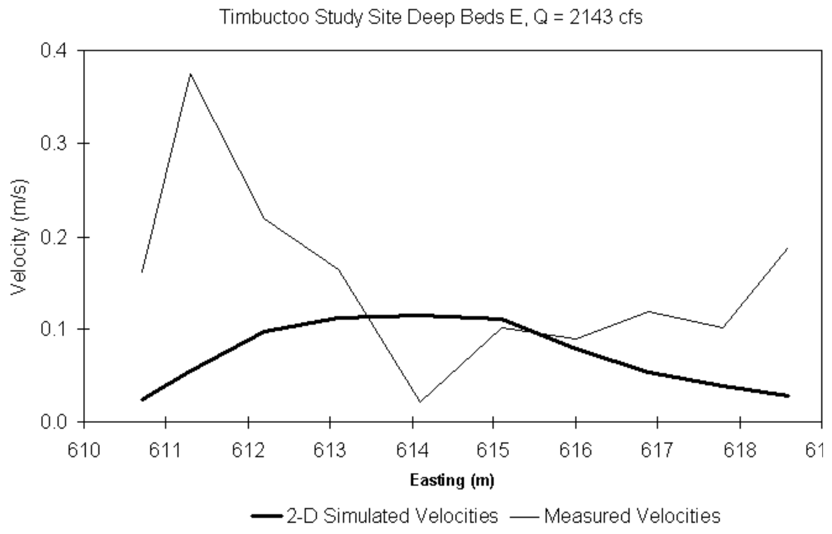

Timbuctoo Study Site Deep Beds D, Q = 2143 cfs

Appendix G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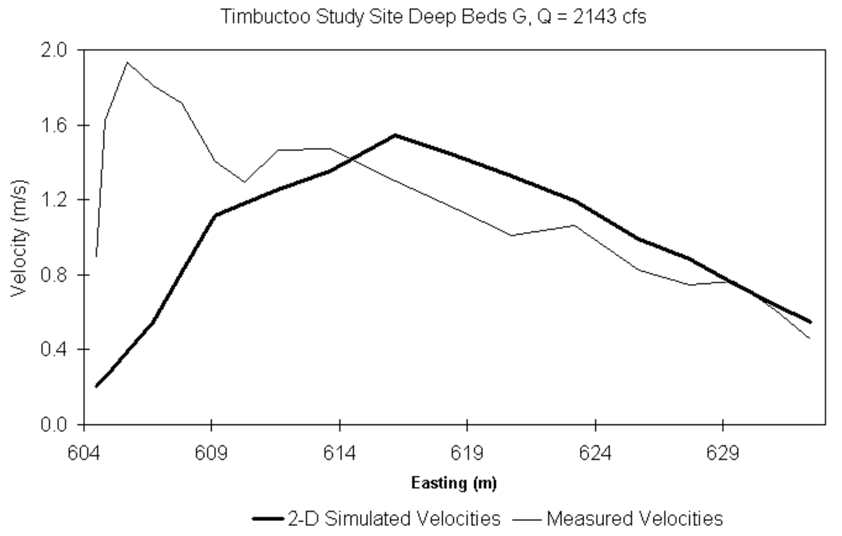
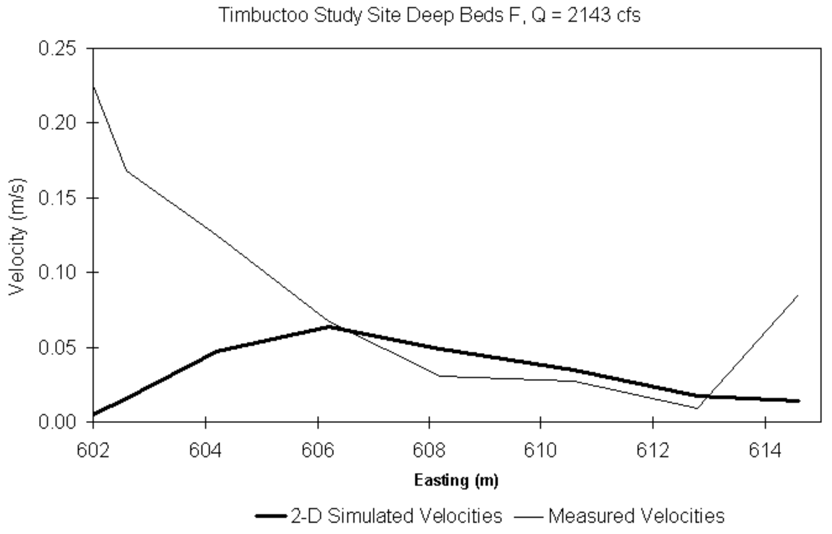
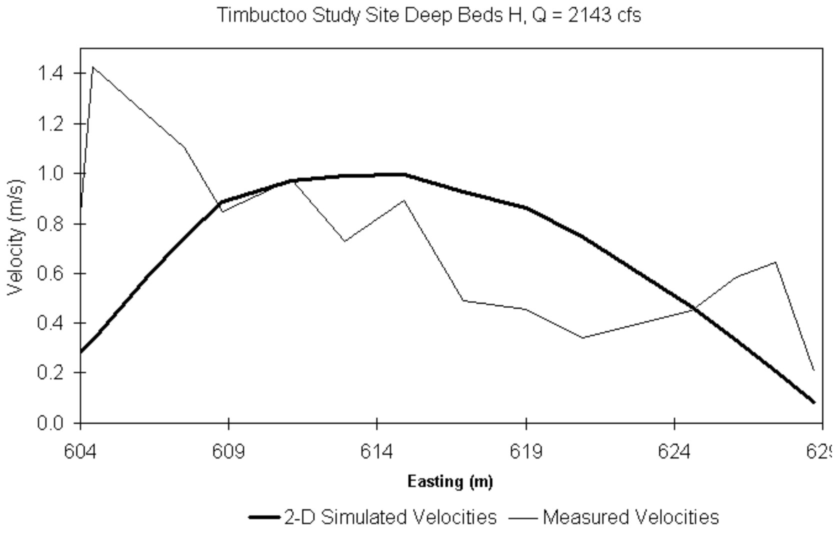
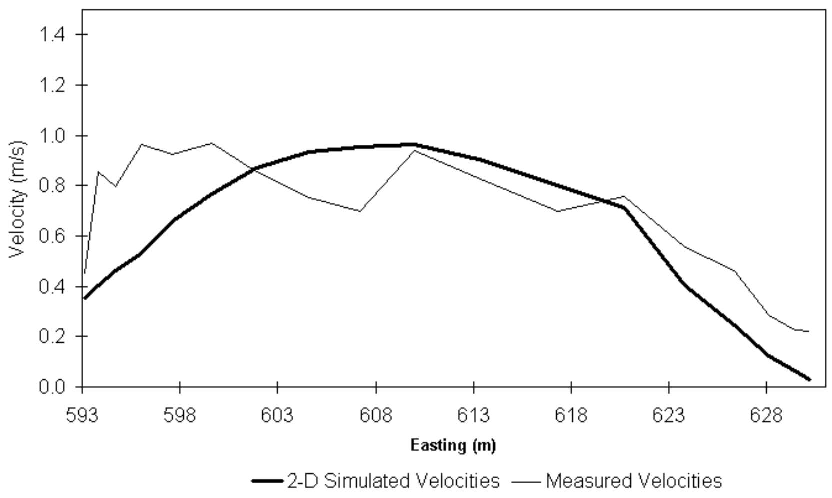

Timbuctoo Study Site Deep Beds G, Q = 2143 cfs

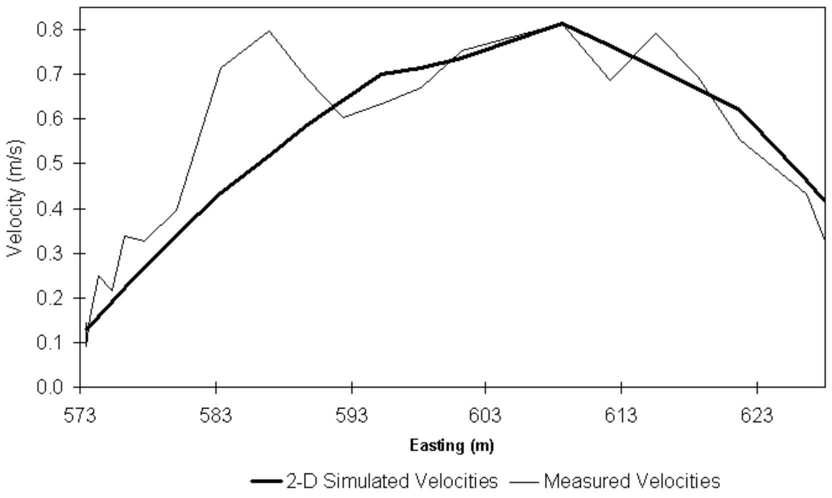

Timbuctoo Study Site Deep Beds F, Q = 2143 cfs


Timbuctoo Study Site Deep Beds H, Q = 2143 cfs

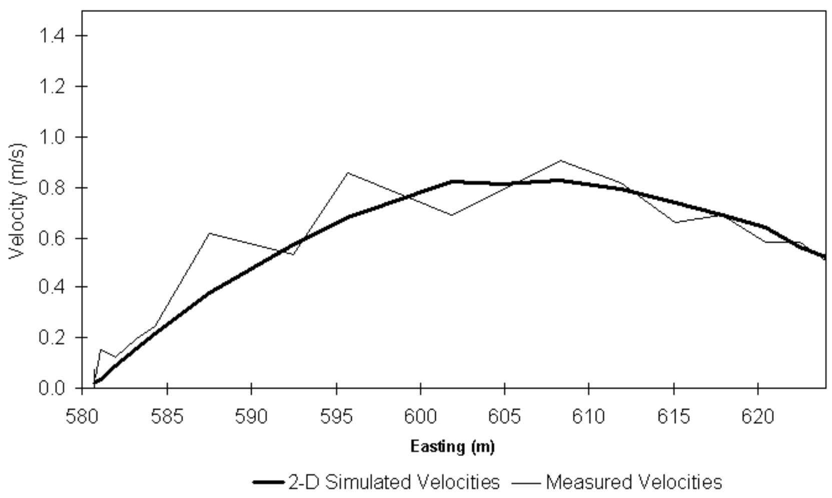
Timbuctoo Study Site Deep Beds I, Q = 2143 cfs



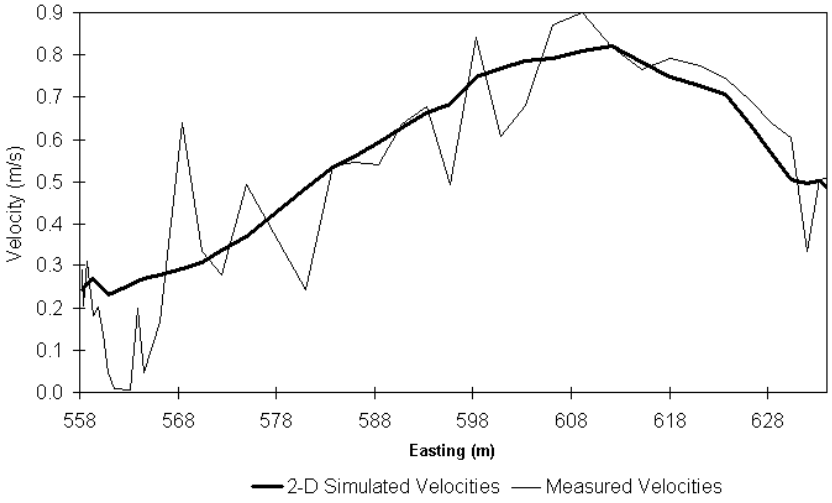
Timbuctoo Study Site Deep Beds K, Q = 2143 cfs



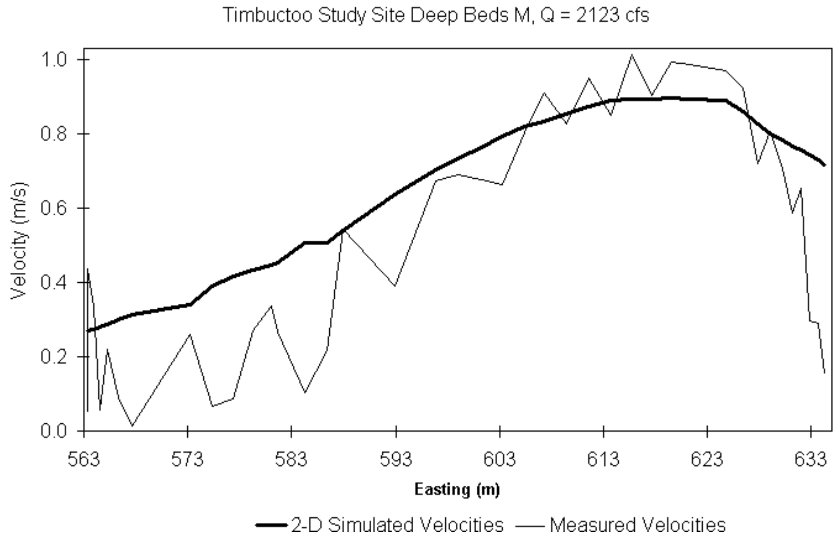
Timbuctoo Study Site Deep Beds J, Q = 2143 cfs

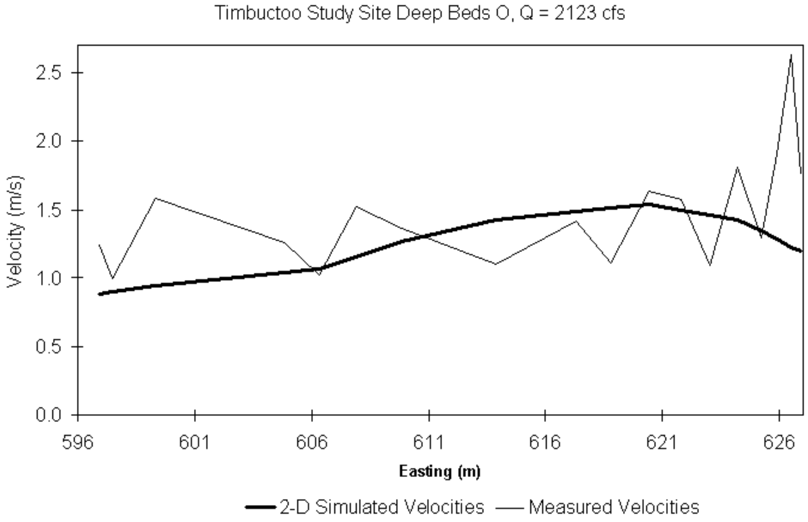


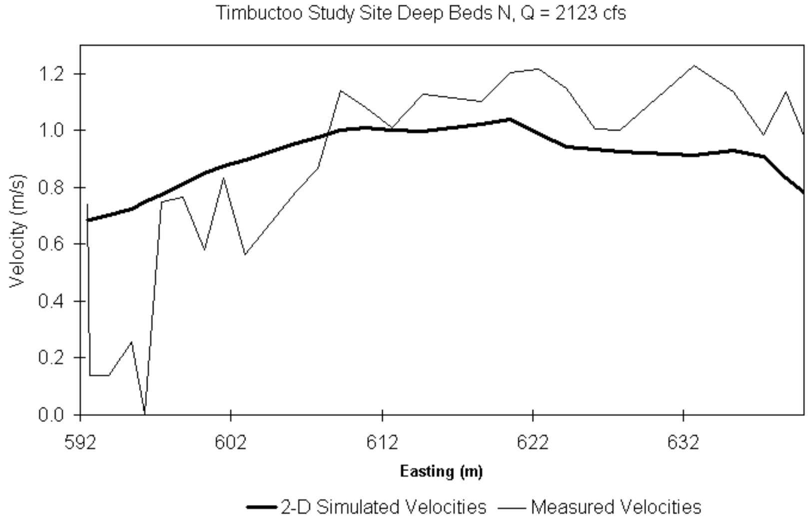
Timbuctoo Study Site Deep Beds L, Q = 2123 cfs

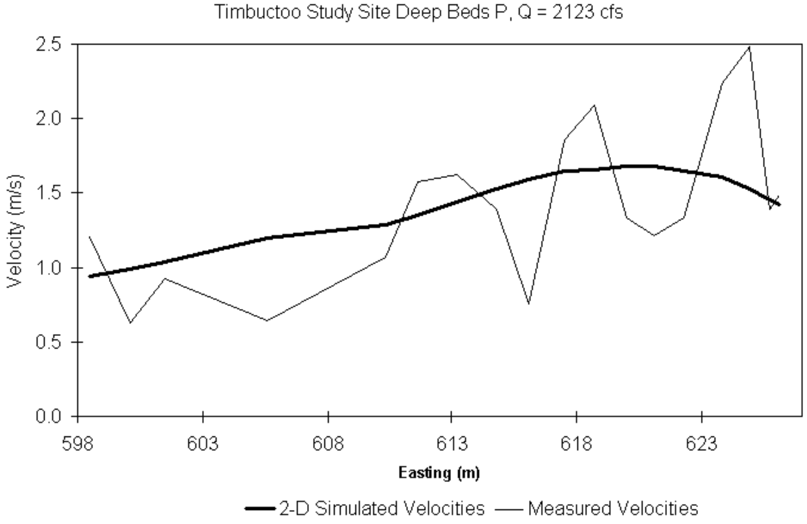


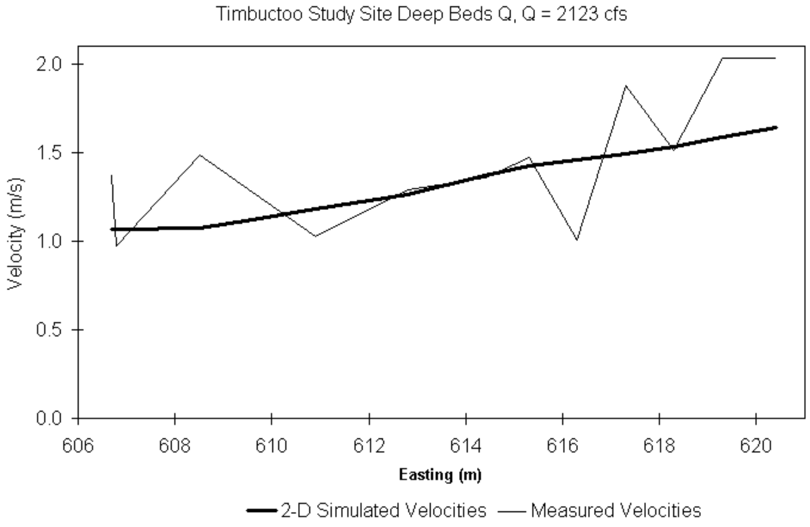
Appendix G


Timbuctoo Study Site Deep Beds M, Q = 2123 cfs
Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
563
573
583
593
603
613
623
633
Easting (m)
2-D Simulated Velocities
Measured Velocities


Timbuctoo Study Site Deep Beds O, Q = 2123 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
2.5
596
601
606
611
616
621
626
Easting (m)
2-D Simulated Velocities
Measured Velocities


Timbuctoo Study Site Deep Beds N, Q = 2123 cfs
Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
592
602
612
622
632
Easting (m)
2-D Simulated Velocities
Measured Velocities


Timbuctoo Study Site Deep Beds P, Q = 2123 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
2.5
598
603
608
613
618
623
Easting (m)
2-D Simulated Velocities
Measured Velocities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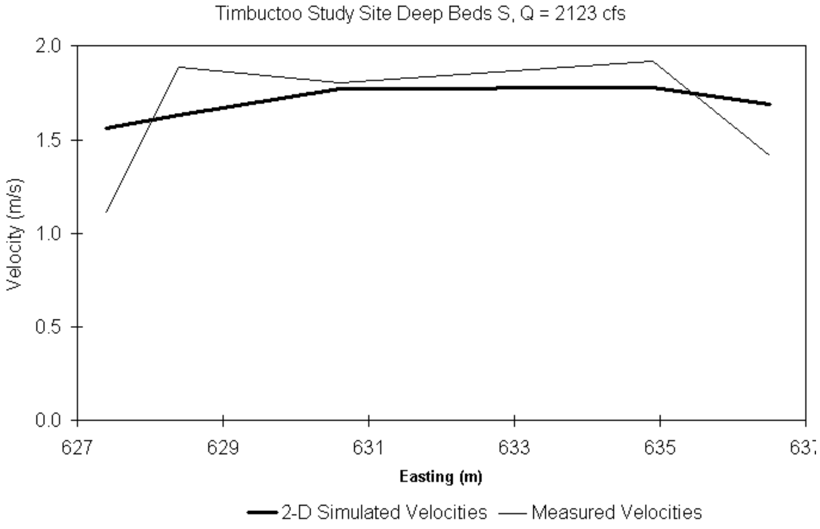
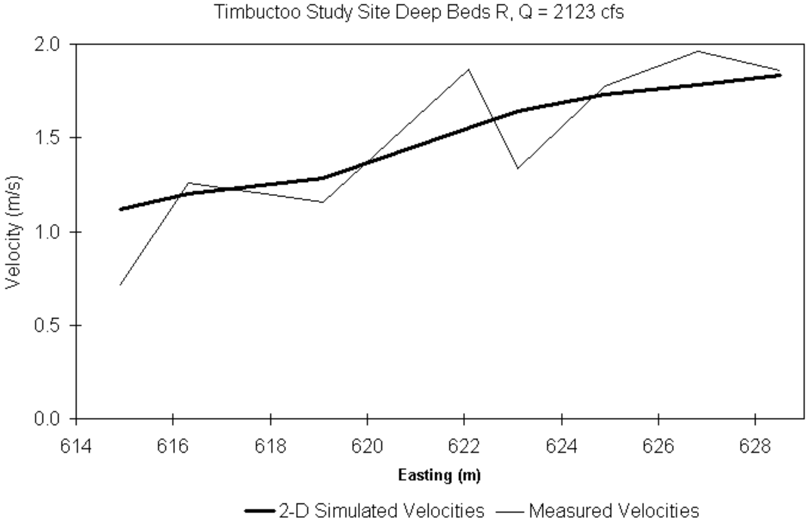
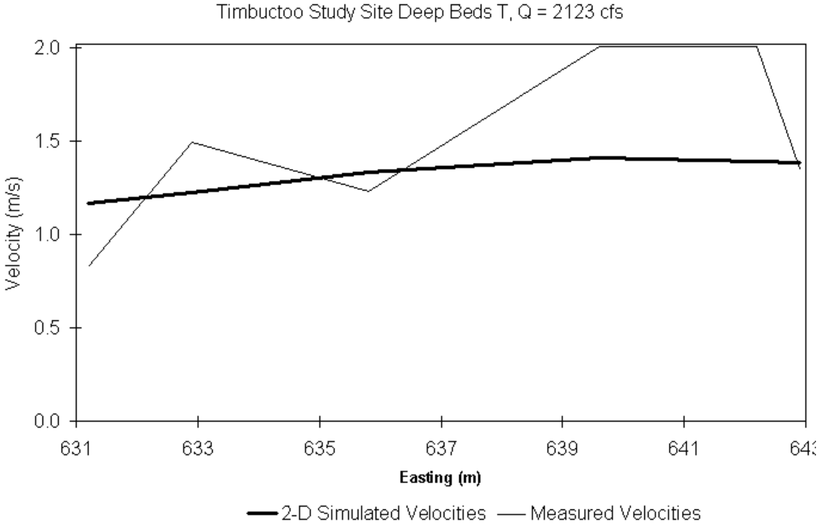
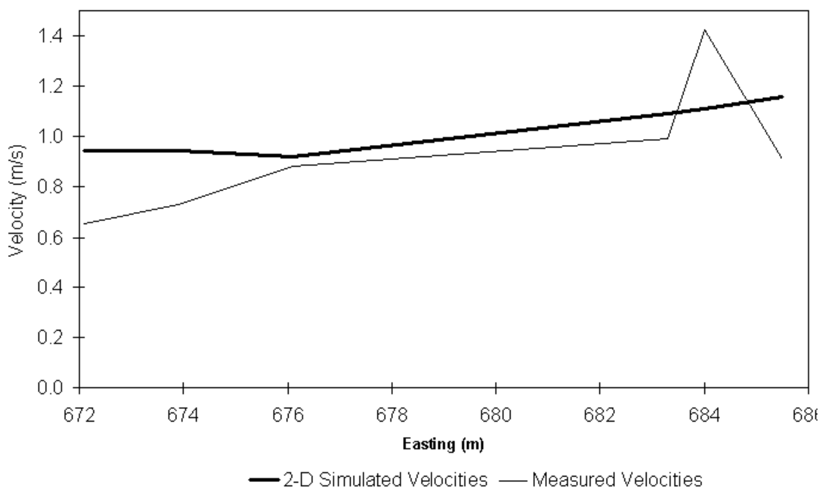
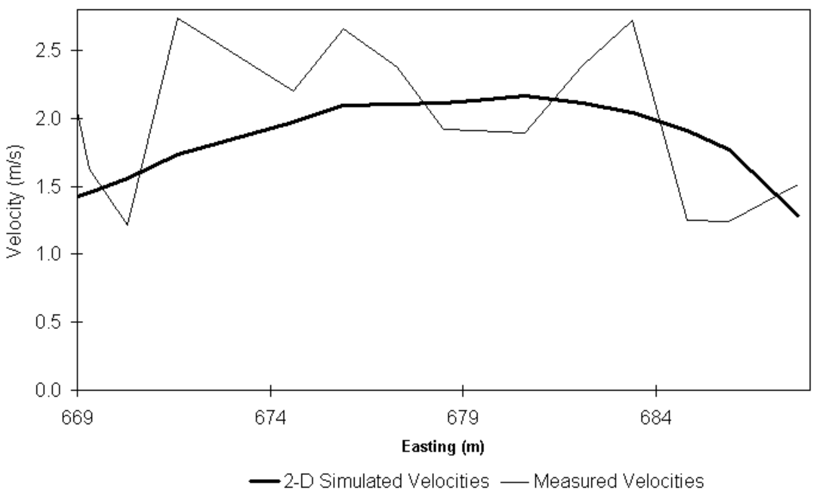

Timbuctoo Study Site Deep Beds S, Q = 2123 cfs

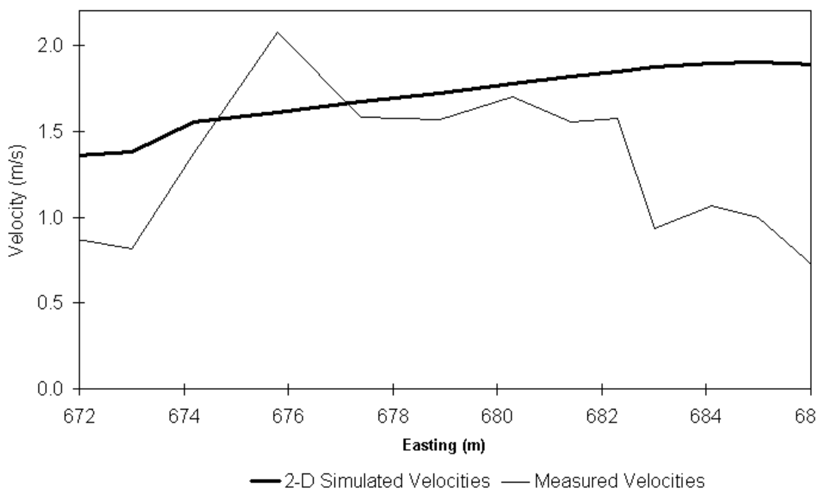

Timbuctoo Study Site Deep Beds R, Q = 2123 cfs

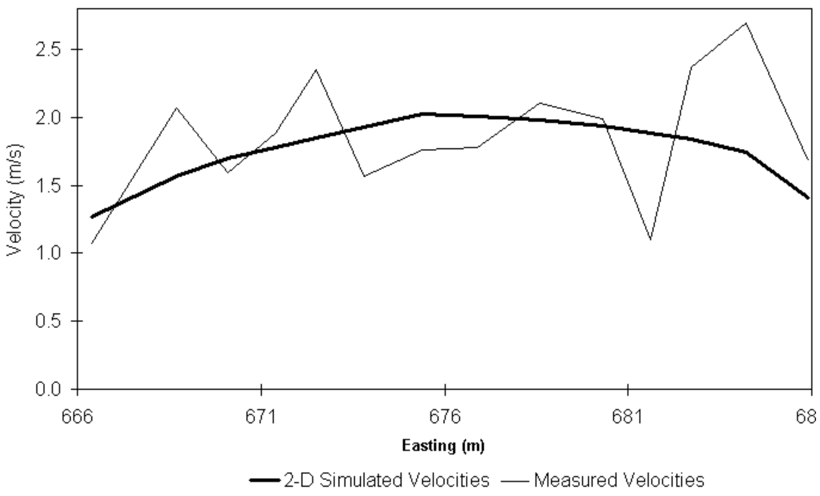

Timbuctoo Study Site Deep Beds T, Q = 2123 cfs

Appendix G

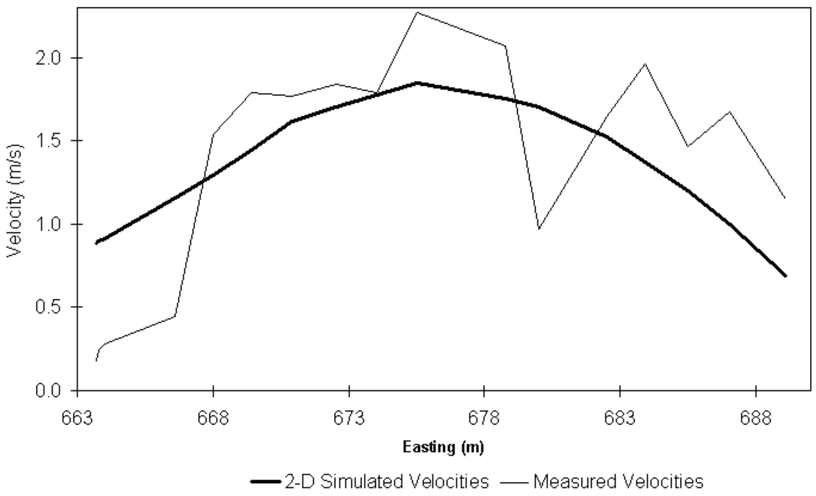

Timbuctoo Study Site Deep Beds U, Q = 2123 cfs

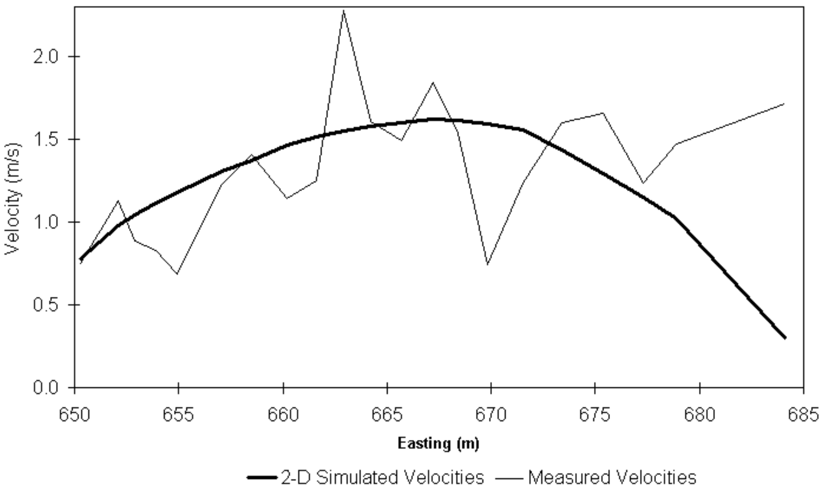

Timbuctoo Study Site Deep Beds W, Q = 2123 cfs

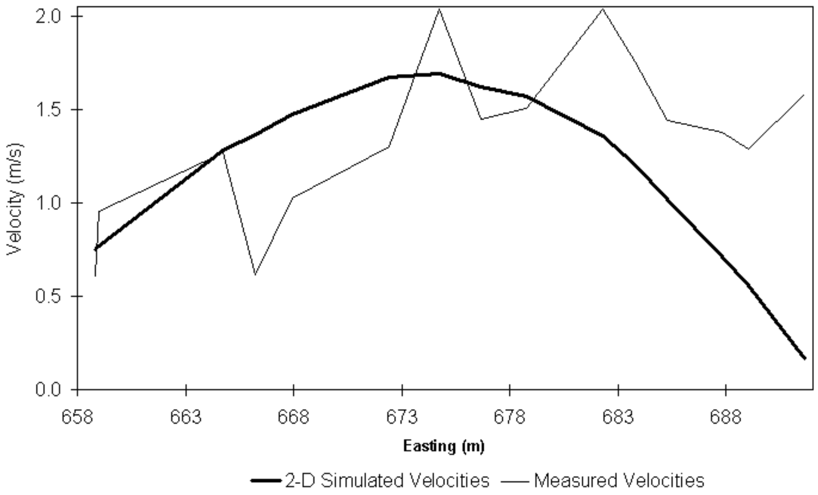

Timbuctoo Study Site Deep Beds V, Q = 2123 cfs


Timbuctoo Study Site Deep Beds X, Q = 2123 cfs

# Appendix G


Timbuctoo Study Site Deep Beds Y, Q = 2123 cfs


Timbuctoo Study Site Deep Beds AA, Q = 2123 cfs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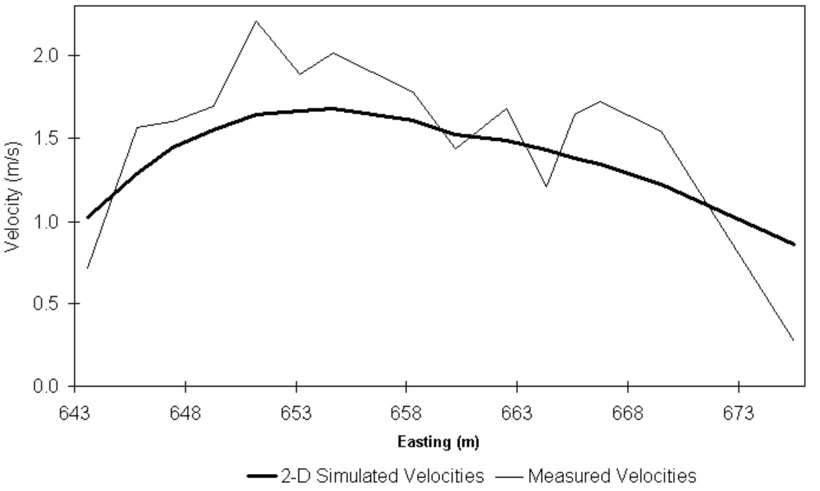
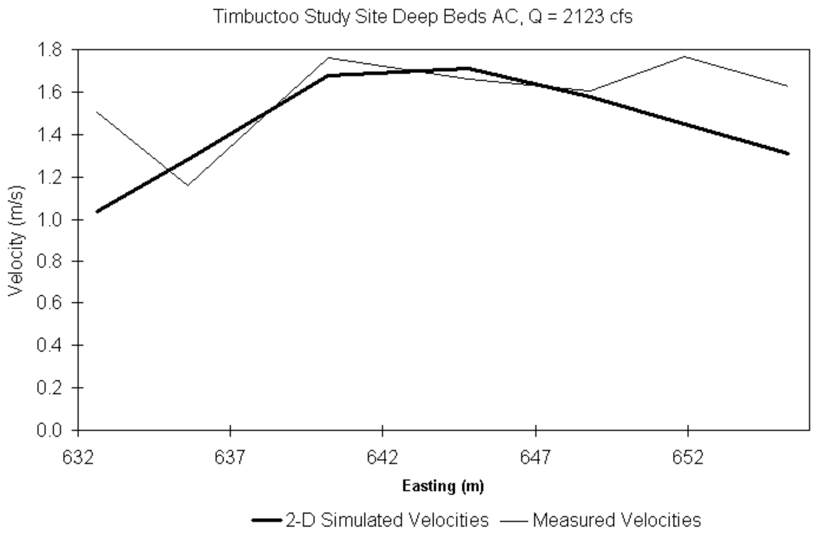
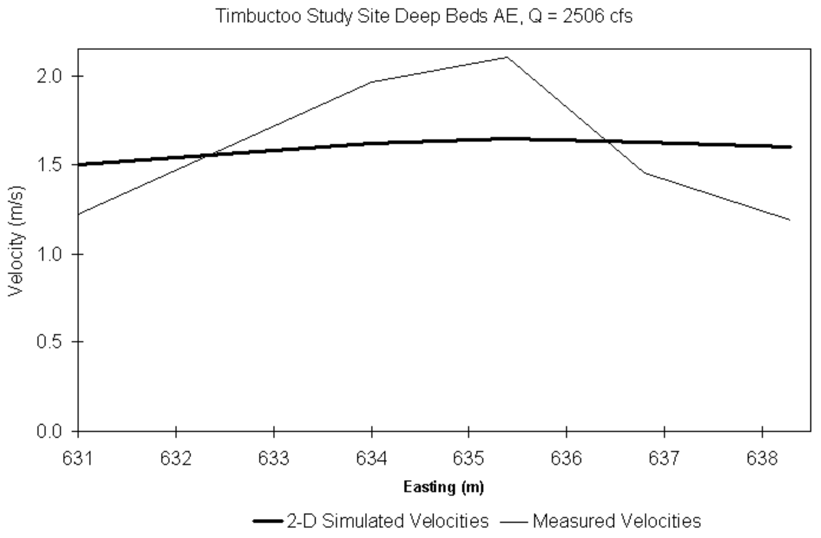
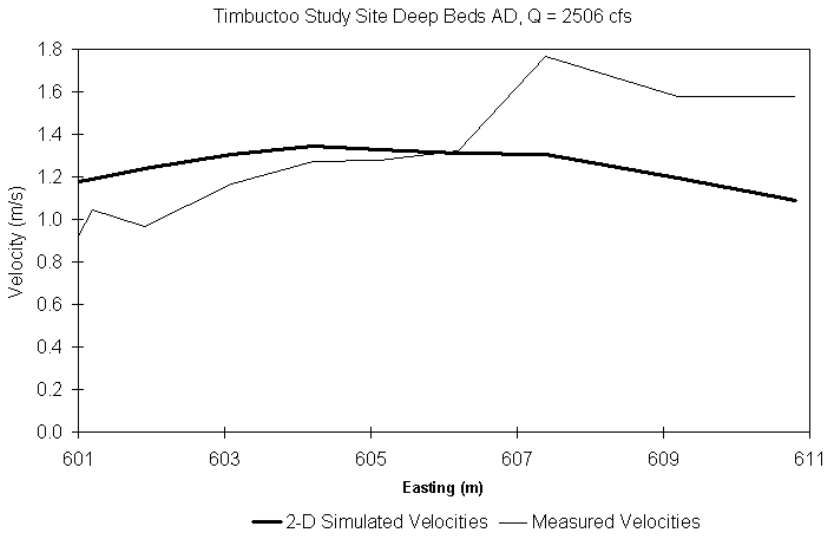
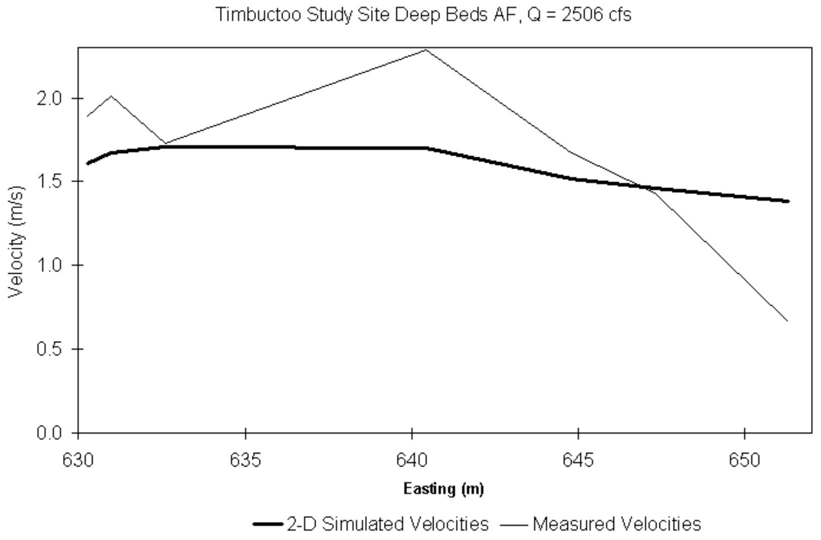

Timbuctoo Study Site Deep Beds AB, Q = 2123 cfs

## Appendix G

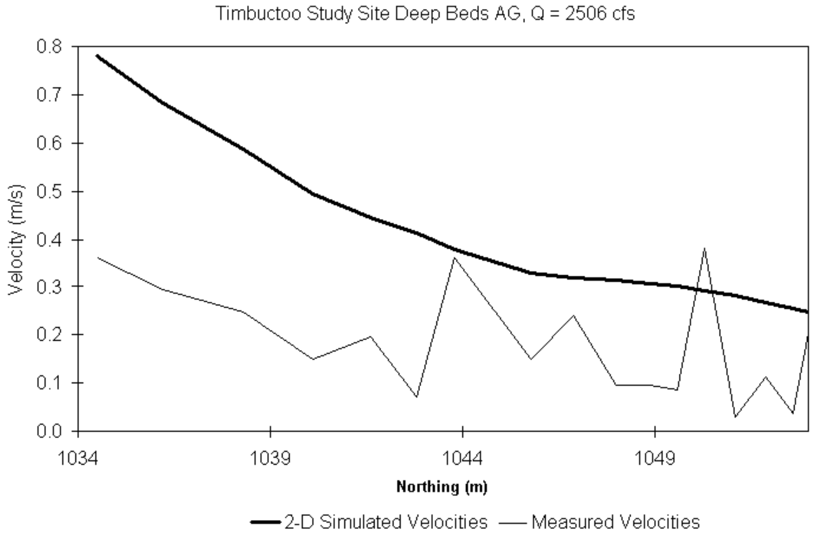

Timbuctoo Study Site Deep Beds AC, Q = 2123 cfs


Timbuctoo Study Site Deep Beds AE, Q = 2506 cfs


Timbuctoo Study Site Deep Beds AD, Q = 2506 cfs


Timbuctoo Study Site Deep Beds AF, Q = 2506 cfs

Appendix G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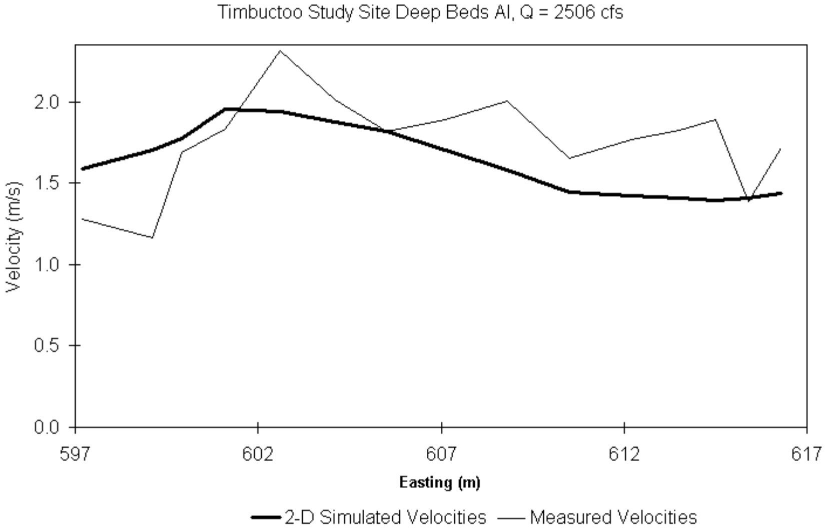
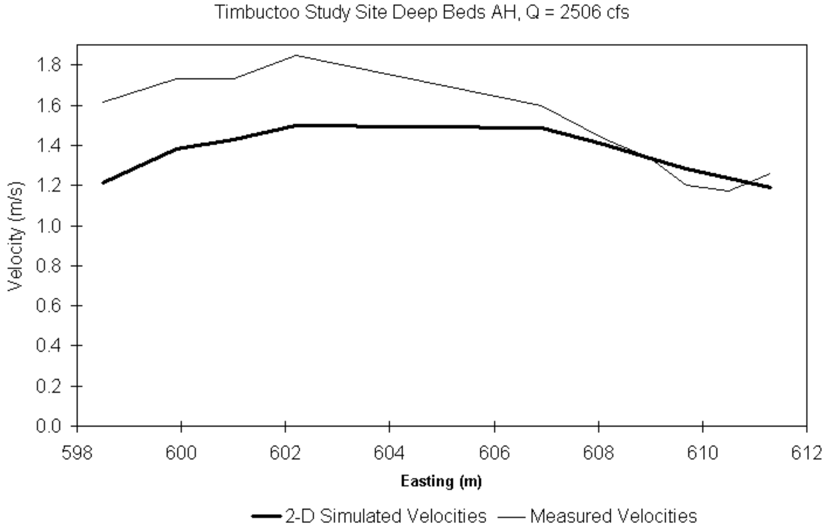
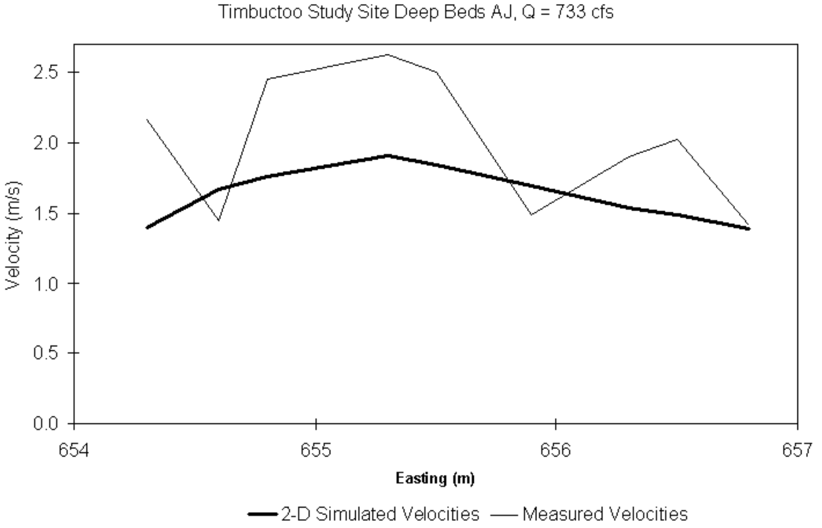
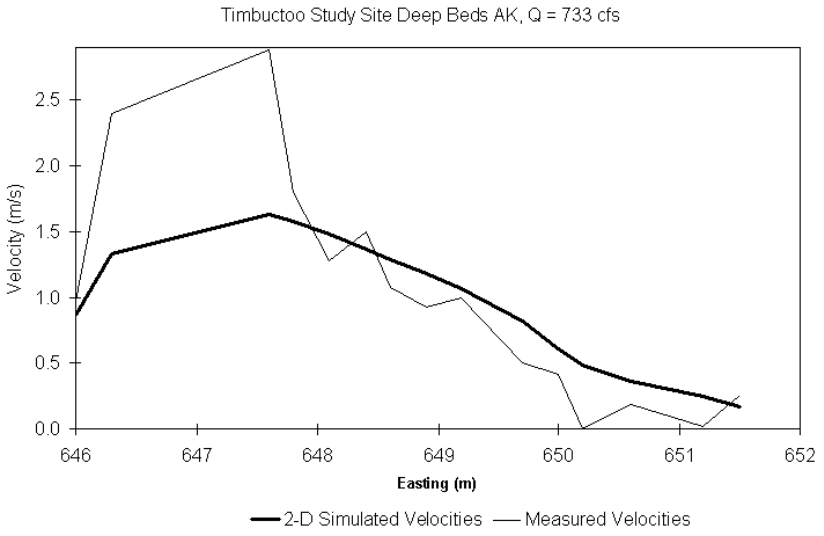
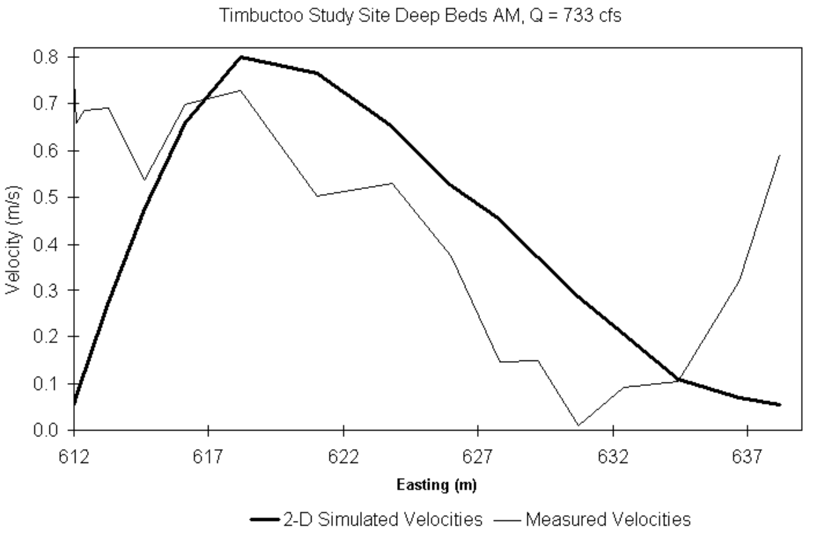
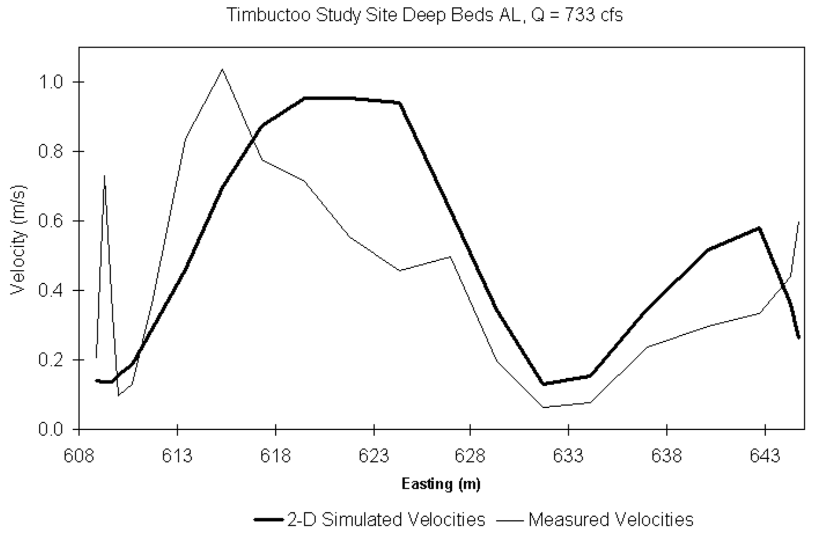

Timbuctoo Study Site Deep Beds AI, Q = 2506 cfs

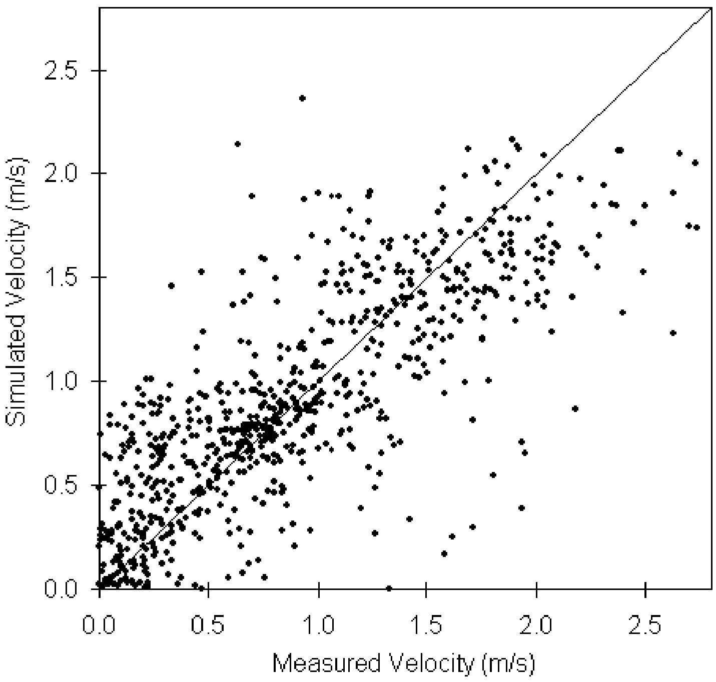

Timbuctoo Study Site Deep Beds AH, Q = 2506 cfs


Timbuctoo Study Site Deep Beds AJ, Q = 733 cfs

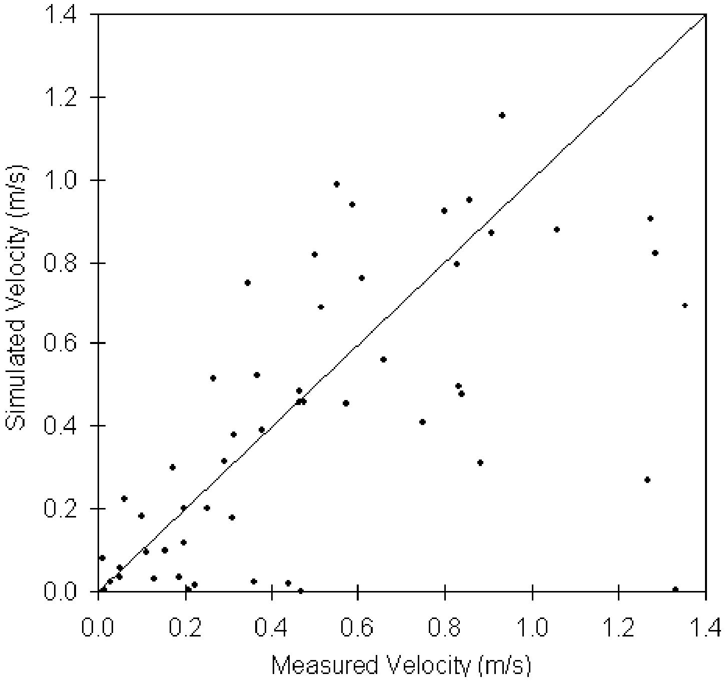

Timbuctoo Study Site Deep Beds AK, Q = 733 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
2.5
646
647
648
649
650
651
652
Easting (m)
2-D Simulated Velocities
Measured Velocities


Timbuctoo Study Site Deep Beds AM, Q = 733 cfs
Velocity (m/s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
612
617
622
627
632
637
Easting (m)
2-D Simulated Velocities
Measured Velocities


Timbuctoo Study Site Deep Beds AL, Q = 733 cfs
Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
608
613
618
623
628
633
638
643
Easting (m)
2-D Simulated Velocities
Measured Velocities

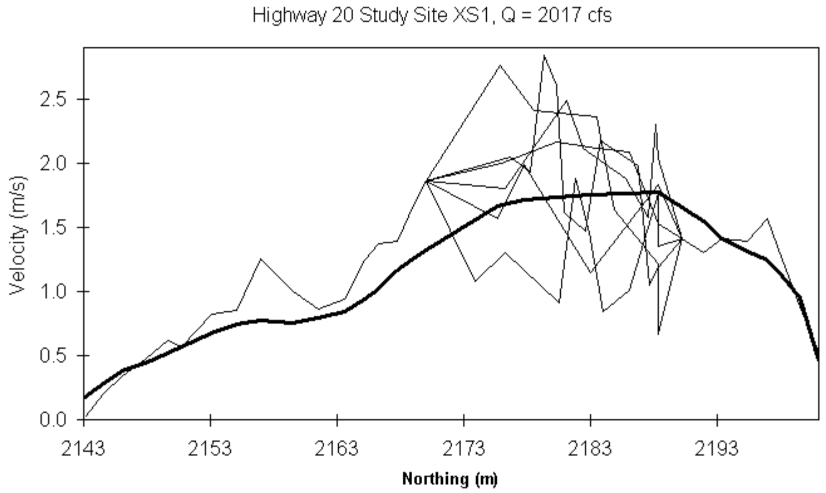


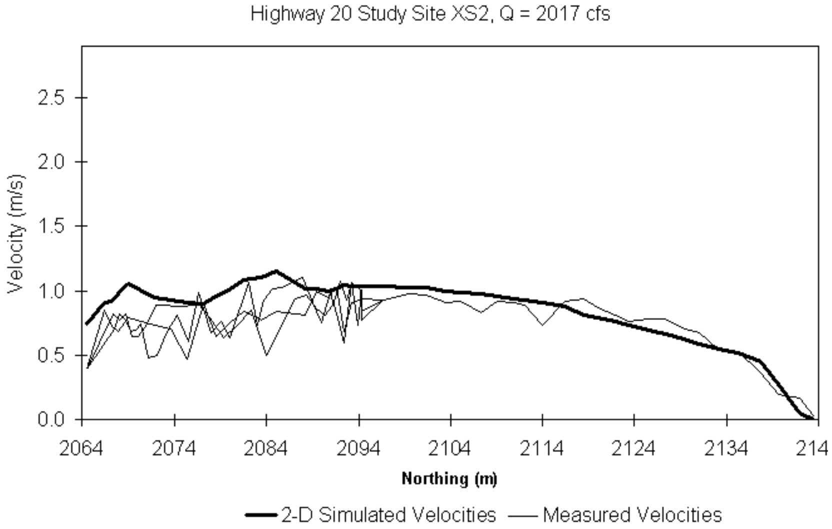
Timbuctoo Study Site
All Validation Velocities

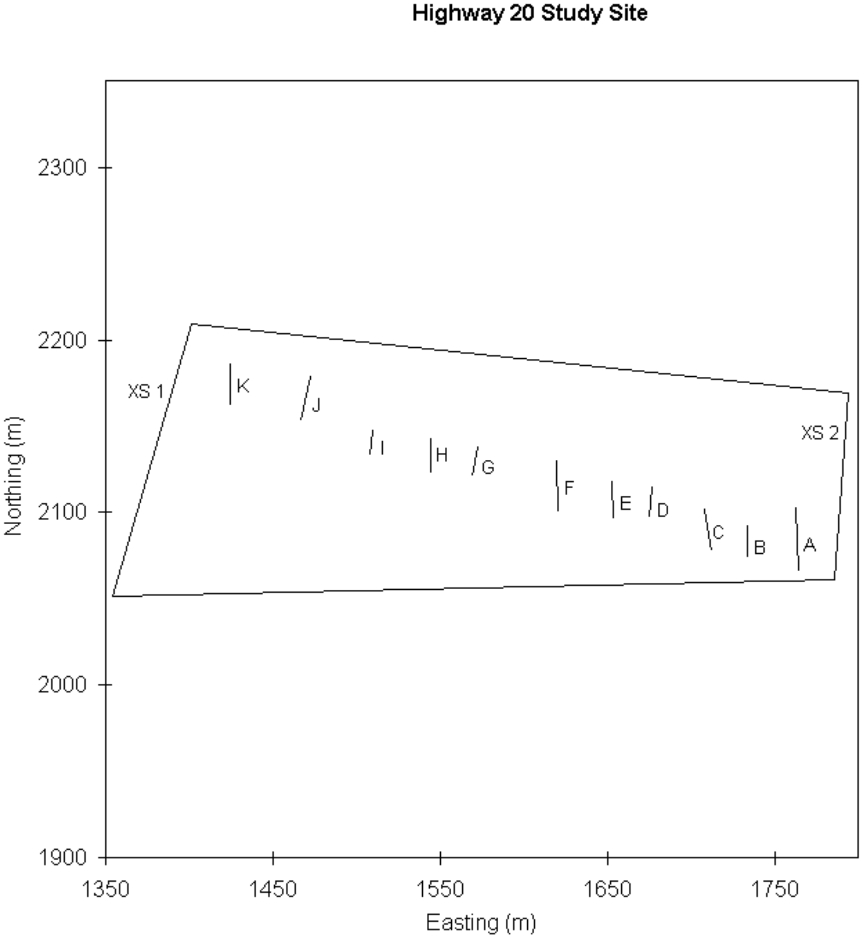


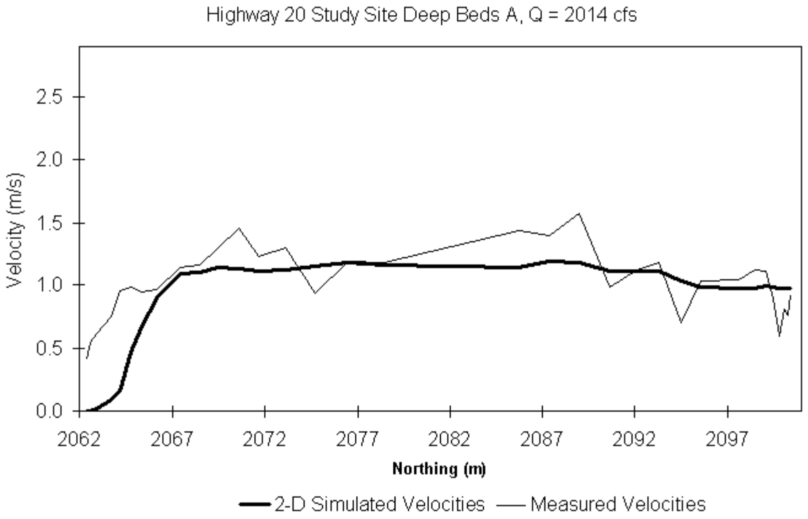
Timbuctoo Study Site
Between Transect Non-ADCP Velocities

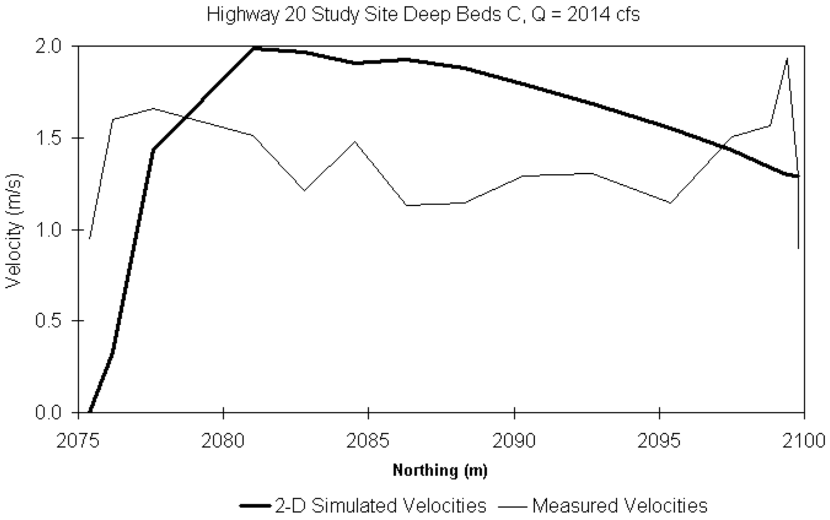
## Highway 20 Study Site

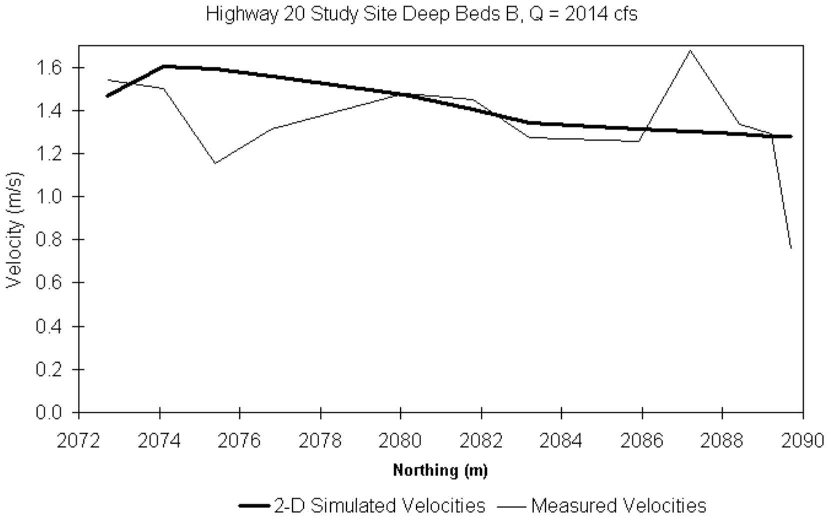


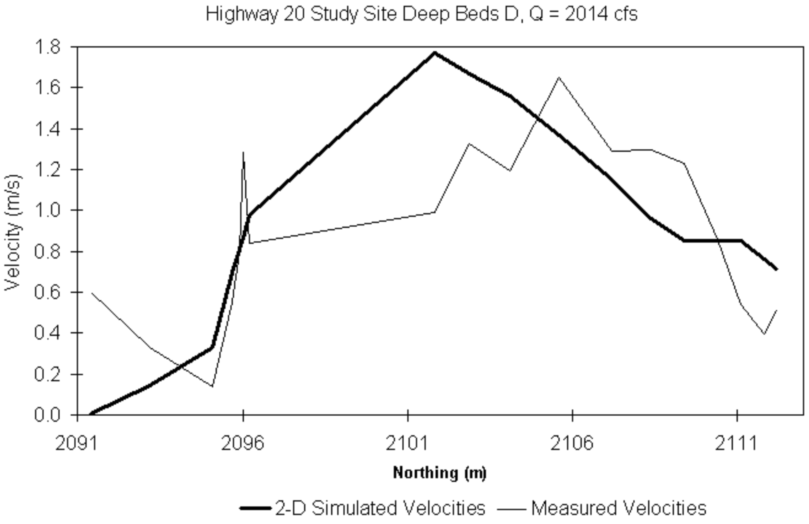




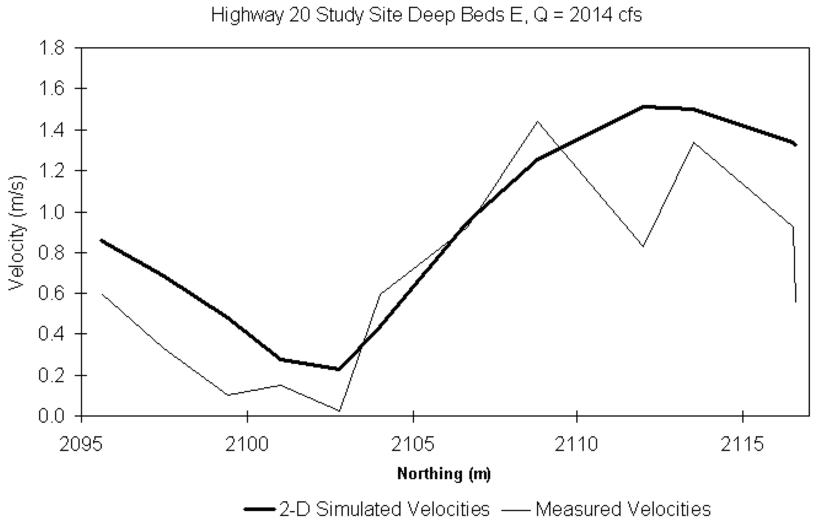

Highway 20 Study Site Deep Beds A, Q = 2014 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
2.5
2062
2067
2072
2077
2082
2087
2092
2097
Northing (m)
2-D Simulated Velocities
Measured Velocities

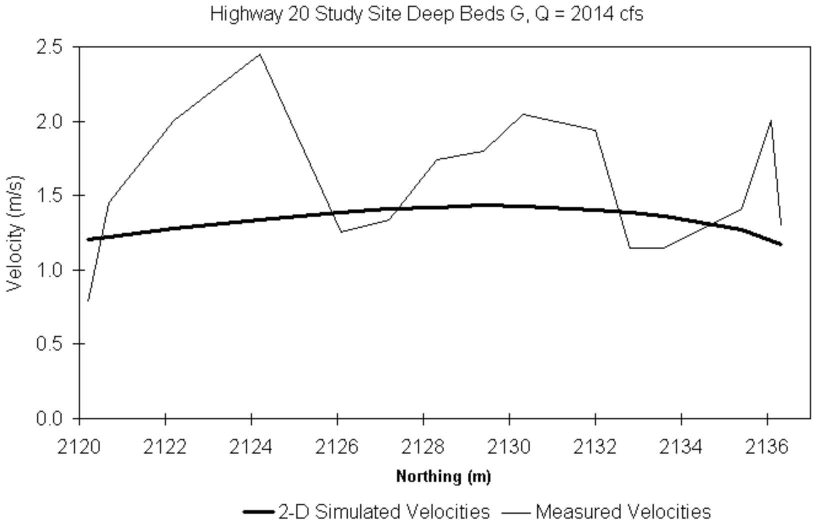

Highway 20 Study Site Deep Beds C, Q = 2014 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
2075
2080
2085
2090
2095
2100
Northing (m)
2-D Simulated Velocities
Measured Velocities

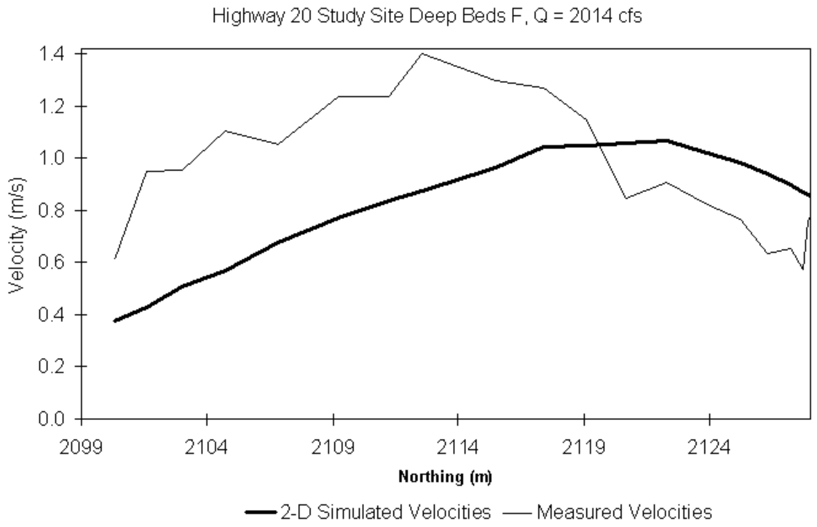

Highway 20 Study Site Deep Beds B, Q = 2014 cfs
Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
2072
2074
2076
2078
2080
2082
2084
2086
2088
2090
Northing (m)
2-D Simulated Velocities
Measured Velocities

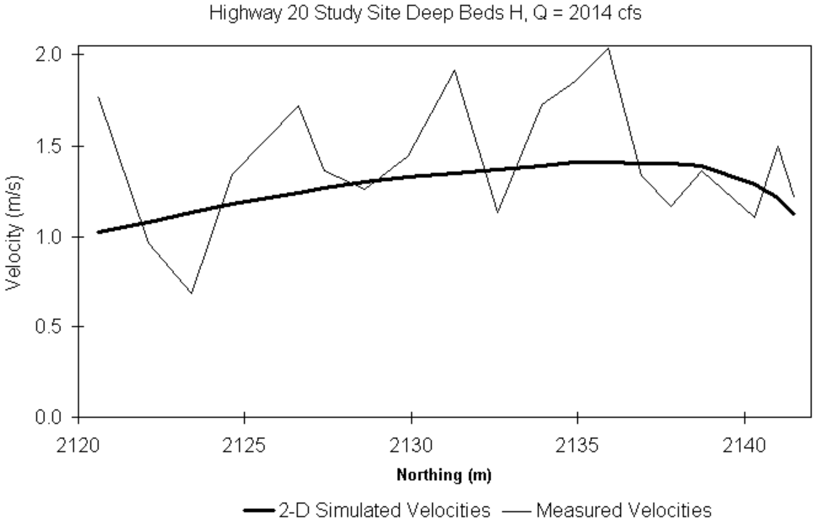

Highway 20 Study Site Deep Beds D, Q = 2014 cfs
Velocity (m/s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2091
2096
2101
2106
2111
Northing (m)
2-D Simulated Velocities
Measured Velocities

# Appendix G

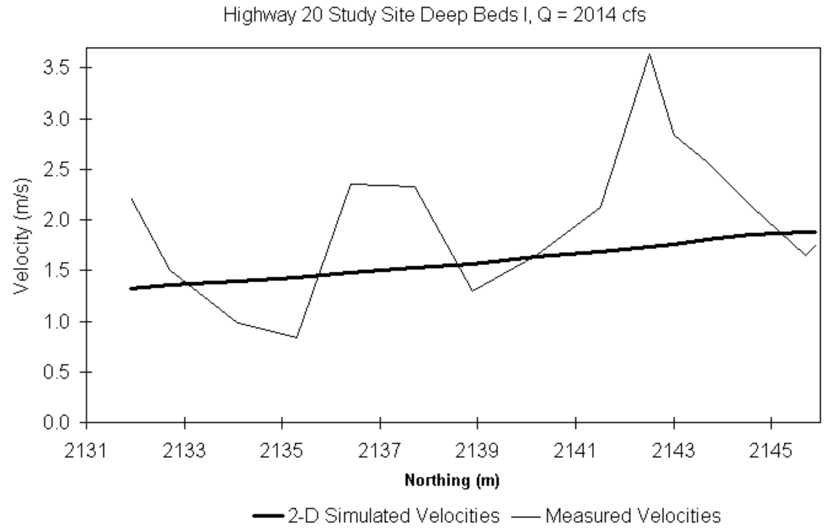

Highway 20 Study Site Deep Beds E, Q = 2014 cfs

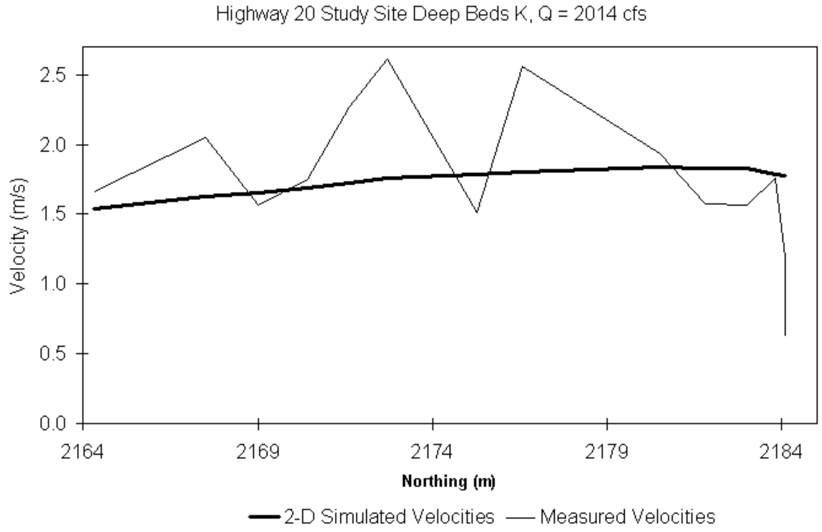

Highway 20 Study Site Deep Beds G, Q = 2014 cfs


Highway 20 Study Site Deep Beds F, Q = 2014 cfs


Highway 20 Study Site Deep Beds H, Q = 2014 cfs

# Appendix G


Highway 20 Study Site Deep Beds I, Q = 2014 cfs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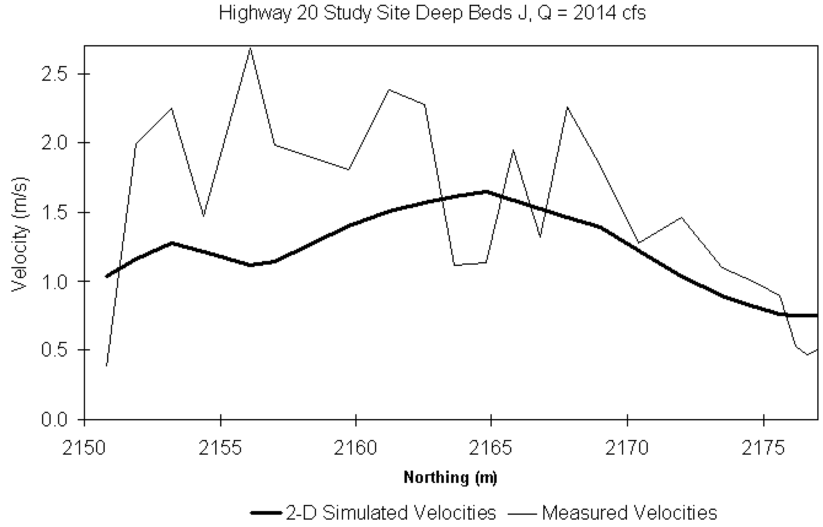
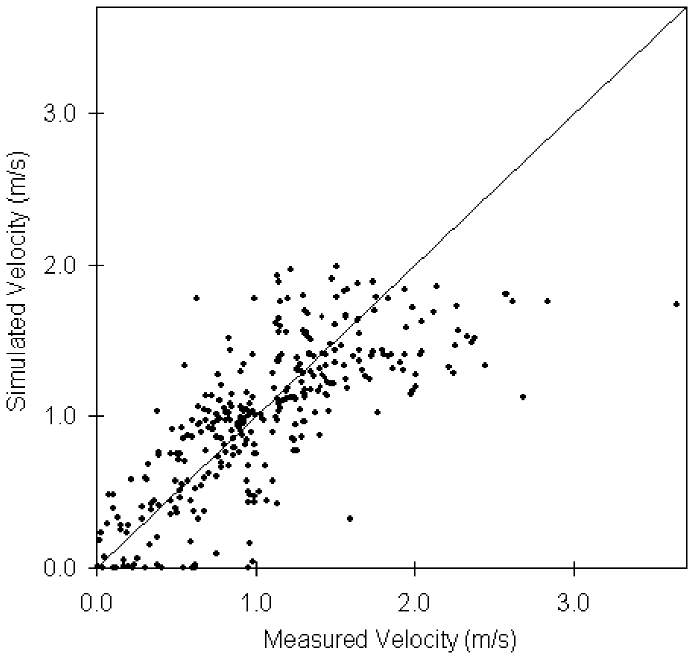
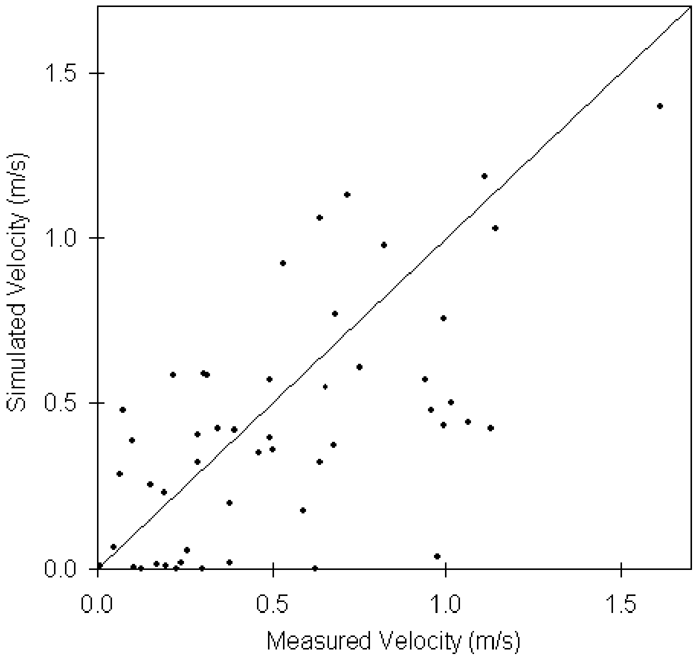

Highway 20 Study Site Deep Beds J, Q = 2014 cfs

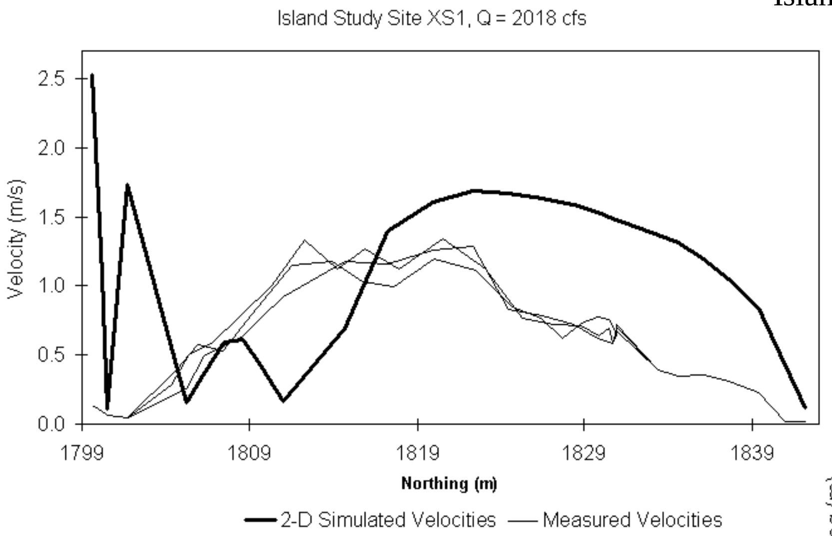
Highway 20 Study Site
All Validation Velocities

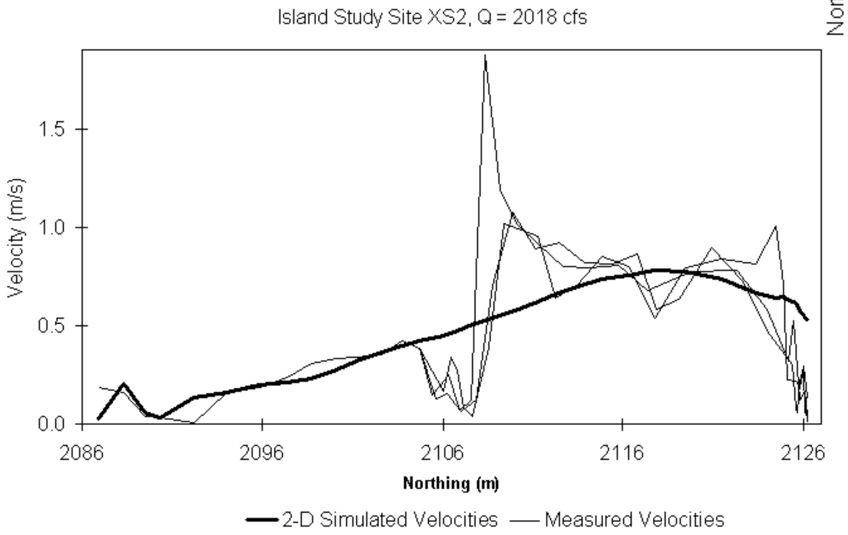


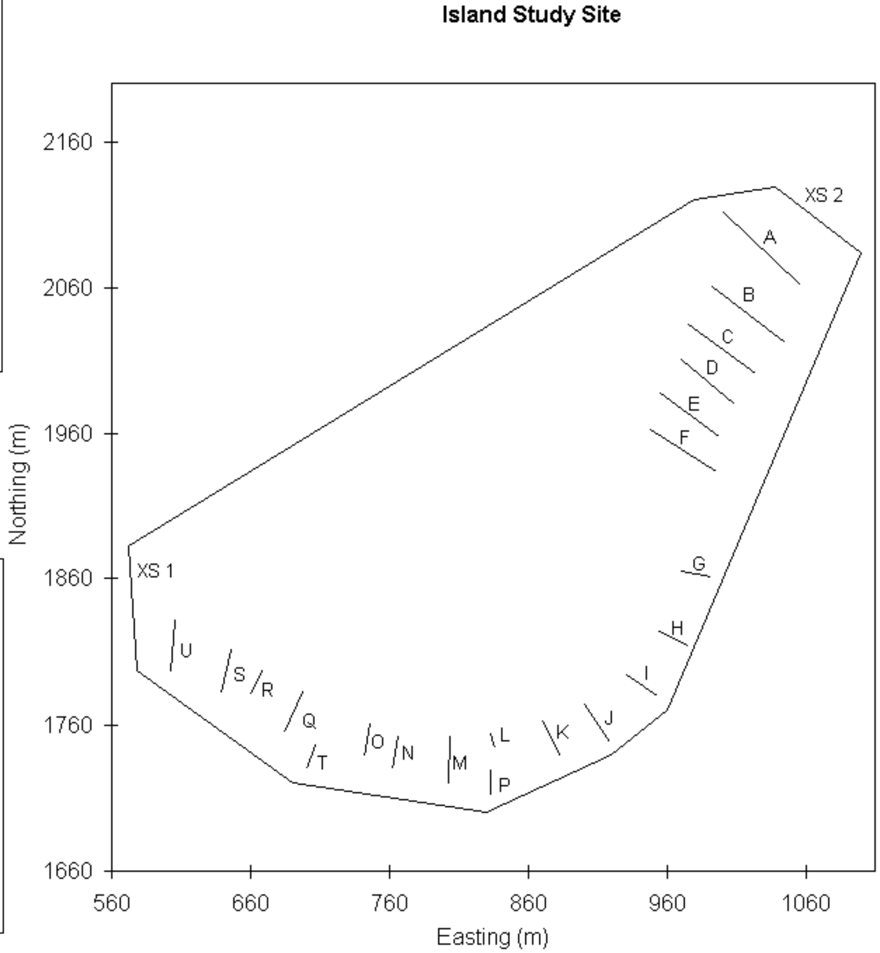
Highway 20 Study Site
Between Transect Non-ADCP Velocities



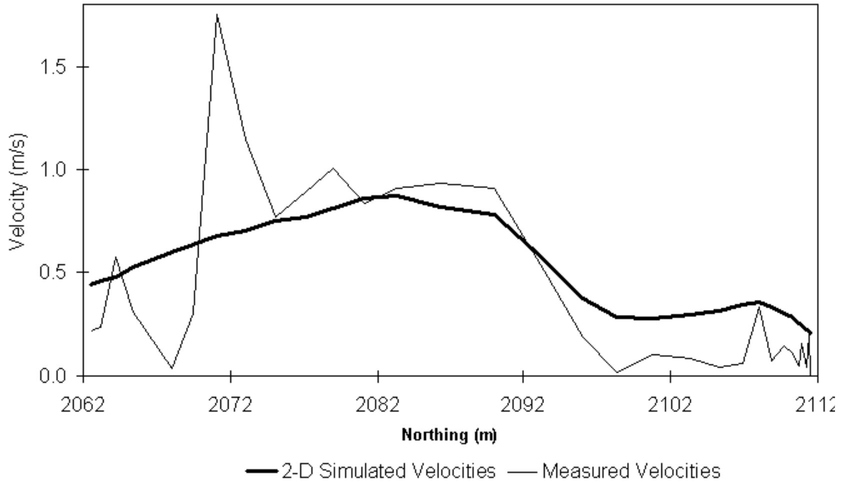
## Island Study Site







Appendix G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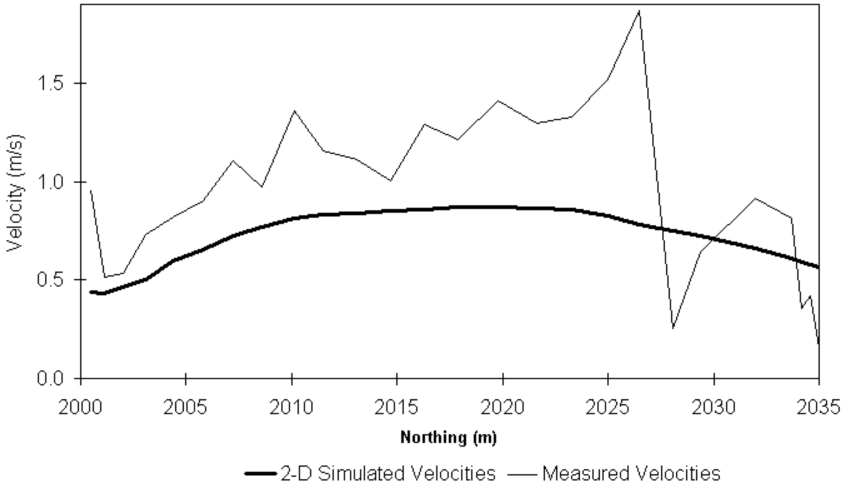
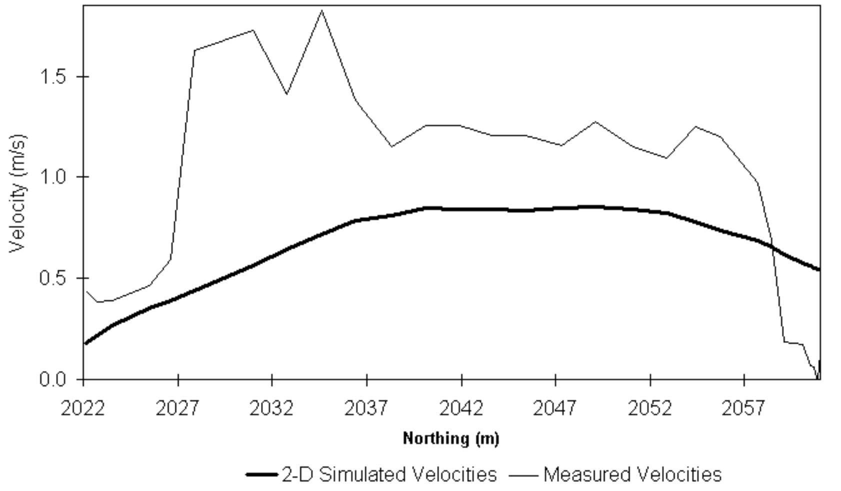
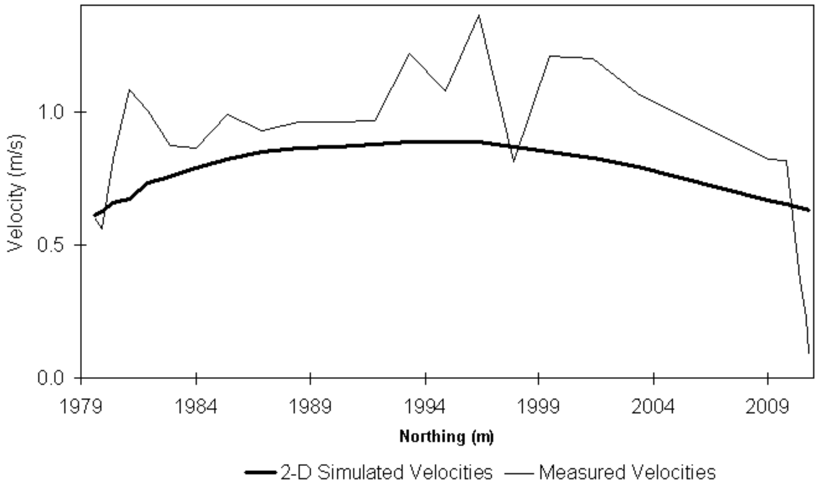
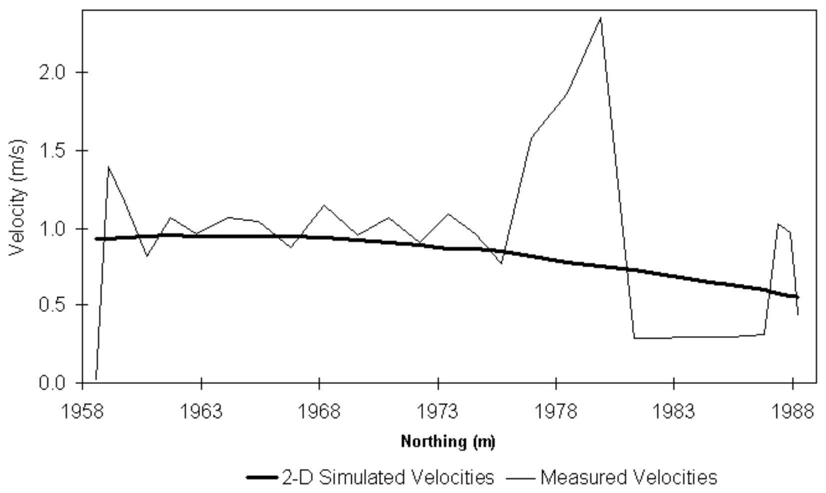

Island Study Site Deep Beds C, Q = 2373 cfs


Island Study Site Deep Beds B, Q = 2373 cfs

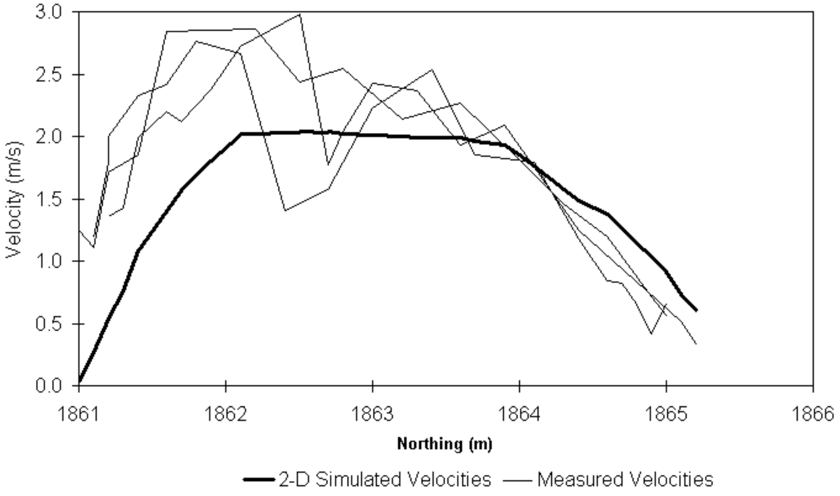

Island Study Site Deep Beds D, Q = 2373 cfs

Appendix G

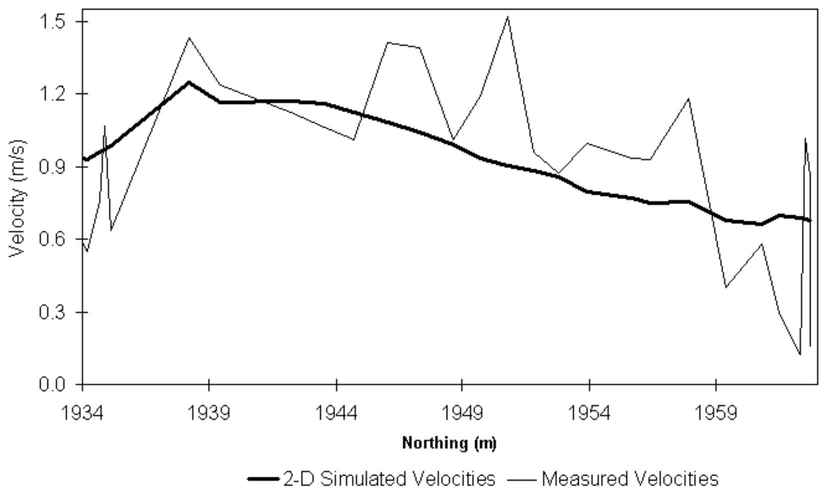
Island Study Site Deep Beds E, Q = 2373 cfs



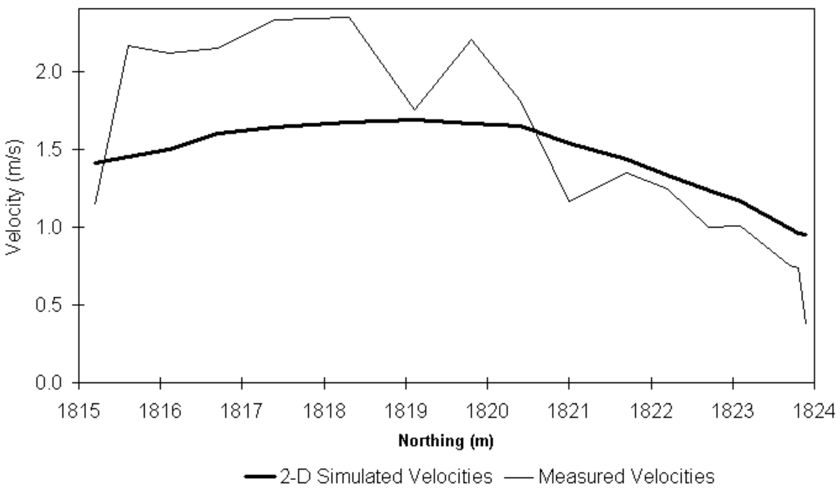
Island Study Site Deep Beds G, Q = 2008 cfs

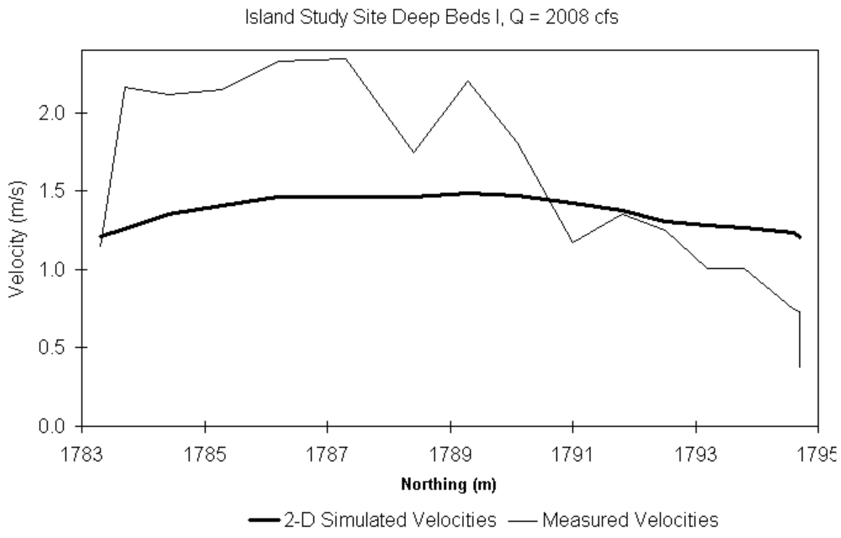


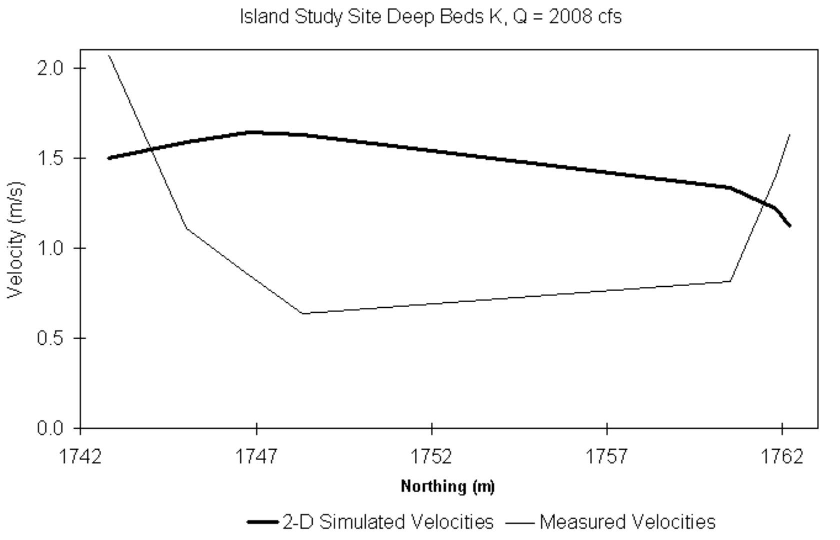
Island Study Site Deep Beds F, Q = 2373 cfs

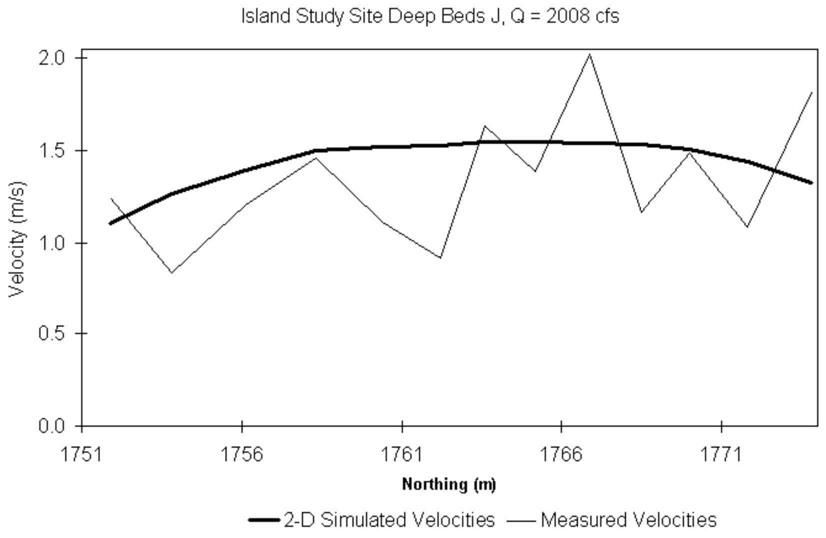


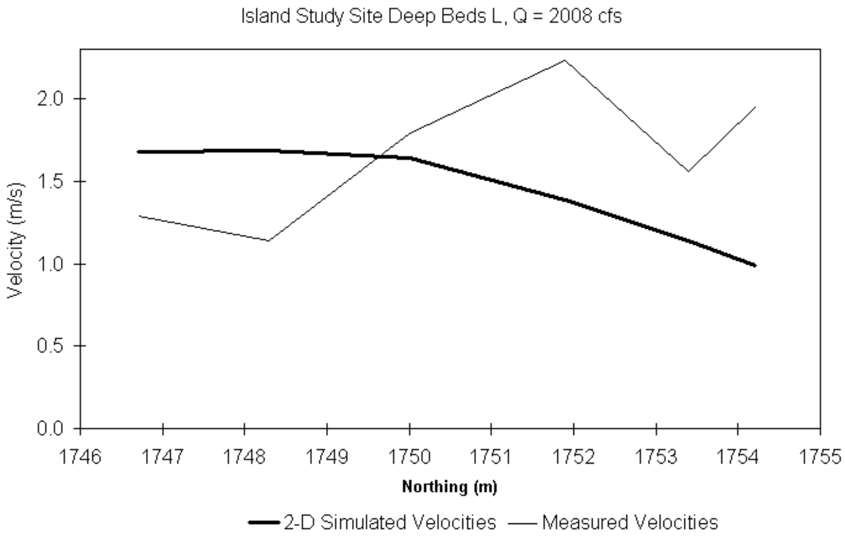
Island Study Site Deep Beds H, Q = 2008 cfs



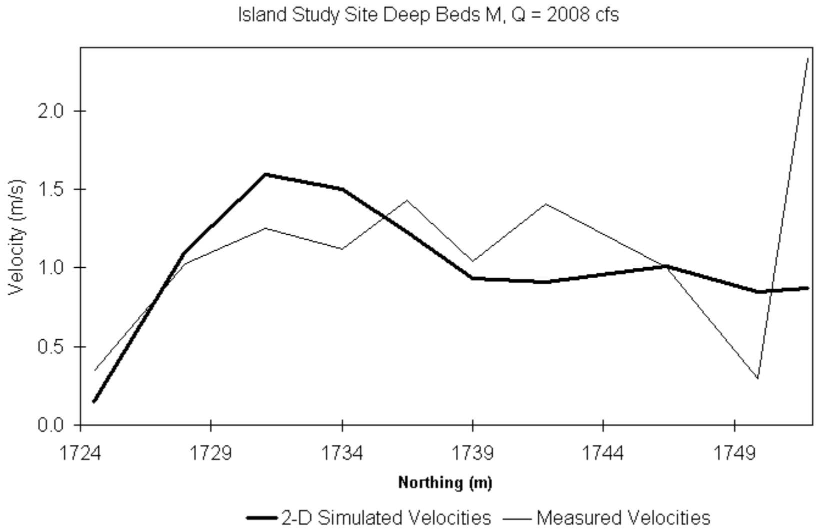

Island Study Site Deep Beds I, Q = 2008 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
1783
1785
1787
1789
1791
1793
1795
Northing (m)
2-D Simulated Velocities
Measured Velocities

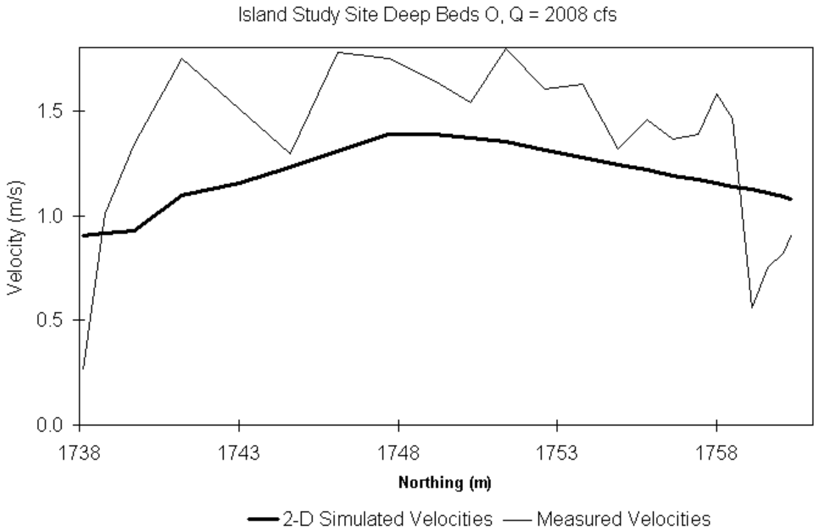

Island Study Site Deep Beds K, Q = 2008 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
1742
1747
1752
1757
1762
Northing (m)
2-D Simulated Velocities
Measured Velocities

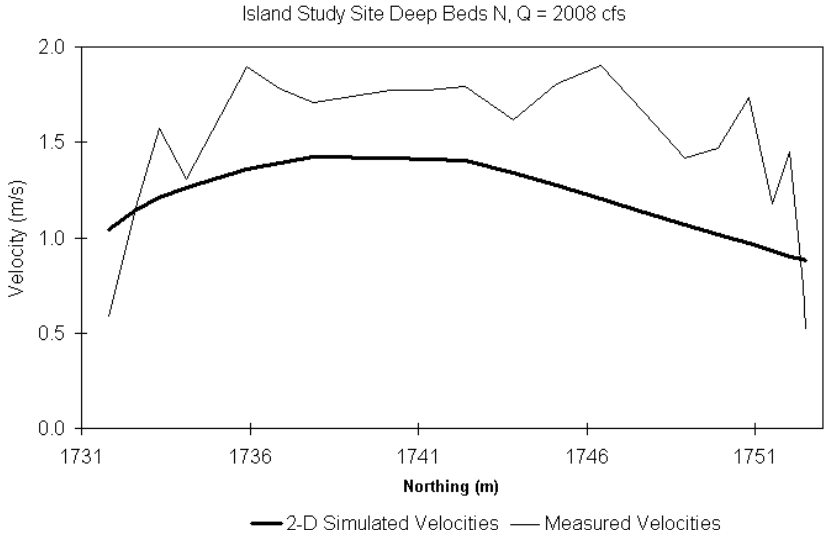

Island Study Site Deep Beds J, Q = 2008 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
1751
1756
1761
1766
1771
Northing (m)
2-D Simulated Velocities
Measured Velocities

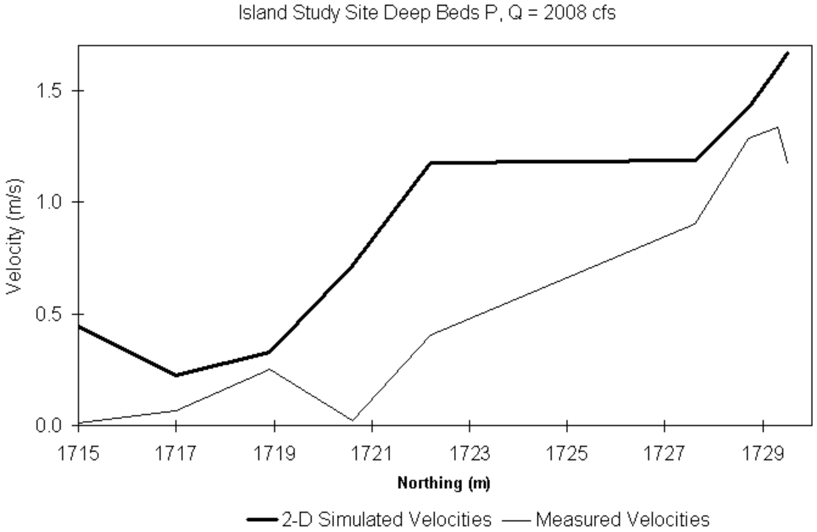

Island Study Site Deep Beds L, Q = 2008 cfs
Velocity (m/s)
0.0
0.5
1.0
1.5
2.0
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
Northing (m)
2-D Simulated Velocities
Measured Velocities

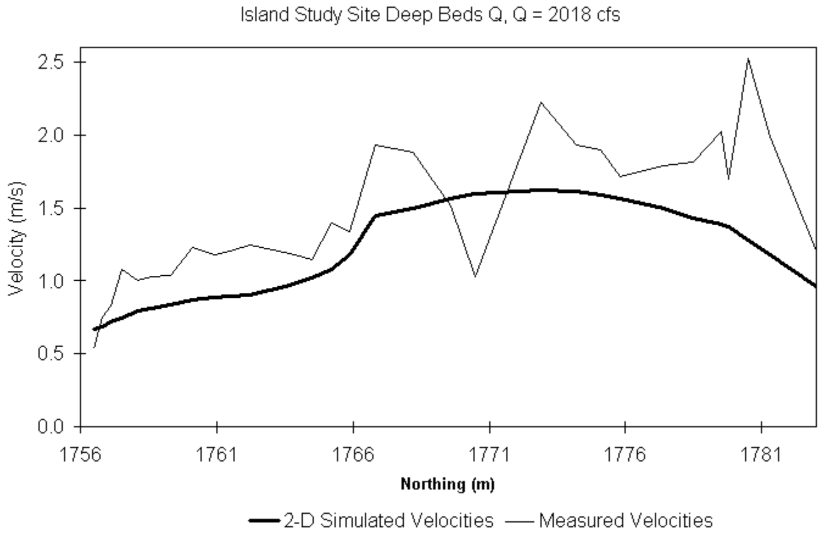
Appendix G

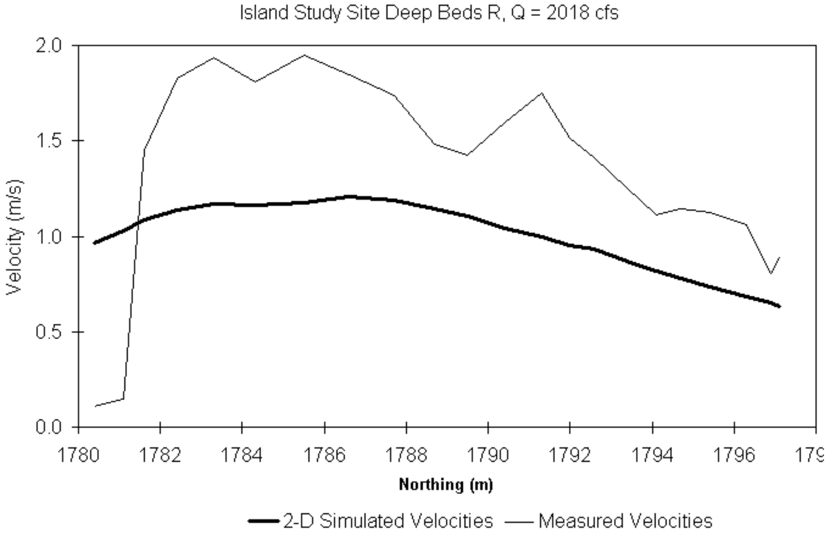

Island Study Site Deep Beds M, Q = 2008 cfs

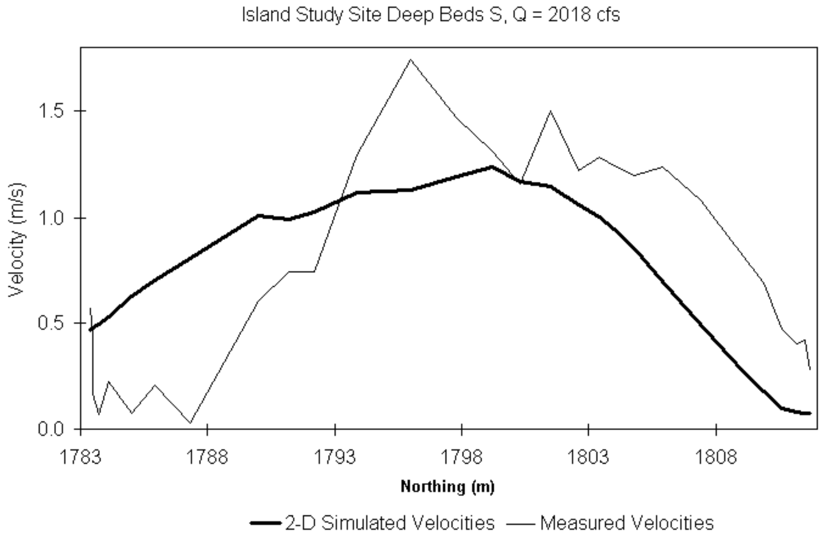

Island Study Site Deep Beds O, Q = 2008 cfs

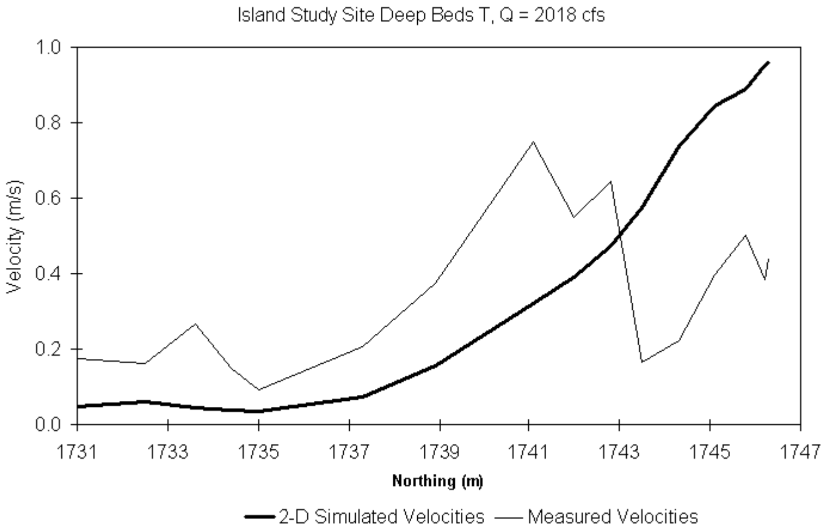

Island Study Site Deep Beds N, Q = 2008 cfs

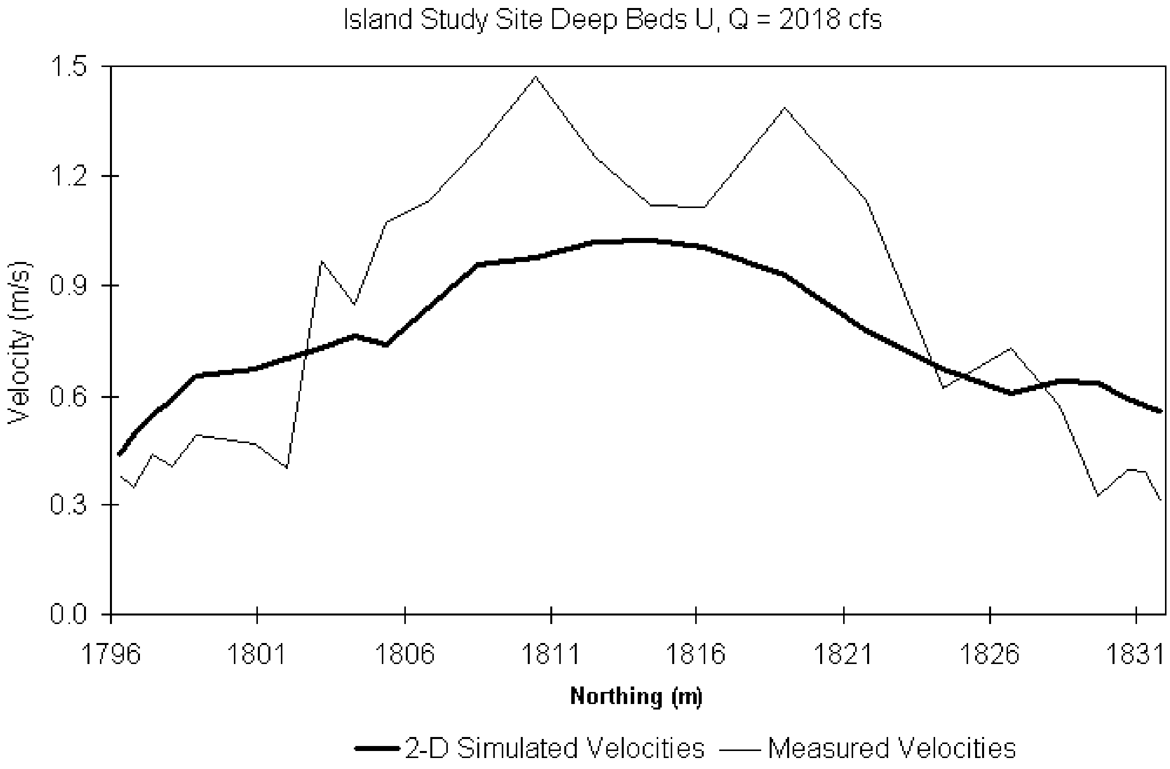

Island Study Site Deep Beds P, Q = 2008 cfs

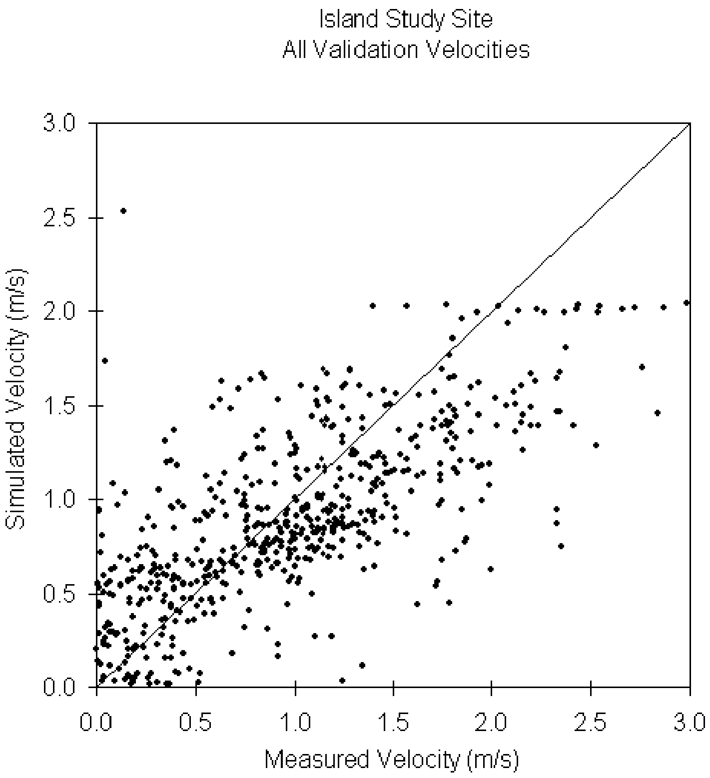

Island Study Site Deep Beds Q, Q = 2018 cfs


Island Study Site Deep Beds R, Q = 2018 cfs

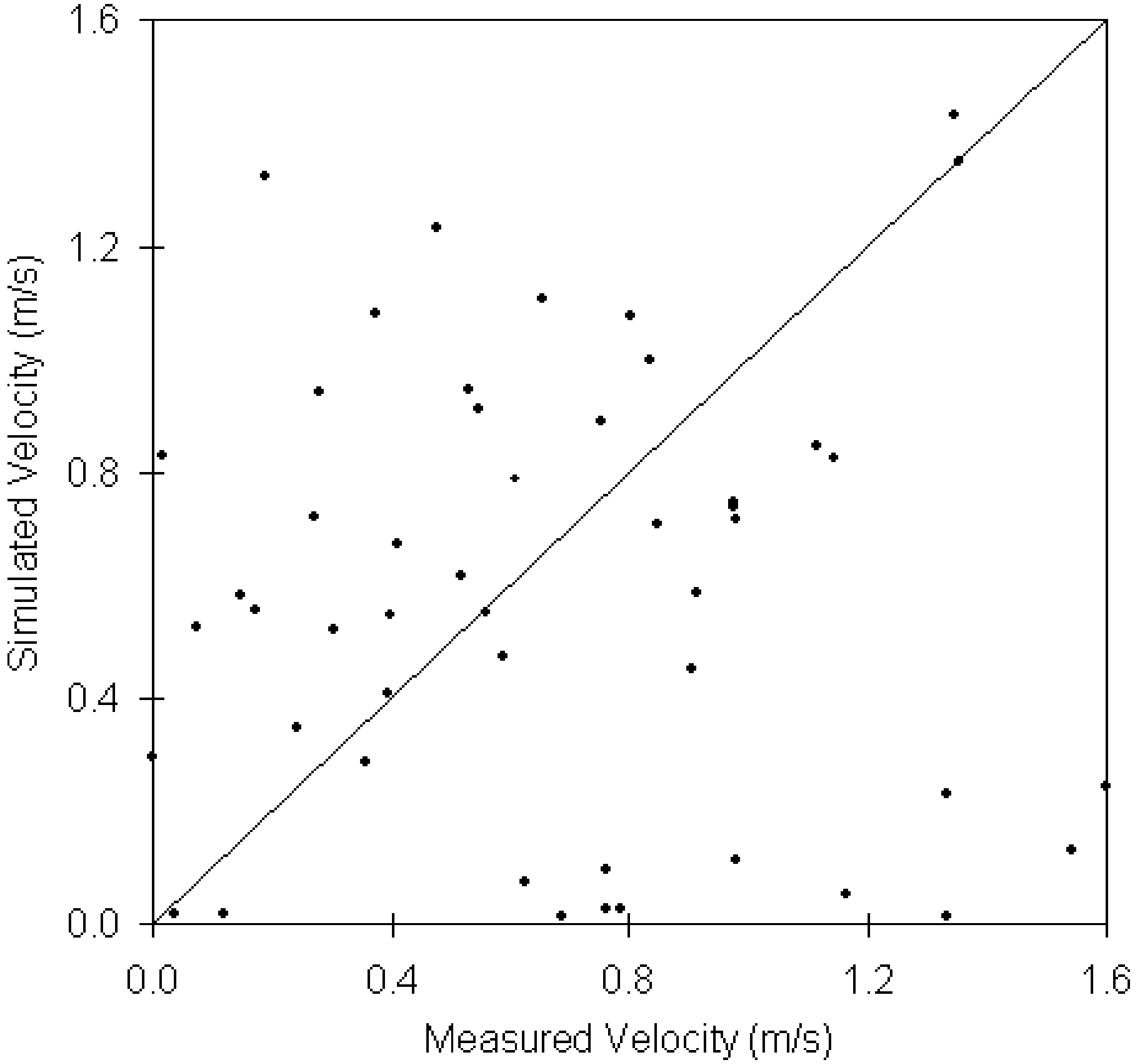

Island Study Site Deep Beds S, Q = 2018 cfs


Island Study Site Deep Beds T, Q = 2018 cfs


Island Study Site Deep Beds U, Q = 2018 cfs
Velocity (m/s)
1.5
1.2
0.9
0.6
0.3
0.0
1796
1801
1806
1811
1816
1821
1826
1831
Northing (m)
2-D Simulated Velocities
Measured Velocities

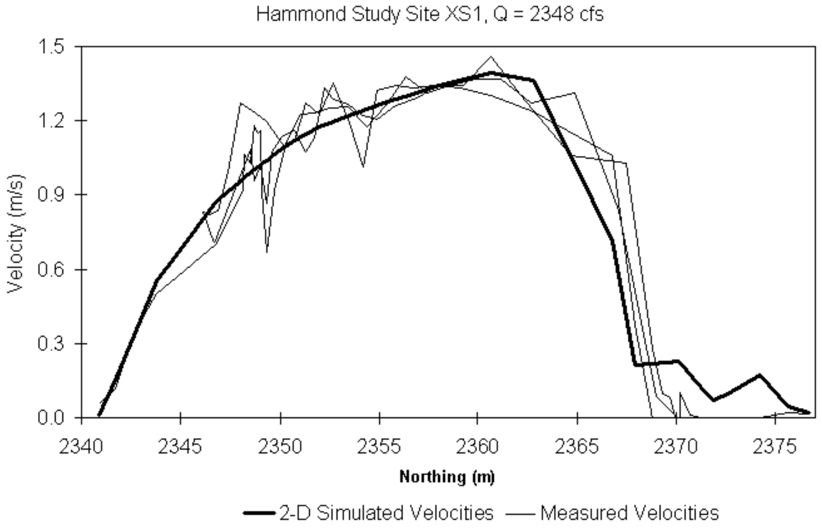

Island Study Site
All Validation Velocities
Simulated Velocity (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Measured Velocity (m/s)

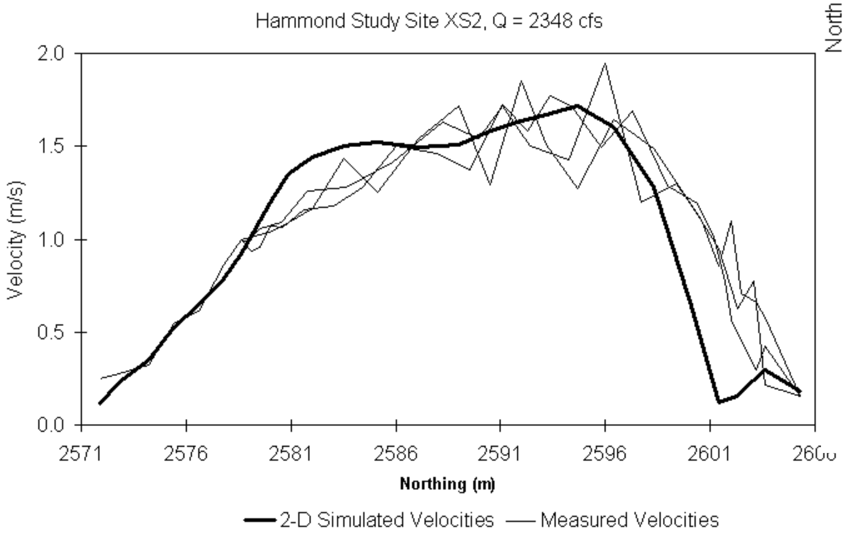
Island Study Site
Between Transect Non-ADCP Velocities

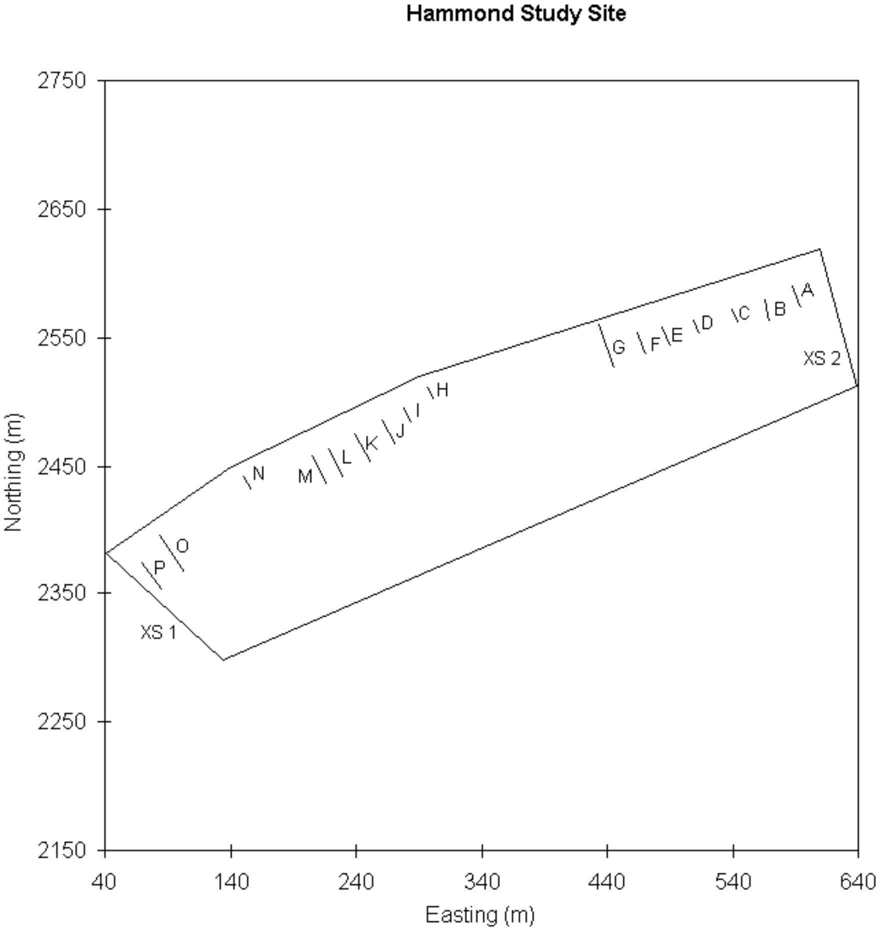


Appendix G

## Hammond Study Site







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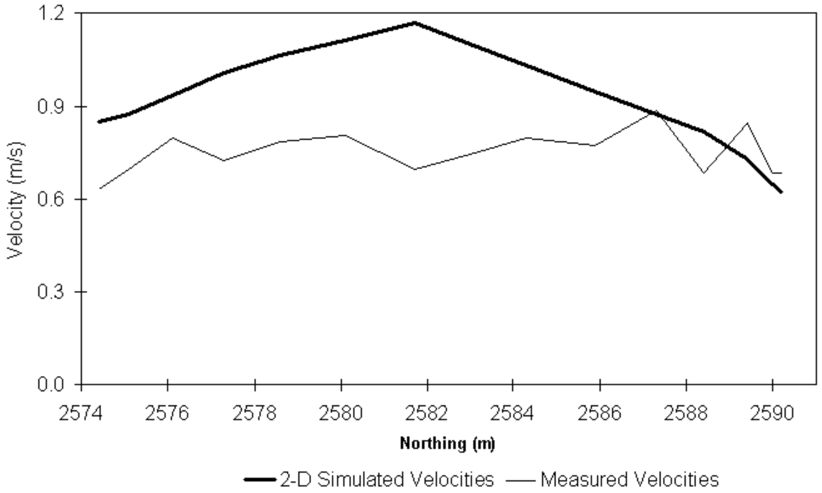
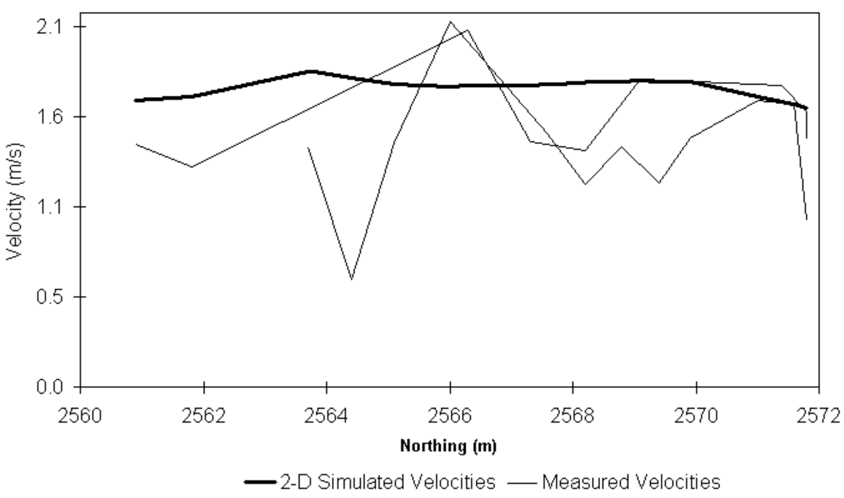
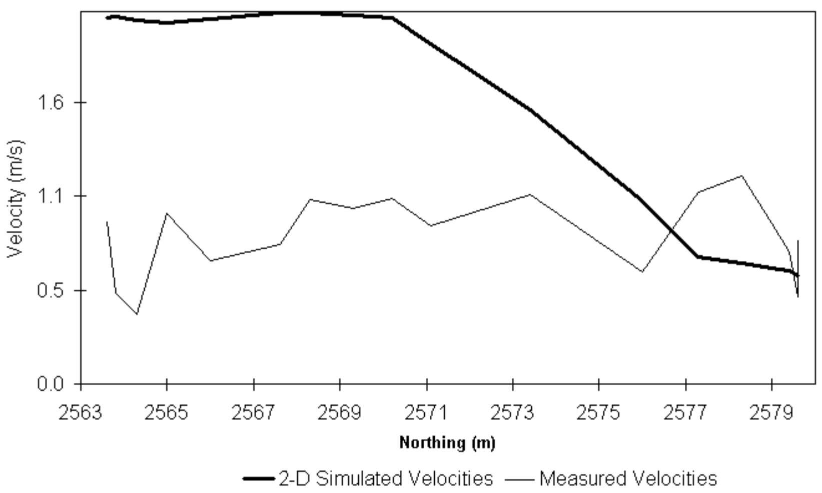
Hammond Study Site Deep Beds A, Q = 955 cfs



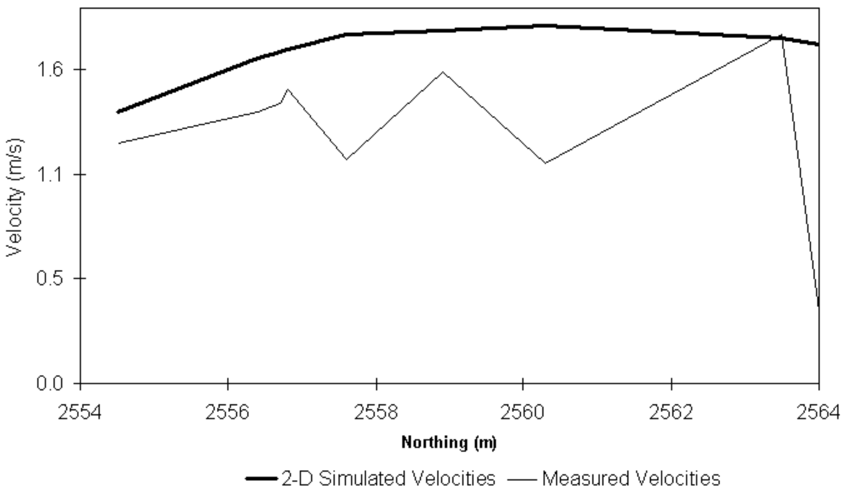
Hammond Study Site Deep Beds C, Q = 955 cfs



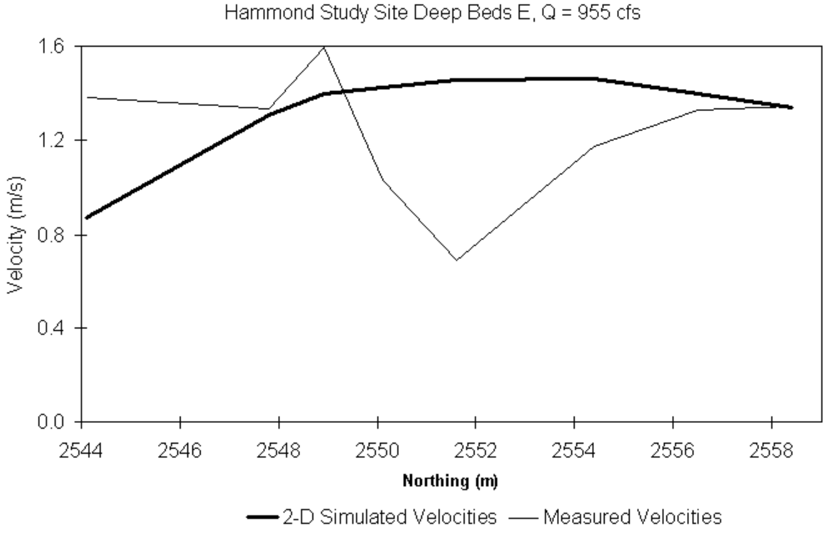
Hammond Study Site Deep Beds B, Q = 955 cfs

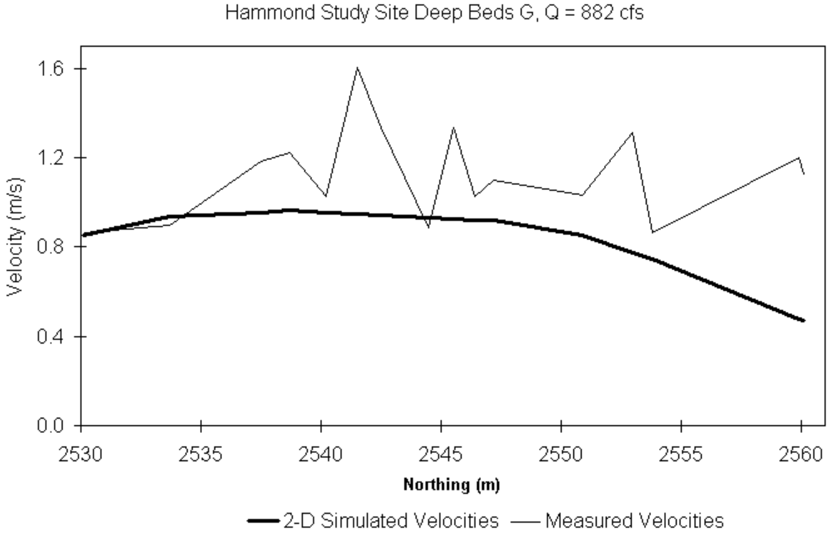


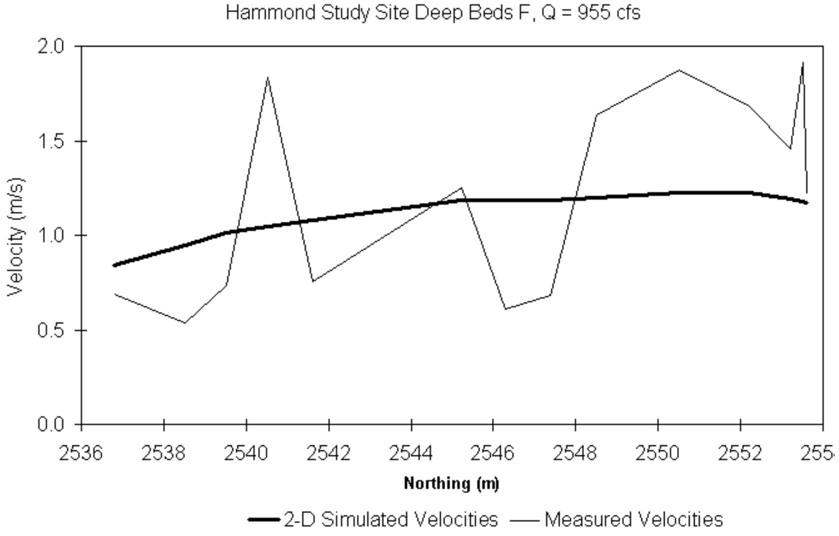
Hammond Study Site Deep Beds D, Q = 955 cfs

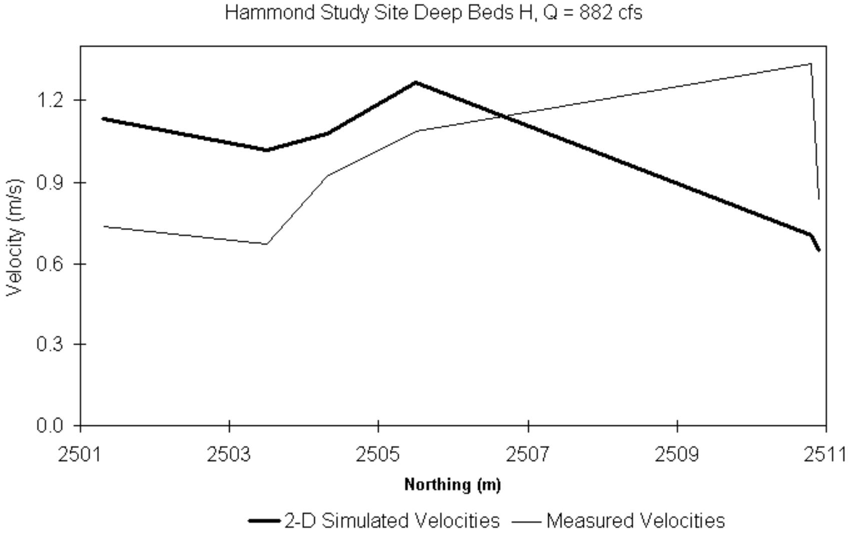


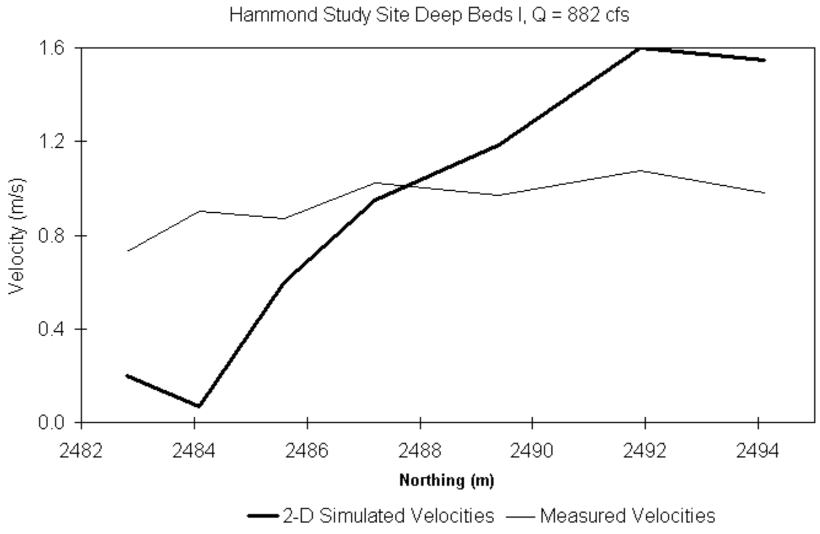
Appendix G

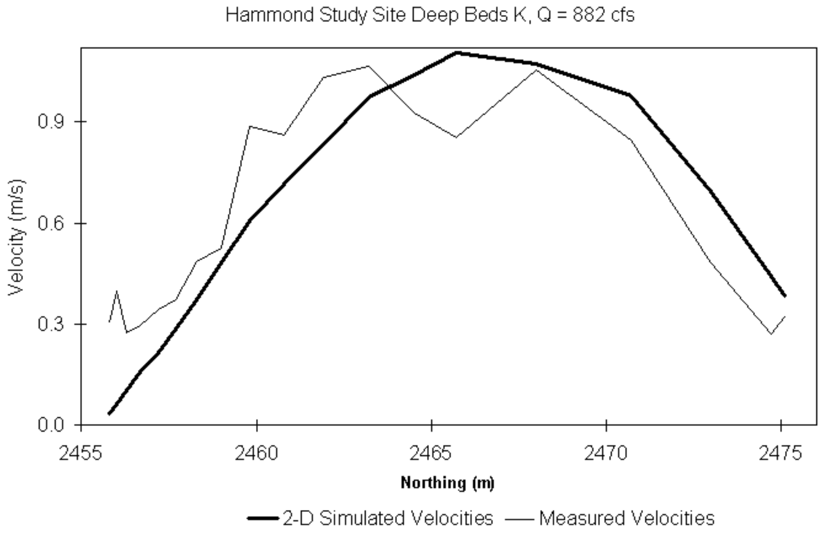

Hammond Study Site Deep Beds E, Q = 955 cfs

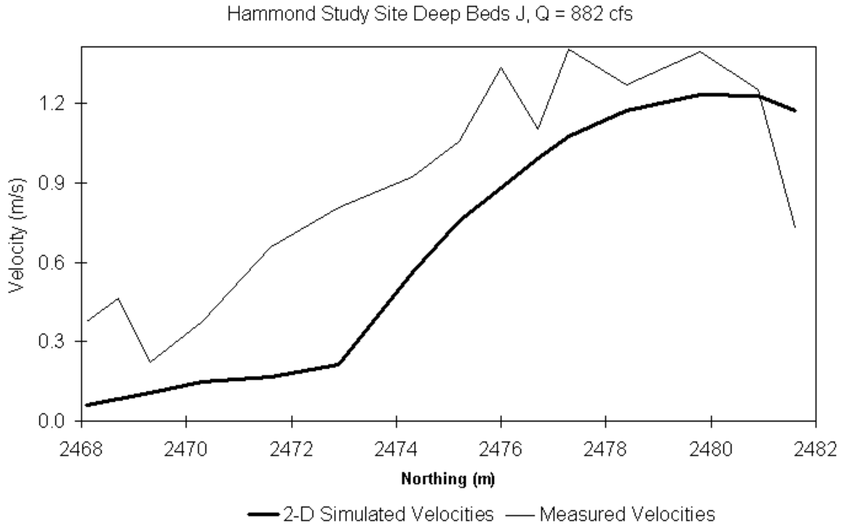

Hammond Study Site Deep Beds G, Q = 882 cfs

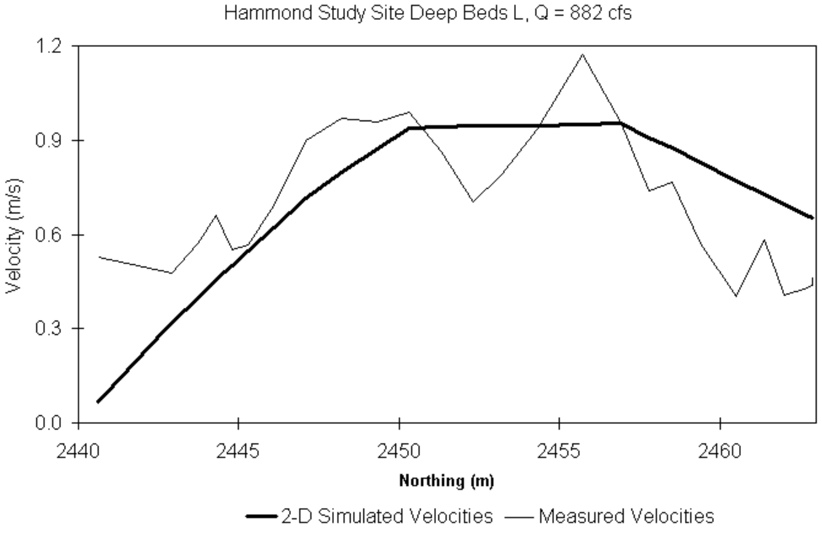

Hammond Study Site Deep Beds F, Q = 955 cfs

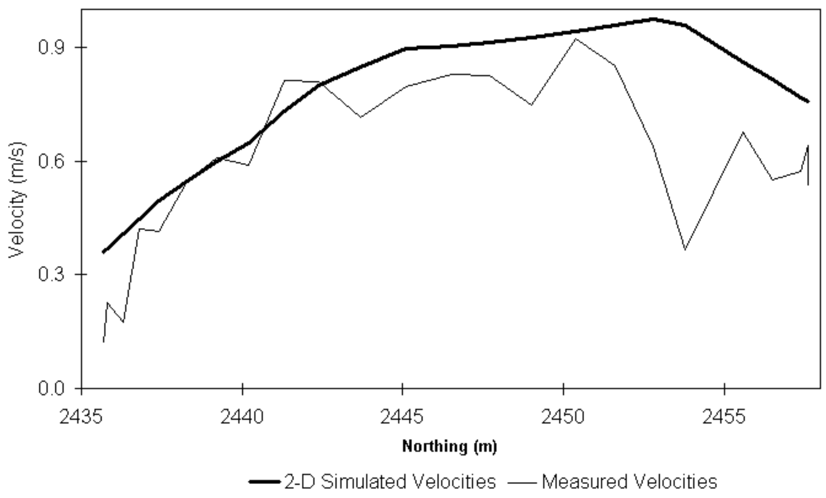

Hammond Study Site Deep Beds H, Q = 882 cfs

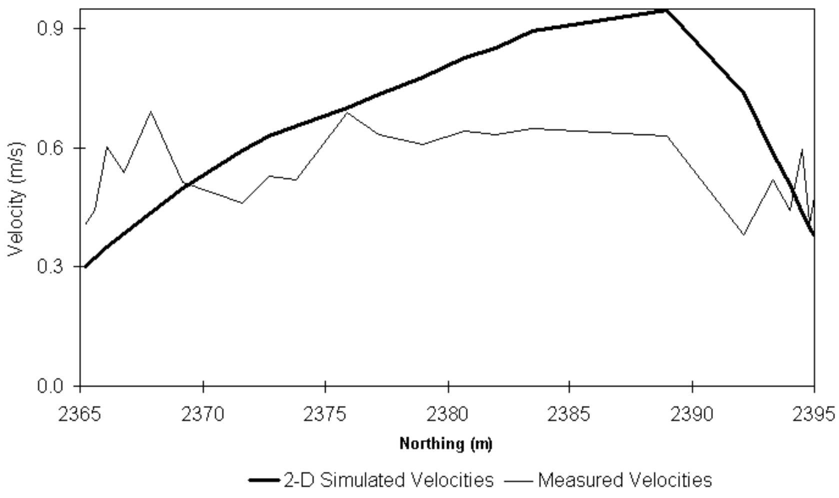

Hammond Study Site Deep Beds I, Q = 882 cfs

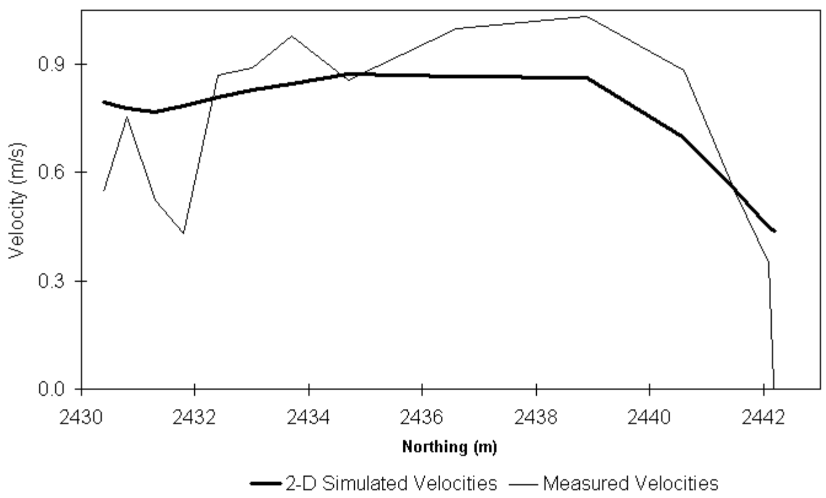

Hammond Study Site Deep Beds K, Q = 882 cfs

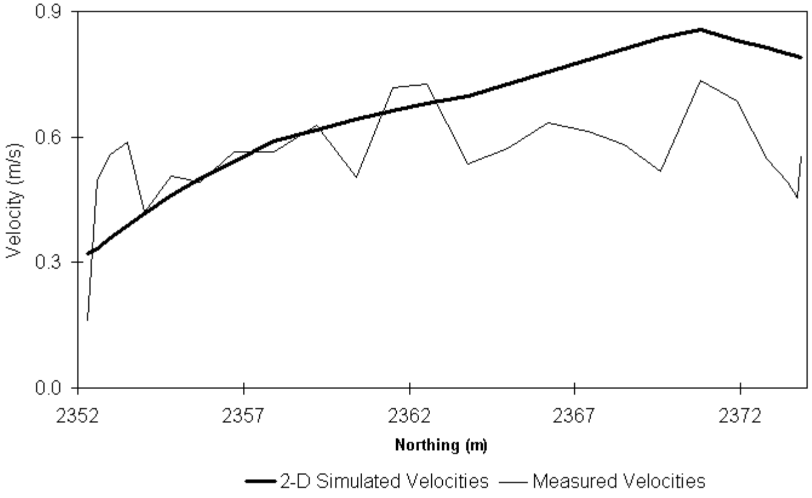

Hammond Study Site Deep Beds J, Q = 882 cfs


Hammond Study Site Deep Beds L, Q = 882 cfs


Hammond Study Site Deep Beds M, Q = 882 cfs


Hammond Study Site Deep Beds O, Q = 882 cfs


Hammond Study Site Deep Beds N, Q = 882 cfs


Hammond Study Site Deep Beds P, Q = 882 cfs

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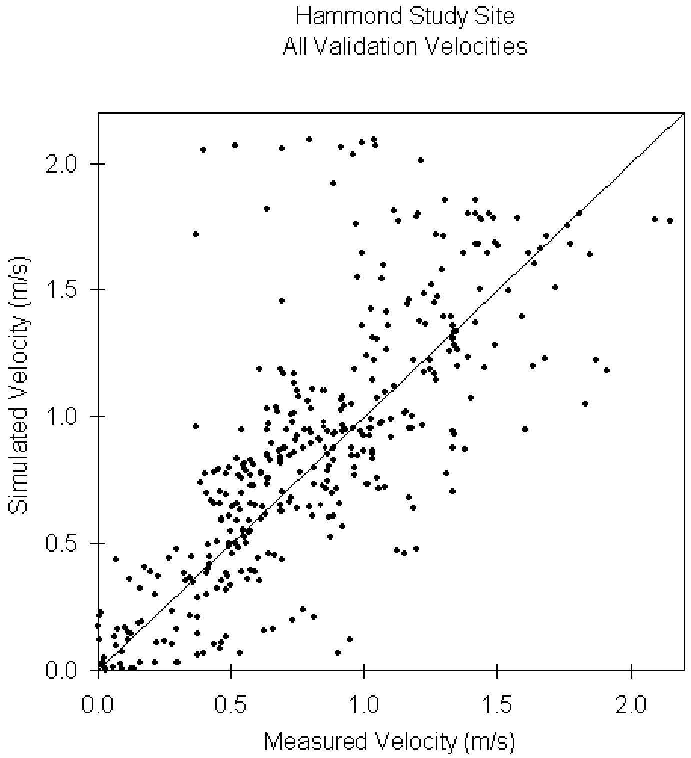
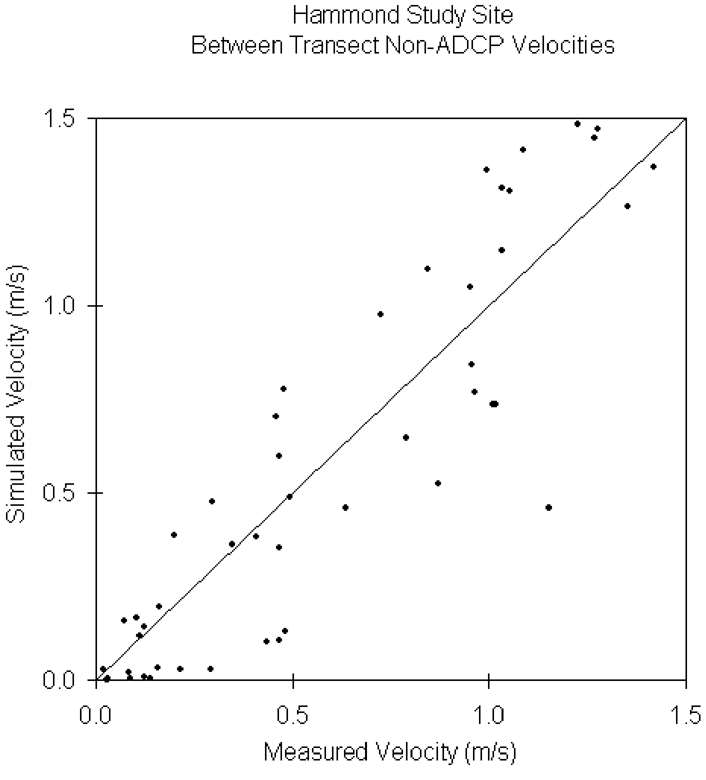
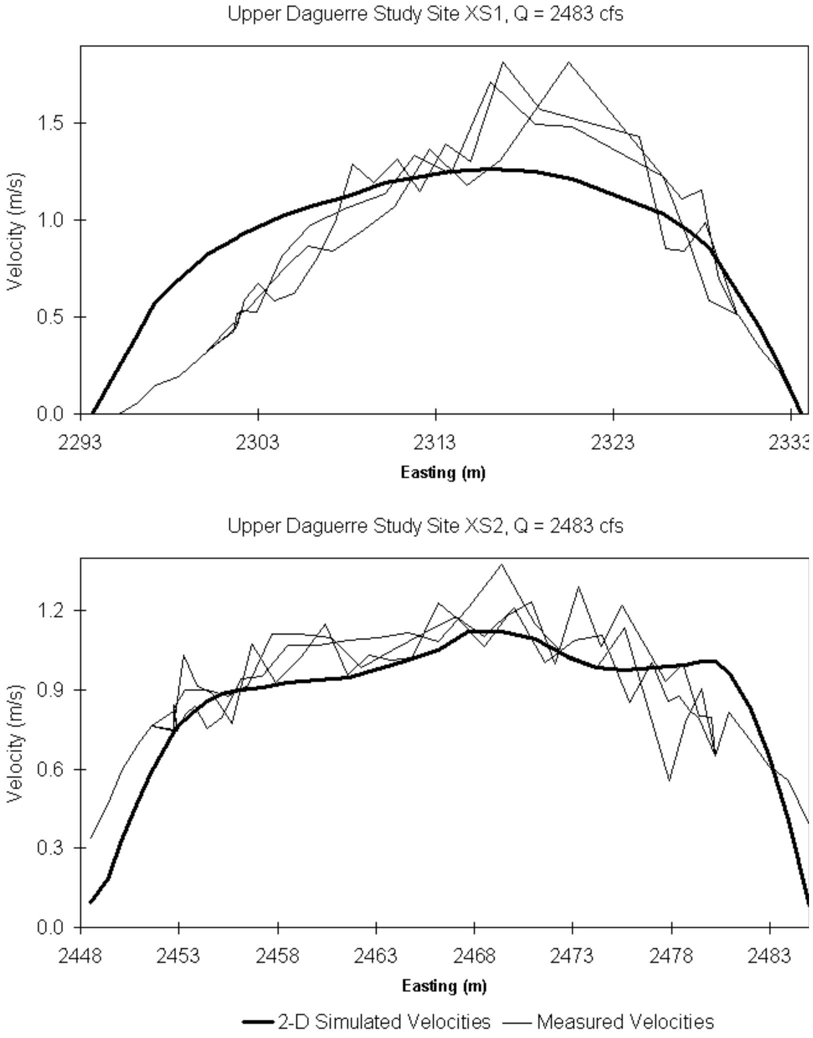
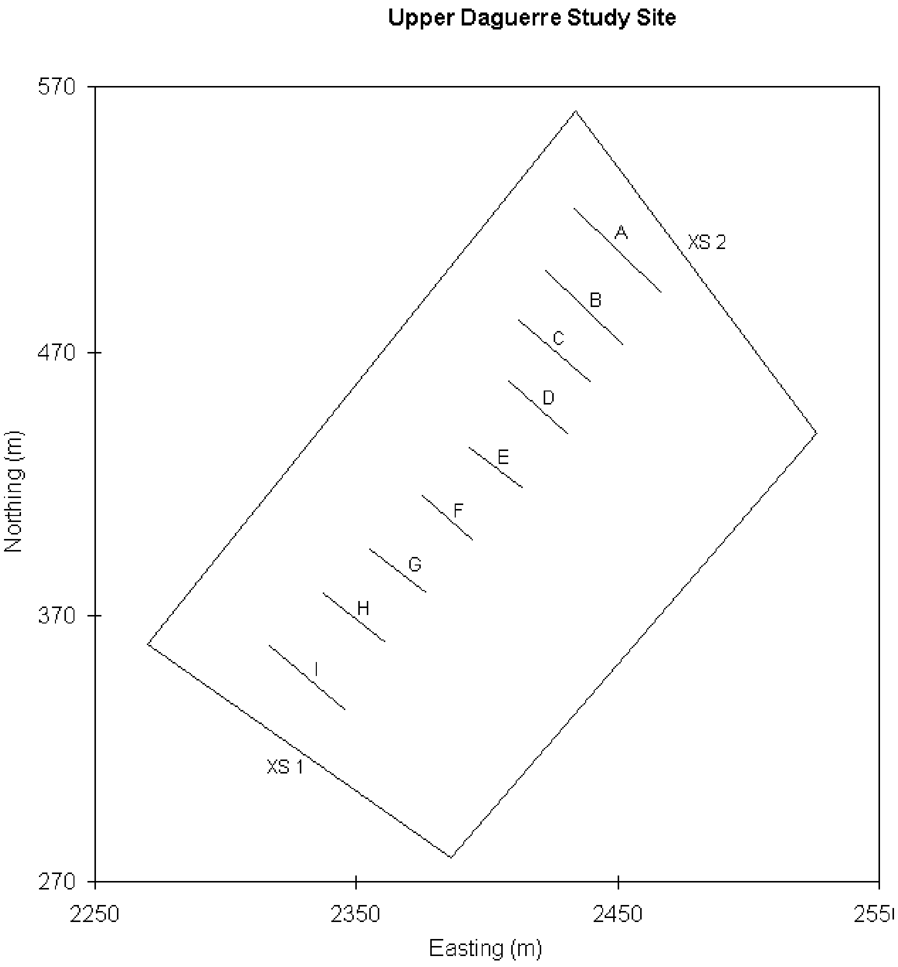

Hammond Study Site
All Validation Velocities
Simulated Velocity (m/s)
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
Measured Velocity (m/s)

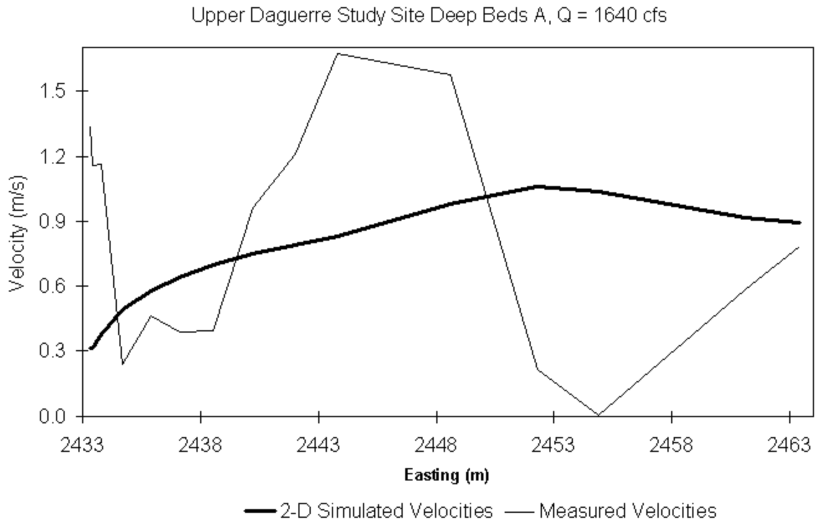

Hammond Study Site
Between Transect Non-ADCP Velocities
Simulated Velocity (m/s)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
Measured Velocity (m/s)

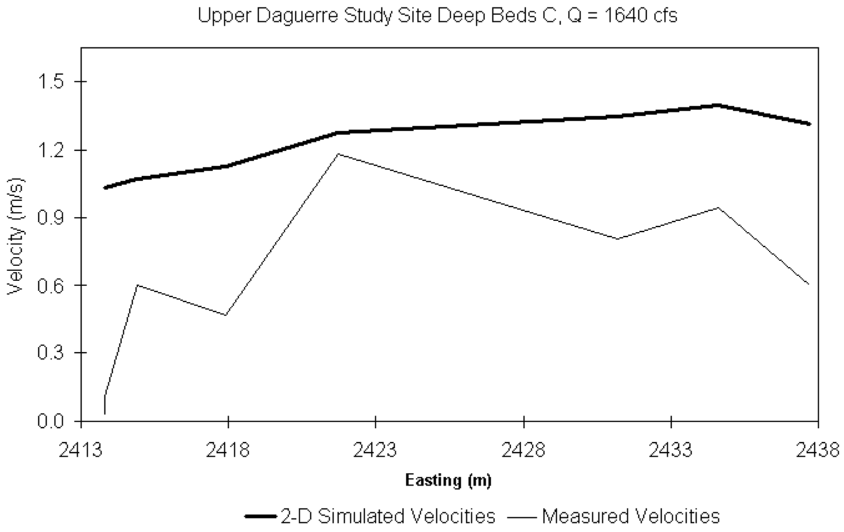
# Upper Daguerre Study Site

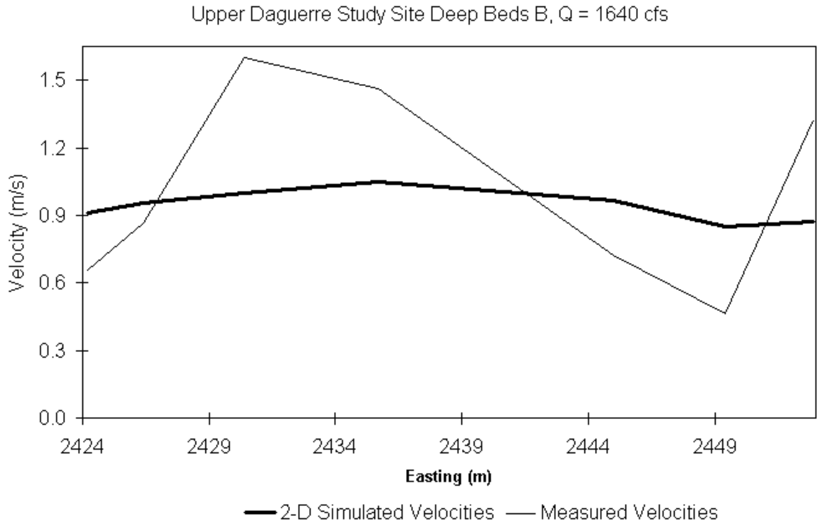


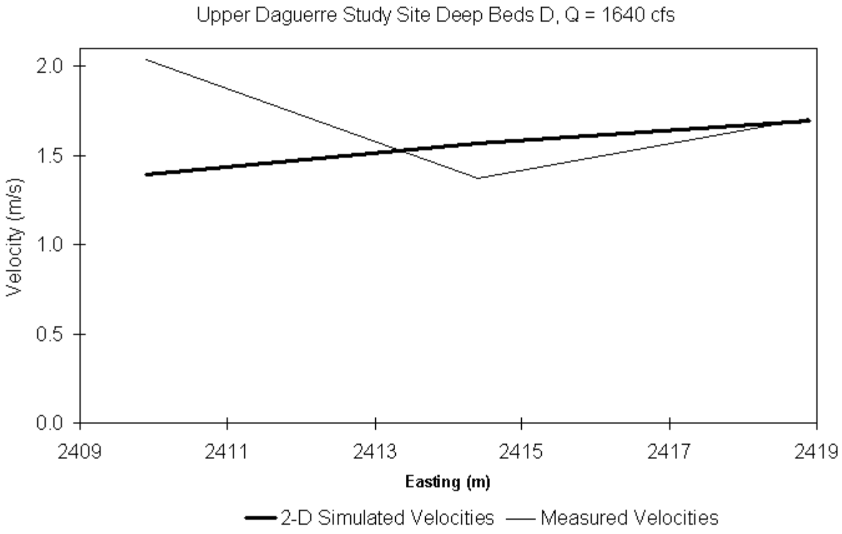


Appendix G

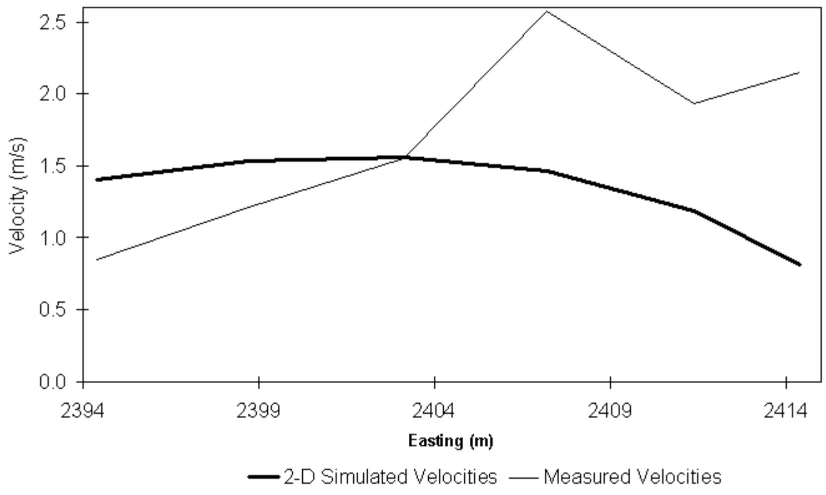

Upper Daguerre Study Site Deep Beds A, Q = 1640 cfs

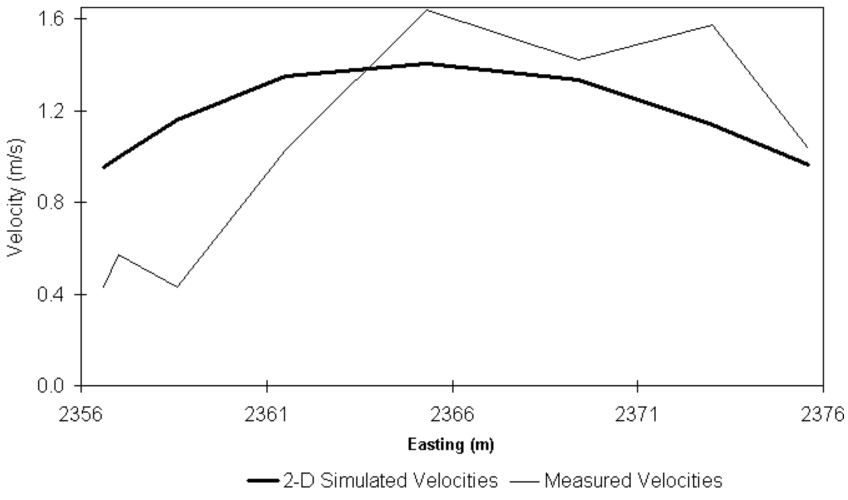

Upper Daguerre Study Site Deep Beds C, Q = 1640 cfs

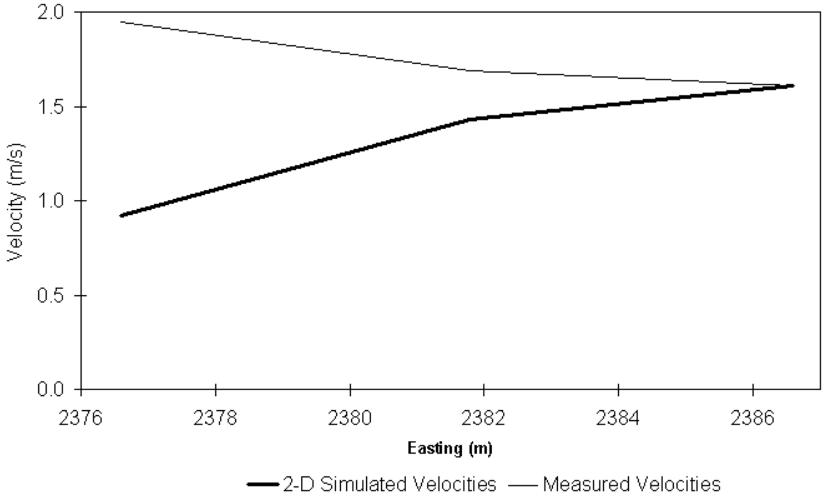

Upper Daguerre Study Site Deep Beds B, Q = 1640 cfs

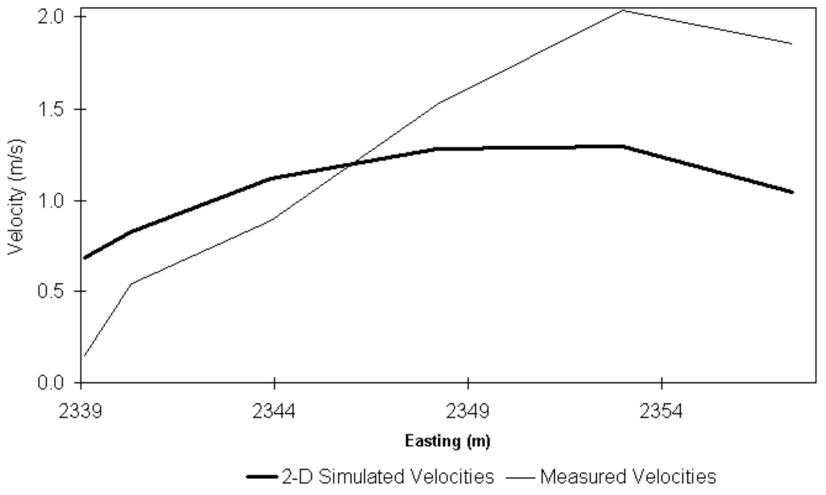

Upper Daguerre Study Site Deep Beds D, Q = 1640 cfs

Appendix G


Upper Daguerre Study Site Deep Beds E, Q = 1640 cfs


Upper Daguerre Study Site Deep Beds G, Q = 1640 cfs


Upper Daguerre Study Site Deep Beds F, Q = 1640 cfs


Upper Daguerre Study Site Deep Beds H, Q = 1640 cfs

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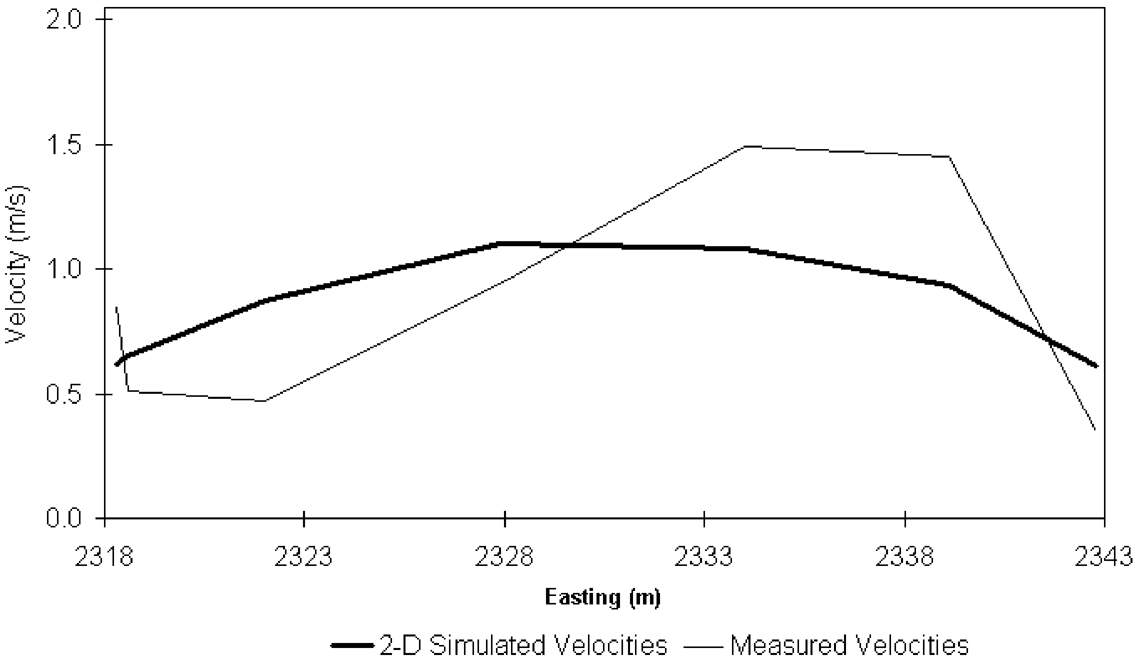
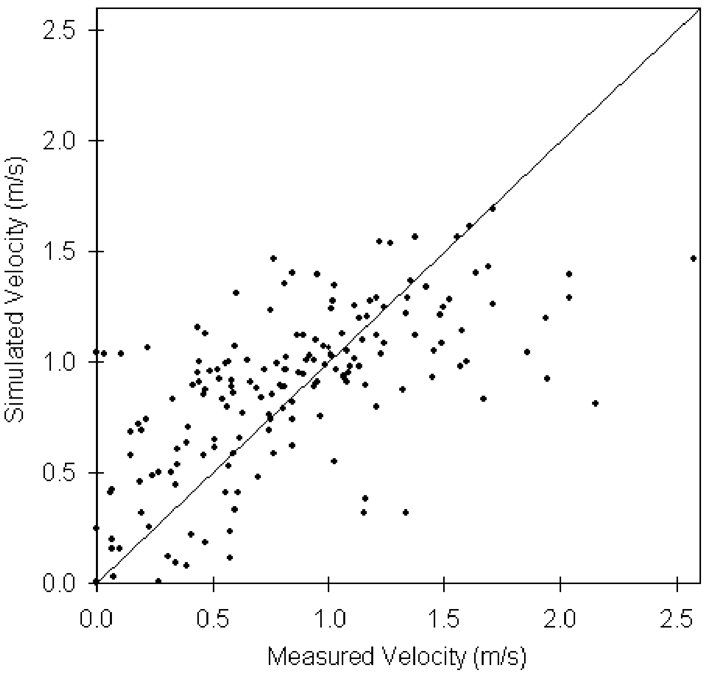
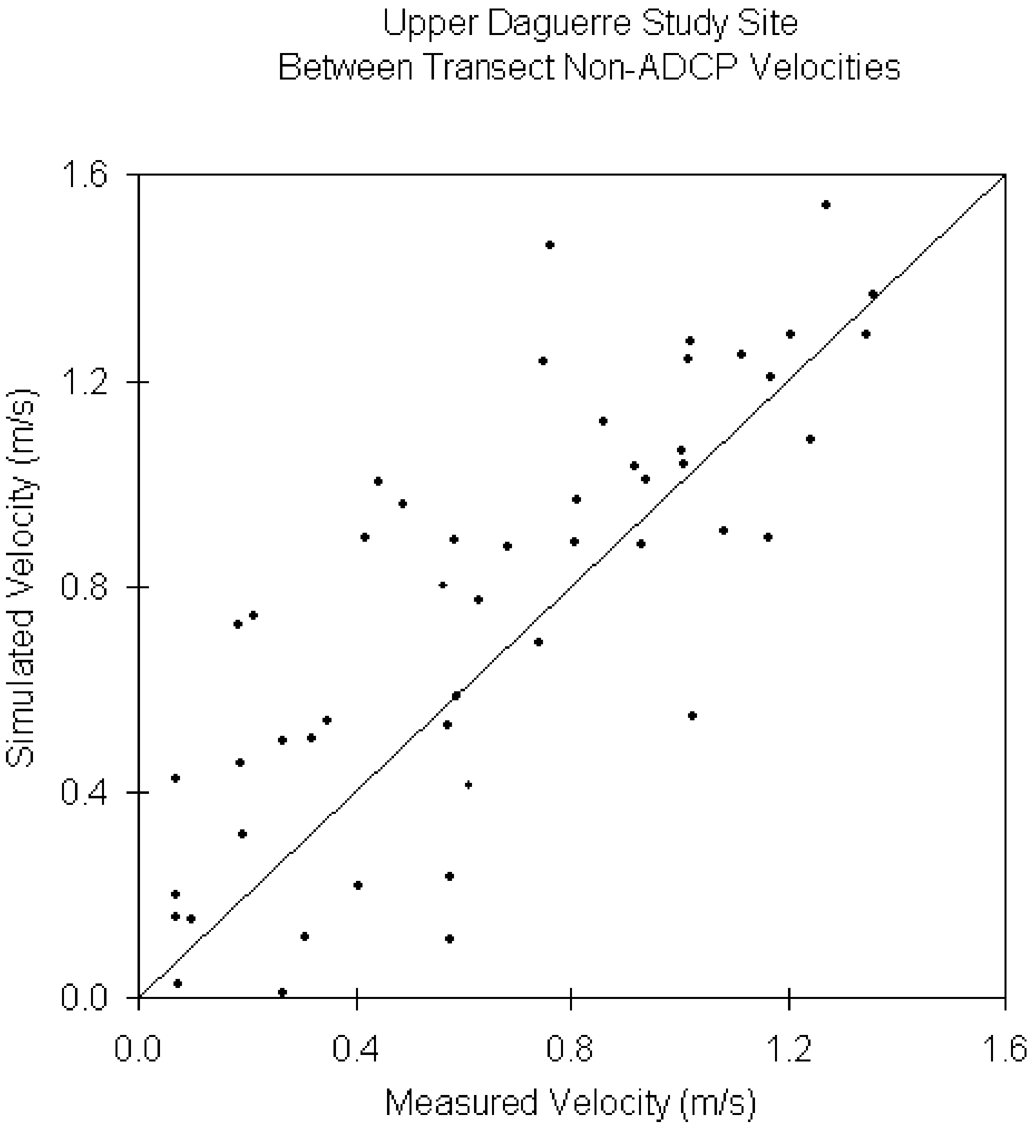

Upper Daguerre Study Site Deep Beds I, Q = 1640 cfs


Upper Daguerre Study Site
All Validation Velocities


Upper Daguerre Study Site
Between Transect Non-ADCP Velocities
Simulated Velocity (m/s)
Measured Velocity (m/s)
0.0
0.4
0.8
1.2
1.6
0.0
0.4
0.8
1.2
1.6

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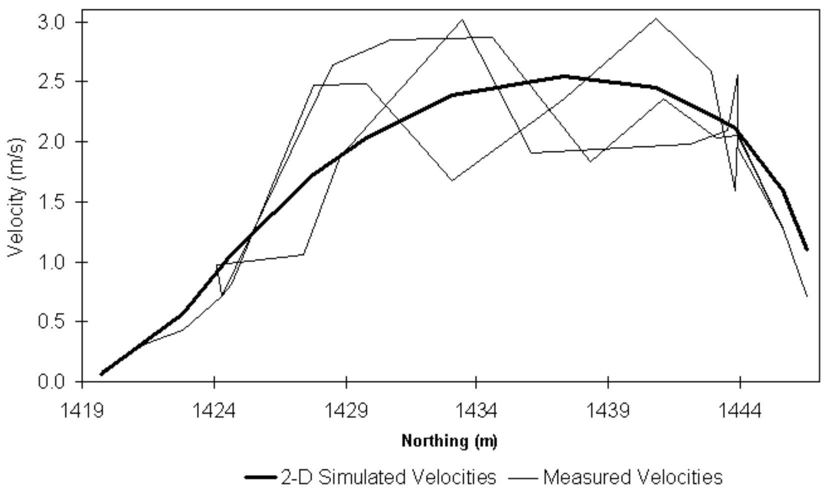
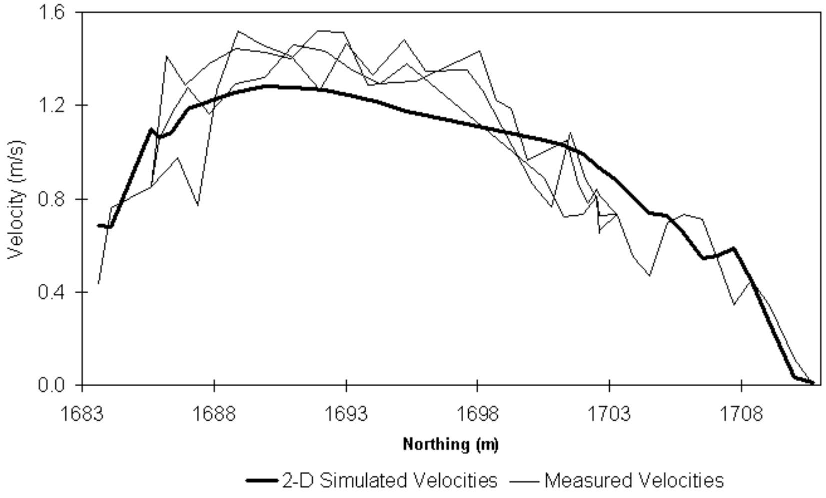
## Lower Daguerre Study Site

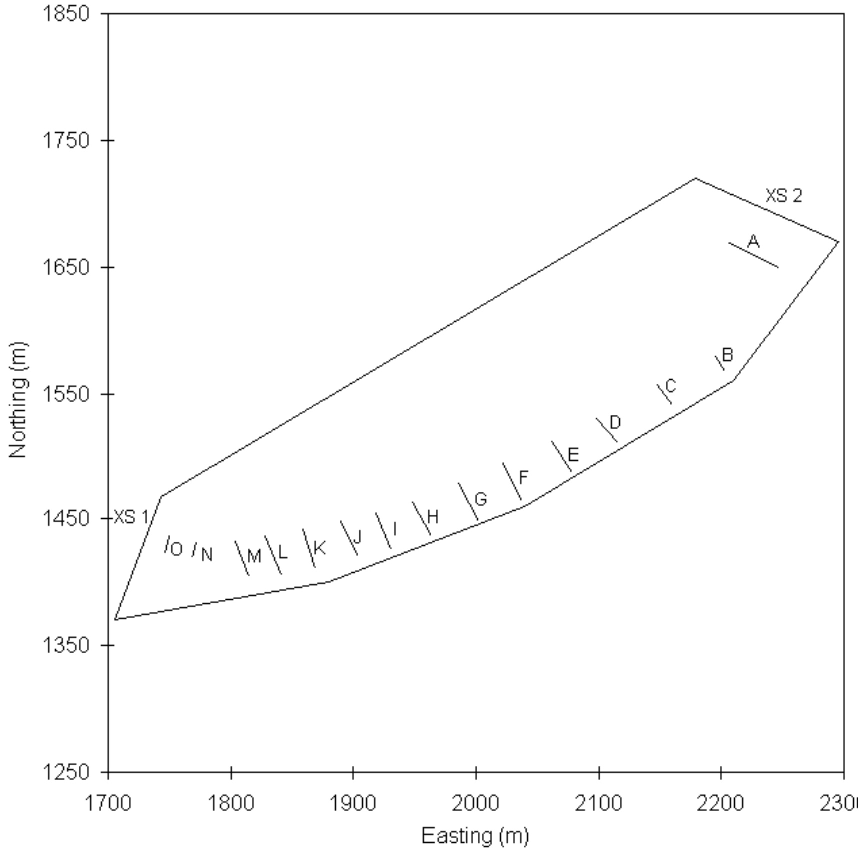
Lower Daguerre Study Site XS1, Q = 2483 cfs



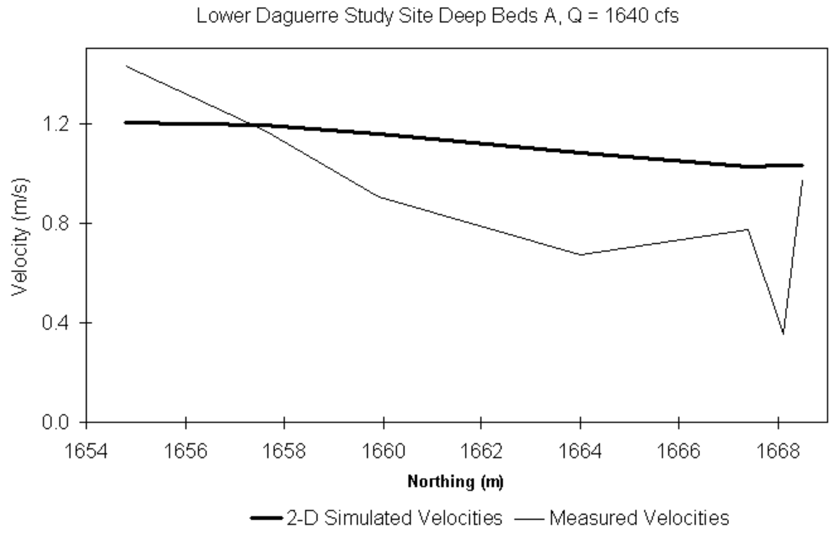
Lower Daguerre Study Site XS2, Q = 2483 cfs

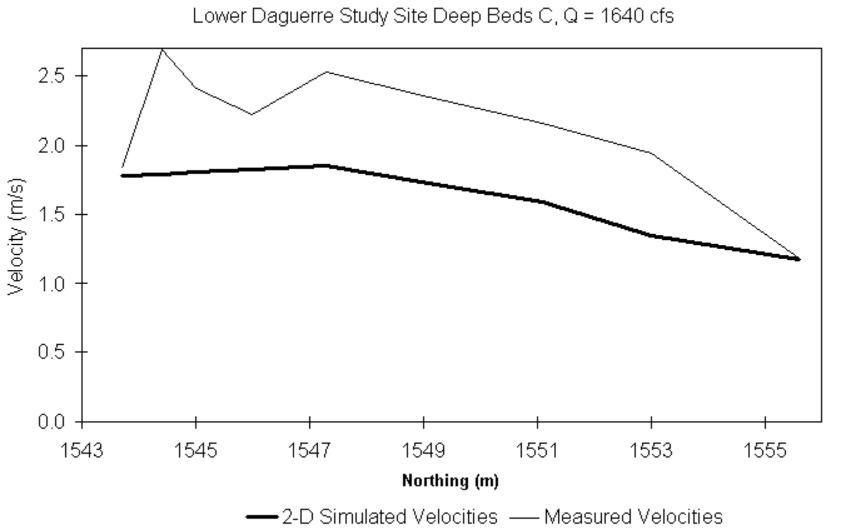


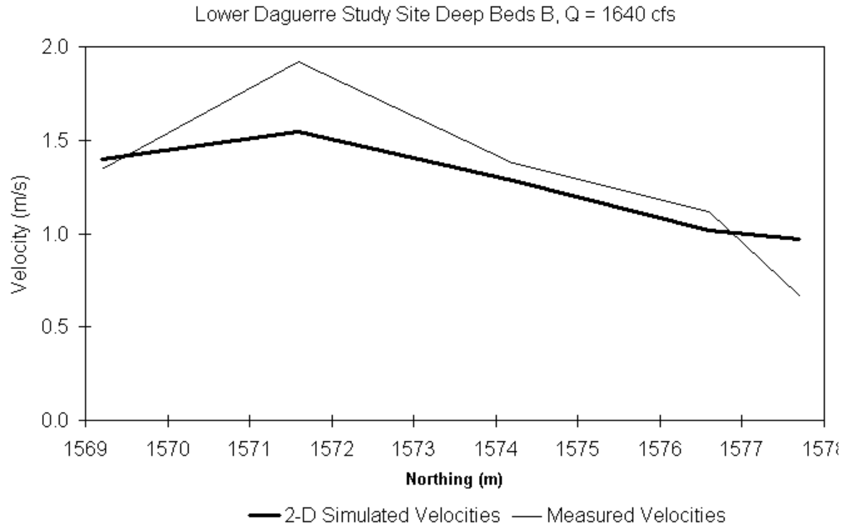
**Lower Daguerre Study Site**

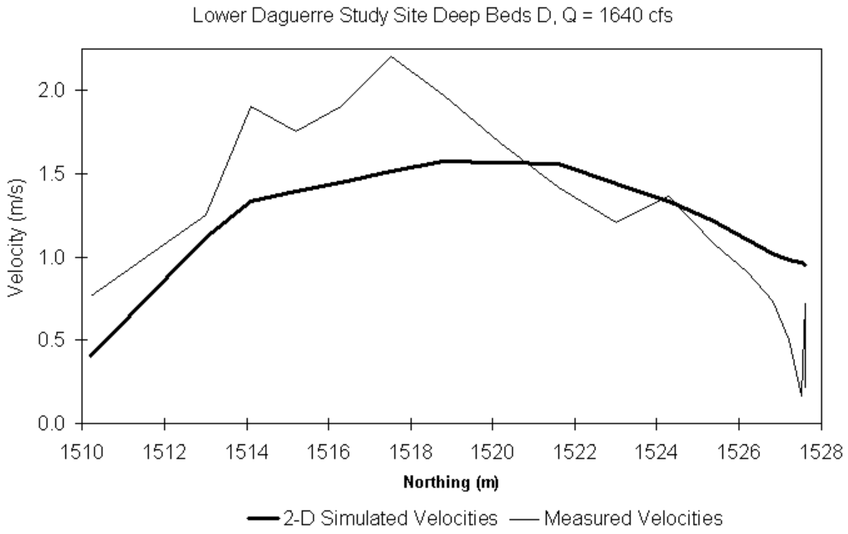


Appendix G

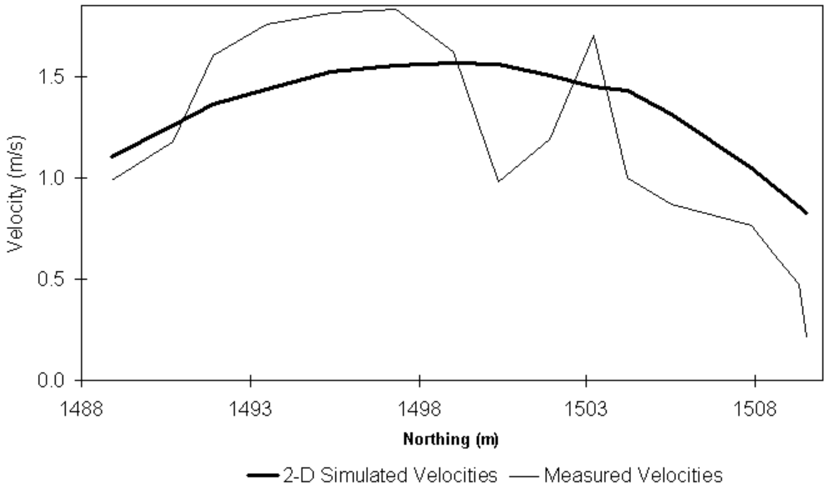

Lower Daguerre Study Site Deep Beds A, Q = 1640 cfs


Lower Daguerre Study Site Deep Beds C, Q = 1640 cfs

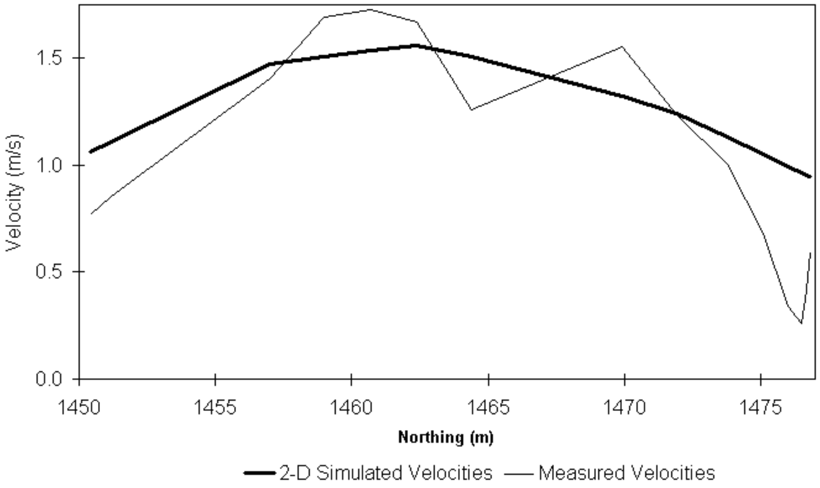

Lower Daguerre Study Site Deep Beds B, Q = 1640 cfs


Lower Daguerre Study Site Deep Beds D, Q = 1640 cfs

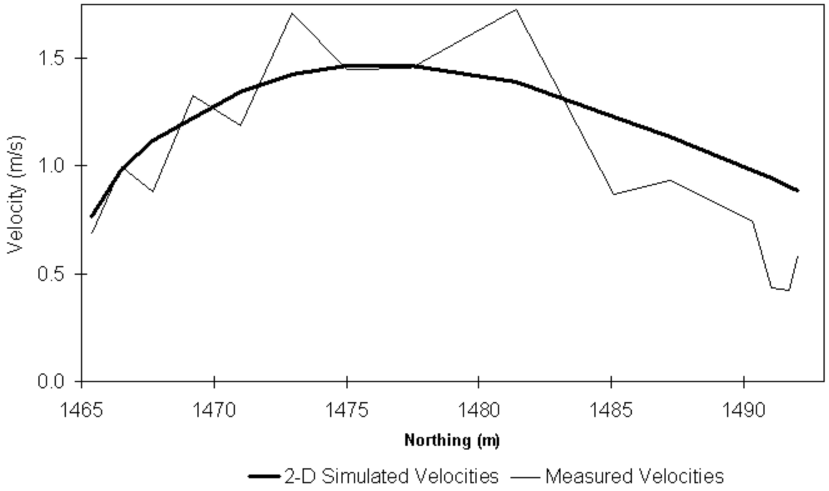
Lower Daguerre Study Site Deep Beds E, Q = 1640 cfs



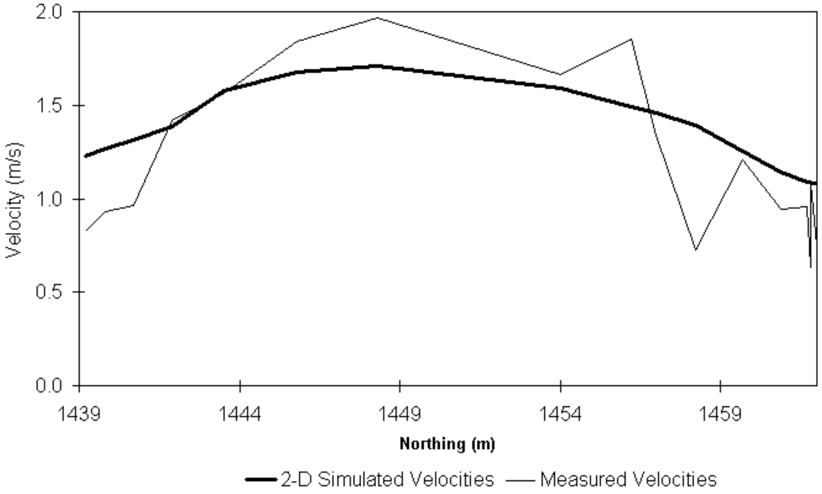
Lower Daguerre Study Site Deep Beds G, Q = 1640 cfs

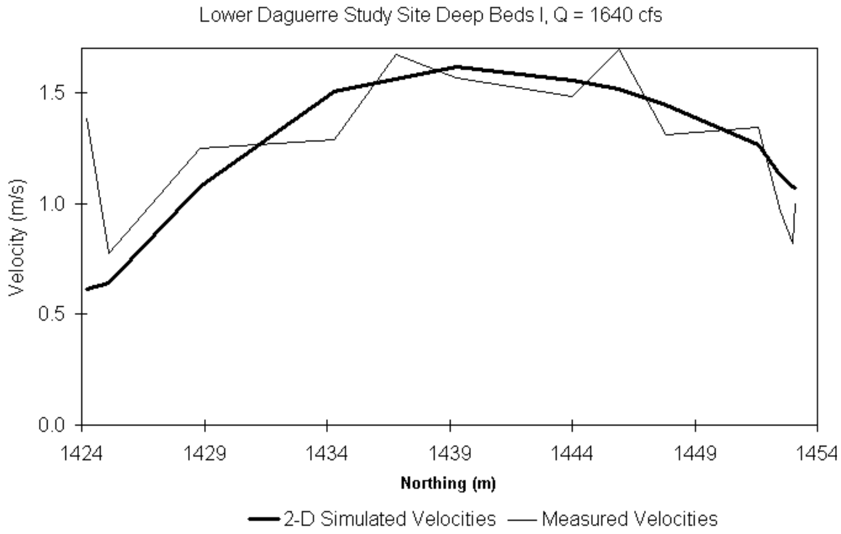


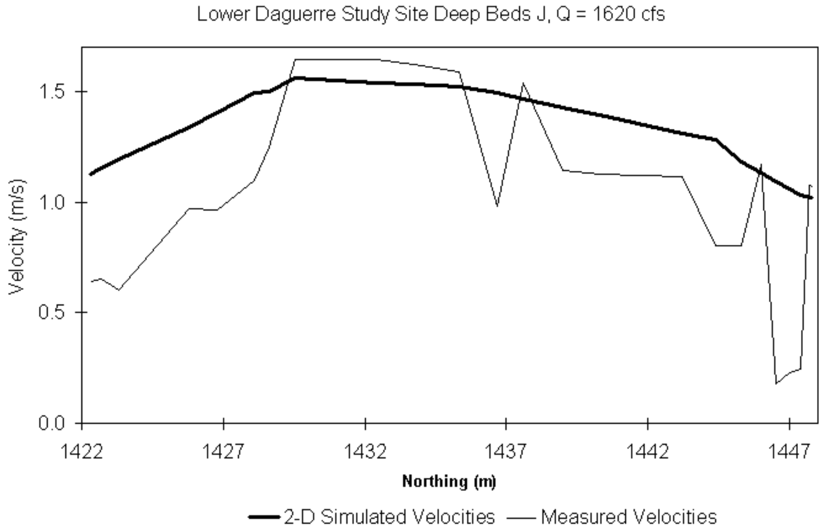
Lower Daguerre Study Site Deep Beds F, Q = 1640 cfs

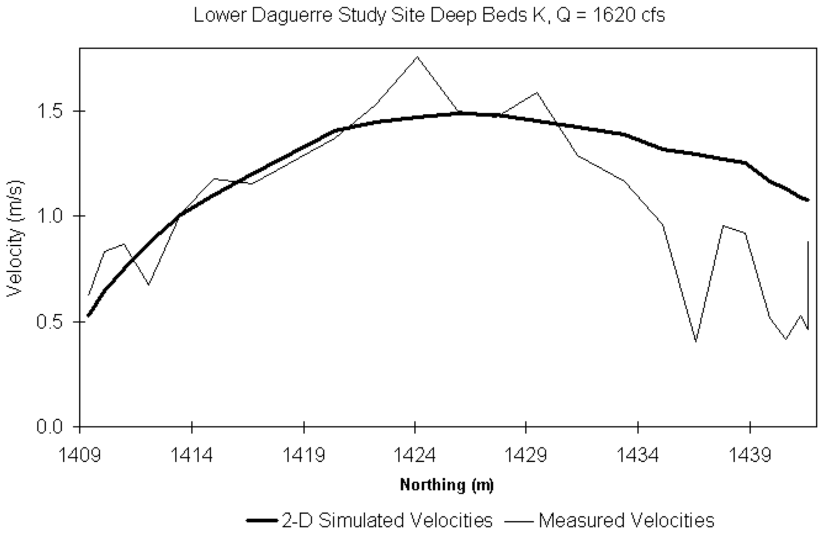


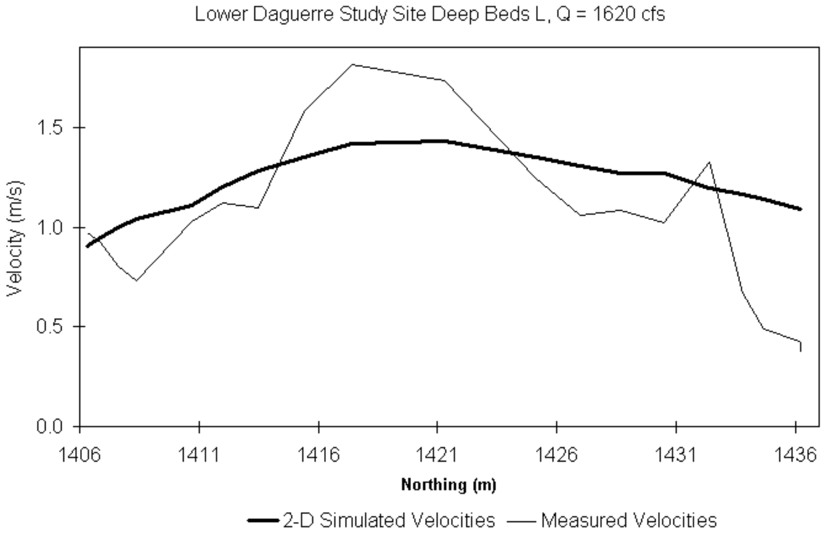
Lower Daguerre Study Site Deep Beds H, Q = 1640 cfs



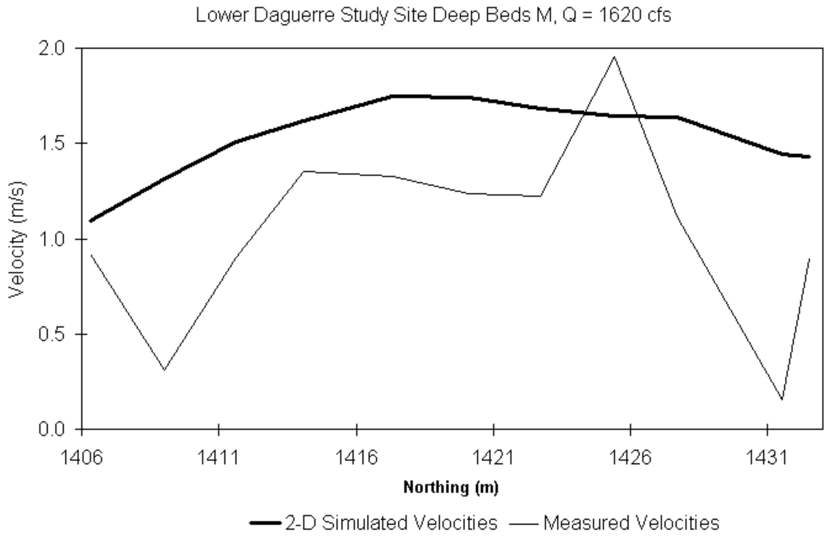

Lower Daguerre Study Site Deep Beds I, Q = 1640 cfs

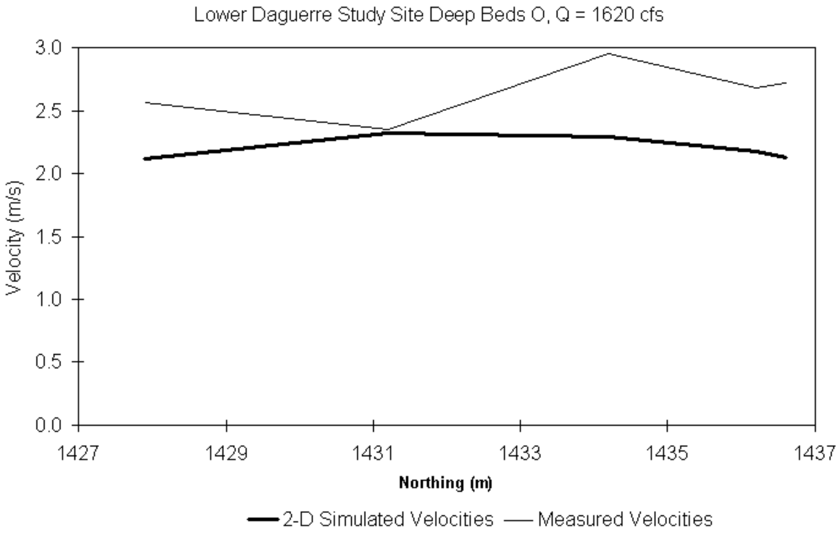

Lower Daguerre Study Site Deep Beds J, Q = 1620 cfs

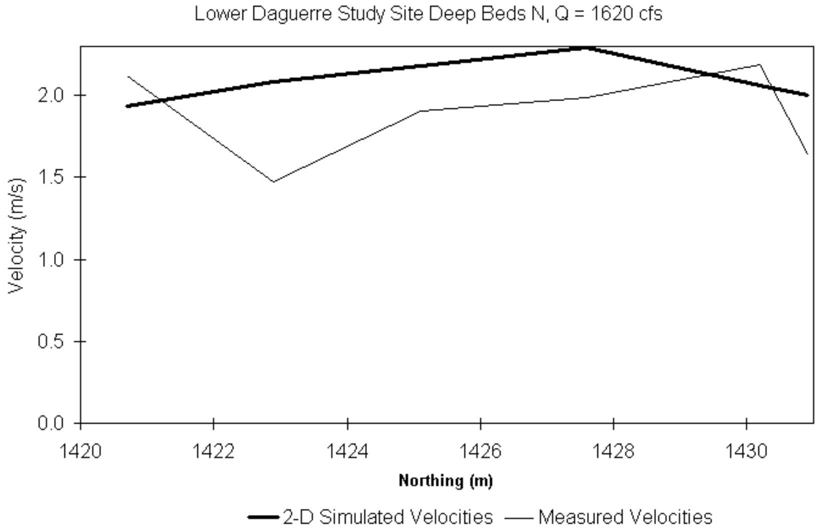

Lower Daguerre Study Site Deep Beds K, Q = 1620 cfs

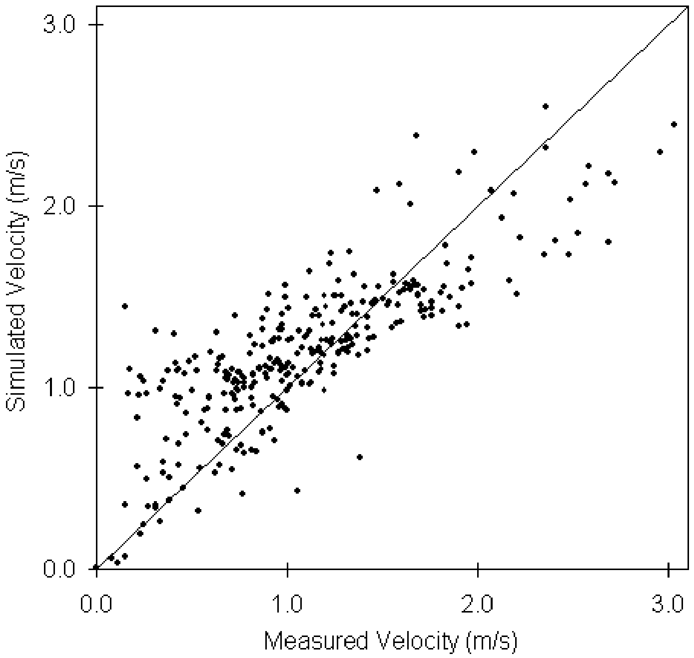

Lower Daguerre Study Site Deep Beds L, Q = 1620 cfs

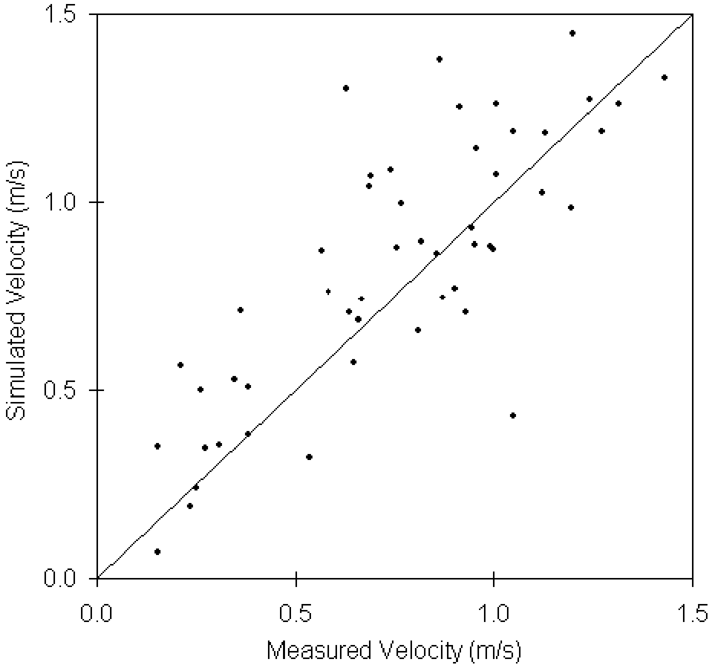
Appendix G


Lower Daguerre Study Site Deep Beds M, Q = 1620 cfs
Velocity (m/s)
2.0
1.5
1.0
0.5
0.0
1406
1411
1416
1421
1426
1431
Northing (m)
2-D Simulated Velocities
Measured Velocities

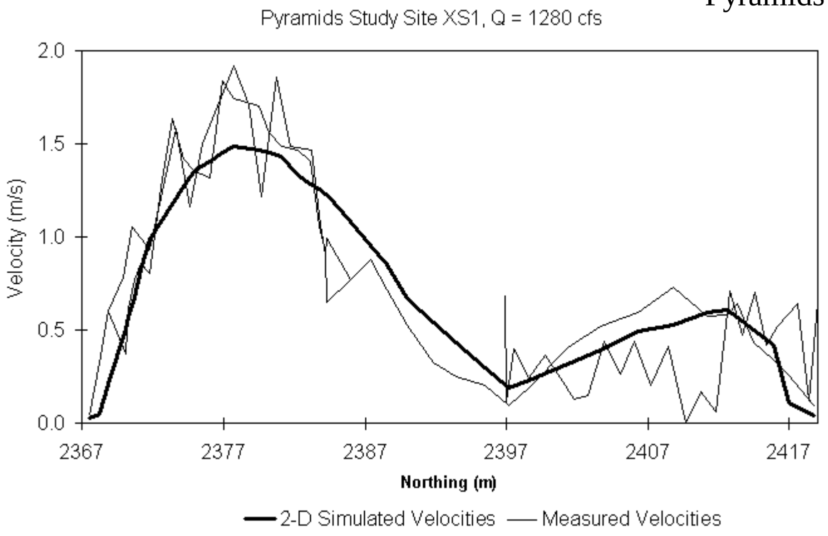

Lower Daguerre Study Site Deep Beds O, Q = 1620 cfs
Velocity (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1427
1429
1431
1433
1435
1437
Northing (m)
2-D Simulated Velocities
Measured Velocities

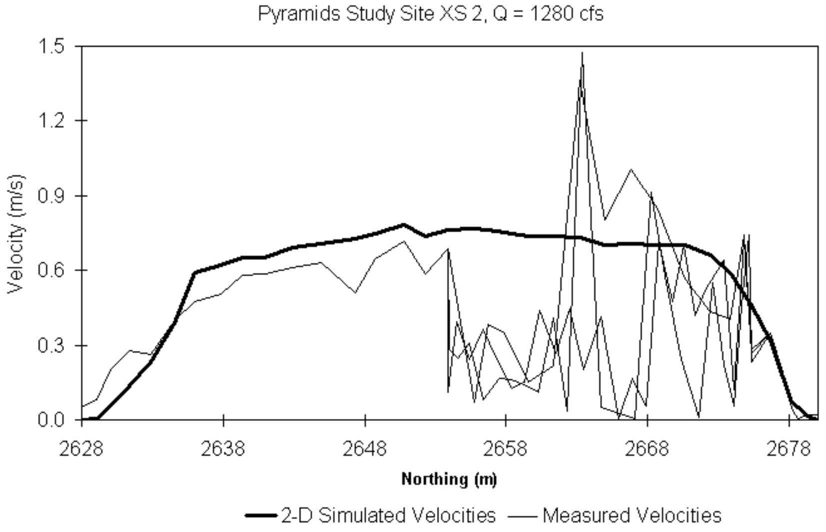

Lower Daguerre Study Site Deep Beds N, Q = 1620 cfs
Velocity (m/s)
2.0
1.5
1.0
0.5
0.0
1420
1422
1424
1426
1428
1430
Northing (m)
2-D Simulated Velocities
Measured Velocities

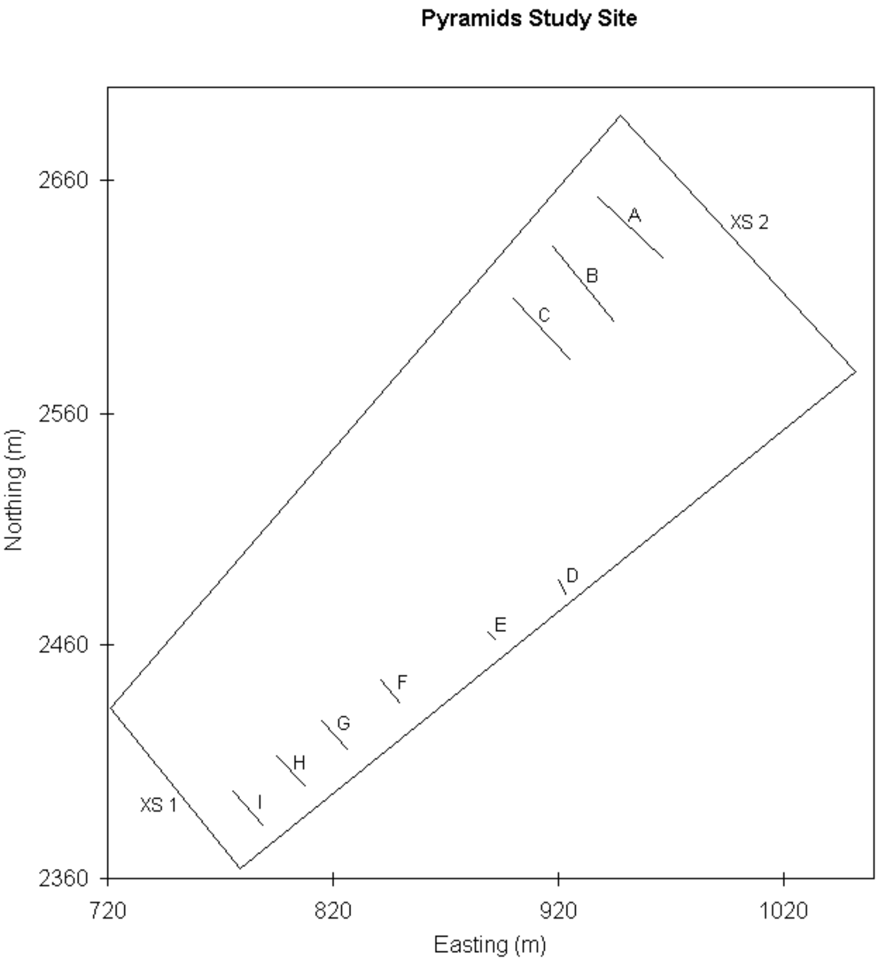

Lower Daguerre Study Site
All Validation Velocities

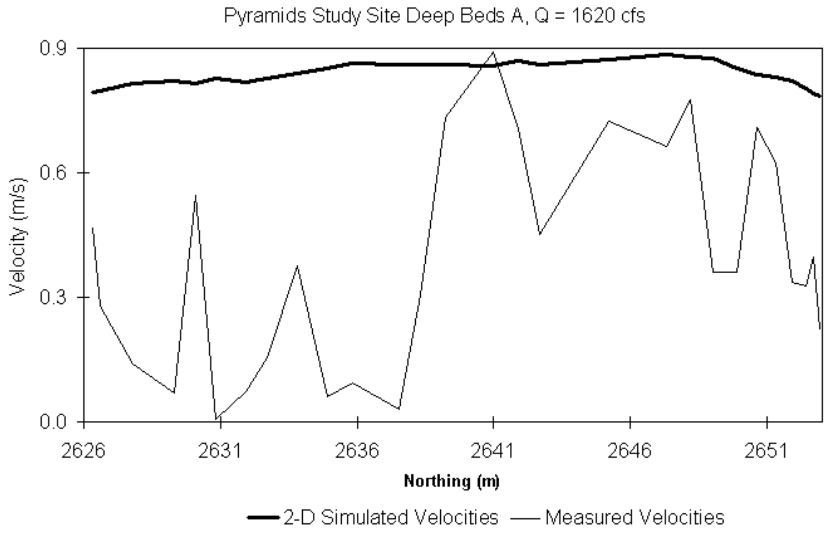

Lower Daguerre Study Site
Between Transect Non-ADCP Velocities

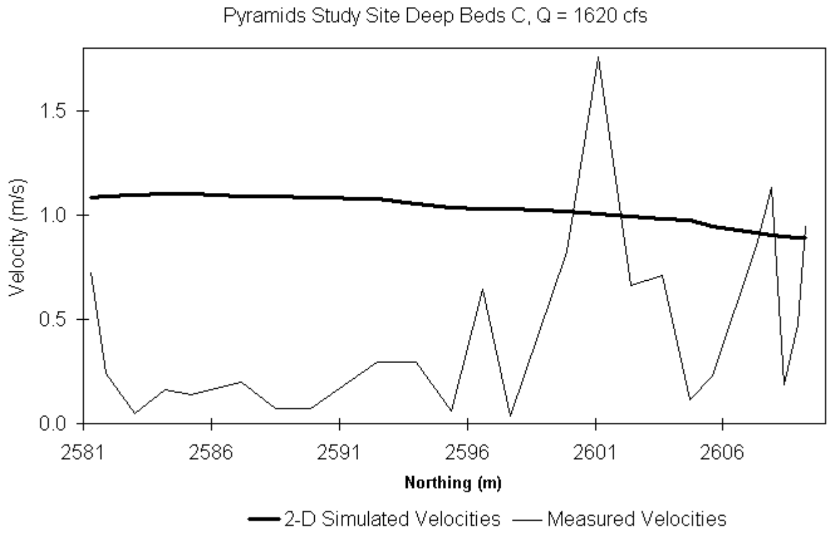
# Pyramids Study Site

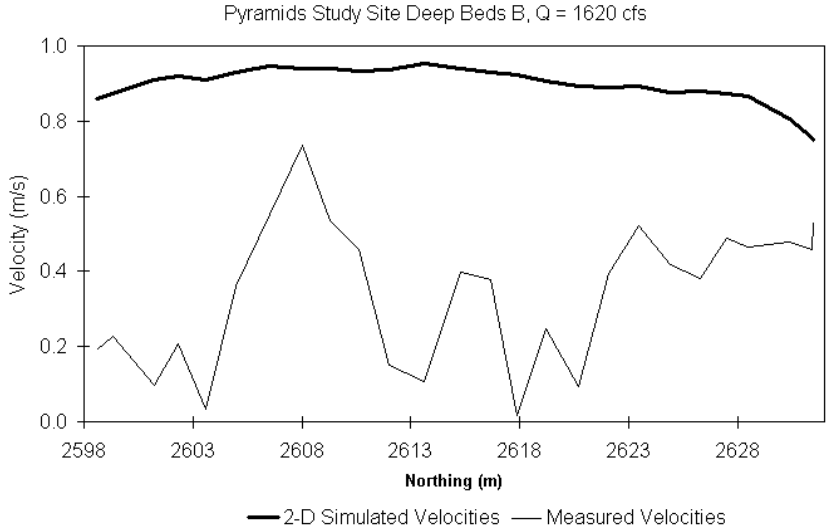


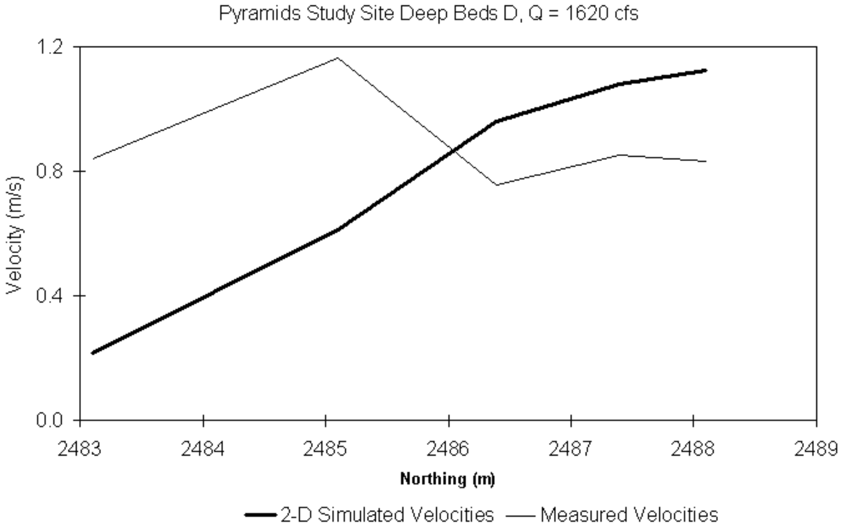





Pyramids Study Site Deep Beds A, Q = 1620 cfs
Velocity (m/s)
0.9
0.6
0.3
0.0
2626
2631
2636
2641
2646
2651
Northing (m)
2-D Simulated Velocities
Measured Velocities

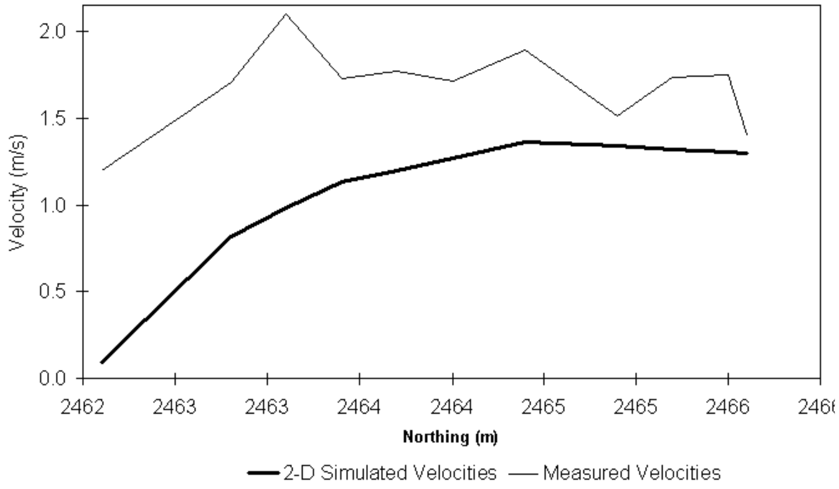

Pyramids Study Site Deep Beds C, Q = 1620 cfs
Velocity (m/s)
1.5
1.0
0.5
0.0
2581
2586
2591
2596
2601
2606
Northing (m)
2-D Simulated Velocities
Measured Velocities


Pyramids Study Site Deep Beds B, Q = 1620 cfs
Velocity (m/s)
1.0
0.8
0.6
0.4
0.2
0.0
2598
2603
2608
2613
2618
2623
2628
Northing (m)
2-D Simulated Velocities
Measured Velocities

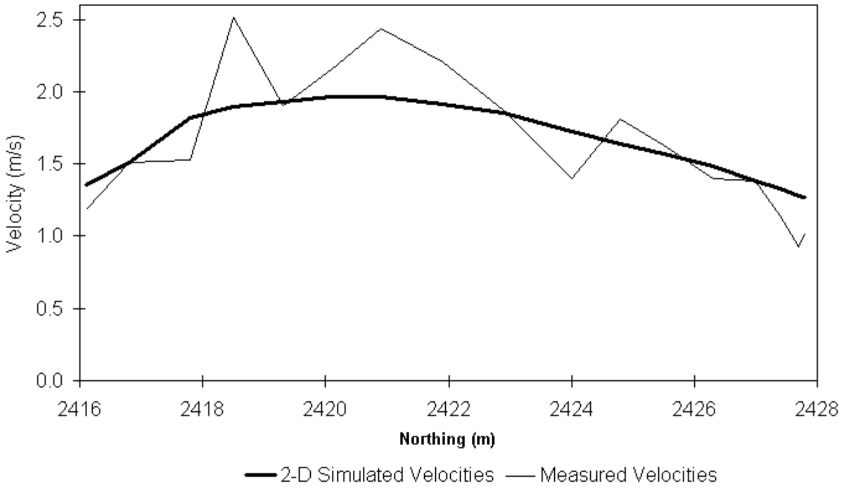

Pyramids Study Site Deep Beds D, Q = 1620 cfs
Velocity (m/s)
1.2
0.8
0.4
0.0
2483
2484
2485
2486
2487
2488
2489
Northing (m)
2-D Simulated Velocities
Measured Velocities

Appendix G

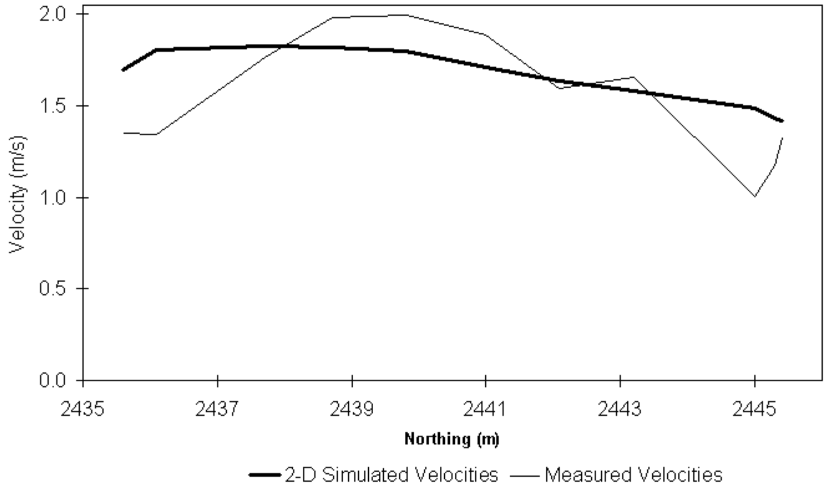
Pyramids Study Site Deep Beds E, Q = 1620 cfs



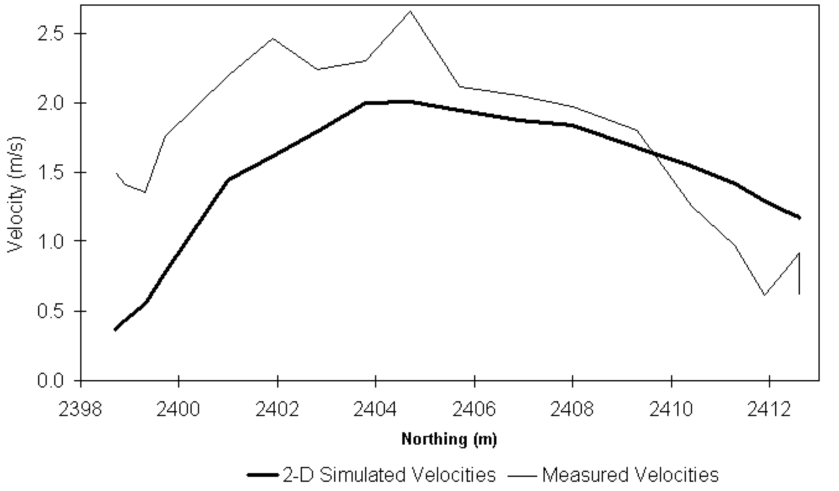
Pyramids Study Site Deep Beds G, Q = 1620 cfs



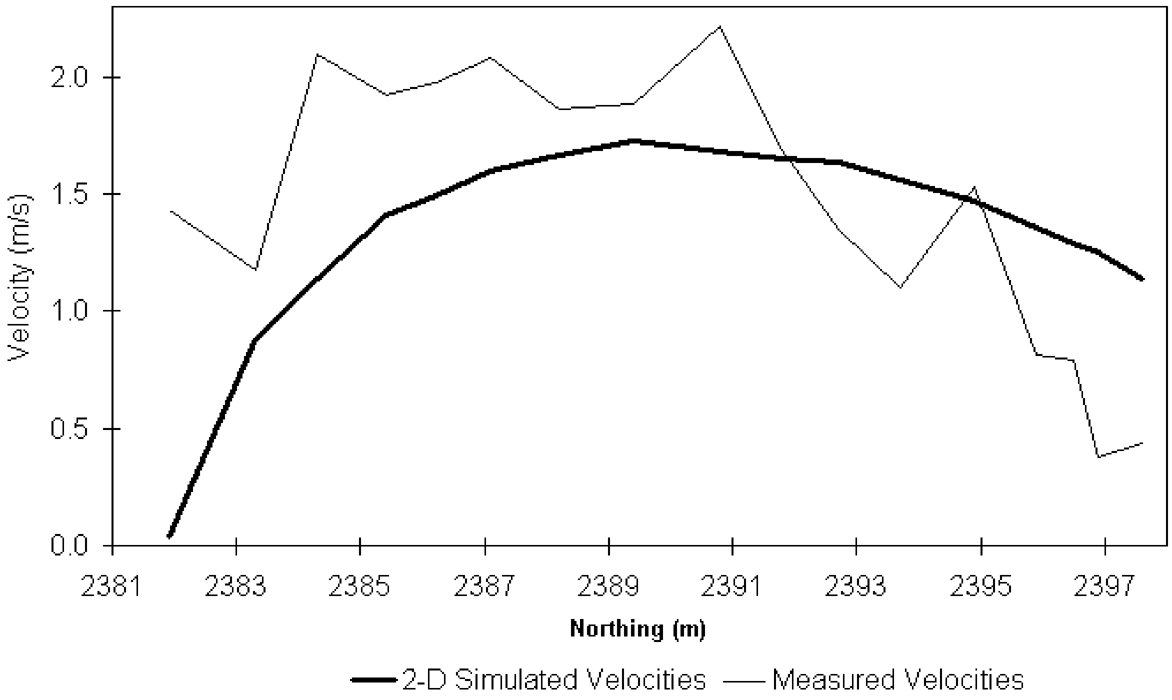
Pyramids Study Site Deep Beds F, Q = 1620 cfs



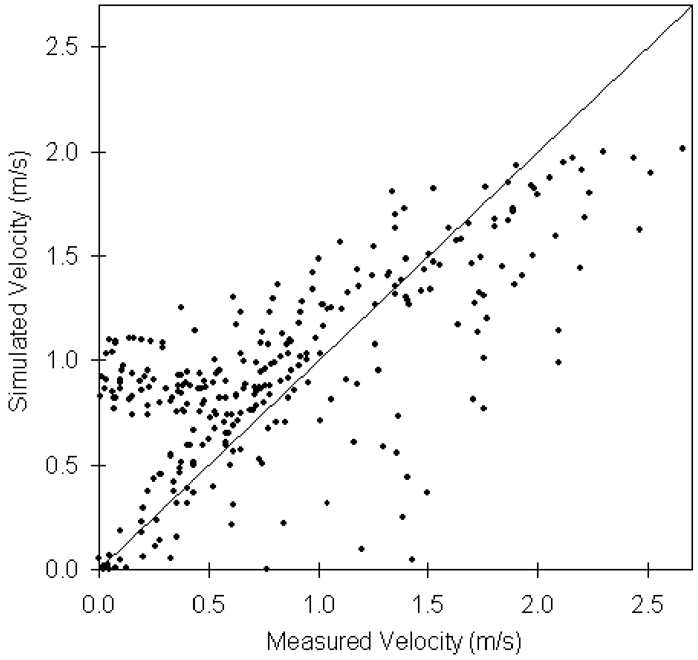
Pyramids Study Site Deep Beds H, Q = 1620 cfs

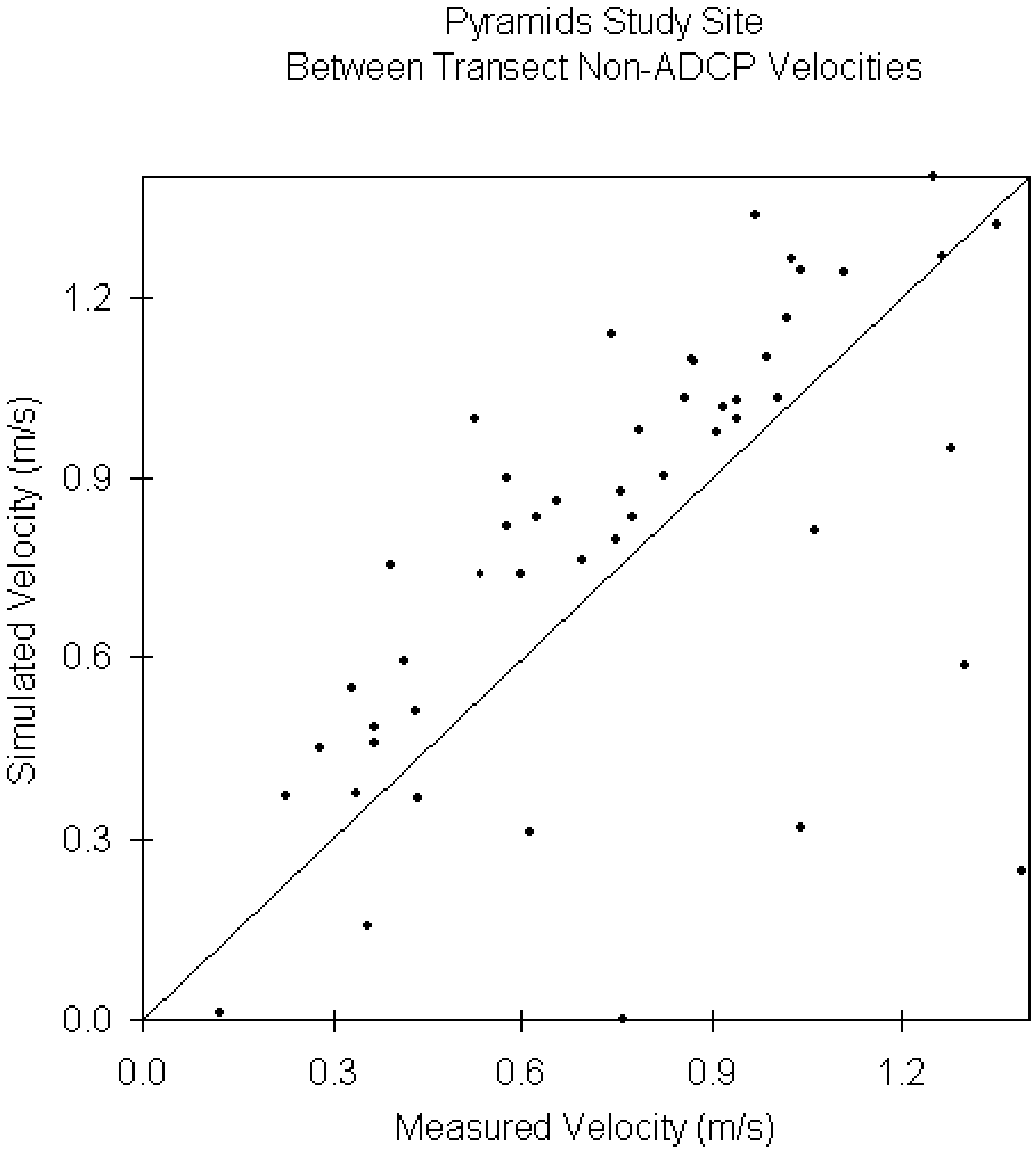


Pyramids Study Site Deep Beds I, Q = 1620 cfs

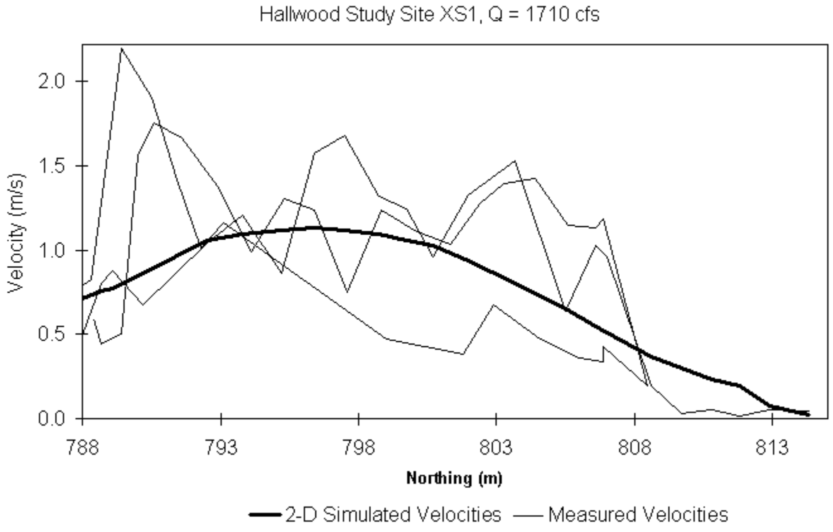


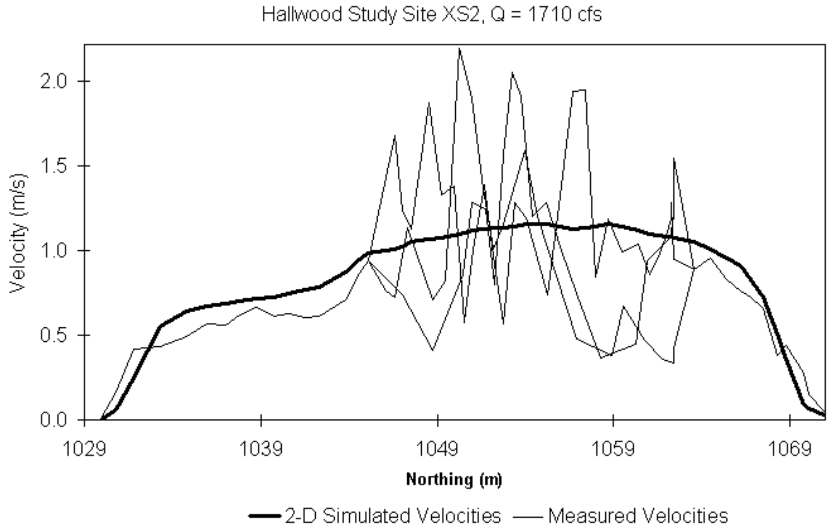
Pyramids Study Site
All Validation Velocities

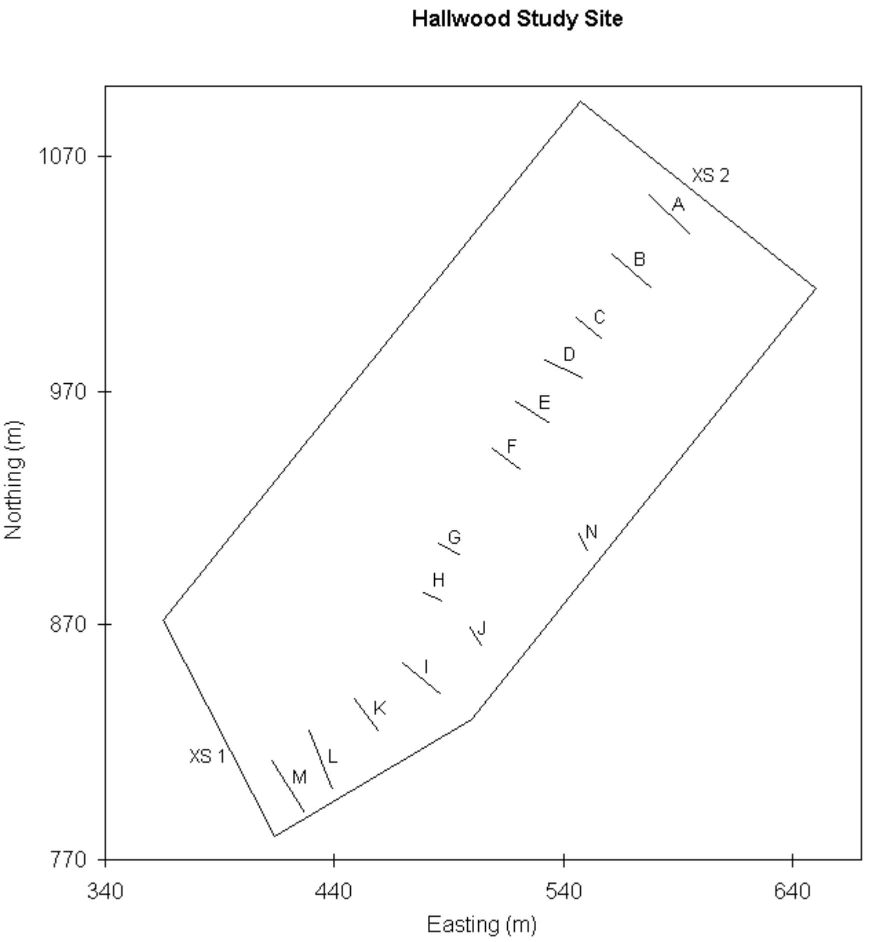



Pyramids Study Site
Between Transect Non-ADCP Velocities
Simulated Velocity (m/s)
0.0
0.3
0.6
0.9
1.2
0.0
0.3
0.6
0.9
1.2
Measured Velocity (m/s)

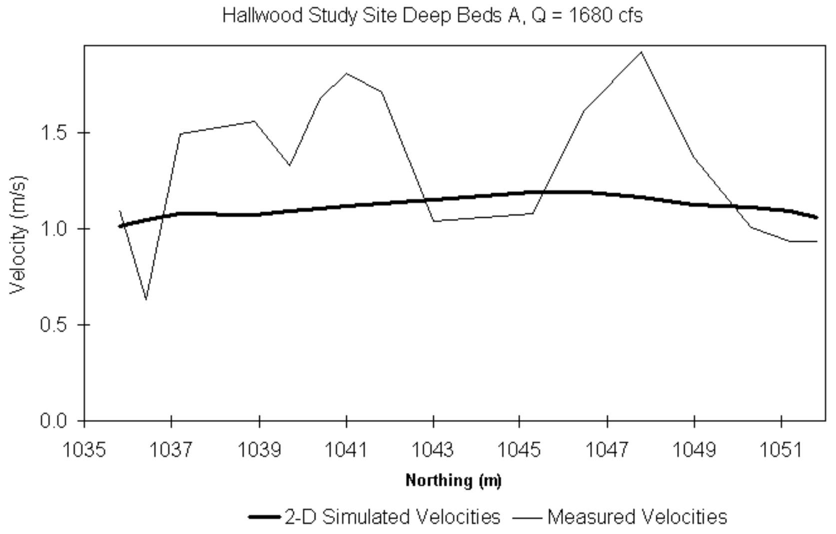
## Hallwood Study Site

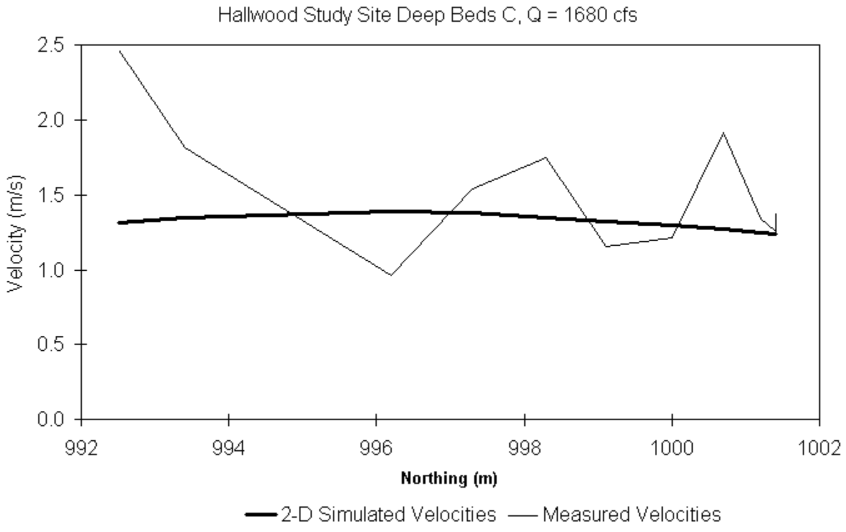

Hallwood Study Site XS1, Q = 1710 cfs

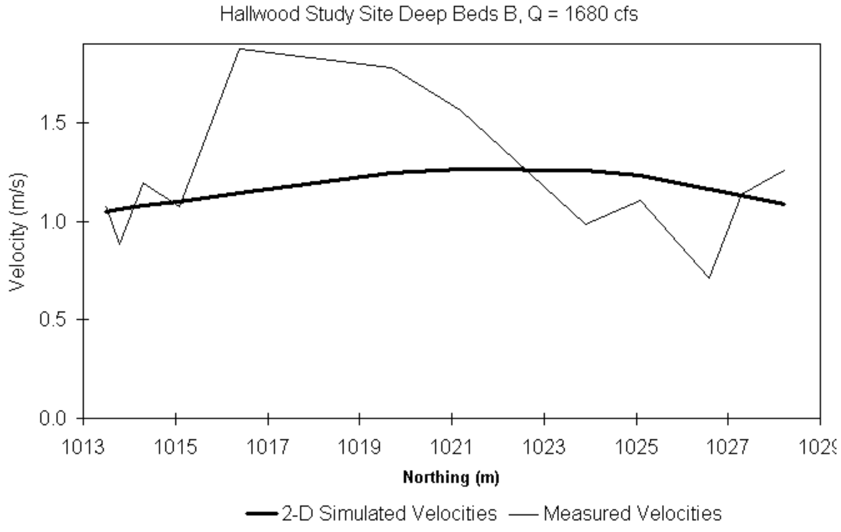

Hallwood Study Site XS2, Q = 1710 cfs

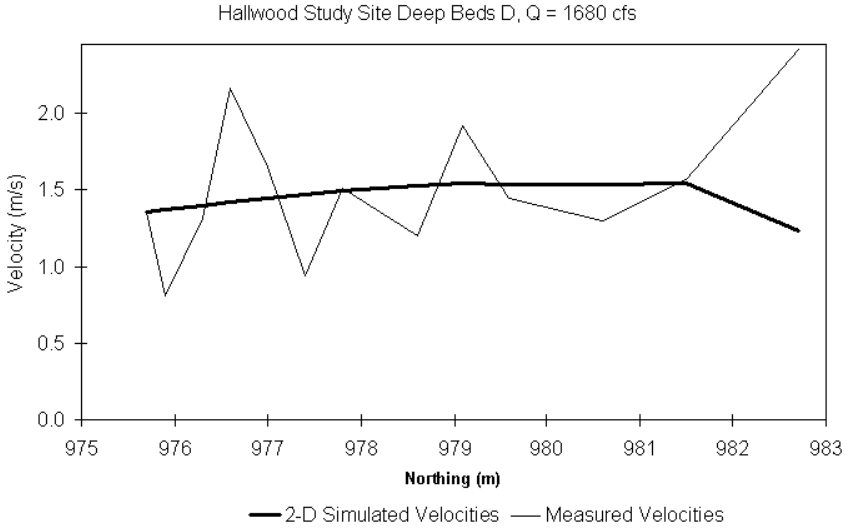

Hallwood Study Site

# Appendix G

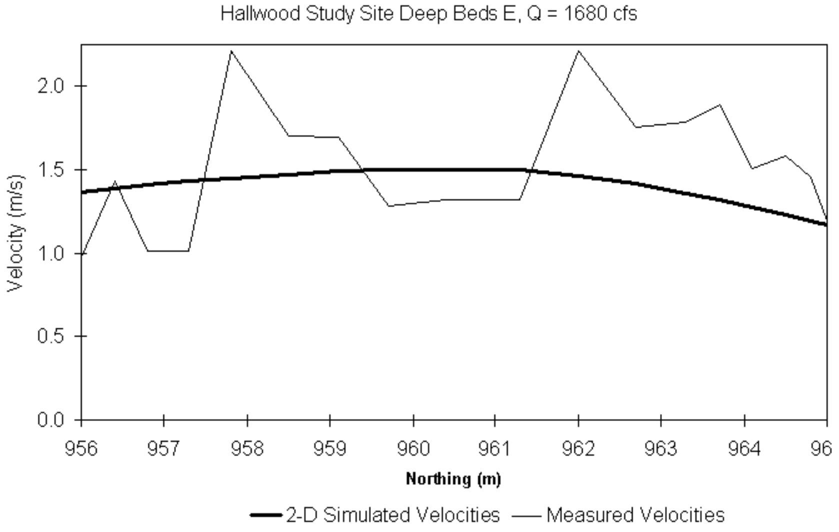

Hallwood Study Site Deep Beds A, Q = 1680 cfs

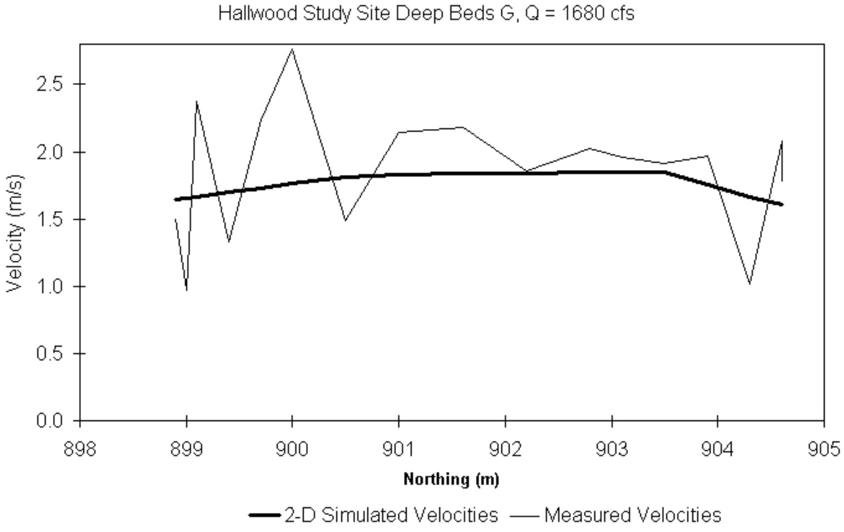

Hallwood Study Site Deep Beds C, Q = 1680 cfs

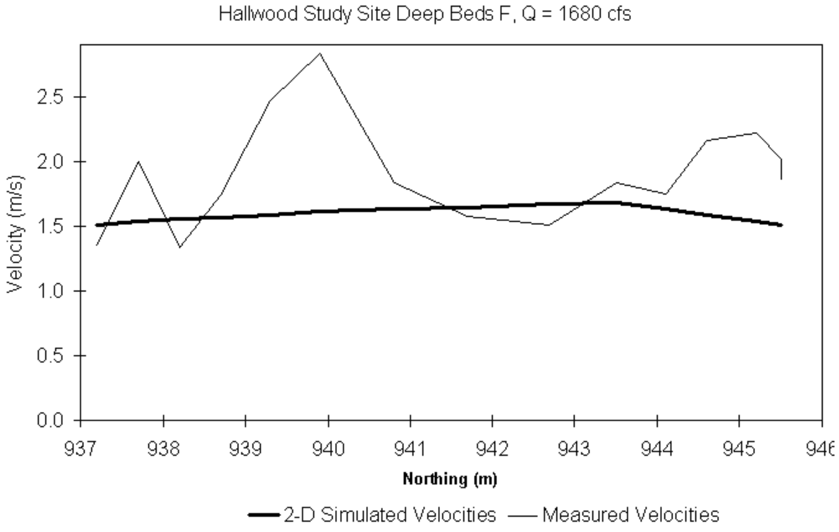

Hallwood Study Site Deep Beds B, Q = 1680 cfs

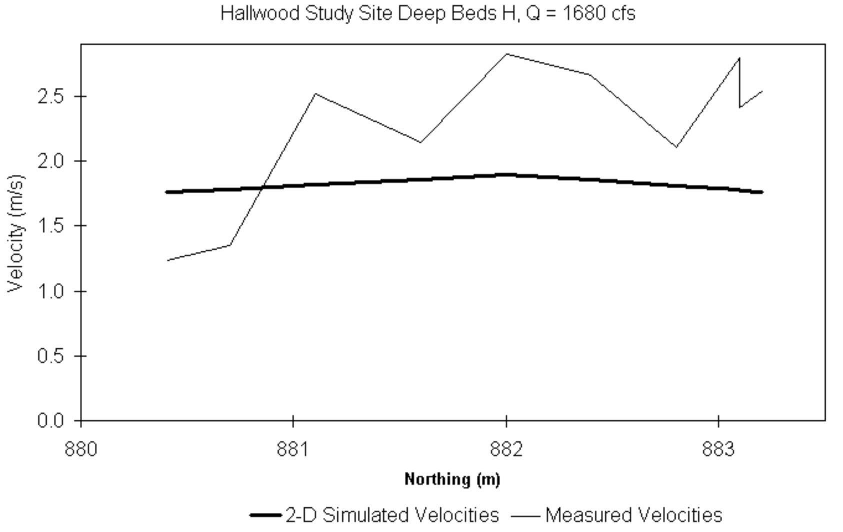

Hallwood Study Site Deep Beds D, Q = 1680 cfs

Appendix G

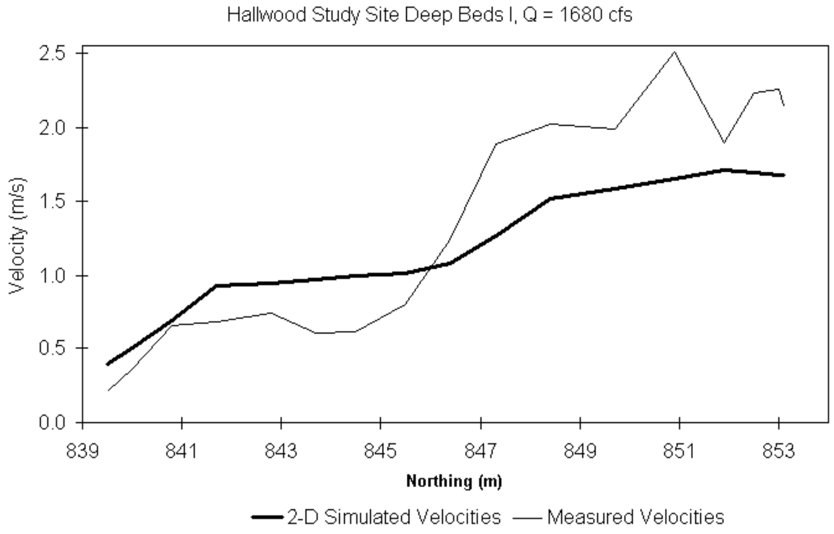

Hallwood Study Site Deep Beds E, Q = 1680 cfs

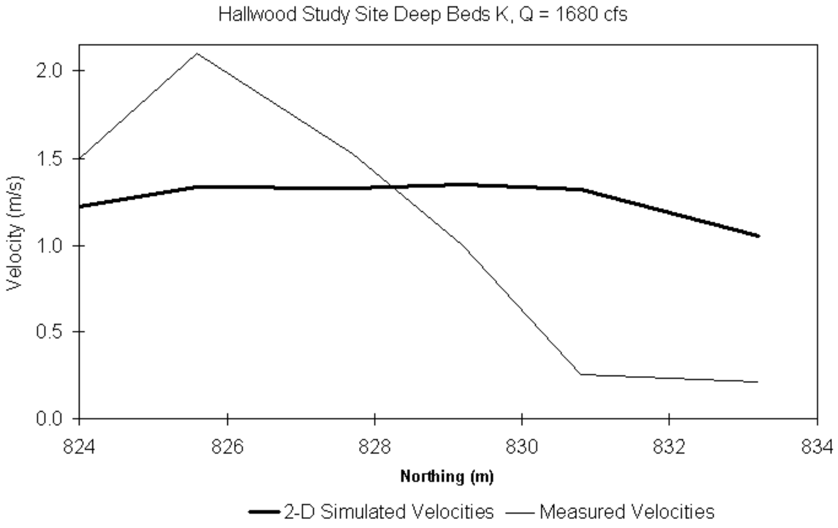

Hallwood Study Site Deep Beds G, Q = 1680 cfs

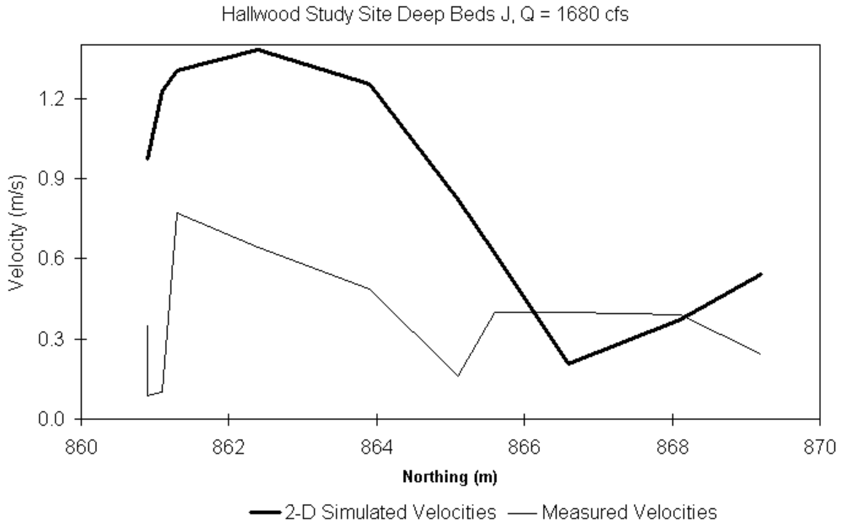

Hallwood Study Site Deep Beds F, Q = 1680 cfs

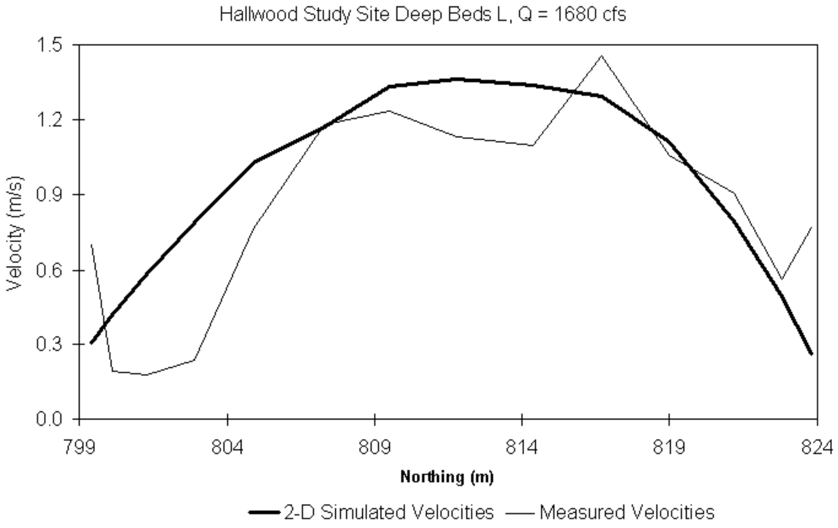

Hallwood Study Site Deep Beds H, Q = 1680 cfs

# Appendix G


Hallwood Study Site Deep Beds I, Q = 1680 cfs

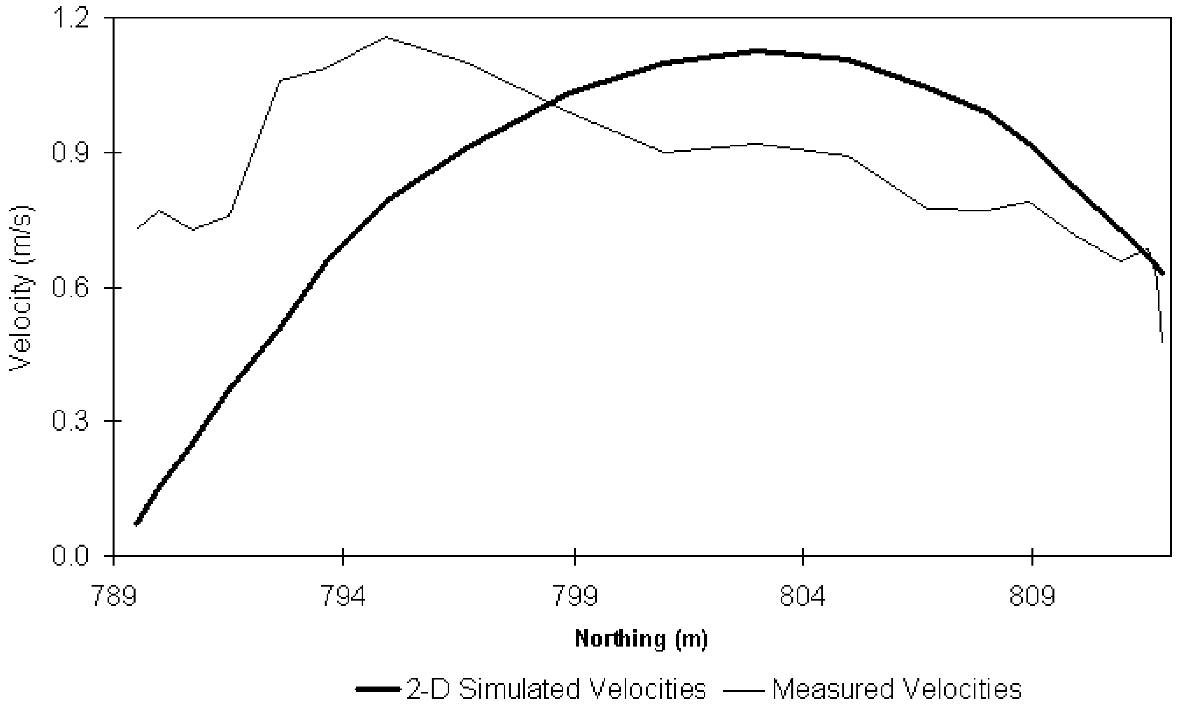

Hallwood Study Site Deep Beds K, Q = 1680 cfs


Hallwood Study Site Deep Beds J, Q = 1680 cfs

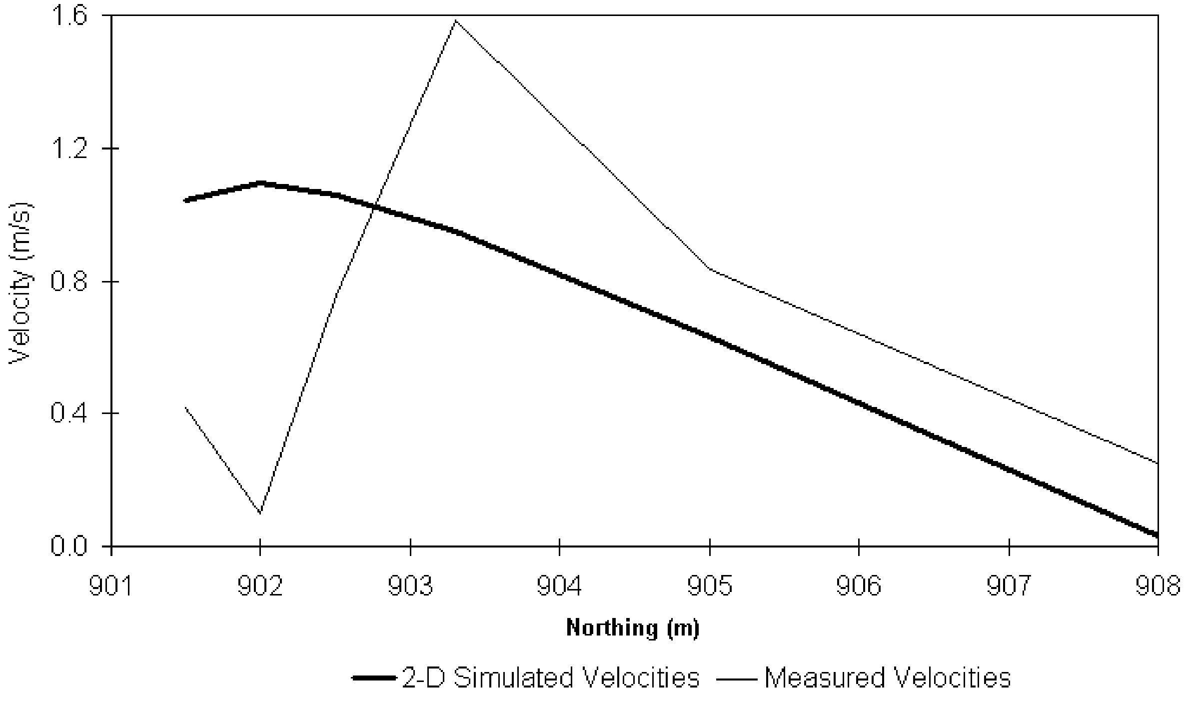

Hallwood Study Site Deep Beds L, Q = 1680 cfs

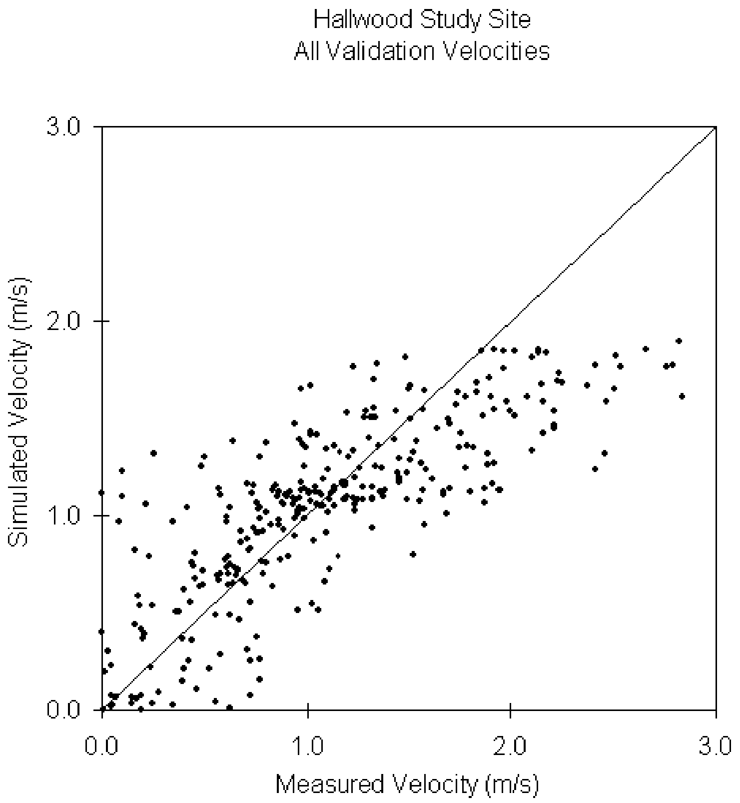
Appendix G

Hallwood Study Site Deep Beds M, Q = 1680 cfs

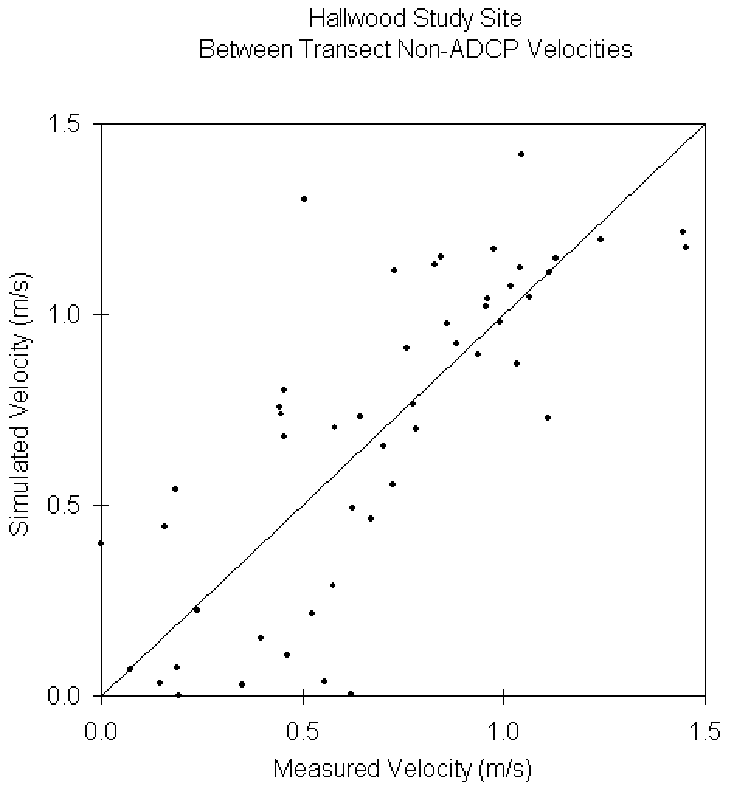


Hallwood Study Site Deep Beds N, Q = 1680 cfs



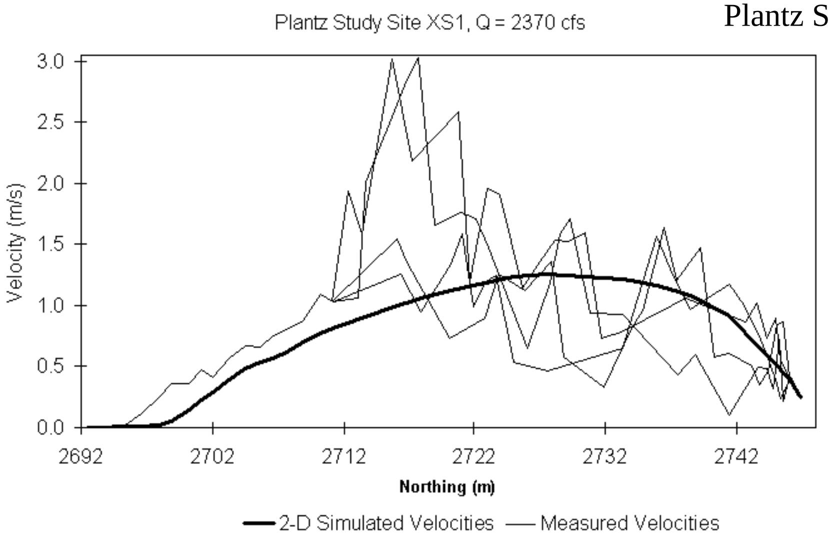


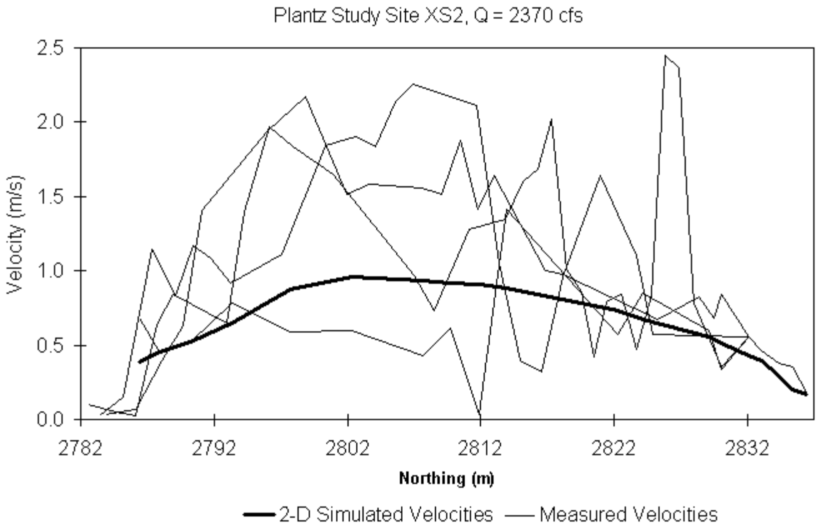
Hallwood Study Site
All Validation Velocities

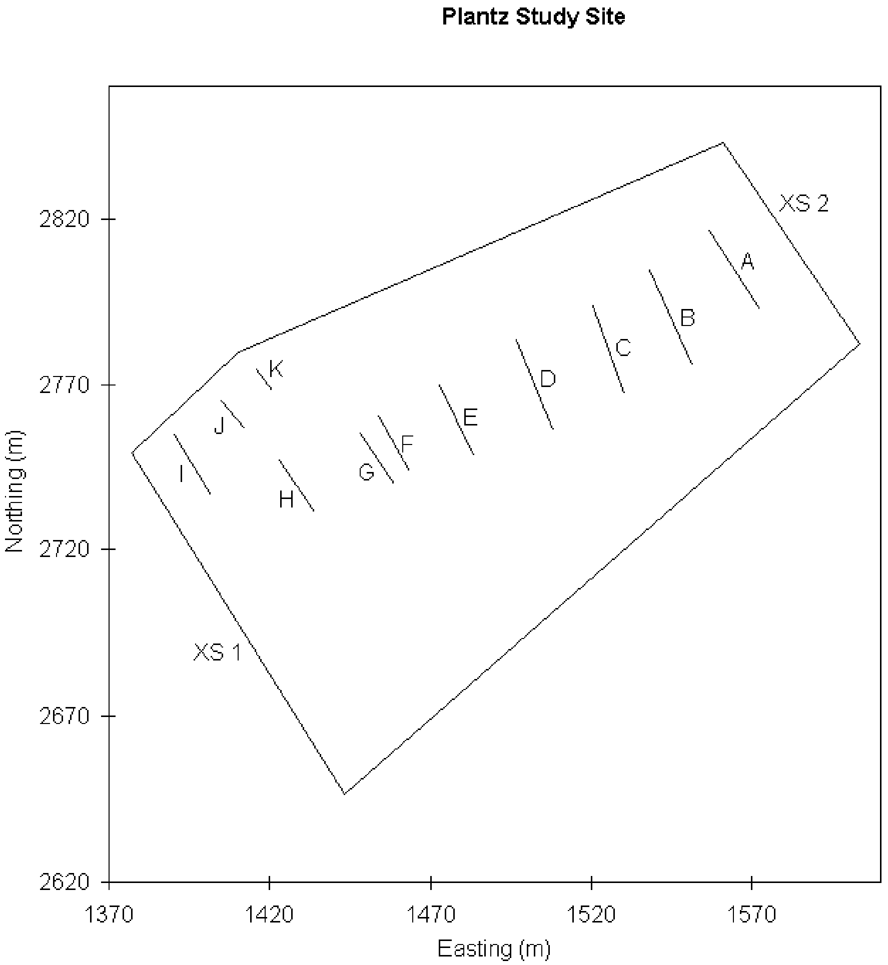


Hallwood Study Site
Between Transect Non-ADCP Velocities

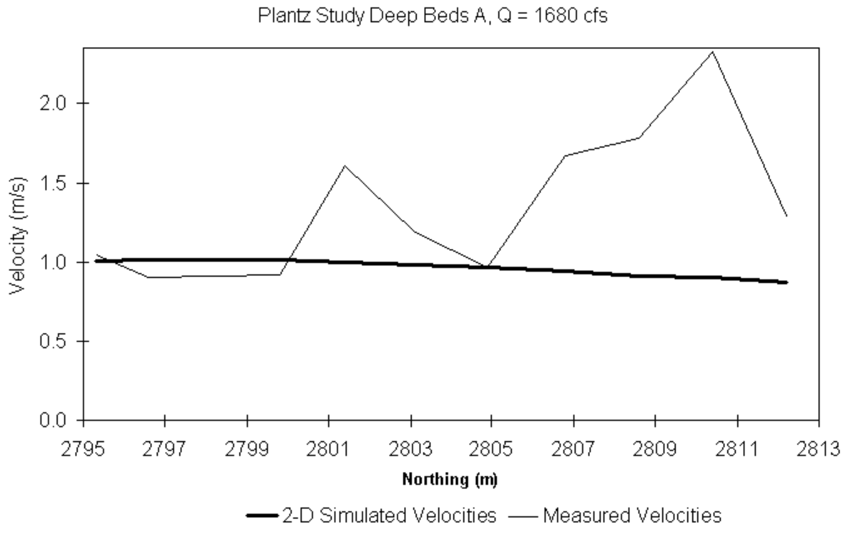
## Plantz Study Site

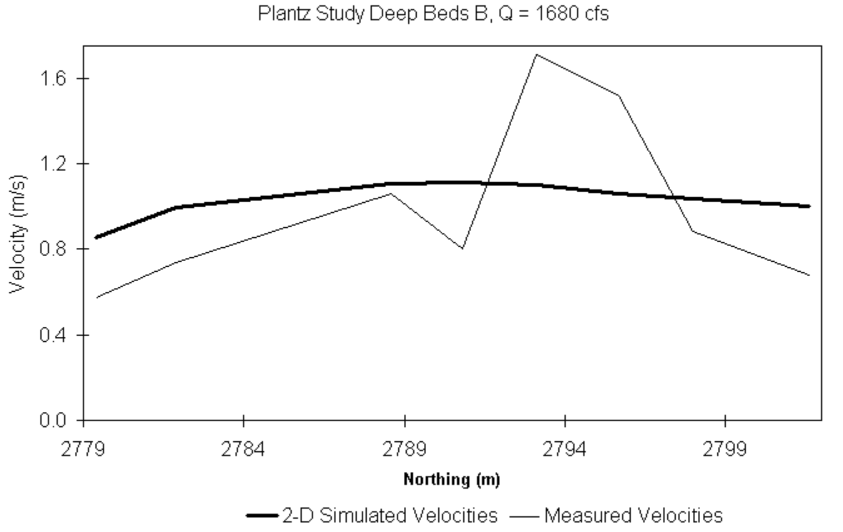


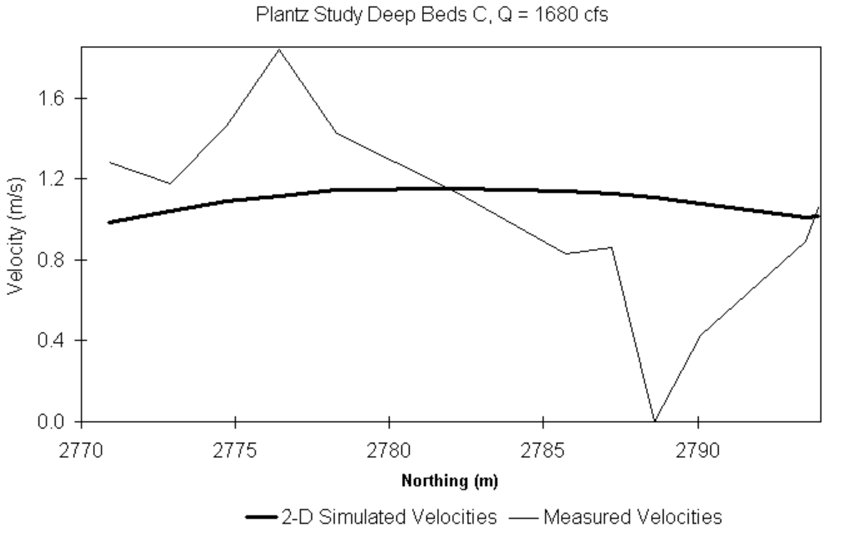


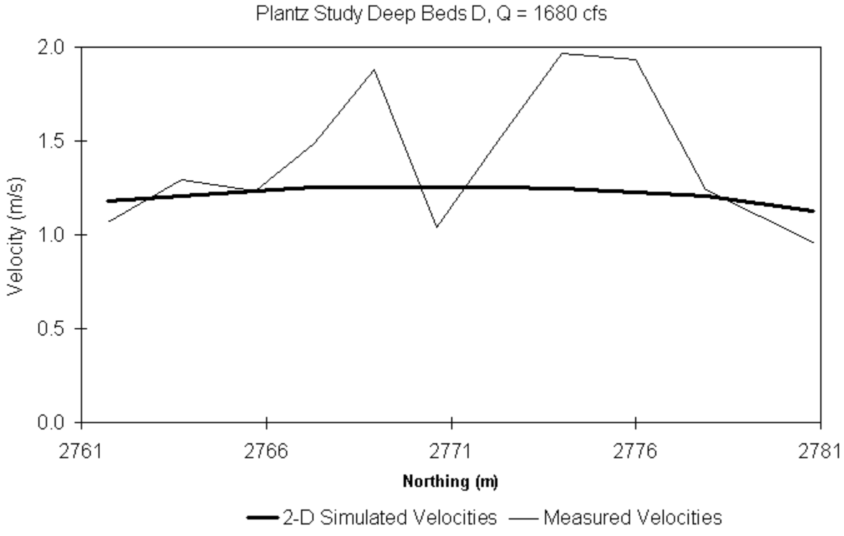


Appendix G

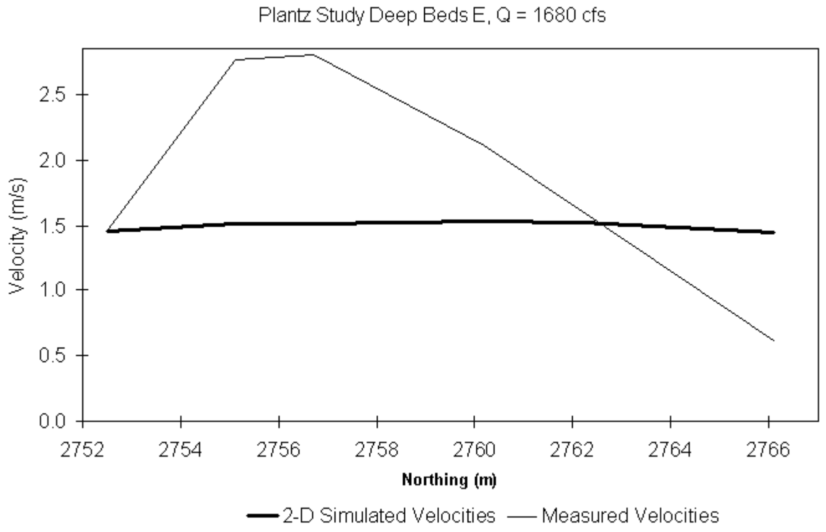

Plantz Study Deep Beds A, Q = 1680 cfs

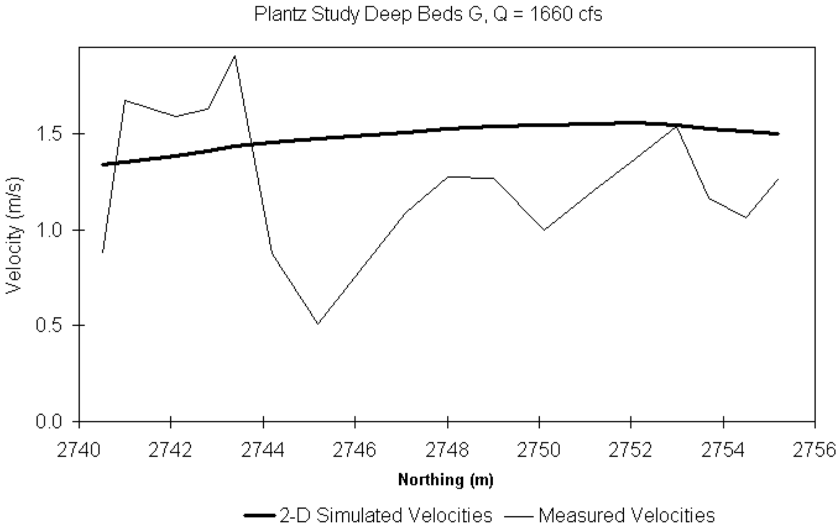

Plantz Study Deep Beds B, Q = 1680 cfs

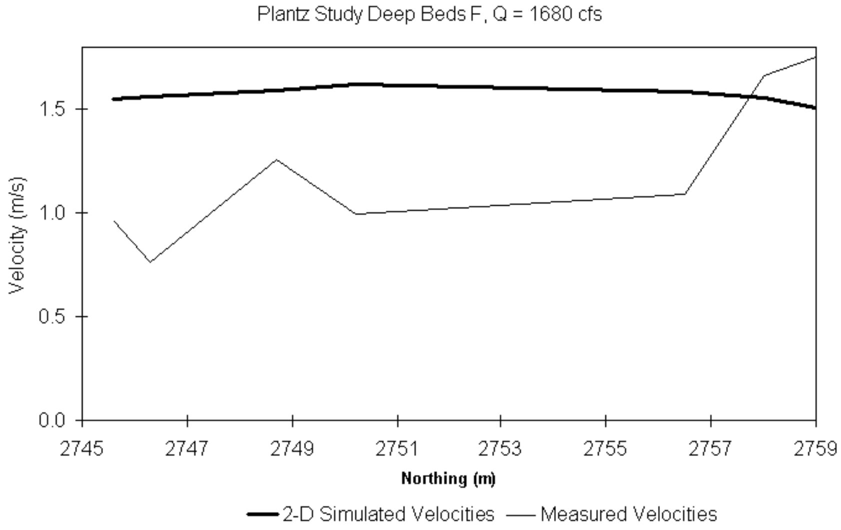

Plantz Study Deep Beds C, Q = 1680 cfs

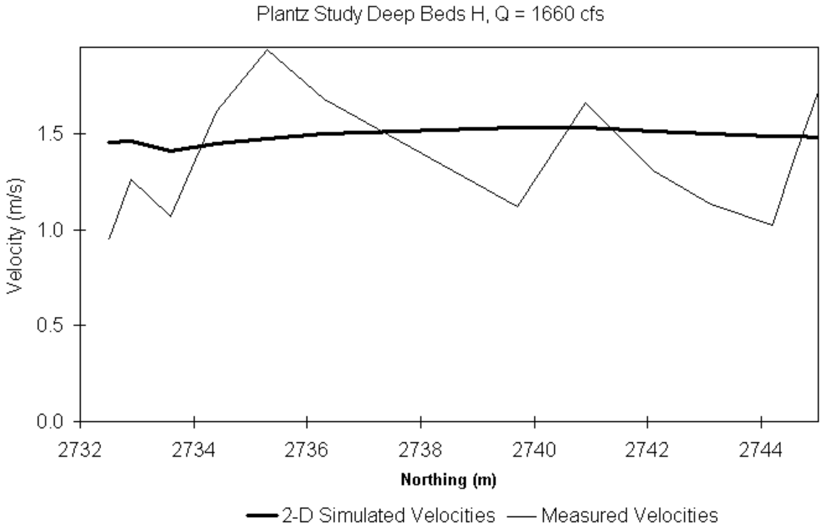

Plantz Study Deep Beds D, Q = 1680 cfs

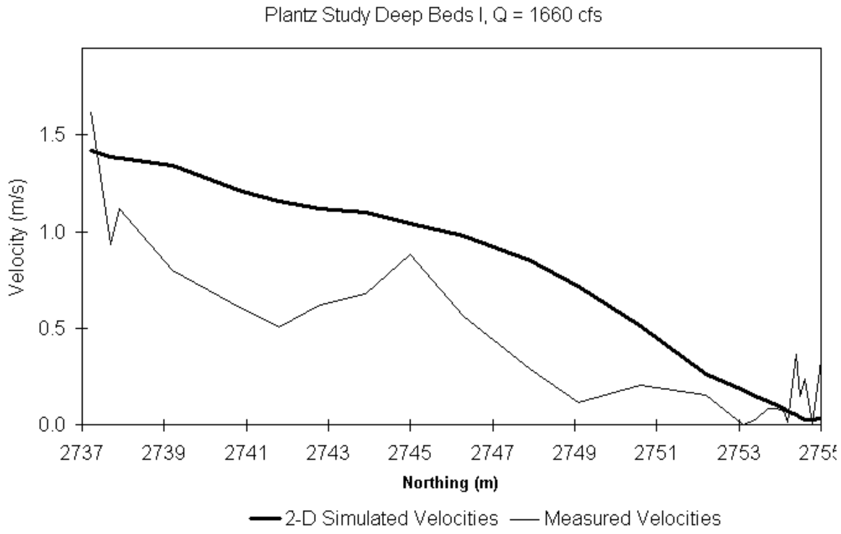
# Appendix G

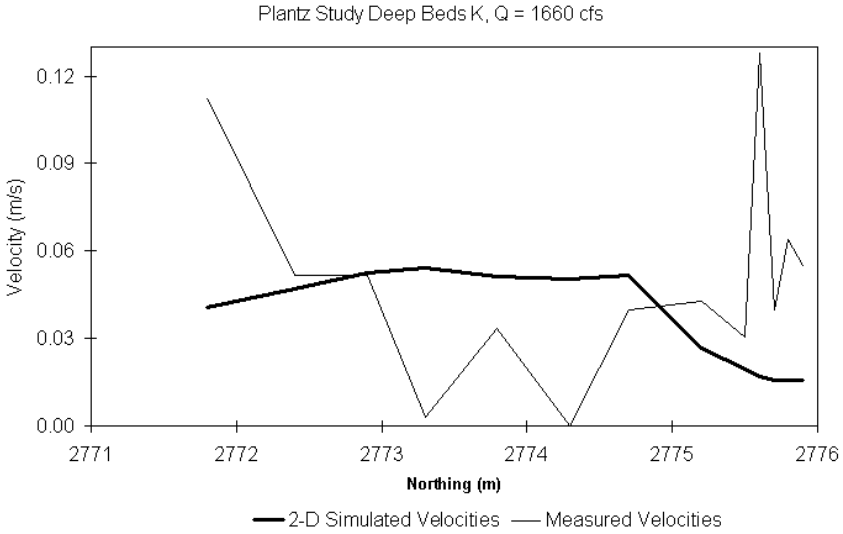

Plantz Study Deep Beds E, Q = 1680 cfs

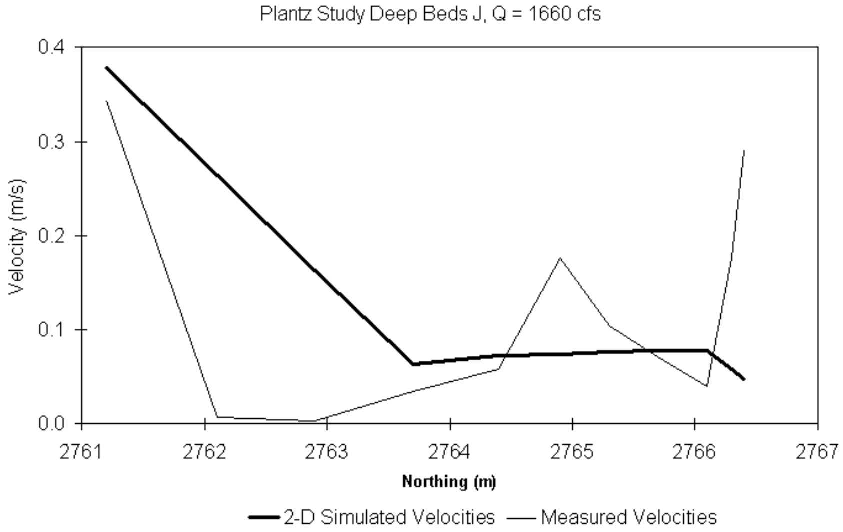

Plantz Study Deep Beds G, Q = 1660 cfs


Plantz Study Deep Beds F, Q = 1680 cfs

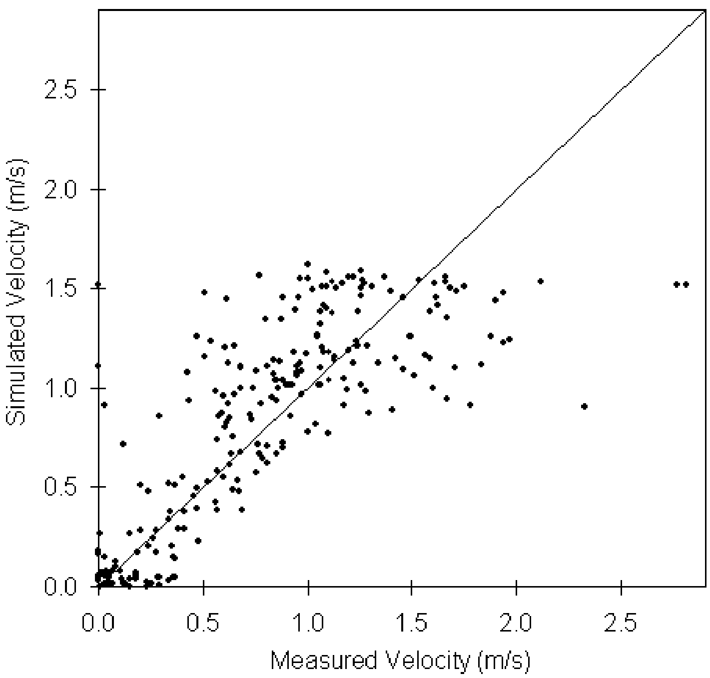

Plantz Study Deep Beds H, Q = 1660 cfs


Plantz Study Deep Beds I, Q = 1660 cfs
Velocity (m/s)
1.5
1.0
0.5
0.0
2737
2739
2741
2743
2745
2747
2749
2751
2753
Northing (m)
2-D Simulated Velocities
Measured Velocities

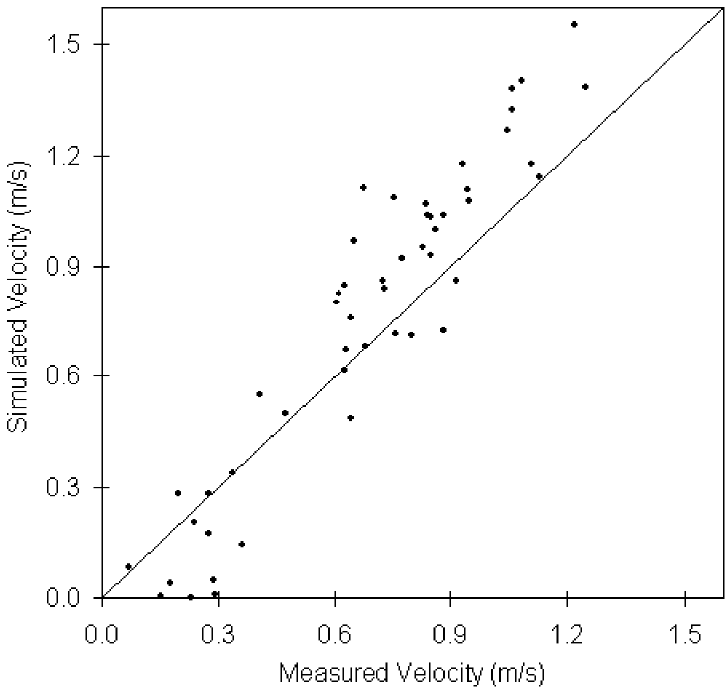

Plantz Study Deep Beds K, Q = 1660 cfs
Velocity (m/s)
0.12
0.09
0.06
0.03
0.00
2771
2772
2773
2774
2775
2776
Northing (m)
2-D Simulated Velocities
Measured Velocities


Plantz Study Deep Beds J, Q = 1660 cfs
Velocity (m/s)
0.4
0.3
0.2
0.1
0.0
2761
2762
2763
2764
2765
2766
2767
Northing (m)
2-D Simulated Velocities
Measured Velocities

Plantz Study Site
All Validation Velocities



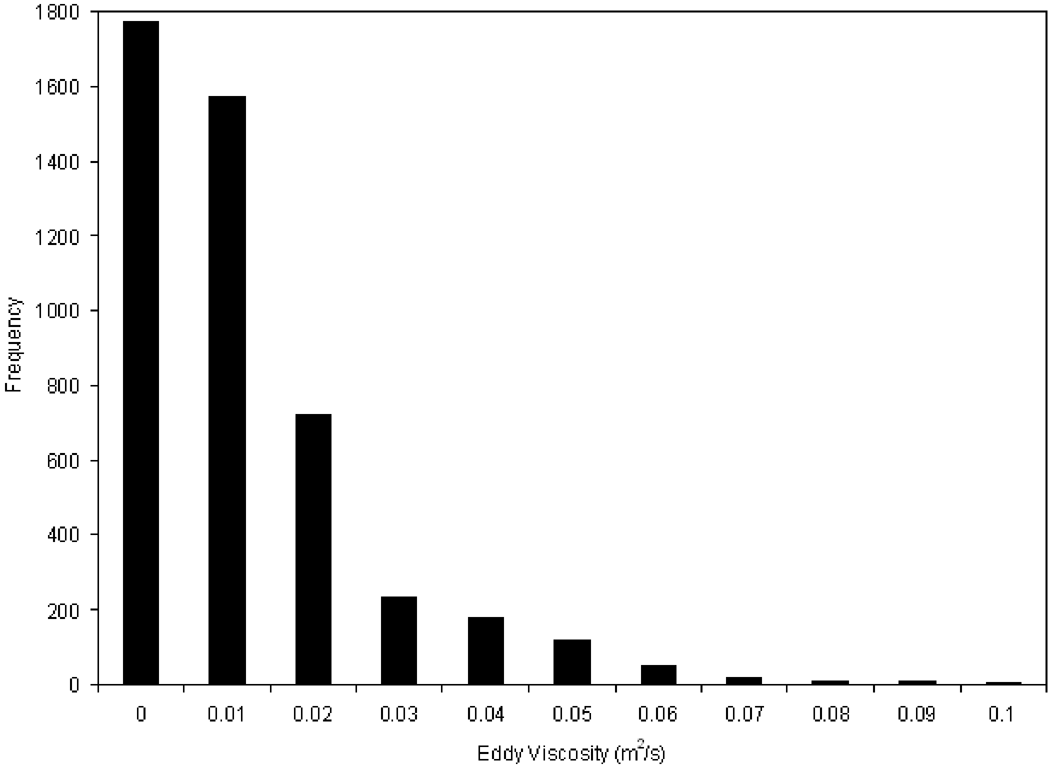
Plantz Study Site
Between Transect Non-ADCP Velocities



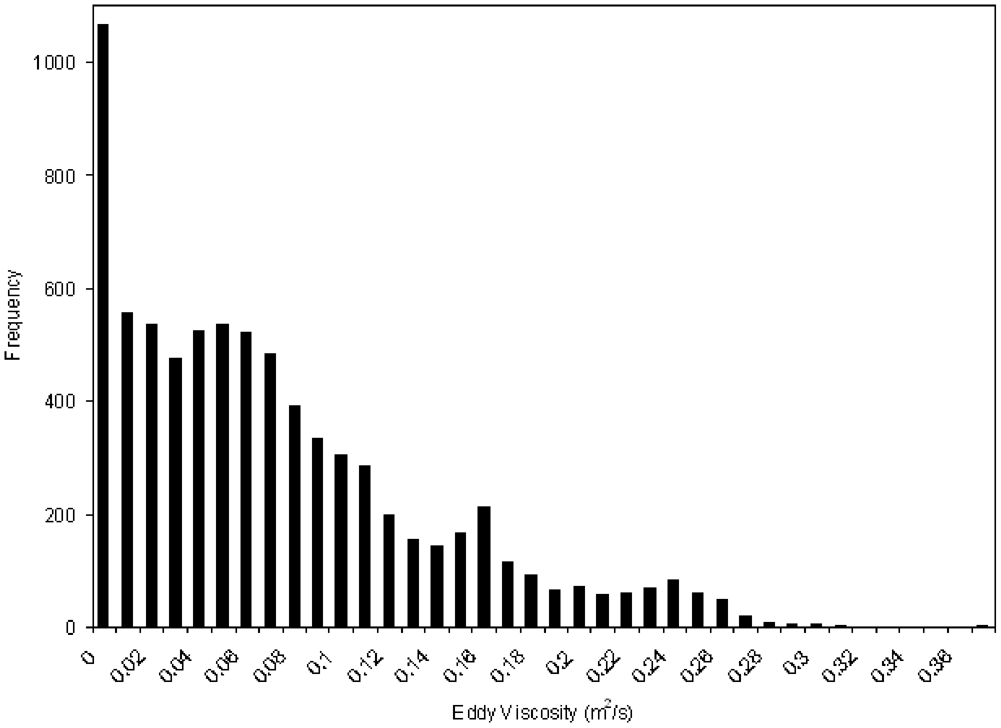
# APPENDIX H
# EXAMPLE HYDRAULIC MODEL OUTPUT

Appendix H

UC Sierra Site at 400 cfs

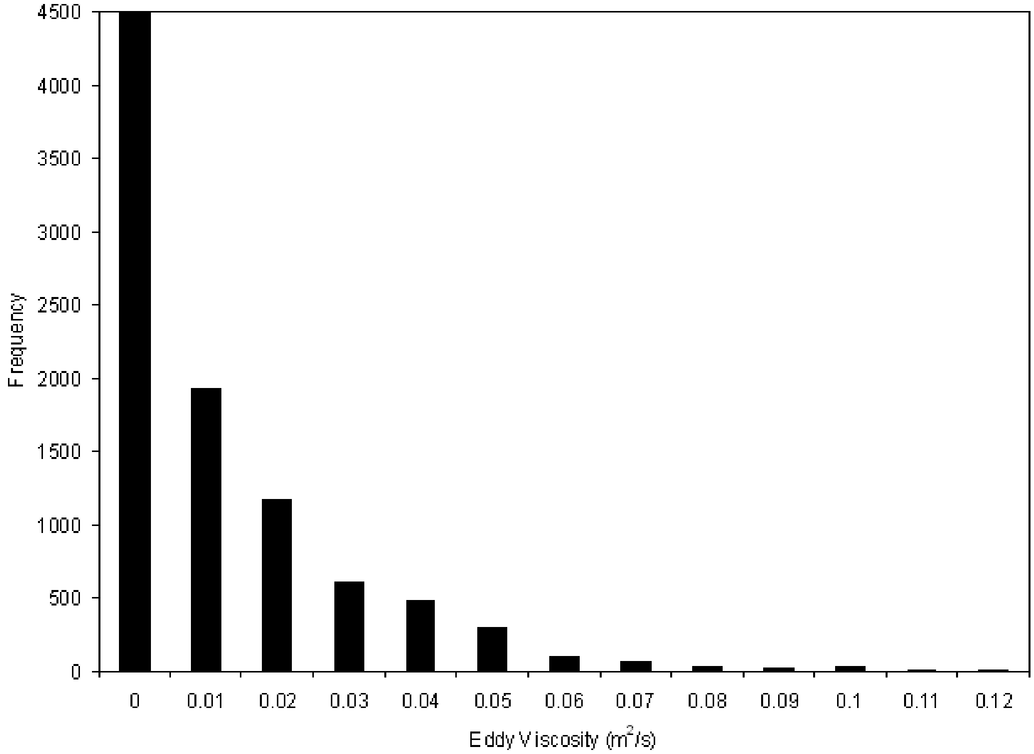


UC Sierra Site at 4,500 cfs

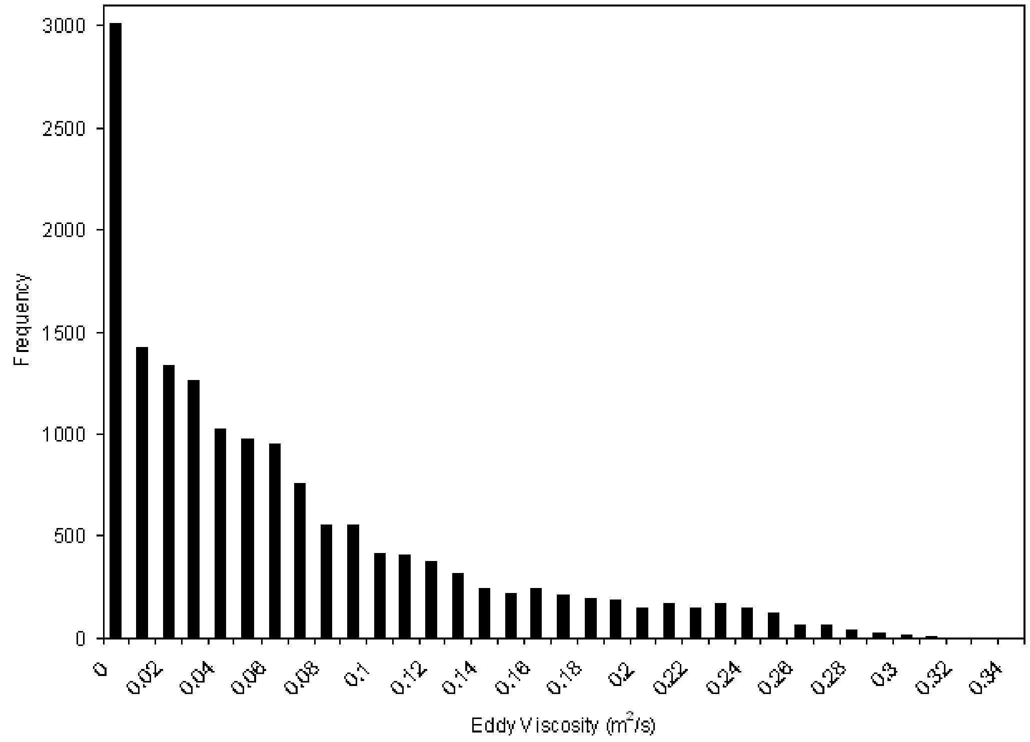


Appendix H

Timbuctoo Site at 400 cfs

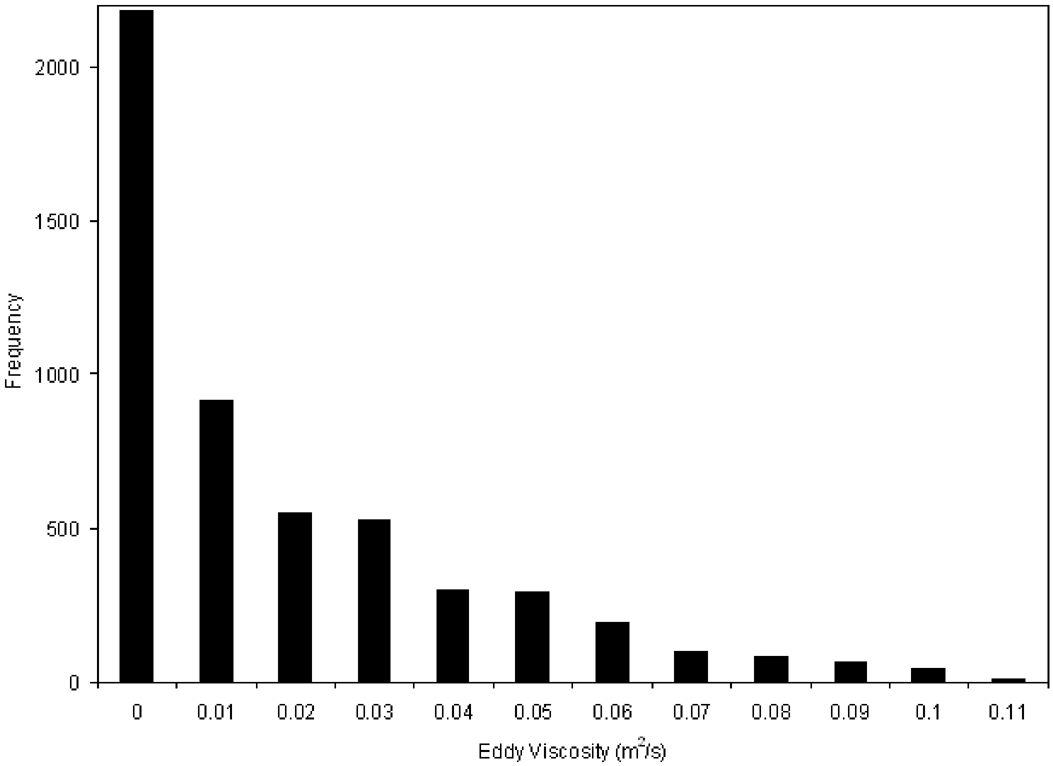


Timbuctoo Site at 4,500 cfs

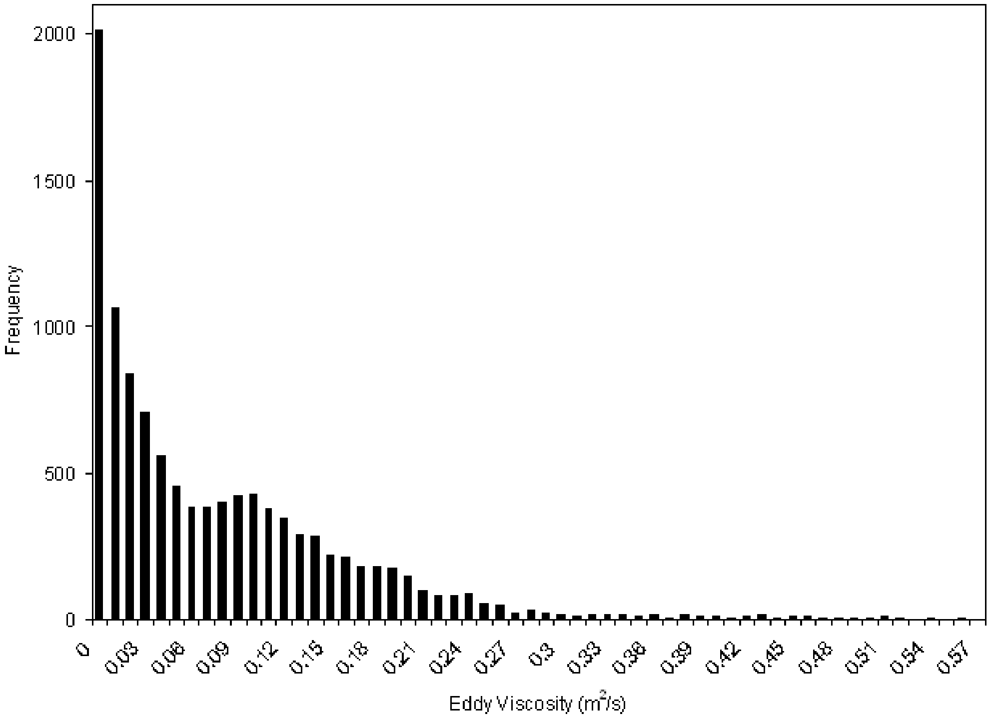


Appendix H

Highway 20 Site at 400 cfs

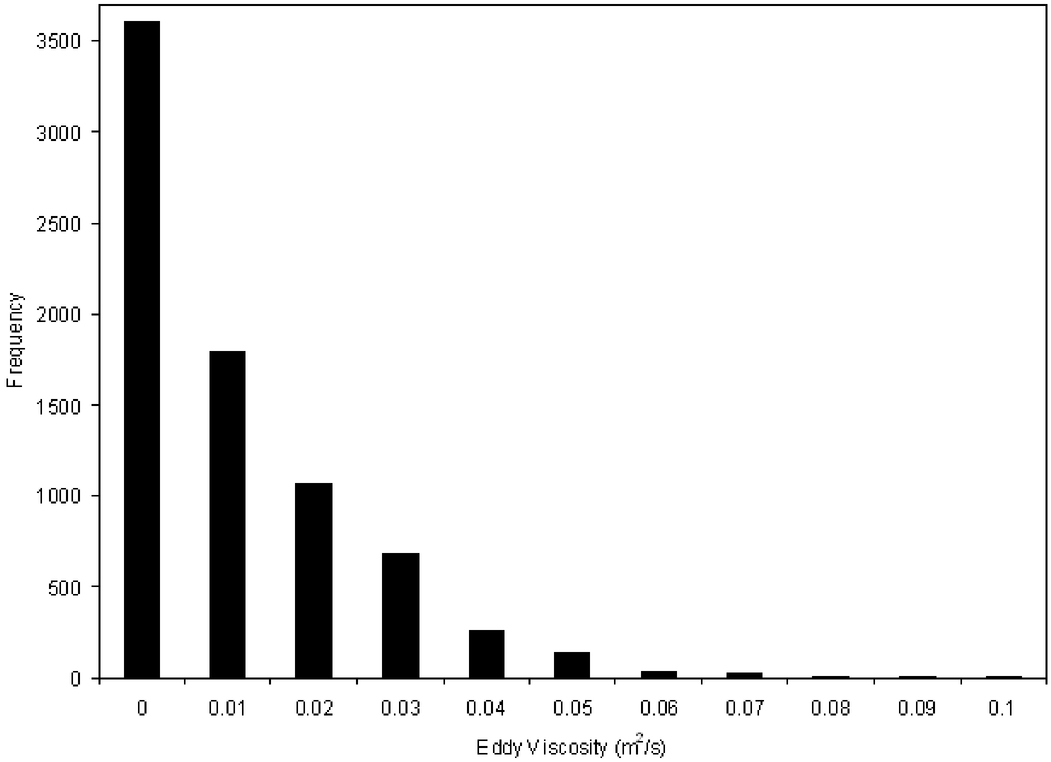


Highway 20 Site at 4,500 cfs

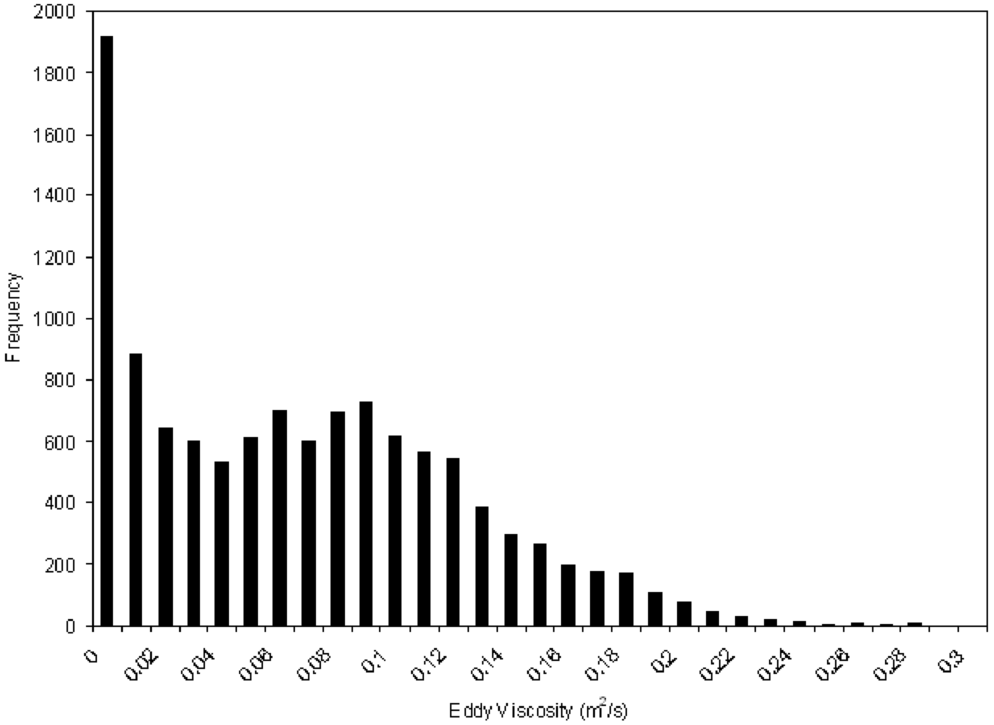


# Appendix H

Island Site at 400 cfs

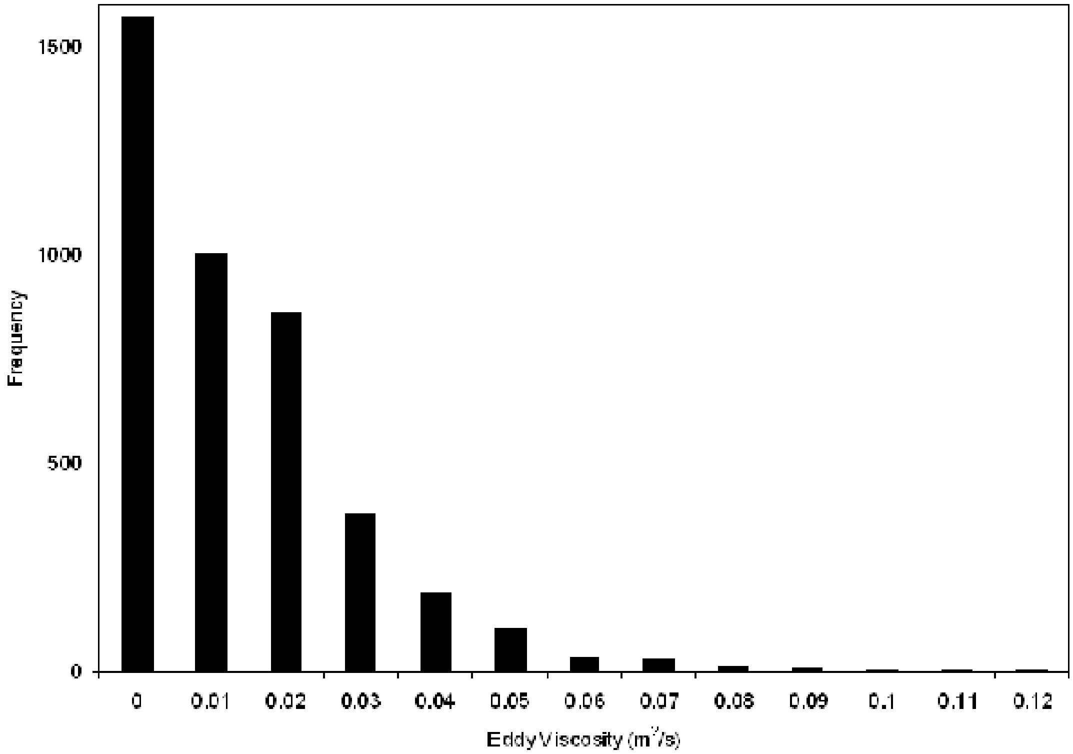


Island Site at 4,500 cfs

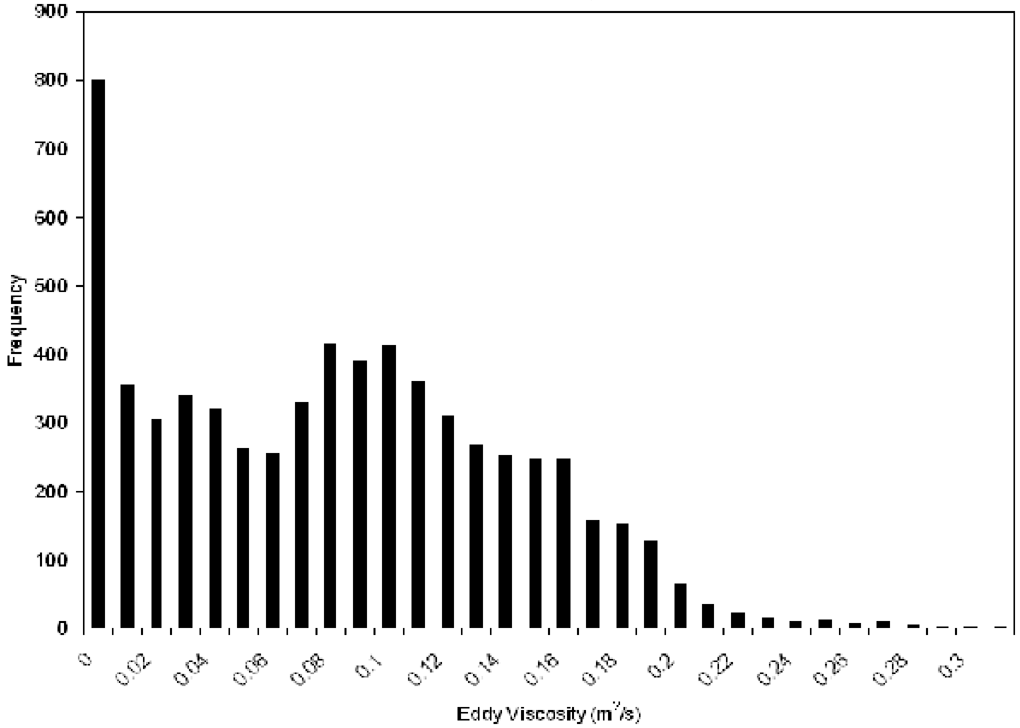


Appendix H

Hammond Site at 400 cfs

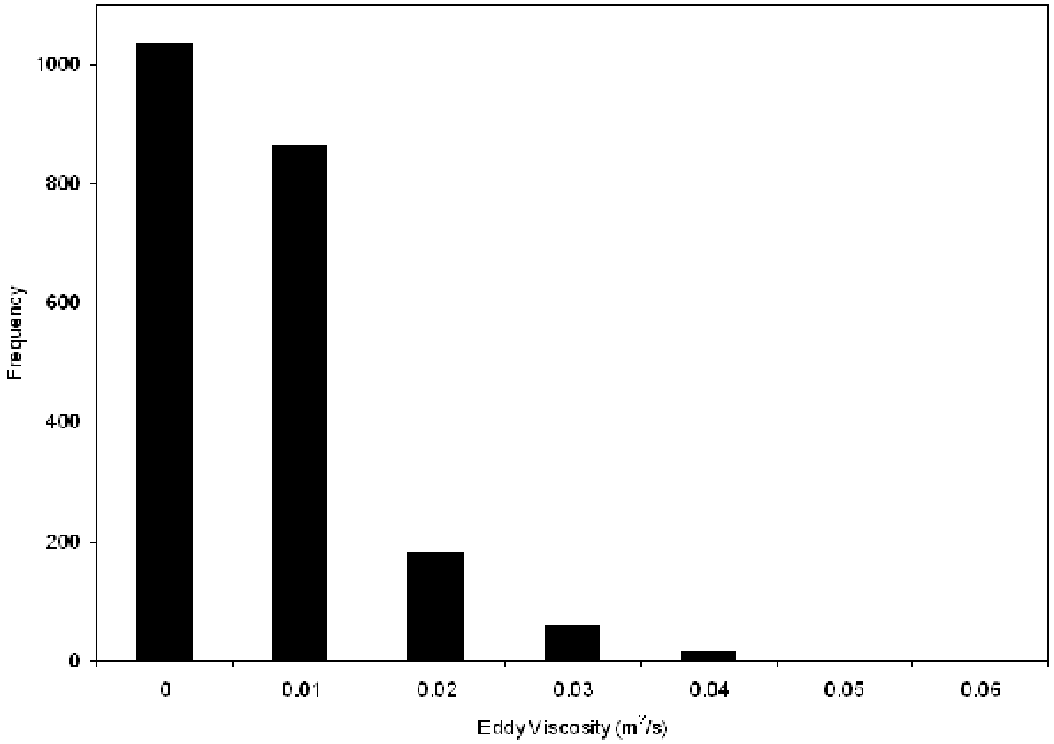


Hammond Site at 4,500 cfs

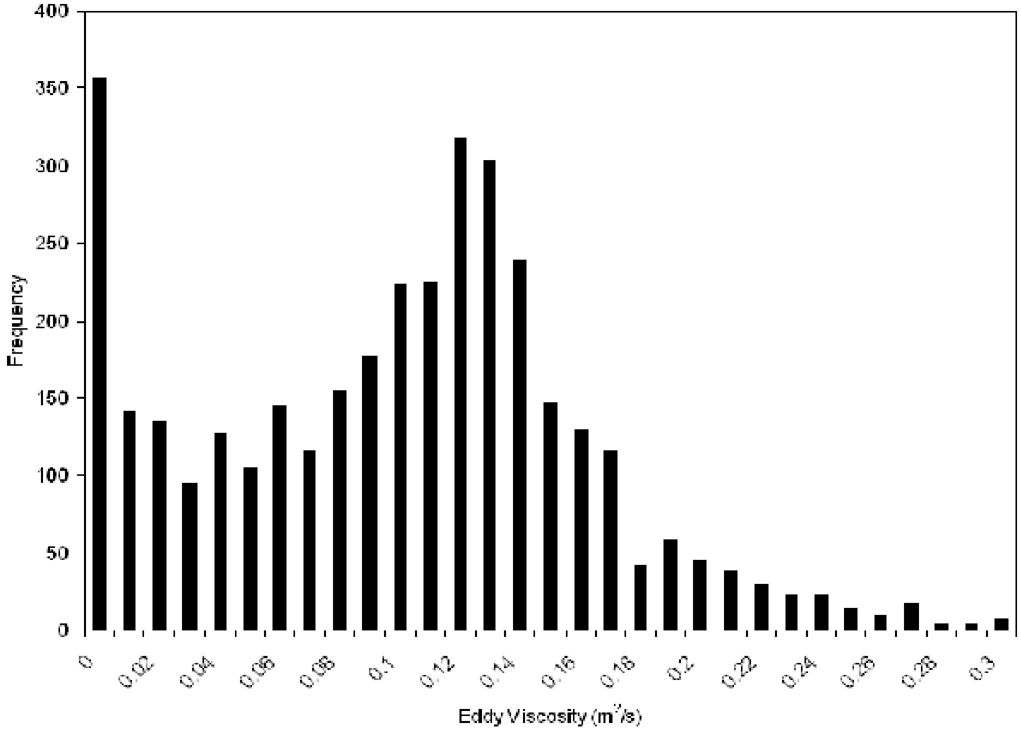


Appendix H

Upper Daguerre Site at 150 cfs

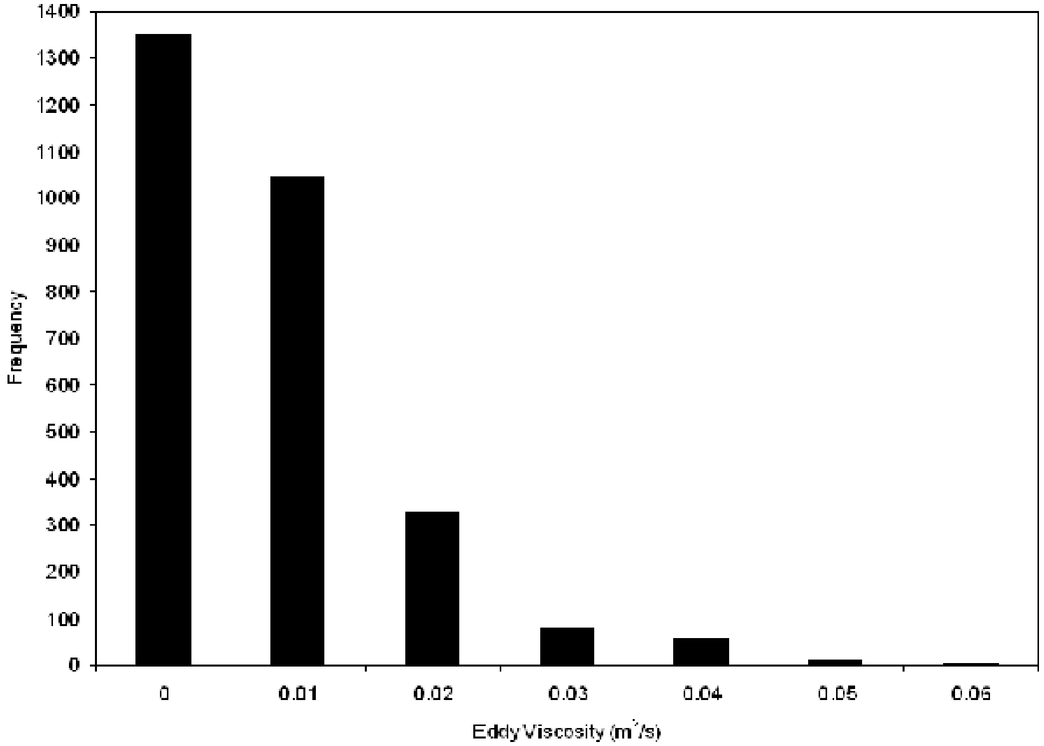


Upper Daguerre Site at 4,500 cfs

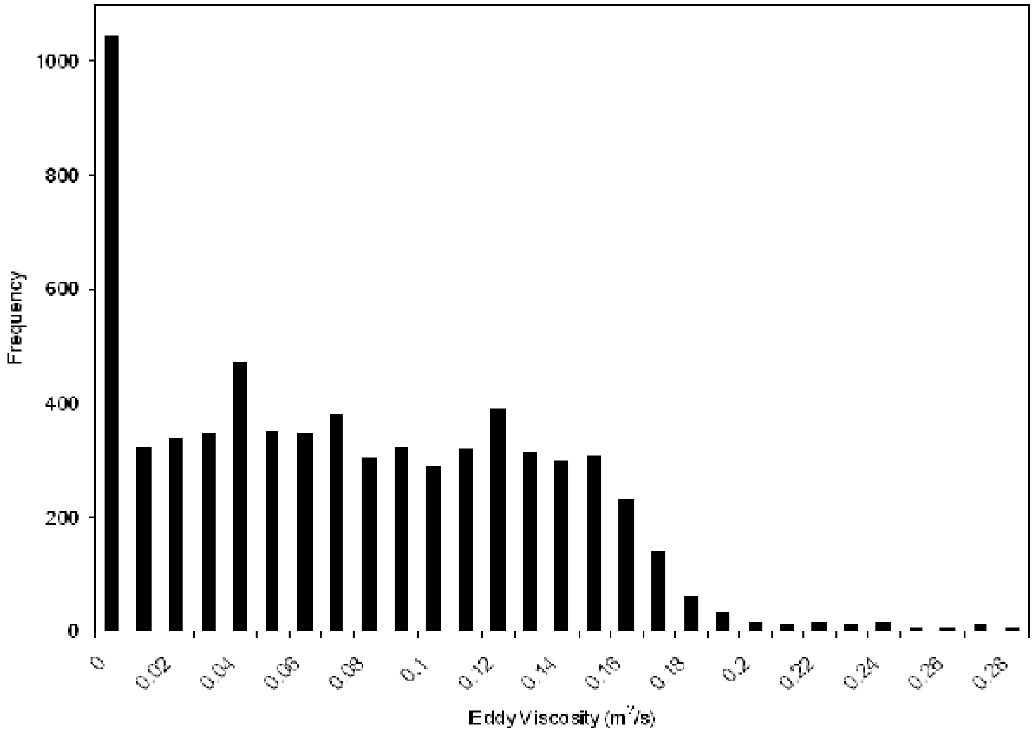


Appendix H

Lower Daguerre Site at 150 cfs

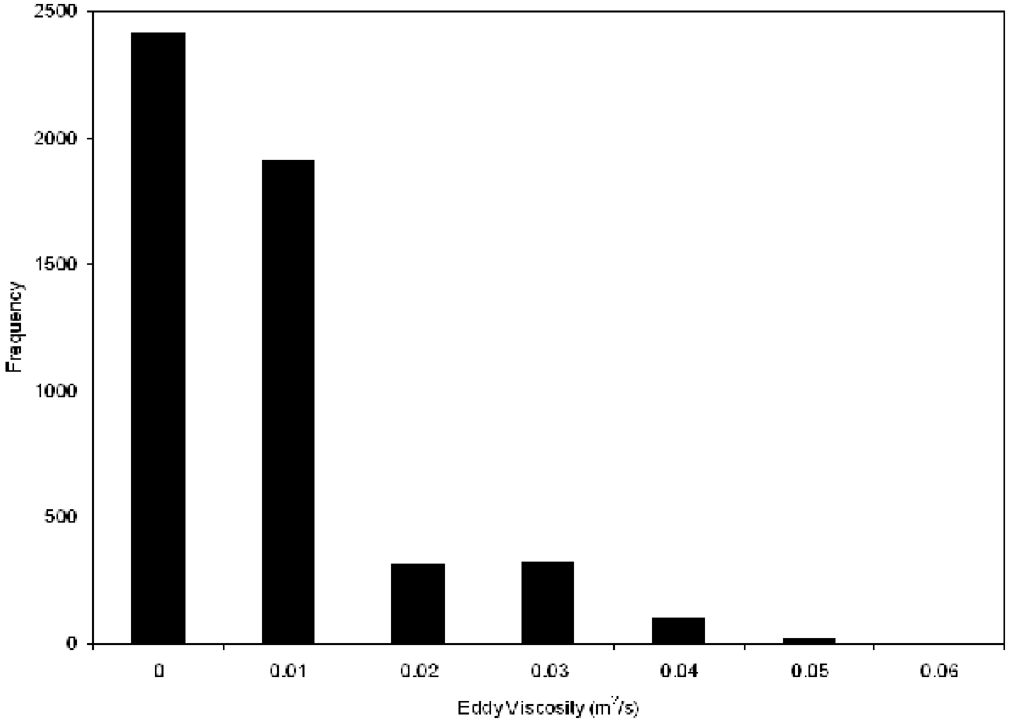


Lower Daguerre Site at 4,500 cfs

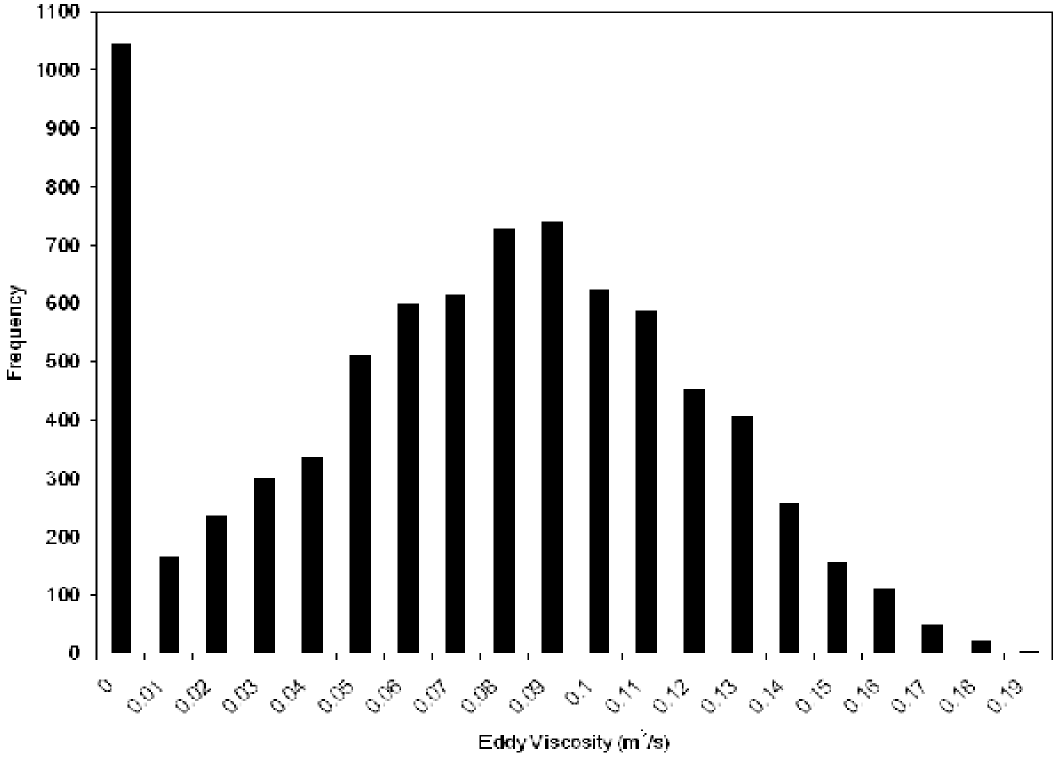


Appendix H

Pyramids Site at 150 cfs

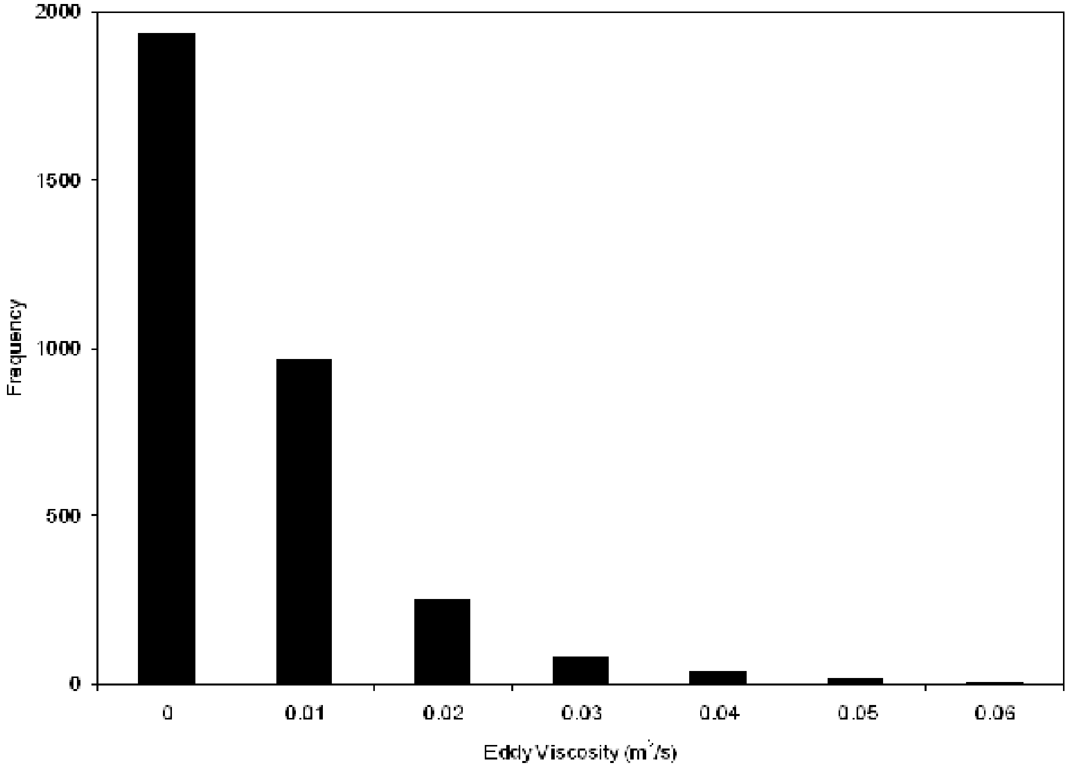


Pyramids Site at 4,500 cfs

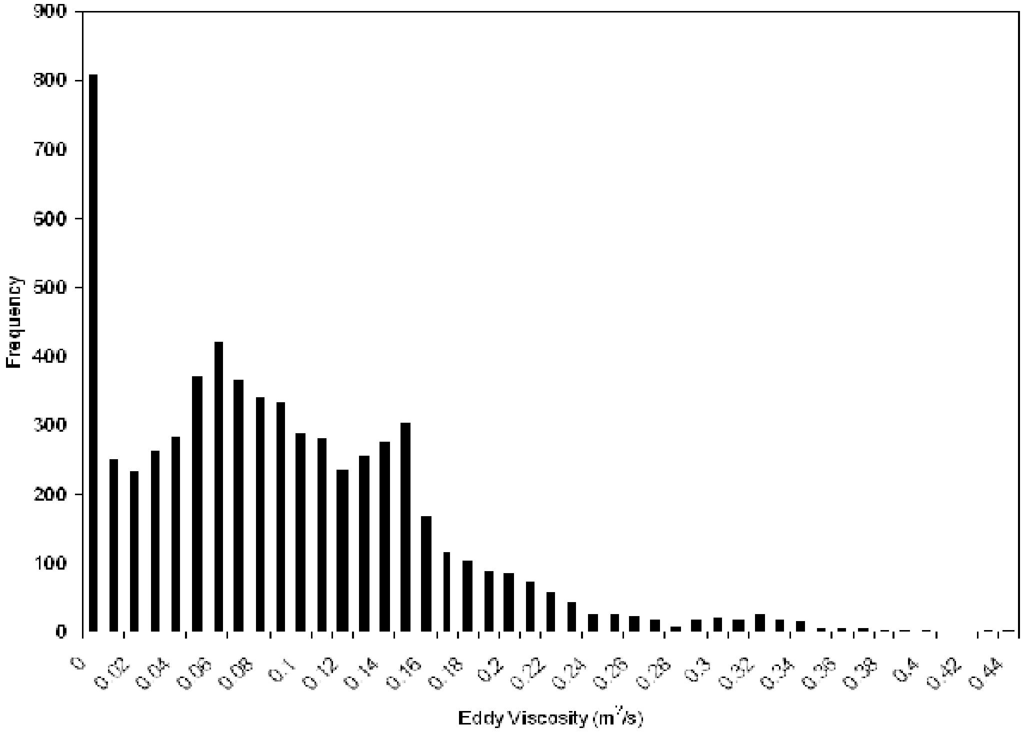


Appendix H

Hallwood Site at 150 cfs

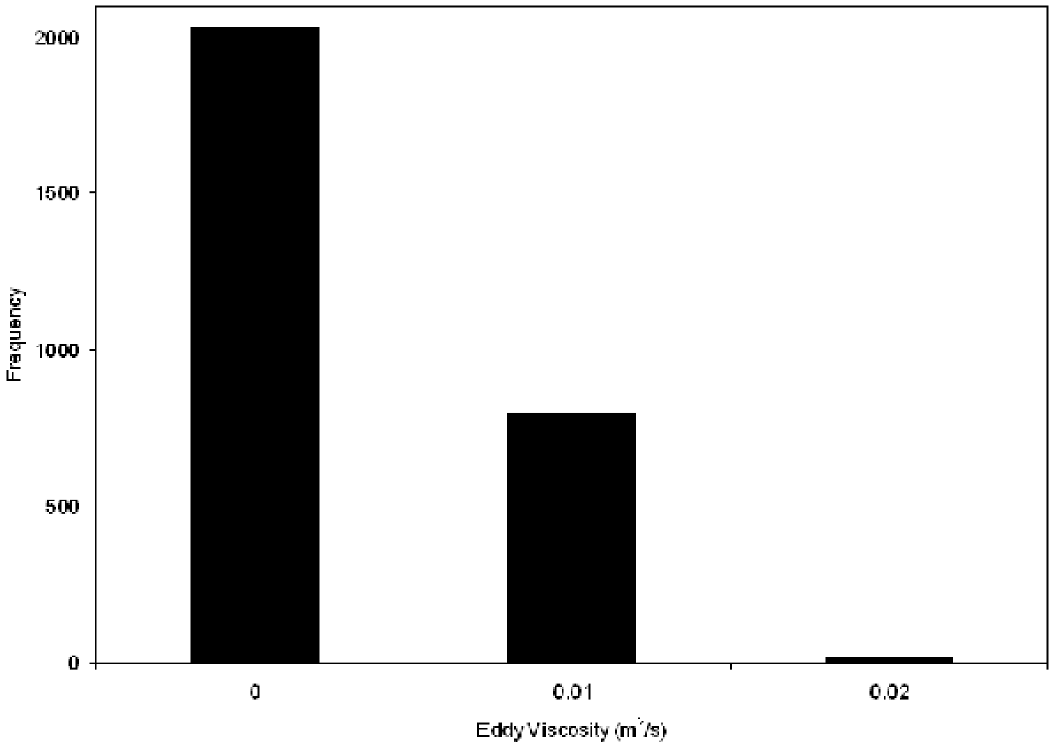


Hallwood Site at 4,500 cfs

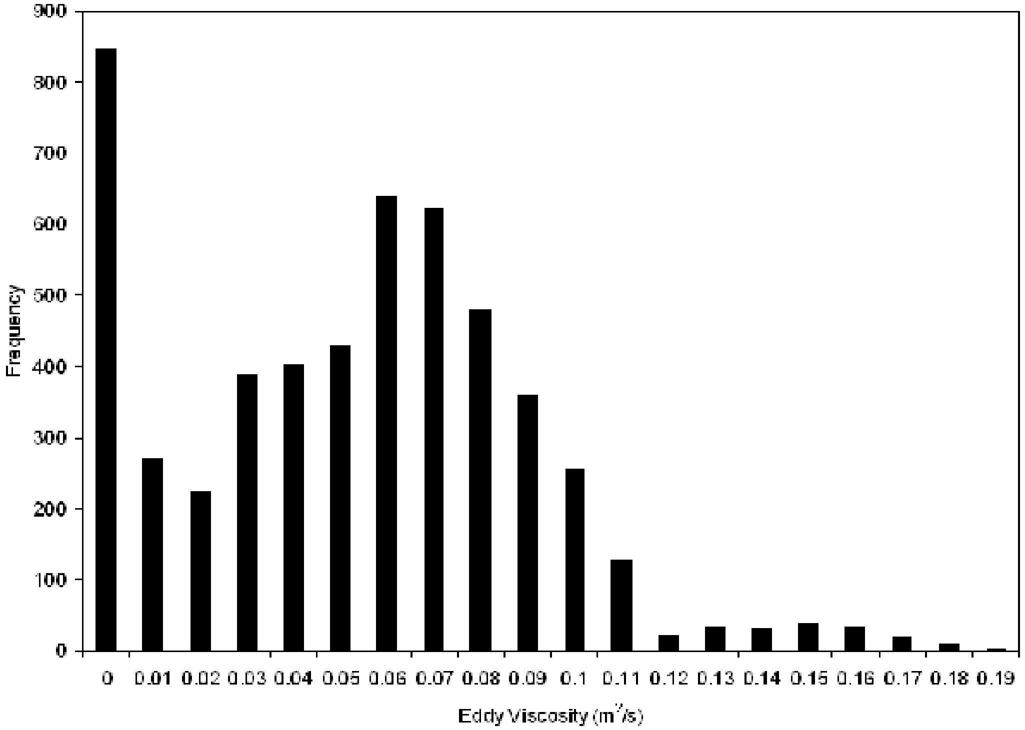


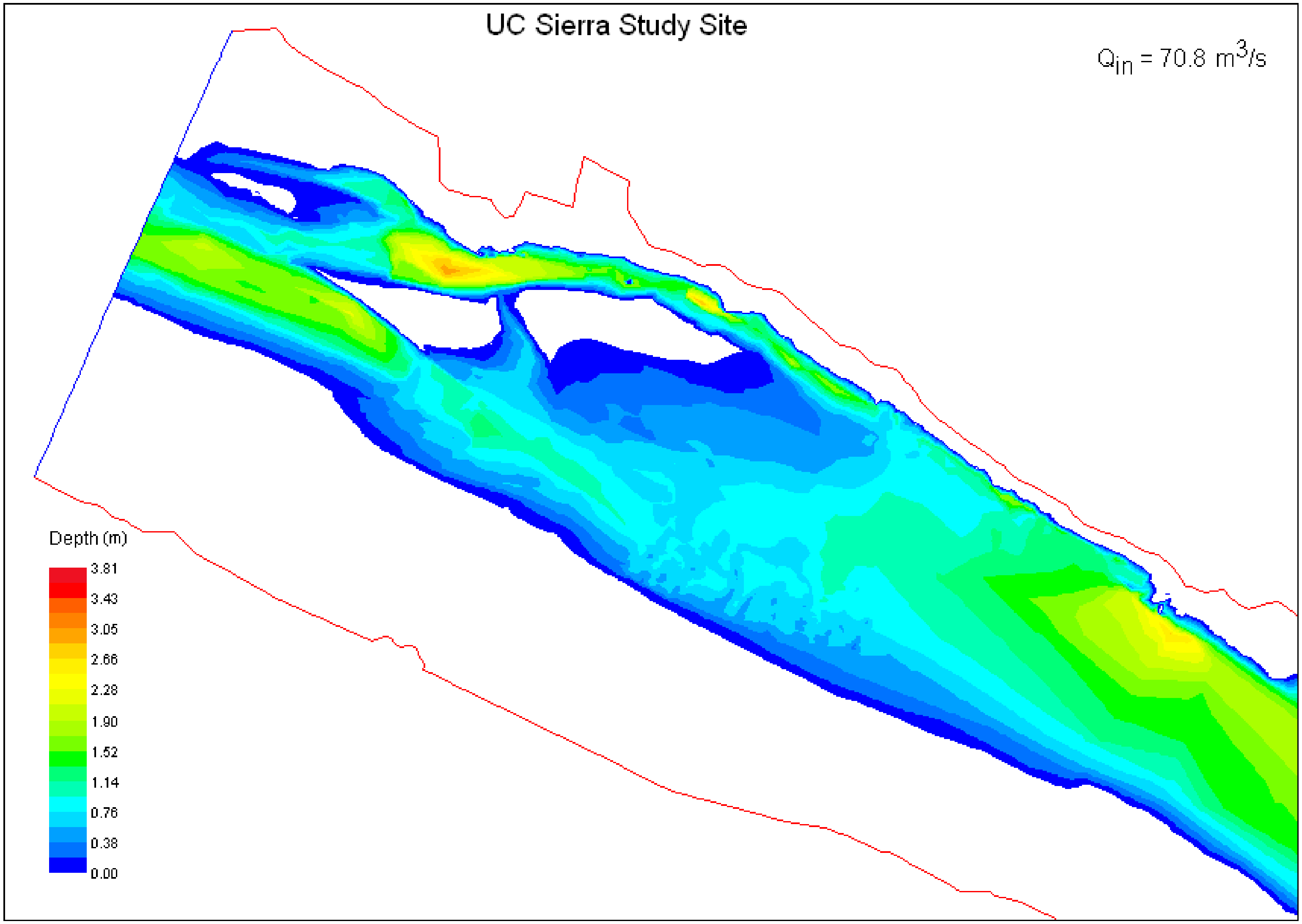
# Appendix H

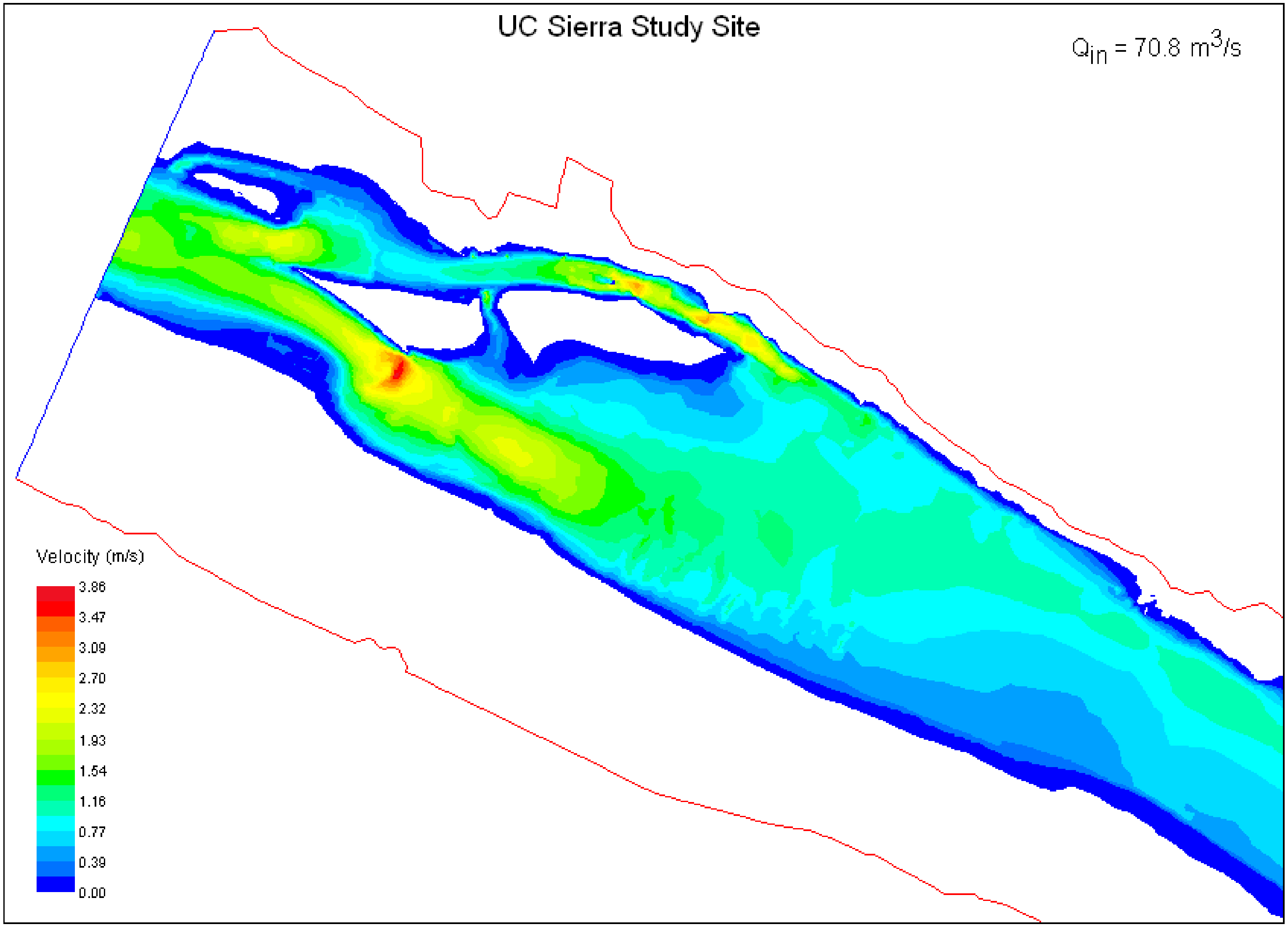
Plantz Site at 150 cfs

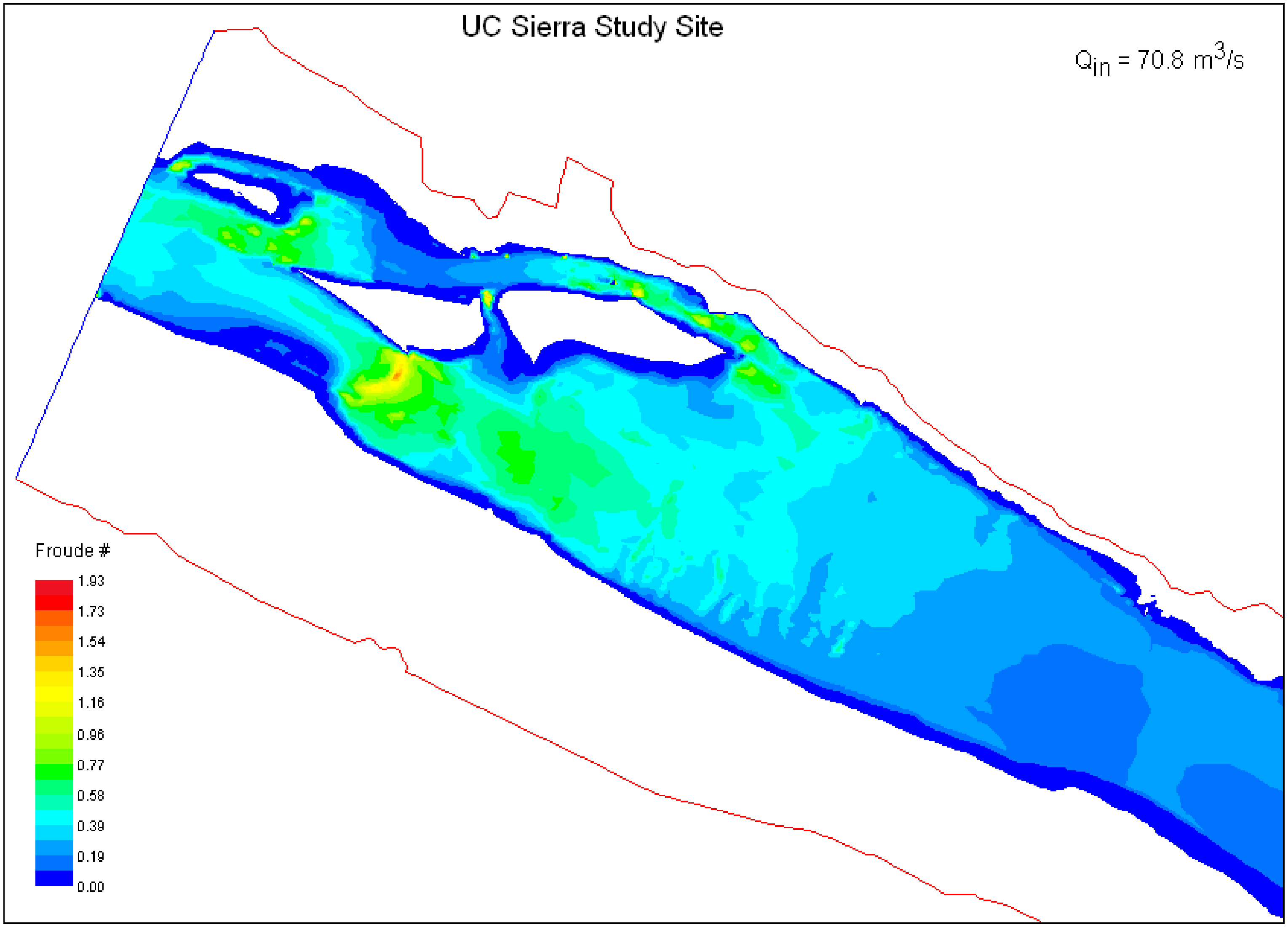


Plantz Site at 4,500 cfs

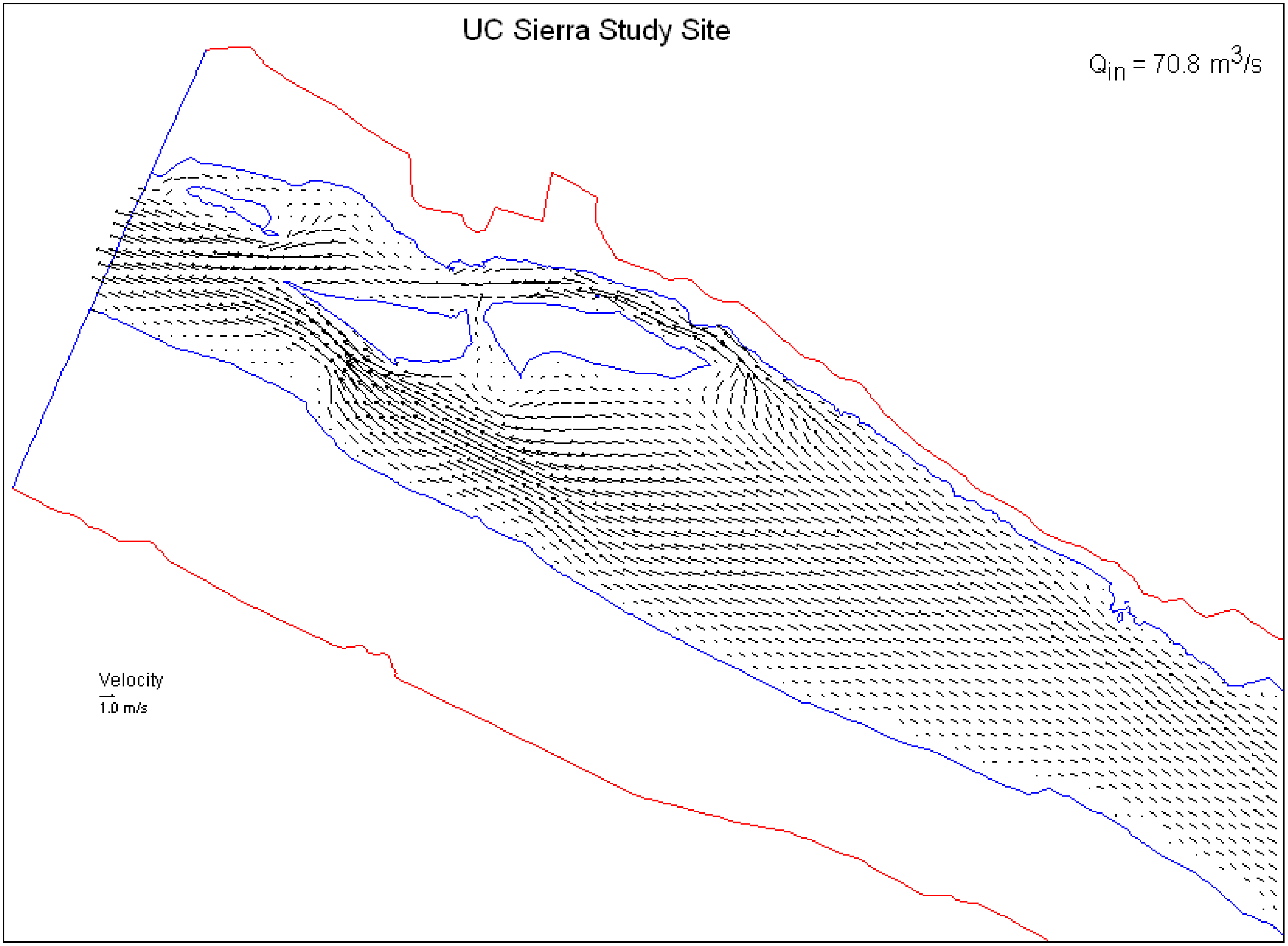


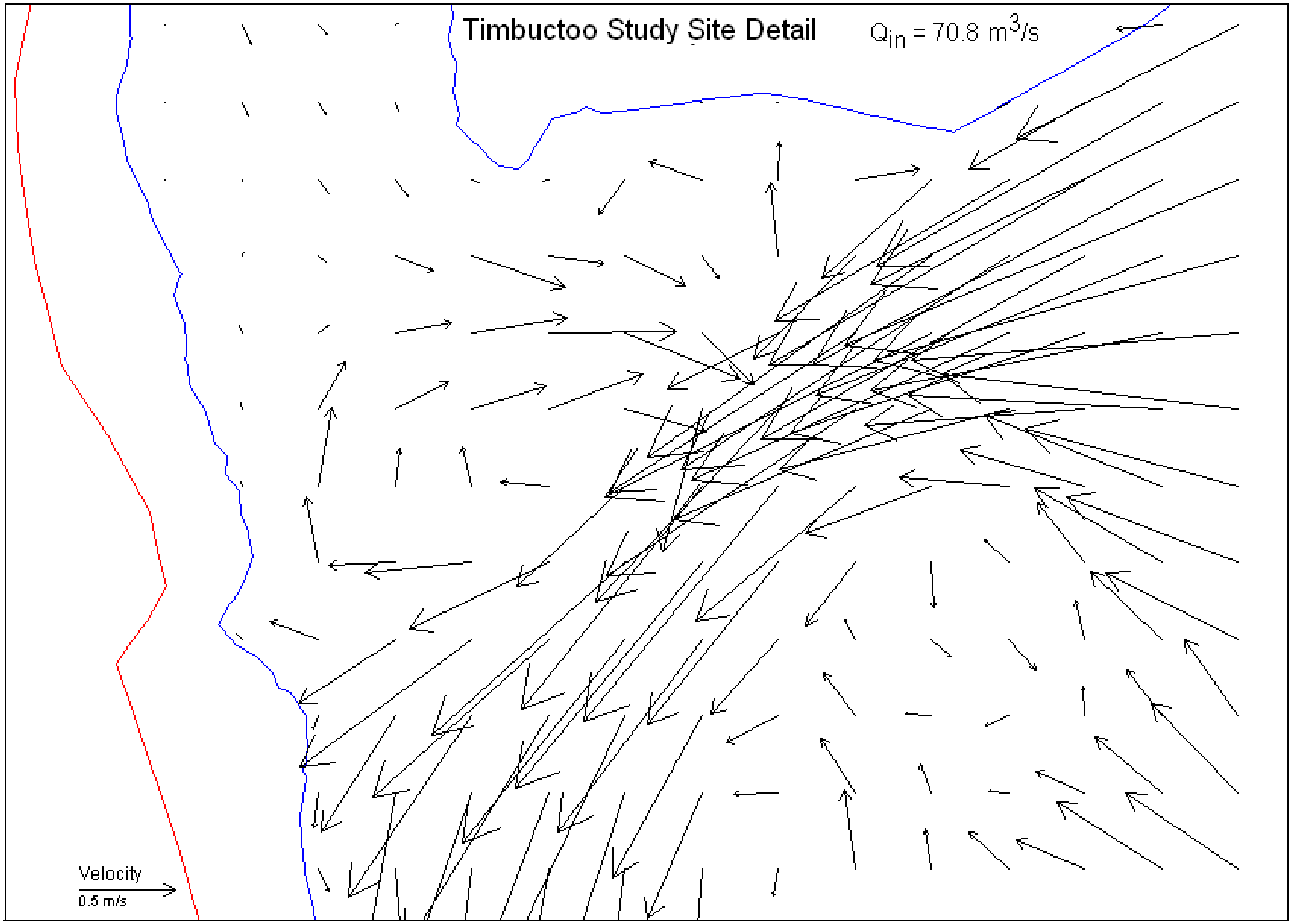

UC Sierra Study Site
Q_in = 70.8 m3/s
Depth (m)
3.81
3.43
3.05
2.66
2.28
1.90
1.52
1.14
0.76
0.38
0.00


UC Sierra Study Site
$Q_{in}$ = 70.8 $m^3/s$
Velocity (m/s)
3.86
3.47
3.09
2.70
2.32
1.93
1.54
1.16
0.77
0.39
0.00


UC Sierra Study Site
$Q_{in}$ = 70.8 m$^3$/s
Froude #
1.93
1.73
1.54
1.35
1.16
0.96
0.77
0.58
0.39
0.19
0.00

Appendix H




Timbuctoo Study Site Detail
$Q_{in}$ = 70.8 $m^3/s$
Velocity
0.5 m/s

# APPENDIX I
# SIMULATION STATISTICS

Appendix I

## UC Sierra Site

| Flow (cfs) | Net Q | Sol Δ | Max F |
|---|---|---|---|
| 400 | 0.2% | < .000001 | 2.47 |
| 500 | 0.1% | .000008 | 2.15 |
| 600 | 0.2% | < .000001 | 2.70 |
| 700 | 0.1% | < .000001 | 4.19 |
| 800 | 0.1% | < .000001 | 3.78 |
| 900 | 0.1% | < .000001 | 2.69 |
| 1,000 | 0.1% | < .000001 | 2.52 |
| 1,100 | 0.1% | .000006 | 1.94 |
| 1,200 | 0.1% | .000002 | 1.73 |
| 1,300 | 0.1% | .000002 | 1.66 |
| 1,400 | 0.1% | .000002 | 3.25 |
| 1,500 | 0.1% | .000008 | 2.41 |
| 1,600 | 0.2% | .000002 | 2.35 |
| 1,700 | 0.2% | < .000001 | 6.09 |
| 1,800 | 0.2% | < .000001 | 3.30 |
| 1,900 | 0.2% | < .000001 | 2.45 |
| 2,000 | 0.2% | .000008 | 2.93 |
| 2,100 | 0.1% | < .000001 | 4.87 |
| 2,300 | 0.1% | < .000001 | 1.94 |
| 2,500 | 0.2% | < .000001 | 1.93 |
| 2,700 | 0.3% | < .000001 | 1.98 |
| 2,900 | 0.1% | .000001 | 6.17 |
| 3,100 | 0.1% | .000003 | 4.28 |
| 3,300 | 0.1% | .000003 | 4.62 |
| 3,500 | 0.1% | .000001 | 5.24 |
| 3,700 | 0.04% | < .000001 | 14.57 |
| 3,900 | 0.1% | < .000001 | 11.97 |
| 4,100 | 0.1% | < .000001 | 7.48 |
| 4,300 | 0.05% | < .000001 | 6.09 |
| 4,500 | 0.04% | < .000001 | 5.21 |

Appendix I

Timbuctoo Site

| **Flow (cfs)** | **Net Q** | **Sol Δ** | **Max F** |
|---|---|---|---|
| 400 | 2.7% | .000003 | 1.33 |
| 500 | 1.7% | .000005 | 1.38 |
| 600 | 0.01% | .000008 | 1.34 |
| 700 | 1.3% | .000001 | 1.52 |
| 800 | 1.4% | .000006 | 1.74 |
| 900 | 1.1% | .000002 | 1.63 |
| 1,000 | 1.1% | .000001 | 1.61 |
| 1,100 | 1.2% | .000008 | 1.52 |
| 1,200 | 1.1% | .000001 | 1.49 |
| 1,300 | 1.1% | .000001 | 1.58 |
| 1,400 | 1.1% | .000003 | 1.58 |
| 1,500 | 1.1% | .000003 | 1.67 |
| 1,600 | 1.1% | .000002 | 1.56 |
| 1,700 | 0.9% | .000007 | 2.55 |
| 1,800 | 0.8% | .000002 | 1.55 |
| 1,900 | 0.8% | .000002 | 1.68 |
| 2,000 | 0.7% | < .000001 | 2.08 |
| 2,100 | 0.6% | .000001 | 1.90 |
| 2,300 | 0.5% | < .000001 | 1.61 |
| 2,500 | 0.5% | .000002 | 1.43 |
| 2,700 | 0.4% | .000005 | 1.69 |
| 2,900 | 0.5% | .000004 | 2.82 |
| 3,100 | 0.7% | .000002 | 2.25 |
| 3,300 | 0.8% | .000002 | 1.97 |
| 3,500 | 0.6% | .000006 | 1.76 |
| 3,700 | 0.6% | < .000001 | 1.63 |
| 3,900 | 0.6% | < .000001 | 1.52 |
| 4,100 | 0.5% | .000001 | 1.44 |
| 4,300 | 0.5% | .000002 | 1.36 |
| 4,500 | 0.9% | .000003 | 13.1 |

Highway 20 Site

| **Flow (cfs)** | **Net Q** | **Sol Δ** | **Max F** |
|---|---|---|---|
| 400 | 0.1% | .000007 | 1.38 |
| 500 | 0.1% | .000006 | 1.09 |
| 600 | 0.02% | .000004 | 1.21 |
| 700 | 0.02% | .000005 | 3.51 |
| 800 | 0.04% | .000004 | 1.75 |
| 900 | 0.01% | .000007 | 1.27 |
| 1,000 | 0.1% | .000004 | 1.66 |
| 1,100 | 0.1% | < .000001 | 1.02 |
| 1,200 | 0.1% | .000002 | 1.10 |
| 1,300 | 0.1% | .000006 | 1.29 |
| 1,400 | 0.1% | .000001 | 1.36 |
| 1,500 | 0.1% | .000002 | 1.41 |
| 1,600 | 0.02% | .000007 | 1.45 |
| 1,700 | 0.04% | .000006 | 1.43 |
| 1,800 | 0.1% | .000006 | 1.28 |
| 1,900 | 0.04% | .000006 | 1.15 |
| 2,000 | 0.1% | .000009 | 1.06 |
| 2,100 | 0.03% | < .000001 | 1.14 |
| 2,300 | 0.01% | .000008 | 4.91 |
| 2,500 | 0.03% | .000009 | 1.67 |
| 2,700 | 0.01% | .000006 | 1.15 |
| 2,900 | 0.01% | .000008 | 0.96 |
| 3,100 | 0.02% | .000008 | 0.86 |
| 3,300 | 0.02% | .000004 | 1.15 |
| 3,500 | 0.03% | .000009 | 2.76 |
| 3,700 | 0.02% | .000004 | 2.37 |
| 3,900 | 0.01% | < .000001 | 2.16 |
| 4,100 | 0.03% | .000007 | 1.32 |
| 4,300 | 0.03% | < .000001 | 2.00 |
| 4,500 | 0.02% | < .000001 | 1.38 |

## Island Site

| Flow (cfs) | Net Q | Sol Δ | Max F |
|---|---|---|---|
| 400 | 0.5% | .000006 | 2.27 |
| 500 | 0.5% | .000006 | 2.11 |
| 600 | 0.6% | 000005 | 2.02 |
| 700 | 0.6% | < .000001 | 3.33 |
| 800 | 0.6% | .000002 | 2.23 |
| 900 | 1.1% | .000004 | 2.19 |
| 1,000 | 3.3% | .000002 | 2.15 |
| 1,100 | 0.4% | .000004 | 2.30 |
| 1,200 | 0.4% | .000003 | 2.13 |
| 1,300 | 0.3% | .000003 | 2.11 |
| 1,400 | 0.3% | .000003 | 2.08 |
| 1,500 | 0.3% | 000005 | 2.06 |
| 1,600 | 0.3% | .000001 | 2.05 |
| 1,700 | 0.6% | .000002 | 10.91 |
| 1,800 | 0.2% | .000001 | 8.00 |
| 1,900 | 0.2% | < .000001 | 5.70 |
| 2,000 | 0.2% | .000002 | 4.54 |
| 2,100 | 0.2% | 000005 | 3.99 |
| 2,300 | 0.3% | .000001 | 2.87 |
| 2,500 | 0.3% | .000003 | 2.44 |
| 2,700 | 0.4% | .000002 | 2.20 |
| 2,900 | 0.7% | < .000001 | 2.08 |
| 3,100 | 2.3% | .000004 | 1.64 |
| 3,300 | 0.01% | .000003 | 1.64 |
| 3,500 | 0.02% | .000009 | 1.77 |
| 3,700 | 0.05% | .000002 | 1.93 |
| 3,900 | 0.01% | .000002 | 2.27 |
| 4,100 | 0.1% | .000001 | 2.72 |
| 4,300 | 0.1% | < .000001 | 3.40 |
| 4,500 | 0.1% | < .000001 | 4.44 |

Hammond Site

| Flow (cfs) | Net Q | Sol Δ | Max F |
|---|---|---|---|
| 400 | 0.1% | .000001 | 1.92 |
| 500 | 0.1% | .000006 | 2.30 |
| 600 | 0.1% | 000005 | 1.67 |
| 700 | 0.1% | .000003 | 1.46 |
| 800 | 0.1% | .000004 | 1.47 |
| 900 | 0.1% | .000002 | 1.41 |
| 1,000 | 0.1% | < .000001 | 1.53 |
| 1,100 | 0.1% | < .000001 | 1.47 |
| 1,200 | 0.1% | < .000001 | 1.38 |
| 1,300 | 0.04% | .000002 | 2.01 |
| 1,400 | 0.03% | < .000001 | 2.29 |
| 1,500 | 0.1% | .000002 | 2.03 |
| 1,600 | 0.02% | 000005 | 1.82 |
| 1,700 | 0.01% | .000002 | 1.69 |
| 1,800 | 0.02% | .000001 | 1.56 |
| 1,900 | 0.02% | .000002 | 1.59 |
| 2,000 | 0.02% | .000002 | 1.60 |
| 2,100 | 0.04% | .000001 | 1.63 |
| 2,300 | 0.04% | < .000001 | 1.66 |
| 2,500 | 0.1% | < .000001 | 1.68 |
| 2,700 | 0.1% | < .000001 | 1.70 |
| 2,900 | 0.04% | < .000001 | 1.71 |
| 3,100 | 0.1% | .000007 | 1.73 |
| 3,300 | 0.1% | .000002 | 2.26 |
| 3,500 | 0.1% | < .000001 | 2.32 |
| 3,700 | 0.1% | < .000001 | 5.42 |
| 3,900 | 0.1% | < .000001 | 4.99 |
| 4,100 | 0.1% | .000009 | 5.14 |
| 4,300 | 0.1% | .000003 | 6.35 |
| 4,500 | 0.03% | .000001 | 7.01 |

Appendix I

## Upper Daguerre Site

| Flow (cfs) | Net Q | Sol Δ | Max F |
|---|---|---|---|
| 150 | 4.5% | .000001 | 0.79 |
| 250 | 2.0% | .000008 | 1.25 |
| 300 | 1.6% | .000008 | 1.18 |
| 350 | 1.4% | < .000001 | 1.12 |
| 400 | 1.4% | .000009 | 0.99 |
| 500 | 0.99% | .000008 | 0.89 |
| 600 | 0.7% | .000002 | 0.74 |
| 700 | 0.6% | .000007 | 0.69 |
| 800 | 0.5% | .000007 | 0.67 |
| 900 | 0.4% | .000007 | 0.67 |
| 1,000 | 0.4% | .000006 | 0.67 |
| 1,100 | 0.3% | .000006 | 0.67 |
| 1,200 | 0.1% | .000004 | 0.67 |
| 1,300 | 0.2% | .000005 | 0.68 |
| 1,400 | 0.2% | .000005 | 0.67 |
| 1,500 | 0.2% | .000005 | 0.65 |
| 1,600 | 0.2% | .000004 | 0.64 |
| 1,700 | 0.1% | .000001 | 0.64 |
| 1,800 | 0.1% | .000002 | 0.64 |
| 1,900 | 0.1% | .000005 | 0.69 |
| 2,000 | 0.1% | .000005 | 0.68 |
| 2,100 | 0.2% | .000007 | 0.62 |
| 2,300 | 0.2% | .000007 | 0.64 |
| 2,500 | 0.1% | .000007 | 0.69 |
| 2,700 | 0.1% | .000007 | 0.67 |
| 2,900 | 0.1% | .000008 | 0.67 |
| 3,300 | 0.1% | < .000001 | 0.65 |
| 3,700 | 0.1% | .000005 | 0.64 |
| 4,100 | 0.02% | .000007 | 0.64 |
| 4,500 | 0.1% | .000005 | 0.64 |

Lower Daguerre Site

| Flow (cfs) | Net Q | Sol Δ | Max F |
|---|---|---|---|
| 150 | 1.9% | .000002 | 1.53 |
| 250 | 0.1% | .000001 | 1.53 |
| 300 | 0.4% | < .000001 | 1.51 |
| 350 | 0.3% | < .000001 | 1.44 |
| 400 | 0.4% | .000001 | 1.41 |
| 500 | 0.2% | .000009 | 1.28 |
| 600 | 0.1% | .000008 | 1.14 |
| 700 | 0.1% | .000008 | 1.11 |
| 800 | 0.1% | .000009 | 1.03 |
| 900 | 0.1% | < .000001 | 0.99 |
| 1,000 | 0.04% | < .000001 | 1.01 |
| 1,100 | 0.03% | .000006 | 1.05 |
| 1,200 | 0.1% | .000007 | 1.07 |
| 1,300 | 0.1% | .000002 | 1.08 |
| 1,400 | 0.1% | .000001 | 1.15 |
| 1,500 | 0.02% | .000006 | 1.12 |
| 1,600 | 0.02% | < .000001 | 1.22 |
| 1,700 | 0.02% | .000009 | 1.18 |
| 1,800 | 0.04% | .000006 | 1.11 |
| 1,900 | 0.02% | .000007 | 1.28 |
| 2,000 | 0.02% | .000004 | 1.16 |
| 2,100 | 0.02% | .000008 | 1.17 |
| 2,300 | 0.02% | .000008 | 1.23 |
| 2,500 | 0.03% | .000008 | 1.18 |
| 2,700 | 0.03% | .000008 | 1.08 |
| 2,900 | 0.001% | .000001 | 0.99 |
| 3,300 | 0.04% | .000007 | 0.97 |
| 3,700 | 0.1% | .000002 | 0.89 |
| 4,100 | 0.3% | .000003 | 0.84 |
| 4,500 | 0.3% | .000002 | 0.79 |

Pyramids Site

| Flow (cfs) | Net Q | Sol Δ | Max F |
|---|---|---|---|
| 150 | 12.9% | .000004 | 6.40 |
| 250 | 11.2% | .000004 | 1.86 |
| 300 | 7.1% | .000002 | 3.66 |
| 350 | 9.6% | .000002 | 4.57 |
| 400 | 7.4% | .000002 | 3.07 |
| 500 | 5.2% | .000004 | 2.85 |
| 600 | 8.7% | < .000001 | 2.20 |
| 700 | 5.4% | < .000001 | 1.76 |
| 800 | 4.7% | < .000001 | 2.11 |
| 900 | 0.04% | < .000001 | 2.12 |
| 1,000 | 0.04% | .000004 | 1.92 |
| 1,100 | 0.1% | .000006 | 1.92 |
| 1,200 | 0.1% | < .000001 | 1.87 |
| 1,300 | 0.1% | .000003 | 1.84 |
| 1,400 | 0.1% | .000003 | 1.78 |
| 1,500 | 0.1% | .000008 | 1.74 |
| 1,600 | 0.1% | .000003 | 1.67 |
| 1,700 | 0.1% | .000004 | 1.60 |
| 1,800 | 0.1% | .000003 | 1.53 |
| 1,900 | 0.1% | .000003 | 1.47 |
| 2,000 | 0.1% | .000005 | 1.40 |
| 2,100 | 0.2% | < .000001 | 1.34 |
| 2,300 | 0.2% | .000004 | 1.24 |
| 2,500 | 0.1% | .000003 | 1.14 |
| 2,700 | 0.1% | .000004 | 1.06 |
| 2,900 | 0.2% | .000006 | 1.00 |
| 3,300 | 0.1% | < .000001 | 0.91 |
| 3,700 | 0.1% | .000002 | 0.85 |
| 4,100 | 0.1% | .000005 | 0.80 |
| 4,500 | 0.1% | .000009 | 0.77 |

## Hallwood Site

| Flow (cfs) | Net Q | Sol Δ | Max F |
|---|---|---|---|
| 150 | 0.5% | .000001 | 0.77 |
| 250 | 0.1% | .000007 | 0.75 |
| 300 | 0.2% | .000008 | 0.78 |
| 350 | 0.2% | .000007 | 0.80 |
| 400 | 0.3% | < .000001 | 0.80 |
| 500 | 0.2% | .000008 | 0.79 |
| 600 | 0.2% | .000009 | 0.80 |
| 700 | 0.1% | .000005 | 1.00 |
| 800 | 0.1% | < .000001 | 1.42 |
| 900 | 0.1% | .000003 | 3.39 |
| 1,000 | 0.1% | .000009 | 2.03 |
| 1,100 | 0.2% | .000009 | 2.28 |
| 1,200 | 0.03% | .000003 | 2.64 |
| 1,300 | 0.03% | .000005 | 3.35 |
| 1,400 | 0.01% | .000001 | 2.71 |
| 1,500 | 0.03% | .000009 | 2.55 |
| 1,600 | 0.03% | .000002 | 2.18 |
| 1,700 | 0.03% | .000003 | 1.87 |
| 1,800 | 0.03% | .000002 | 1.52 |
| 1,900 | 0.03% | .000002 | 1.36 |
| 2,000 | 0.1% | .000002 | 1.29 |
| 2,100 | 0.1% | .000002 | 1.25 |
| 2,300 | 0.1% | .000006 | 1.48 |
| 2,500 | 0.1% | .000006 | 1.04 |
| 2,700 | 0.2% | .000005 | 0.92 |
| 2,900 | 0.2% | .000007 | 0.89 |
| 3,300 | 0.2% | .000006 | 0.90 |
| 3,700 | 0.1% | .000005 | 1.21 |
| 4,100 | 0.1% | .000004 | 1.31 |
| 4,500 | 0.02% | .000004 | 1.42 |

Appendix I

Plantz Site

| Flow (cfs) | Net Q | Sol Δ | Max F |
|---|---|---|---|
| 150 | 2.4% | < .000001 | 0.70 |
| 250 | 0.4% | < .000001 | 0.54 |
| 300 | 0.5% | < .000001 | 0.58 |
| 350 | 0.4% | .000001 | 0.87 |
| 400 | 0.5% | .000002 | 0.58 |
| 500 | 0.4% | < .000001 | 0.73 |
| 600 | 0.2% | < .000001 | 0.61 |
| 700 | 0.2% | < .000001 | 0.73 |
| 800 | 0.2% | < .000001 | 0.60 |
| 900 | 0.1% | .000006 | 0.62 |
| 1,000 | 0.1% | < .000001 | 0.63 |
| 1,100 | 0.1% | .000003 | 0.65 |
| 1,200 | 0.1% | .000007 | 0.69 |
| 1,300 | 0.1% | < .000001 | 0.66 |
| 1,400 | 0.1% | .000003 | 0.67 |
| 1,500 | 0.1% | .000005 | 0.69 |
| 1,600 | 0.02% | .000002 | 0.78 |
| 1,700 | 0.02% | < .000001 | 1.04 |
| 1,800 | 0.04% | .000002 | 1.93 |
| 1,900 | 0.02% | .000002 | 1.77 |
| 2,000 | 0.02% | .000001 | 1.74 |
| 2,100 | 0.02% | .000001 | 1.68 |
| 2,300 | 0.03% | < .000001 | 2.30 |
| 2,500 | 0.03% | < .000001 | 1.86 |
| 2,700 | 0.01% | .000002 | 1.50 |
| 2,900 | 0.01% | .000002 | 1.30 |
| 3,300 | 0.01% | .000002 | 2.04 |
| 3,700 | 0.01% | .000003 | 1.31 |
| 4,100 | 0.01% | .000007 | 1.07 |
| 4,500 | 0.02% | .000006 | 0.92 |

# APPENDIX J
# HABITAT SUITABILITY CRITERIA

## Spring-run Chinook Salmon Spawning

| Water Velocity (ft/s) | SI Value | Water Depth (ft) | SI Value | Substrate Code | SI Value |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| 0.28 | 0.00 | 0.4 | 0.00 | 1.2 | 0.00 |
| 0.29 | 0.04 | 0.5 | 0.17 | 1.3 | 0.31 |
| 0.30 | 0.04 | 0.6 | 0.22 | 2.4 | 1.00 |
| 0.40 | 0.06 | 0.7 | 0.29 | 3.5 | 0.14 |
| 0.50 | 0.09 | 0.8 | 0.36 | 4.6 | 0.12 |
| 0.60 | 0.12 | 0.9 | 0.43 | 6.8 | 0.00 |
| 0.70 | 0.15 | 1.0 | 0.51 | 100 | 0.00 |
| 0.80 | 0.20 | 1.1 | 0.60 | | |
| 0.90 | 0.25 | 1.2 | 0.68 | | |
| 1.00 | 0.31 | 1.3 | 0.75 | | |
| 1.10 | 0.38 | 1.4 | 0.82 | | |
| 1.20 | 0.45 | 1.5 | 0.88 | | |
| 1.30 | 0.52 | 1.6 | 0.93 | | |
| 1.40 | 0.60 | 1.7 | 0.97 | | |
| 1.50 | 0.67 | 1.8 | 0.99 | | |
| 1.60 | 0.74 | 1.9 | 1.00 | | |
| 1.70 | 0.80 | 2.0 | 1.00 | | |
| 1.90 | 0.90 | 5.3 | 0.00 | | |
| 2.00 | 0.94 | 100 | 0.00 | | |
| 2.10 | 0.97 | | | | |
| 2.20 | 0.99 | | | | |
| 2.30 | 1.00 | | | | |
| 2.40 | 1.00 | | | | |
| 2.50 | 0.99 | | | | |
| 2.60 | 0.97 | | | | |
| 2.70 | 0.95 | | | | |
| 2.80 | 0.92 | | | | |
| 3.00 | 0.84 | | | | |
| 3.10 | 0.79 | | | | |
| 3.50 | 0.59 | | | | |
| 3.60 | 0.53 | | | | |
| 3.70 | 0.48 | | | | |
| 3.80 | 0.44 | | | | |
| 3.90 | 0.39 | | | | |
| 4.00 | 0.35 | | | | |
| 4.10 | 0.31 | | | | |
| 4.20 | 0.28 | | | | |
| 4.30 | 0.24 | | | | |
| 4.40 | 0.22 | | | | |
| 4.41 | 0.00 | | | | |
| 100.00 | 0.00 | | | | |

## Fall-run Chinook Salmon Spawning

| Water Velocity (ft/s) | SI Value | Water Depth (ft) | SI Value | Substrate Code | SI Value |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| 0.22 | 0.00 | 0.1 | 0.00 | 0.1 | 0.00 |
| 0.23 | 0.09 | 0.2 | 0.09 | 1 | 0.00 |
| 0.30 | 0.13 | 0.3 | 0.15 | 1.2 | 0.05 |
| 0.40 | 0.21 | 0.4 | 0.24 | 1.3 | 0.58 |
| 0.50 | 0.30 | 0.5 | 0.34 | 2.4 | 1.00 |
| 0.80 | 0.63 | 0.6 | 0.46 | 3.5 | 0.65 |
| 1.00 | 0.81 | 0.7 | 0.58 | 4.6 | 0.29 |
| 1.10 | 0.87 | 0.8 | 0.70 | 6.8 | 0.01 |
| 1.20 | 0.92 | 0.9 | 0.79 | 8 | 0.00 |
| 1.30 | 0.96 | 1.0 | 0.87 | 100 | 0.00 |
| 1.50 | 1.00 | 1.1 | 0.93 | | |
| 1.70 | 1.00 | 1.2 | 0.97 | | |
| 1.80 | 0.99 | 1.3 | 0.99 | | |
| 1.90 | 0.97 | 1.4 | 1.00 | | |
| 2.00 | 0.96 | 4.8 | 0.02 | | |
| 2.60 | 0.84 | 7.8 | 0.02 | | |
| 2.70 | 0.83 | 7.9 | 0.00 | | |
| 2.80 | 0.81 | 100 | 0.00 | | |
| 3.10 | 0.78 | | | | |
| 3.20 | 0.78 | | | | |
| 3.30 | 0.77 | | | | |
| 3.40 | 0.77 | | | | |
| 3.50 | 0.76 | | | | |
| 3.60 | 0.76 | | | | |
| 3.80 | 0.74 | | | | |
| 3.90 | 0.72 | | | | |
| 4.00 | 0.71 | | | | |
| 4.20 | 0.65 | | | | |
| 4.30 | 0.61 | | | | |
| 4.40 | 0.56 | | | | |
| 4.50 | 0.51 | | | | |
| 4.60 | 0.45 | | | | |
| 4.70 | 0.38 | | | | |
| 4.80 | 0.31 | | | | |
| 4.90 | 0.24 | | | | |
| 5.10 | 0.12 | | | | |
| 5.20 | 0.08 | | | | |
| 5.30 | 0.05 | | | | |
| 5.31 | 0.05 | | | | |
| 5.32 | 0.00 | | | | |
| 100 | 0.00 | | | | |

## Steelhead/Rainbow Trout Spawning

| Water Velocity (ft/s) | SI Value | Water Depth (ft) | SI Value | Substrate Code | SI Value |
|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.0 | 0.00 | 0 | 0.00 |
| 0.08 | 0.00 | 0.3 | 0.00 | 0.1 | 0.00 |
| 0.09 | 0.02 | 0.4 | 0.01 | 1 | 0.13 |
| 0.20 | 0.02 | 0.5 | 0.01 | 1.2 | 1.00 |
| 0.30 | 0.03 | 0.6 | 0.01 | 1.3 | 0.85 |
| 0.40 | 0.05 | 0.7 | 0.01 | 2.4 | 0.28 |
| 0.50 | 0.07 | 0.8 | 0.02 | 3.5 | 0.16 |
| 0.60 | 0.09 | 0.9 | 0.02 | 4.6 | 0.05 |
| 0.70 | 0.12 | 1.0 | 0.03 | 6.8 | 0.00 |
| 0.80 | 0.15 | 1.1 | 0.04 | 100 | 0.00 |
| 0.90 | 0.20 | 1.2 | 0.06 | | |
| 1.00 | 0.24 | 1.3 | 0.08 | | |
| 1.10 | 0.30 | 1.4 | 0.10 | | |
| 1.20 | 0.35 | 1.5 | 0.14 | | |
| 1.30 | 0.41 | 1.6 | 0.18 | | |
| 1.40 | 0.48 | 1.7 | 0.23 | | |
| 1.50 | 0.54 | 1.8 | 0.29 | | |
| 1.60 | 0.60 | 1.9 | 0.36 | | |
| 1.70 | 0.67 | 2.0 | 0.43 | | |
| 1.80 | 0.72 | 2.1 | 0.51 | | |
| 1.90 | 0.78 | 2.2 | 0.58 | | |
| 2.00 | 0.83 | 2.3 | 0.64 | | |
| 2.10 | 0.87 | 2.4 | 0.70 | | |
| 2.20 | 0.91 | 2.5 | 0.74 | | |
| 2.40 | 0.96 | 2.6 | 0.78 | | |
| 2.60 | 1.00 | 2.7 | 0.82 | | |
| 2.90 | 1.00 | 2.8 | 0.84 | | |
| 3.30 | 0.94 | 2.9 | 0.86 | | |
| 3.40 | 0.91 | 3.0 | 0.88 | | |
| 3.50 | 0.88 | 3.1 | 0.89 | | |
| 3.80 | 0.79 | 3.2 | 0.90 | | |
| 4.10 | 0.68 | 3.3 | 0.91 | | |
| 4.20 | 0.65 | 3.4 | 0.92 | | |
| 4.30 | 0.61 | 3.5 | 0.92 | | |
| 4.40 | 0.58 | 3.6 | 0.92 | | |
| 4.60 | 0.51 | 3.7 | 0.92 | | |
| 5.10 | 0.38 | 3.8 | 0.92 | | |
| 5.20 | 0.36 | 6.5 | 0.94 | | |
| 5.30 | 0.34 | 6.6 | 0.96 | | |
| 6.10 | 0.27 | 6.7 | 0.97 | | |
| 6.20 | 0.26 | 6.8 | 0.98 | | |
| 6.30 | 0.27 | 6.9 | 0.99 | | |

## Steelhead/Rainbow Trout Spawning (continued)

| Water Velocity (ft/s) | SI Value | Water Depth (ft) | SI Value |
|---|---|---|---|
| 6.80 | 0.30 | 7.0 | 1.00 |
| 6.90 | 0.32 | 19.9 | 1.00 |
| 6.92 | 0.33 | 100.0 | 0.00 |
| 6.93 | 0.00 | | |
| 100.00 | 0.00 | | |

# APPENDIX K
# HABITAT MODELING RESULTS

UC Sierra Site WUA (ft$^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 400 | 21,312 | 52,947 | 4,039 |
| 500 | 26,447 | 57,414 | 6,058 |
| 600 | 31,248 | 60,181 | 8,317 |
| 700 | 35,090 | 61,666 | 10,828 |
| 800 | 38,287 | 62,527 | 13,552 |
| 900 | 40,784 | 62,710 | 16,307 |
| 1,000 | 42,743 | 62,441 | 18,966 |
| 1,100 | 44,121 | 61,763 | 21,582 |
| 1,200 | 44,875 | 60,891 | 24,208 |
| 1,300 | 45,294 | 60,009 | 26,587 |
| 1,400 | 45,402 | 59,244 | 28,793 |
| 1,500 | 44,810 | 57,630 | 30,989 |
| 1,600 | 43,917 | 56,252 | 32,916 |
| 1,700 | 42,840 | 54,863 | 34,670 |
| 1,800 | 41,527 | 53,593 | 36,307 |
| 1,900 | 40,063 | 52,302 | 37,706 |
| 2,000 | 38,535 | 51,053 | 38,954 |
| 2,100 | 36,920 | 49,815 | 40,106 |
| 2,300 | 34,218 | 47,770 | 41,958 |
| 2,500 | 31,603 | 45,746 | 43,389 |
| 2,700 | 28,847 | 43,895 | 44,369 |
| 2,900 | 26,361 | 41,785 | 44,993 |
| 3,100 | 24,068 | 39,794 | 45,327 |
| 3,300 | 21,883 | 37,738 | 45,359 |
| 3,500 | 19,741 | 35,833 | 45,133 |
| 3,700 | 18,008 | 33,895 | 44,767 |
| 3,900 | 16,404 | 32,023 | 44,250 |
| 4,100 | 14,865 | 30,257 | 43,583 |
| 4,300 | 13,240 | 28,384 | 42,797 |
| 4,500 | 12,066 | 26,598 | 41,904 |

Appendix K

Timbuctoo Site WUA ($ft^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 400 | 42,097 | 110,136 | 13,110 |
| 500 | 52,861 | 121,535 | 18,708 |
| 600 | 61,429 | 128,456 | 24,294 |
| 700 | 69,513 | 134,559 | 30,408 |
| 800 | 77,048 | 136,884 | 37,178 |
| 900 | 83,312 | 137,595 | 43,271 |
| 1,000 | 88,339 | 137,164 | 50,870 |
| 1,100 | 91,611 | 135,894 | 57,005 |
| 1,200 | 94,259 | 134,495 | 64,260 |
| 1,300 | 96,164 | 133,278 | 70,697 |
| 1,400 | 97,359 | 131,857 | 77,457 |
| 1,500 | 98,059 | 130,523 | 83,129 |
| 1,600 | 97,445 | 128,994 | 88,501 |
| 1,700 | 96,552 | 128,585 | 92,957 |
| 1,800 | 95,465 | 127,476 | 97,714 |
| 1,900 | 94,205 | 127,067 | 101,503 |
| 2,000 | 93,463 | 127,918 | 104,549 |
| 2,100 | 92,946 | 128,951 | 107,886 |
| 2,300 | 92,537 | 131,761 | 112,676 |
| 2,500 | 91,633 | 134,645 | 117,079 |
| 2,700 | 90,772 | 137,508 | 120,028 |
| 2,900 | 90,826 | 140,598 | 122,590 |
| 3,100 | 92,063 | 143,289 | 124,925 |
| 3,300 | 93,043 | 144,828 | 126,798 |
| 3,500 | 93,872 | 145,280 | 128,068 |
| 3,700 | 94,571 | 144,946 | 129,016 |
| 3,900 | 94,550 | 143,493 | 129,586 |
| 4,100 | 94,367 | 141,975 | 129,823 |
| 4,300 | 94,130 | 140,673 | 129,845 |
| 4,500 | 93,570 | 139,188 | 129,629 |

Appendix K

## Highway 20 Site WUA ($ft^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 400 | 14,047 | 26,791 | 2,801 |
| 500 | 17,373 | 32,302 | 3,746 |
| 600 | 20,268 | 36,877 | 4,768 |
| 700 | 23,153 | 41,129 | 5,914 |
| 800 | 25,823 | 44,347 | 7,300 |
| 900 | 28,104 | 46,134 | 8,801 |
| 1,000 | 29,708 | 46,930 | 10,428 |
| 1,100 | 30,731 | 46,554 | 12,292 |
| 1,200 | 31,194 | 46,468 | 14,294 |
| 1,300 | 31,312 | 46,209 | 16,286 |
| 1,400 | 30,989 | 45,617 | 18,406 |
| 1,500 | 30,311 | 44,605 | 20,516 |
| 1,600 | 29,558 | 43,658 | 22,453 |
| 1,700 | 28,653 | 42,926 | 24,240 |
| 1,800 | 27,512 | 42,227 | 25,919 |
| 1,900 | 26,425 | 41,366 | 27,362 |
| 2,000 | 25,241 | 40,354 | 28,621 |
| 2,100 | 24,014 | 39,245 | 29,708 |
| 2,300 | 21,689 | 37,146 | 31,258 |
| 2,500 | 19,440 | 34,832 | 32,324 |
| 2,700 | 17,491 | 32,744 | 33,002 |
| 2,900 | 15,984 | 31,032 | 33,400 |
| 3,100 | 14,553 | 29,245 | 33,659 |
| 3,300 | 13,584 | 28,115 | 33,755 |
| 3,500 | 12,831 | 27,803 | 33,745 |
| 3,700 | 12,185 | 27,286 | 33,637 |
| 3,900 | 11,883 | 26,662 | 33,573 |
| 4,100 | 11,851 | 26,641 | 33,379 |
| 4,300 | 11,937 | 26,092 | 33,153 |
| 4,500 | 12,152 | 25,930 | 32,894 |

Appendix K

Island Site WUA ($ft^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 400 | 39,654 | 65,929 | 19,084 |
| 500 | 41,732 | 70,406 | 25,521 |
| 600 | 42,786 | 76,962 | 31,118 |
| 700 | 44,476 | 85,024 | 37,383 |
| 800 | 46,661 | 92,785 | 42,657 |
| 900 | 49,923 | 98,414 | 46,758 |
| 1,000 | 53,658 | 102,903 | 51,634 |
| 1,100 | 57,285 | 107,004 | 56,123 |
| 1,200 | 60,934 | 109,027 | 60,741 |
| 1,300 | 64,217 | 109,555 | 64,777 |
| 1,400 | 66,392 | 108,995 | 69,126 |
| 1,500 | 68,975 | 108,155 | 72,990 |
| 1,600 | 71,289 | 107,036 | 75,875 |
| 1,700 | 73,453 | 105,497 | 79,351 |
| 1,800 | 74,841 | 103,796 | 81,967 |
| 1,900 | 75,767 | 102,257 | 84,948 |
| 2,000 | 76,240 | 100,890 | 87,273 |
| 2,100 | 76,736 | 99,770 | 89,049 |
| 2,300 | 76,294 | 97,015 | 92,828 |
| 2,500 | 74,647 | 93,592 | 95,680 |
| 2,700 | 71,935 | 89,286 | 96,929 |
| 2,900 | 68,738 | 85,239 | 98,242 |
| 3,100 | 63,055 | 80,837 | 92,419 |
| 3,300 | 58,652 | 76,854 | 91,708 |
| 3,500 | 54,541 | 73,087 | 89,911 |
| 3,700 | 51,204 | 70,170 | 88,597 |
| 3,900 | 48,330 | 67,145 | 87,047 |
| 4,100 | 45,208 | 63,916 | 84,948 |
| 4,300 | 42,743 | 62,743 | 82,580 |
| 4,500 | 40,461 | 60,870 | 80,298 |

Hammond Site WUA ($ft^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 400 | 53,744 | 80,019 | 13,821 |
| 500 | 58,631 | 77,952 | 18,428 |
| 600 | 60,256 | 75,724 | 22,766 |
| 700 | 58,760 | 72,904 | 26,425 |
| 800 | 55,918 | 71,504 | 29,235 |
| 900 | 52,625 | 71,128 | 31,495 |
| 1,000 | 49,083 | 69,395 | 33,637 |
| 1,100 | 45,219 | 67,113 | 35,090 |
| 1,200 | 41,215 | 64,874 | 36,629 |
| 1,300 | 37,878 | 62,420 | 37,792 |
| 1,400 | 35,187 | 60,827 | 38,901 |
| 1,500 | 32,905 | 58,189 | 39,557 |
| 1,600 | 30,752 | 54,734 | 40,052 |
| 1,700 | 27,814 | 51,171 | 40,160 |
| 1,800 | 24,940 | 48,373 | 40,225 |
| 1,900 | 22,776 | 45,068 | 40,214 |
| 2,000 | 21,108 | 41,796 | 39,869 |
| 2,100 | 19,396 | 38,653 | 39,590 |
| 2,300 | 16,479 | 32,744 | 38,632 |
| 2,500 | 13,627 | 27,599 | 37,060 |
| 2,700 | 11,711 | 23,648 | 35,704 |
| 2,900 | 9,943 | 20,796 | 34,369 |
| 3,100 | 8,823 | 18,212 | 33,142 |
| 3,300 | 7,872 | 16,889 | 32,044 |
| 3,500 | 7,383 | 15,468 | 30,871 |
| 3,700 | 7,242 | 14,693 | 29,902 |
| 3,900 | 6,922 | 13,810 | 28,718 |
| 4,100 | 6,750 | 13,562 | 27,674 |
| 4,300 | 6,701 | 13,896 | 26,931 |
| 4,500 | 6,728 | 14,090 | 26,253 |

## Upper Daguerre Site WUA (ft$^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 150 | 6,948 | 18,471 | 264 |
| 250 | 11,754 | 24,768 | 723 |
| 300 | 13,627 | 26,436 | 1,026 |
| 350 | 15,339 | 27,749 | 1,377 |
| 400 | 16,781 | 28,341 | 1,687 |
| 500 | 18,761 | 28,761 | 2,659 |
| 600 | 19,762 | 28,567 | 3,538 |
| 700 | 20,139 | 28,137 | 4,421 |
| 800 | 20,236 | 27,534 | 5,289 |
| 900 | 19,741 | 26,522 | 6,085 |
| 1,000 | 18,869 | 25,392 | 6,819 |
| 1,100 | 18,191 | 24,509 | 7,481 |
| 1,200 | 17,599 | 23,831 | 8,121 |
| 1,300 | 17,115 | 23,336 | 8,679 |
| 1,400 | 16,673 | 23,207 | 9,169 |
| 1,500 | 16,253 | 22,679 | 9,622 |
| 1,600 | 15,791 | 21,861 | 9,976 |
| 1,700 | 15,112 | 21,076 | 10,305 |
| 1,800 | 14,434 | 20,344 | 10,598 |
| 1,900 | 13,767 | 19,687 | 10,839 |
| 2,000 | 13,014 | 19,138 | 11,044 |
| 2,100 | 12,282 | 18,449 | 11,184 |
| 2,300 | 11,130 | 17,728 | 11,356 |
| 2,500 | 10,807 | 18,094 | 11,507 |
| 2,700 | 10,861 | 18,148 | 11,625 |
| 2,900 | 10,828 | 17,890 | 11,690 |
| 3,300 | 10,500 | 16,964 | 11,808 |
| 3,700 | 9,875 | 16,845 | 11,851 |
| 4,100 | 9,544 | 17,427 | 11,926 |
| 4,500 | 9,572 | 17,491 | 12,012 |

Lower Daguerre Site WUA ($ft^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 150 | 31,301 | 60,030 | 2,291 |
| 250 | 44,649 | 69,061 | 4,982 |
| 300 | 48,341 | 70,977 | 6,303 |
| 350 | 50,256 | 71,870 | 7,633 |
| 400 | 50,967 | 72,635 | 8,906 |
| 500 | 50,655 | 73,022 | 11,302 |
| 600 | 48,986 | 73,959 | 13,261 |
| 700 | 46,877 | 75,315 | 14,725 |
| 800 | 44,745 | 77,015 | 15,941 |
| 900 | 43,691 | 79,340 | 16,878 |
| 1,000 | 43,206 | 81,773 | 17,728 |
| 1,100 | 43,055 | 85,271 | 18,471 |
| 1,200 | 43,518 | 89,157 | 19,235 |
| 1,300 | 45,241 | 91,697 | 19,978 |
| 1,400 | 46,715 | 91,665 | 20,677 |
| 1,500 | 48,125 | 92,526 | 21,377 |
| 1,600 | 49,708 | 92,752 | 22,055 |
| 1,700 | 51,645 | 93,796 | 22,841 |
| 1,800 | 53,400 | 94,744 | 23,734 |
| 1,900 | 54,745 | 95,809 | 24,671 |
| 2,000 | 55,886 | 95,981 | 26,425 |
| 2,100 | 55,908 | 96,057 | 26,436 |
| 2,300 | 57,102 | 96,358 | 28,137 |
| 2,500 | 57,005 | 95,066 | 29,741 |
| 2,700 | 56,456 | 93,409 | 31,226 |
| 2,900 | 55,143 | 91,116 | 32,550 |
| 3,300 | 51,613 | 85,723 | 34,875 |
| 3,700 | 46,704 | 79,610 | 36,683 |
| 4,100 | 38,588 | 74,454 | 37,900 |
| 4,500 | 37,555 | 71,537 | 38,352 |

Appendix K

## Pyramids Site WUA (ft$^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 150 | 11,248 | 43,508 | 546 |
| 250 | 20,667 | 64,314 | 1,474 |
| 300 | 25,274 | 71,935 | 2,082 |
| 350 | 29,708 | 78,210 | 2,778 |
| 400 | 33,863 | 83,205 | 3,588 |
| 500 | 41,032 | 90,309 | 5,473 |
| 600 | 46,478 | 94,076 | 7,466 |
| 700 | 50,655 | 96,810 | 9,564 |
| 800 | 53,593 | 98,102 | 11,679 |
| 900 | 55,638 | 99,964 | 13,595 |
| 1,000 | 56,801 | 101,428 | 15,317 |
| 1,100 | 57,092 | 101,934 | 16,824 |
| 1,200 | 56,715 | 101,998 | 18,417 |
| 1,300 | 56,317 | 102,332 | 19,795 |
| 1,400 | 55,768 | 103,064 | 21,076 |
| 1,500 | 55,176 | 102,913 | 22,270 |
| 1,600 | 54,261 | 102,440 | 23,325 |
| 1,700 | 52,958 | 101,482 | 24,240 |
| 1,800 | 51,376 | 100,179 | 25,101 |
| 1,900 | 49,159 | 98,468 | 25,812 |
| 2,000 | 46,974 | 96,616 | 26,425 |
| 2,100 | 44,918 | 94,819 | 26,985 |
| 2,300 | 40,278 | 89,459 | 27,857 |
| 2,500 | 35,521 | 82,516 | 28,513 |
| 2,700 | 30,882 | 75,110 | 28,976 |
| 2,900 | 26,479 | 67,629 | 30,591 |
| 3,300 | 19,074 | 53,152 | 30,569 |
| 3,700 | 13,014 | 40,838 | 30,171 |
| 4,100 | 9,319 | 31,883 | 29,439 |
| 4,500 | 7,216 | 24,832 | 28,352 |

Hallwood Site WUA ($ft^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 150 | 5,882 | 20,602 | 1,311 |
| 250 | 8,702 | 22,217 | 2,991 |
| 300 | 9,503 | 22,270 | 3,984 |
| 350 | 10,029 | 22,087 | 5,023 |
| 400 | 10,343 | 22,001 | 6,131 |
| 500 | 10,796 | 22,087 | 8,032 |
| 600 | 10,958 | 23,444 | 9,574 |
| 700 | 11,291 | 25,823 | 10,925 |
| 800 | 12,034 | 28,417 | 12,206 |
| 900 | 12,755 | 30,279 | 13,326 |
| 1,000 | 13,347 | 31,926 | 14,499 |
| 1,100 | 13,789 | 33,185 | 15,457 |
| 1,200 | 14,434 | 34,304 | 16,404 |
| 1,300 | 14,929 | 34,778 | 17,050 |
| 1,400 | 15,360 | 35,510 | 17,470 |
| 1,500 | 15,694 | 35,994 | 17,976 |
| 1,600 | 16,049 | 36,027 | 18,342 |
| 1,700 | 16,372 | 36,037 | 18,643 |
| 1,800 | 16,619 | 36,479 | 19,063 |
| 1,900 | 16,889 | 36,823 | 19,235 |
| 2,000 | 17,222 | 37,028 | 19,450 |
| 2,100 | 17,502 | 37,017 | 19,666 |
| 2,300 | 18,008 | 37,135 | 20,193 |
| 2,500 | 18,288 | 36,888 | 20,828 |
| 2,700 | 18,374 | 36,909 | 21,560 |
| 2,900 | 18,395 | 36,371 | 22,346 |
| 3,300 | 17,158 | 34,358 | 23,777 |
| 3,700 | 14,876 | 31,258 | 24,477 |
| 4,100 | 12,615 | 28,148 | 24,940 |
| 4,500 | 10,166 | 24,606 | 25,187 |

Plantz Site WUA (ft$^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 150 | 9,662 | 23,121 | 2,063 |
| 250 | 15,844 | 27,900 | 6,372 |
| 300 | 17,567 | 27,965 | 9,314 |
| 350 | 18,966 | 28,707 | 12,346 |
| 400 | 19,364 | 29,267 | 15,145 |
| 500 | 20,021 | 31,549 | 20,451 |
| 600 | 20,236 | 33,411 | 24,811 |
| 700 | 19,902 | 34,391 | 28,632 |
| 800 | 19,709 | 35,090 | 32,130 |
| 900 | 18,665 | 34,412 | 34,703 |
| 1,000 | 17,610 | 34,197 | 37,049 |
| 1,100 | 16,641 | 33,659 | 39,148 |
| 1,200 | 15,984 | 33,766 | 41,032 |
| 1,300 | 16,060 | 33,465 | 42,711 |
| 1,400 | 15,209 | 32,249 | 43,734 |
| 1,500 | 14,564 | 31,538 | 44,928 |
| 1,600 | 14,004 | 30,731 | 45,520 |
| 1,700 | 13,853 | 30,257 | 46,231 |
| 1,800 | 14,036 | 30,526 | 47,393 |
| 1,900 | 13,864 | 30,074 | 47,932 |
| 2,000 | 13,498 | 29,224 | 48,211 |
| 2,100 | 13,562 | 29,773 | 48,513 |
| 2,300 | 13,509 | 29,439 | 48,631 |
| 2,500 | 13,412 | 28,966 | 49,180 |
| 2,700 | 12,992 | 27,631 | 49,083 |
| 2,900 | 12,508 | 26,447 | 48,341 |
| 3,300 | 12,454 | 26,027 | 47,878 |
| 3,700 | 11,980 | 24,079 | 46,500 |
| 4,100 | 11,334 | 22,572 | 45,090 |
| 4,500 | 10,968 | 21,732 | 44,724 |

## Appendix K

### Englebright Dam to Daguerre Point Dam WUA ($ft^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 400 | 375,881 | 738,808 | 93,025 |
| 500 | 433,495 | 791,142 | 127,530 |
| 600 | 475,173 | 832,038 | 160,624 |
| 700 | 508,184 | 869,619 | 195,287 |
| 800 | 536,221 | 897,704 | 228,663 |
| 900 | 560,447 | 915,157 | 258,072 |
| 1,000 | 579,770 | 921,432 | 291,342 |
| 1,100 | 591,729 | 920,319 | 320,483 |
| 1,200 | 599,448 | 914,660 | 352,233 |
| 1,300 | 604,705 | 905,235 | 380,404 |
| 1,400 | 605,724 | 894,389 | 409,521 |
| 1,500 | 605,132 | 878,026 | 435,039 |
| 1,600 | 600,514 | 859,484 | 457,242 |
| 1,700 | 592,486 | 842,695 | 477,626 |
| 1,800 | 581,428 | 826,023 | 496,552 |
| 1,900 | 570,321 | 809,731 | 513,450 |
| 2,000 | 560,091 | 796,423 | 526,711 |
| 2,100 | 550,027 | 784,156 | 539,158 |
| 2,300 | 530,680 | 762,157 | 558,538 |
| 2,500 | 508,089 | 740,111 | 572,936 |
| 2,700 | 485,664 | 719,580 | 580,854 |
| 2,900 | 466,073 | 702,790 | 587,125 |
| 3,100 | 445,636 | 685,030 | 579,869 |
| 3,300 | 429,074 | 669,732 | 580,210 |
| 3,500 | 414,407 | 654,435 | 576,800 |
| 3,700 | 403,061 | 640,179 | 573,618 |
| 3,900 | 391,796 | 622,892 | 568,787 |
| 4,100 | 380.690 | 607,973 | 562,156 |
| 4,300 | 371,251 | 597,933 | 554,939 |
| 4,500 | 362,954 | 586,685 | 547,323 |

## Daguerre Point Dam to Feather River WUA ($ft^2$)

| Flow (cfs) | Spring-run | Fall-run | Steelhead/Rainbow Trout |
|---|---|---|---|
| 150 | 154,149 | 392,783 | 8,093 |
| 250 | 240,828 | 493,575 | 20,677 |
| 300 | 270,918 | 520,411 | 28,386 |
| 350 | 294,586 | 541,840 | 36,446 |
| 400 | 311,224 | 558,014 | 44,320 |
| 500 | 334,798 | 582,376 | 59,897 |
| 600 | 347,018 | 600,693 | 73,313 |
| 700 | 352,808 | 617,325 | 85,333 |
| 800 | 356,252 | 630,795 | 96,557 |
| 900 | 356,660 | 641,127 | 105,732 |
| 1,000 | 355,104 | 651,076 | 114,265 |
| 1,100 | 352,579 | 660,183 | 121,726 |
| 1,200 | 351,354 | 670,846 | 129,012 |
| 1,300 | 354,696 | 676,892 | 135,265 |
| 1,400 | 354,849 | 677,096 | 140,156 |
| 1,500 | 355,053 | 676,994 | 145,217 |
| 1,600 | 355,053 | 672,632 | 149,023 |
| 1,700 | 355,385 | 669,877 | 152,825 |
| 1,800 | 355,181 | 668,984 | 157,362 |
| 1,900 | 351,762 | 665,642 | 160,610 |
| 2,000 | 347,426 | 658,831 | 164,445 |
| 2,100 | 341,686 | 654,392 | 165,979 |
| 2,300 | 331,864 | 640,183 | 170,217 |
| 2,500 | 320,028 | 619,825 | 174,711 |
| 2,700 | 307,068 | 595,361 | 178,088 |
| 2,900 | 292,349 | 567,504 | 181,896 |
| 3,300 | 262,591 | 512,452 | 186,134 |
| 3,700 | 228,583 | 456,534 | 187,103 |
| 4,100 | 192,922 | 413,523 | 186,619 |
| 4,500 | 178,884 | 379,671 | 185,784 |

# APPENDIX L
# RIVER2D COMBINED HABITAT SUITABILITY OF REDD LOCATIONS[1]

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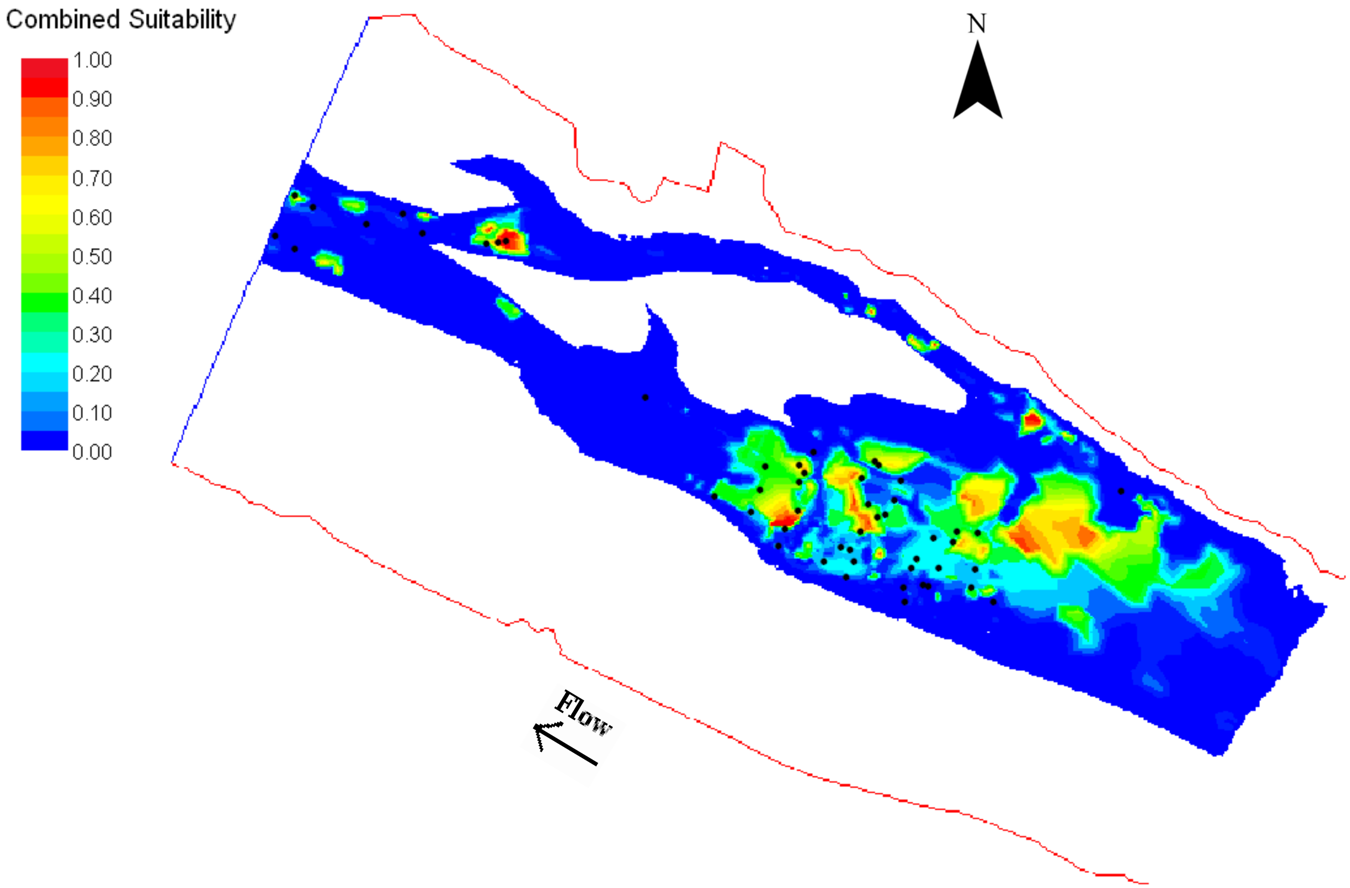
[1] For all pages, Combined Suitability: 1 = optimal, 0 = unusable

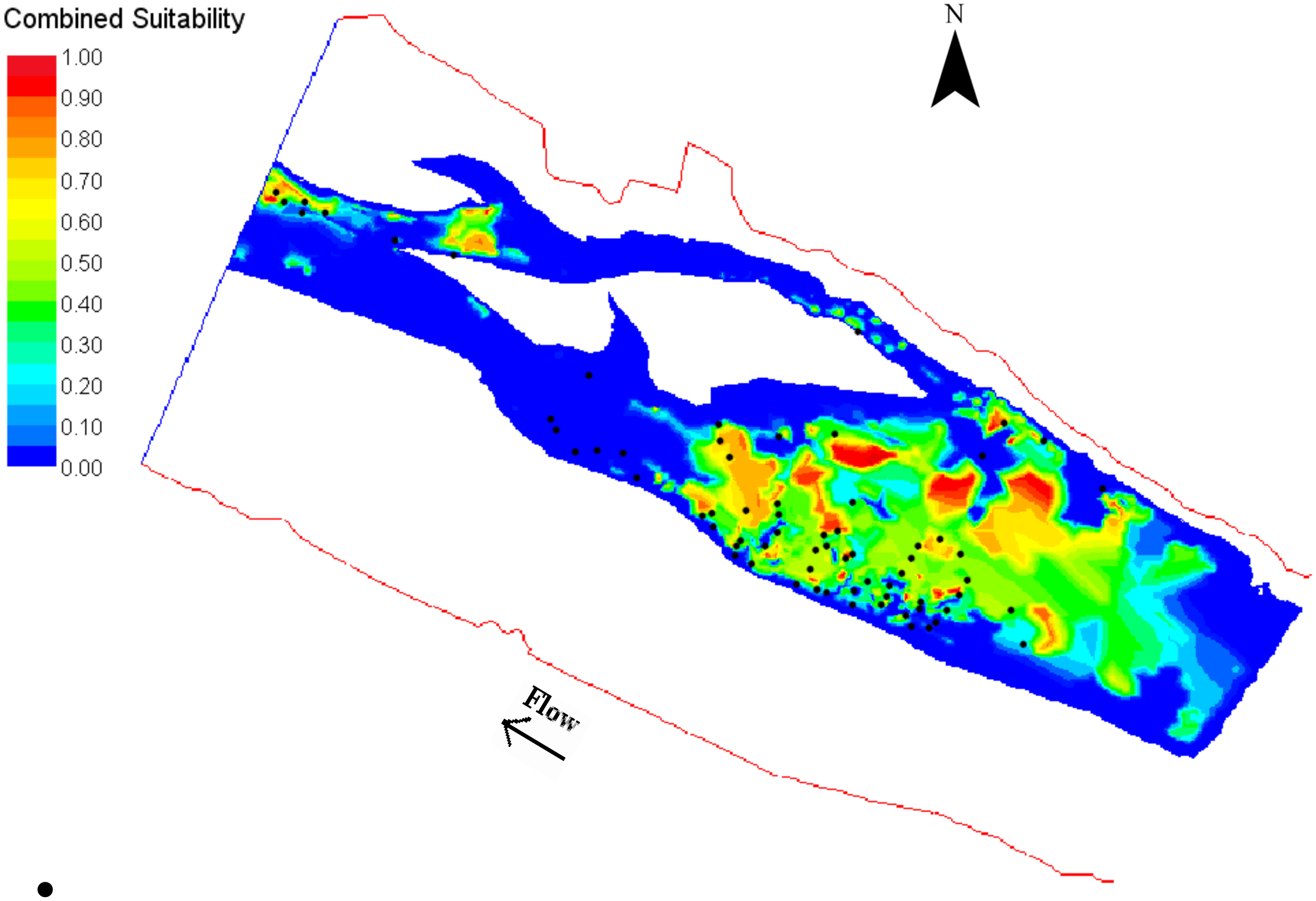
## U.C. SIERRA STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 649 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING



**Scale: 1: 1925**

Redd locations: ●

## U.C. SIERRA STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 878 CFS
## FALL-RUN CHINOOK SALMON SPAWNING

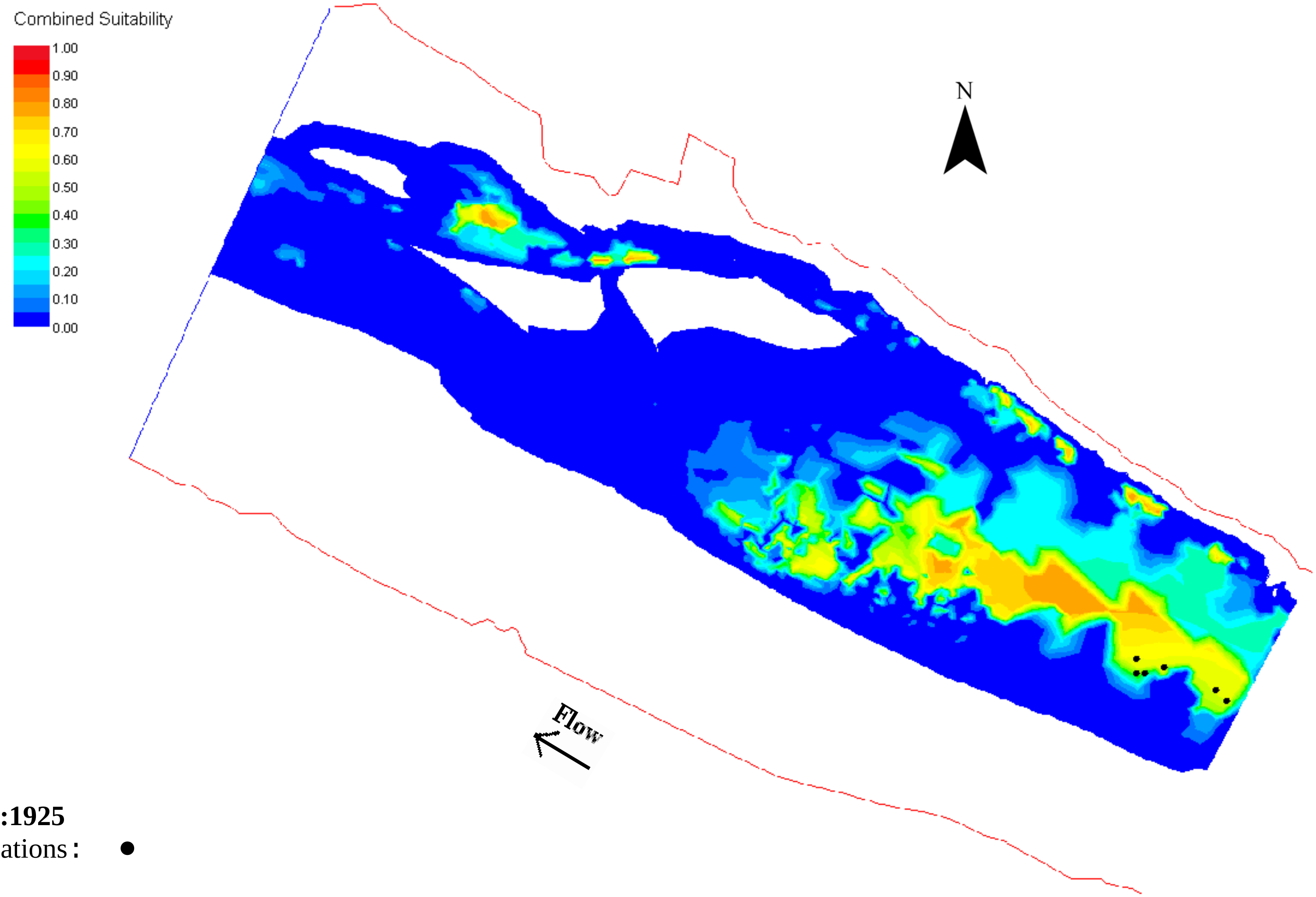


**Scale: 1:1925**

Redd locations: ●

Appendix L

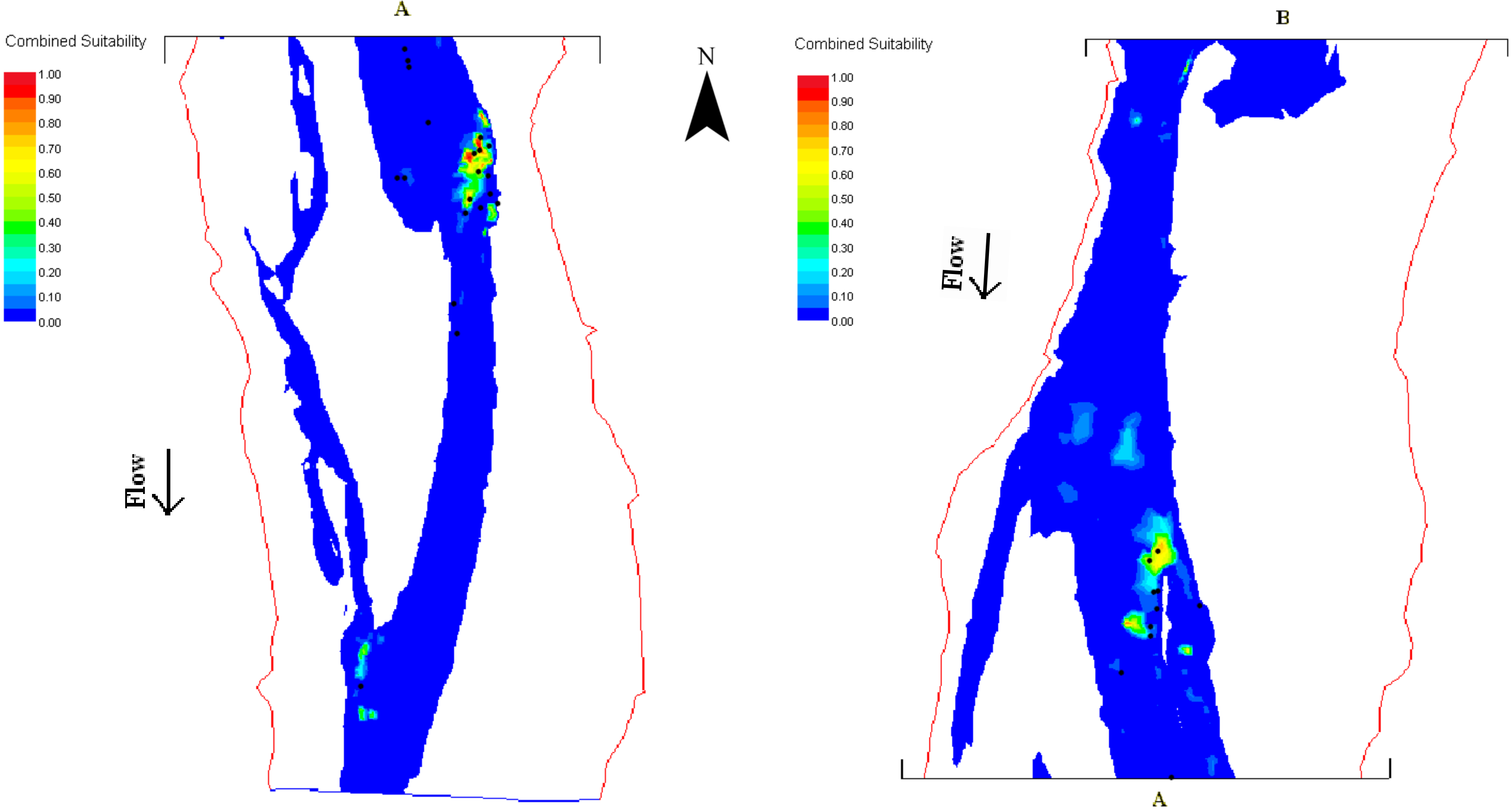
## U.C. SIERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING



**Scale: 1:1925**

Redd locations : ●

## TIMBUCTOO STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 649 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING

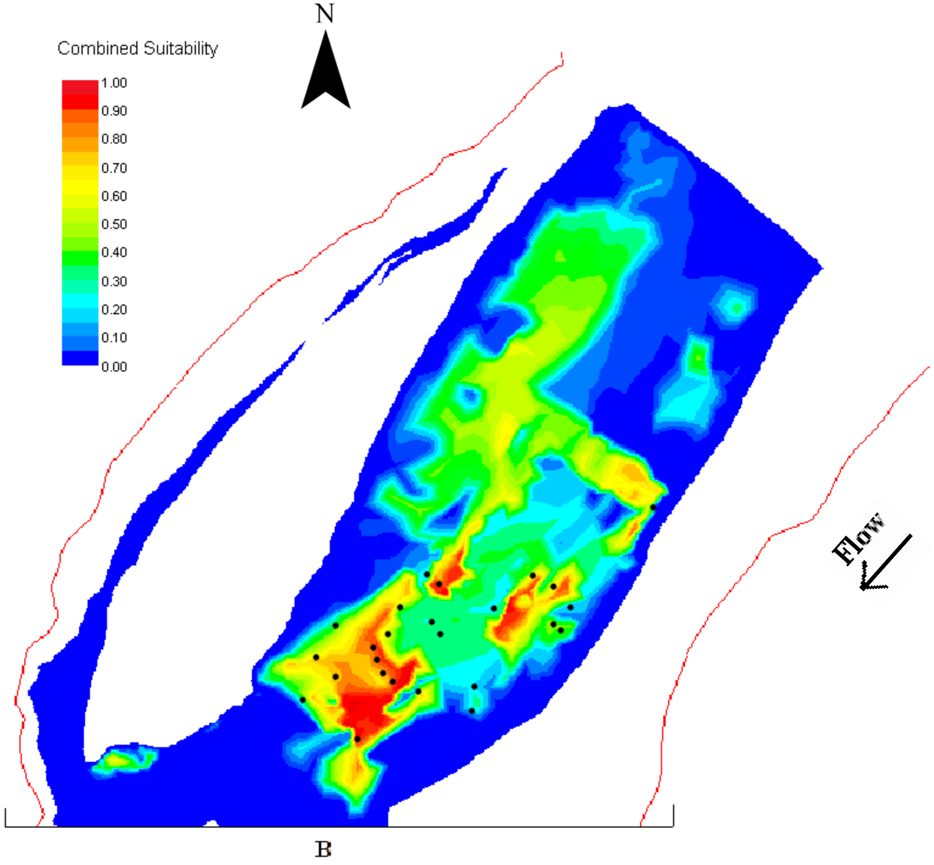


**Scale: 1:2570**

**Scale: 1:2131**

Redd locations: ●

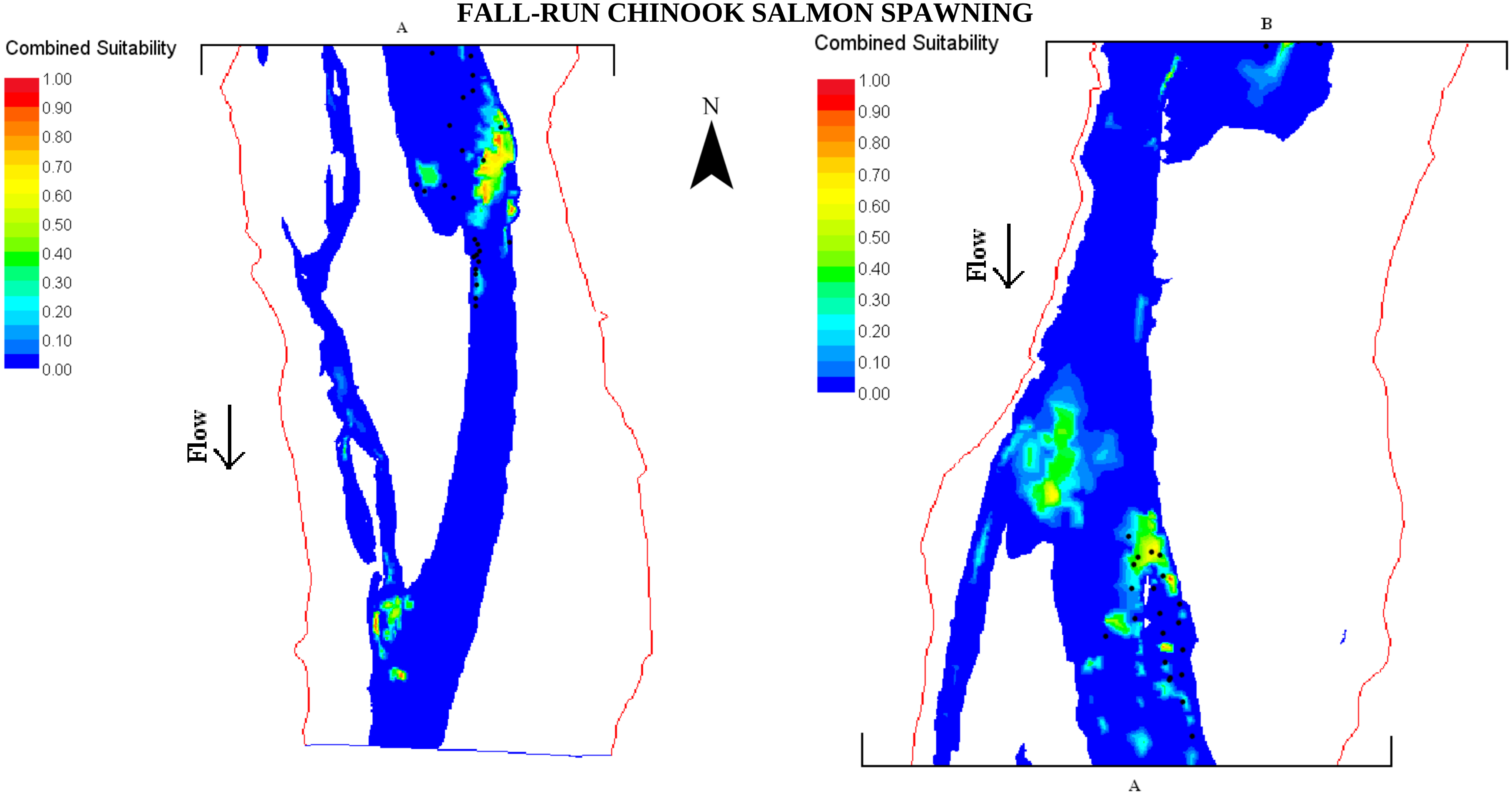
## TIMBUCTOO STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 649 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING (CONTINUED)



**Scale: 1:1026**

Redd locations : ●

## TIMBUCTOO STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 878 CFS
## FALL-RUN CHINOOK SALMON SPAWNING

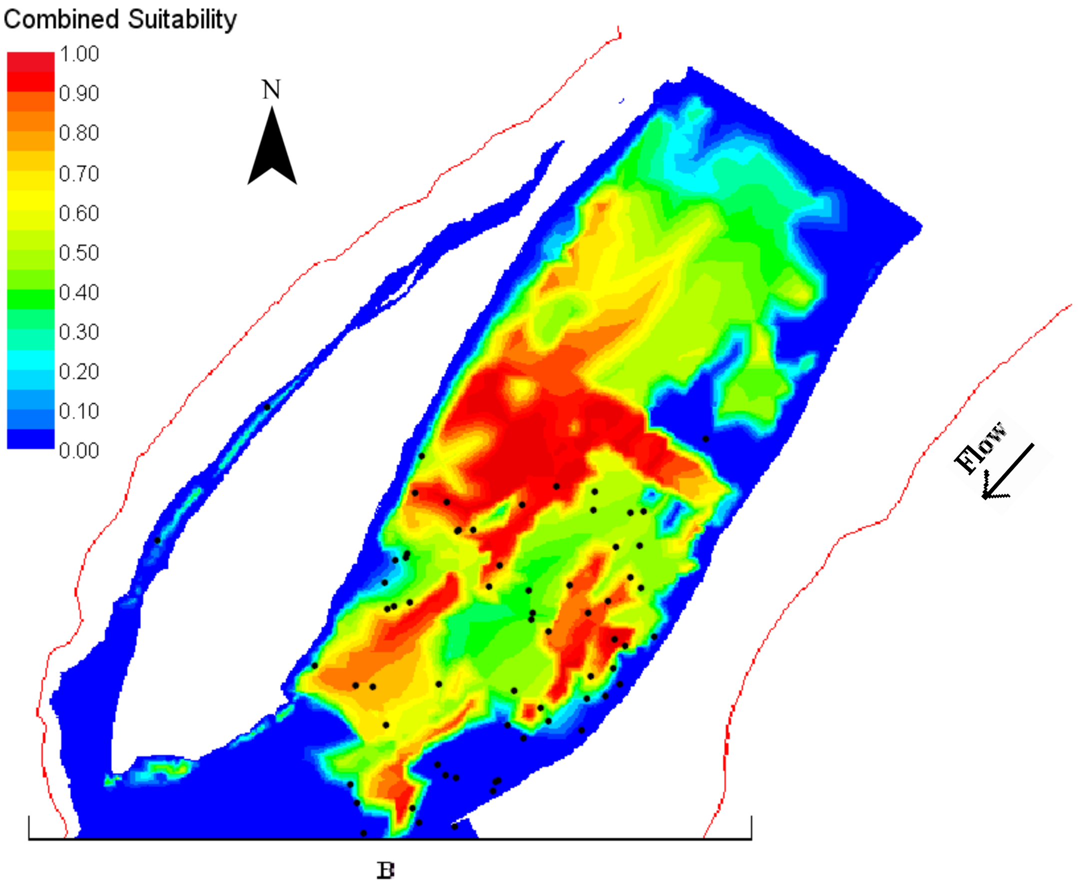


**Scale: 1:2748**

**Scale: 1:2145**

Redd locations: ●

## TIMBUCTOO STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 878 CFS
## FALL-RUN CHINOOK SALMON SPAWNING (CONTINUED)

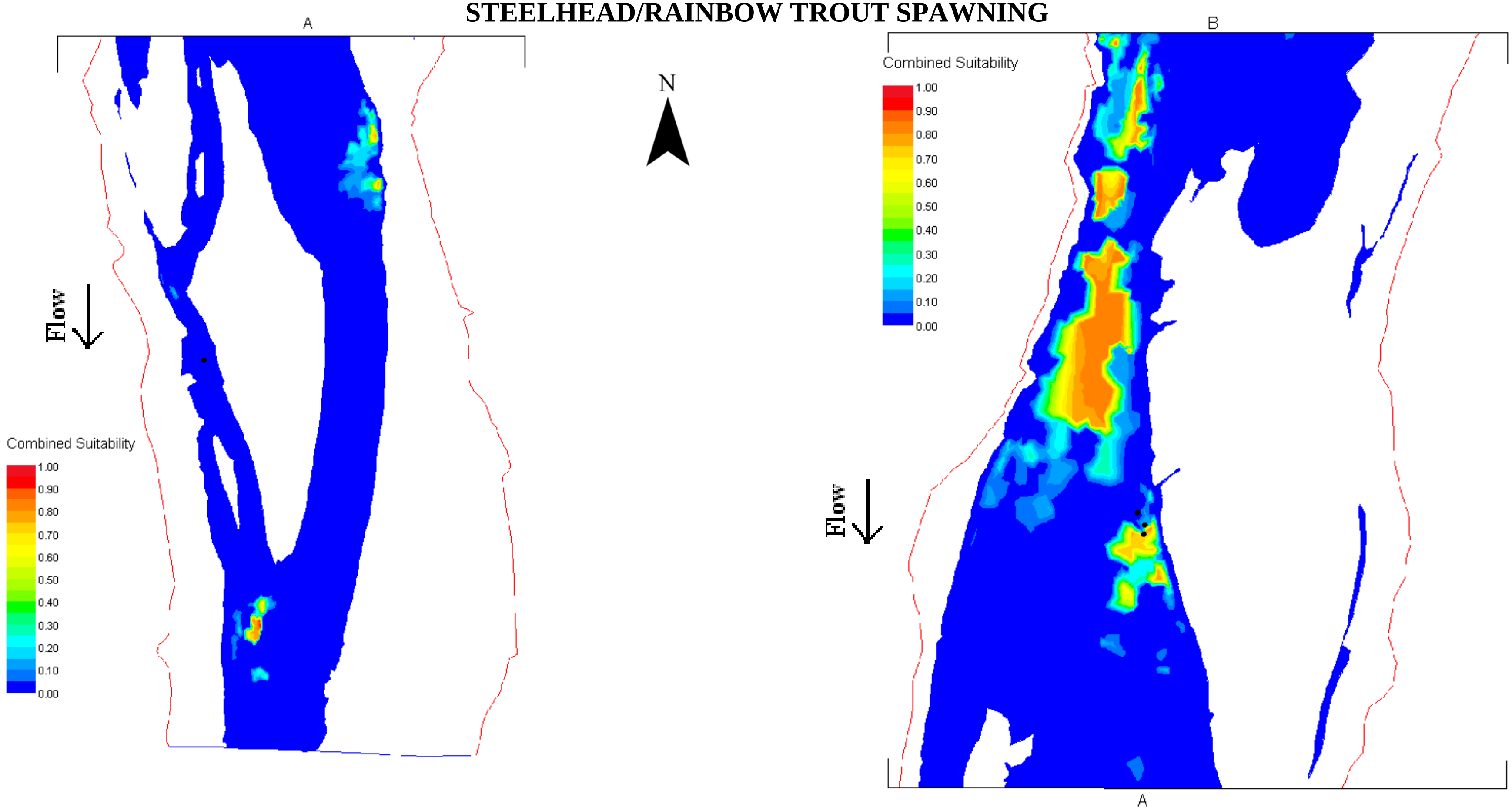


**Scale: 1:888**

Redd locations : ●

Appendix L

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING

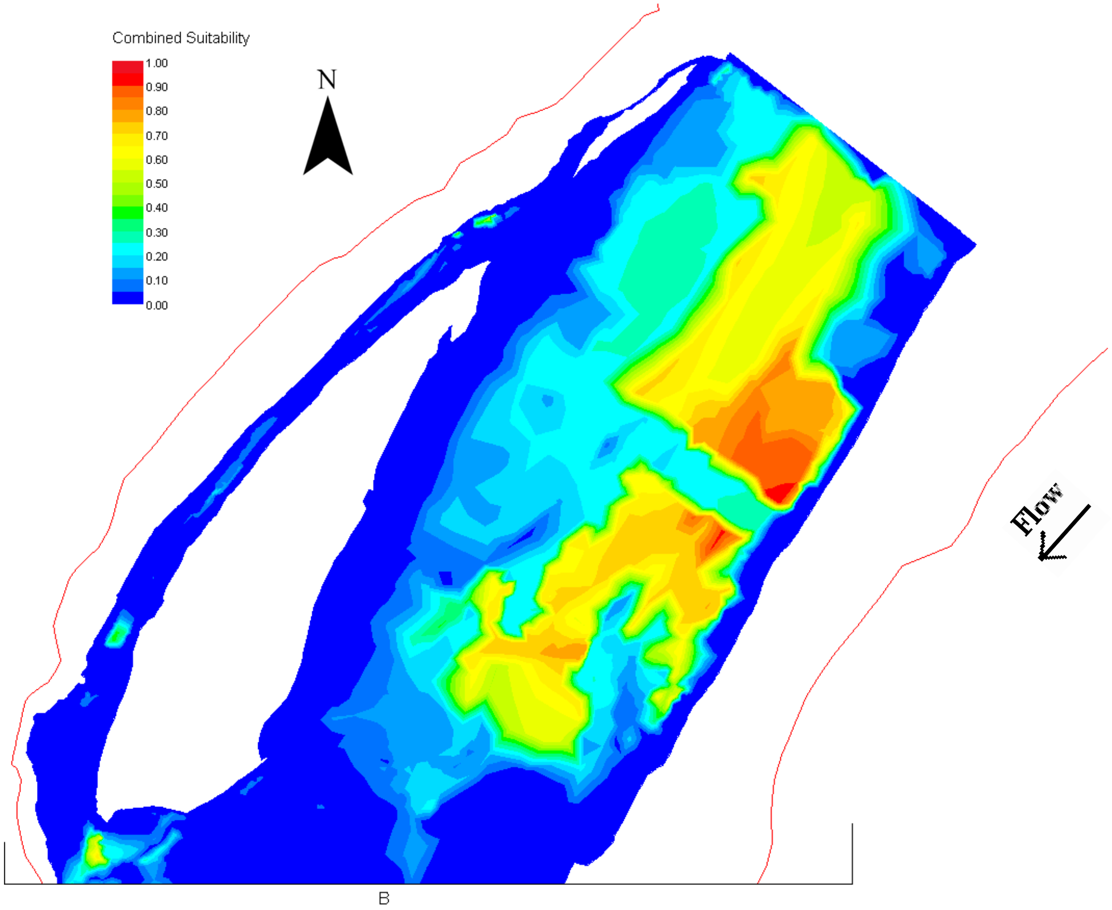


**Scale: 1:2748**

**Scale: 1:2094**

Redd locations : ●

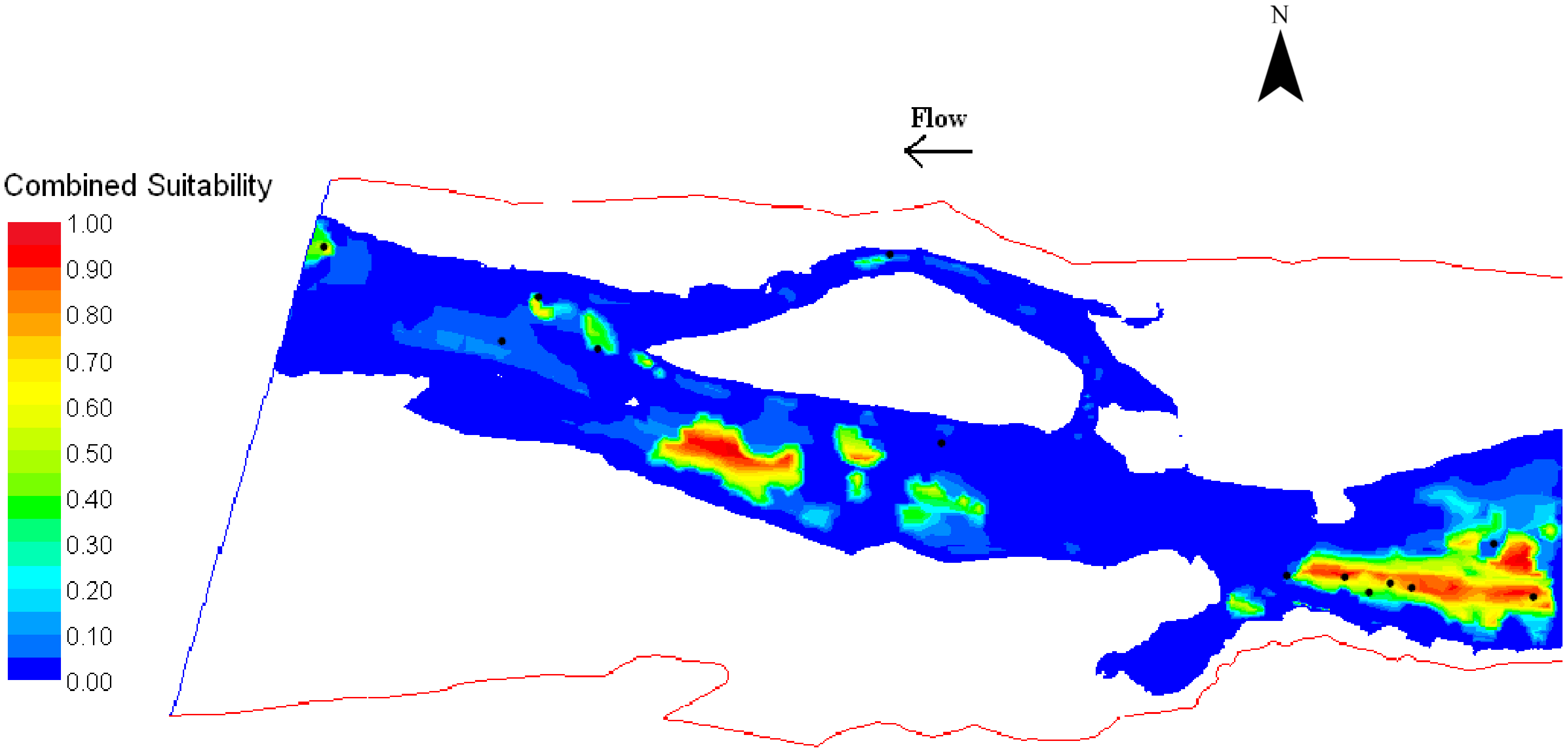
## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING (CONTINUED)



**Scale: 1:866**

Redd locations: ●

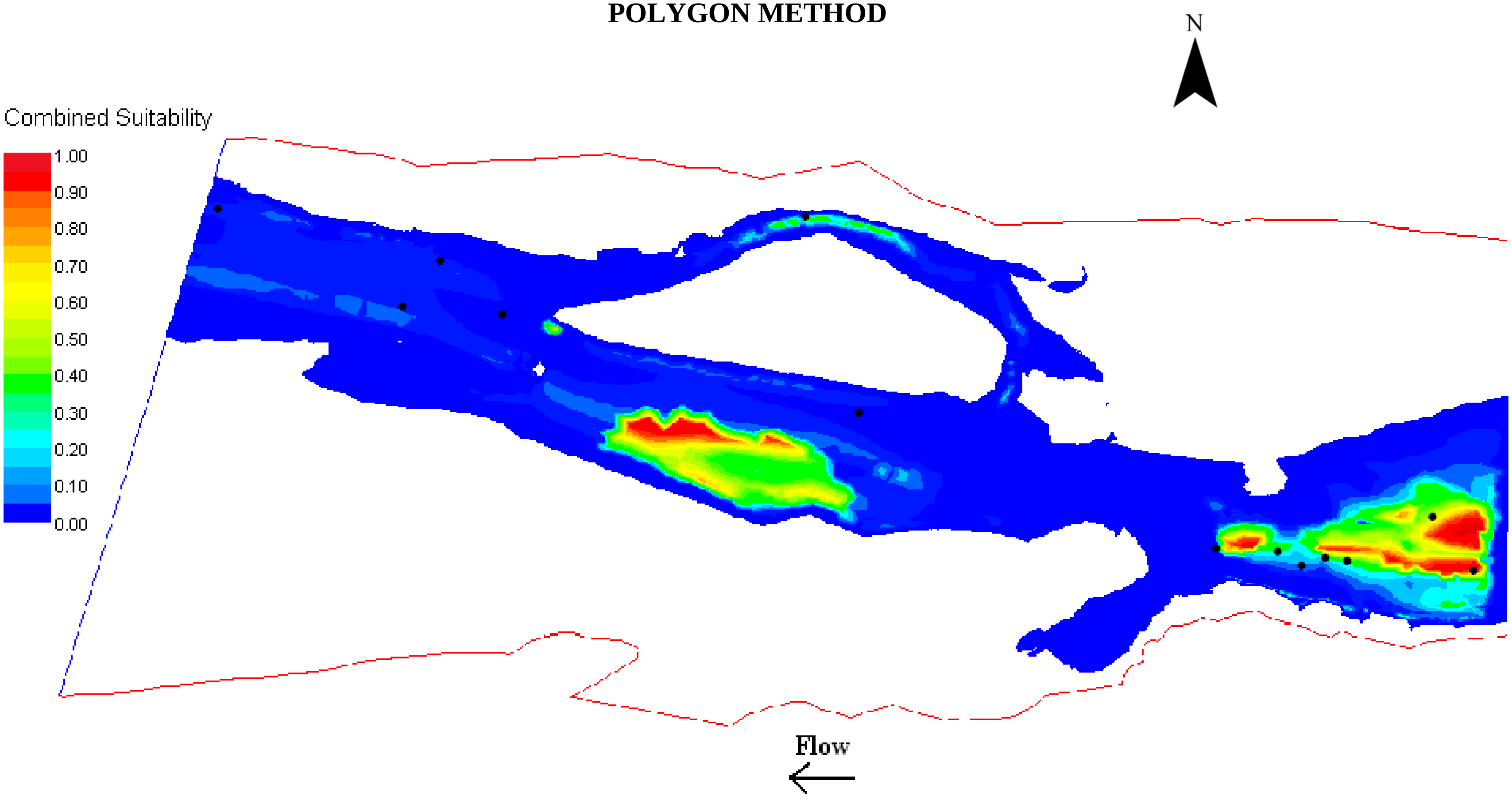
## HIGHWAY 20 STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 648 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING



**Scale: 1:2033**

Redd locations : ●

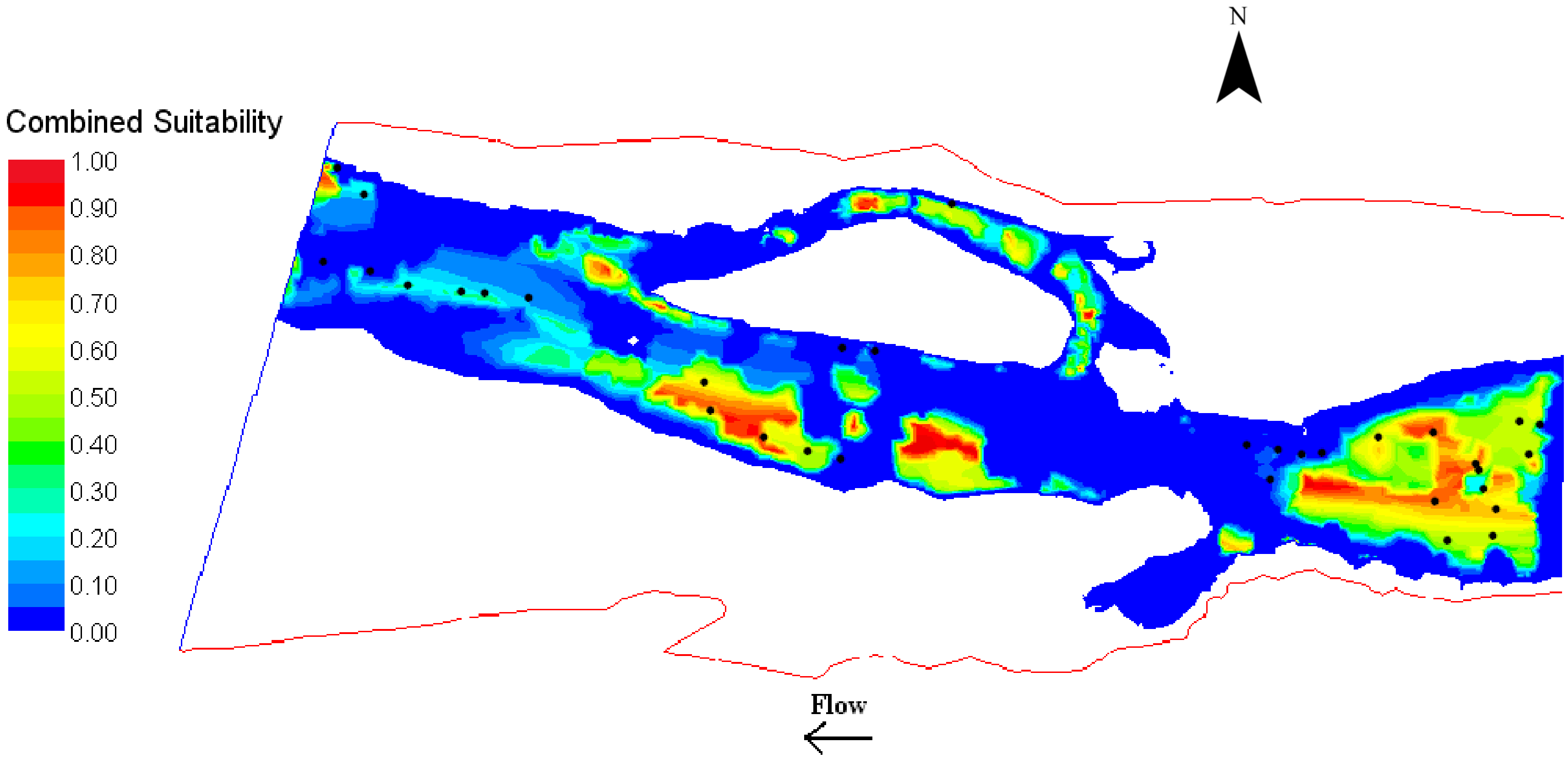
## HIGHWAY 20 STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 648 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING
## POLYGON METHOD



**Scale: 1:1920**

Redd locations : ●

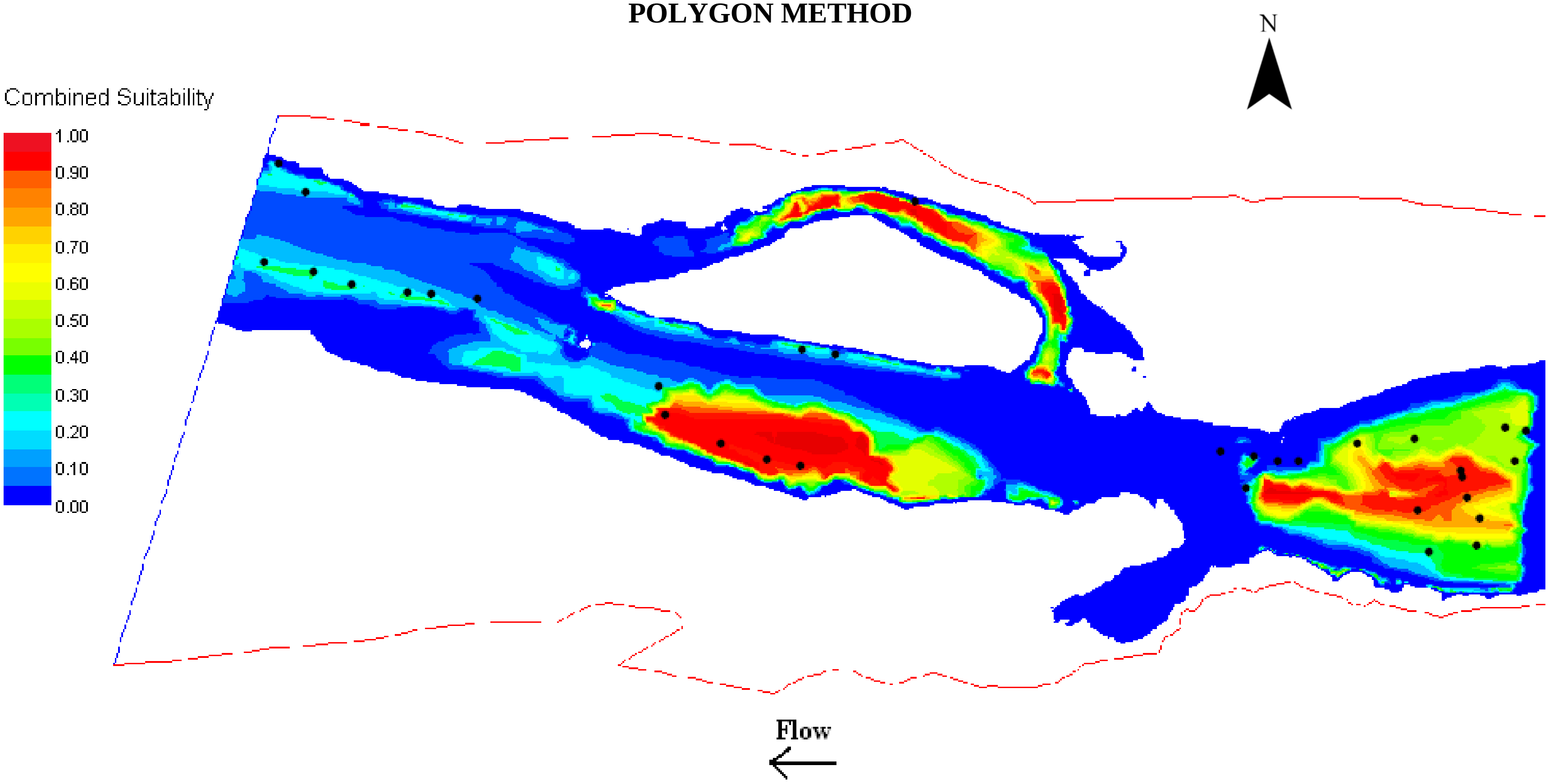
## HIGHWAY 20 STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 887 CFS
## FALL-RUN CHINOOK SALMON SPAWNING



**Scale: 1:1920**

Redd locations : ●

# HIGHWAY 20 STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 887 CFS
## FALL-RUN CHINOOK SALMON SPAWNING
## POLYGON METHOD

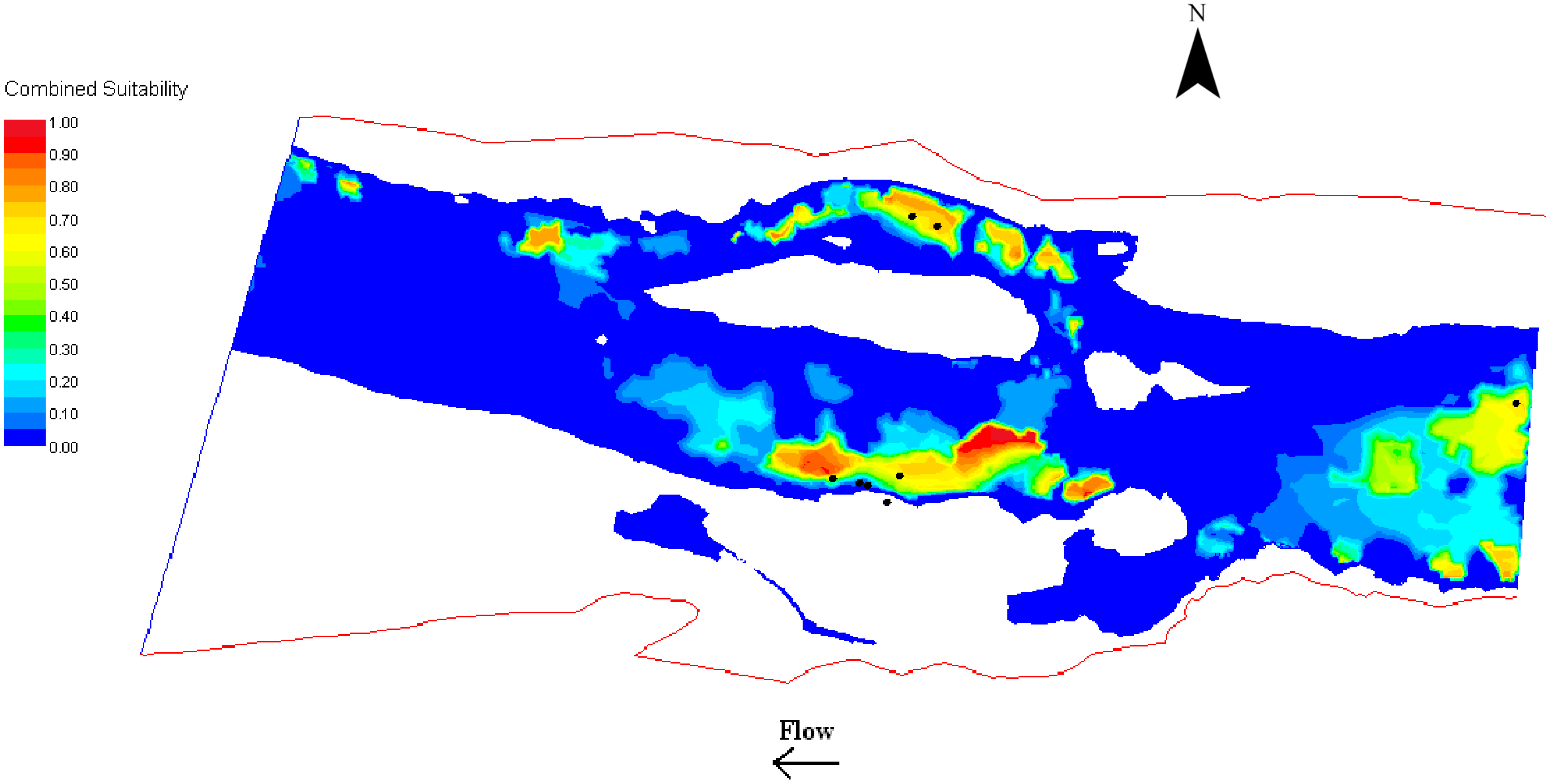


**Scale: 1:2074**

Redd locations: ●

Appendix L

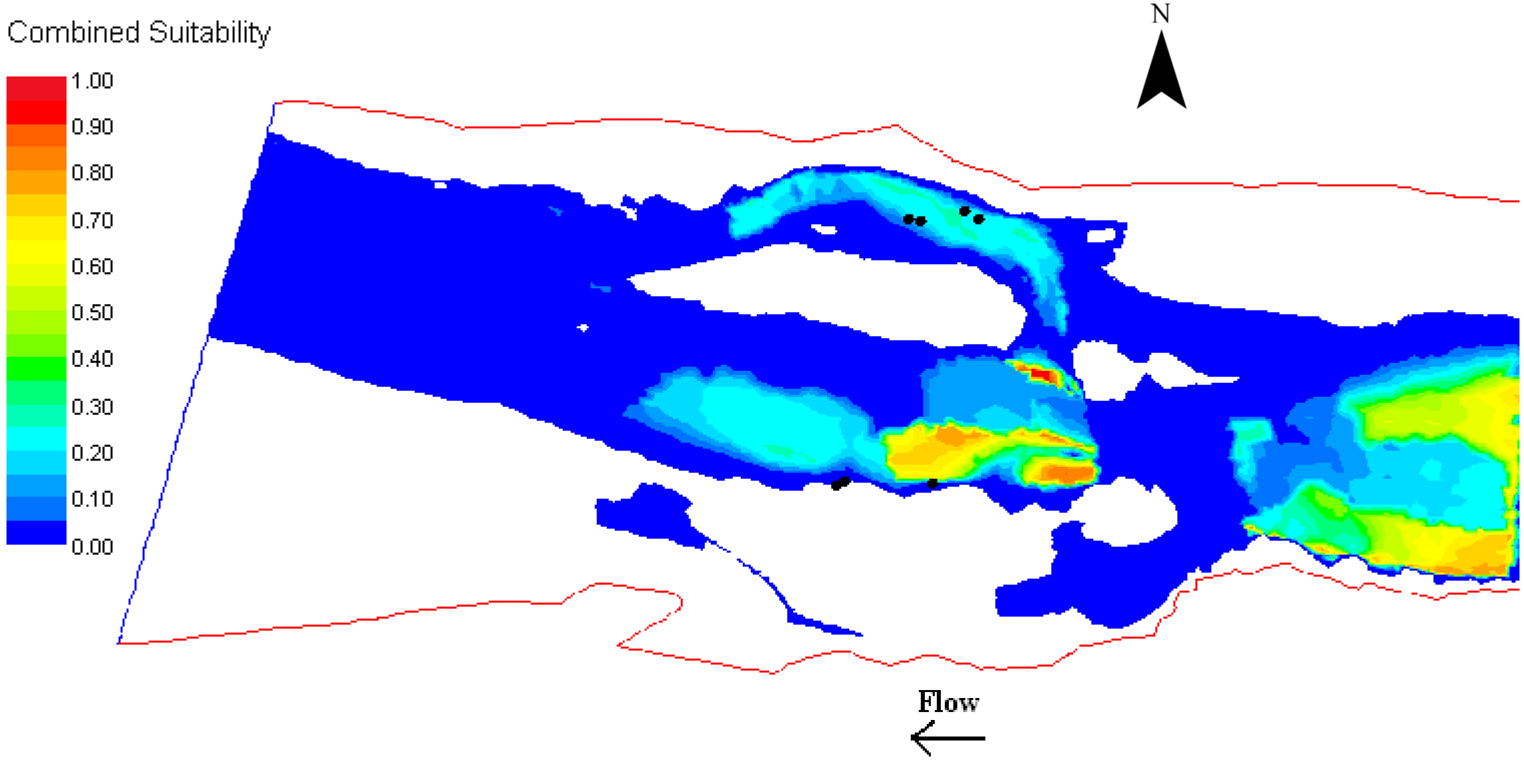
## HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2385 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING



**Scale: 1:1956**

Redd locations : ●

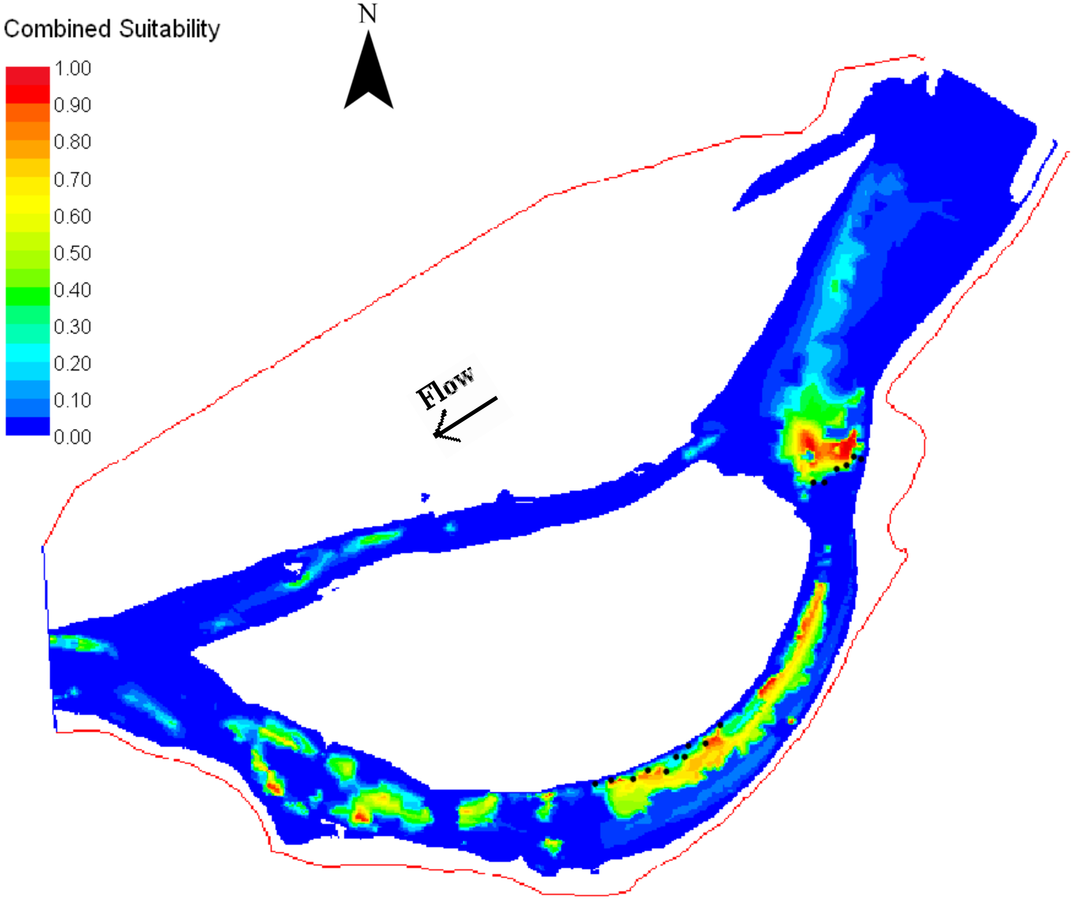
## HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2385 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING
## POLYGON METHOD



**Scale: 1:2206**

Redd locations : ●

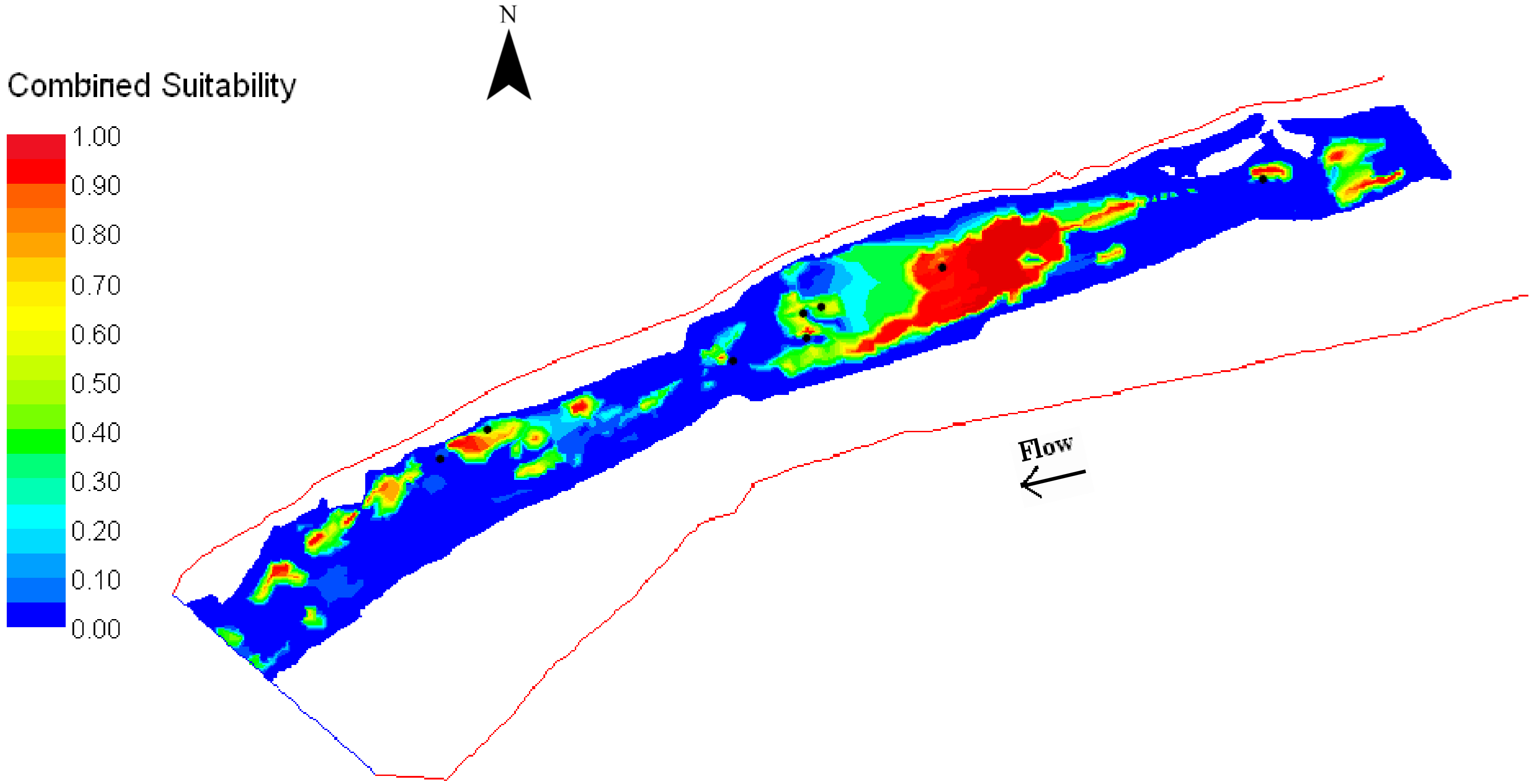
## ISLAND STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 648 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING



**Scale: 1:3930**

Redd locations: ●

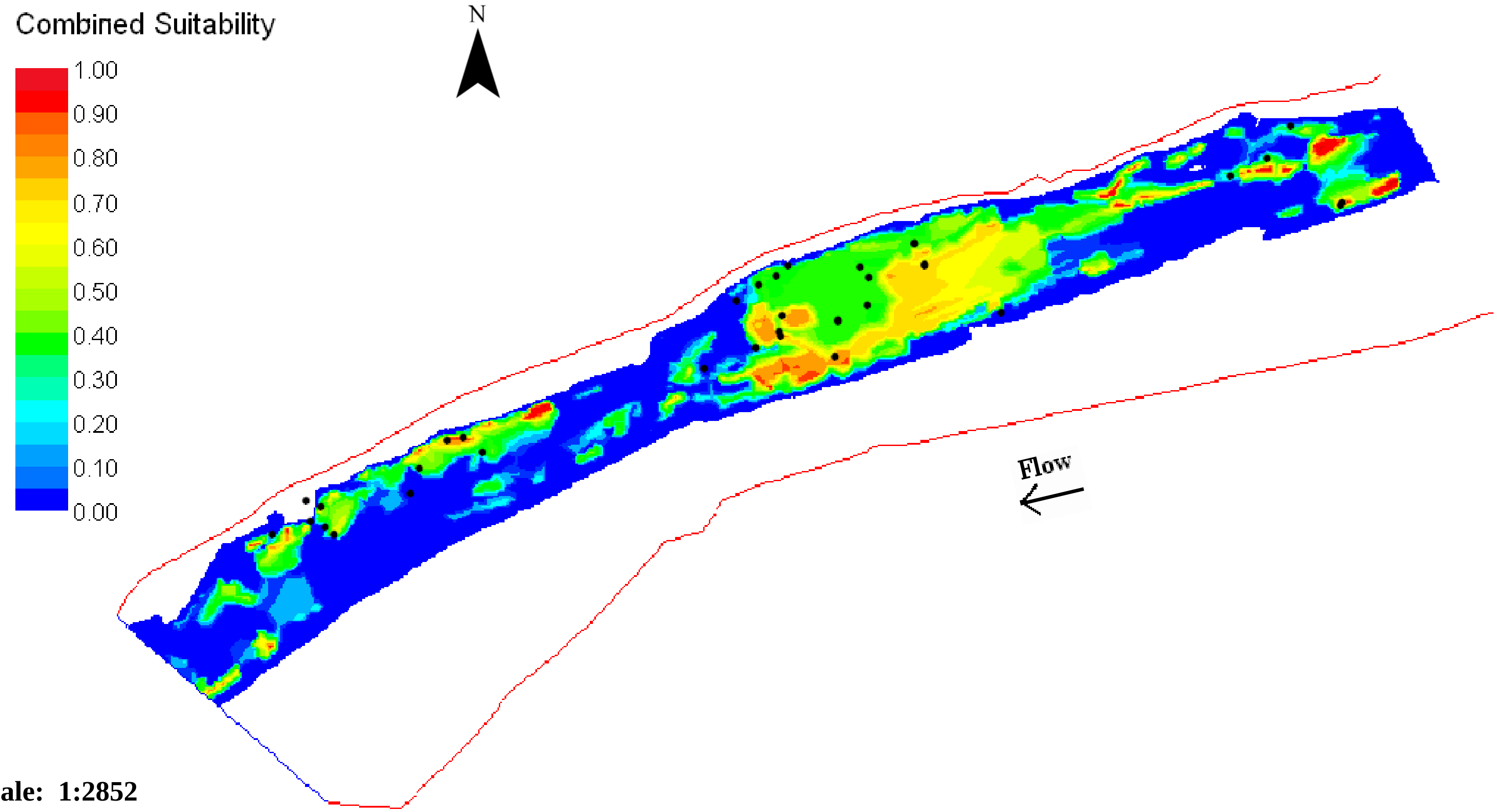
## HAMMOND STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 646 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING



**Scale: 1:3080**

Redd locations : ●

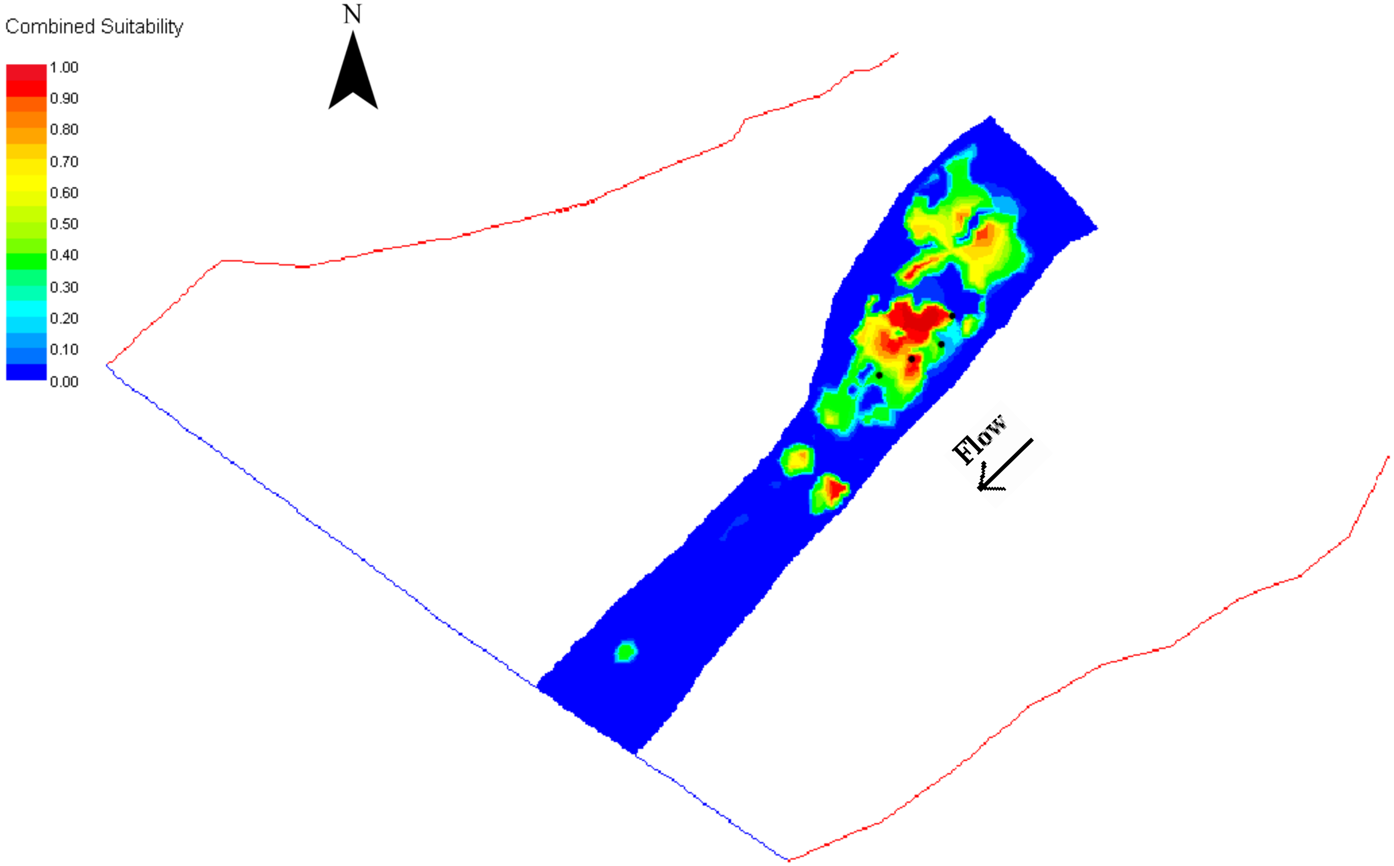
## HAMMOND STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 887 CFS
## FALL-RUN CHINOOK SALMON SPAWNING



**Scale: 1:2852**

Redd locations: ●

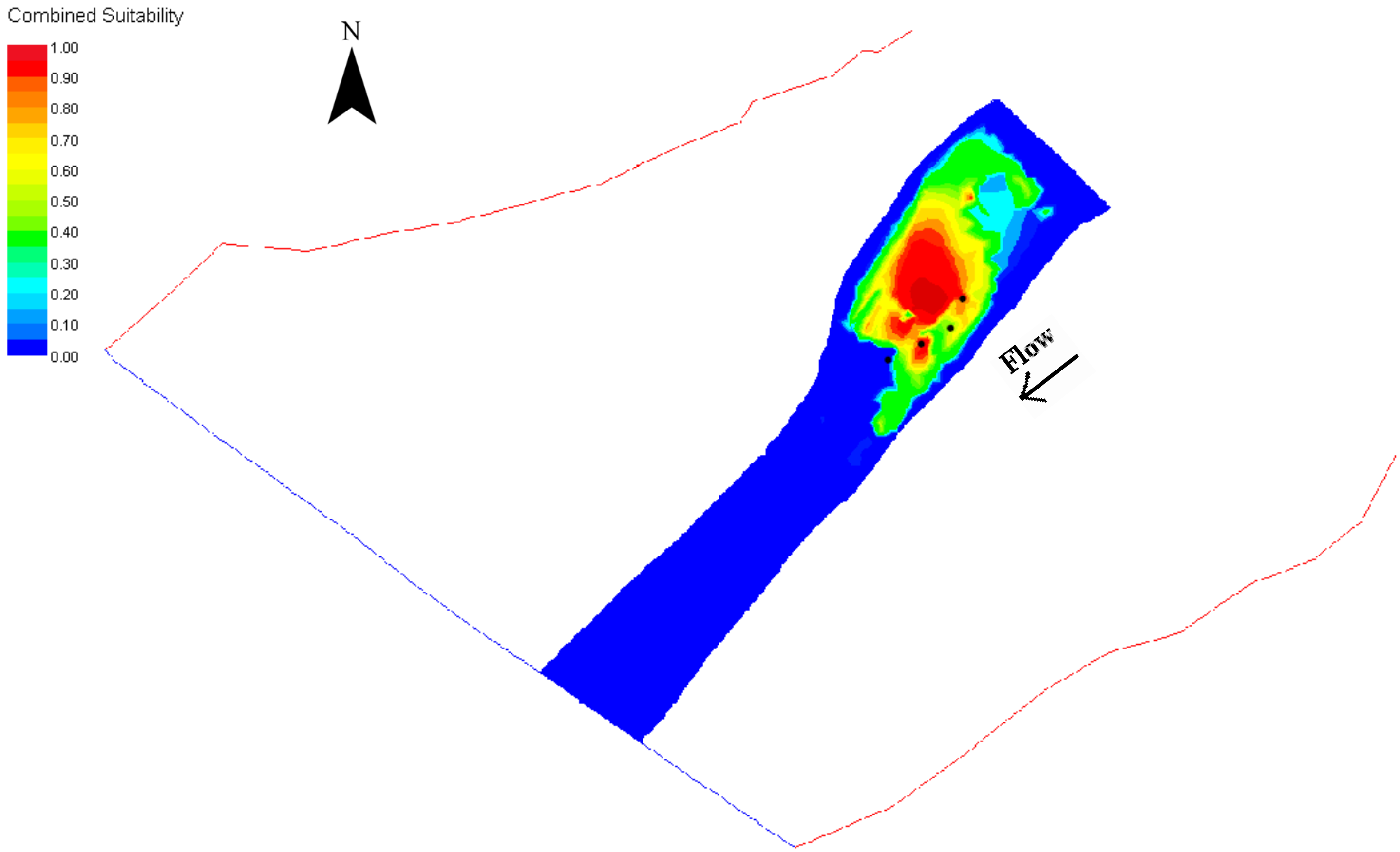
## UPPER DAGUERRE STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 450 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING



**Scale: 1:1270**

Redd locations: ●

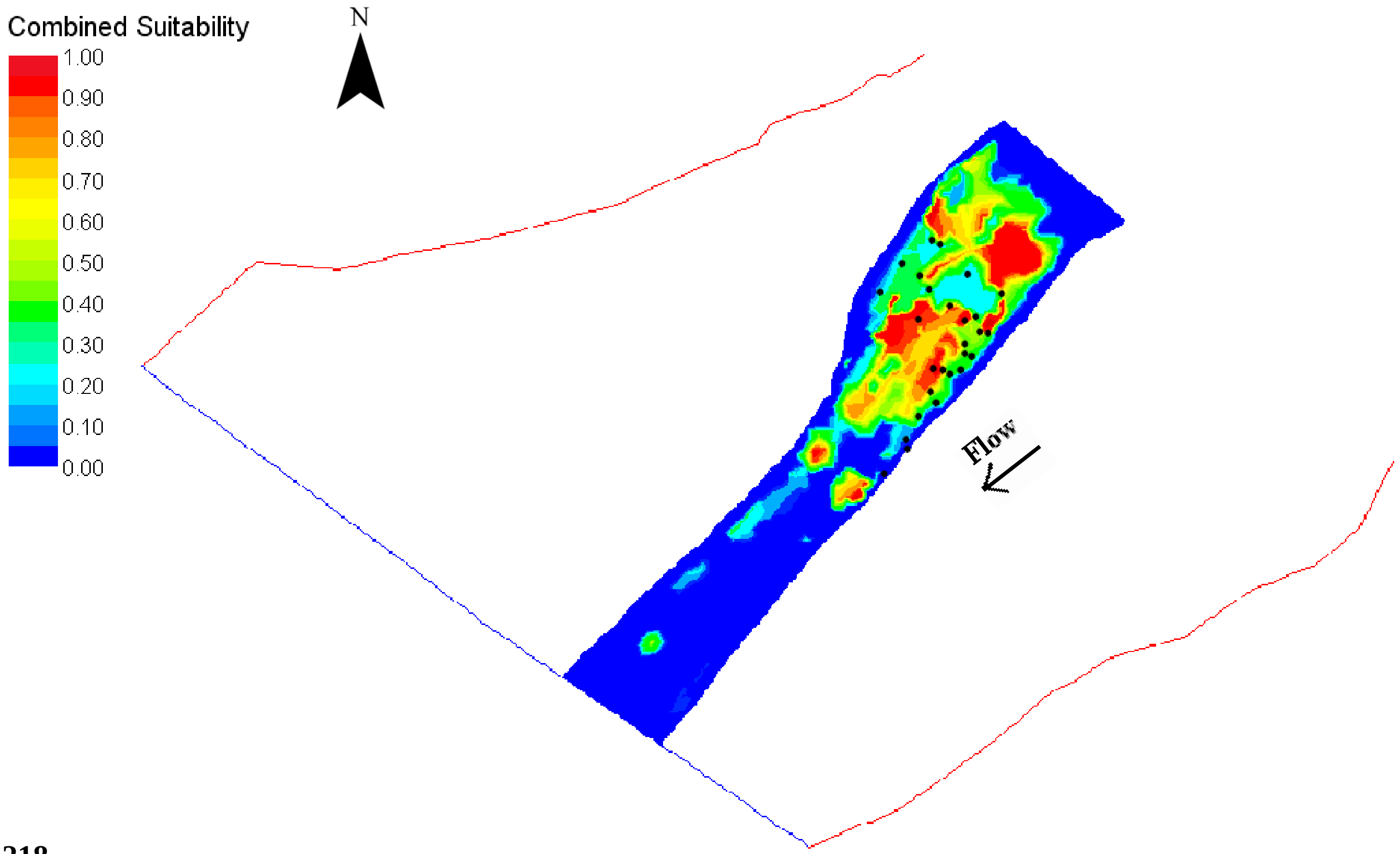
## UPPER DAGUERRE STUDY SITE, SEPTEMBER 23-26, 2002, FLOW = 450 CFS
## SPRING-RUN CHINOOK SALMON SPAWNING
## POLYGON METHOD



**Scale: 1:1218**

Redd locations: ●

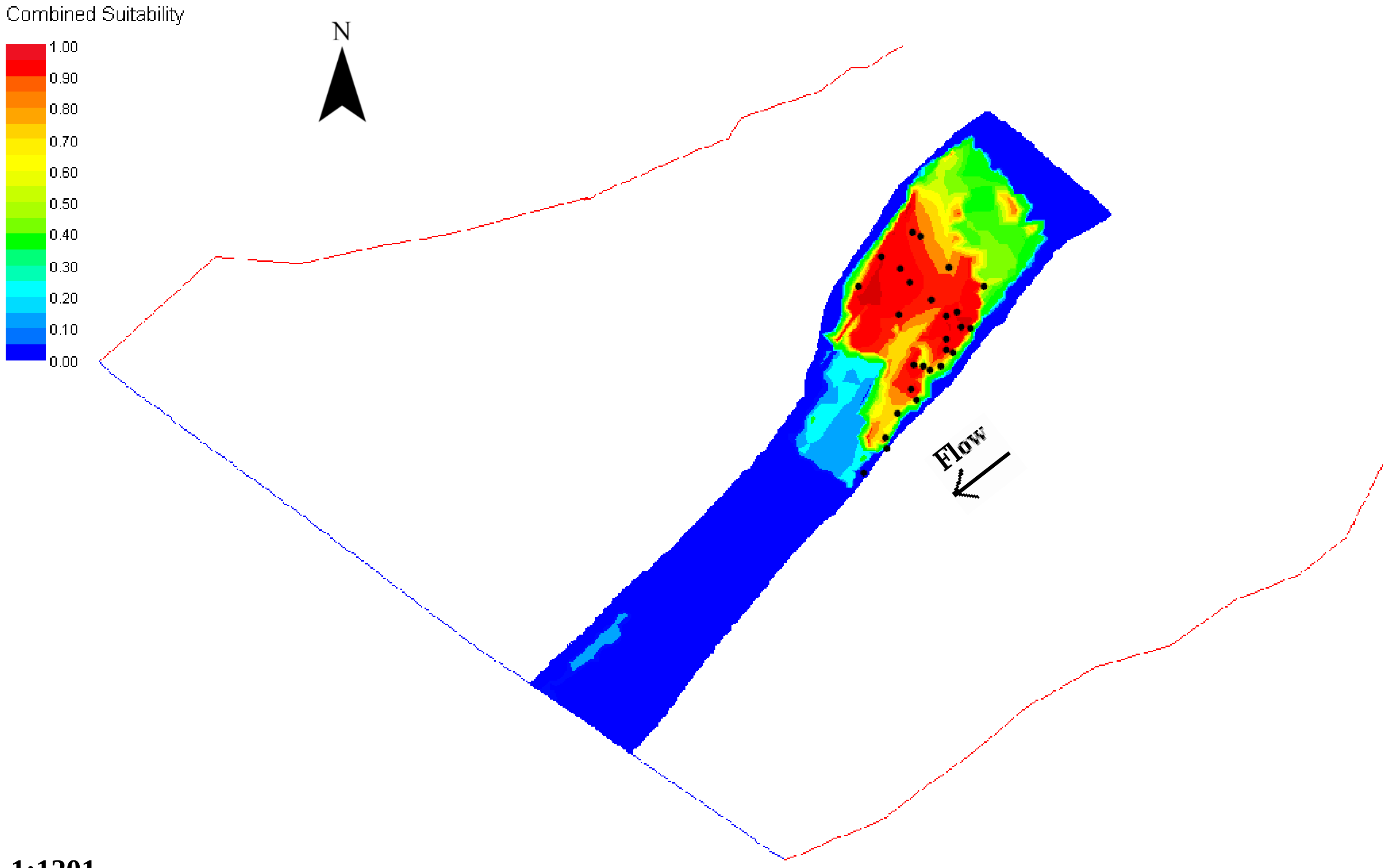
# UPPER DAGUERRE STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 474 CFS
# FALL-RUN CHINOOK SALMON SPAWNING



**Scale: 1:1218**

Redd locations : ●

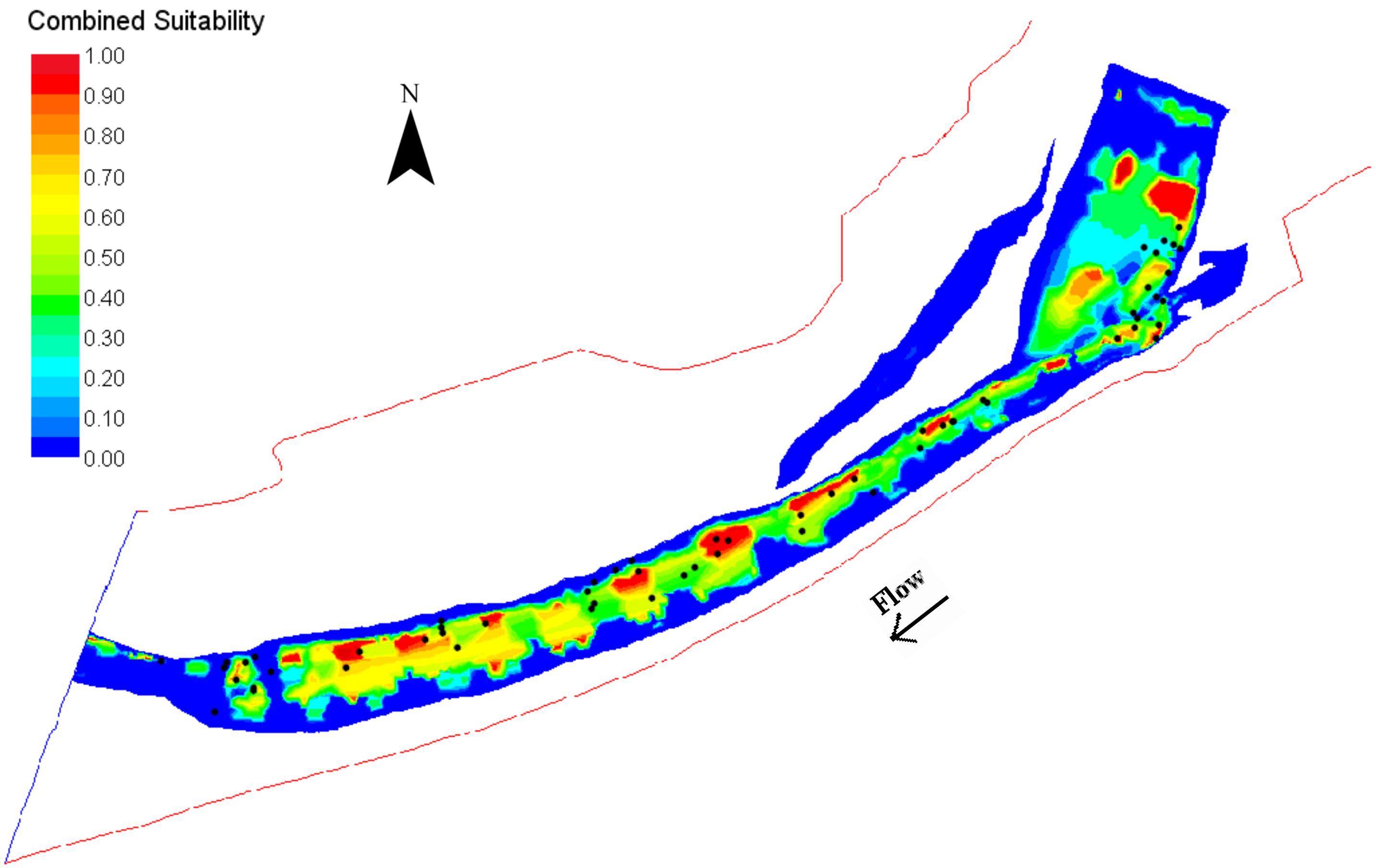
## UPPER DAGUERRE STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 474 CFS
## FALL-RUN CHINOOK SALMON SPAWNING
## POLYGON METHOD



**Scale: 1:1201**

Redd locations: ●

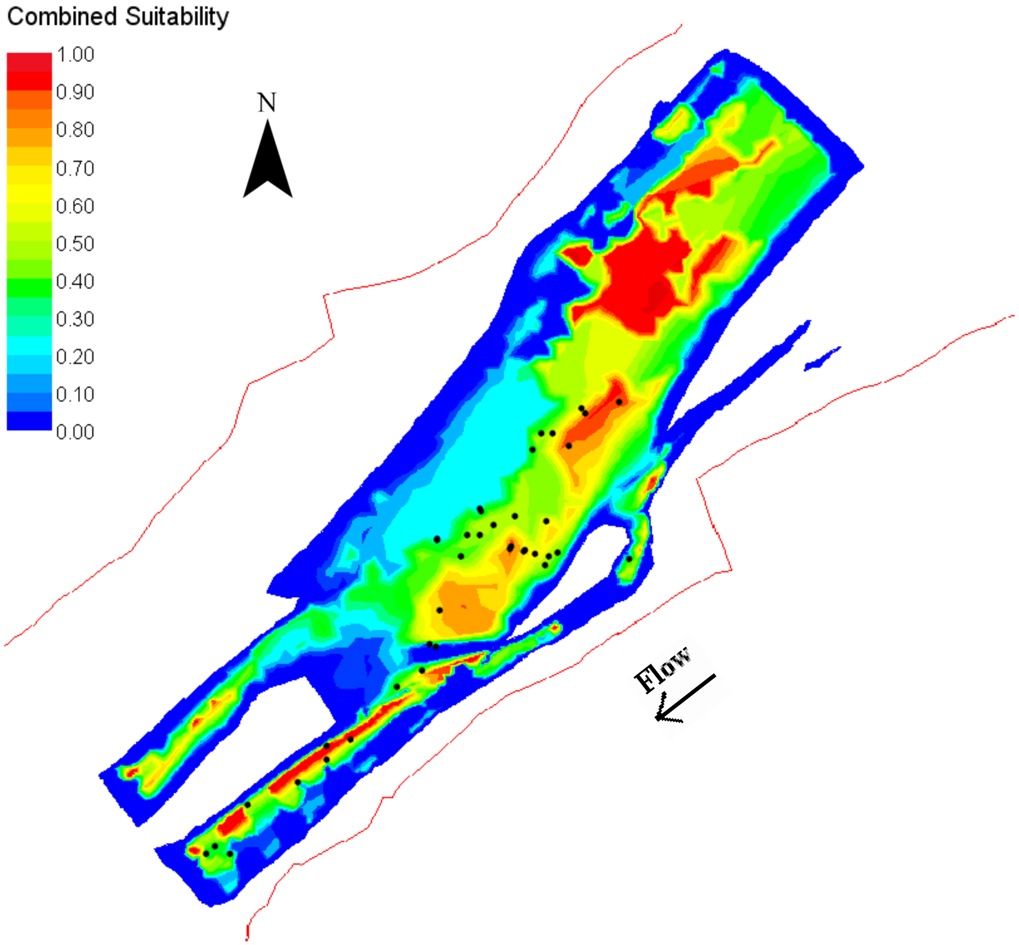
## LOWER DAGUERRE STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 474 CFS
## FALL-RUN CHINOOK SALMON SPAWNING



**Scale: 1:2034**

Redd locations : ●

## PYRAMIDS STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 473 CFS
## FALL-RUN CHINOOK SALMON SPAWNING

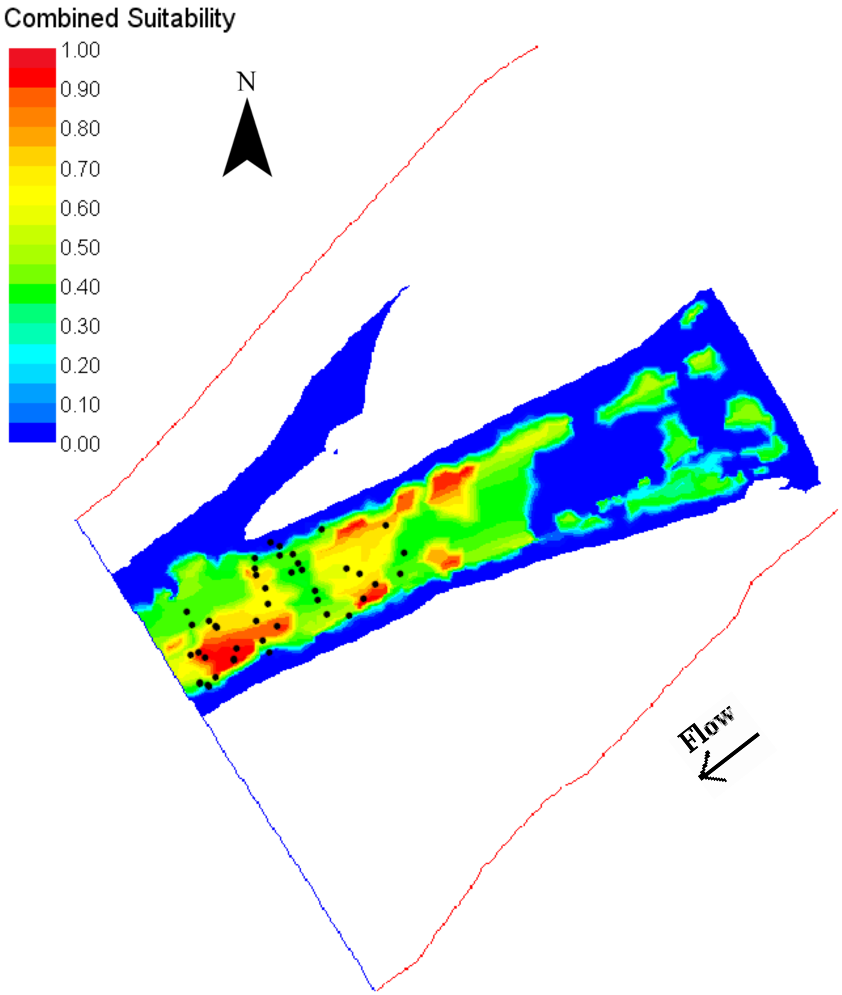


**Scale: 1:2651**

Redd locations: ●

Appendix L

## PLANTZ STUDY SITE, NOVEMBER 4-6 AND 18-21, 2002, FLOW = 473 CFS FALL-RUN CHINOOK SALMON SPAWNING

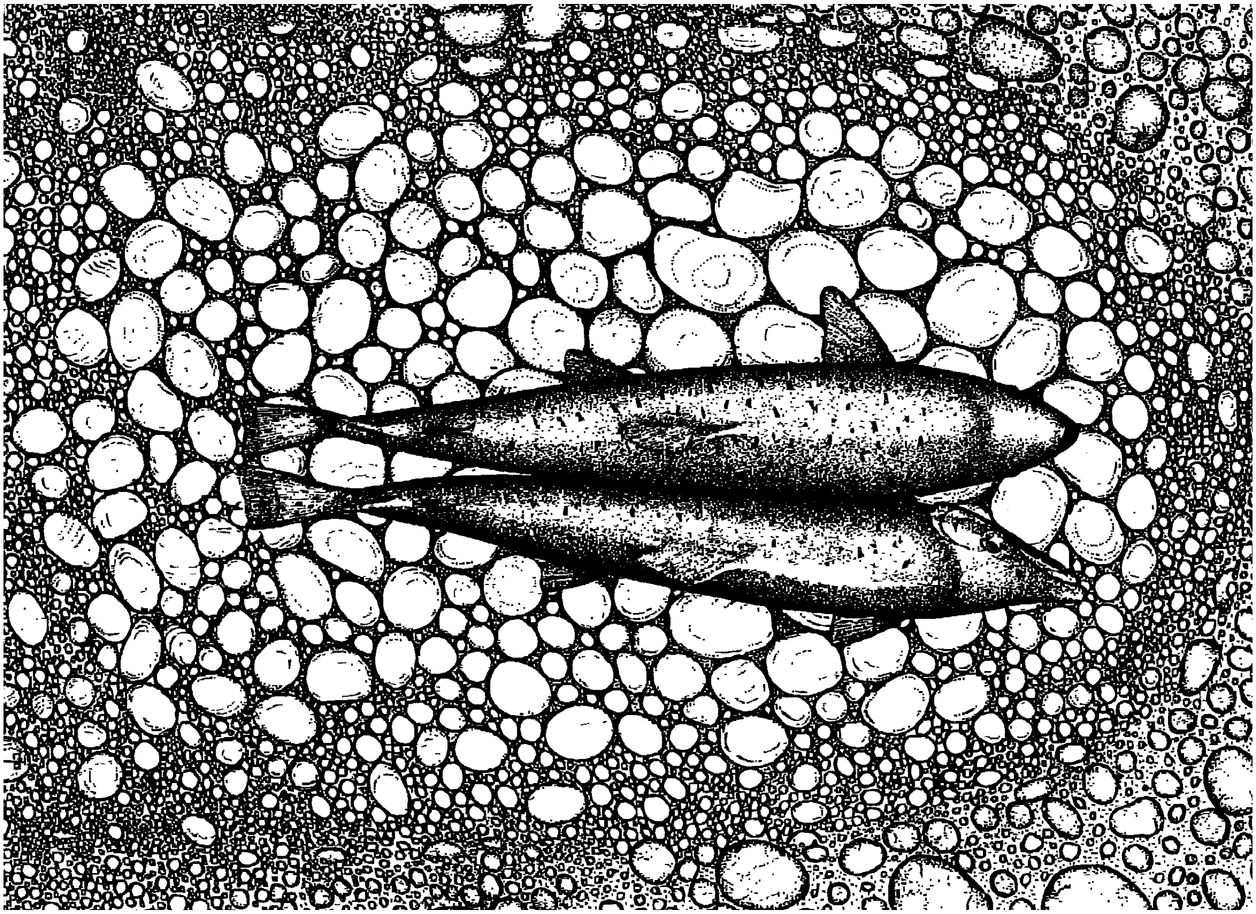


**Scale: 1:1661**

Redd locations : ●

# APPENDIX M

# SENSITIVITY ANALYSIS FOR FLOW-HABITAT RELATIONSHIPS FOR STEELHEAD/RAINBOW TROUT SPAWNING IN THE YUBA RIVER



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

Prepared by staff of
The Energy Planning and Instream Flow Branch

# CVPIA INSTREAM FLOW INVESTIGATIONS
# YUBA RIVER STEELHEAD/RAINBOW TROUT SPAWNING HABITAT SENSITIVITY ANALYSIS

## PREFACE

The following is the final report for the U.S. Fish and Wildlife Service's sensitivity analysis for steelhead/rainbow trout spawning habitat in the Yuba River between Englebright Dam and the Feather River, part of the Central Valley Project Improvement Act (CVPIA) Instream Flow Investigations, a 6-year effort which began in October, 2001.[1] Title 34, Section 3406(b)(1)(B) of the CVPIA, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U.S. Fish and Wildlife Service after consultation with the California Department of Fish and Game. The purpose of these investigations is to provide scientific information to the U.S. Fish and Wildlife Service Central Valley Project Improvement Act Program to assist in developing such recommendations for Central Valley rivers.

Written comments or information can be submitted to:

Mark Gard, Senior Biologist
Energy Planning and Instream Flow Branch
U.S. Fish and Wildlife Service
Sacramento Fish and Wildlife Office
2800 Cottage Way, Room W-2605
Sacramento, CA 95825

Mark_Gard@fws.gov

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

# ACKNOWLEDGMENTS

Data analysis and report preparation were performed by Ed Ballard, Mark Gard and Bill Pelle. Funding was provided by the Central Valley Project Improvement Act.

# ABSTRACT

A sensitivity analysis was conducted to examine the effects of alternative criteria on flow-habitat relationships and biological validation for steelhead/rainbow trout spawning in the Yuba River. Four alternative criteria were used in the sensitivity analysis: 1) criteria calculated using only occupied and unoccupied data collected upstream of Highway 20; 2) Clear Creek criteria; 3) density-based criteria; and 4) geometric mean-based criteria. Flow-habitat relationships were developed for the two segments of the Yuba River using each of the four alternative criteria. Biological verification was accomplished for each of the four alternative criteria by testing, with a Mann-Whitney U test, whether the combined suitability predicted by RIVER2D was higher at redd locations versus at locations where redds were absent. A Mann-Whitney U test was also used to assess the effects of errors in the simulation of substrate at redd locations. Overlays were generated of redd locations relative to the combined suitability from the four alternative criteria, as well as the univariate suitability for depth, velocity and substrate for the original criteria. The Clear Creek criteria fail to capture the preference of Yuba River steelhead/rainbow trout for deeper conditions and do not reflect the entire range of velocities where steelhead/rainbow trout redds were found in the Yuba River. There were no clear trends from the biological verification results. With the exception of the Clear Creek criteria, the flow-habitat relationships were not sensitive to the choice of criteria. Based on the results of this sensitivity analysis, we feel that the flow-habitat relationships for steelhead/rainbow trout spawning using the alternative criteria calculated only using occupied and unoccupied data from upstream of Highway 20 best characterize the habitat requirements for steelhead/rainbow trout spawning in the Yuba River.

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# INTRODUCTION

U. S. Fish and Wildlife Service (2008) presented flow-habitat relationships for spring and fall-run Chinook salmon and steelhead/rainbow trout spawning in the Yuba River, as well as biological validation of the habitat models used to develop the flow-habitat relationships. At the request of stakeholders, we have prepared this report as a sensitivity analysis of the flow-habitat relationships and biological validation presented in U. S. Fish and Wildlife Service (2008). The focus of this report is on steelhead/rainbow trout, since stakeholders had the most concern with the information in U. S. Fish and Wildlife Service (2008) concerning this species. The objective of this report is to examine the sensitivity of steelhead/rainbow trout spawning flow-habitat relationships and biological verification to a number of alternative habitat suitability criteria. This sensitivity analysis looks at the model sensitivity to alternative habitat suitability criteria on flow-habitat relationships and biological validation. There are other types of sensitivity analyses that could be explored, but were outside the scope of this report.

# METHODS

## *Habitat Suitability Criteria (HSC) Development*

U. S. Fish and Wildlife Service (2008) used a polynomial logistic regression (SYSTAT 2002), with dependent variable frequency (with a value of 1 for occupied locations and 0 for unoccupied locations) and independent variable depth or velocity, to develop depth and velocity HSI. The logistic regression fits the data to the following expression:

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

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

For the purpose of this sensitivity analysis, we used the following alternative habitat suitability criteria: 1) depth and velocity criteria developed using the same methods as above, but only using occupied and unoccupied data collected upstream of Highway 20; 2) steelhead/rainbow trout spawning criteria from Clear Creek (U. S. Fish and Wildlife Service 2006); 3) depth and velocity criteria developed using density-based methods given in Rubin et al. (1991) and TRPA (2001); and 4) the criteria from U. S. Fish and Wildlife Service (2008) but with combined suitability calculated using the geometric mean of the individual depth, velocity and substrate suitabilities. All of the above criteria except the Clear Creek criteria used the same substrate criteria as in U. S. Fish and Wildlife Service (2008). Half of the unoccupied data used to develop the steelhead/rainbow trout spawning criteria presented in U. S. Fish and Wildlife Service (2008) were from the Below Daguerra Segment, while only 5 out of 184 occupied locations were from the Below Daguerra Segment (Figure 1).

The density-based criteria were developed as follows. The number of steelhead/rainbow trout redds was determined for 1.0 foot depth and 0.5 ft/s velocity increments. The area within each 1.0 foot depth and 0.5 ft/s velocity increment was then determined from the RIVER2D cdg files for the sites where we observed steelhead/rainbow trout redds (Table 1). The first step in determining area was to construct multiple sets of HSC, differing only in the suitabilities assigned for each depth or velocity increment. The range of depths and velocities selected for use in the HSCs was the range of depths and velocities where we found steelhead/rainbow trout redds. For the depth HSC sets: (1) all of the sets had the same velocity and substrate HSC curves, with HSI values of 1.0 for all velocities and substrates; and (2) each depth HSC had a different depth HSC curve. To develop the depth HSC curves, each HSC set was assigned a different one-foot depth increment within the selected depth range to have an HSC value of 1.0, and the other one-foot depth increments and depths outside of the depth range a value of 0.0 (e.g., 1.5-2.47 foot (0.46-0.75 meters) depth HSC value equal 1.0, < 1.5 feet (0.46 meters) and > 2.47 feet (0.75 meters) depths HSC value equals 0.0 for a depth increment of 1.5-2.47 feet (0.46-0.75 meters). For the velocity HSC sets: (1) all of the sets had the same depth and substrate HSC curves, with HSI values of 1.0 for all depths and substrates; and (2) each velocity HSC had a different velocity HSC curve. To develop the velocity HSC curves, each HSC set was assigned a different half-ft/s velocity increment within the selected velocity range to have an HSC value of 1.0, and the other half-ft/s velocity increments and velocities outside of the velocity range a value of 0.0 (e.g., 1.75-2.24 ft/s (0.53-0.68 m/s) velocity HSC value equal 1.0, < 1.75 ft/s (0.53 m/s) and > 2.24 ft/s (0.68 m/s) velocities HSC value equals 0.0 for a velocity increment of 1.75-2.24 ft/s (0.53-0.68 m/s)). Each HSC set was used in RIVER2D with the calibrated RIVER2D file for each study site at which HSC data were collected (Table 1). The resulting habitat output was used to determine the area for all one-foot depth and half-ft/s velocity increments. Redd densities were calculated by dividing the number of redds in each 1.0 foot (0.30 m) depth or 0.5 ft/s (0.15 m/s) velocity increment by the area for the corresponding 1.0 foot (0.30 m depth or 0.5 ft/s (0.15 m/s) velocity increment. The density-based criteria were then “smoothed” using a kernel-type scatterplot smoother (SYSTAT 2002), and then were rescaled so that the highest HSC value was 1.0.

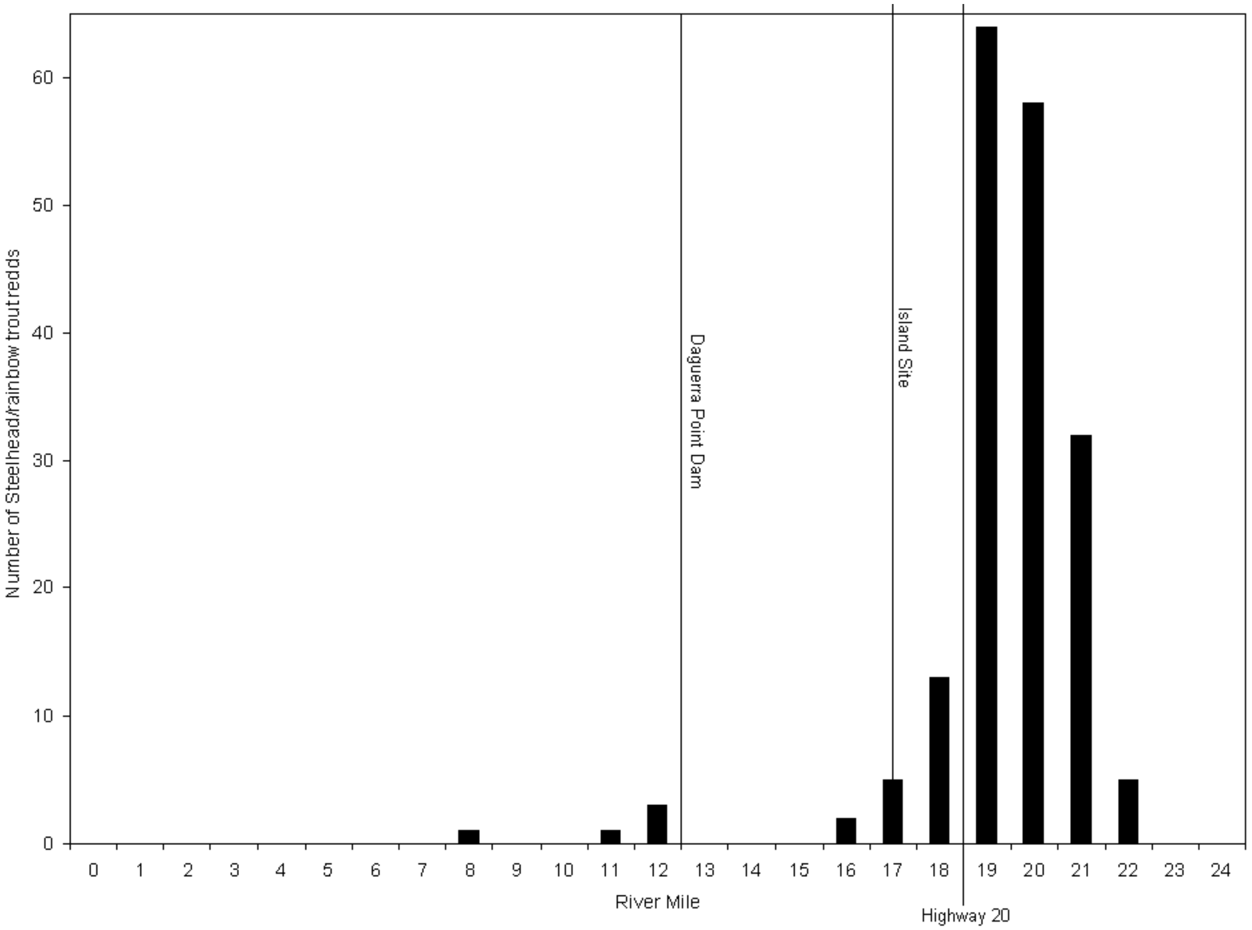

Figure 1. Distribution of steelhead/rainbow trout redds (2002 to 2004).

Table 1. Average flows prior to steelhead/rainbow trout HSI data collection.

| Dates | Sites | Flows (cfs) |
|---|---|---|
| Jan 7-Feb 6, 2002 | Timbuctoo | 1,838 |
| Mar 12-Apr 11, 2002 | Timbuctoo, Highway 20 | 2,353 |
| Mar 24-Apr 23, 2002 | UC Sierra | 2,281 |
| Mar 10-Apr 9, 2003 | UC Sierra, Timbuctoo, Highway 20 | 2,386 |
| Mar 11-Apr 10, 2003 | Upper Daguerra, Lower Daguerra | 2,364 |
| Mar 11-Apr 10, 2003 | Hallwood | 2,455 |
| Mar 6-Apr 5, 2004 | Timbuctoo, Highway 20, Island | 2,546 |

### *Biological Verification*

We computed the univariate (depth, velocity and substrate) habitat suitability predicted by RIVER2D using the criteria in U. S. Fish and Wildlife Service (2008) at each redd location in the six study sites where steelhead/rainbow trout redds locations were recorded in 2003. We compared the combined habitat suitability predicted by RIVER2D at each redd location in the six study sites where steelhead/rainbow trout redds locations were recorded for each of the four alternative habitat suitability criteria, except for the alternative criteria that only used data collected upstream of Highway 20, we only made the comparison for the three study sites upstream of Highway 20 where steelhead/rainbow trout redds locations were recorded in 2003. We ran the RIVER2D cdg files at the averaged flows for the month preceding the date of redd location data collection for steelhead/rainbow trout (Table 1) to determine the combined habitat suitability at individual points for RIVER2D. We used the horizontal location measured for each redd to determine the location of each redd in the RIVER2D sites. We used a random number generator to select locations without redds in each site. Locations were eliminated that: 1) were less than 3 feet (0.91 meters) from a previously-selected location; 2) were less than 3 feet (0.91 meters) from a redd location; 3) were located in the wetted part of the site; and 4) were located in the site (between the upstream and downstream transects). We used one-tailed Mann-Whitney U tests (Zar 1984) to determine whether the combined suitability predicted by RIVER2D for each of the four alternative habitat suitability criteria was higher at redd locations versus locations where redds were absent (Gard 2006, Gard 2009, McHugh and Budy 2004).

We also prepared overlays of combined suitability with steelhead/rainbow trout redds locations recorded in 2002 and 2004 using both the criteria in U. S. Fish and Wildlife Service (2008) and the four alternative criteria. The locations of redds in 2002 and 2004 were recorded with GPS, and thus are not sufficiently accurate for purposes of conducting Mann-Whitney U tests (Zar 1984) to determine whether the combined suitability predicted by RIVER2D was higher at redd locations versus locations where redds were absent. However, the overlays are useful to better illustrate the entire range of habitat conditions used by spawning steelhead/rainbow trout in the Yuba River. To determine the extent that errors in substrate simulation affected the biovalidation results in U. S. Fish and Wildlife Service (2008), we repeated the Mann-Whitney U tests (Zar 1984) in U. S. Fish and Wildlife Service (2008) to determine whether the combined suitability predicted by RIVER2D was higher at redd locations versus locations where redds were absent, but substituted the actual measured substrate at redd locations in computing the combined suitability of occupied locations.

### *Habitat Simulation*

The final step was to simulate available habitat for each site. Preference curve files were created containing each of the four alternative digitized HSC for steelhead/rainbow trout. RIVER2D was used with the final cdg production files, the substrate files and the preference curve files to compute WUA for each site over the desired range of 30 flows for all 10 sites. The WUA values for the sites in each segment were added together and multiplied by the ratio of total redds counted in the segment to number of redds in the modeling sites for that segment to produce the total WUA per reach. The steelhead/rainbow trout multipliers were calculated using redd counts from 2002-2004.

## RESULTS

### *Habitat Suitability Criteria (HSC) Development*

The logistic regression using only occupied and unoccupied data from upstream of Highway 20 used 159 occupied (86 percent of the total number of steelhead/rainbow trout redds) and 600 unoccupied (200 each from Highway 20, Timbuctoo and UC Sierra sites) observations. The coefficients for the final logistic regressions are shown in Table 2. The p values for all of the non-zero coefficients in Table 2 were less than 0.05, as were the p values for the overall regressions. The steelhead/rainbow trout HSC showed suitability reaching 0.9 at a depth of 3.2 feet (0.98 meters) and not decreasing with increasing depth. We were not able to apply the depth correction method of Gard (1998) because the final criteria stayed at a suitability of 1.00 up to the depth of the deepest steelhead/rainbow trout redd we observed. The final depth and velocity criteria determined from only occupied and unoccupied data from upstream of Highway 20, compared to the depth and velocity criteria from U. S. Fish and Wildlife Service (2008), are shown in Figures 2 and 3.

We were not able to calculate a density of steelhead/rainbow trout redds for the depth increment of 19.5 to 20.5 feet (5.94 to 6.25 meters), since there was no area in any of the six study sites with depths greater than 19.4 feet (5.91 meters). We only observed one redd in this depth increment and it was not located in any of our study sites. The highest density we were able to compute (652 redds/10,000 $m^2$) was for the depth increment of 18.5 to 19.5 feet (5.64 to 5.94 meters); we did not use this data point in developing the density-based depth HSC, since it was such an obvious outlier, with a density that was more than an order of magnitude greater than the density for any of the other depth increments. An initial polynomial linear regression indicated that the density for the depth increment of 16.5 to 17.5 feet (5.03 to 5.33 meters) was an outlier and had a large leverage and influence; accordingly, we did not use this data point in developing the density-based depth HSC. We used a bandwidth of 5 for the kernel smoothing of the depth density-based HSC to remove trough or dips in the HSC that were likely artifacts of small sample sizes (TRPA 2001). The smoothed depth HSC reached a maximum value at 15.4 feet (4.69 meters); we used a linear decrease in suitability from that depth to a suitability of zero at 20 feet (6.10 meters), which is greater than the deepest steelhead/rainbow trout redd we observed (19.9 feet (6.07 meters)). We used a bandwidth of 1 for the kernel smoothing of the velocity density-based HSC to best represent the densities up to 4 ft/s (1.22 m/s). However, we used a linear increase from the smoothed HSC value of 0.33 at 4.25 ft/s (1.30 m/s) to the smoothed HSC value of 0.34 at 6.73 ft/s (2.05 m/s) to remove a trough in the smoothed HSC values between those velocities that we concluded was an artifact of small sample sizes for the velocity increments

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

| parameter | I | J | K | L | M | $R^2$ |
|---|---|---|---|---|---|---|
| depth | -5.2817 | --- | 2.50813 | -0.75673 | 0.059971 | 0.65 |
| velocity | -5.5523 | 4.209993 | -1.09807 | 0.081385 | --- | 0.12 |

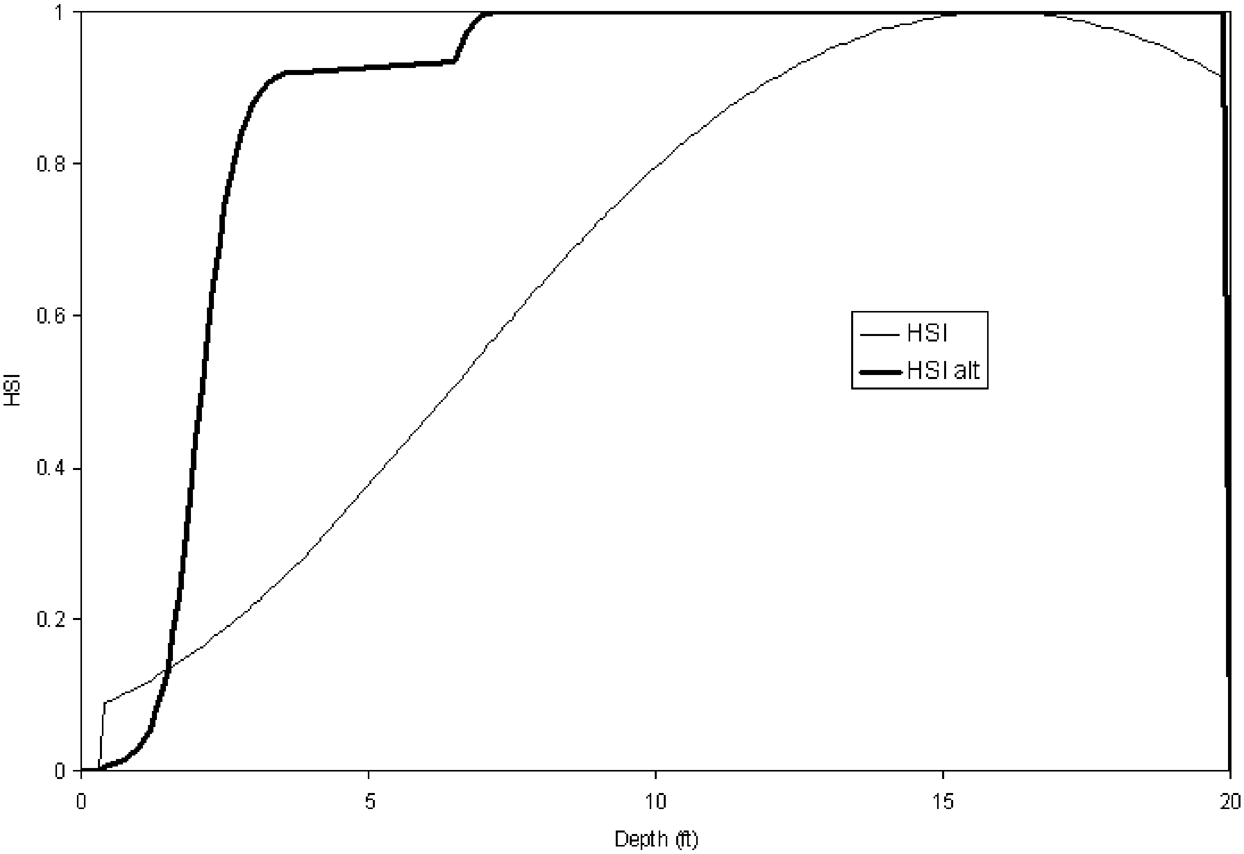

Figure 2. Steelhead/rainbow trout spawning depth HSC determined only using occupied and unoccupied data from upstream of Highway 20 (HSI alt) and the depth HSC from U. S. Fish and Wildlife Service (2008). The HSC determined only using occupied and unoccupied data from upstream of Highway 20 show that steelhead/rainbow trout spawning reaches a suitability of 0.9 at a depth of 3.2 feet (0.98 meters) and an optimum suitability at depths of 7.0 to 19.9 feet (2.13 to 6.07 meters).

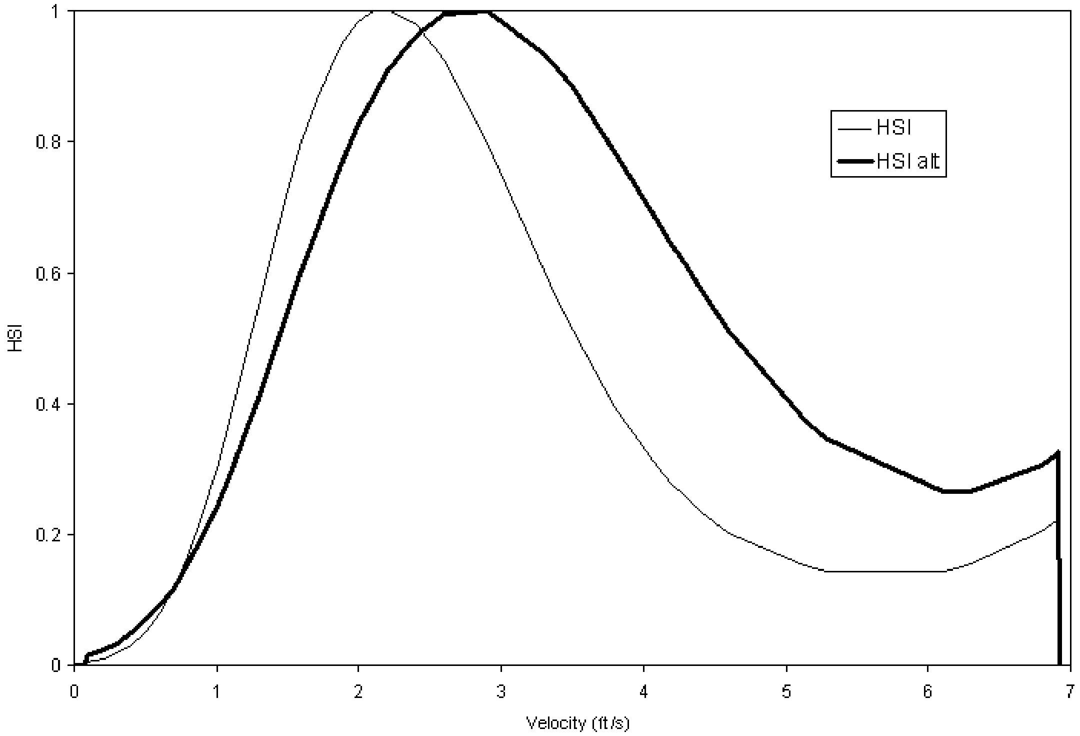

Figure 3. Steelhead/rainbow trout spawning velocity HSC determined only using occupied and unoccupied data from upstream of Highway 20 (HSI alt) and the velocity HSC from U. S. Fish and Wildlife Service (2008). The HSC determined only using occupied and unoccupied data from upstream of Highway 20 show that steelhead/rainbow trout spawning has an optimum suitability at velocities of 2.6 to 2.9 feet/sec (0.79 to 0.88 meters/sec).

greater than 4.25 to 4.75 ft/s (1.30 to 1.45 m/s); the densities in this velocity range were based on velocity increments with 4 or fewer redds. The final density-based depth and velocity criteria, along with the frequency distributions of redd densities, are shown in Figures 4 and 5. The alternative criteria used in the sensitivity analysis, with the exception of the geometric mean calculations, are given in Appendix A. The geometric mean alternative criteria used the univariate criteria in U. S. Fish and Wildlife Service (2008), with the geometric mean calculation performed using an alternative habitat calculation option in River2D.

*Biological Verification*

Univariate (depth, velocity and substrate) habitat suitability predicted by RIVER2D using the criteria in U. S. Fish and Wildlife Service (2008) at each redd location in the six study sites where steelhead/rainbow trout redds locations were recorded in 2003 is shown in Appendix B. The performance of the 2-D model relative to redd locations with a combined suitability of zero were the same for all four alternative HSC (except for the Clear Creek criteria) and the HSC in U. S. Fish and Wildlife Service (2008). The 2-D model predicted that 4 of the 36 (11%) redd

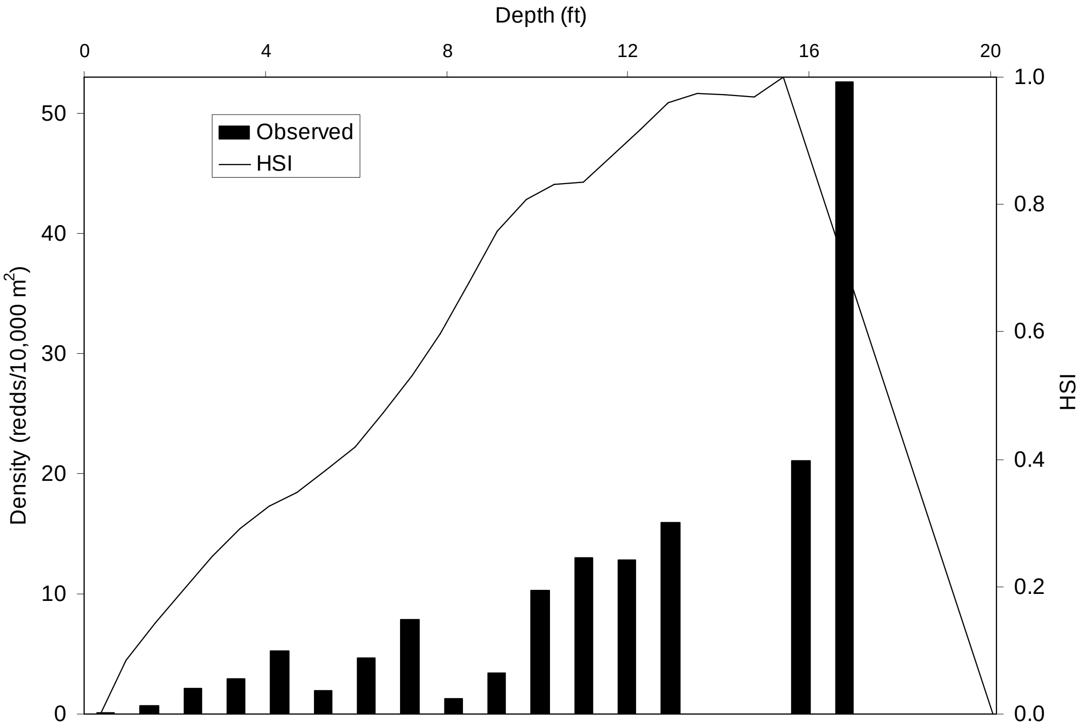

Figure 4. Steelhead/rainbow trout spawning density-based depth HSC.

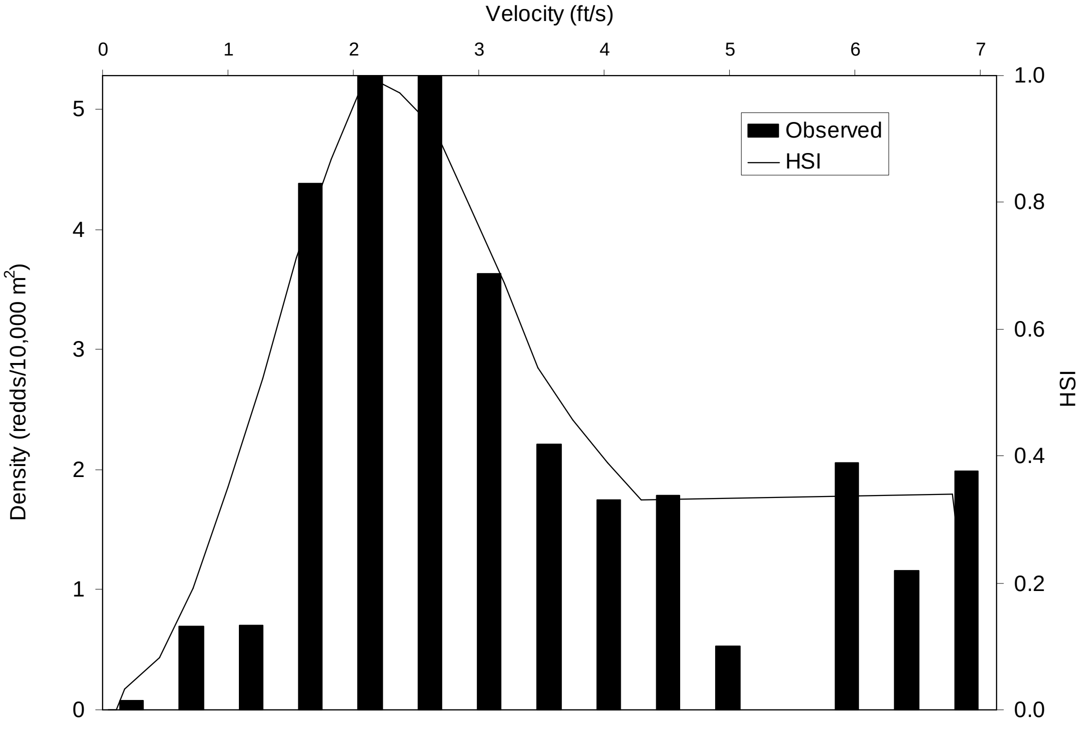

Figure 5. Steelhead/rainbow trout spawning density-based velocity HSC.

locations had a combined suitability of zero. Two had a combined suitability of zero due to the predicted substrate being too large (substrate codes of 6.8, 8, 9 and 10), and two had a combined suitability of zero because the location was predicted to be dry by the 2-D model. Both the original HSC in U. S. Fish and Wildlife Service (2008) and the four alternative HSC have zero suitabilities for these conditions. The Clear Creek criteria had an additional 4 redd locations with a combined suitability of zero, for a total of 8 of the 36 (22%) of the redd location with zero suitability. For these additional locations, two had zero suitability because the velocity was too low (less than 0.61 ft/s (0.19 m/s)) and two because the velocity was too high (greater than 3.89 ft/s (1.19 m/s)).

The combined habitat suitability predicted by the 2-D model using the alternative criteria determined only from occupied and unoccupied data upstream of Highway 20 was significantly higher for locations with redds (median = 0.245, n =32) than for locations without redds (median = 0.0004, n = 600), based on the Mann-Whitney U test (U = 4298, p < 0.000001). The frequency distribution of combined habitat suitability using the alternative criteria determined only from occupied and unoccupied data upstream of Highway 20 for locations with steelhead/rainbow trout redds is shown in Figure 6, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 7.

The combined habitat suitability predicted by the 2-D model using the Clear Creek criteria was significantly higher for locations with redds (median = 0.18, n =36) than for locations without redds (median = 0, n = 1200), based on the Mann-Whitney U test (U = 8065, p < 0.000001). The frequency distribution of combined habitat suitability using the Clear Creek criteria for locations with steelhead/rainbow trout redds is shown in Figure 8, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 9.

The combined habitat suitability predicted by the 2-D model using the density-based criteria was significantly higher for locations with redds (median = 0.10, n =36) than for locations without redds (median = 0.006, n = 1200), based on the Mann-Whitney U test (U = 9121, p < 0.000001). The frequency distribution of combined habitat suitability using the density-based criteria for locations with steelhead/rainbow trout redds is shown in Figure 10, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 11.

The combined habitat suitability predicted by the 2-D model using the geometric mean-based criteria was significantly higher for locations with redds (median = 0.42, n =36) than for locations without redds (median = 0.142, n = 1200), based on the Mann-Whitney U test (U = 9601, p < 0.000001). The frequency distribution of combined habitat suitability using the geometric mean criteria for locations with steelhead/rainbow trout redds is shown in Figure 12, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 13.

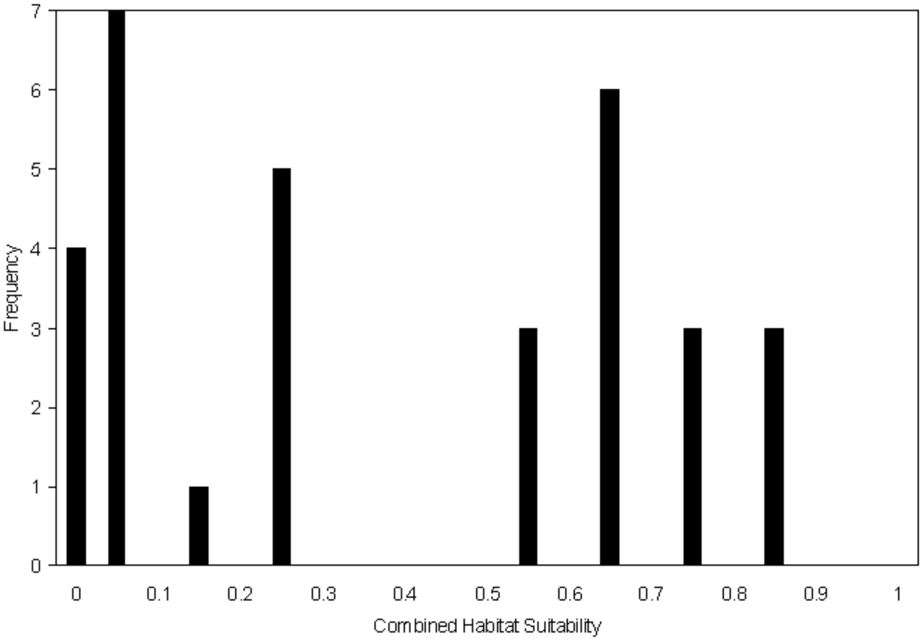

Figure 6. Combined suitability using the alternative criteria determined only from occupied and unoccupied data upstream of Highway 20 for 2-D model locations with steelhead/rainbow trout redds. The median combined suitability for occupied locations was 0.245.

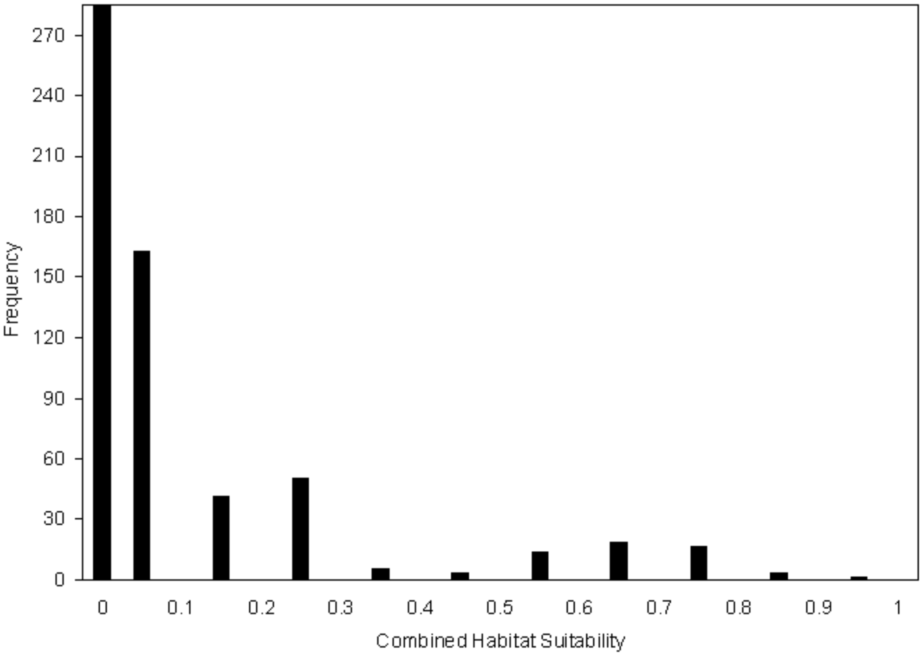

Figure 7. Combined suitability using the alternative criteria determined only from occupied and unoccupied data upstream of Highway 20 for 2-D model locations without steelhead/rainbow trout redds. The median combined suitability for unoccupied locations was 0.0004.

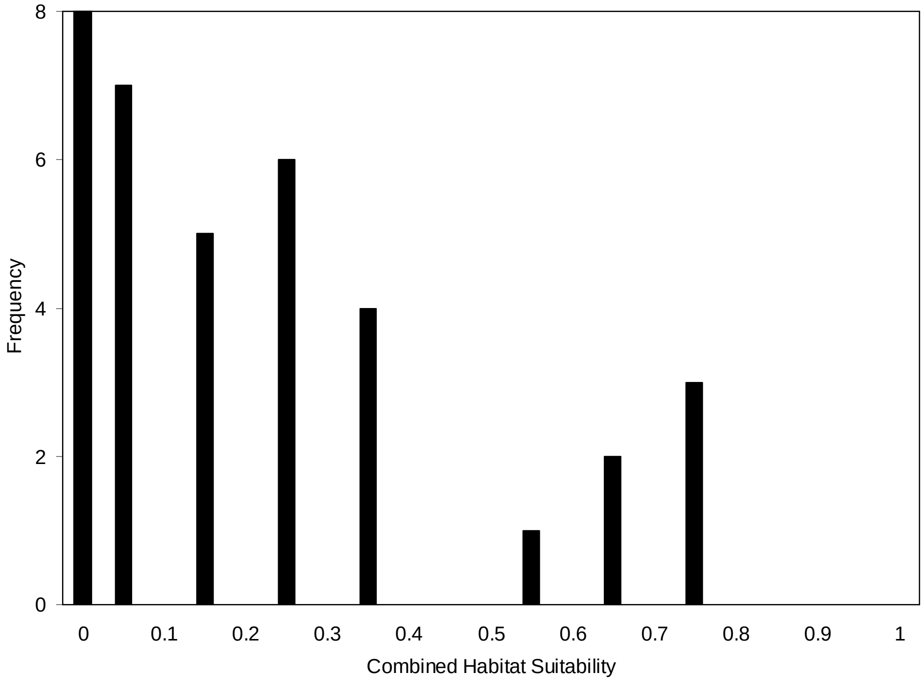

Figure 8. Combined suitability using the Clear Creek alternative criteria for 2-D model locations with steelhead/rainbow trout redds. The median combined suitability for occupied locations was 0.18.

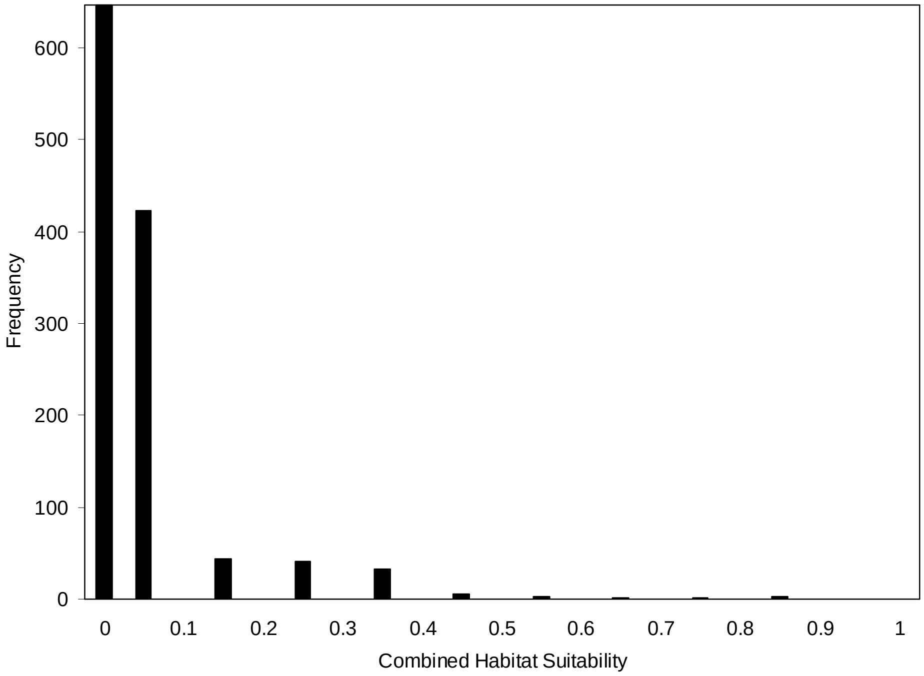

Figure 9. Combined suitability using the Clear Creek alternative criteria for 2-D model locations without steelhead/rainbow trout redds. The median combined suitability for unoccupied locations was 0.

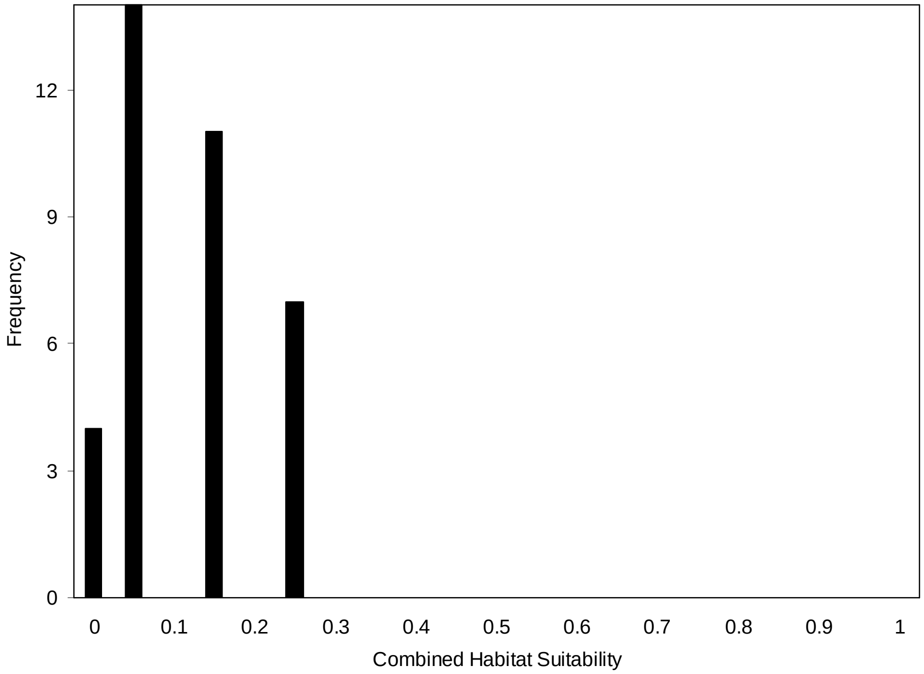

Figure 10. Combined suitability using the density-based alternative criteria for 2-D model locations with steelhead/rainbow trout redds. The median combined suitability for occupied locations was 0.10.

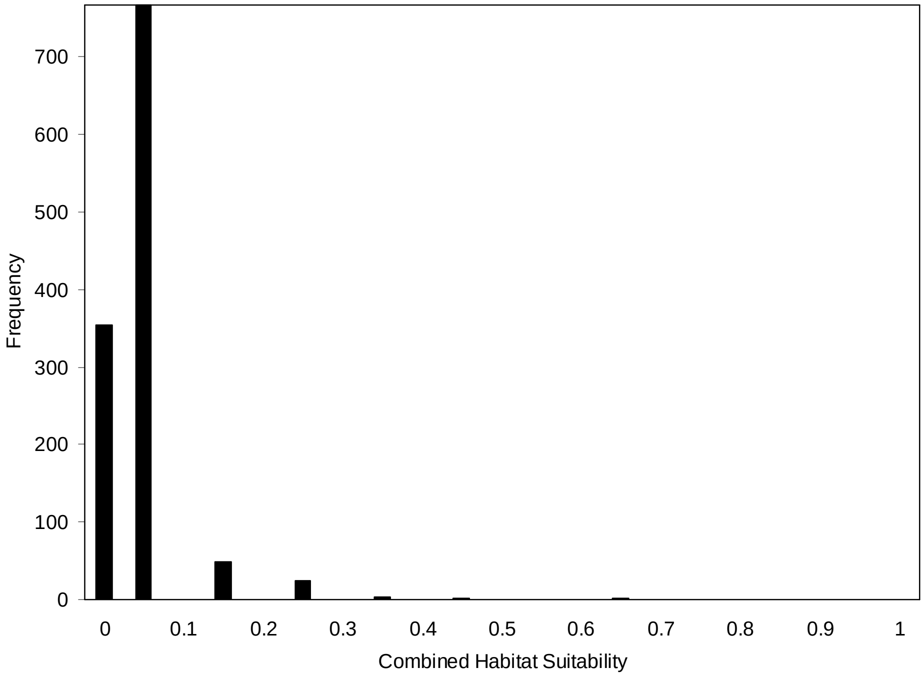

Figure 11. Combined suitability using the density-based alternative criteria for 2-D model locations without steelhead/rainbow trout redds. The median combined suitability for unoccupied locations was 0.006.

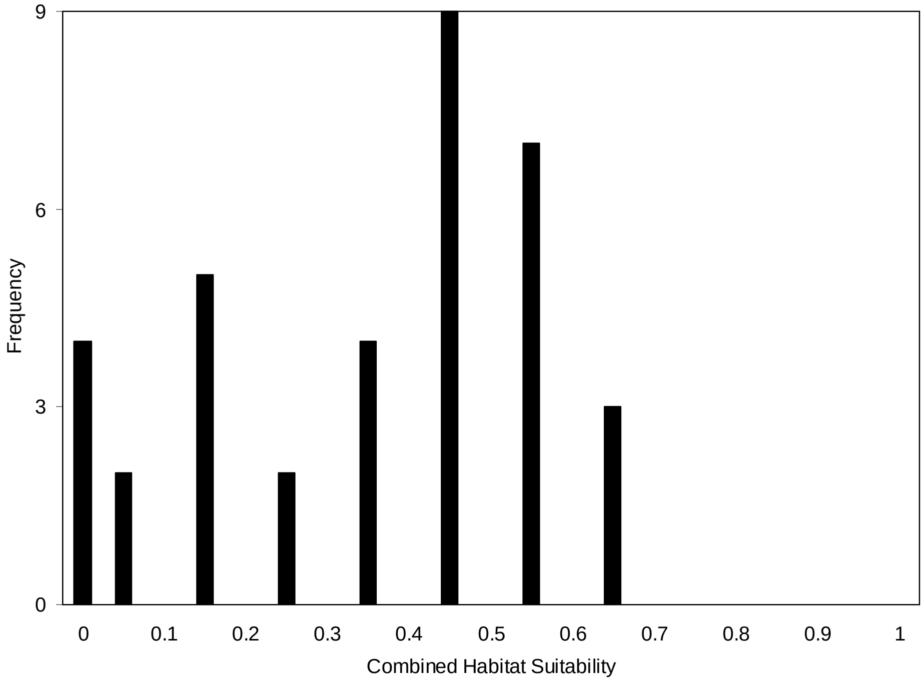

Figure 12. Combined suitability using the geometric mean-based alternative criteria for 2-D model locations with steelhead/rainbow trout redds. The median combined suitability for occupied locations was 0.42.

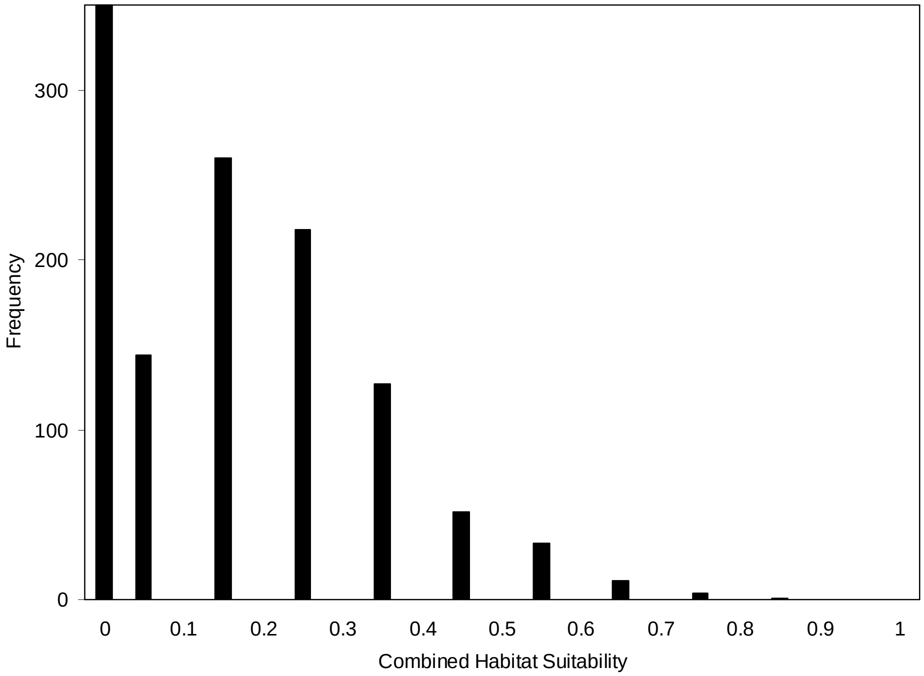

Figure 13. Combined suitability using the geometric mean-based alternative criteria for 2-D model locations without steelhead/rainbow trout redds. The median combined suitability for unoccupied locations was 0.142.

Using the actual measured substrate at redd locations in computing the combined suitability of occupied locations, the combined habitat suitability predicted by the 2-D model using the original criteria in U. S. Fish and Wildlife Service (2008) was significantly higher for locations with redds (median = 0.10, n =36) than for locations without redds (median = 0.004, n = 1200), based on the Mann-Whitney U test (U = 7487, $p < 0.000001$). The frequency distribution of combined habitat suitability at redd locations using the actual measured substrate at these locations is shown in Figure 14, while the frequency distribution of combined habitat suitability for locations without redds is unchanged from that presented in U. S. Fish and Wildlife Service (2008). Using the actual measured substrate at redd locations, the 2-D model predicted that 2 of the 36 (6%) redd locations had a combined suitability of zero, in both cases because the location was predicted to be dry by the 2-D model.

The location of steelhead/rainbow trout redds in 2003 relative to the distribution of combined suitability for all of the four alternative criteria is shown in Appendix C[2]. The location of steelhead/rainbow trout redds in 2002 and 2004 relative to the distribution of combined suitability for the original criteria in U. S. Fish and Wildlife Service (2008) and all of the four alternative criteria are shown in Appendix D.

### *Habitat Simulation*

The ratios of total redds counted in the segment to number of redds in the modeling sites for that segment were as follows: steelhead/rainbow trout Above Daguerra Segment = 1.76, Below Daguerra Segment = 1.25. The flow habitat relationships for the four alternative criteria are shown in Figures 15 to 22. Table 3 shows the flows at which the 2-D model predicts the highest total WUA for the Above Daguerra and Below Daguerra Segments using the criteria in U. S. Fish and Wildlife Service (2008) and the four alternative criteria.

## DISCUSSION

### *Habitat Suitability Criteria (HSC) Development*

The differences between the criteria in U.S. Fish and Wildlife Service (2008) and the alternative criteria calculated only using data from upstream of Highway 20 can be attributed primarily to the greater availability of deeper yet slower conditions upstream of Daguerra Point Dam, versus downstream of Daguerra Point Dam. Since 86 percent of the steelhead/rainbow trout redds were upstream of Highway 20, both sets of criteria used mostly the same data for occupied locations. The greater availability of deeper conditions upstream of Daguerra Point Dam shifted the

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[2] For the criteria calculated only from data upstream of Highway 20, results are only given in Appendix C for the three sites upstream of Daguerra Point Dam, since data from downstream of Daguerra Point Dam was not used to develop these criteria.

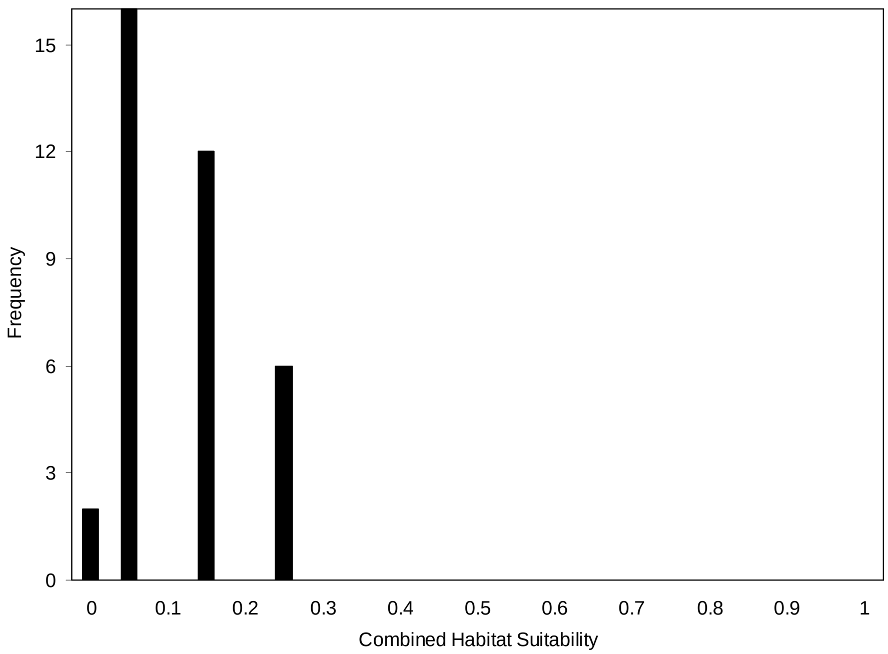

Figure 14. Combined suitability using the criteria from U. S. Fish and Wildlife Service (2008) and the measured substrate at redd locations for 2-D model locations with steelhead/rainbow trout redds. The median combined suitability for occupied locations was 0.10.

distribution of the unoccupied locations to deeper conditions, but the criteria still showed a preference for deeper conditions. However, the suitability of areas with depths in the range of 3 to 8 feet (0.91 to 2.44 meters) was significantly higher with the alternative criteria calculated only using data from upstream of Highway 20, compared to the criteria in U.S. Fish and Wildlife Service (2008), resulting in approximately the same suitability for depths of 3 to 19.9 feet (0.91 to 6.07 meters). In contrast, the slightly slower conditions upstream of Daguerra Point Dam, versus downstream of Daguerra Point Dam, shifted the distribution of unoccupied locations to slightly slower conditions, and thus resulted in the alternative criteria calculated only using data from upstream of Highway 20 reaching an optimum suitability at velocities of 2.6 to 2.9 feet/sec (0.79 to 0.88 meters/sec), compared to an optimum suitability for velocities of 2.1 to 2.2 feet/sec (0.64 to 0.67 meters/sec) to for the criteria in U.S. Fish and Wildlife Service (2008).

There are two possible hypotheses to explain the distribution of steelhead/rainbow trout spawning shown in Figure 1: 1) the lower availability of deeper conditions downstream of Daguerra Point Dam results in most steelhead/rainbow trout spawning upstream of Daguerra Point Dam, where there is greater availability of their preferred deeper spawning habitat; or 2) some other factor than the differential availability of depths upstream versus downstream of Daguerra Point Dam is controlling the distribution of steelhead/rainbow trout spawning. If the

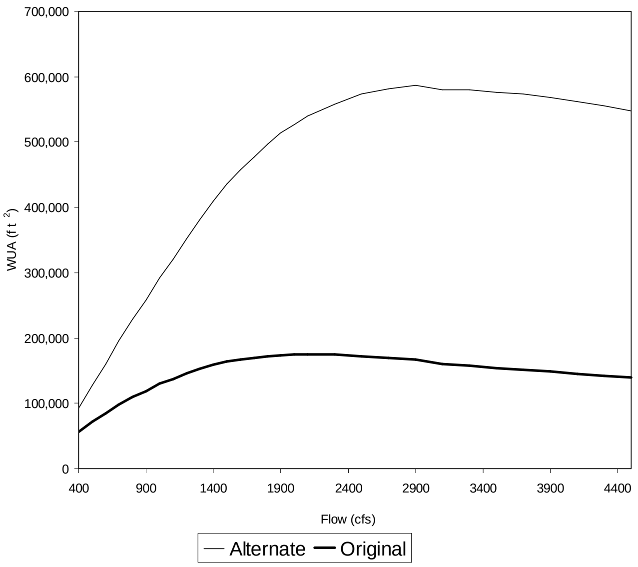

Figure 15. Flow-habitat relationships above Daguerra Point Dam using the criteria from U. S. Fish and Wildlife Service (2008) (original) and the criteria determined only using occupied and unoccupied data from upstream of Highway 20 (Alternate). The flow with the maximum steelhead/rainbow trout spawning habitat using the alternate criteria was 2,900 cfs.

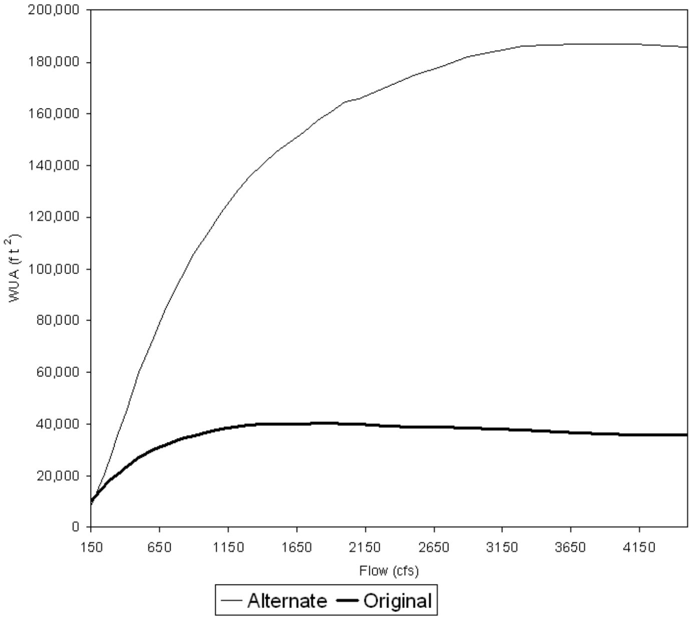

Figure 16. Flow-habitat relationship below Daguerra Point Dam using the criteria from U. S. Fish and Wildlife Service (2008) (original) and the criteria determined only using occupied and unoccupied data from upstream of Highway 20 (Alternate). The flow with the maximum steelhead/rainbow trout spawning habitat using the alternate criteria was 3,700 cfs.

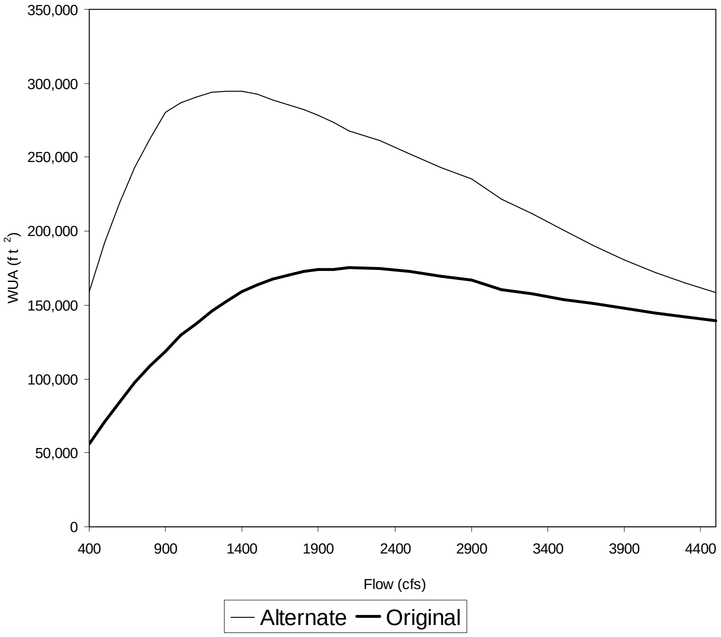

Figure 17. Flow-habitat relationships above Daguerra Point Dam using the criteria from U. S. Fish and Wildlife Service (2008) (original) and the Clear Creek criteria (Alternate). The flow with the maximum steelhead/rainbow trout spawning habitat using the Clear Creek criteria was 1,300 cfs.

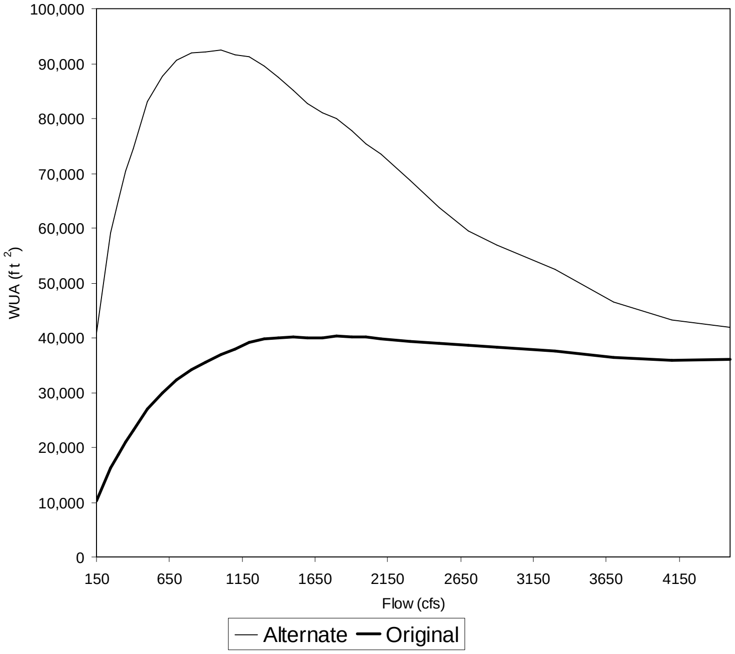

Figure 18. Flow-habitat relationships below Daguerra Point Dam using the criteria from U. S. Fish and Wildlife Service (2008) (original) and the Clear Creek criteria (Alternate). The flow with the maximum steelhead/rainbow trout spawning habitat using the Clear Creek criteria was 1,000 cfs.

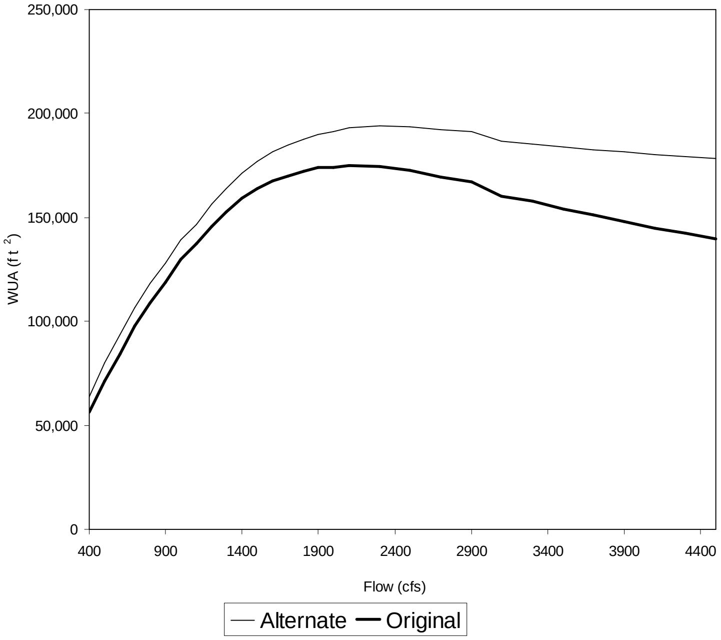

Figure 19. Flow-habitat relationships above Daguerra Point Dam using the criteria from U. S. Fish and Wildlife Service (2008) (original) and the density-based criteria (Alternate). The flow with the maximum steelhead/rainbow trout spawning habitat using the density-based criteria was 2,300 cfs.

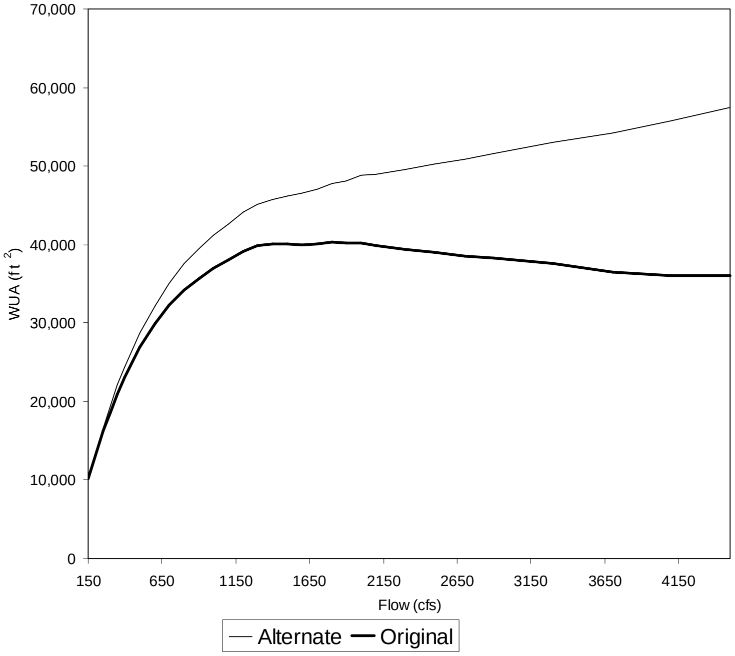

Figure 20. Flow-habitat relationships below Daguerra Point Dam using the criteria from U. S. Fish and Wildlife Service (2008) (original) and the density-based criteria (Alternate). The flow with the maximum steelhead/rainbow trout spawning habitat using the density-based criteria was 4,500 cfs.

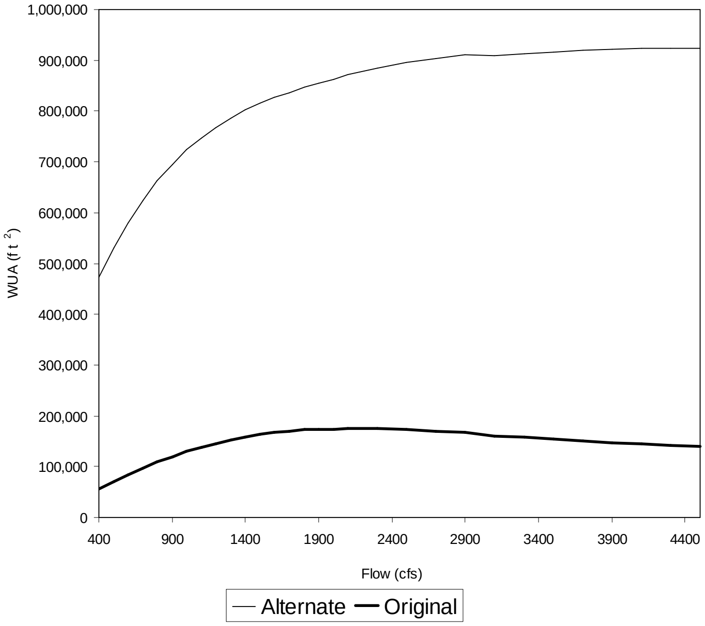

Figure 21. Flow-habitat relationships above Daguerra Point Dam using the criteria from U. S. Fish and Wildlife Service (2008) (original) and the geometric mean-based criteria (Alternate). The flow with the maximum steelhead/rainbow trout spawning habitat using the geometric mean-based criteria was 4,500 cfs.

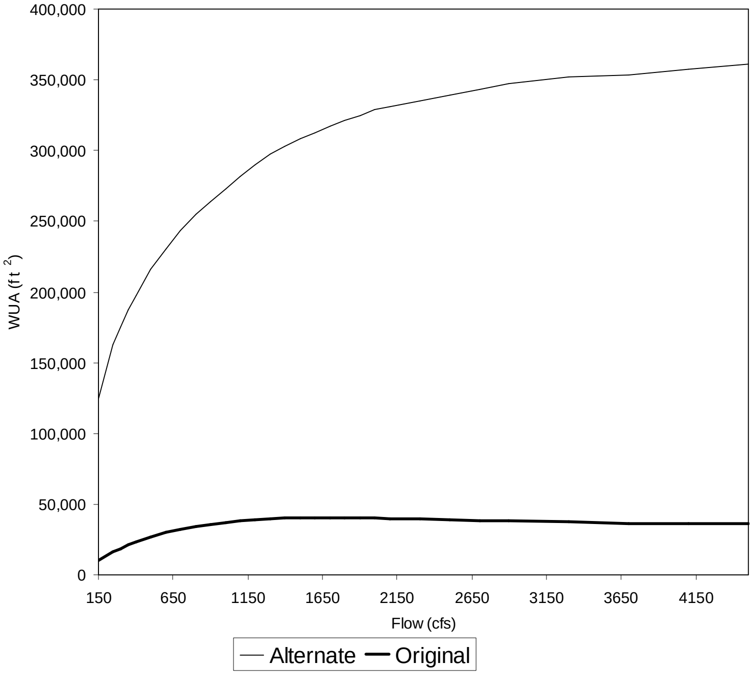

Figure 22. Flow-habitat relationships below Daguerra Point Dam using the criteria from U. S. Fish and Wildlife Service (2008) (original) and the geometric mean-based criteria (Alternate). The flow with the maximum steelhead/rainbow trout spawning habitat using the geometric mean-based criteria was 4,500 cfs.

Table 3. Flows (cfs) where the 2-D model predicts the highest total steelhead/rainbow trout spawning WUA.

| Criteria | Above Daguerra | Below Daguerra |
|---|---|---|
| U. S. Fish and Wildlife Service (2008) | 2,100 | 1,800 |
| Only using data from upstream of Highway 20 | 2,900 | 3,700 |
| Clear Creek | 1,300 | 1,000 |
| Density-based | 2,300 | 4,500 |
| Geometric mean-based | 4,500 | 4,500 |

first hypothesis is correct, the criteria in U.S. Fish and Wildlife Service (2008) should be used. If the second hypothesis is correct, the criteria calculated only using data from upstream of Highway 20 should be used. We are not aware of any data that could be used to test which hypothesis is correct.

The differences between the criteria in U.S. Fish and Wildlife Service (2008) and the Clear Creek criteria can be attributed largely to Clear Creek being a much smaller stream than the Yuba River; typical spawning flows for Clear Creek are 200 cfs, while the typical flows in the Yuba River during steelhead/rainbow trout spawning are on the order of 2,000 cfs. In Clear Creek, the near absence of deeper conditions limits steelhead/rainbow trout spawning to depths of less than 4 feet (1.22 meters), while the availability, albeit low, of deeper conditions in the Yuba River resulted in 34 percent of the steelhead/rainbow trout redds being in depths greater than 4 feet (1.22 meters). Application of the Gard (1998) depth correction methodology for Clear Creek rainbow trout/steelhead indicated that steelhead/rainbow trout use was almost entirely controlled by the availability of deep water having suitable velocities and substrates, resulting in the depth suitability not reaching zero until 28.6 feet (8.72 meters). For depths of 1.5 to 15.1 feet (0.46 to 4.60 meters), the Clear Creek and U.S. Fish and Wildlife Service (2008) depth criteria are essentially mirror images; the Clear Creek criteria decrease from a suitability of 1.0 at 1.5 feet (0.30 to 0.46 meters) to 0.5 at 15.1 feet (4.60 meters), while the U.S. Fish and Wildlife Service (2008) criteria increase from a suitability of 0.13 at 1.5 feet (0.46 meters) to a suitability of 1.0 at 15.1 feet (4.60 meters). We feel that the U.S. Fish and Wildlife Service (2008) criteria better capture the preference of Yuba River steelhead/rainbow trout for deeper conditions than the Clear Creek criteria, and thus the U.S. Fish and Wildlife Service (2008) criteria should be used instead of the Clear Creek criteria. The Clear Creek velocity criteria do not capture the full range of velocities where we found steelhead/rainbow trout redds in the Yuba River. The Clear Creek criteria have zero suitability for velocities less than 0.61 feet/sec (0.19 meters/sec) or greater than 3.89 feet/sec (1.19 meters/sec). Three of the Yuba River steelhead/rainbow trout redds were found at velocities less than 0.61 feet/sec (0.19 meters/sec) and 22 (12 percent) of the Yuba River steelhead/rainbow trout redds were found at velocities greater than 3.89 feet/sec (1.19 meters/sec).

While there are some instances in the literature where combined suitability has been calculated using a geometric mean (Hanrahan et al. 2004, Prewitt 1982, Hardy and Addley 2001), most applications of habitat modeling use a product to obtain combined suitability (Vadas and Orth 2001). Geometric mean calculations imply that good habitat for one variable can compensate for poor conditions for another variable, but yield zero combined suitability when any habitat variable is unsuitable (Vadas and Orth 2001). Vadas and Orth (2001) concluded that the product method was superior to the geometric mean method because it was consistently accurate and was a simpler regression model. The density-based alternative criteria were generally similar to the criteria in U.S. Fish and Wildlife Service (2008), with both showing suitability increasing up to depths of 15 feet (4.57 meters) and having optimal suitability for velocities around 2 feet/sec (0.61 meters/sec). The density-based criteria seemed to be more sensitive to outliers than the criteria in U.S. Fish and Wildlife Service (2008). TRPA (2001) also found similar results for density-based and logistic regression-based criteria.

### *Biological Verification*

There were no clear trends from the biological verification results. The univariate plots in Appendix A show that the low suitability of occupied locations using original criteria from U.S. Fish and Wildlife Service (2008) was due in some cases to depth, in some cases to velocity and in other cases to substrate. Overall, the univariate depth suitability plots show the low availability of deeper conditions with high depth suitability

We did not use a parametric test because the assumption of normality of parametric tests was violated, as shown in Figures 6 to 14, indicating the appropriateness of nonparametric tests. A large unbalanced sample size was appropriate for this test to reduce type II errors, since unoccupied depths, velocities and substrates have a much greater range of values than occupied depths, velocities and substrates, and thus did not bias results. Analogously, Thomas and Bovee (1993) found that a minimum of 55 occupied and 200 unoccupied locations were required to reduce type II errors.The combined suitability of occupied locations was significantly greater than the combined suitability of unoccupied locations for the original criteria from U.S. Fish and Wildlife Service (2008) and all four of the alternative criteria. The original criteria from U.S. Fish and Wildlife Service (2008) had the highest U statistic from the Mann-Whitney U test (Table 4), while the geometric-mean based criteria had the highest median combined suitability for occupied locations. Overall, three of the alternative criteria (the criteria based only on data from upstream of Highway 20, the Clear Creek criteria and the geometric-mean based criteria) had higher combined suitabilities for occupied locations than the original criteria from U.S. Fish and Wildlife Service (2008), but also had higher combined suitabilities for unoccupied locations (Appendix C). Thus, while a case could be made that the original criteria from U.S. Fish and

Table 4. Summary statistics of biological verification.

| | Median CSI | | |
|---|---|---|---|
| Criteria | Occupied | Unoccupied | U |
| U. S. Fish and Wildlife Service (2008) | 0.08 | 0.004 | 9881 |
| Only using data from upstream of Highway 20 | 0.245 | 0.0004 | 4298 |
| Clear Creek | 0.18 | 0 | 8065 |
| Density-based | 0.10 | 0.006 | 9121 |
| Geometric mean-based | 0.42 | 0.142 | 9601 |

Wildlife Service (2008) underestimated the combined suitability of occupied locations, it could also be argued that the above three alternative criteria overestimated the combined suitability of unoccupied locations. Finally, the Clear Creek criteria performed worse than the other three alternative criteria and the original criteria from U.S. Fish and Wildlife Service (2008), with the Clear Creek criteria predicting twice as many redd locations with a combined suitability of zero than the other criteria.

The plots of combined suitability versus redd locations in 2002 and 2004 (Appendix D) clearly showed the errors associated with the GPS data (for example, the redd shown on dry land for Highway 20 Study Site in 2004). In general, the 2002 and 2004 data show similar patterns to the 2003 data (in Appendix C). However, the 2004 data does show some of the redds that we found in deeper waters (for example in the middle section of the Timbuctoo Study Site), although the redd locations do not correspond to areas that were predicted to have high suitability using the criteria from U.S. Fish and Wildlife Service (2008). This lack of correspondence could be due to errors in the GPS data, since redds in the middle section of the Timbuctoo Study Site are located near areas that were predicted to have high suitability using the criteria from U.S. Fish and Wildlife Service (2008).

### *Habitat Simulation*

With the exception of the Clear Creek criteria, the flow-habitat relationships were not sensitive to the criteria, with all of the flow-habitat relationships from criteria derived from data collected on the Yuba River having similar shapes. In fact, the three alternative criteria developed from Yuba River data had the highest total steelhead/rainbow trout spawning WUA at higher flows than the original criteria from U.S. Fish and Wildlife Service (2008) for both the Above Daguerra and Below Daguerra segments (Table 3). The flow-habitat relationships from the density-based criteria were closest to the flow-habitat relationships given in U.S. Fish and Wildlife Service

(2008), reflecting the similarity between the density-based criteria and the original criteria from U.S. Fish and Wildlife Service (2008). The biggest difference between the flow-habitat relationships using the three other alternative criteria, versus the original criteria from U.S. Fish and Wildlife Service (2008), was a much greater magnitude of habitat at all flows. Geometric mean-based criteria typically show this trend, since the combined suitability will be greater for any given point than the combined suitability calculated from the product of the individual suitabilities, simply because the geometric mean is the product raised to the 1/3 power. The greater magnitude of habitat at all flows for the criteria developed only from data upstream of Highway 20 and the Clear Creek criteria, as compared to the original criteria from U.S. Fish and Wildlife Service (2008), is largely due to the higher suitability of intermediate depths for these two alternative criteria.

## CONCLUSION

Based on the results of this sensitivity analysis, we feel that the flow-habitat relationships for steelhead/rainbow trout spawning using the alternative criteria calculated only using occupied and unoccupied data from upstream of Highway 20 best characterize the habitat requirements for steelhead/rainbow trout spawning in the Yuba River.

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# APPENDIX A
# STEELHEAD/RAINBOW TROUT SPAWNING HABITAT SUITABILITY CRITERIA

## Criteria calculated with only data from upstream of Highway 20

| Water Velocity (ft/s) | SI Value | Water Depth (ft) | SI Value | Substrate Code | SI Value |
|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.0 | 0.00 | 0 | 0.00 |
| 0.08 | 0.00 | 0.3 | 0.00 | 0.1 | 0.00 |
| 0.09 | 0.02 | 0.4 | 0.01 | 1 | 0.13 |
| 0.20 | 0.02 | 0.7 | 0.01 | 1.2 | 1.00 |
| 0.30 | 0.03 | 0.8 | 0.02 | 1.3 | 0.85 |
| 0.60 | 0.09 | 0.9 | 0.02 | 2.4 | 0.28 |
| 0.70 | 0.12 | 1.0 | 0.03 | 3.5 | 0.16 |
| 0.80 | 0.15 | 1.1 | 0.04 | 4.6 | 0.05 |
| 0.90 | 0.20 | 1.2 | 0.06 | 6.8 | 0.00 |
| 1.00 | 0.24 | 1.3 | 0.08 | 100 | 0.00 |
| 1.10 | 0.30 | 1.4 | 0.10 | | |
| 1.20 | 0.35 | 1.5 | 0.14 | | |
| 1.30 | 0.41 | 1.6 | 0.18 | | |
| 1.40 | 0.48 | 1.7 | 0.23 | | |
| 1.50 | 0.54 | 1.8 | 0.29 | | |
| 1.60 | 0.60 | 1.9 | 0.36 | | |
| 1.70 | 0.67 | 2.0 | 0.43 | | |
| 1.80 | 0.72 | 2.1 | 0.51 | | |
| 1.90 | 0.78 | 2.2 | 0.58 | | |
| 2.00 | 0.83 | 2.3 | 0.64 | | |
| 2.10 | 0.87 | 2.4 | 0.70 | | |
| 2.20 | 0.91 | 2.5 | 0.74 | | |
| 2.40 | 0.96 | 2.6 | 0.78 | | |
| 2.60 | 1.00 | 2.7 | 0.82 | | |
| 2.90 | 1.00 | 2.8 | 0.84 | | |
| 3.30 | 0.94 | 2.9 | 0.86 | | |
| 3.40 | 0.91 | 3.0 | 0.88 | | |
| 3.50 | 0.88 | 3.1 | 0.89 | | |
| 3.80 | 0.79 | 3.2 | 0.90 | | |
| 4.10 | 0.68 | 3.3 | 0.91 | | |
| 4.20 | 0.65 | 3.4 | 0.92 | | |
| 4.30 | 0.61 | 3.8 | 0.92 | | |
| 4.40 | 0.58 | 6.5 | 0.94 | | |
| 4.60 | 0.51 | 6.6 | 0.96 | | |
| 5.10 | 0.38 | 6.7 | 0.97 | | |
| 5.20 | 0.36 | 6.8 | 0.98 | | |
| 5.30 | 0.34 | 6.9 | 0.99 | | |
| 6.10 | 0.27 | 7.0 | 1.00 | | |
| 6.20 | 0.26 | 19.9 | 1.00 | | |
| 6.30 | 0.27 | 20.0 | 0.00 | | |
| 6.80 | 0.30 | 100.0 | 0.00 | | |
| 6.90 | 0.32 | | | | |
| 6.92 | 0.33 | | | | |
| 6.93 | 0.00 | | | | |
| 100.00 | 0.00 | | | | |

## Clear Creek criteria

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

| Water Depth (ft) | SI Value |
|---|---|
| 0.0 | 0.00 |
| 0.3 | 0.00 |
| 0.4 | 0.16 |
| 0.5 | 0.26 |
| 0.6 | 0.38 |
| 0.7 | 0.51 |
| 0.8 | 0.64 |
| 0.9 | 0.75 |
| 1.0 | 0.85 |
| 1.1 | 0.92 |
| 1.2 | 0.96 |
| 1.3 | 0.99 |
| 1.4 | 1.00 |
| 1.5 | 1.00 |
| 28.6 | 0.00 |
| 100 | 0.00 |

| Substrate Composition | SI Value |
|---|---|
| 0 | 0.00 |
| 0.1 | 0.00 |
| 1 | 0.38 |
| 1.2 | 1.00 |
| 1.3 | 0.44 |
| 2.3 | 0.26 |
| 2.4 | 0.07 |
| 3.4 | 0.06 |
| 3.5 | 0.04 |
| 4.6 | 0.01 |
| 6.8 | 0.00 |
| 10 | 0.00 |
| 100 | 0.00 |

## Density criteria

| Water Velocity (ft/s) | SI Value | Water Depth (ft) | SI Value | Substrate Composition | SI Value |
|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.0 | 0.00 | 0 | 0.00 |
| 0.06 | 0.00 | 0.3 | 0.00 | 0.1 | 0.00 |
| 0.13 | 0.03 | 0.9 | 0.09 | 1 | 0.13 |
| 0.40 | 0.08 | 1.5 | 0.14 | 1.2 | 1.00 |
| 0.68 | 0.19 | 2.1 | 0.19 | 1.3 | 0.85 |
| 0.95 | 0.35 | 2.8 | 0.25 | 2.4 | 0.28 |
| 1.23 | 0.52 | 3.4 | 0.29 | 3.5 | 0.16 |
| 1.50 | 0.71 | 4.0 | 0.33 | 4.6 | 0.05 |
| 1.78 | 0.87 | 4.7 | 0.35 | 6.8 | 0.00 |
| 2.05 | 1.00 | 5.3 | 0.38 | 100 | 0.00 |
| 2.33 | 0.97 | 5.9 | 0.42 | | |
| 2.60 | 0.92 | 6.6 | 0.47 | | |
| 2.88 | 0.80 | 7.2 | 0.53 | | |
| 3.15 | 0.67 | 7.8 | 0.60 | | |
| 3.43 | 0.54 | 8.4 | 0.68 | | |
| 3.70 | 0.46 | 9.1 | 0.76 | | |
| 3.98 | 0.39 | 9.7 | 0.81 | | |
| 4.25 | 0.33 | 10.3 | 0.83 | | |
| 6.73 | 0.34 | 11.0 | 0.84 | | |
| 6.93 | 0.00 | 11.6 | 0.88 | | |
| 100.00 | 0.00 | 12.2 | 0.92 | | |
| | | 12.9 | 0.96 | | |
| | | 13.5 | 0.97 | | |
| | | 14.1 | 0.97 | | |
| | | 14.7 | 0.97 | | |
| | | 15.4 | 1.00 | | |
| | | 20.0 | 0.00 | | |
| | | 100.0 | 0.00 | | |

# APPENDIX B
# RIVER2D UNIVARIATE HABITAT SUITABILITY OF REDD LOCATIONS[1]

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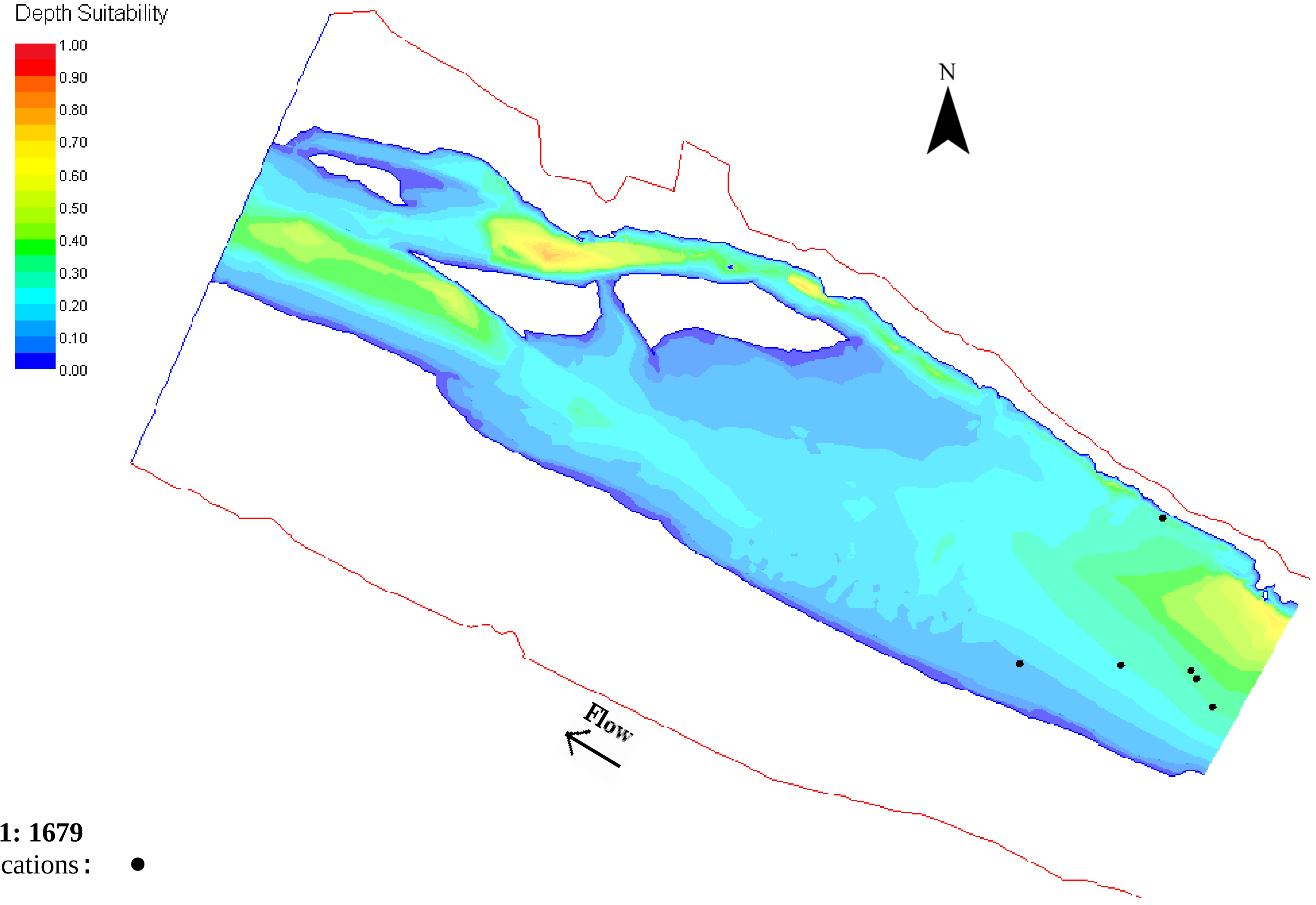
[1] For all pages, for Velocity, Depth, and Substrate Suitability : 1 = optimal, 0 = unusable.

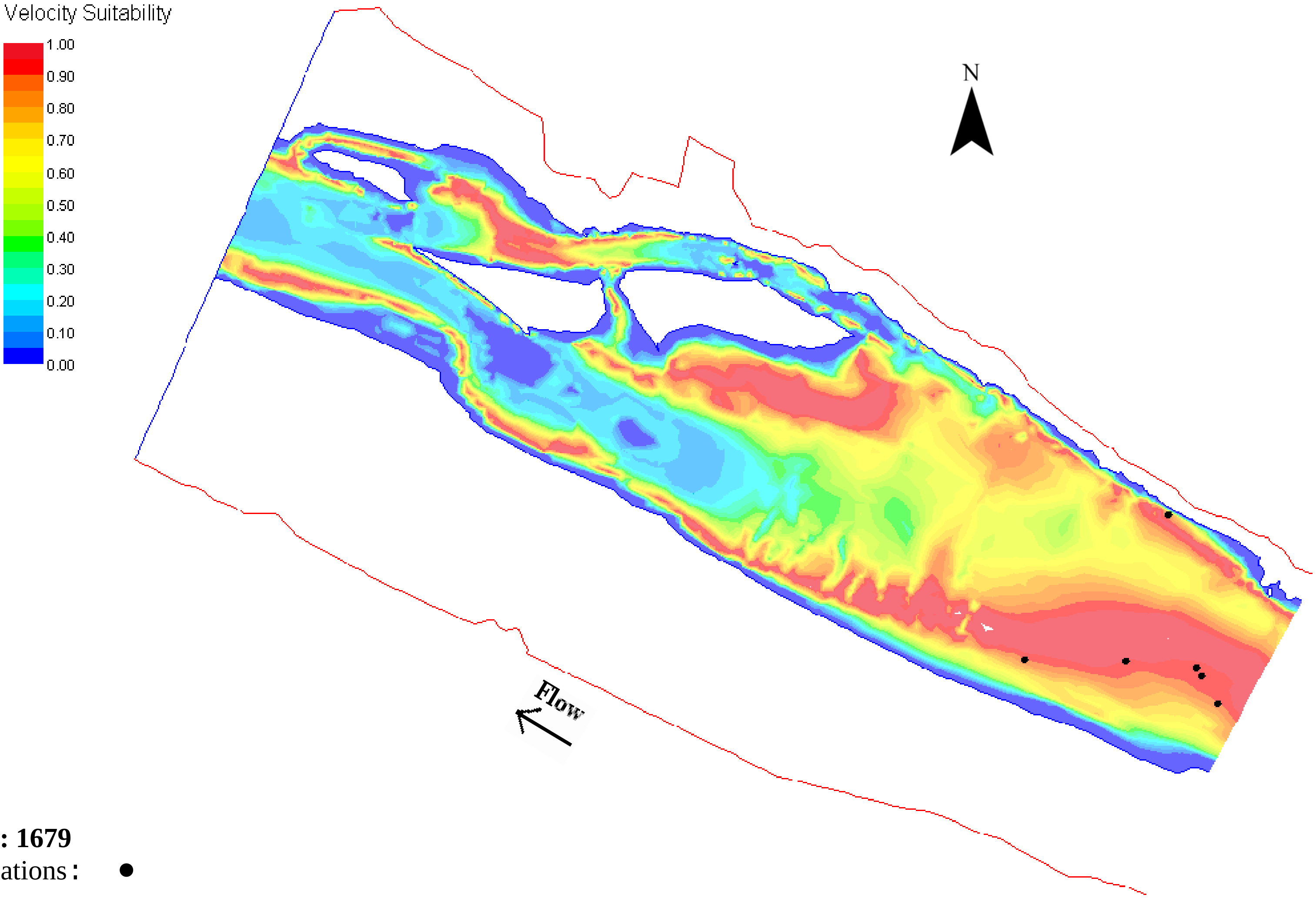
## U.C. SIERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING



**Scale: 1: 1679**

Redd locations: ●

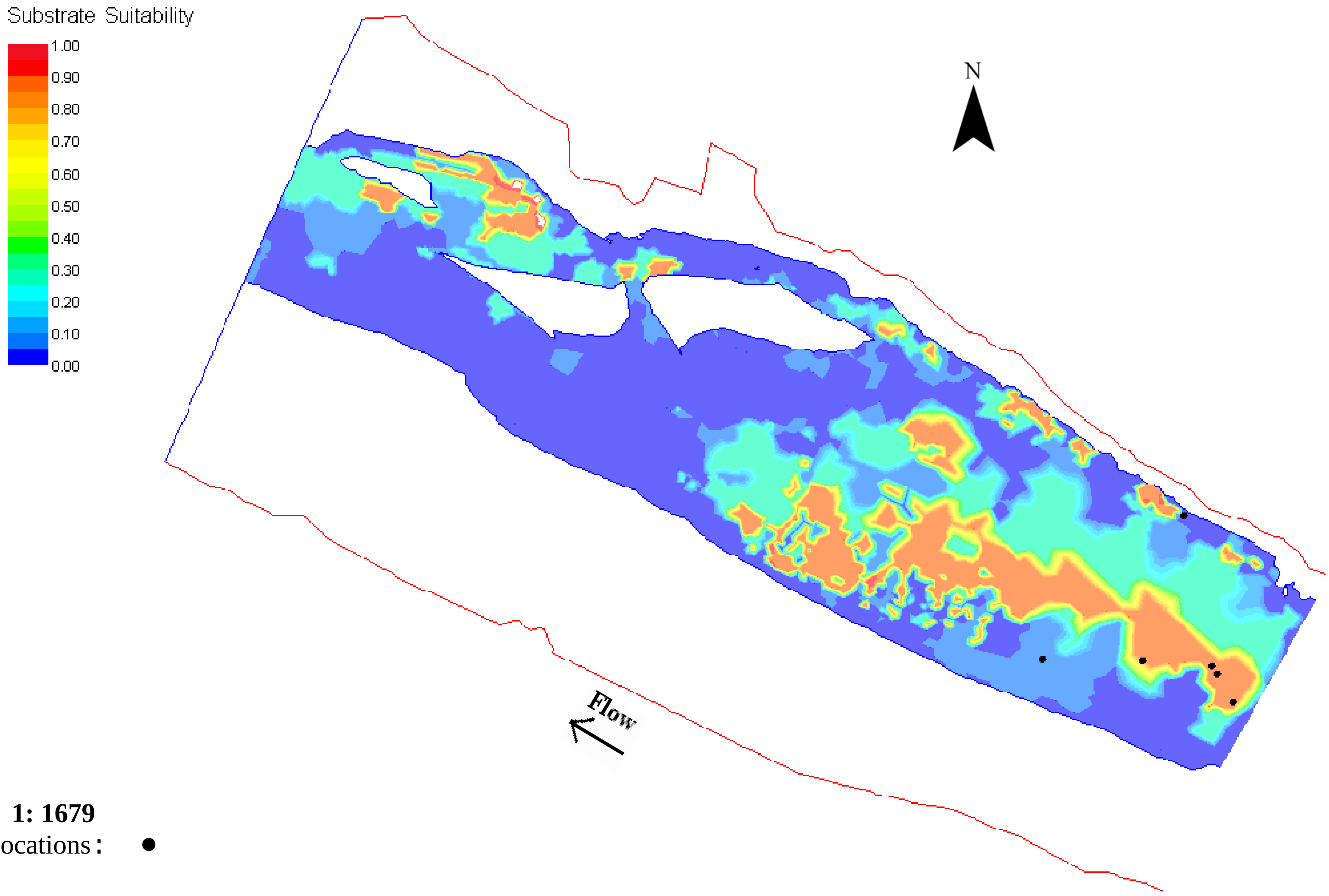
# U.C. SIERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
# STEELHEAD/RAINBOW TROUT SPAWNING



**Scale: 1: 1679**

Redd locations: ●

## U.C. SIERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING

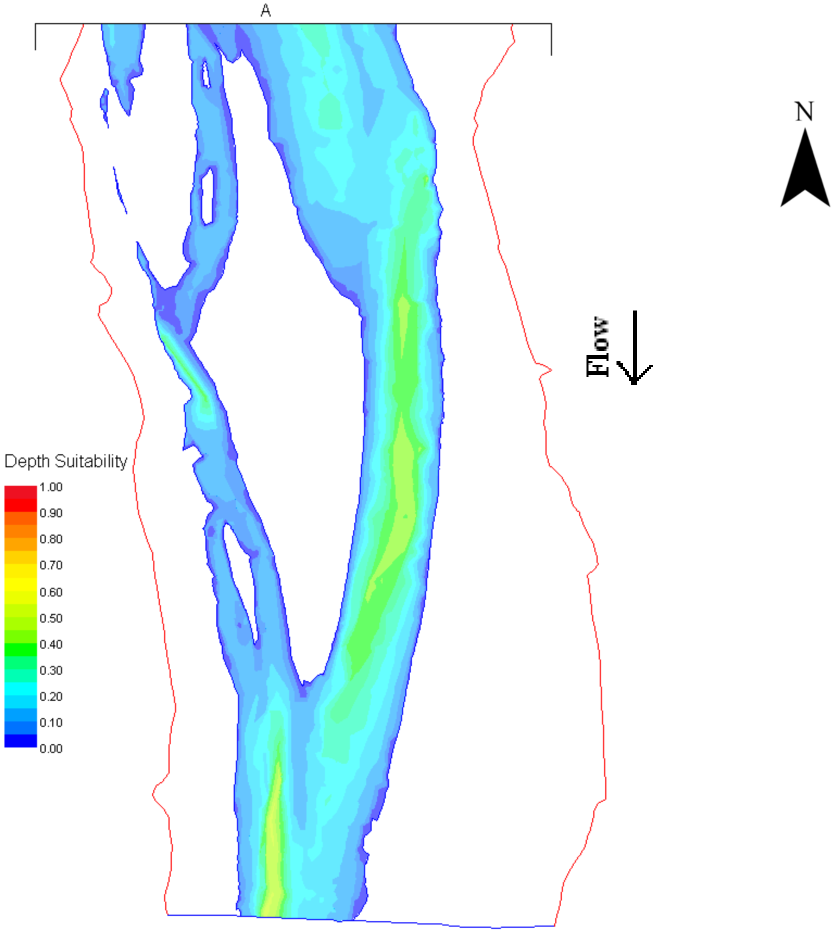


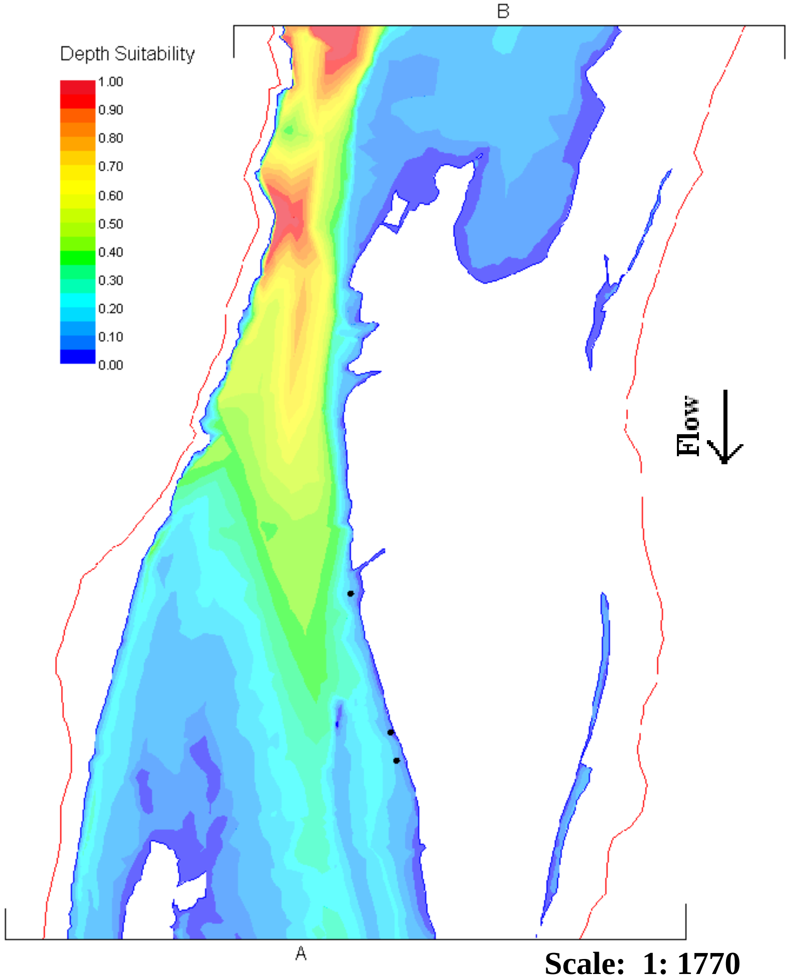
**Scale: 1: 1679**

Redd locations : ●

Appendix B

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING





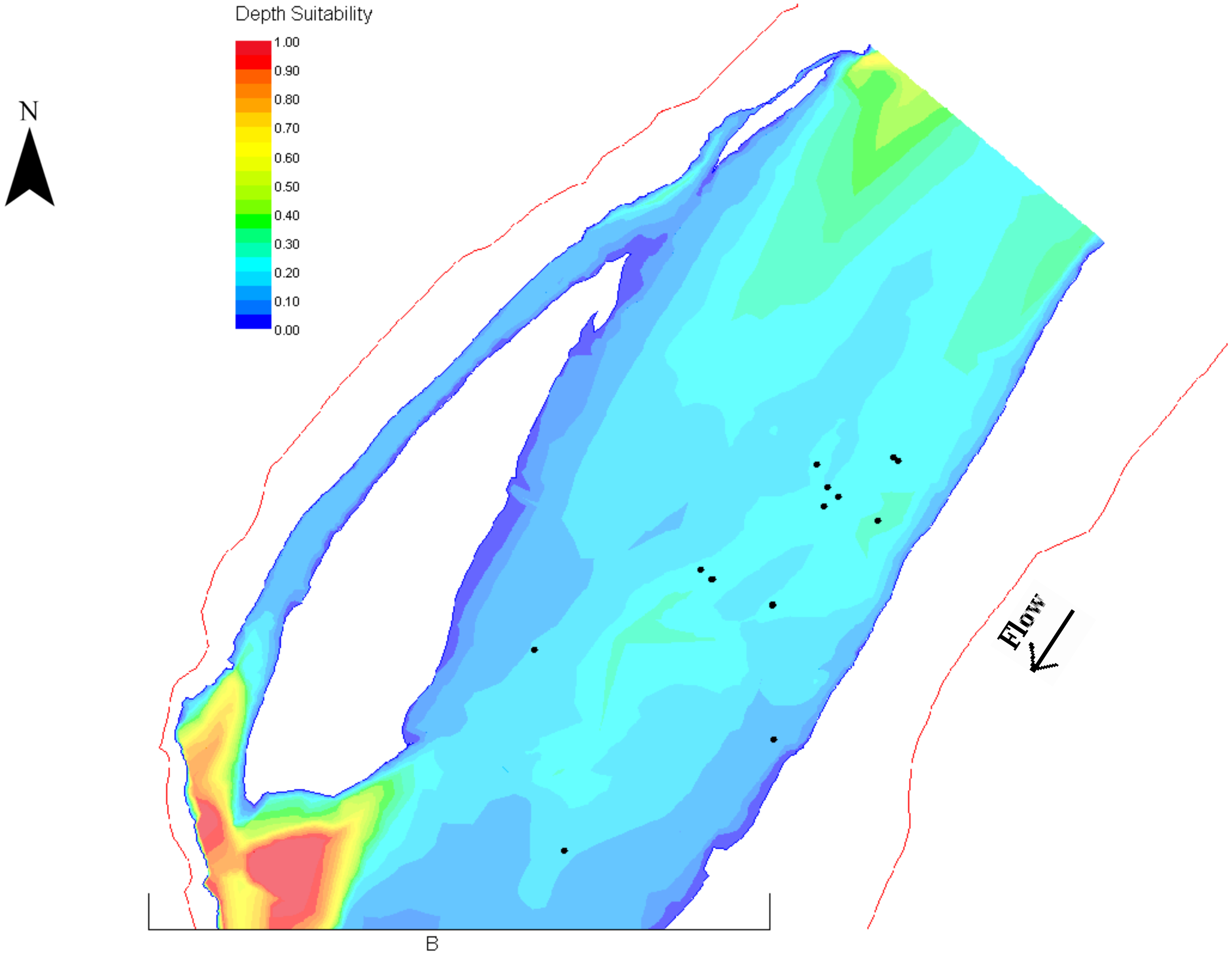
**Scale: 1: 2490**

Redd locations: ●

**Scale: 1: 1770**

Appendix B

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING (CONTINUED)

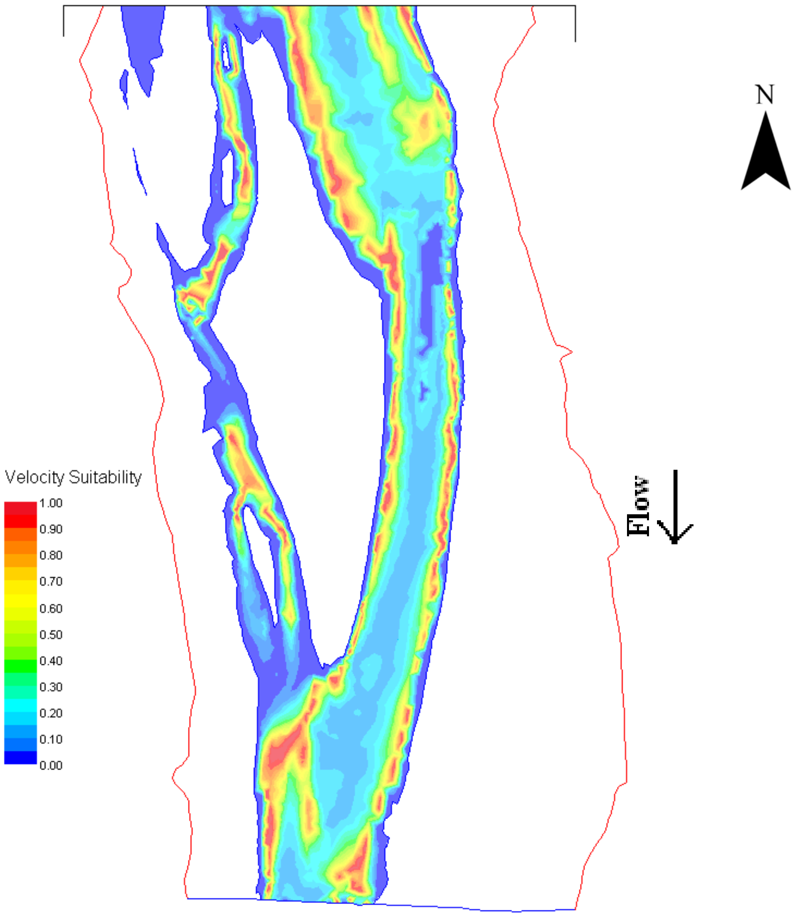


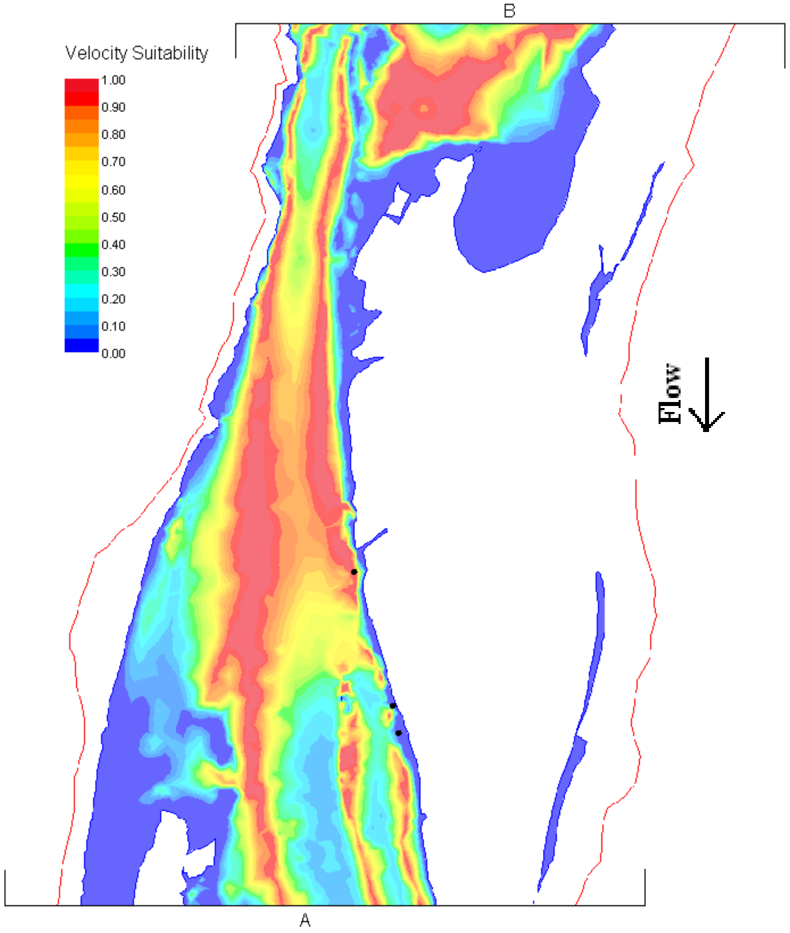
**Scale: 1: 623**

Redd locations: ●

Appendix B

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING



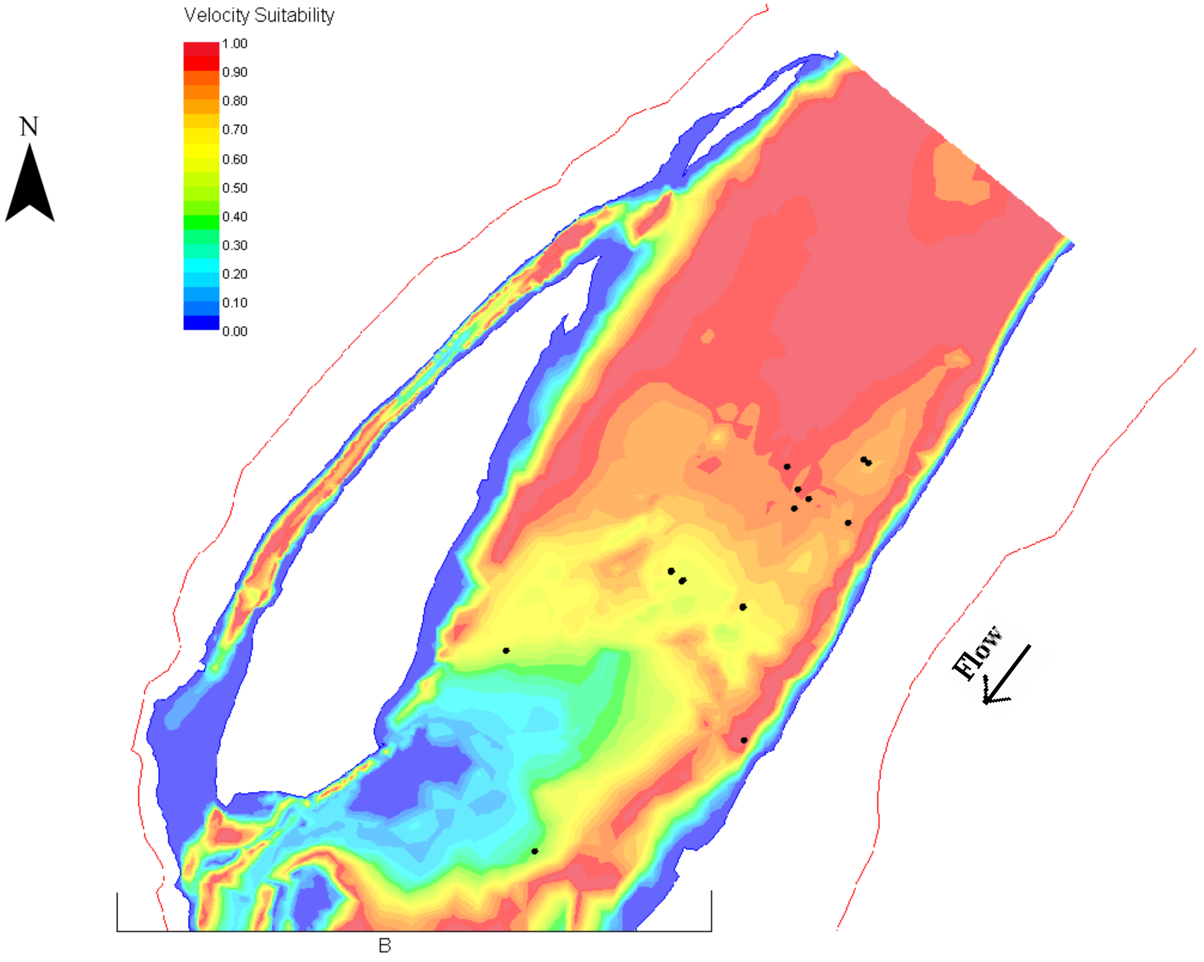


**Scale: 1: 2490**

**Scale: 1:1770**

Redd locations: ●

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING (CONTINUED)

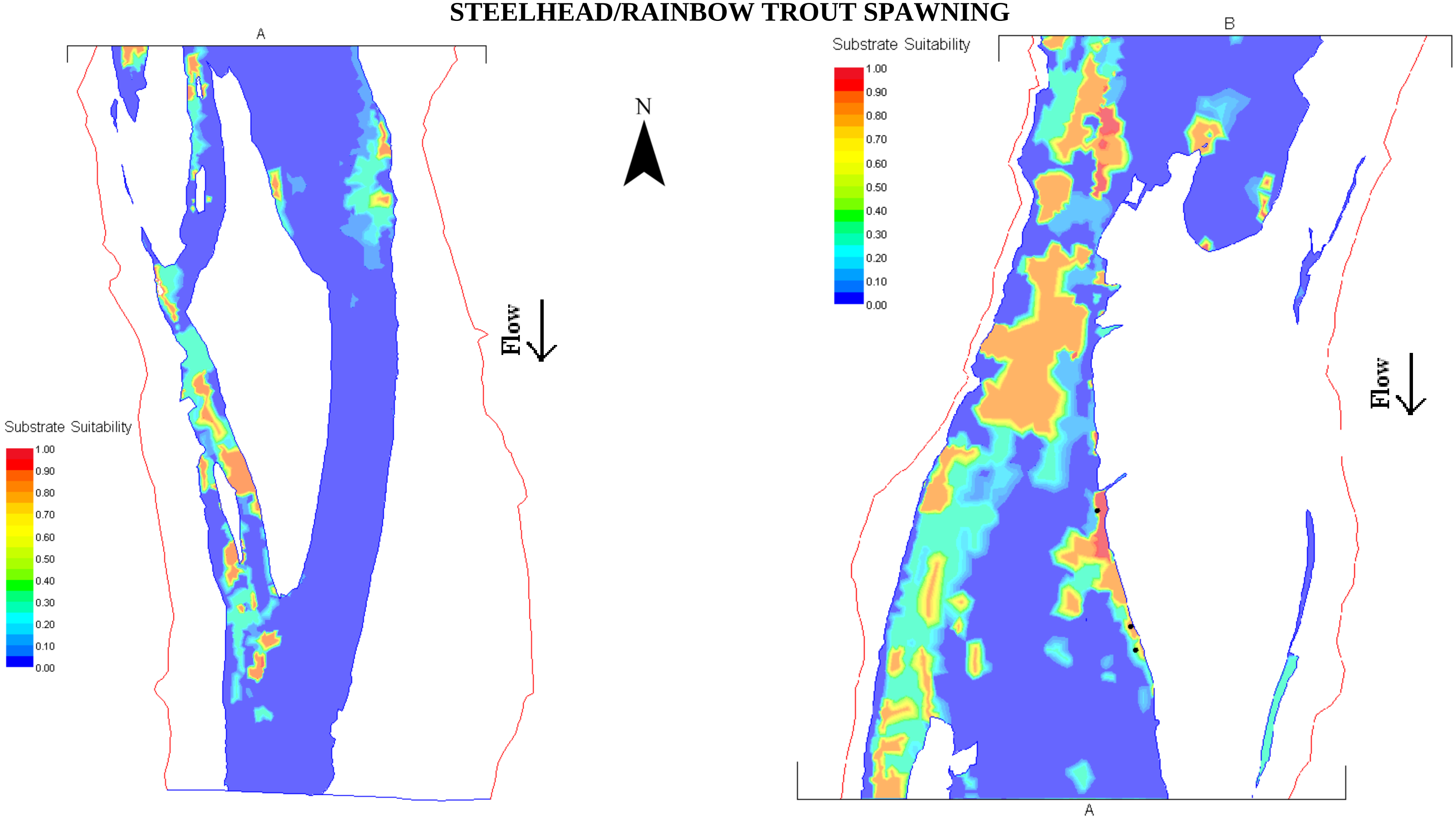


**Scale: 1: 623**

Redd locations: ●

Appendix B

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING

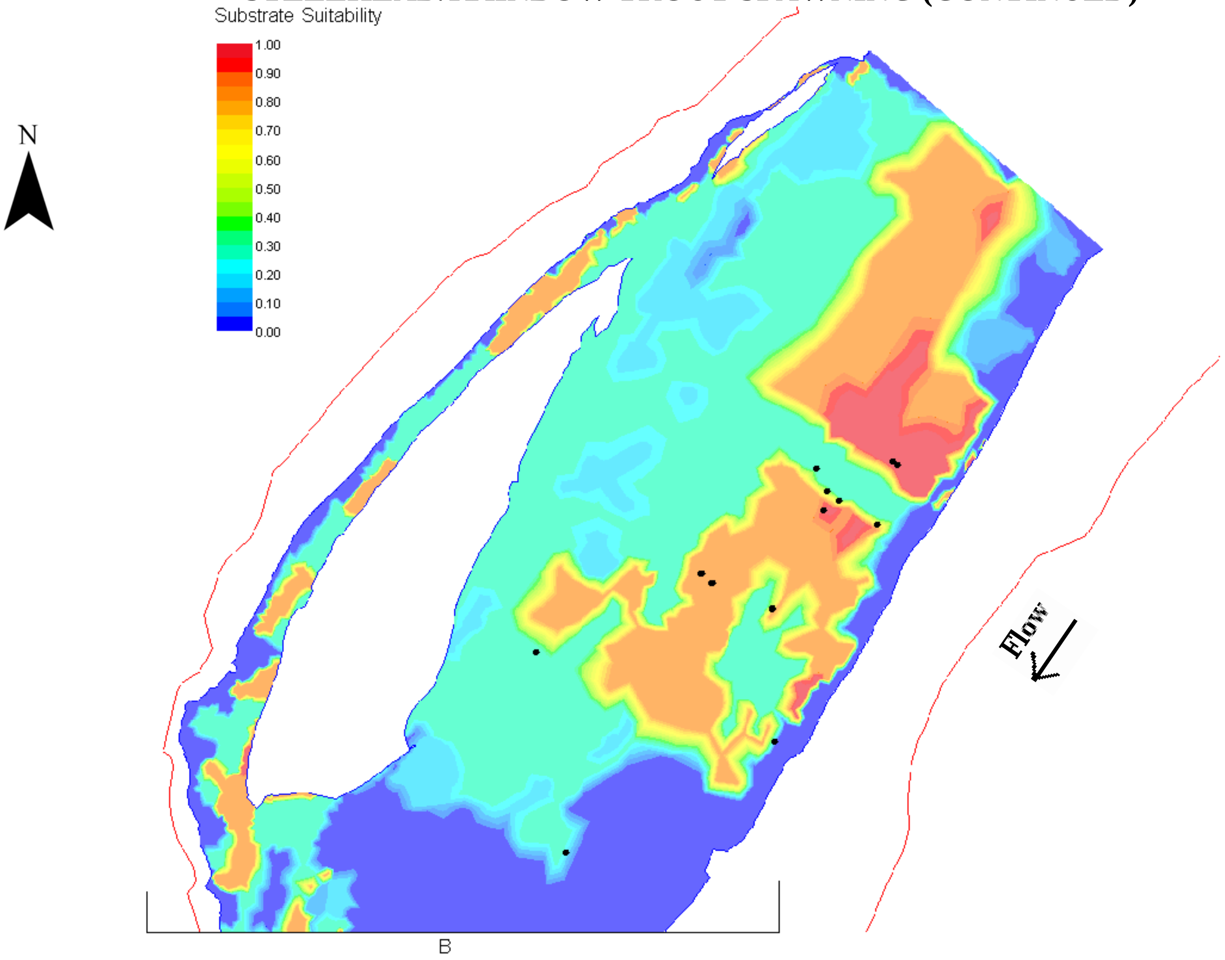


**Scale: 1: 2490**

**Scale: 1:1770**

Redd locations : ●

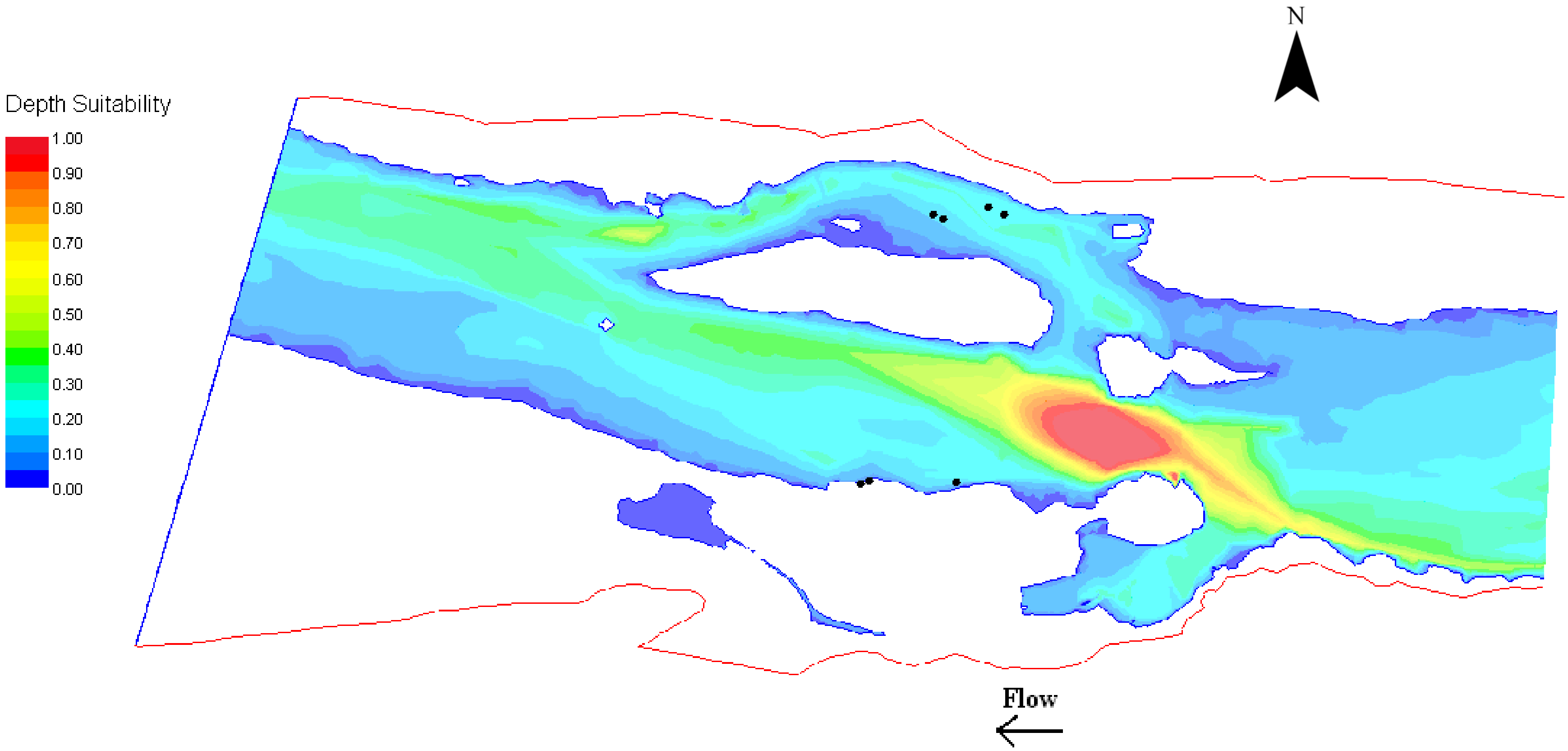
# TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
# STEELHEAD/RAINBOW TROUT SPAWNING (CONTINUED)



**Scale: 1: 623**

Redd locations: ●

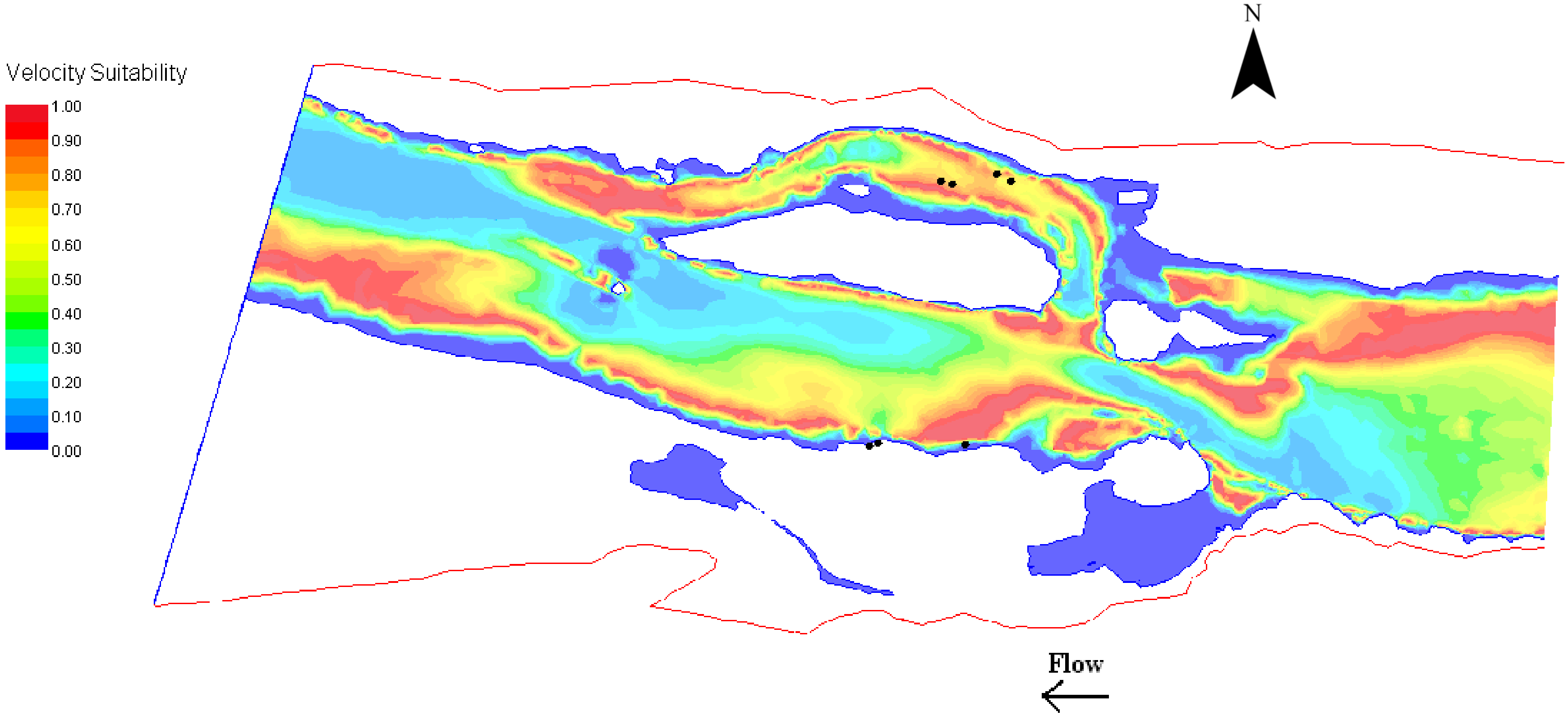
## HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING



**Scale: 1: 1994**

Redd locations: ●

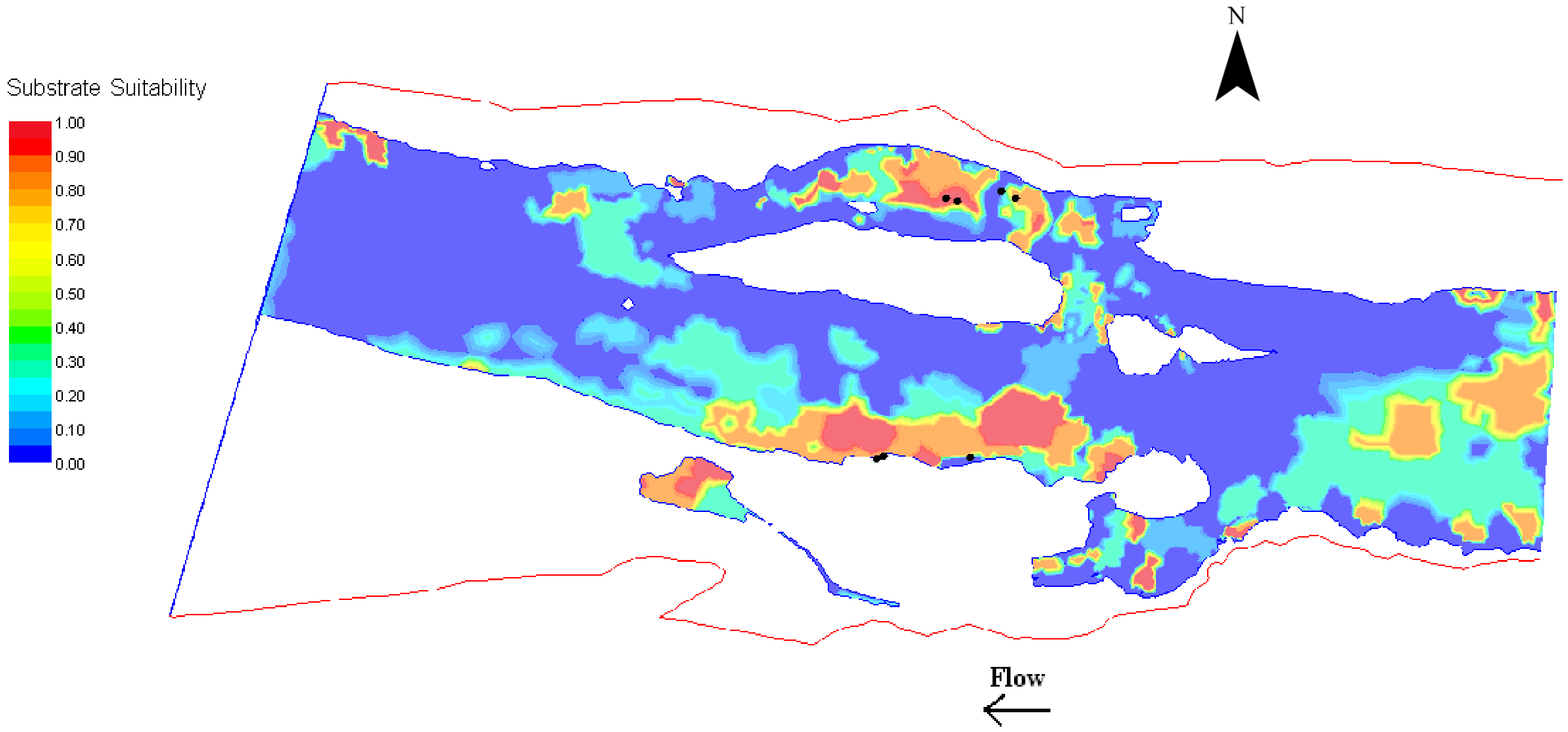
# HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
# STEELHEAD/RAINBOW TROUT SPAWNING



**Scale: 1: 1994**

Redd locations : ●

## HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2386 CFS
## STEELHEAD/RAINBOW TROUT SPAWNING

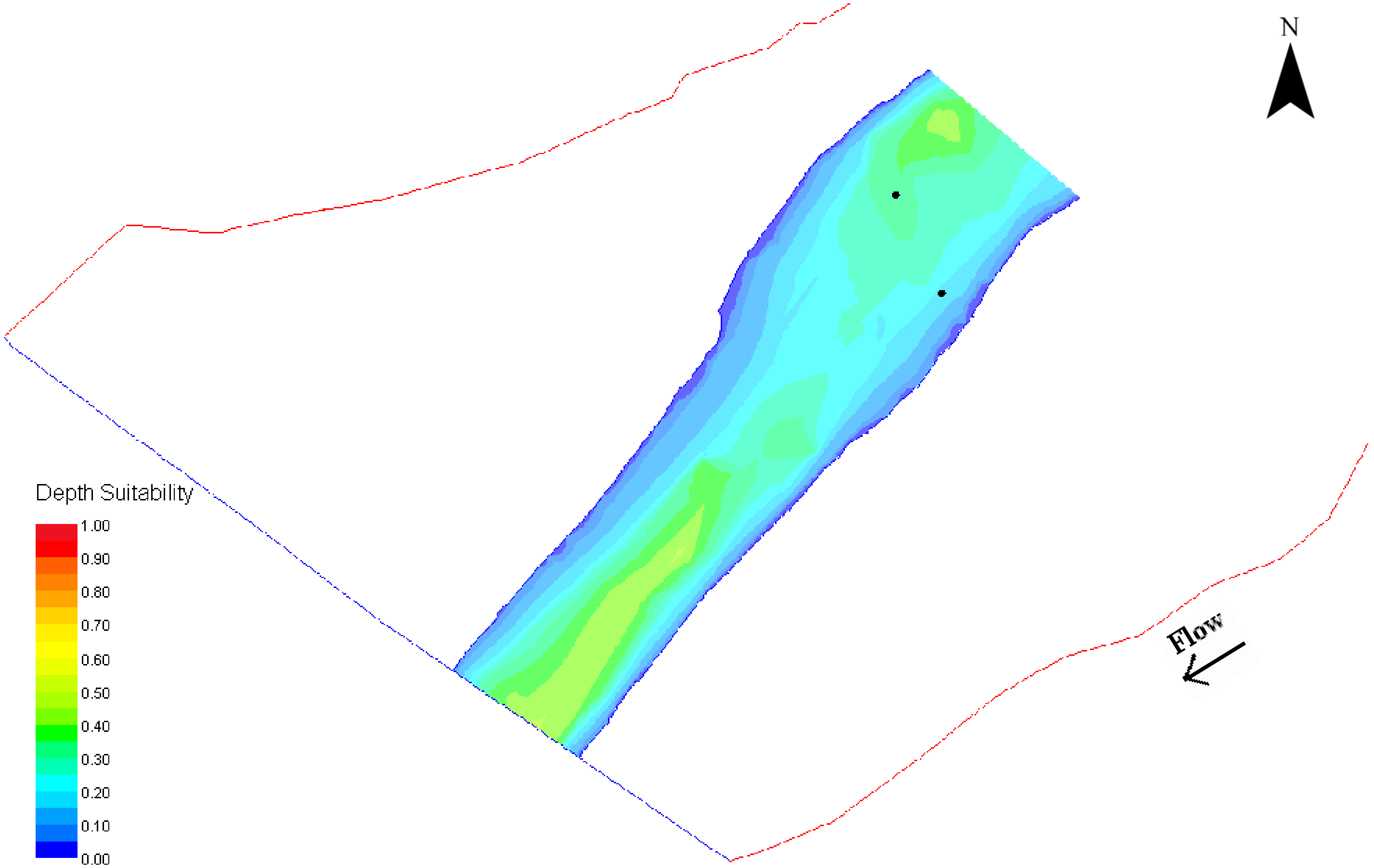


**Scale: 1: 1994**

Redd locations : ●

Appendix B

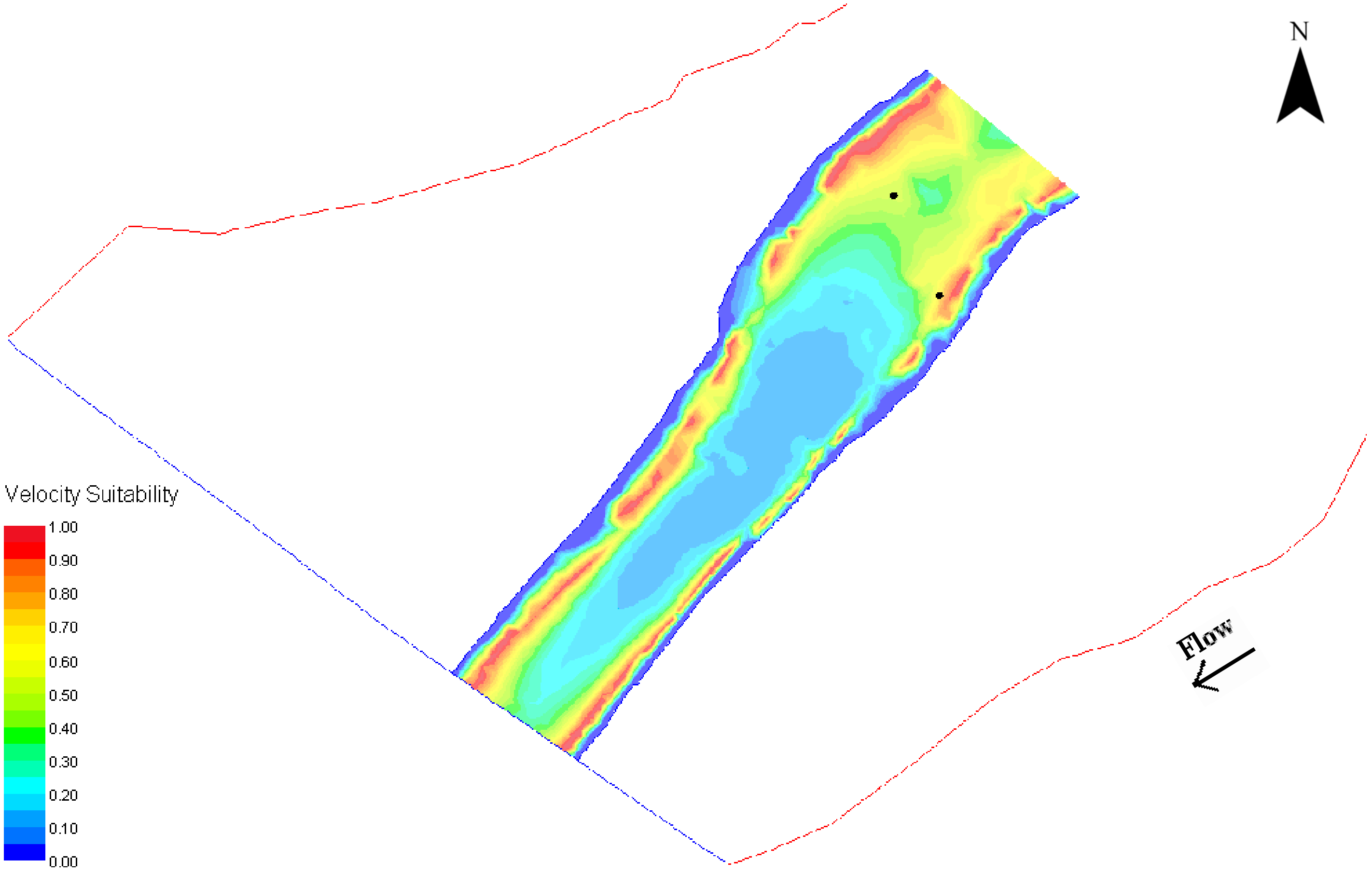
## UPPER DAGUERRA STUDY SITE
## STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2364 CFS



**Scale: 1: 1140**

Redd locations : ●

## UPPER DAGUERRA STUDY SITE
## STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2364 CFS

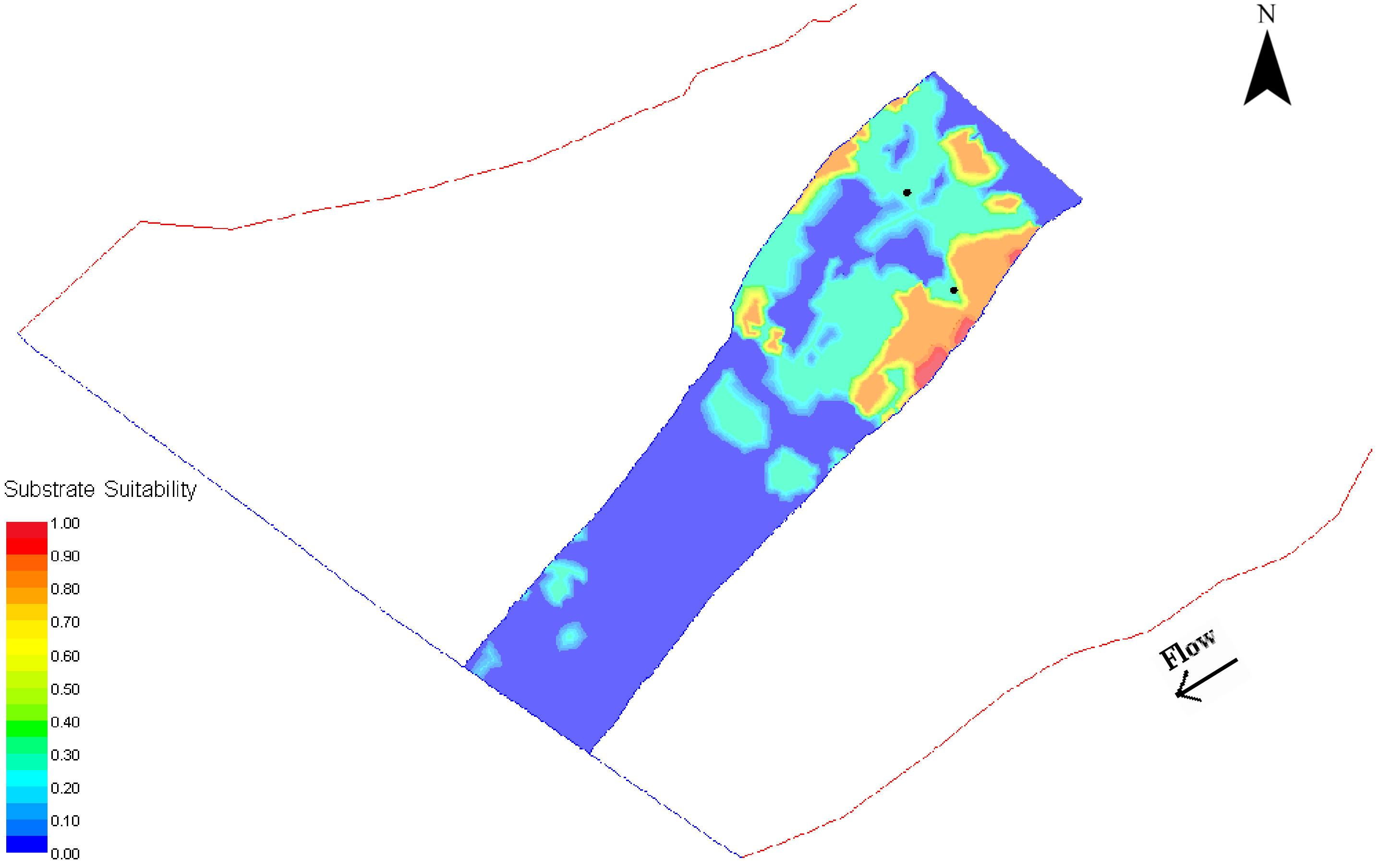


**Scale: 1: 1140**

Redd locations : ●

Appendix B

## UPPER DAGUERRA STUDY SITE
## STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2364 CFS

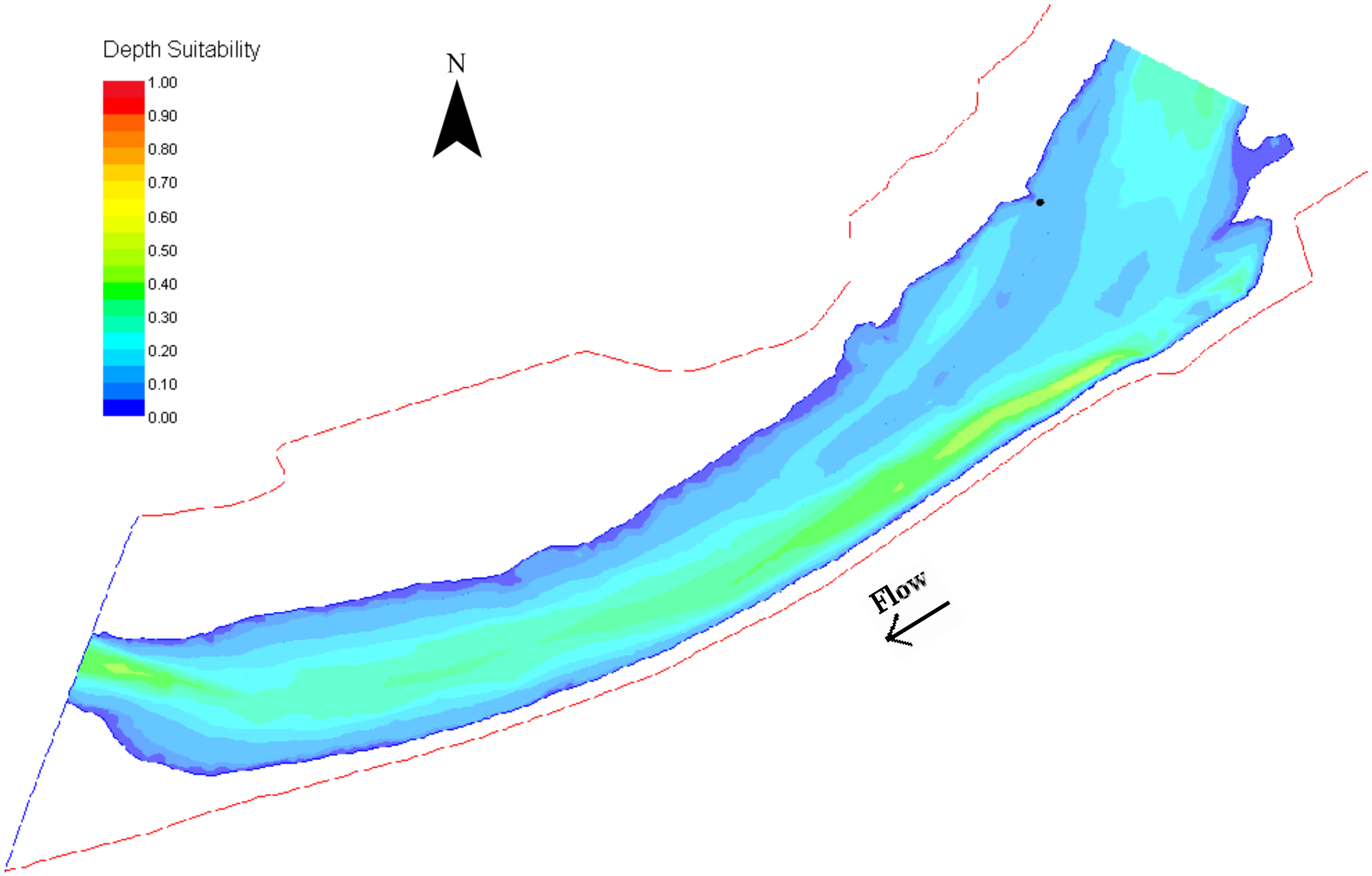


**Scale: 1: 1140**

Redd locations : ●

Appendix B

## LOWER DAGUERRA STUDY SITE
## STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2364 CFS

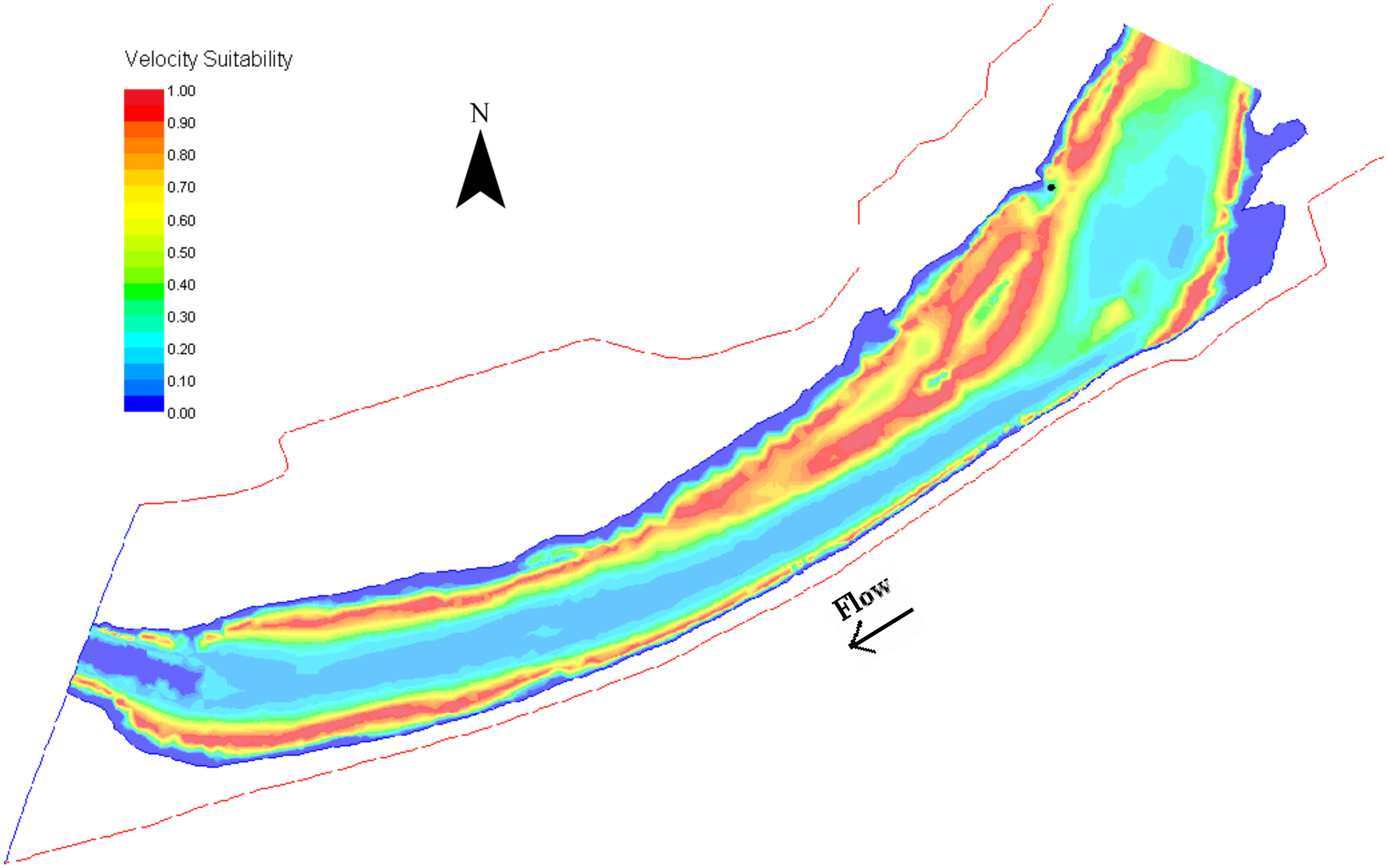


**Scale: 1: 2034**

Redd locations : ●

USFWS, SFWO, Energy Planning and Instream Flow Branch
Yuba River Spawning Sensitivity Analysis Report
August 26, 2010

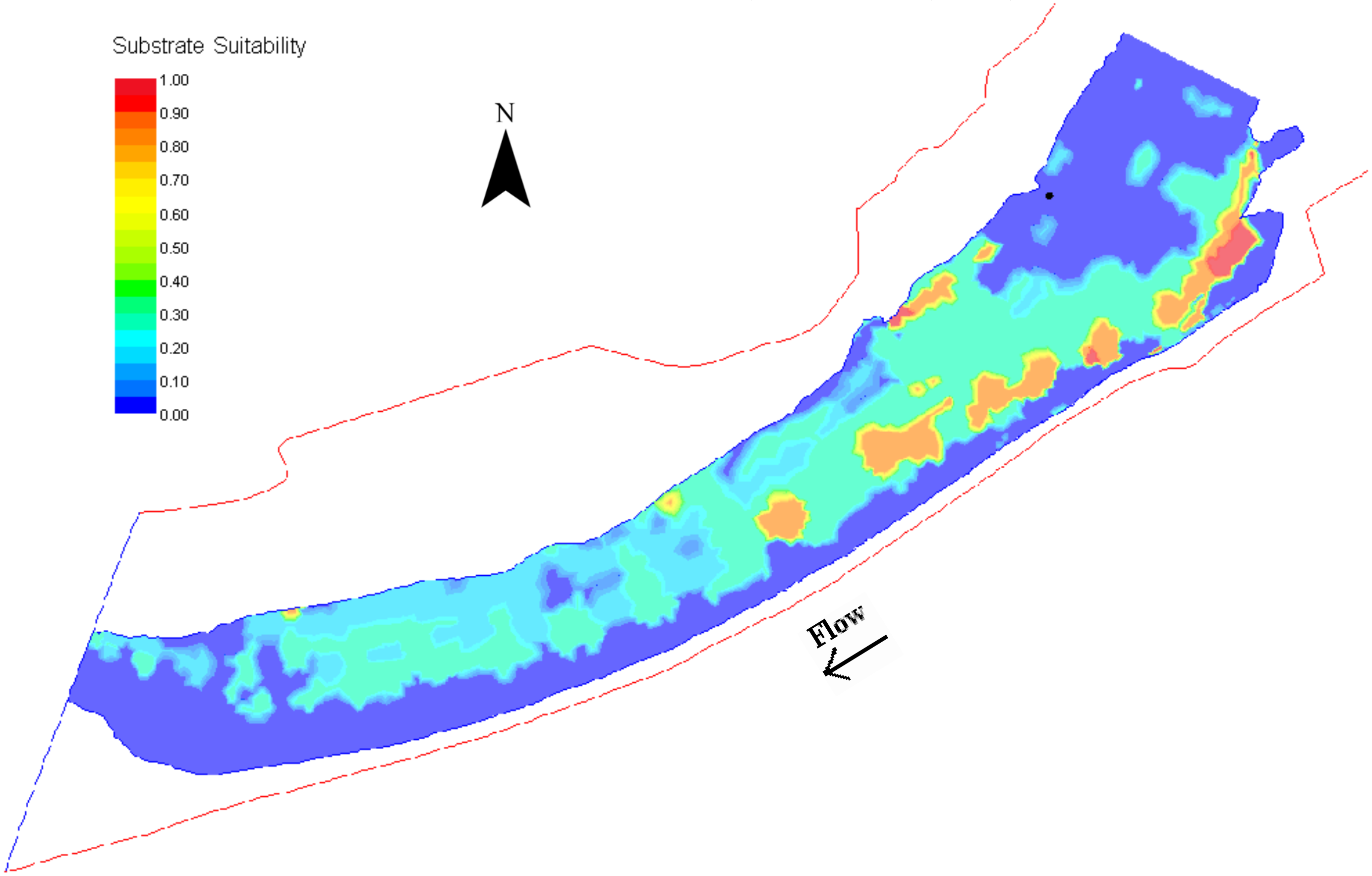
## LOWER DAGUERRA STUDY SITE
## STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2364 CFS



**Scale: 1: 2034**

Redd locations: ●

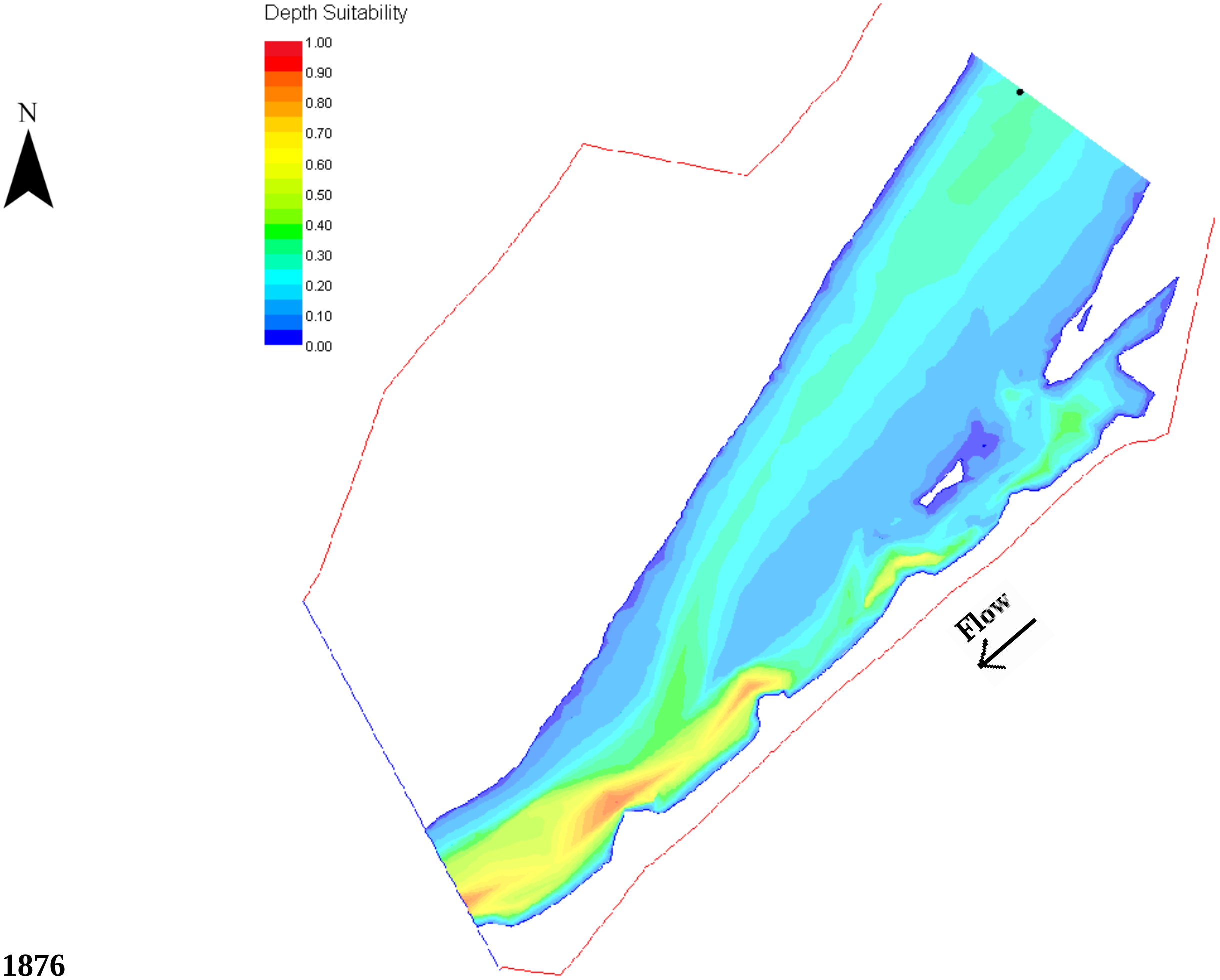
# LOWER DAGUERRA STUDY SITE
# STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2364 CFS



**Scale: 1: 2034**

Redd locations : ●

# HALLWOOD STUDY SITE
## STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2455 CFS

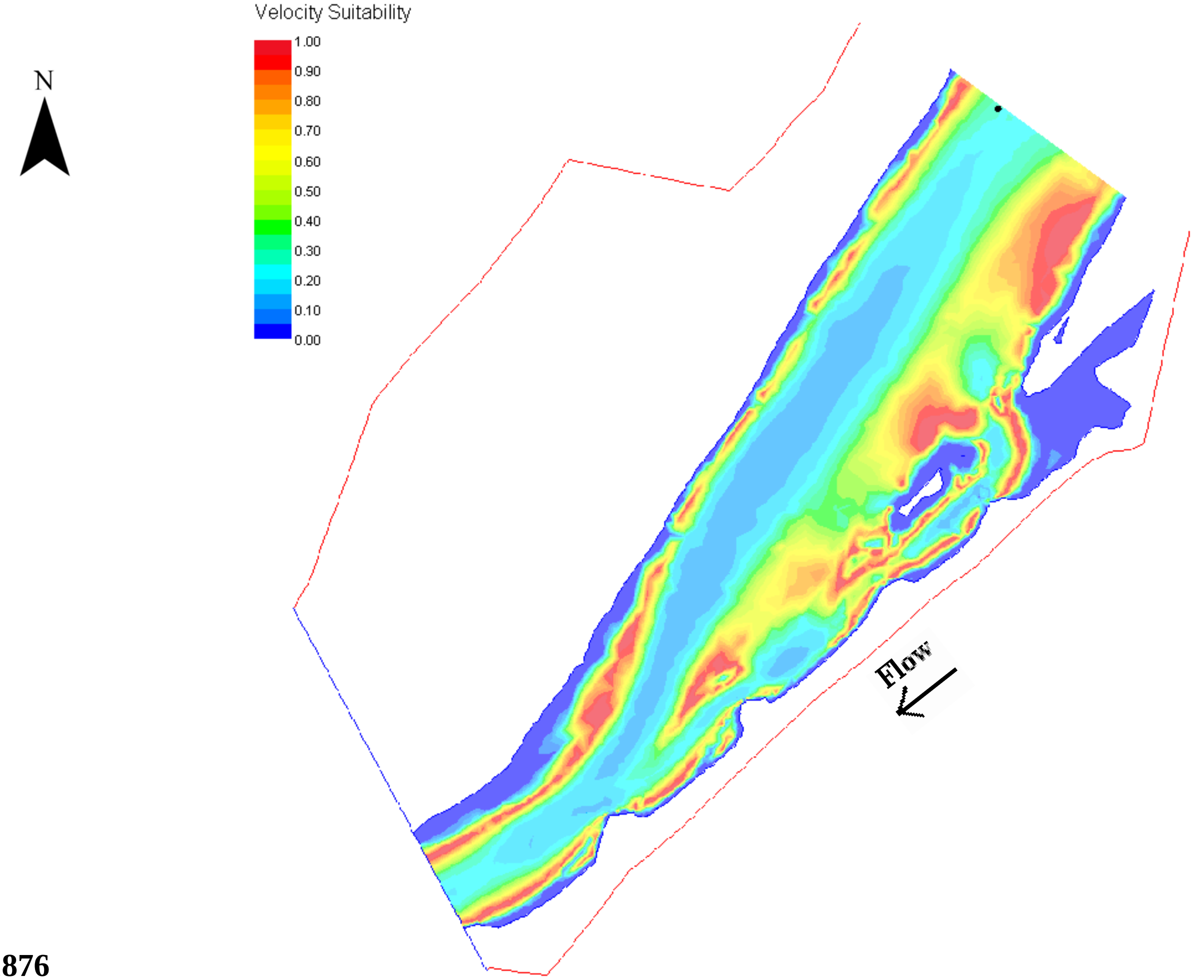


**Scale: 1: 1876**

Redd locations: ●

Appendix B

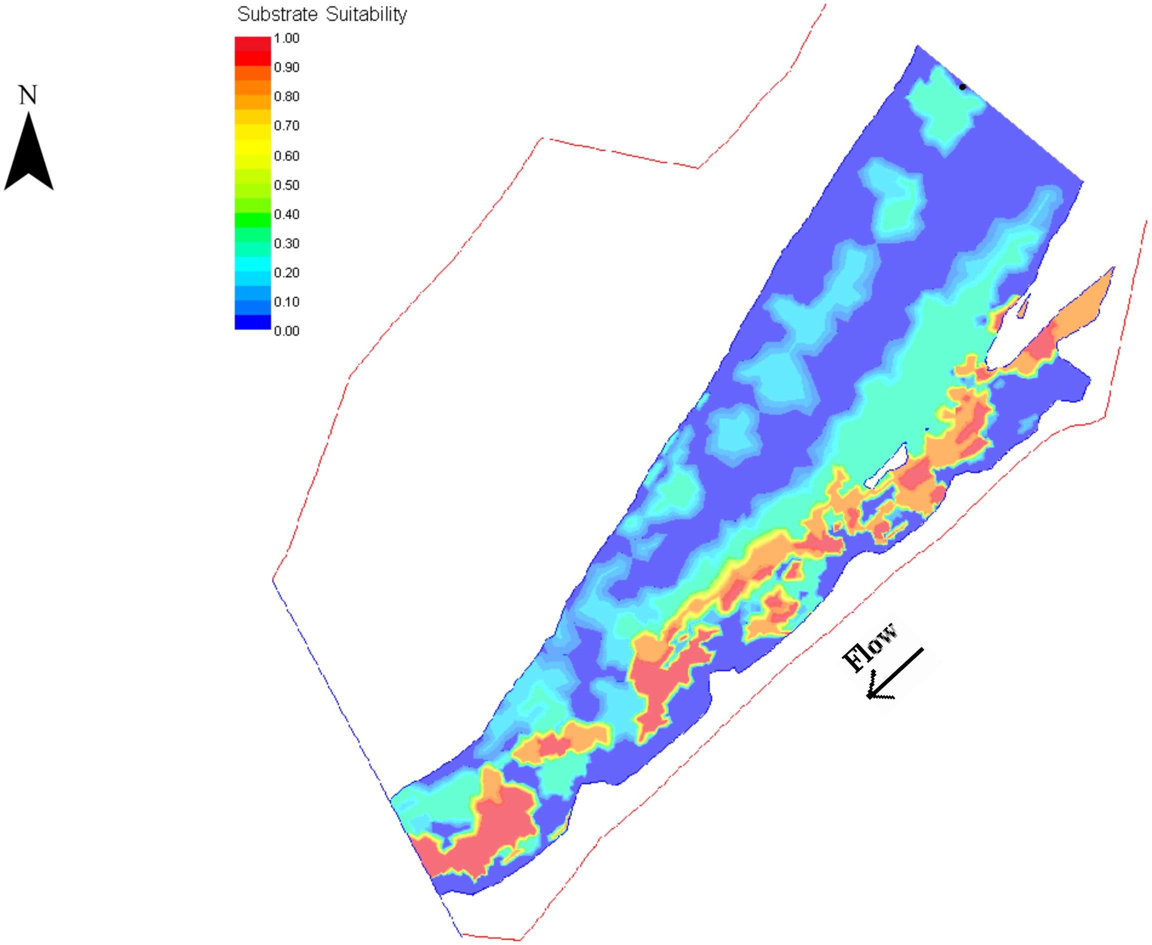
## HALLWOOD STUDY SITE
## STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2455 CFS



**Scale: 1: 1876**

Redd locations: ●

## HALLWOOD STUDY SITE
## STEELHEAD/RAINBOW TROUT SPAWNING, APRIL 8-10, 2003, FLOW = 2455 CFS



**Scale: 1: 1876**

Redd locations: ●

# APPENDIX C
# RIVER2D HABITAT SUITABILITY OF 2003 STEELHEAD/RAINBOW TROUT REDD LOCATIONS[1]

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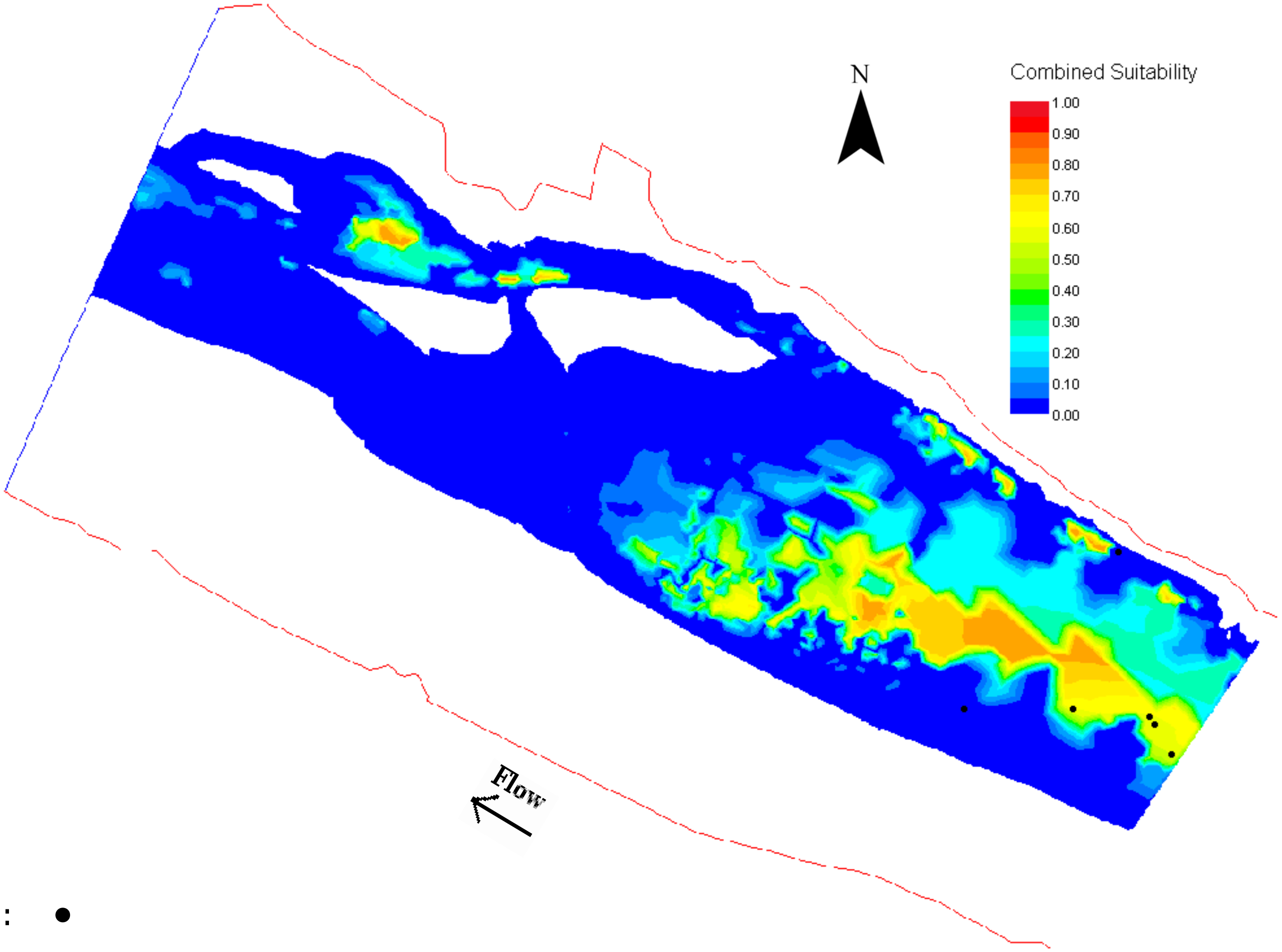
[1] For all pages, Combined Suitability: 1 = optimal, 0 = unusable

Appendix C

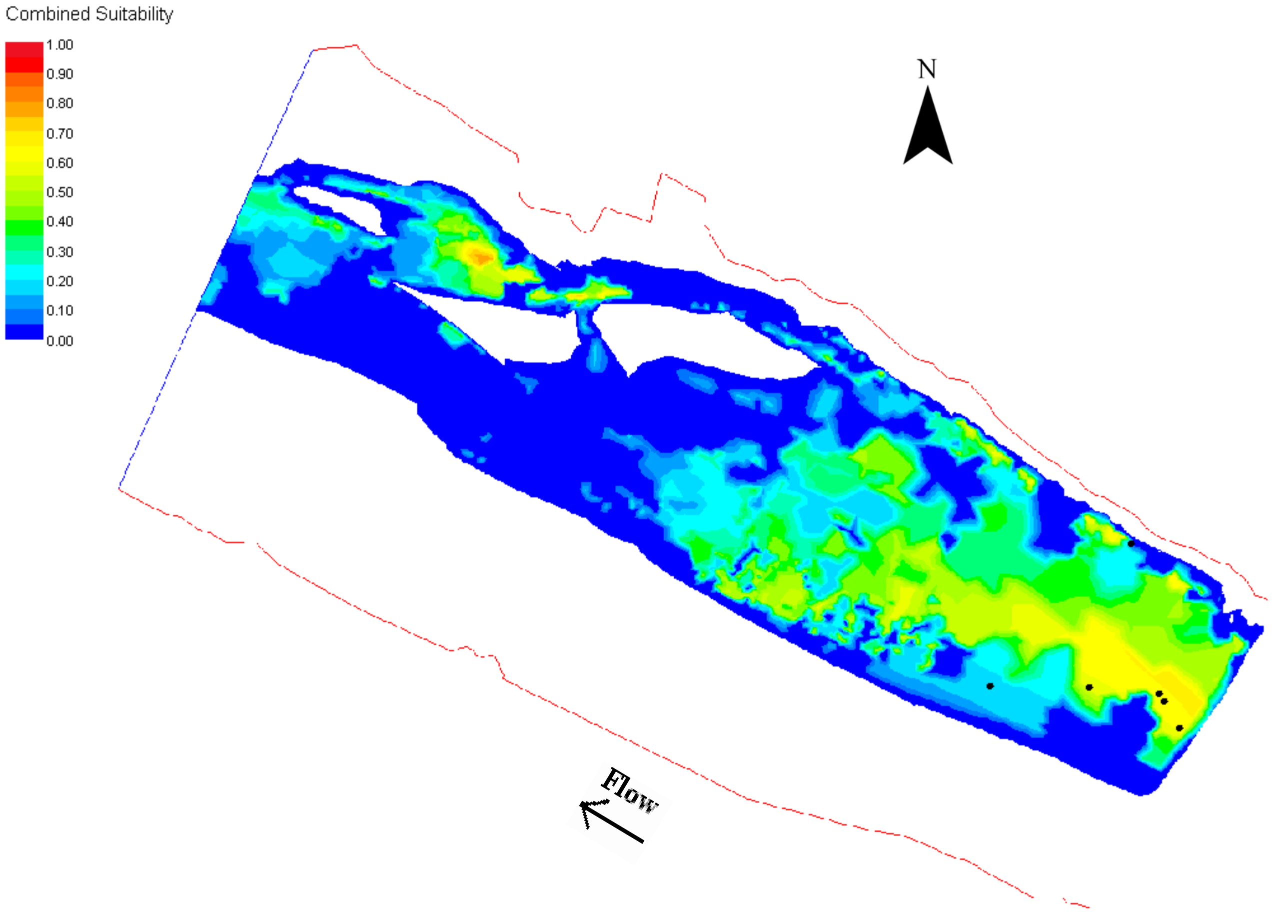
## U.C. SIERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20



**Scale: 1:1715**

Redd locations: ●

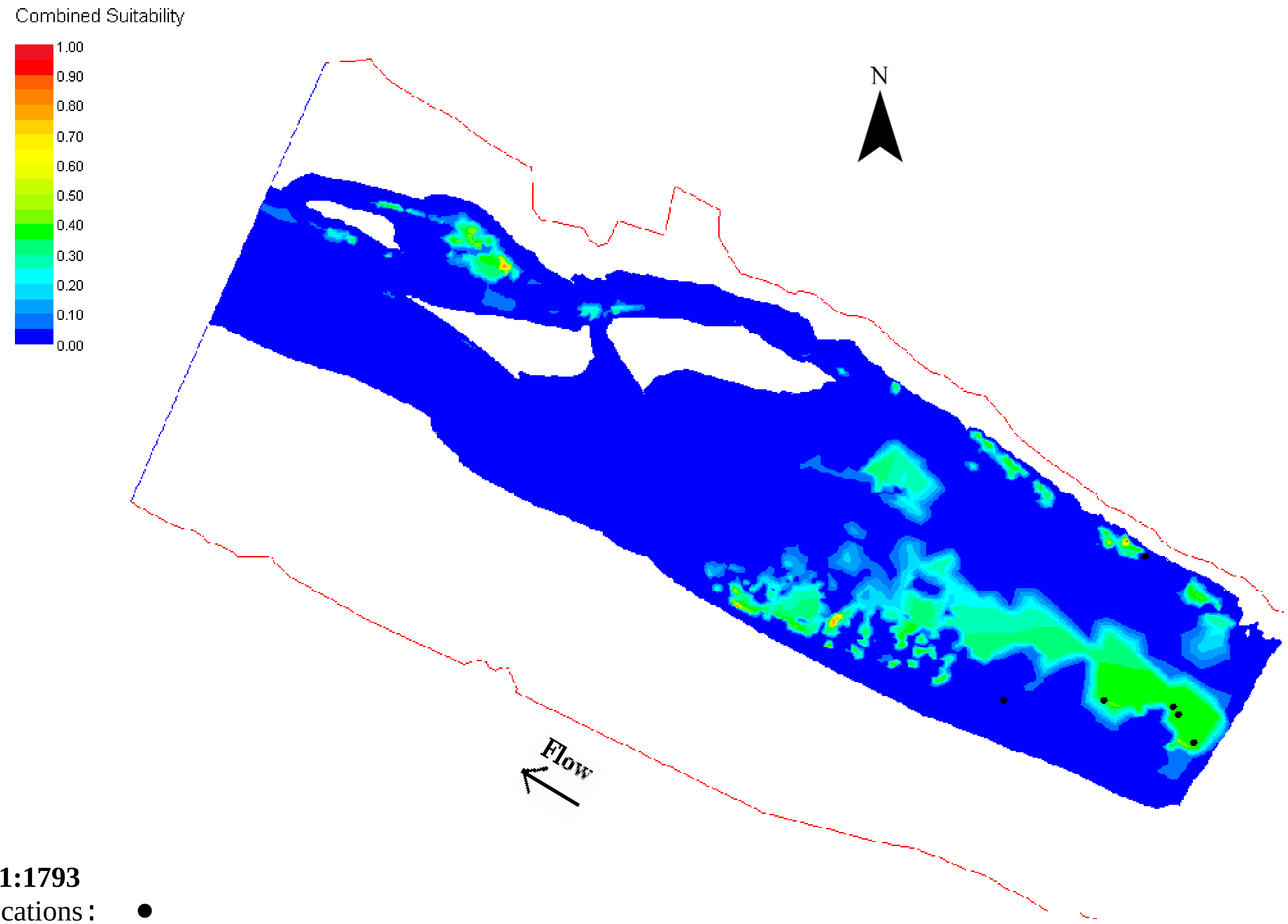
# U.C. SIERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
# GEOMETRIC MEAN CRITERIA



**Scale: 1:1973**

Redd locations: ●

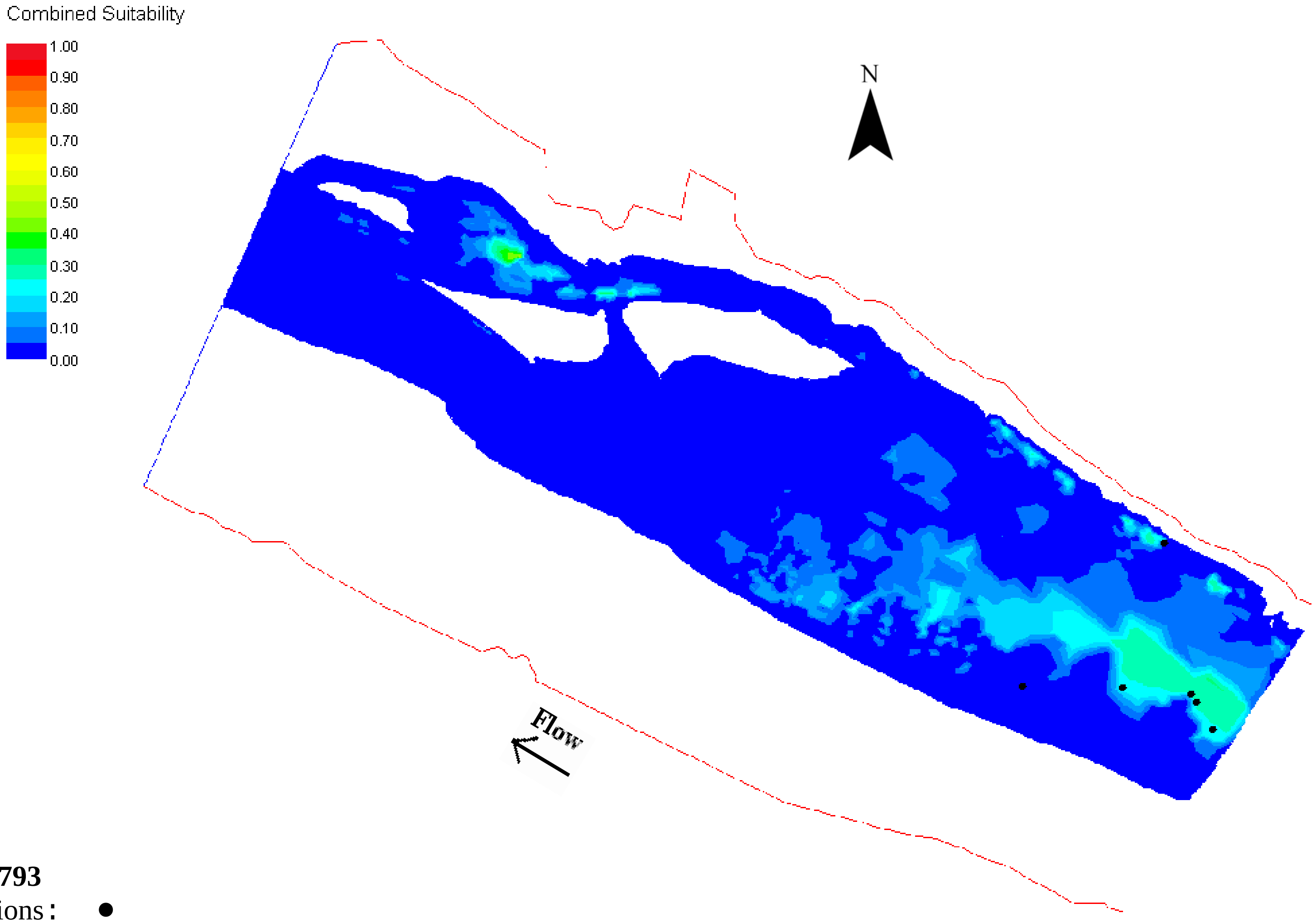
## U.C. SIERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CLEAR CREEK CRITERIA



**Scale: 1:1793**

Redd locations: ●

## U.C. SIERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS DENSITY CRITERIA

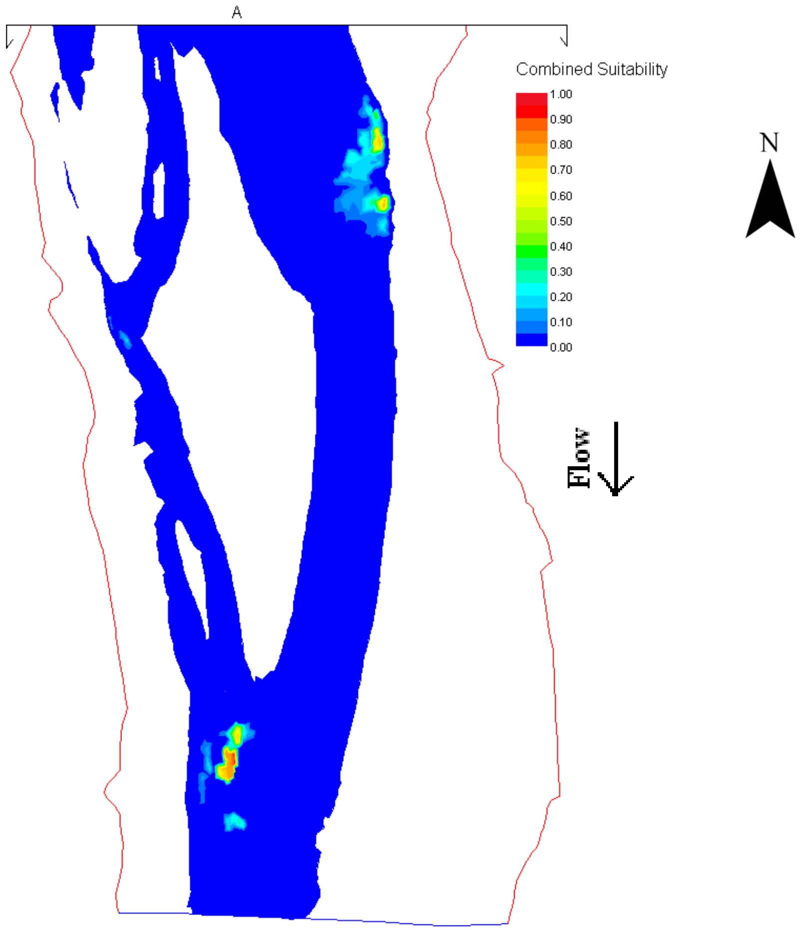


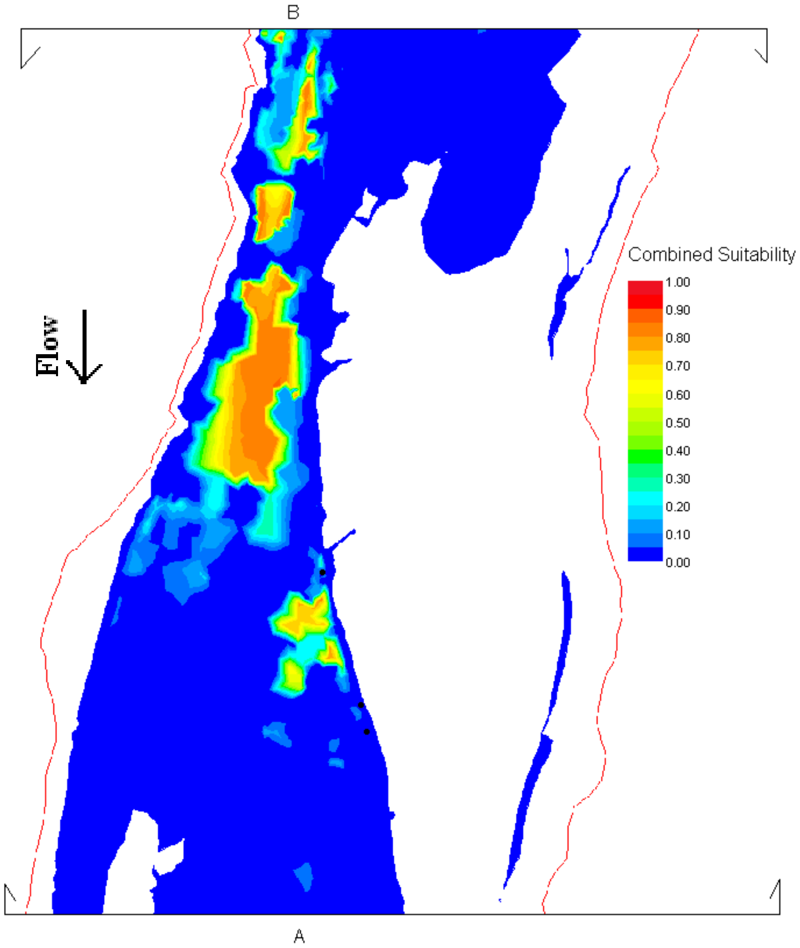
**Scale: 1:1793**

Redd locations: ●

Appendix C

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20





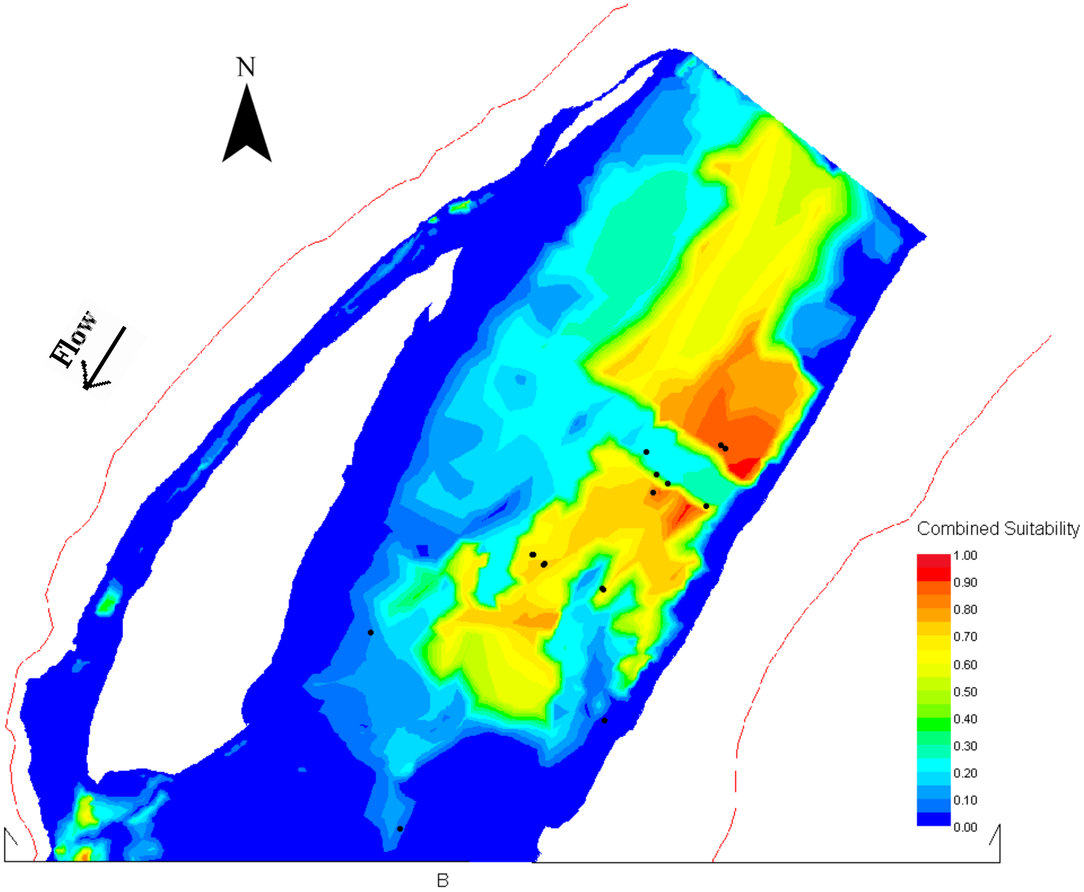
**Scale: 1: 2490**

**Scale: 1:2085**

Redd locations : ●

Appendix C

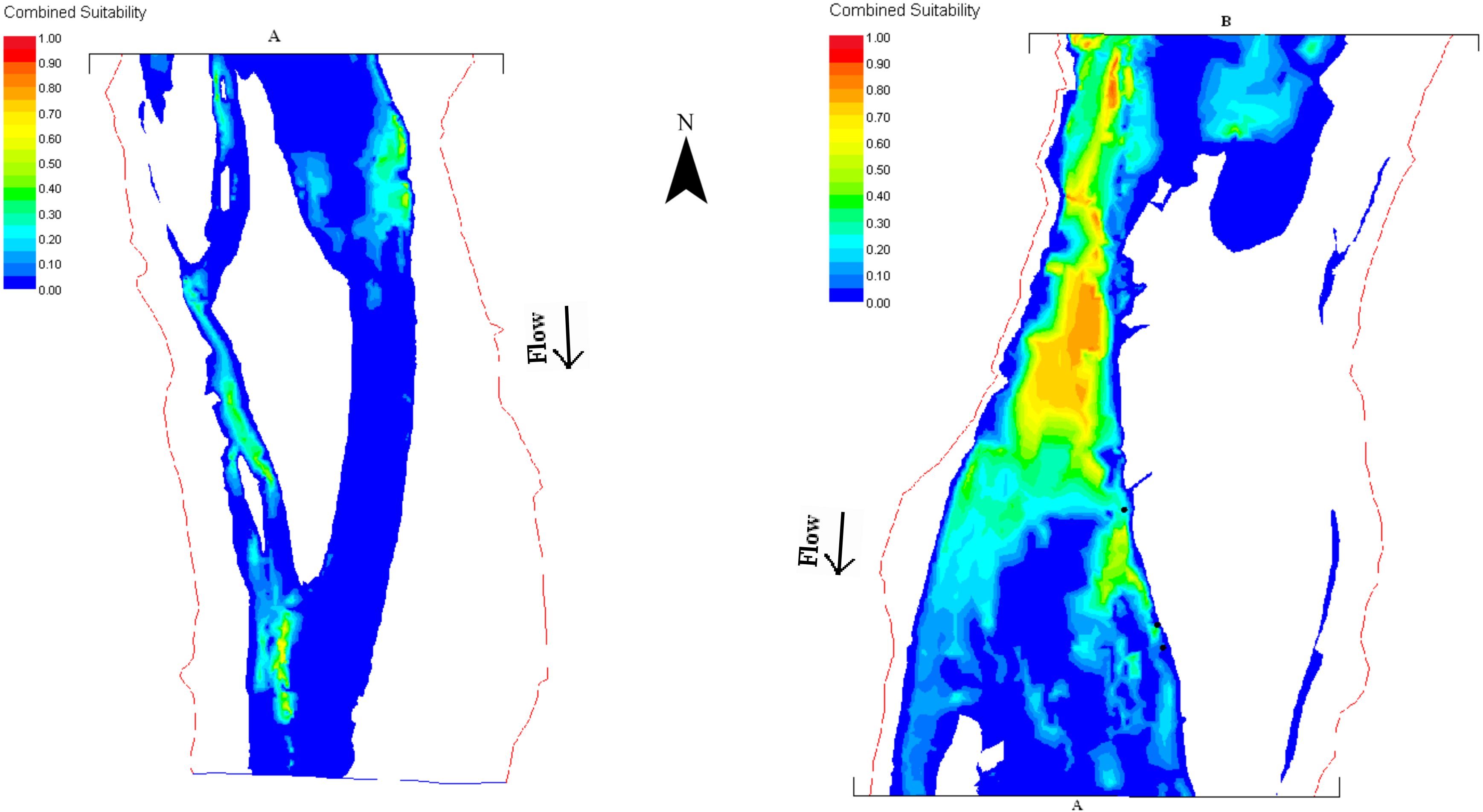
## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20 (CONTINUED)



**Scale: 1:949**

Redd locations: ●

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## GEOMETRIC MEAN CRITERIA

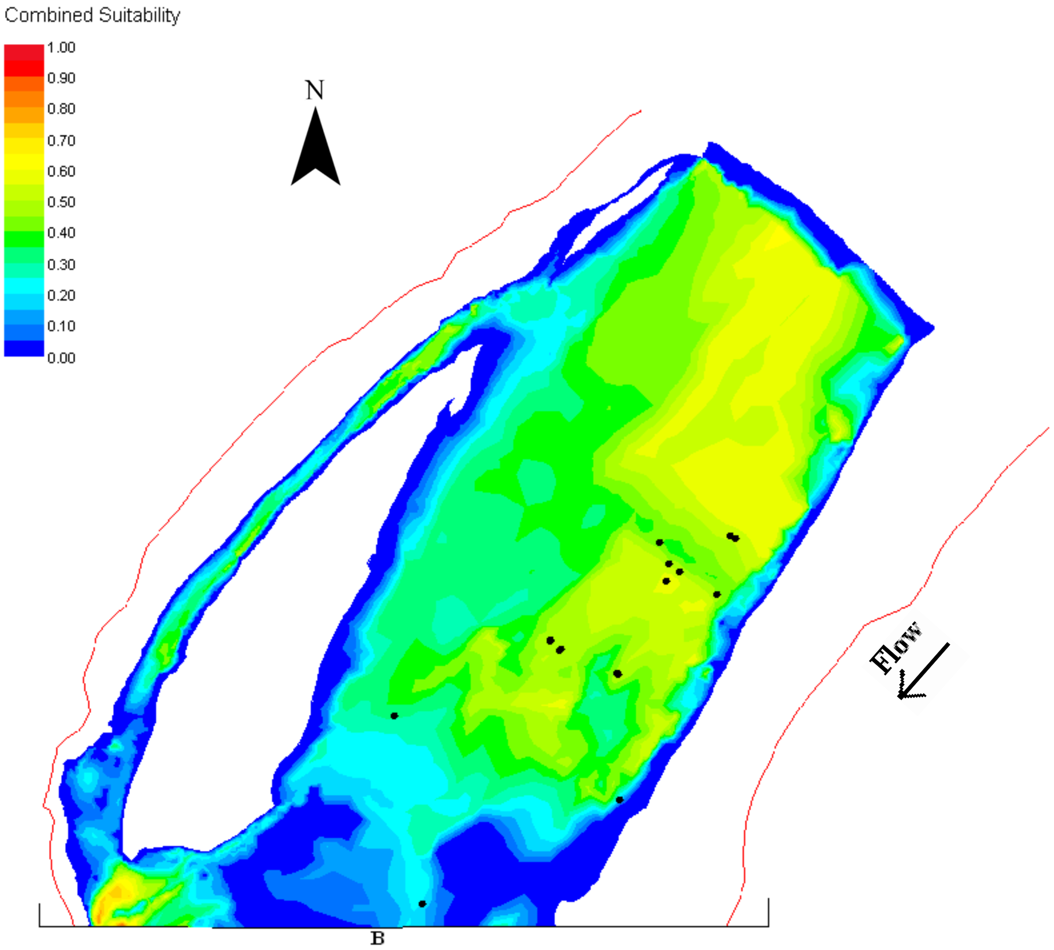


**Scale: 1:2570**

Redd locations : ●

**Scale: 1:2032**

# TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
# GEOMETRIC MEAN CRITERIA (CONTINUED)

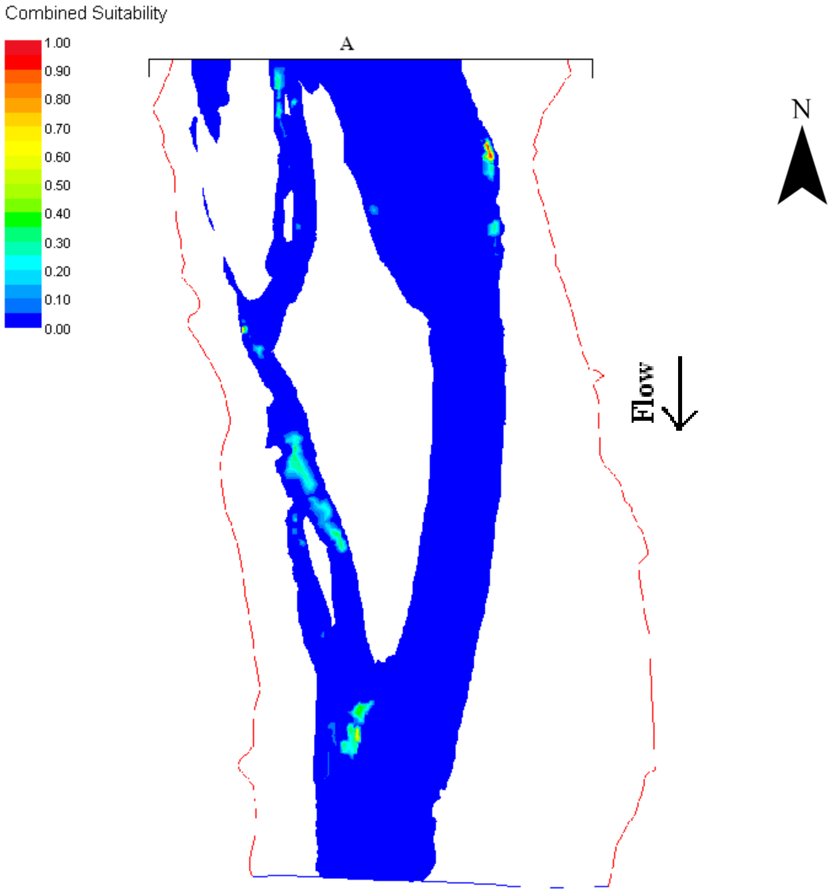


**Scale: 1:894**

Redd locations : ●

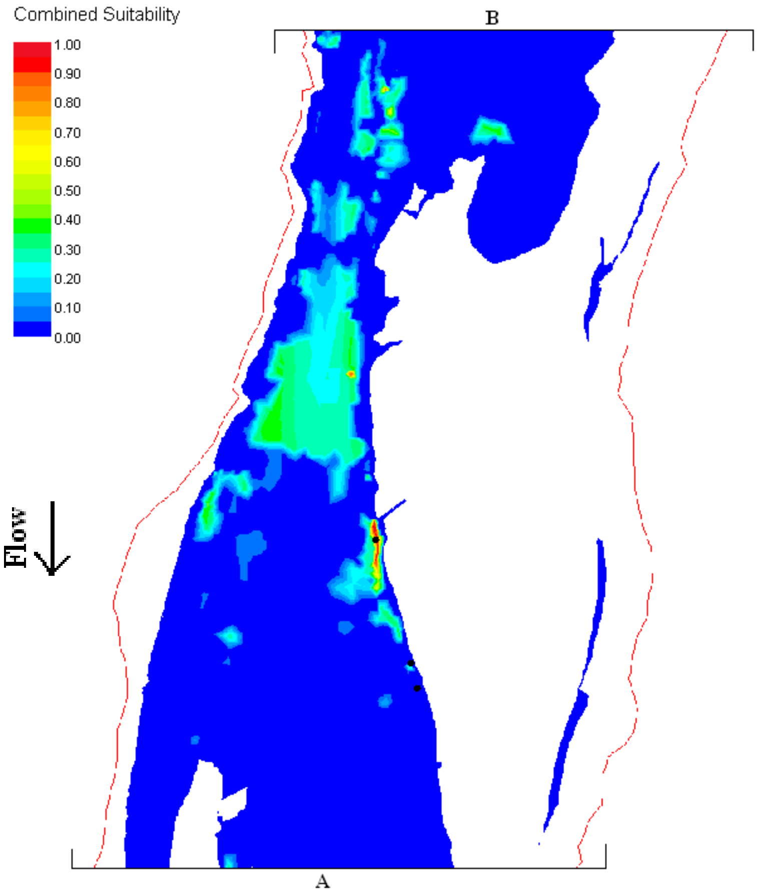
Appendix C

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CLEAR CREEK CRITERIA



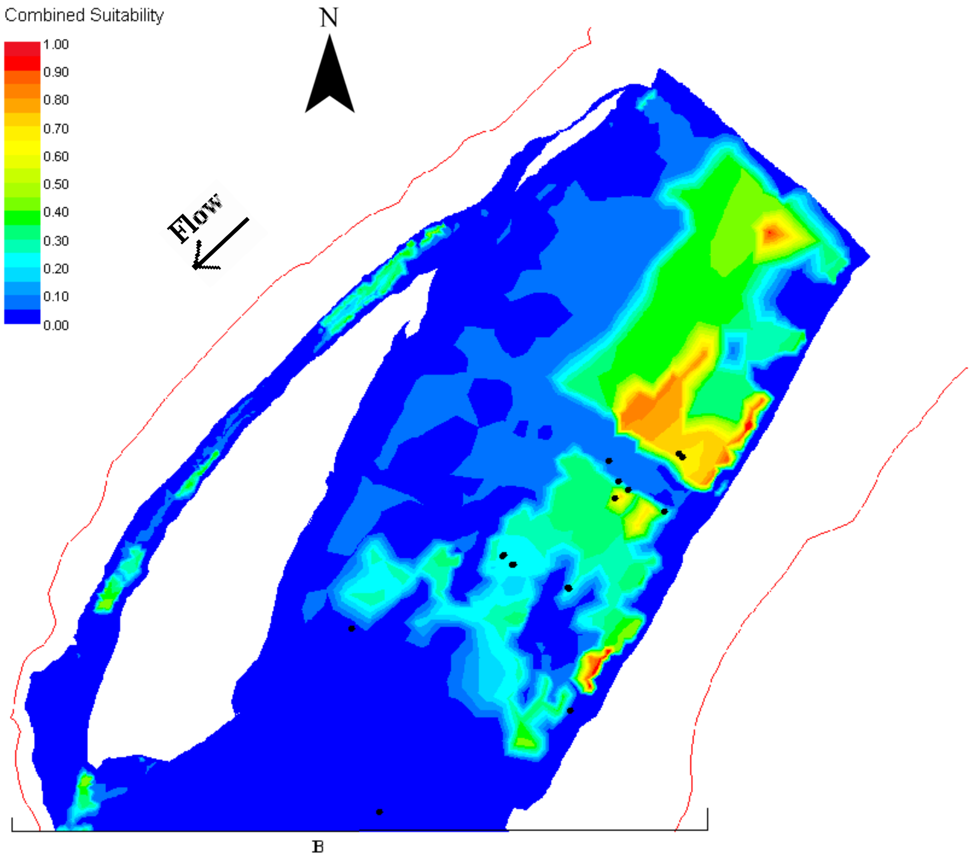
**Scale: 1:2656**

Redd locations : ●



**Scale: 1:2138**

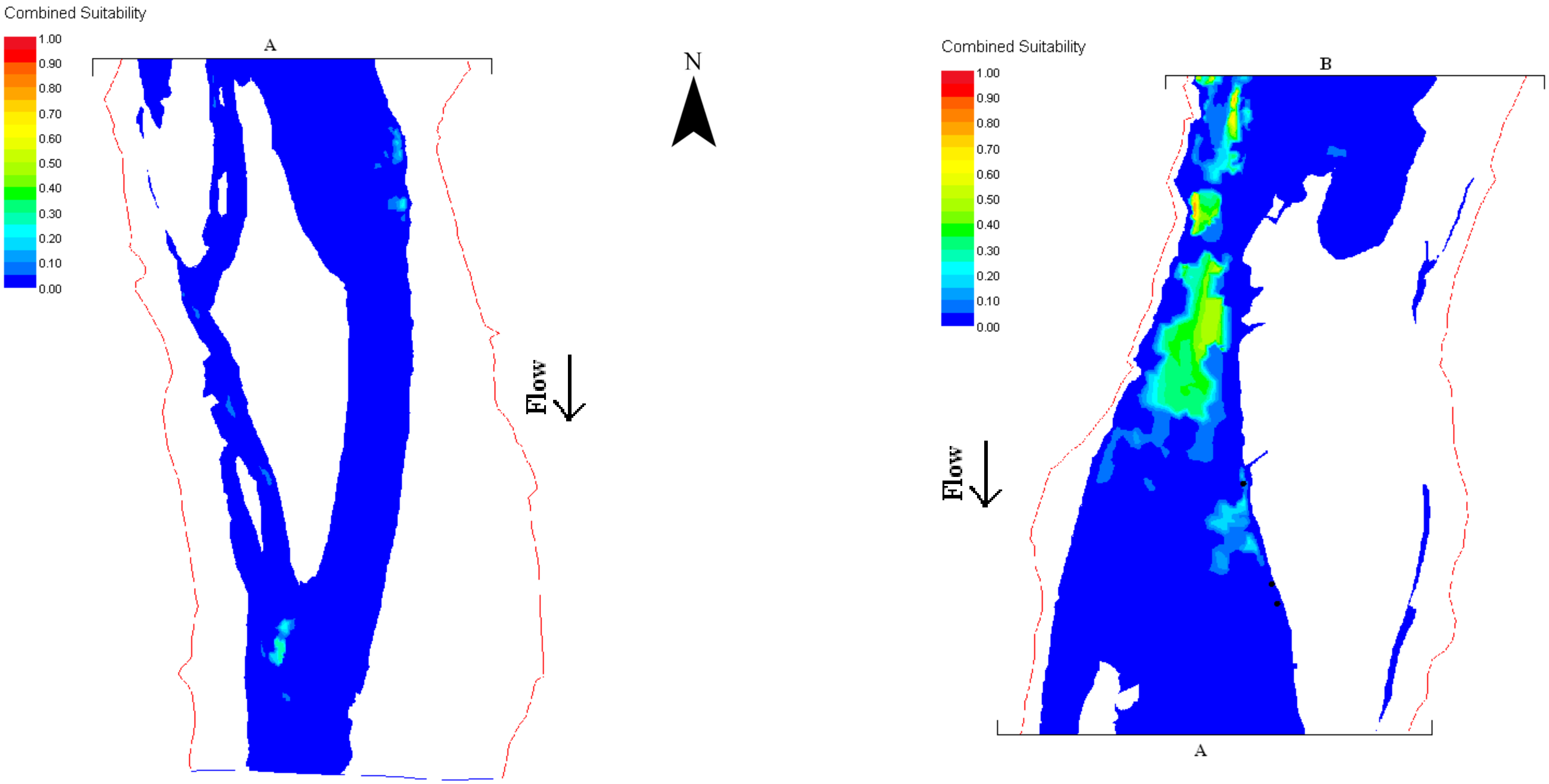
# TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
# CLEAR CREEK CRITERIA (CONTINUED)



**Scale: 1:915**

Redd locations: ●

## TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## DENSITY CRITERIA

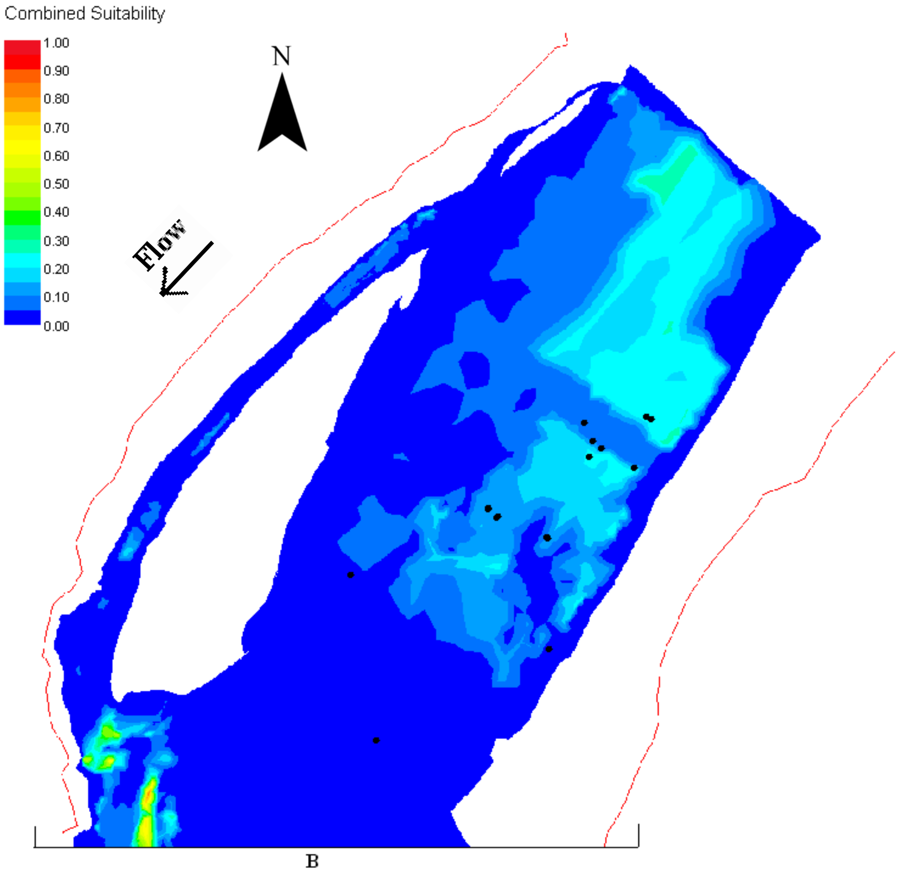


**Scale: 1:2748**

Redd locations: ●

**Scale: 1:2442**

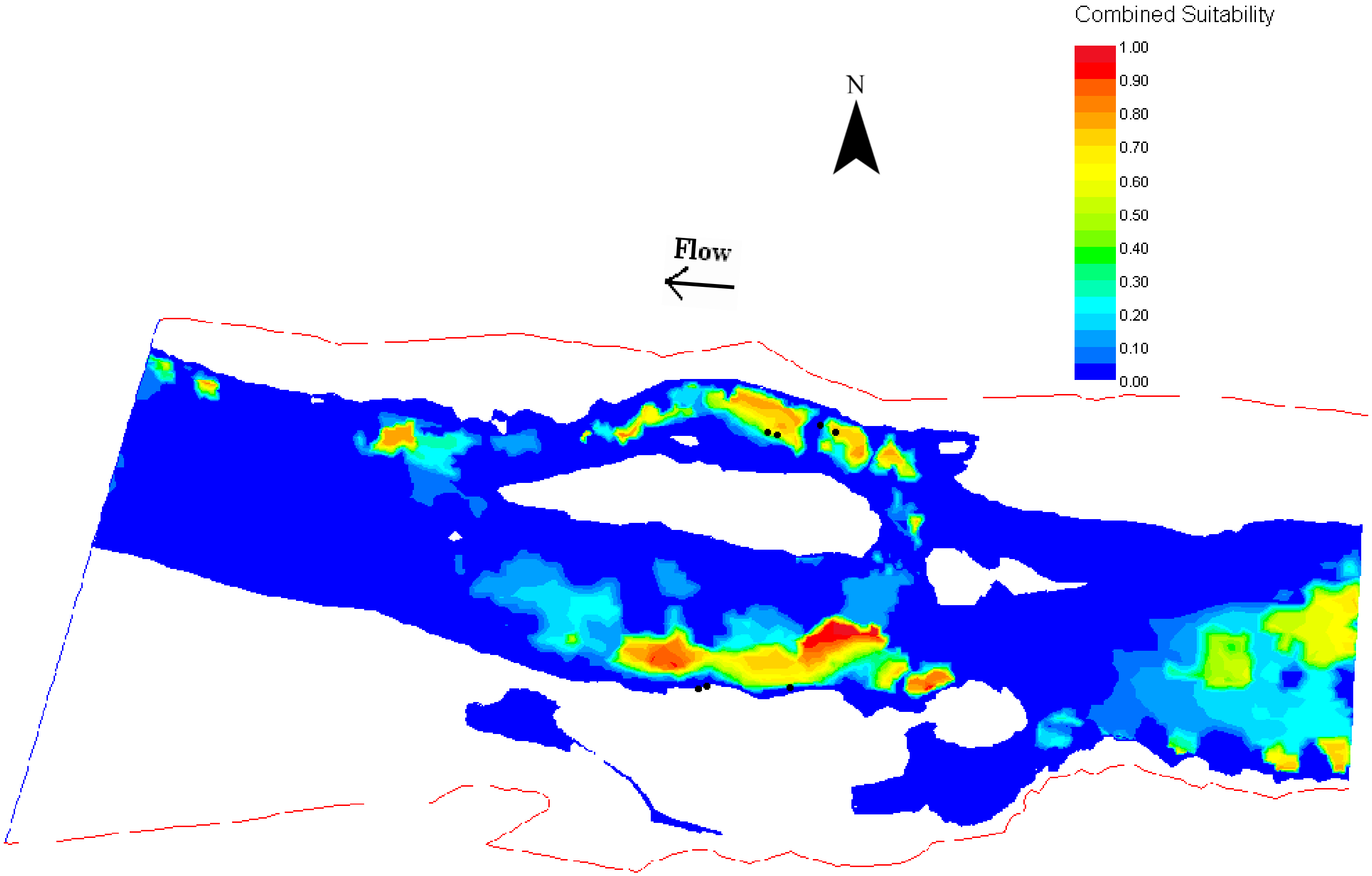
# TIMBUCTOO STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
# DENSITY CRITERIA (CONTINUED)



**Scale: 1:1329**

Redd locations: ●

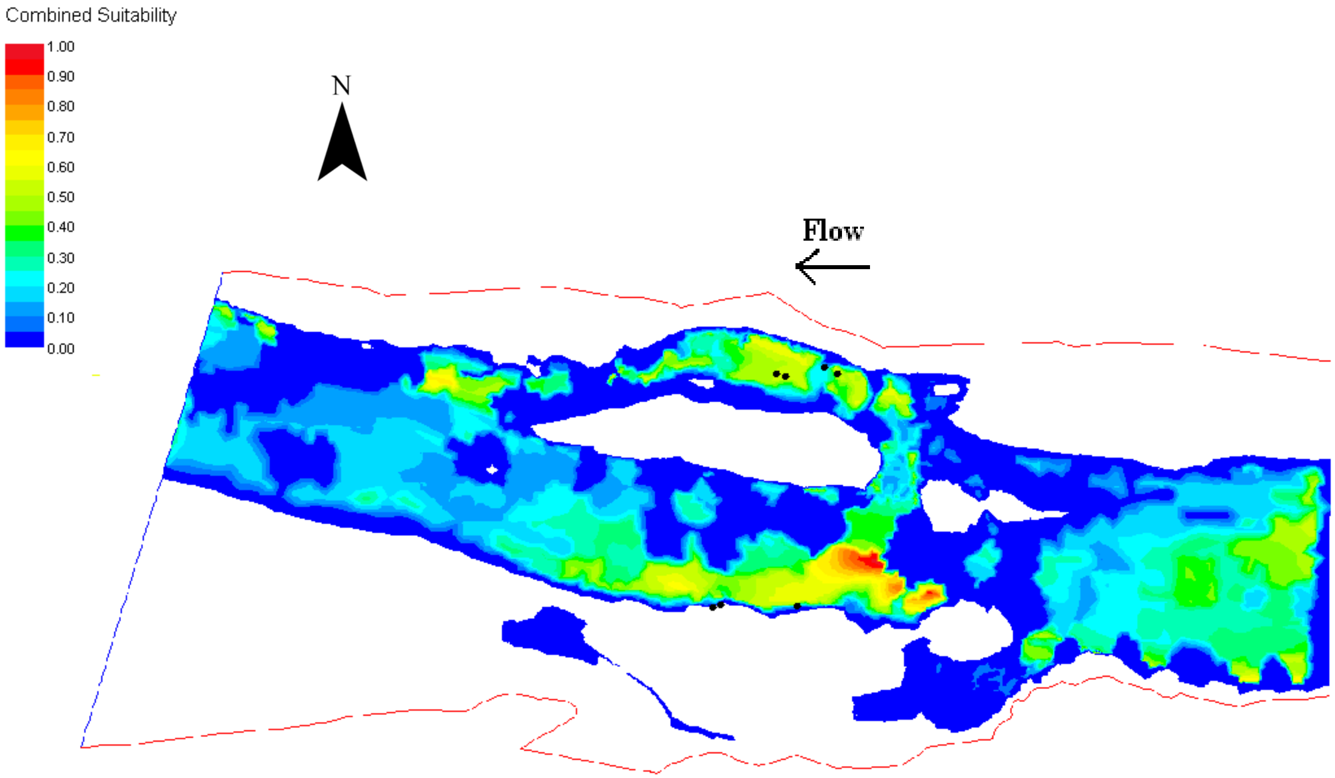
## HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20



**Scale: 1:2160**

Redd locations: ●

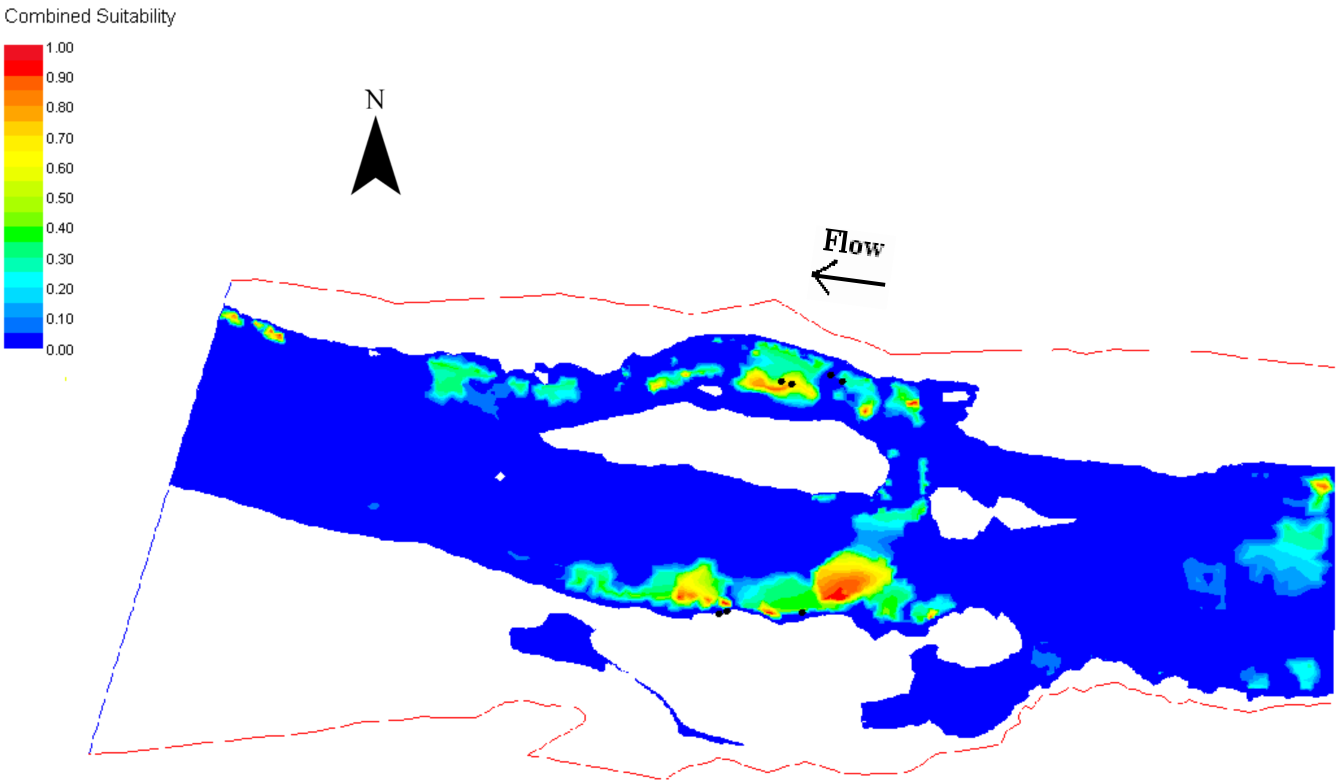
# HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
# GEOMETRIC MEAN CRITERIA



**Scale: 1:2529**

Redd locations: ●

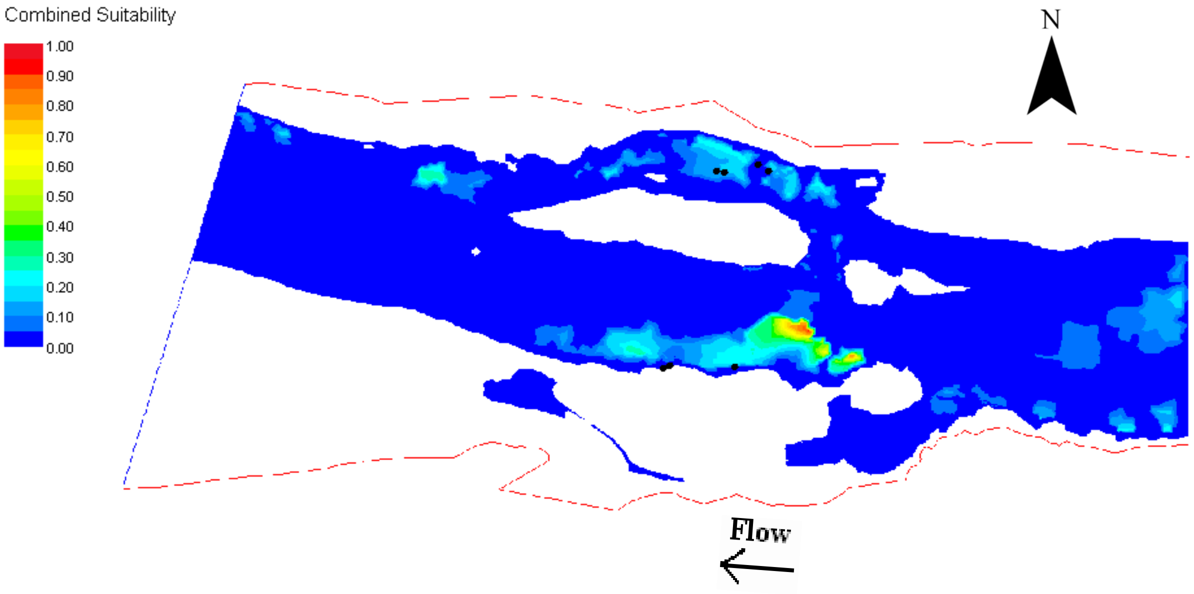
## HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CLEAR CREEK CRITERIA



**Scale: 1:2529**

Redd locations: ●

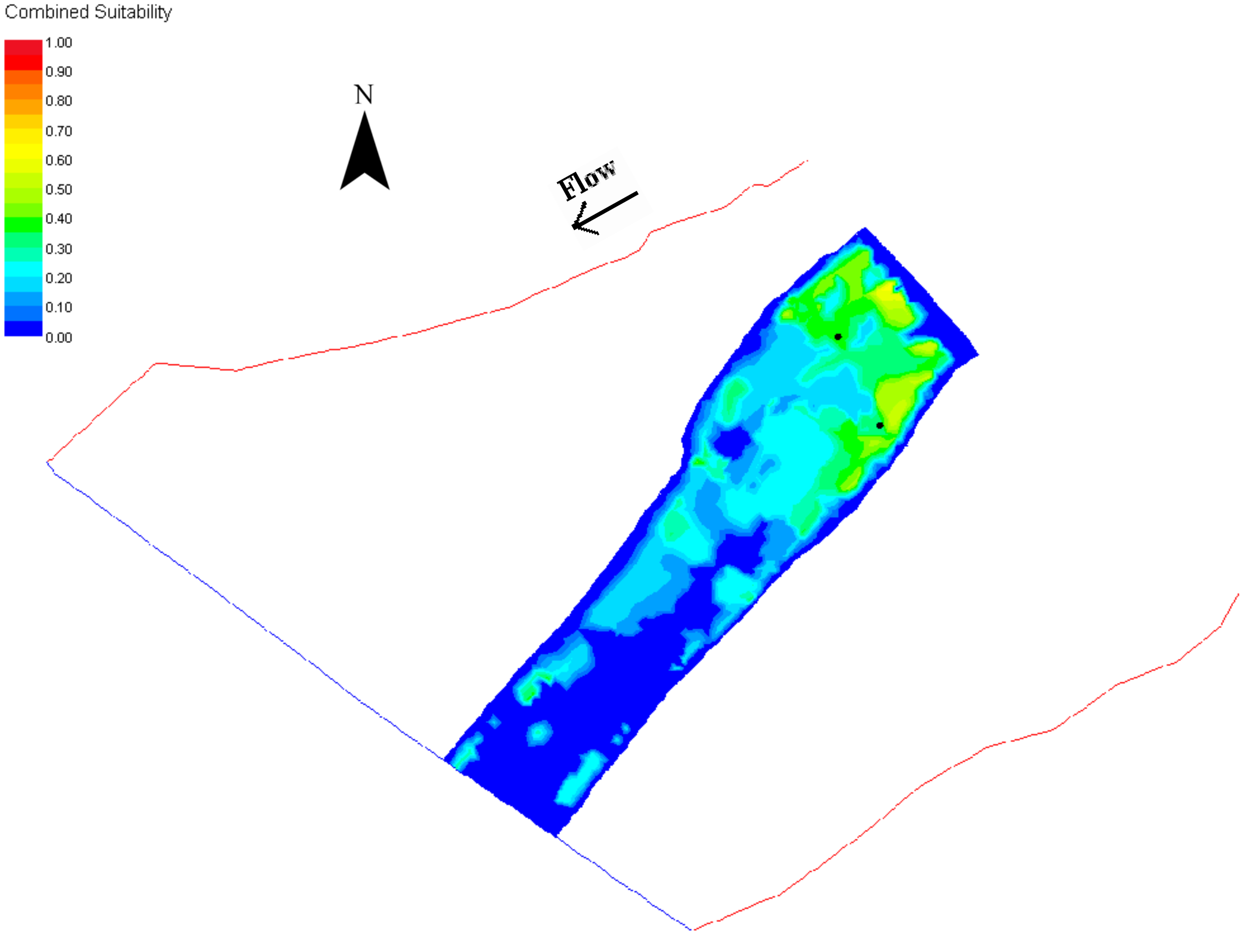
## HIGHWAY 20 STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS DENSITY CRITERIA



**Scale: 1:2880**

Redd locations: ●

# UPPER DAGUERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
# GEOMETRIC MEAN CRITERIA

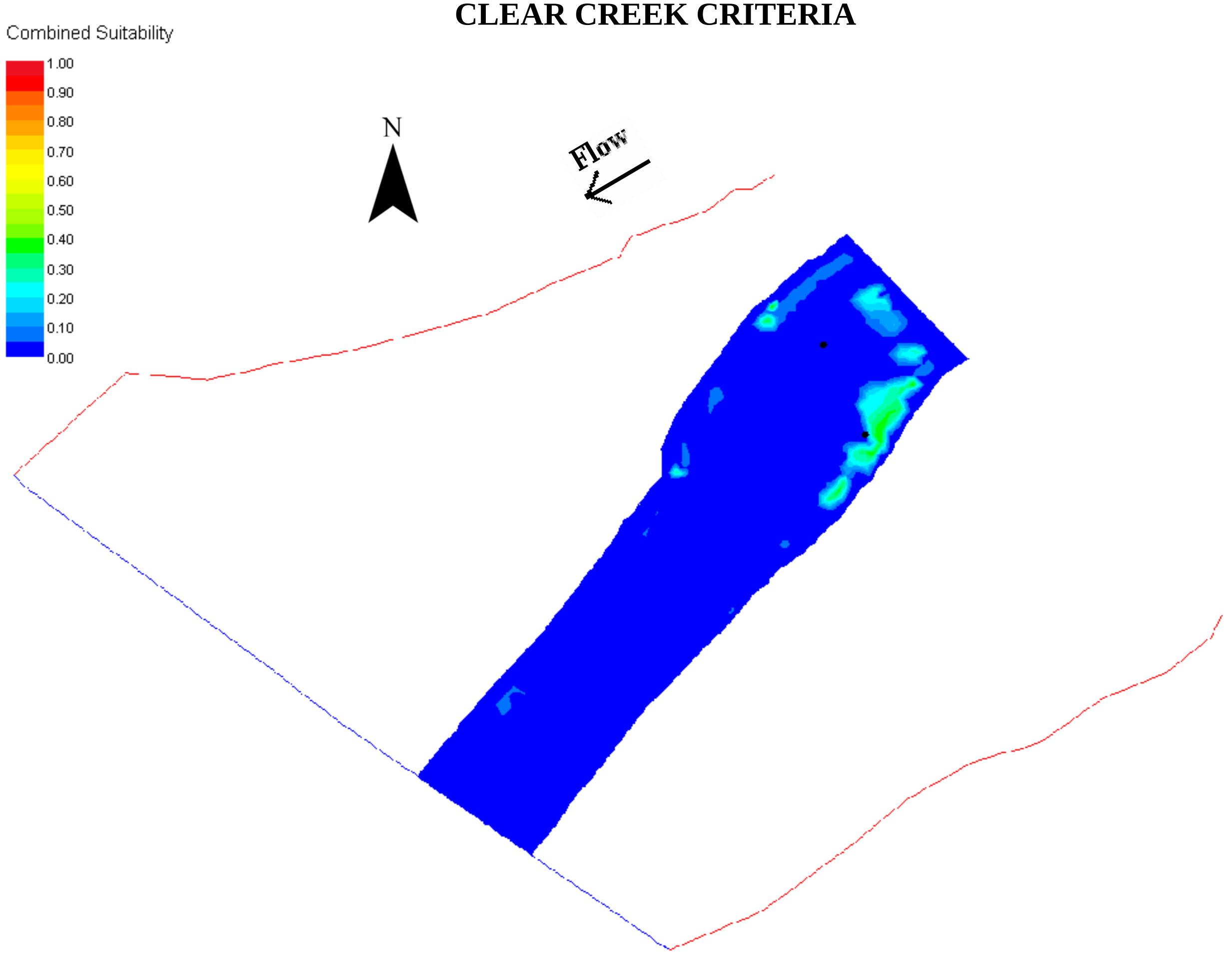


**Scale: 1:1327**

Redd locations: ●

Appendix C

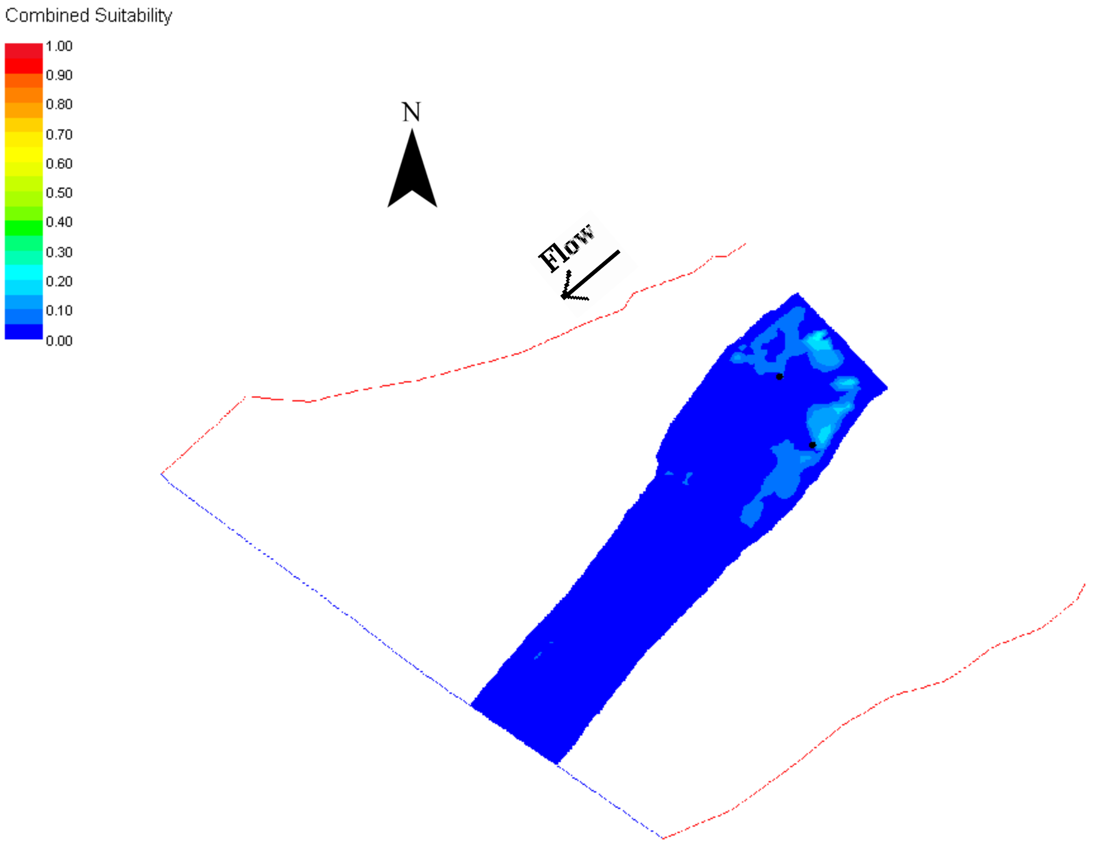
## UPPER DAGUERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CLEAR CREEK CRITERIA



**Scale: 1:1327**

Redd locations: ●

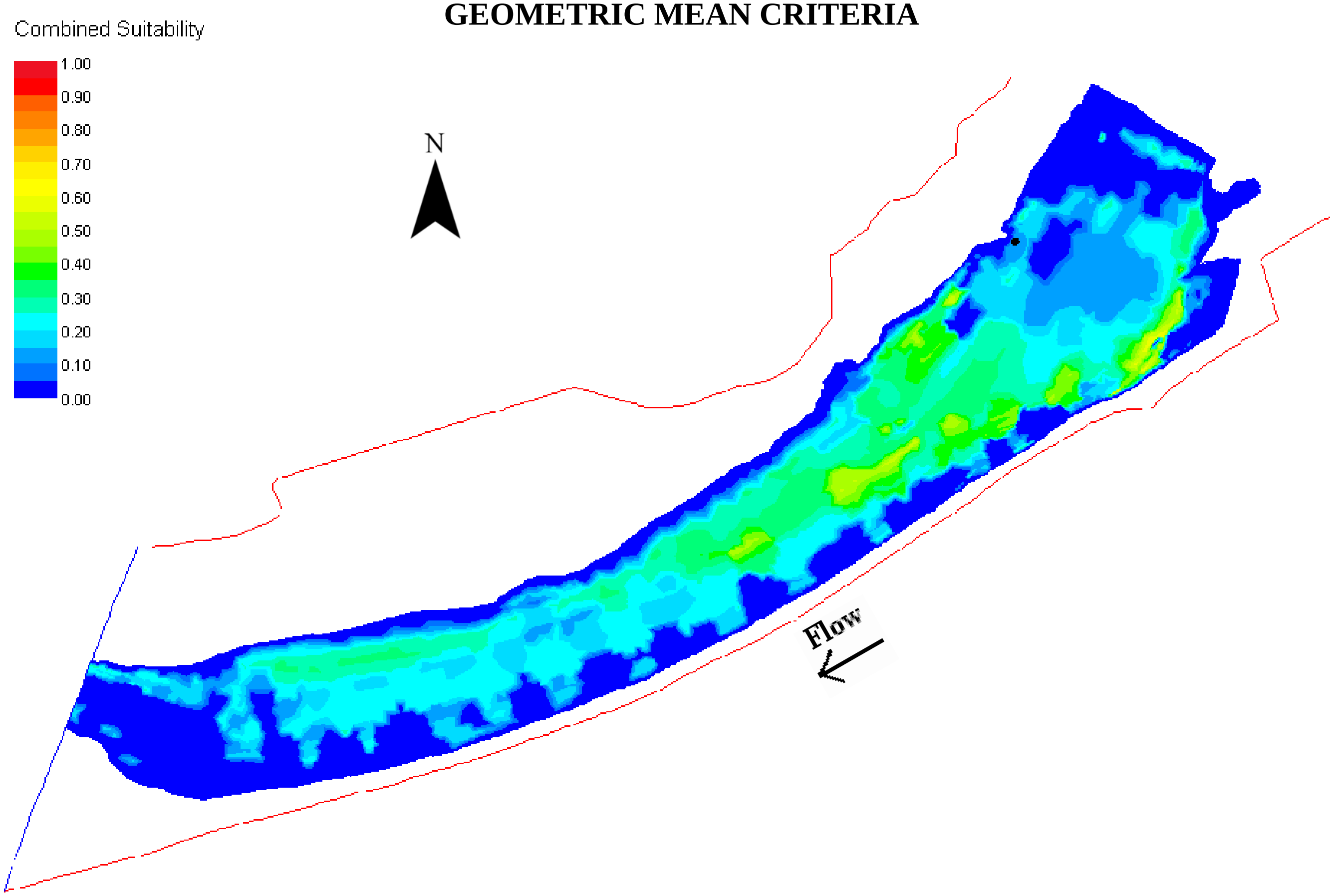
## UPPER DAGUERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## DENSITY CRITERIA



**Scale: 1:1710**

Redd locations: ●

## LOWER DAGUERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## GEOMETRIC MEAN CRITERIA

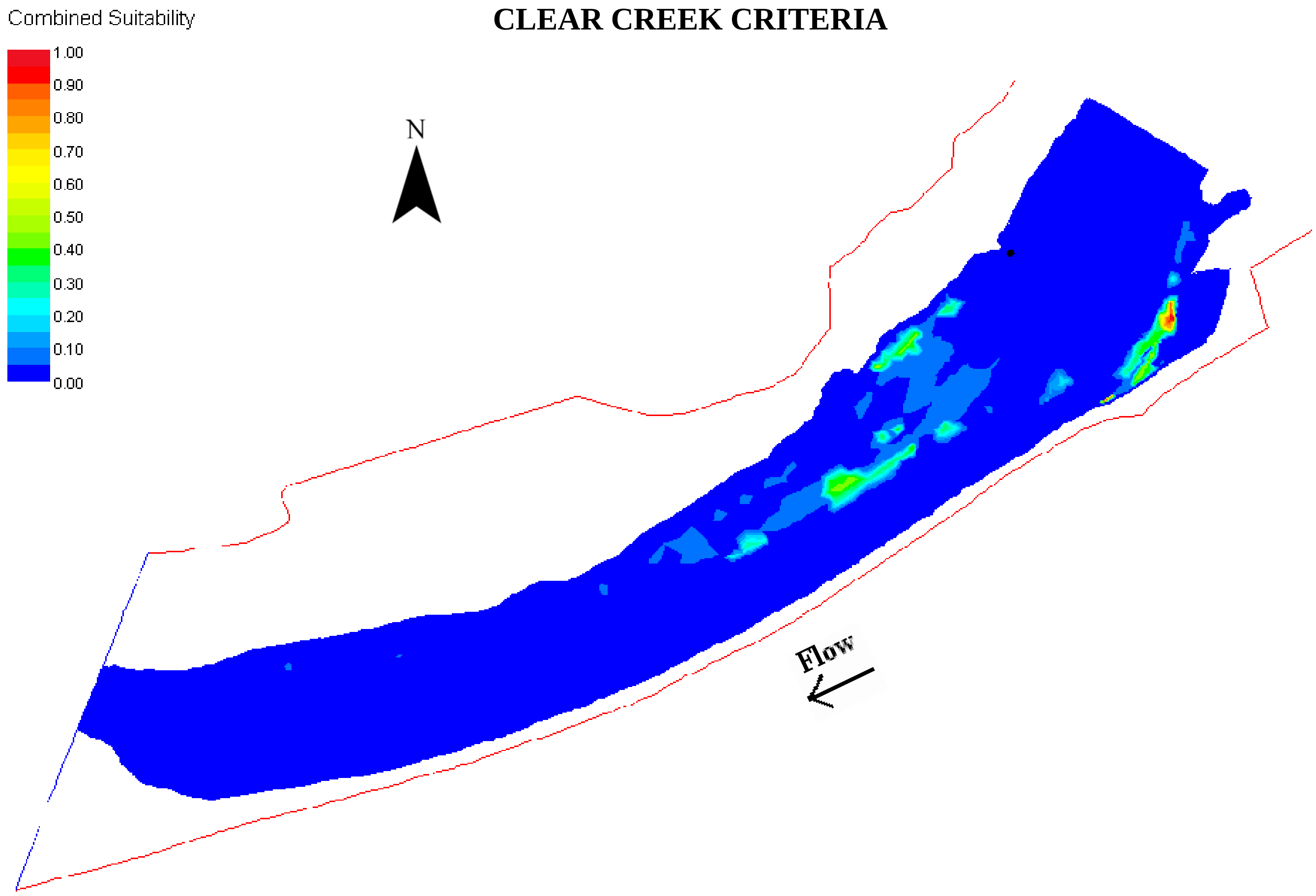


**Scale: 1:2963**

Redd locations: ●

Append

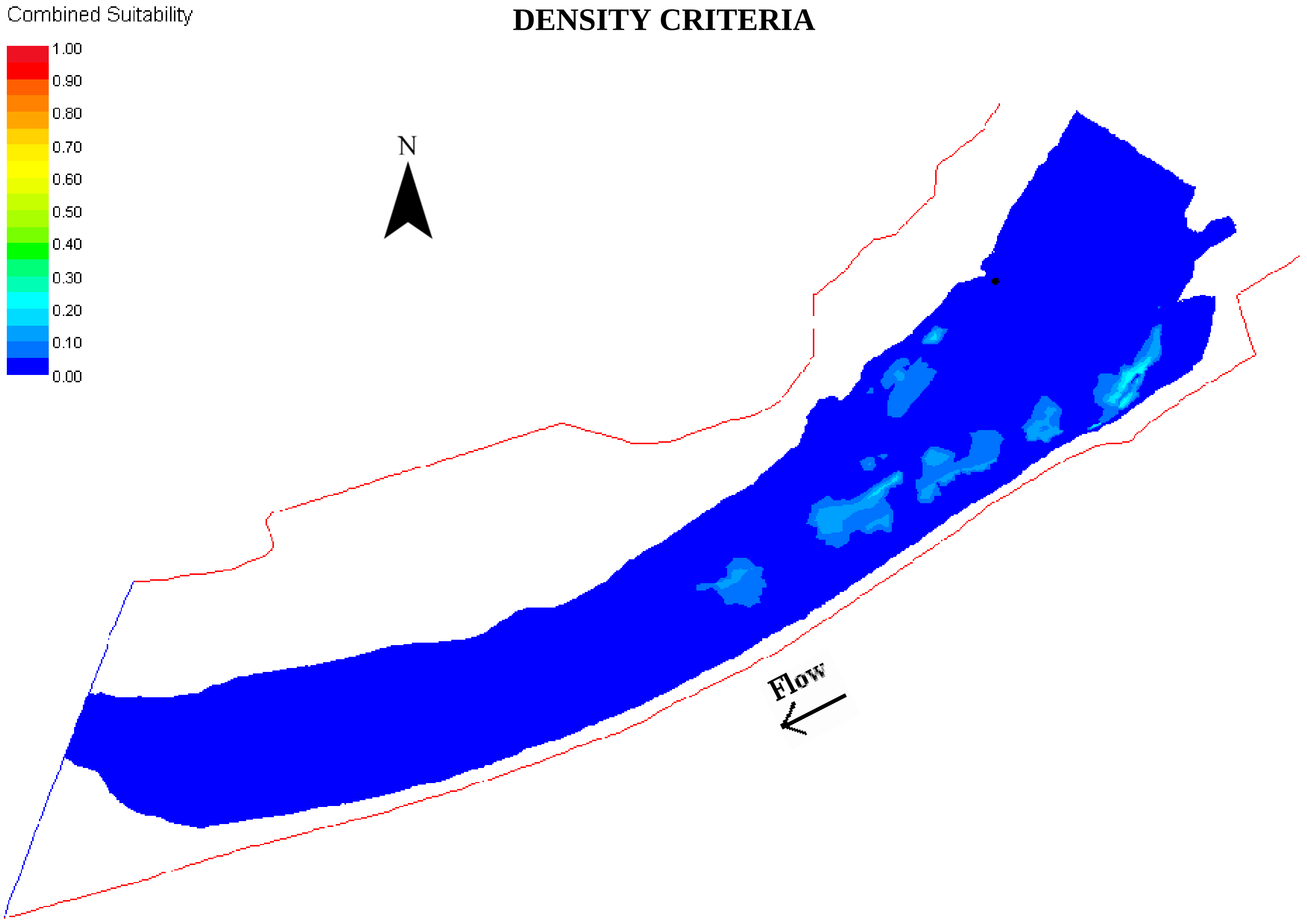
## LOWER DAGUERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CLEAR CREEK CRITERIA



**Scale: 1: 2963**

Redd locations: ●

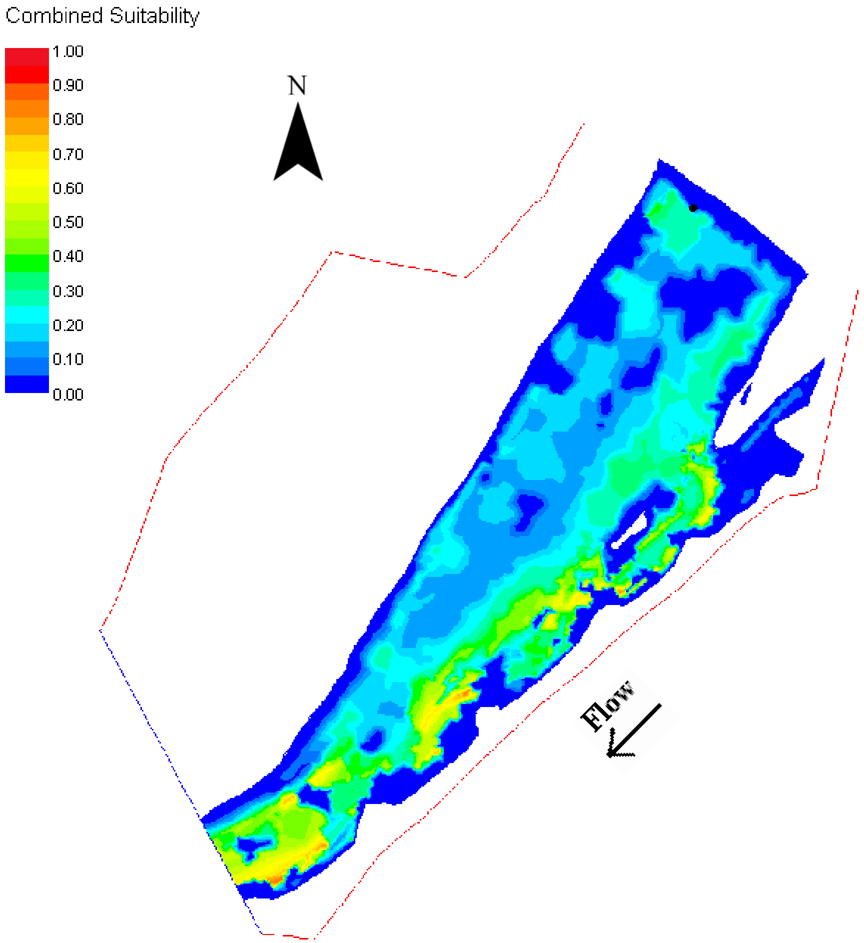
## LOWER DAGUERRA STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## DENSITY CRITERIA



**Scale: 1: 2963**

Redd locations: ●

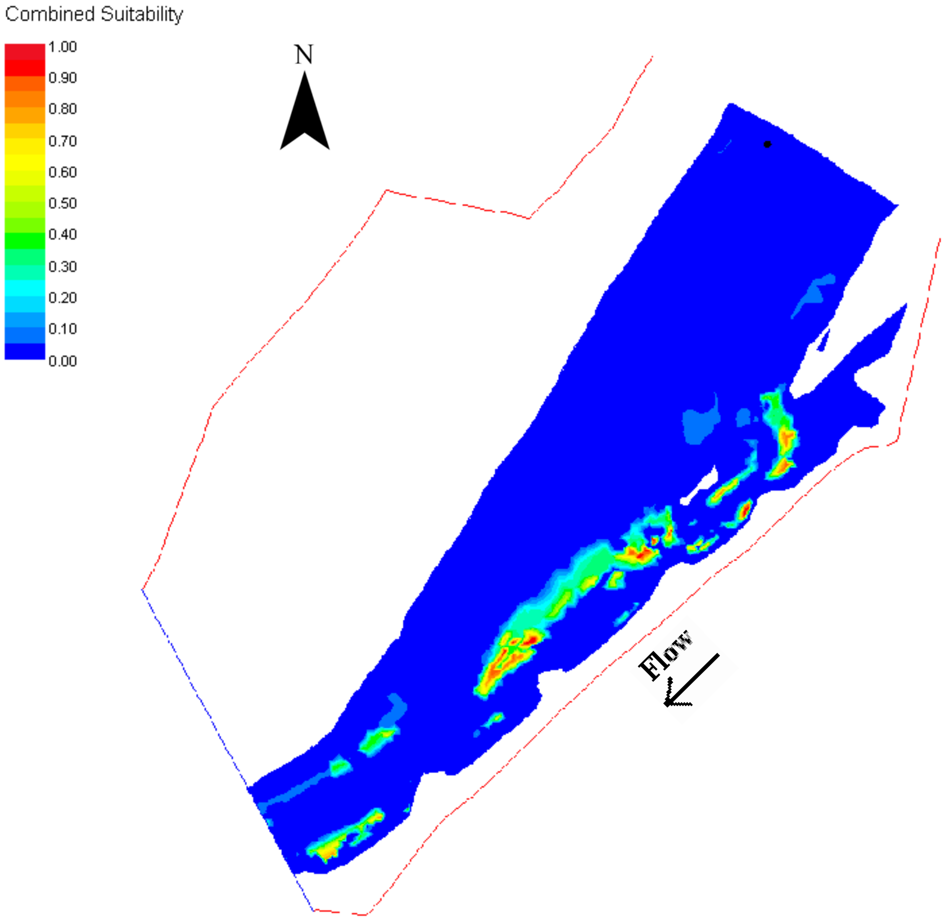
## HALLWOOD STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## GEOMETRIC MEAN CRITERIA



**Scale: 1:2345**

Redd locations: ●

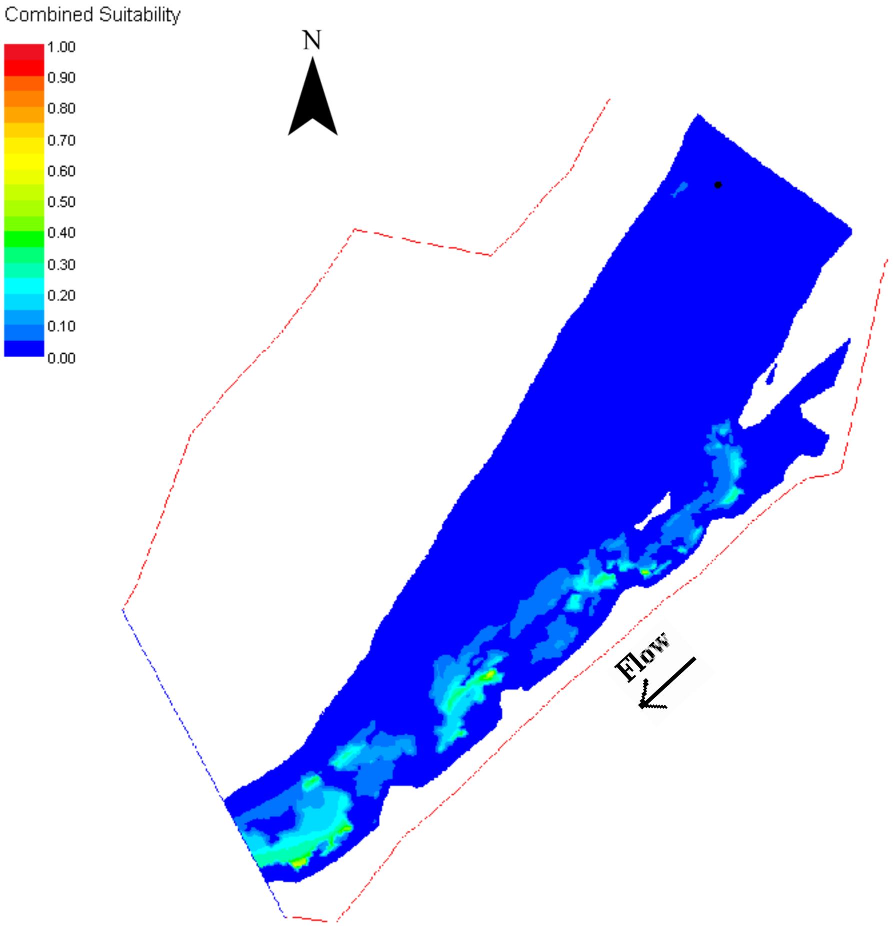
## HALLWOOD STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## CLEAR CREEK CRITERIA



**Scale: 1:2189**

Redd locations: ●

## HALLWOOD STUDY SITE, APRIL 8-10, 2003, FLOW = 2399 CFS
## DENSITY CRITERIA



**Scale: 1:2264**
Redd locations: ●

# APPENDIX D
# RIVER2D HABITAT SUITABILITY OF 2002 AND 2004 STEELHEAD/RAINBOW TROUT REDD LOCATIONS[1]

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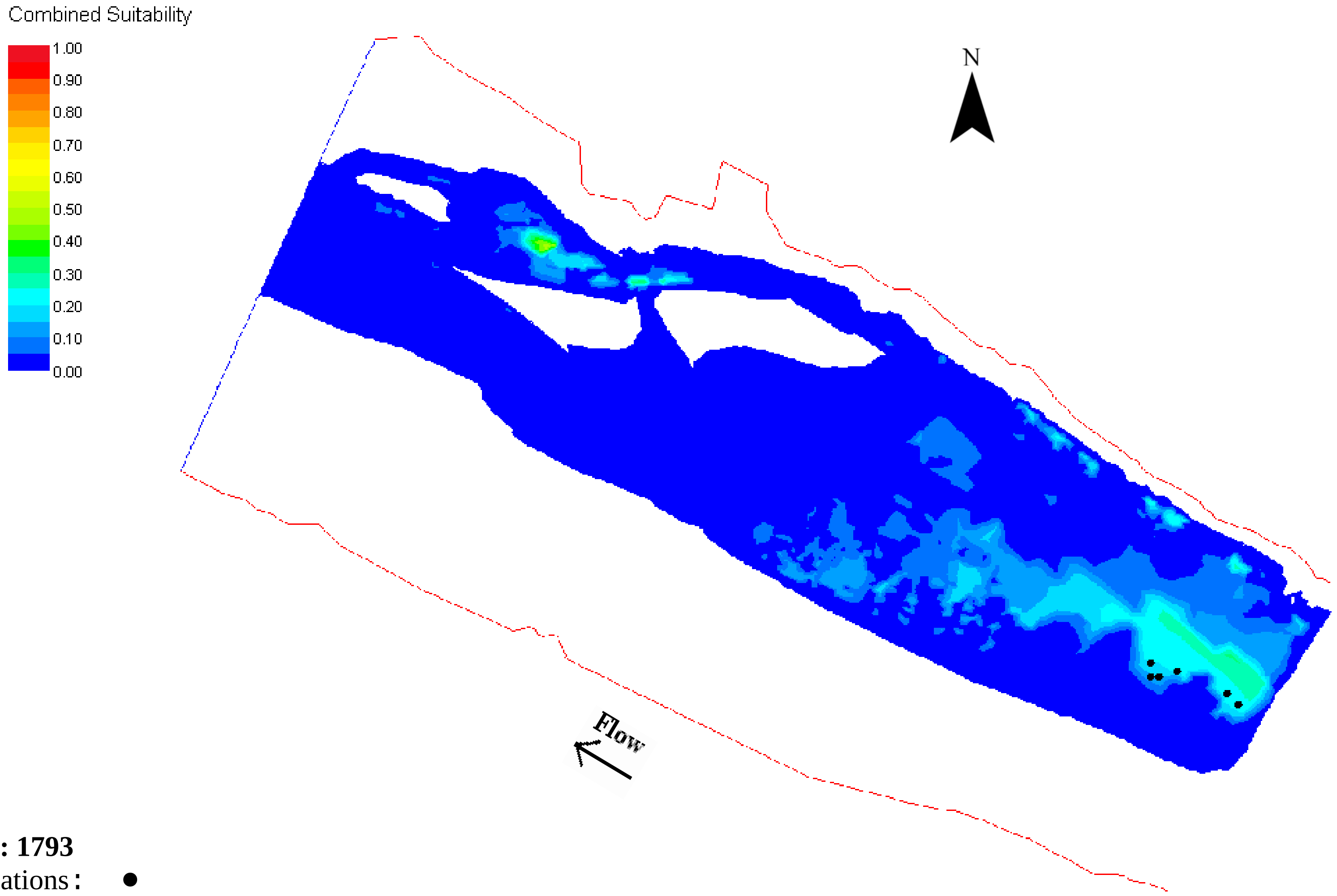
[1] For all pages, Combined Suitability: 1 = optimal, 0 = unusable

Appendix D

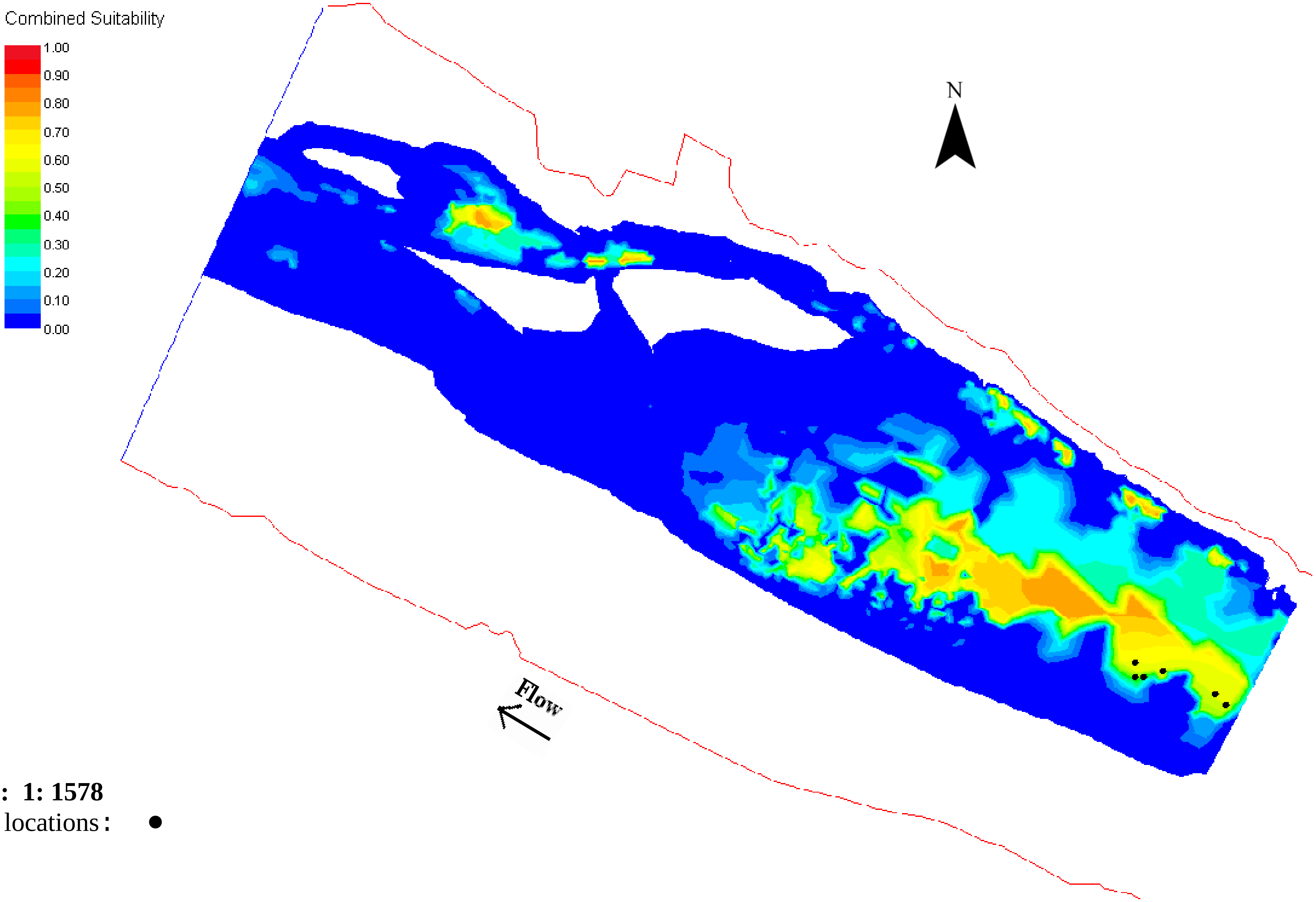
## U.C. SIERRA STUDY SITE 2002, MARCH 4-APRIL 23, 2002, FLOW = 2281 CFS
## CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008)



**Scale: 1: 1793**

Redd locations: ●

## U.C. SIERRA STUDY SITE 2002, MARCH 4-APRIL 23, 2002, FLOW = 2281 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20

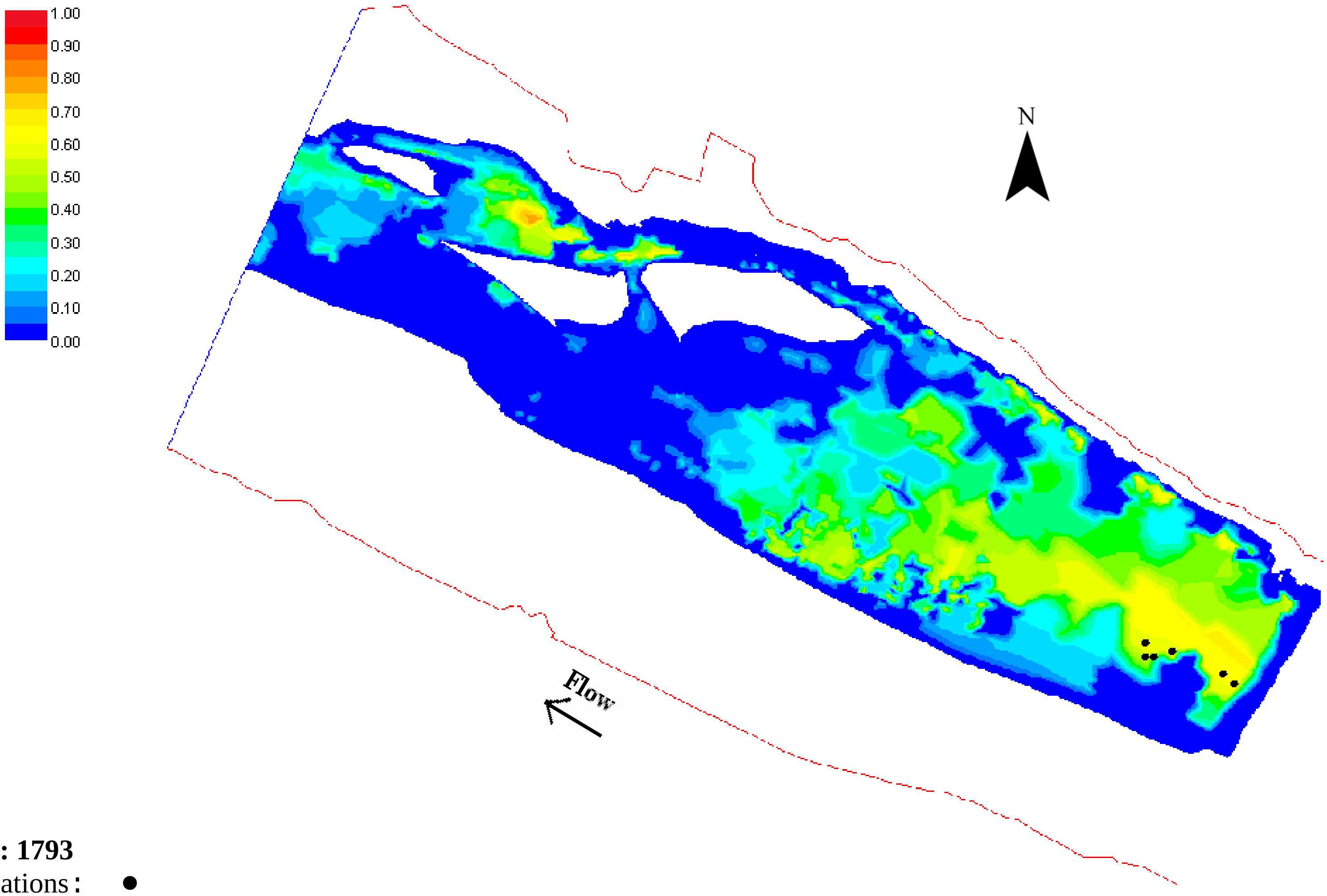


**Scale: 1: 1578**

Redd locations: ●

Appendix D

# U.C. SIERRA STUDY SITE 2002, MARCH 4-APRIL 23, 2002, FLOW = 2281 CFS
# GEOMETRIC MEAN CRITERIA

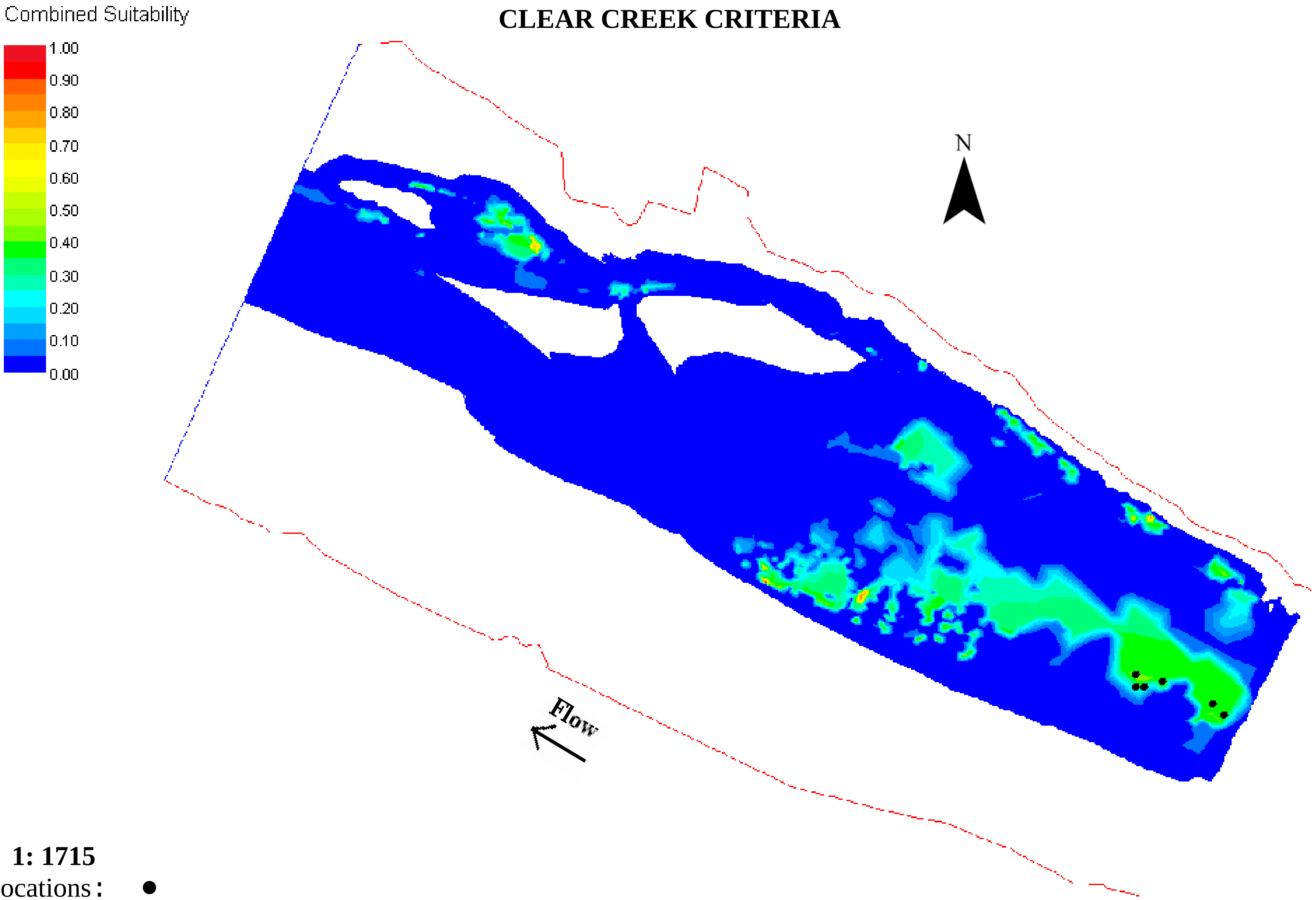


**Scale: 1: 1793**

Redd locations: ●

Appendix D

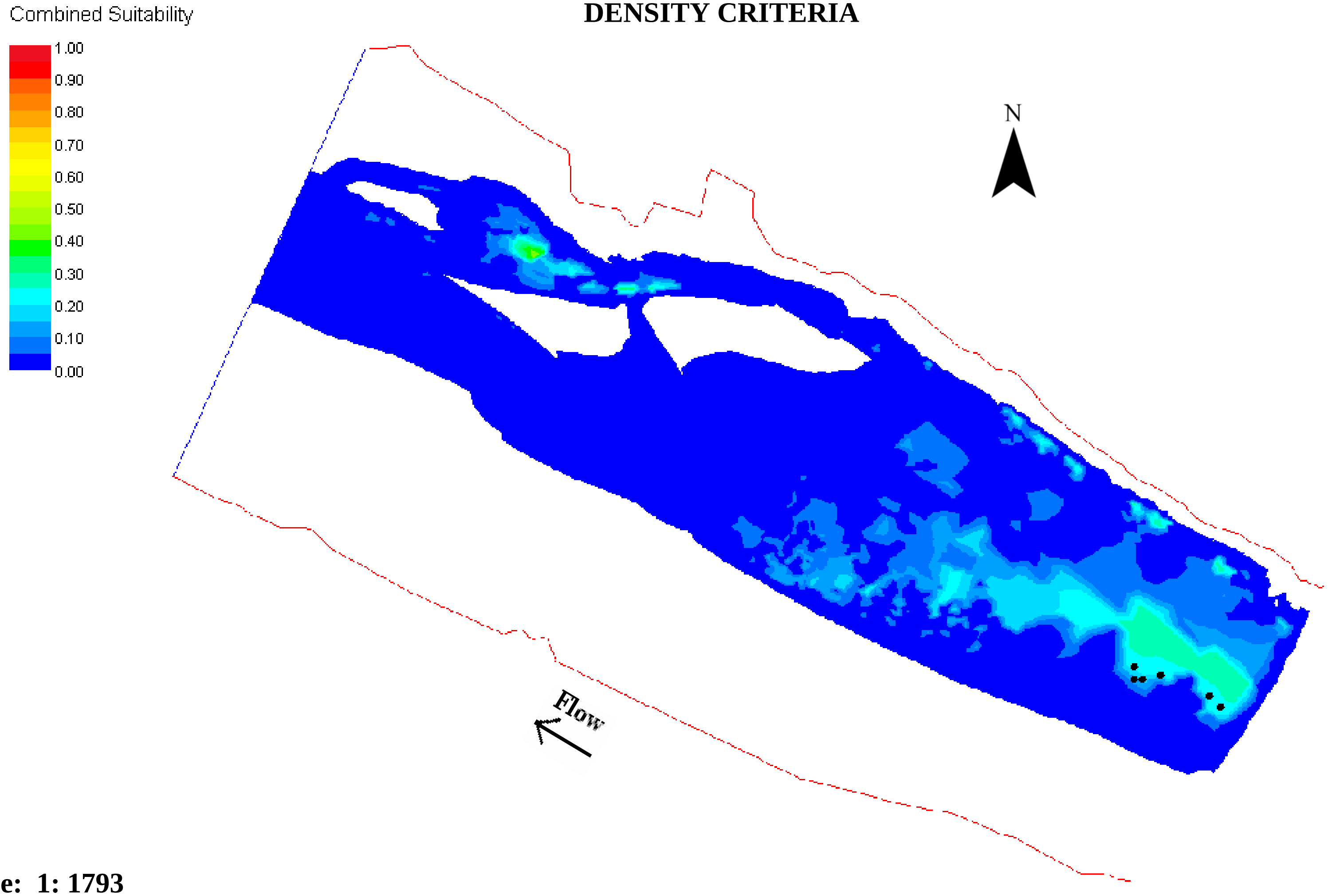
## U.C. SIERRA STUDY SITE 2002, MARCH 4-APRIL 23, 2002, FLOW = 2281 CFS
## CLEAR CREEK CRITERIA



**Scale: 1: 1715**

Redd locations: ●

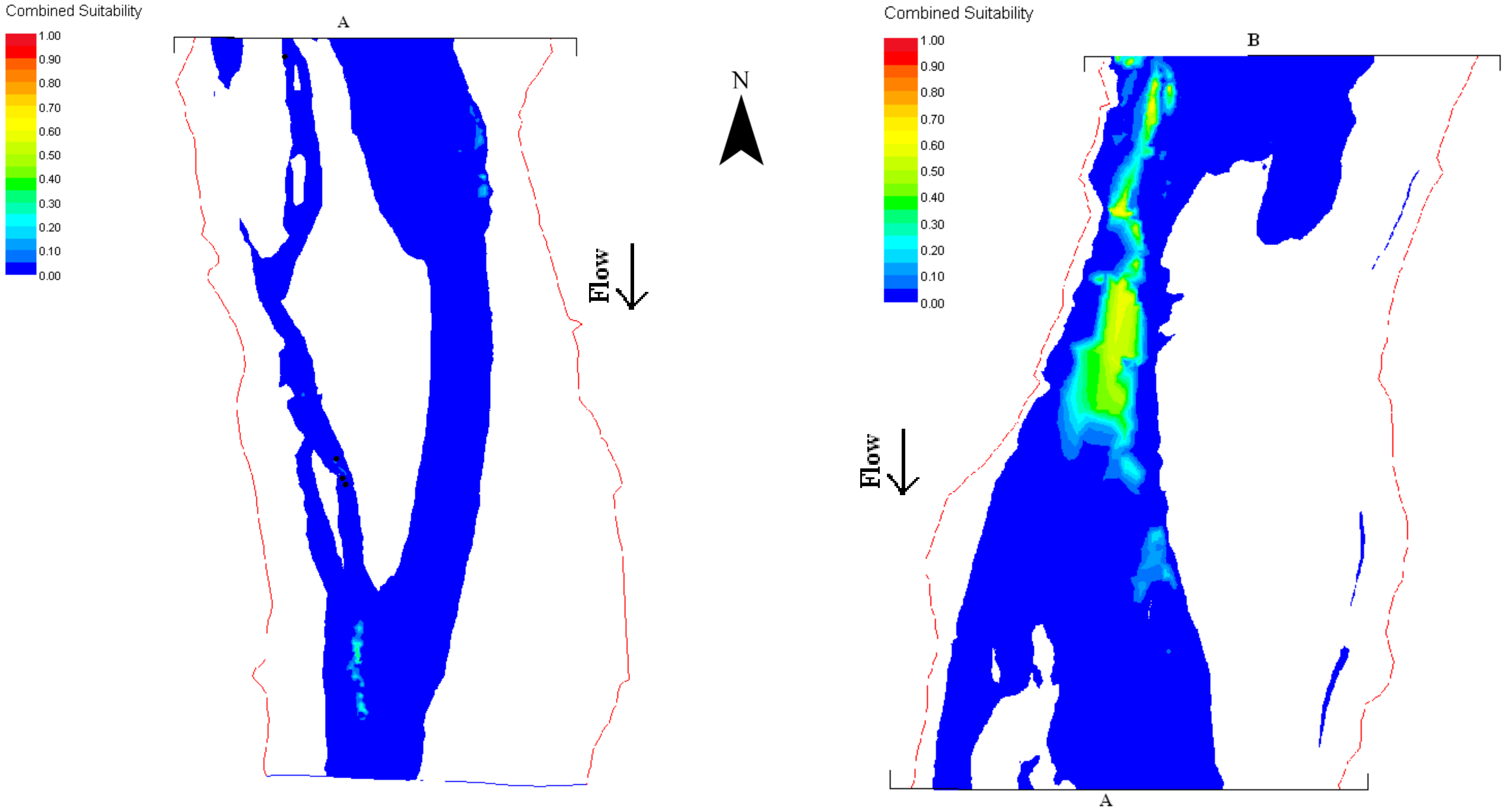
## U.C. SIERRA STUDY SITE 2002, MARCH 4-APRIL 23, 2002, FLOW = 2281 CFS
## DENSITY CRITERIA



**Scale: 1: 1793**

Redd locations: ●

## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS
## CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008)

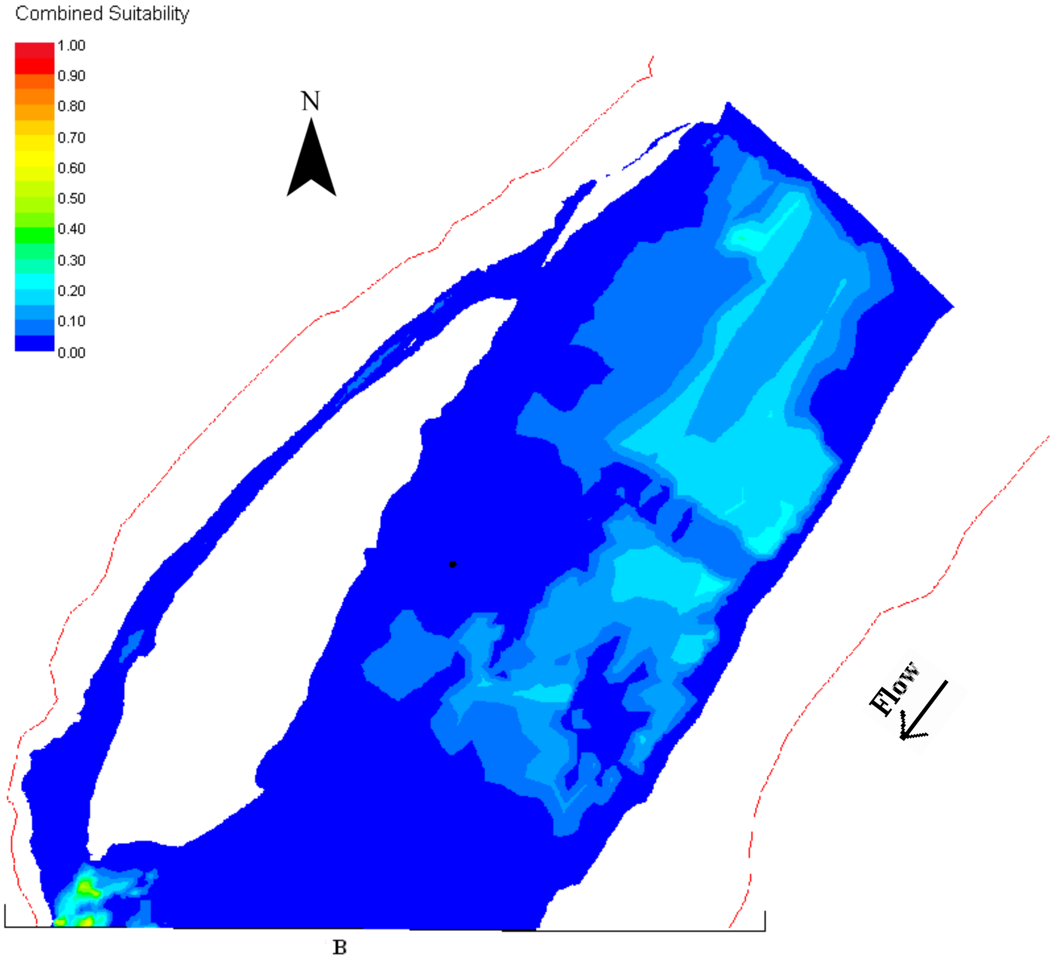


**Scale: 1:2656**

Redd locations : ●

**Scale: 1:2191**

## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008) (CONTINUED)

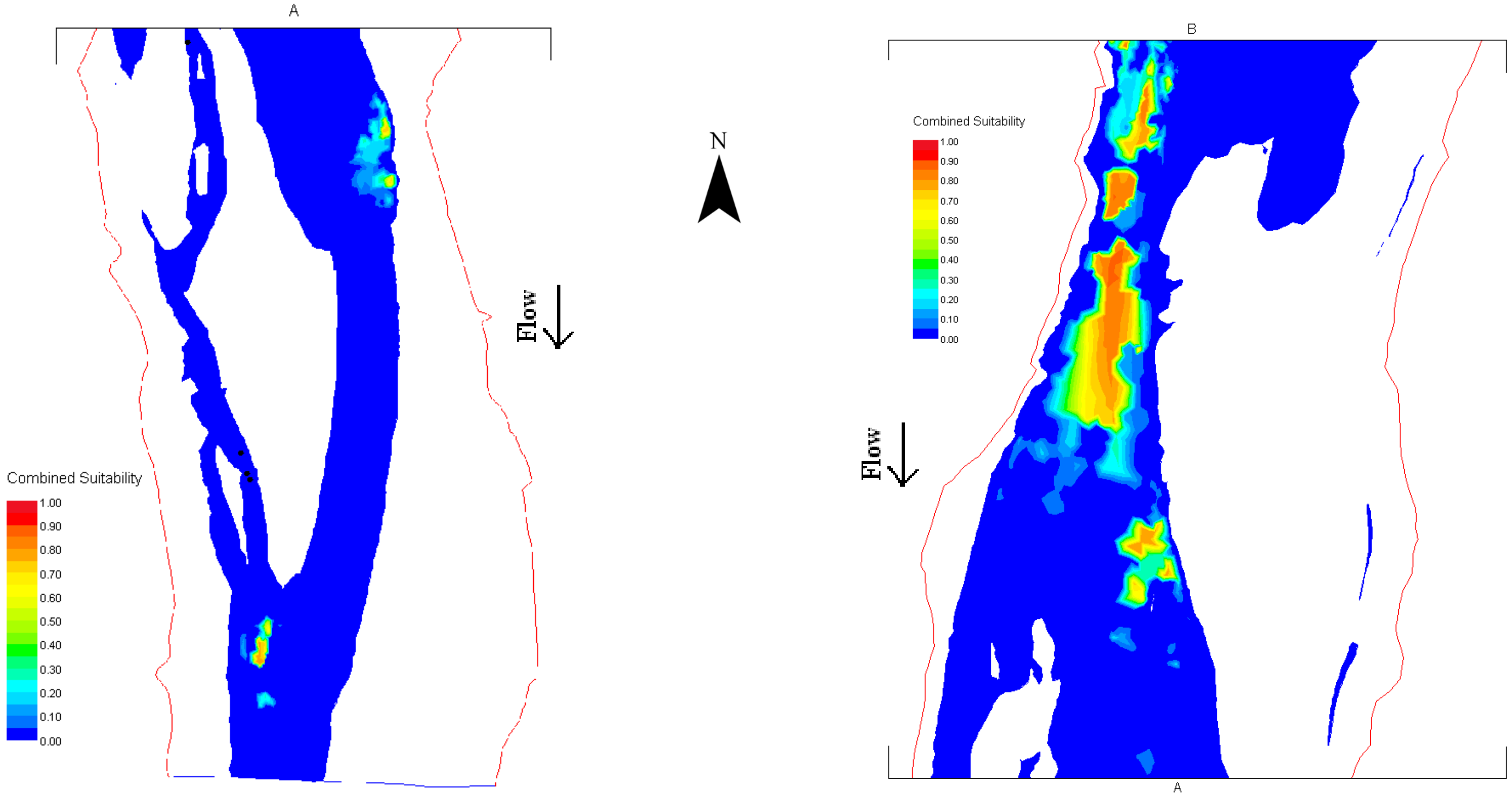


**Scale: 1:889**

Redd locations : ●

Appendix D

## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20

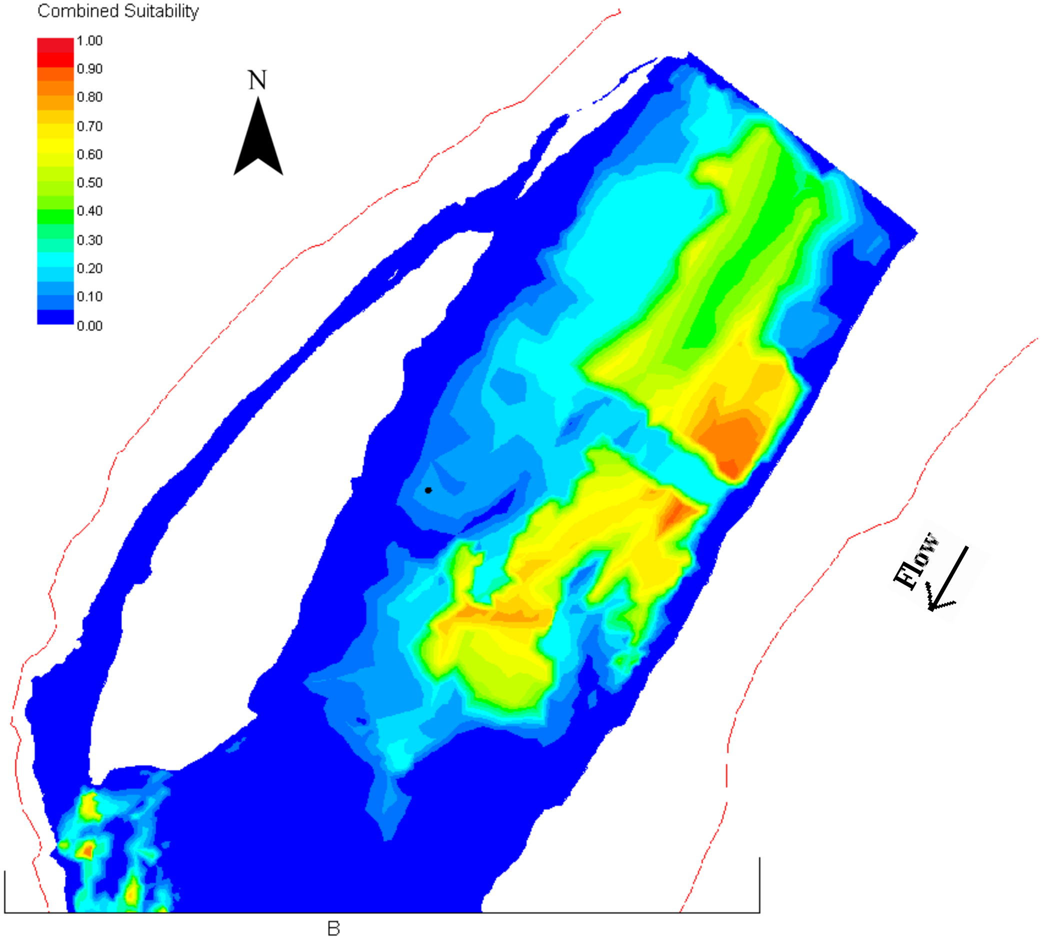


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:2075**

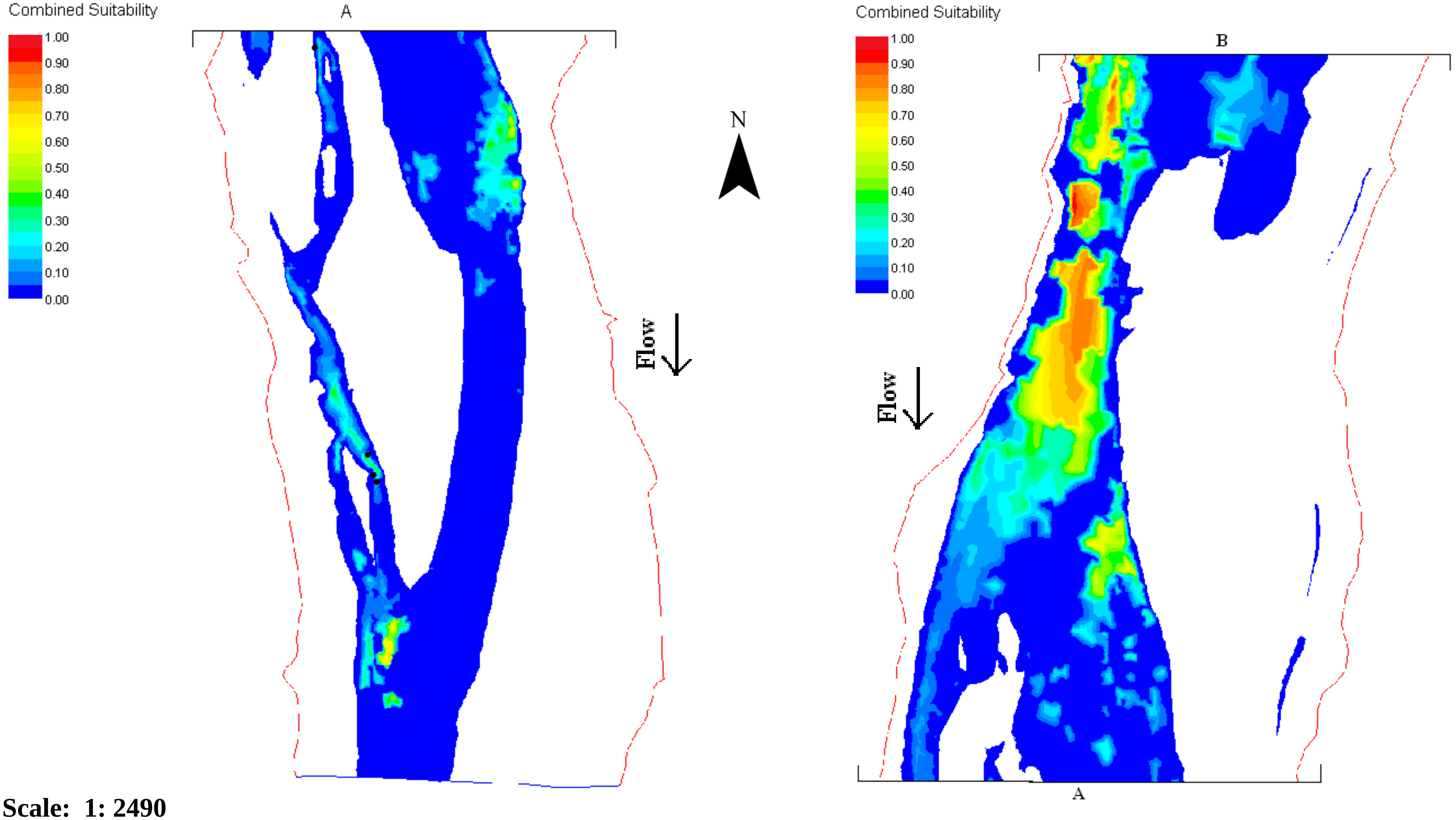
## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20 (CONTINUED)



**Scale: 1:1025**

Redd locations : ●

## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS
## GEOMETRIC MEAN CRITERIA



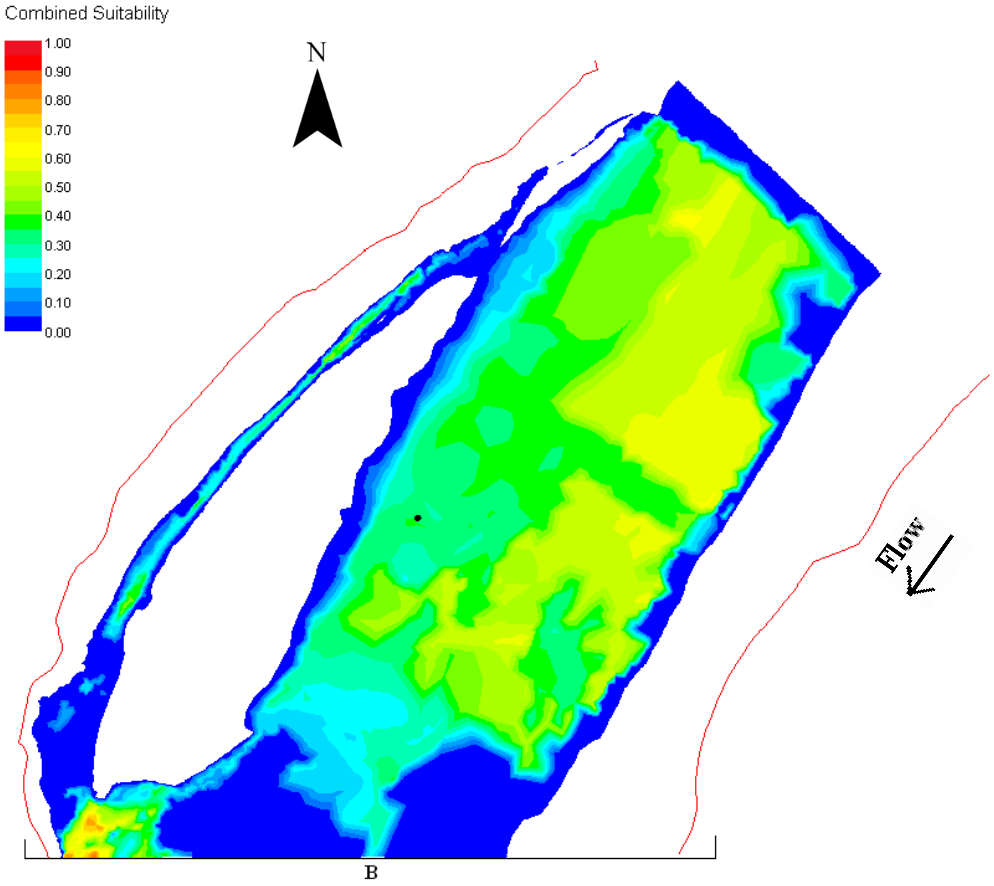
**Scale: 1: 2490**

Redd locations : ●

**Scale: 1:2134**

Appendix D

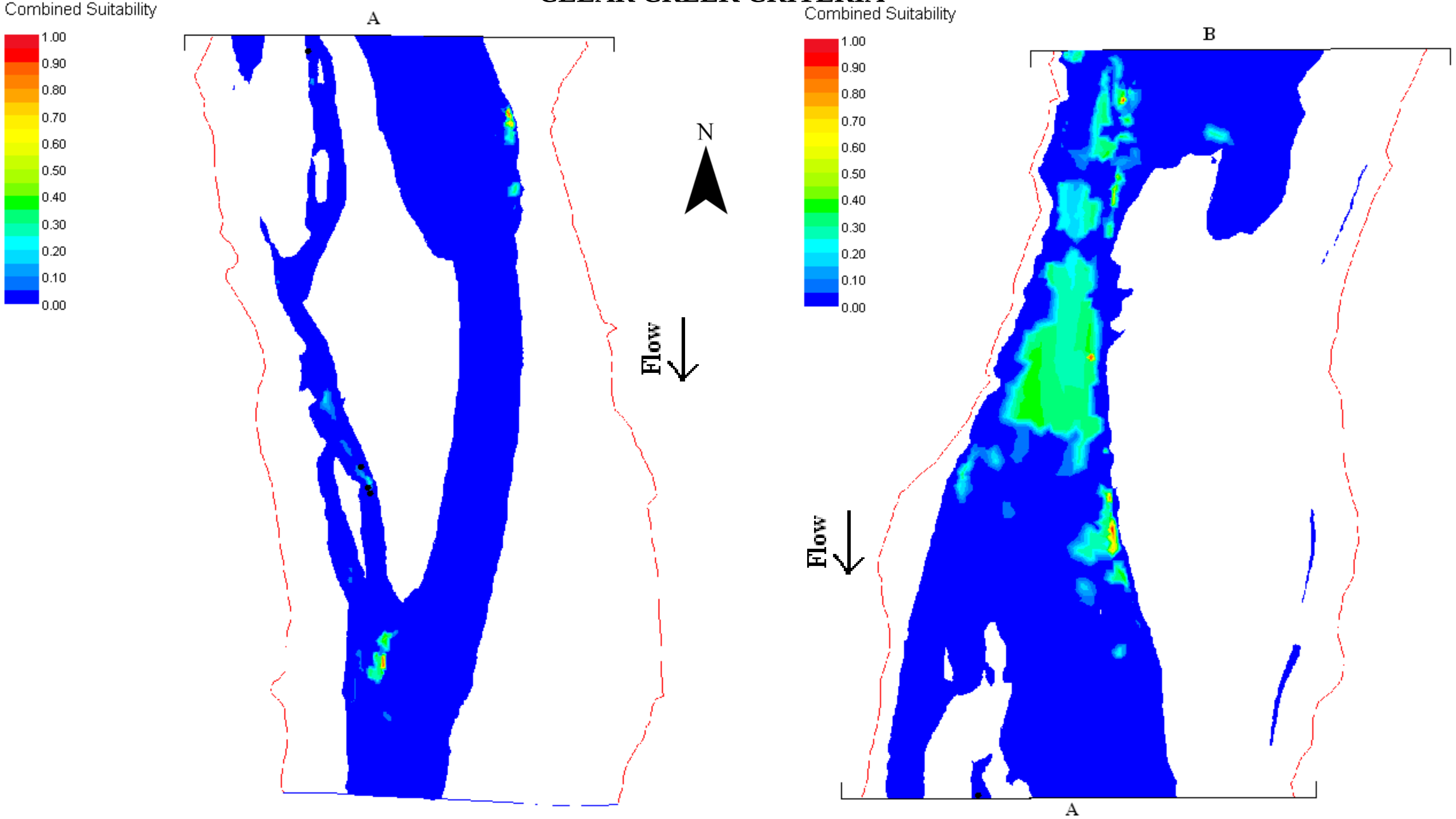
## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS
## GEOMETRIC MEAN CRITERIA (CONTINUED)



**Scale: 1:1085**

Redd locations : ●

## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS
## CLEAR CREEK CRITERIA

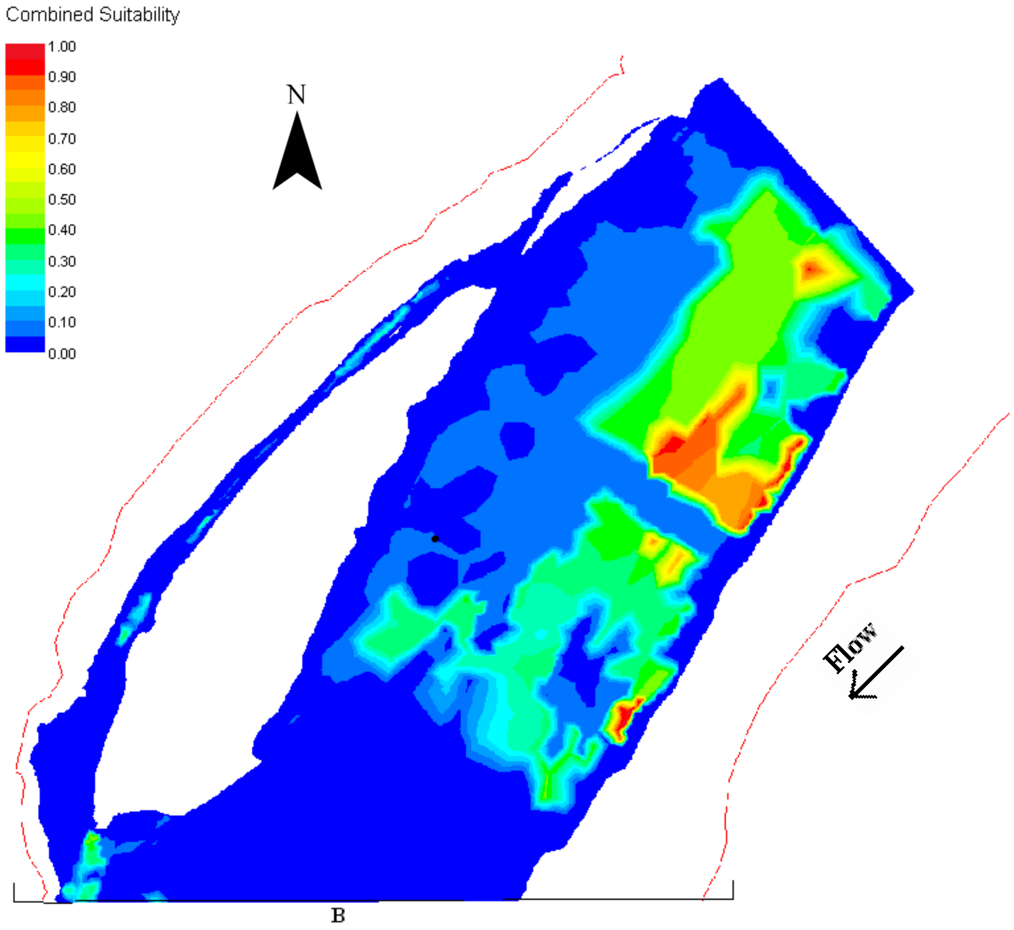


**Scale: 1:2415**

Redd locations : ●

**Scale: 1:2070**

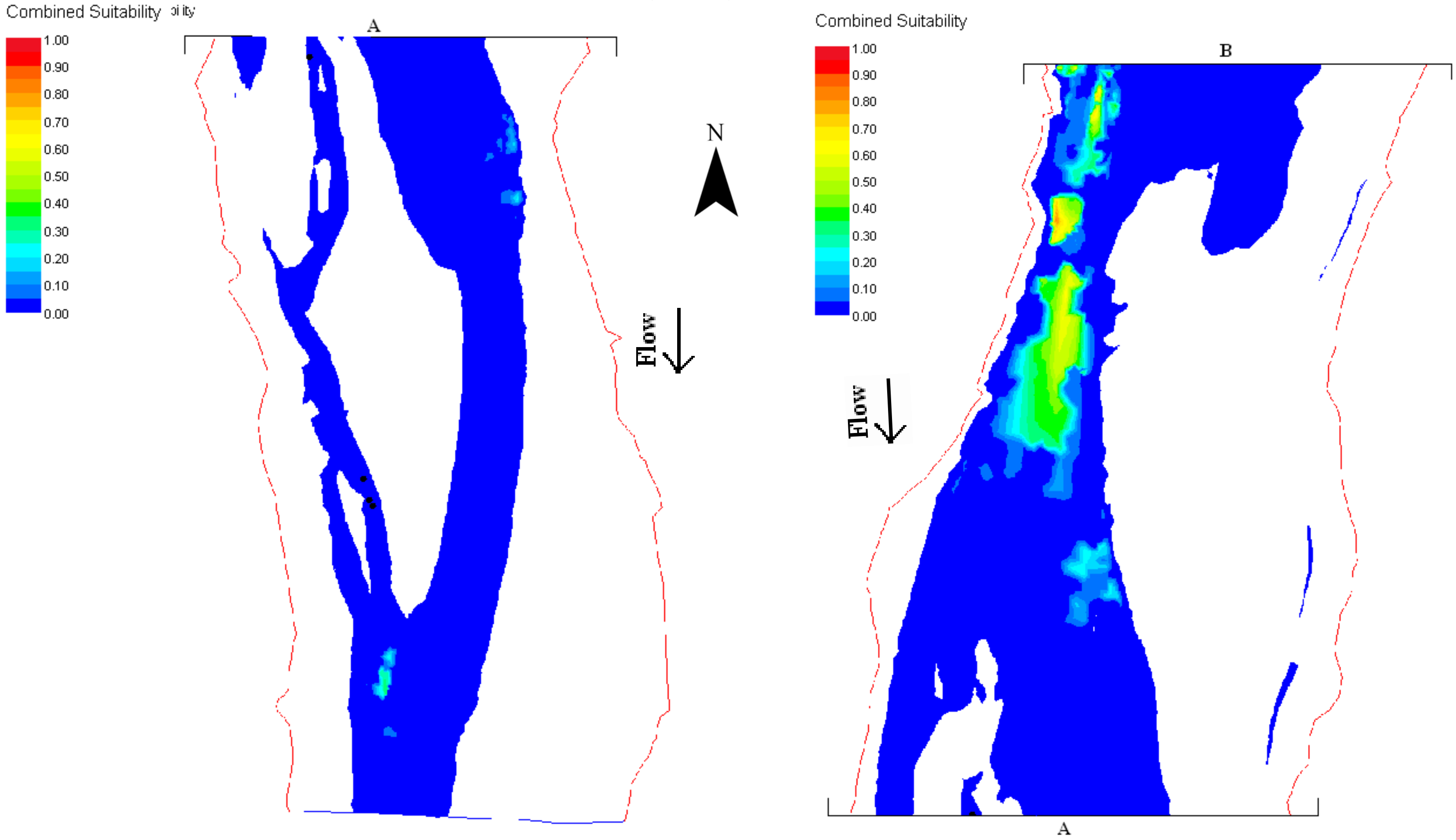
## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS
## CLEAR CREEK CRITERIA (CONTINUED)



**Scale: 1:996**

Redd locations : ●

## TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS
## DENSITY CRITERIA

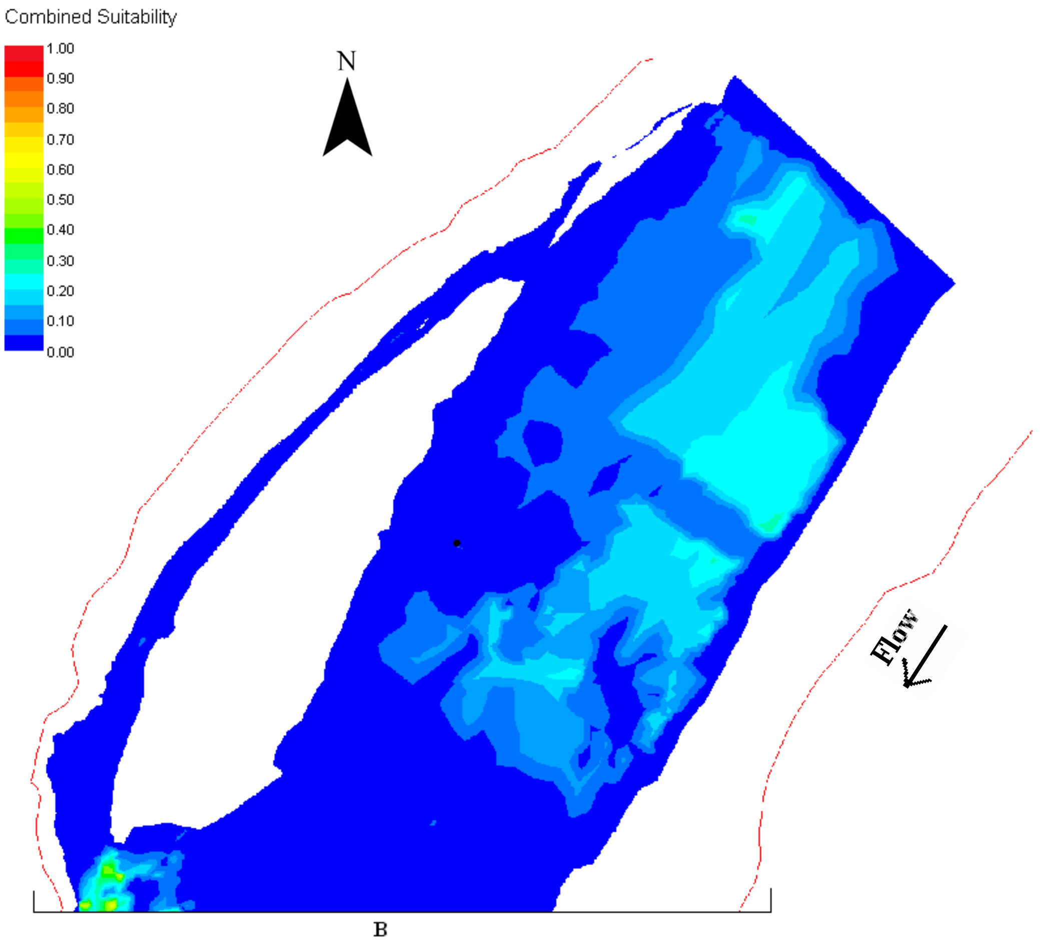


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:2134**

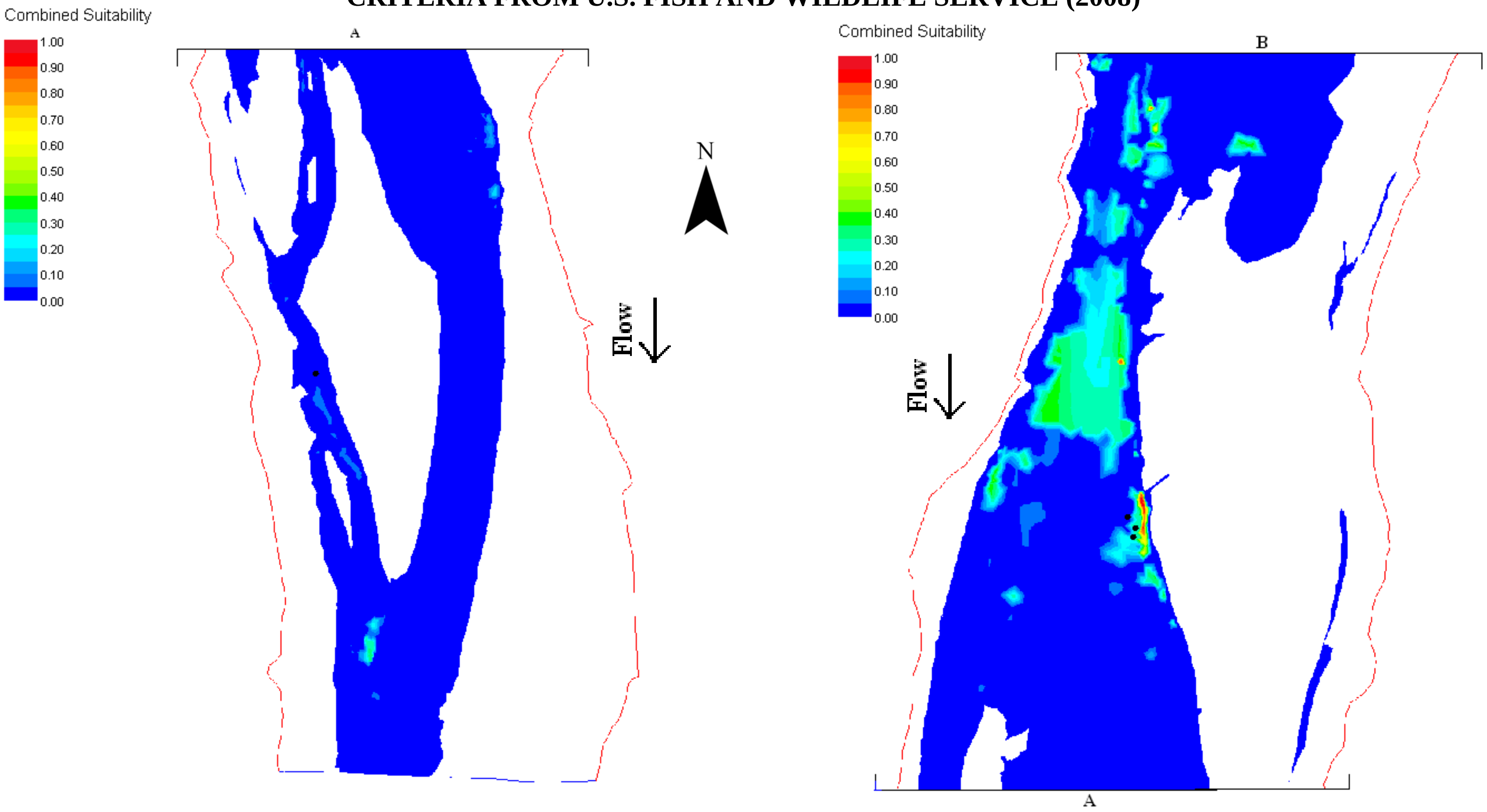
# TIMBUCTOO STUDY SITE, JANUARY 7 – FEBRUARY 6, 2002, FLOW = 1838 CFS
# DENSITY CRITERIA



**Scale: 1:980**

Redd locations: ●

## TIMBUCTOO STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008)

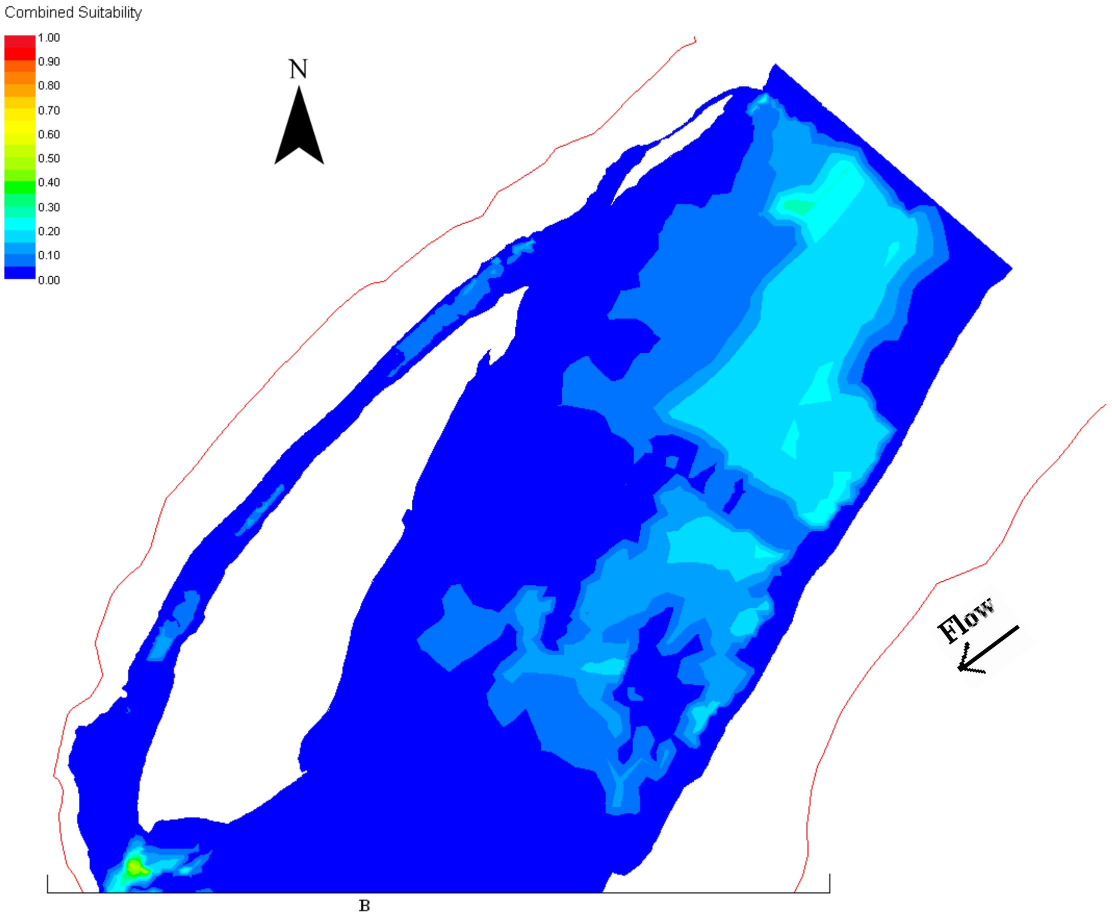


**Scale: 1:2656**

Redd locations: ●

**Scale: 1:2203**

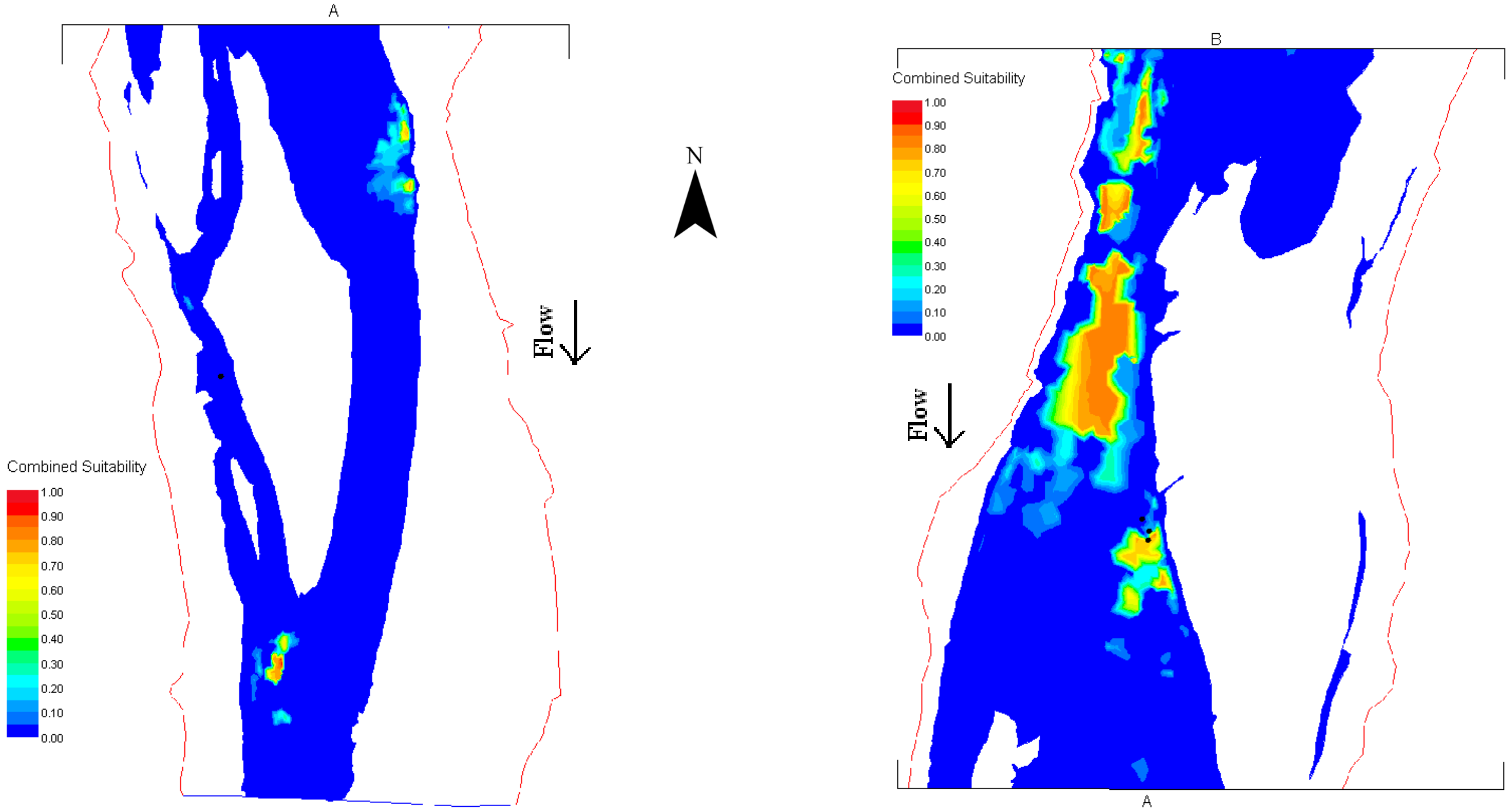
## TIMBUCTOO STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008) (CONTINUED)



**Scale: 1:925**

Redd locations: ●

## TIMBUCTOO STUDY, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20

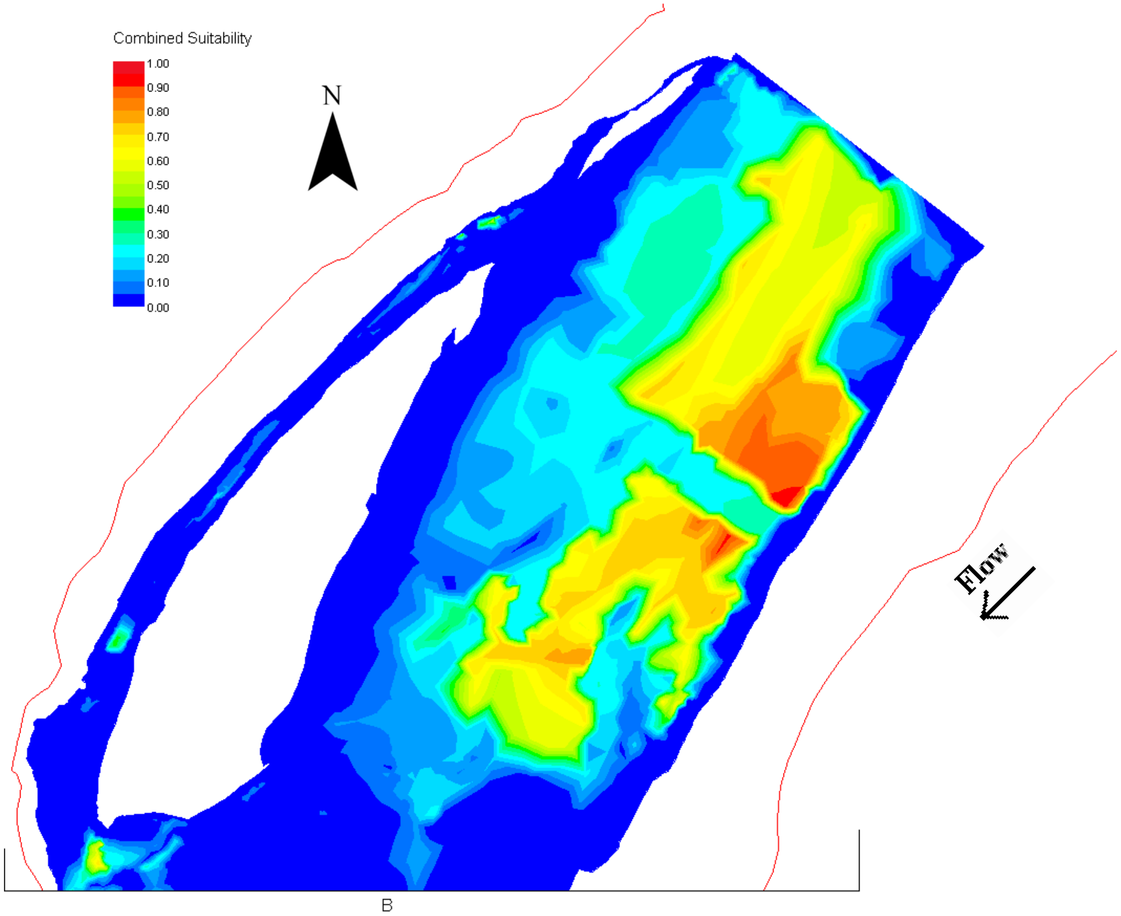


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:2134**

# TIMBUCTOO STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20 (CONTINUED)

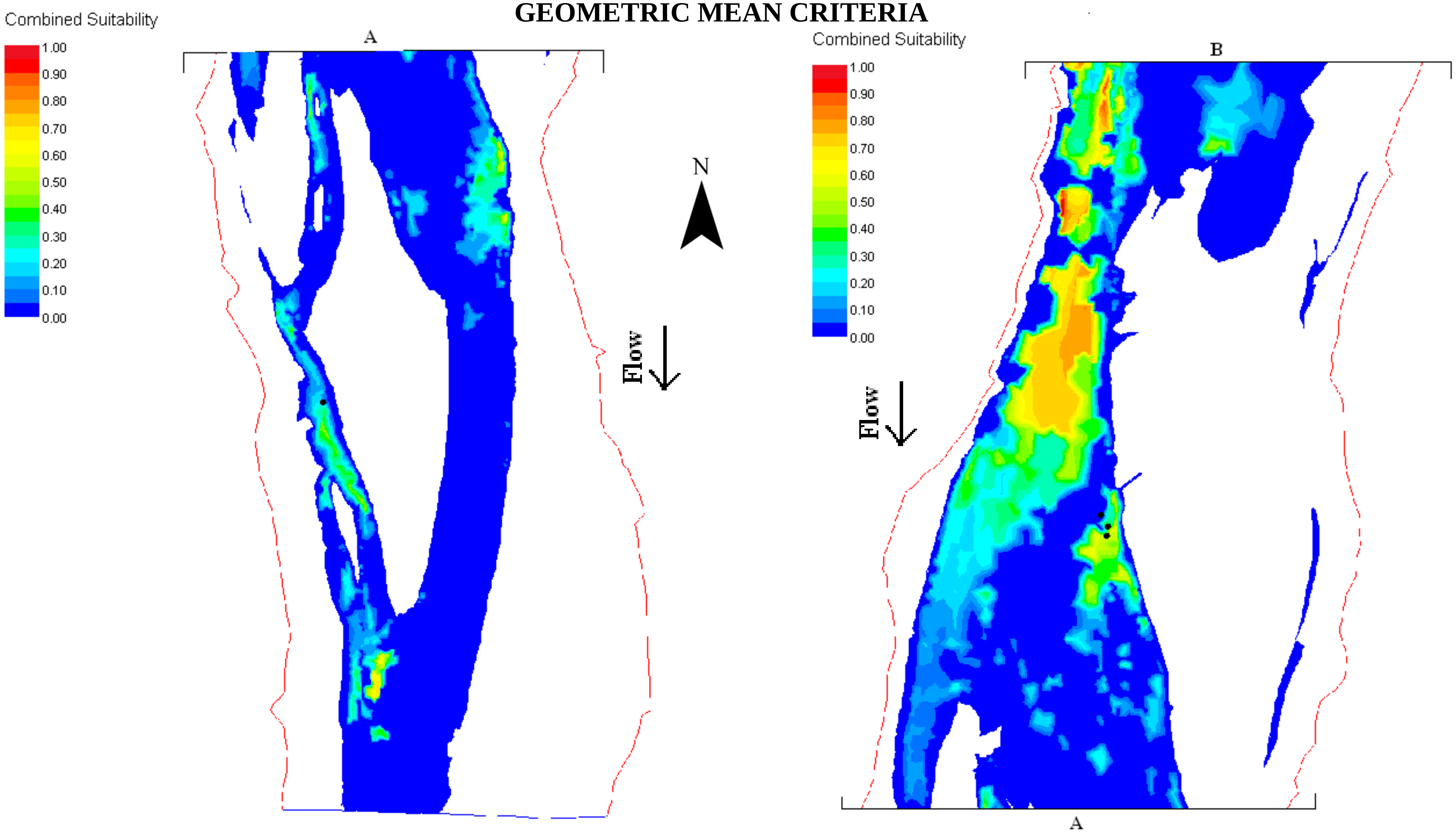


**Scale: 1:967**

Redd locations: ●

Appendix D

## TIMBUCTOO STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## GEOMETRIC MEAN CRITERIA

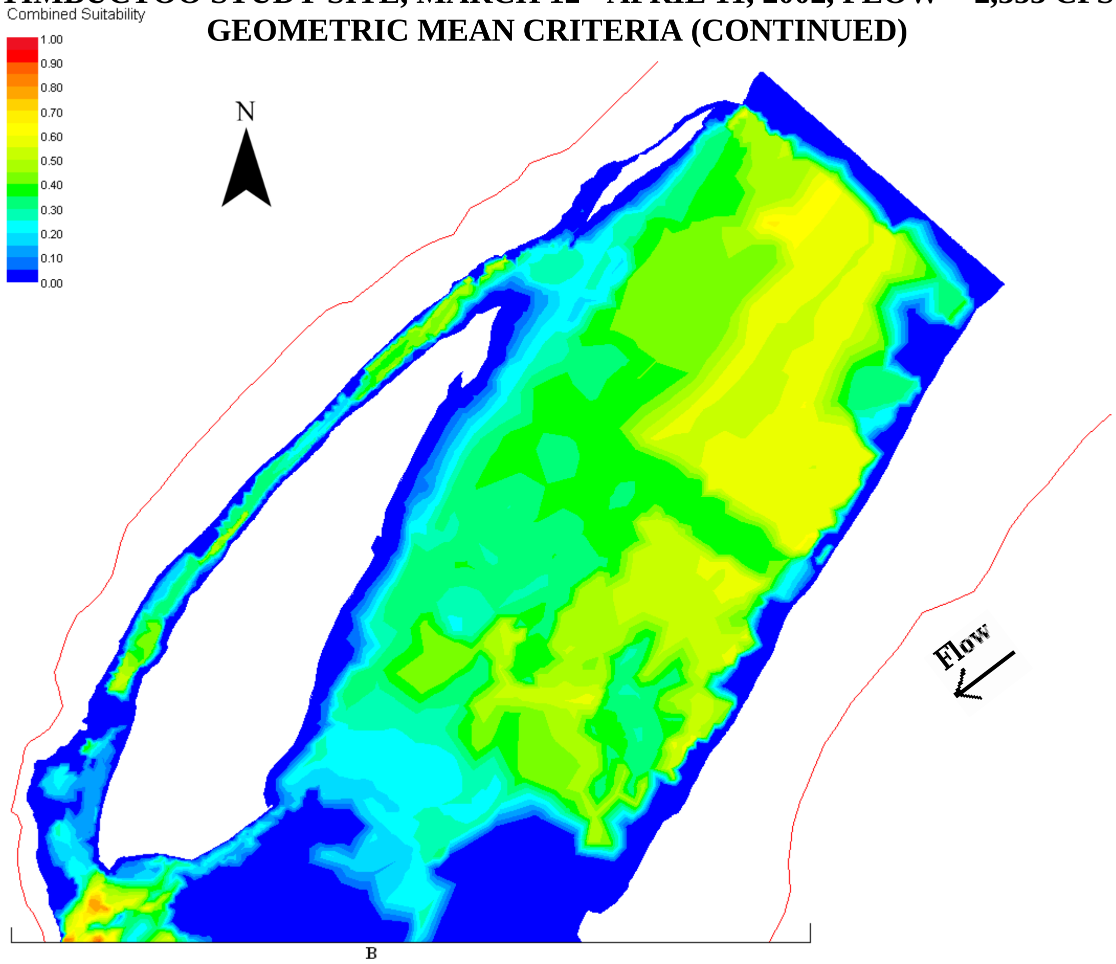


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:2064**

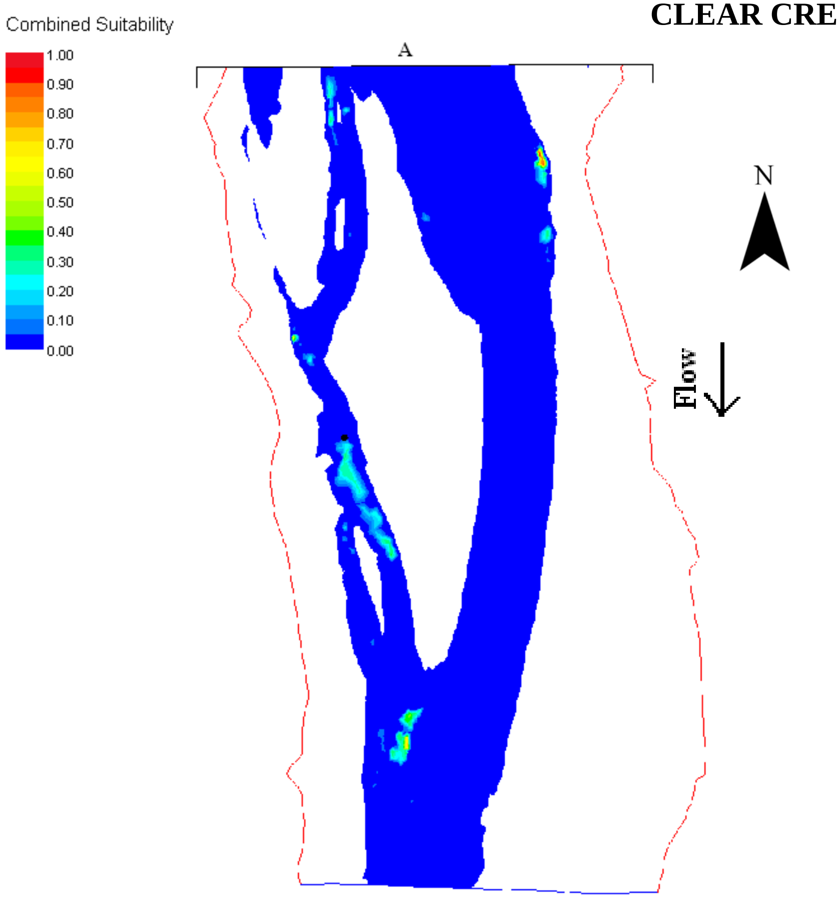
# TIMBUCTOO STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
# GEOMETRIC MEAN CRITERIA (CONTINUED)

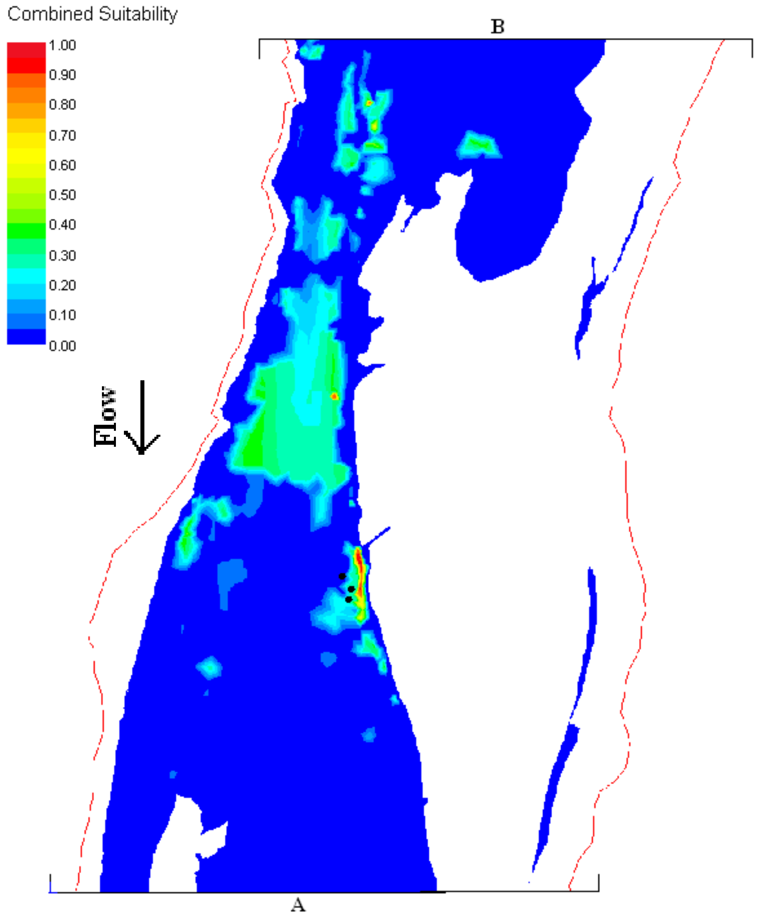


**Scale: 1:828**

Redd locations: ●

## TIMBUCTOO STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## CLEAR CREEK CRITERIA



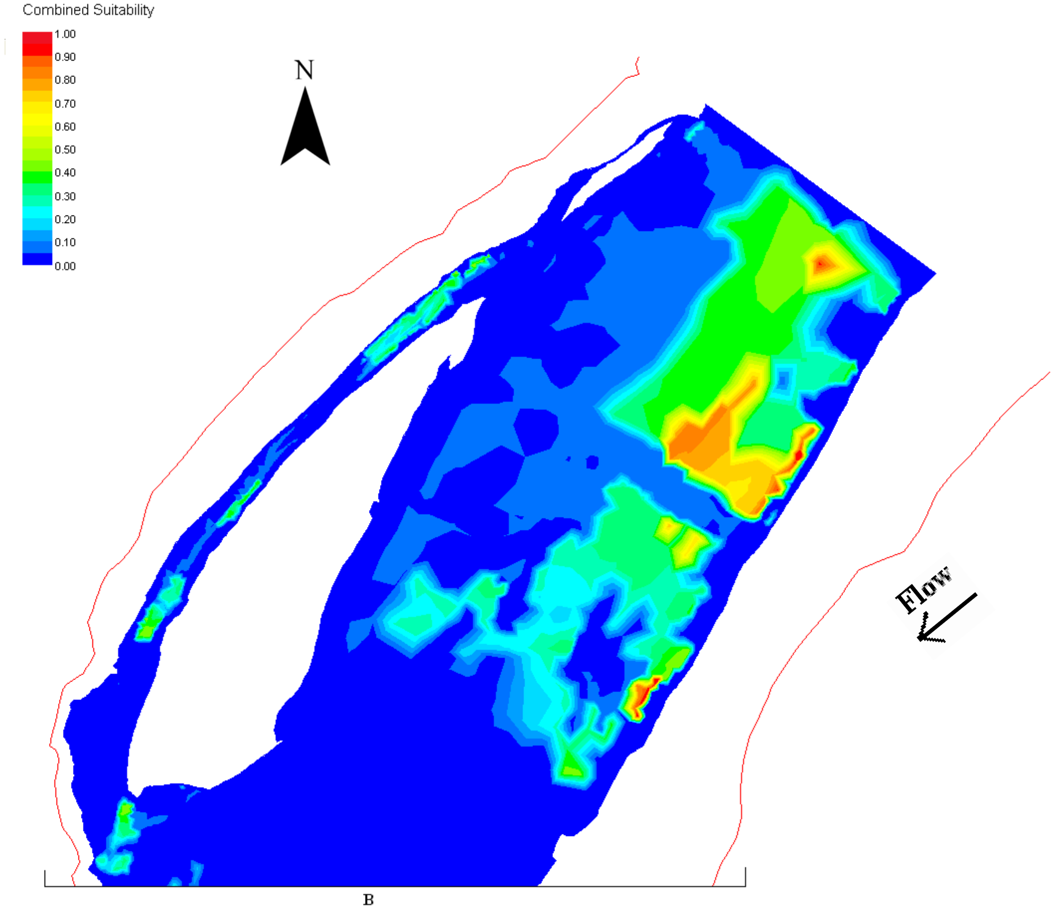


**Scale: 1:2656**

Redd locations: ●

**Scale: 1:2138**

# TIMBUCTOO STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
# CLEAR CREEK CRITERIA (CONTINUED)

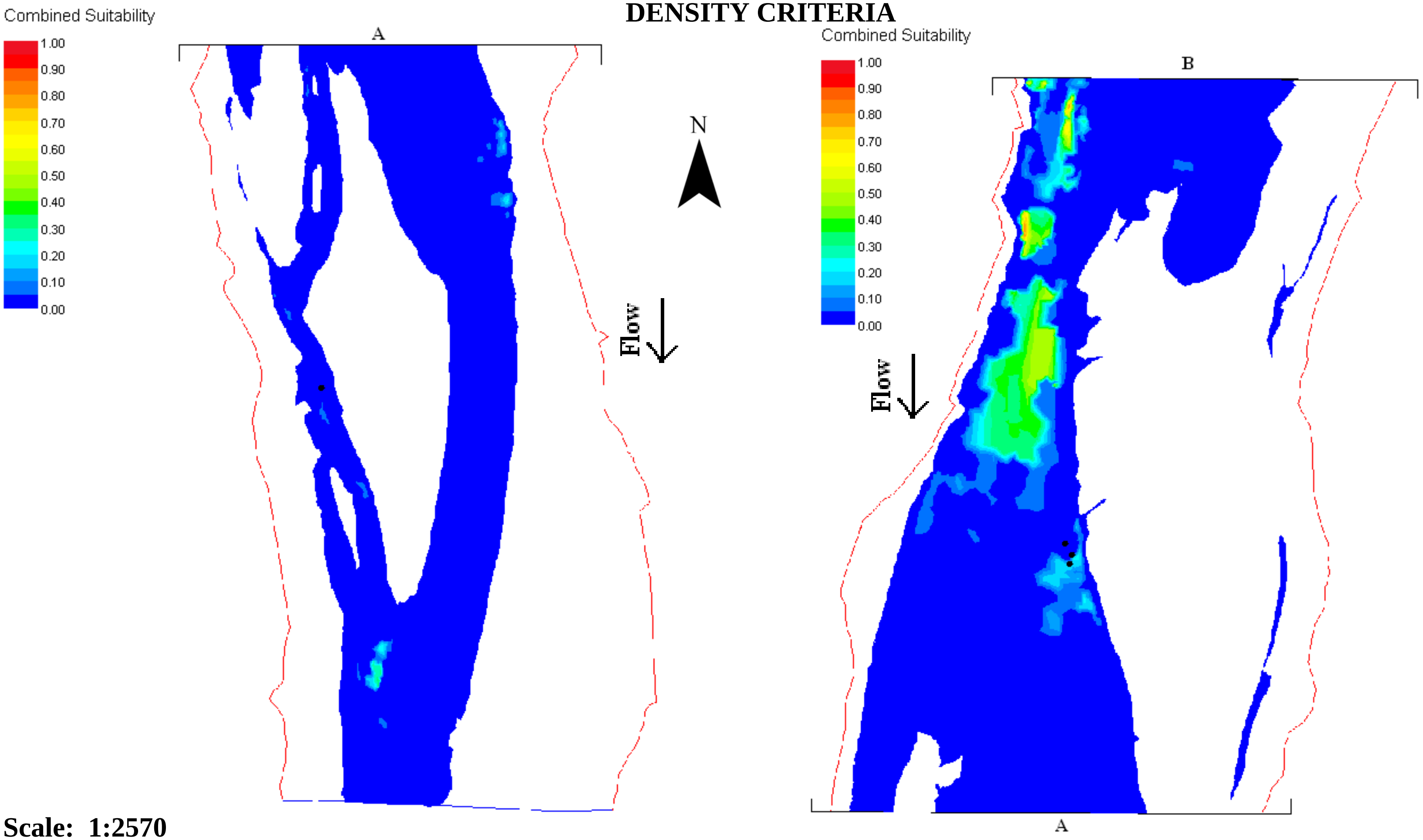


**Scale: 1:1452**

Redd locations: ●

Appendix D

## TIMBUCTOO STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## DENSITY CRITERIA

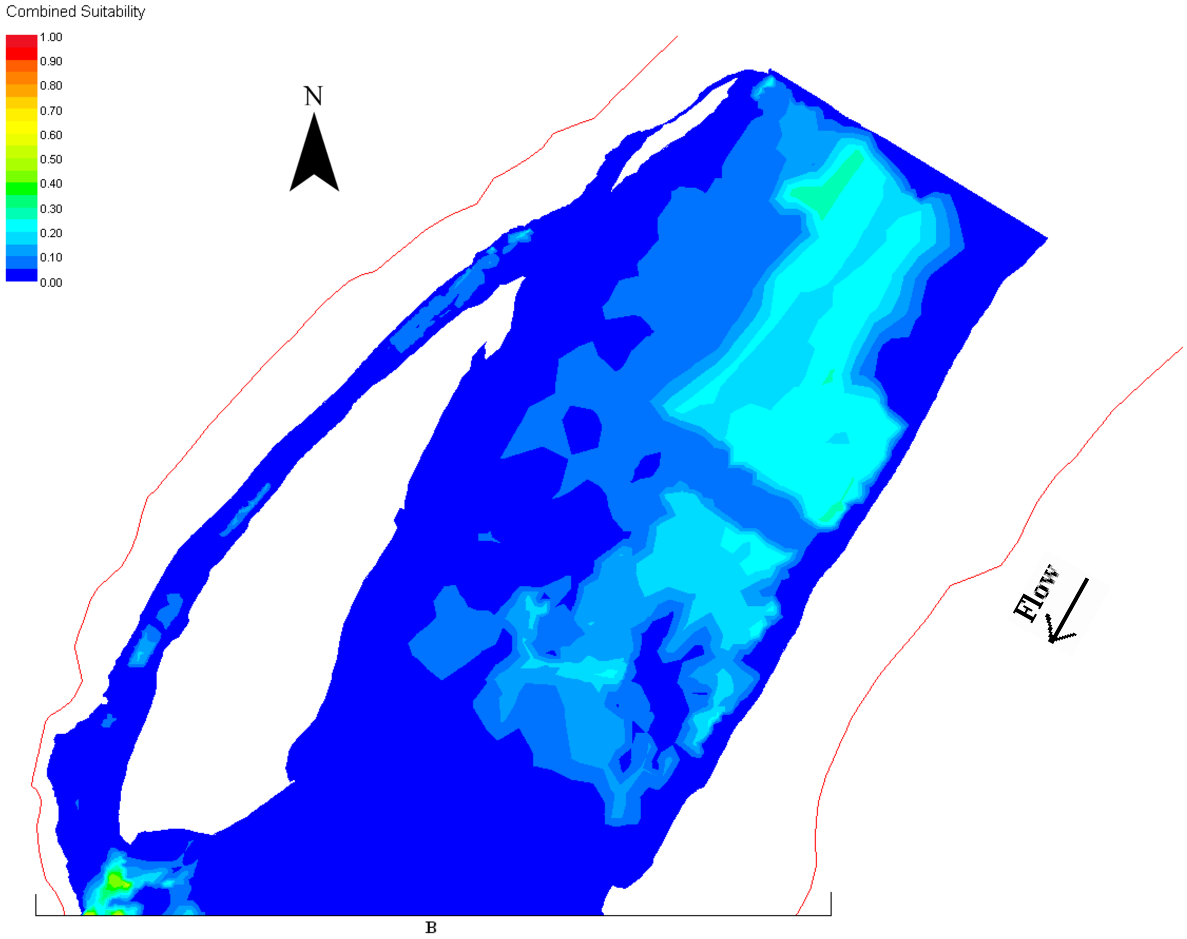


**Scale: 1:2570**

Redd locations: ●

**Scale: 1:2193**

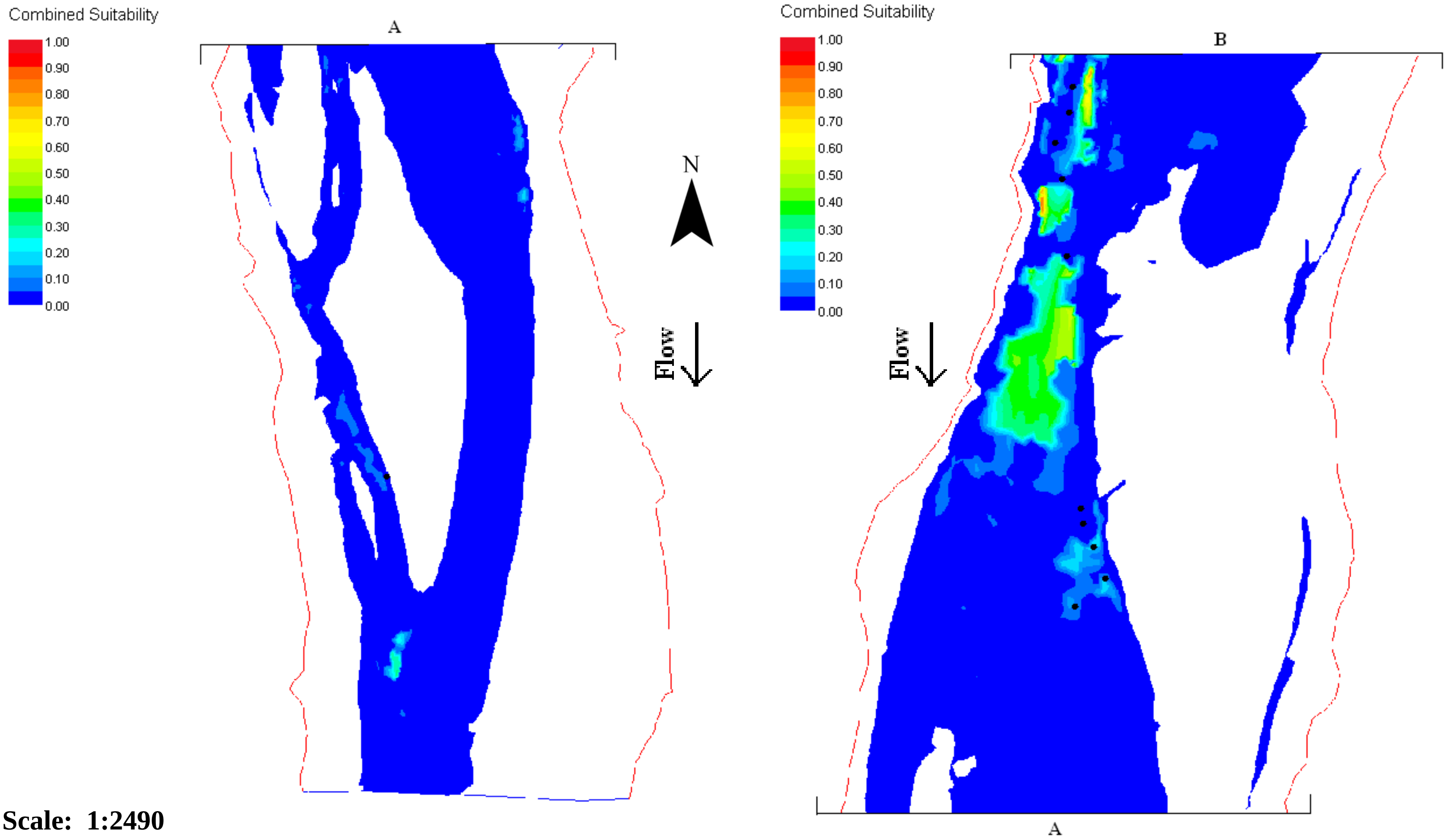
## TIMBUCTOO STUDY, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## DENSITY CRITERIA (CONTINUED)



**Scale: 1:1294**

Redd locations: ●

## TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008)

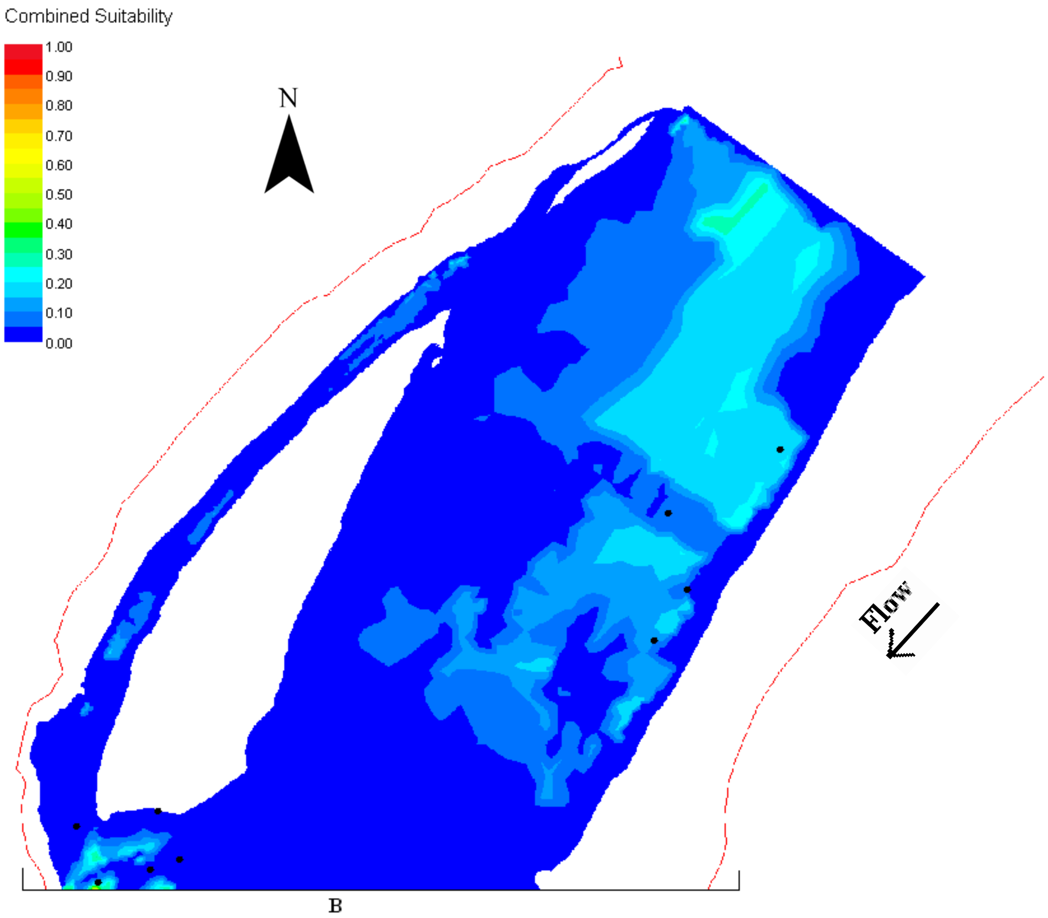


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:1981**

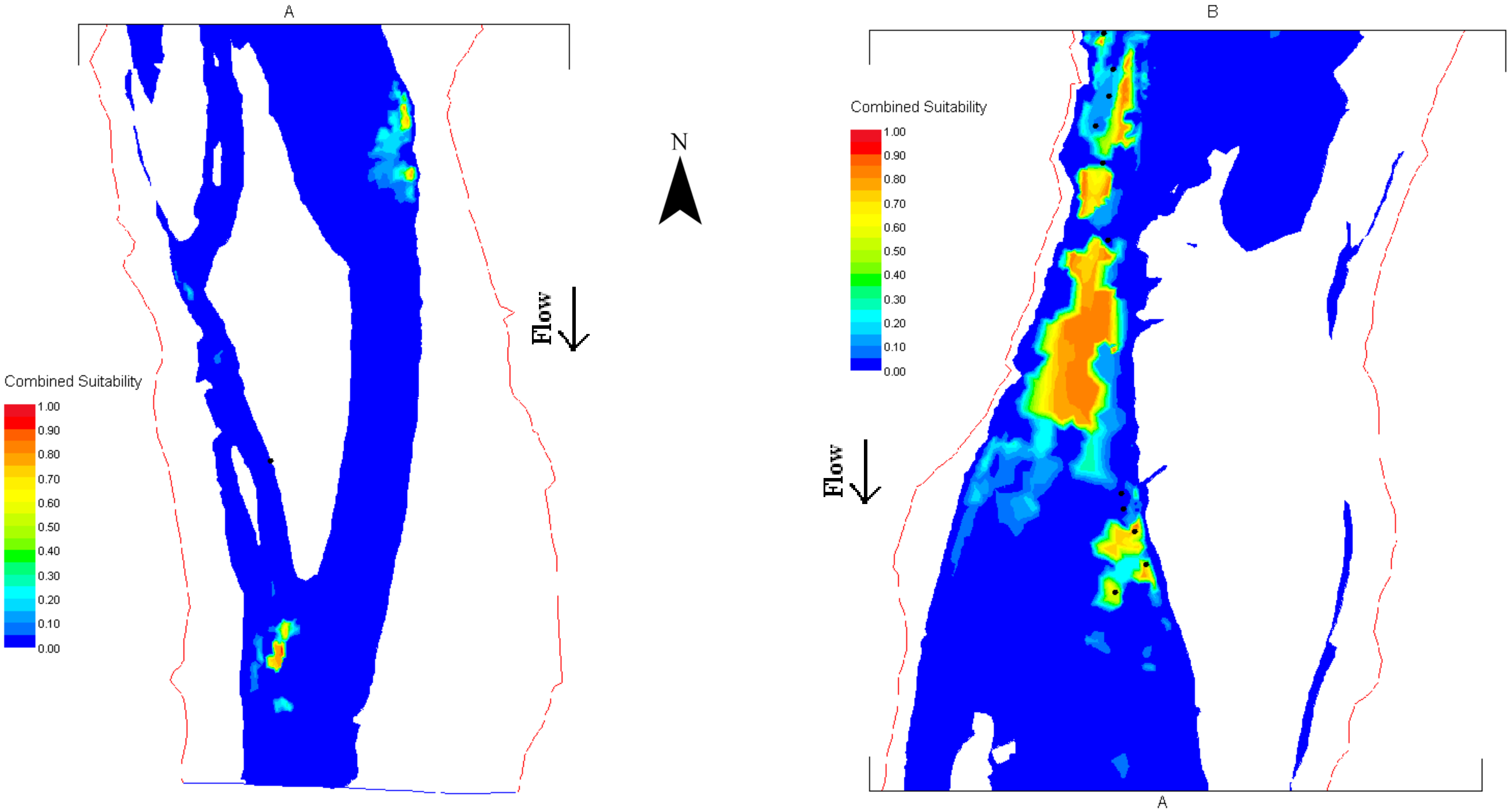
## TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008) (CONTINUED)



**Scale: 1:1585**

Redd locations: ●

# TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
# CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20

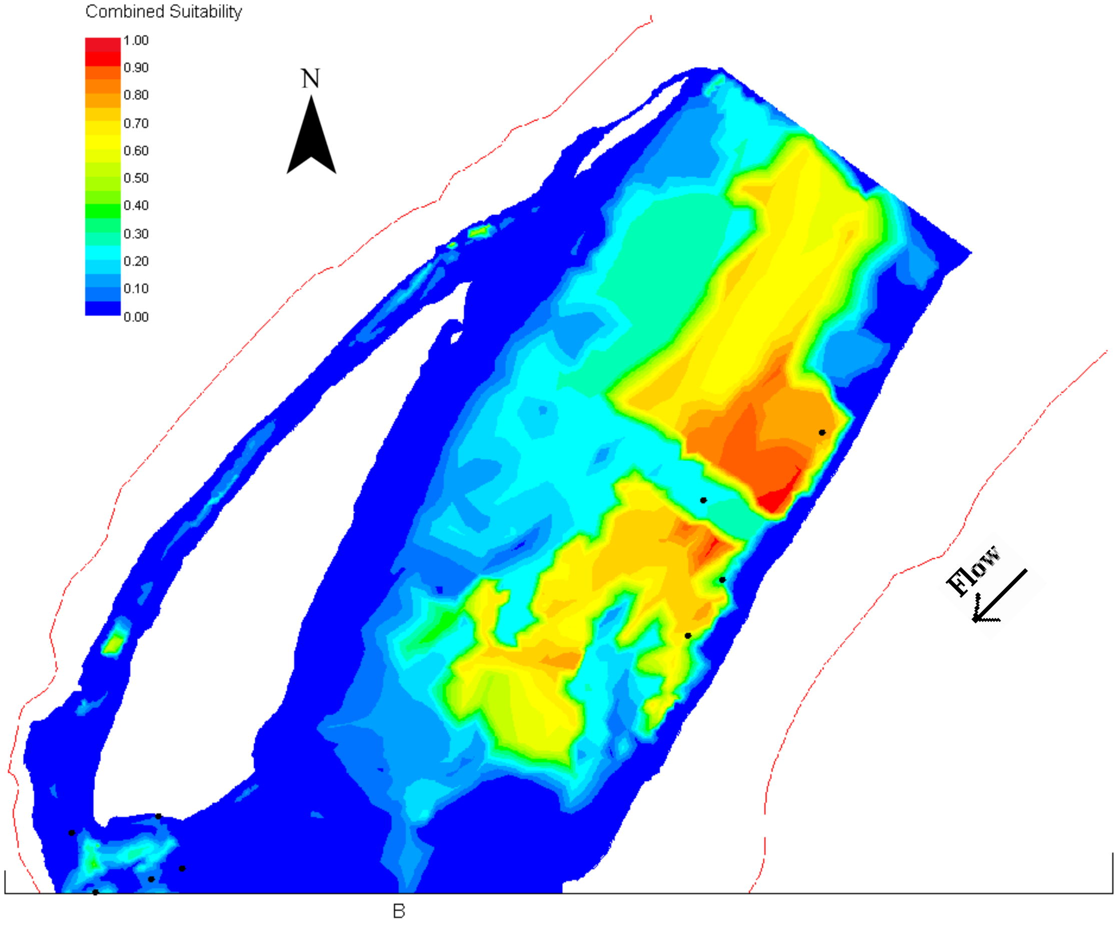


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:2085**

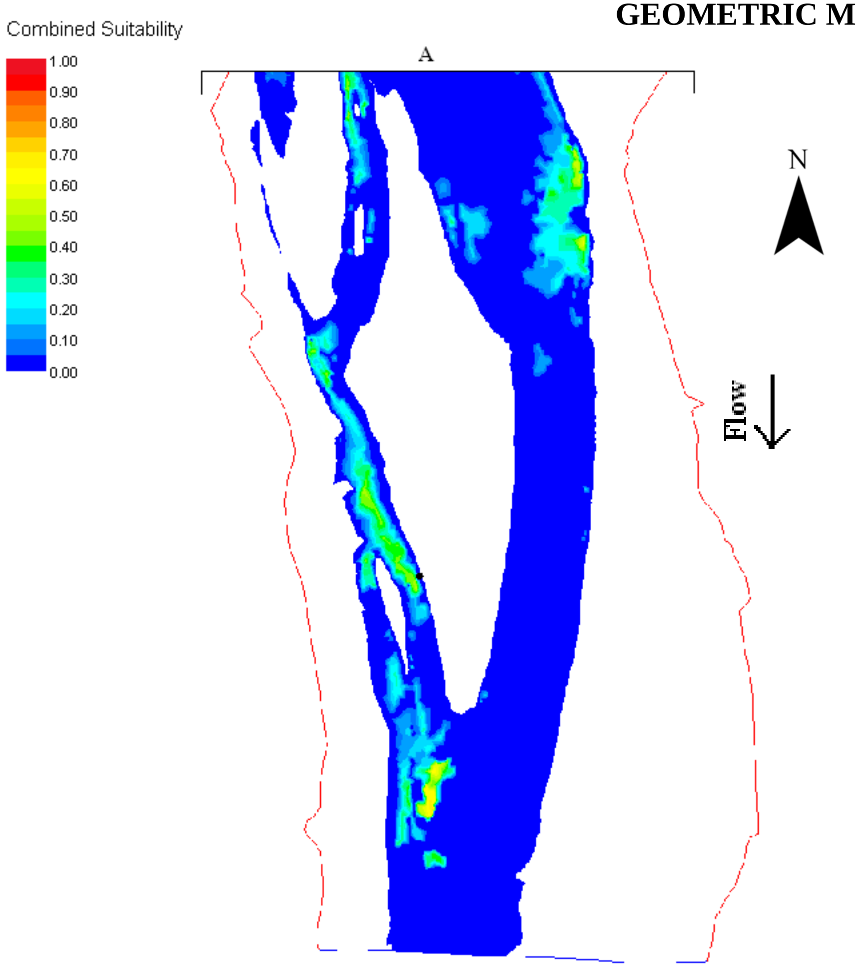
# TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
# CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20 (CONTINUED)

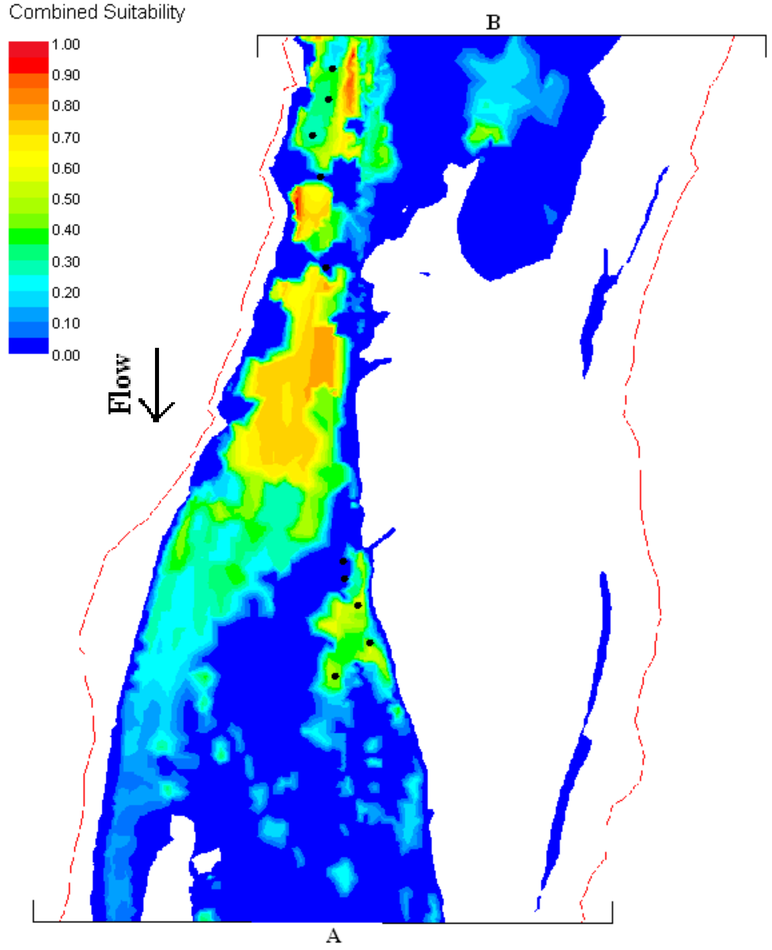


**Scale: 1:1308**

Redd locations: ●

## TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## GEOMETRIC MEAN CRITERIA



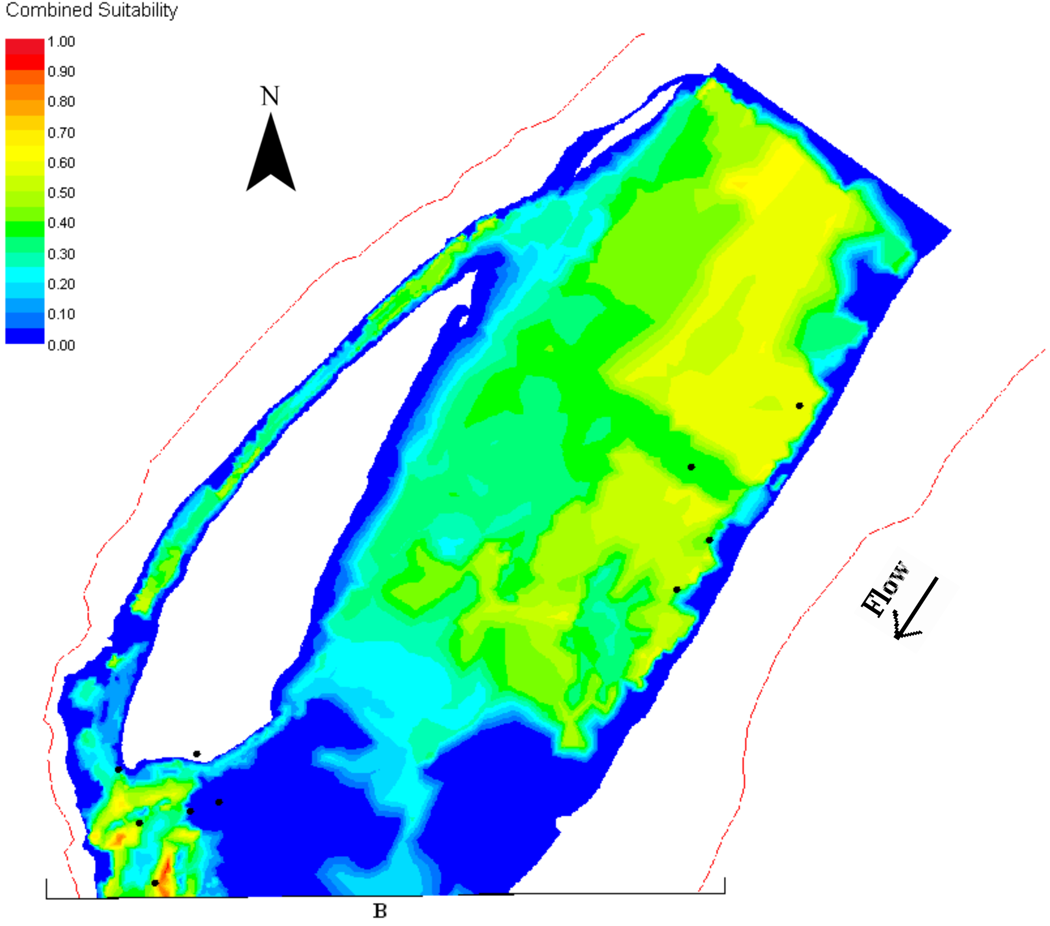


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:2037**

## TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## GEOMETRIC MEAN CRITERIA (CONTINUED)

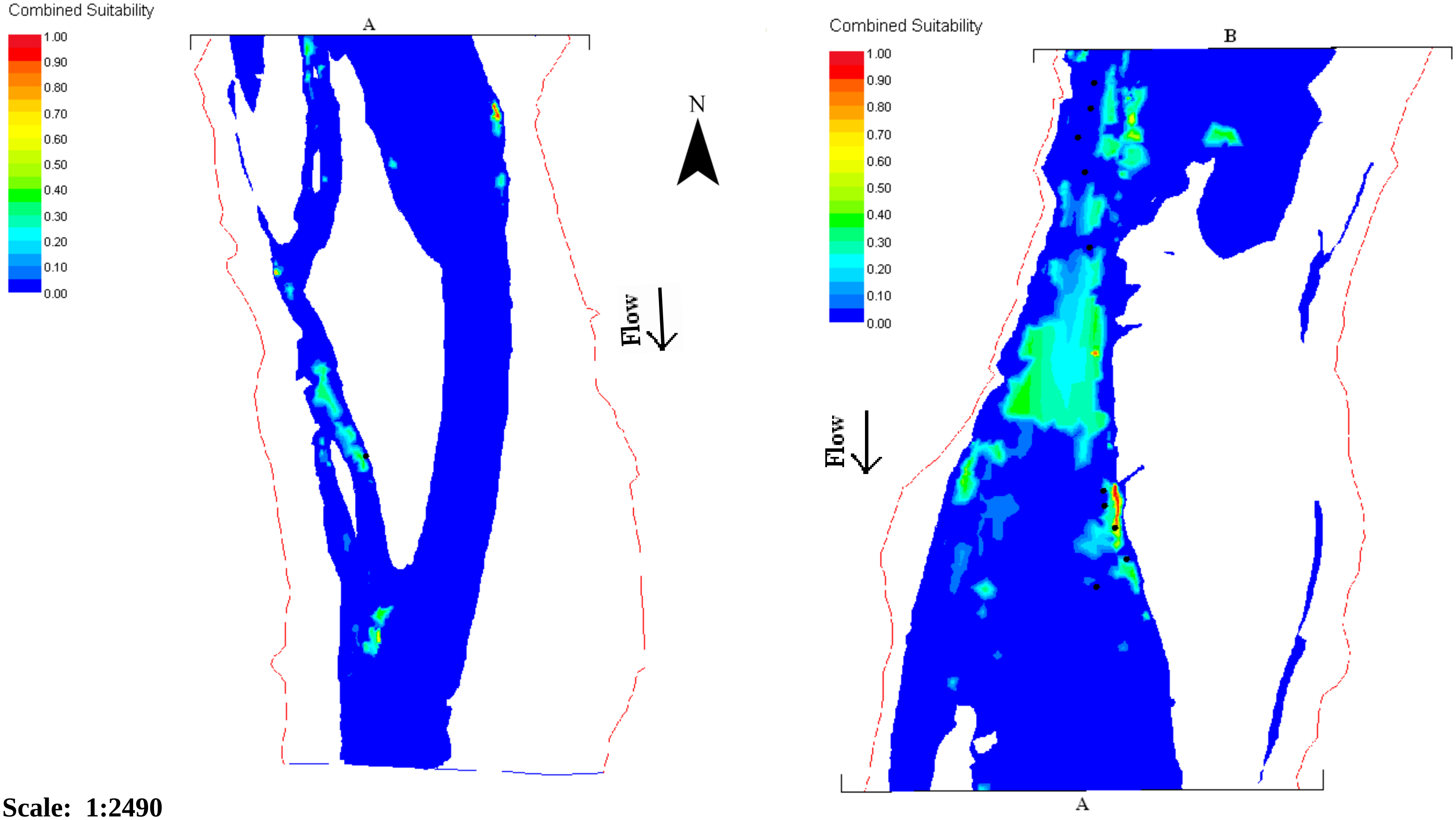


**Scale: 1:1478**

Redd locations: ●

Appendix D

## TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## CLEAR CREEK CRITERIA

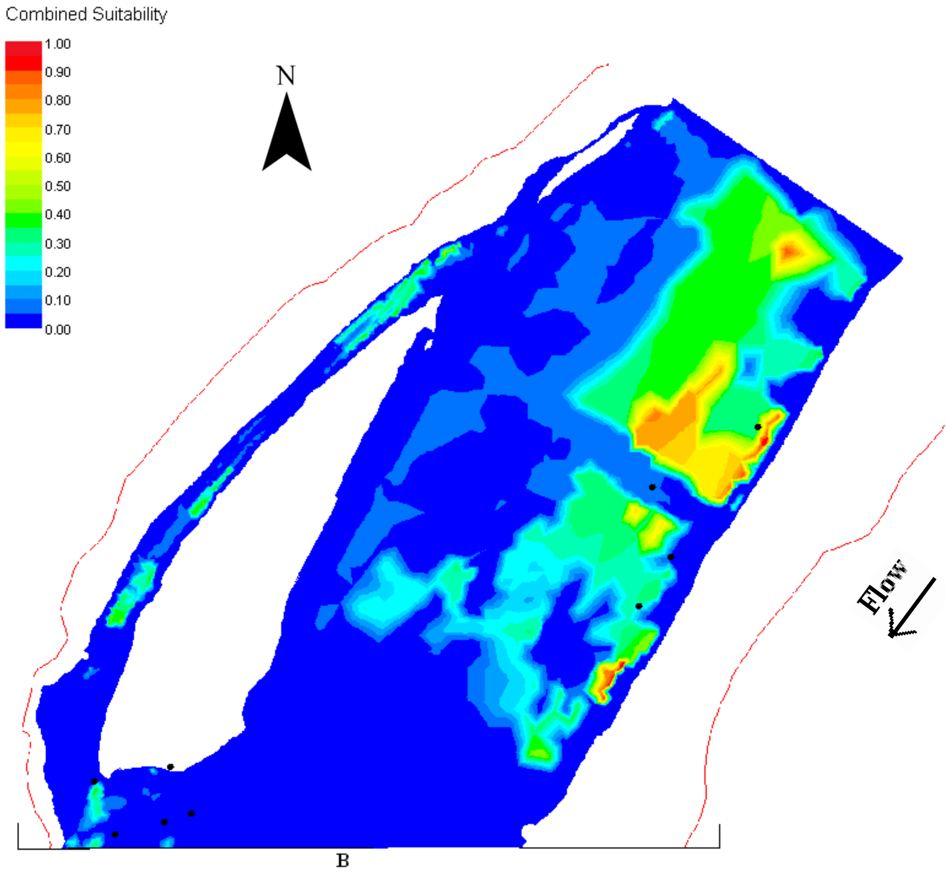


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:2027**

# TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS CLEAR CREEK CRITERIA (CONTINUED)

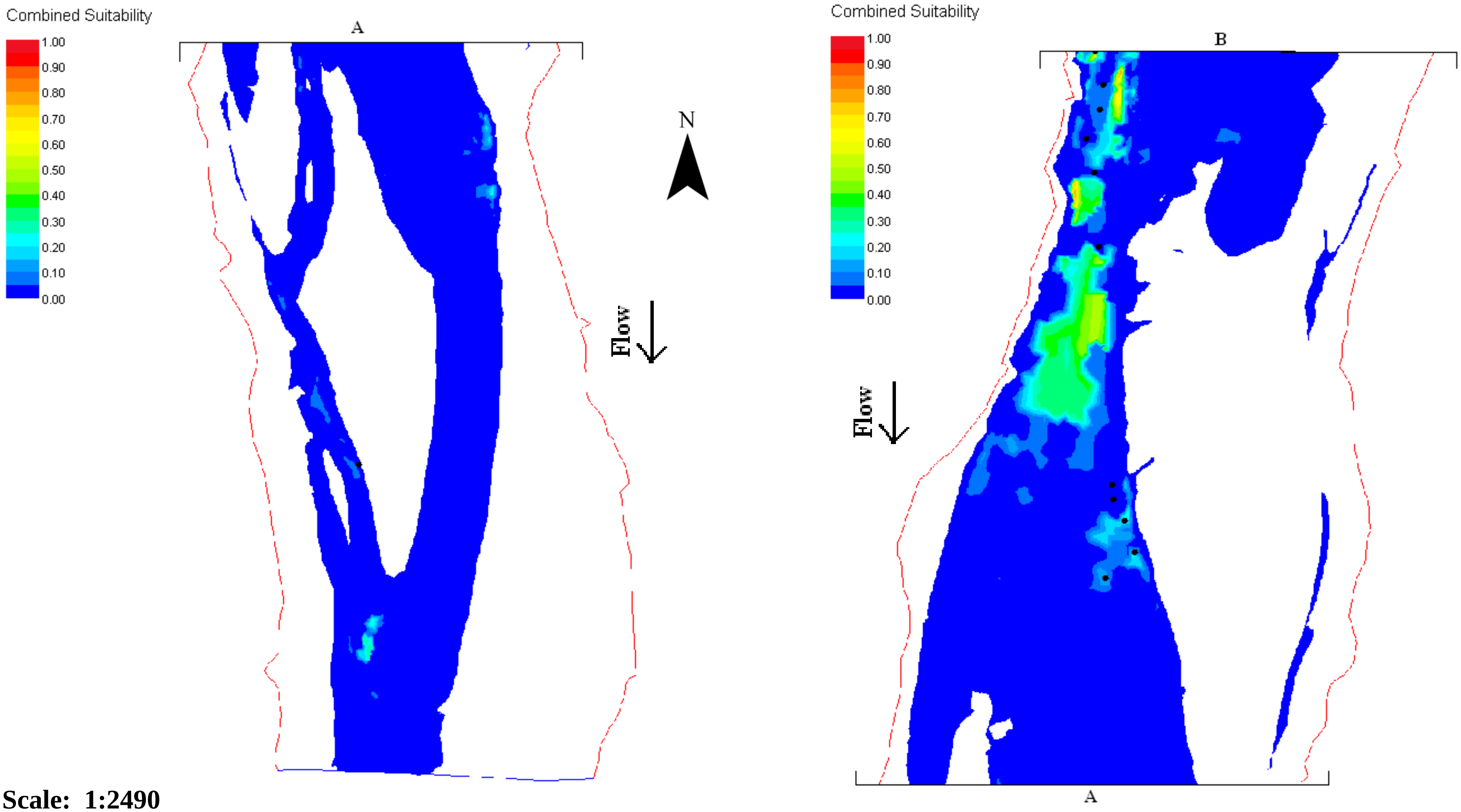


**Scale: 1:1377**

Redd locations: ●

Appendix D

## TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## DENSITY CRITERIA

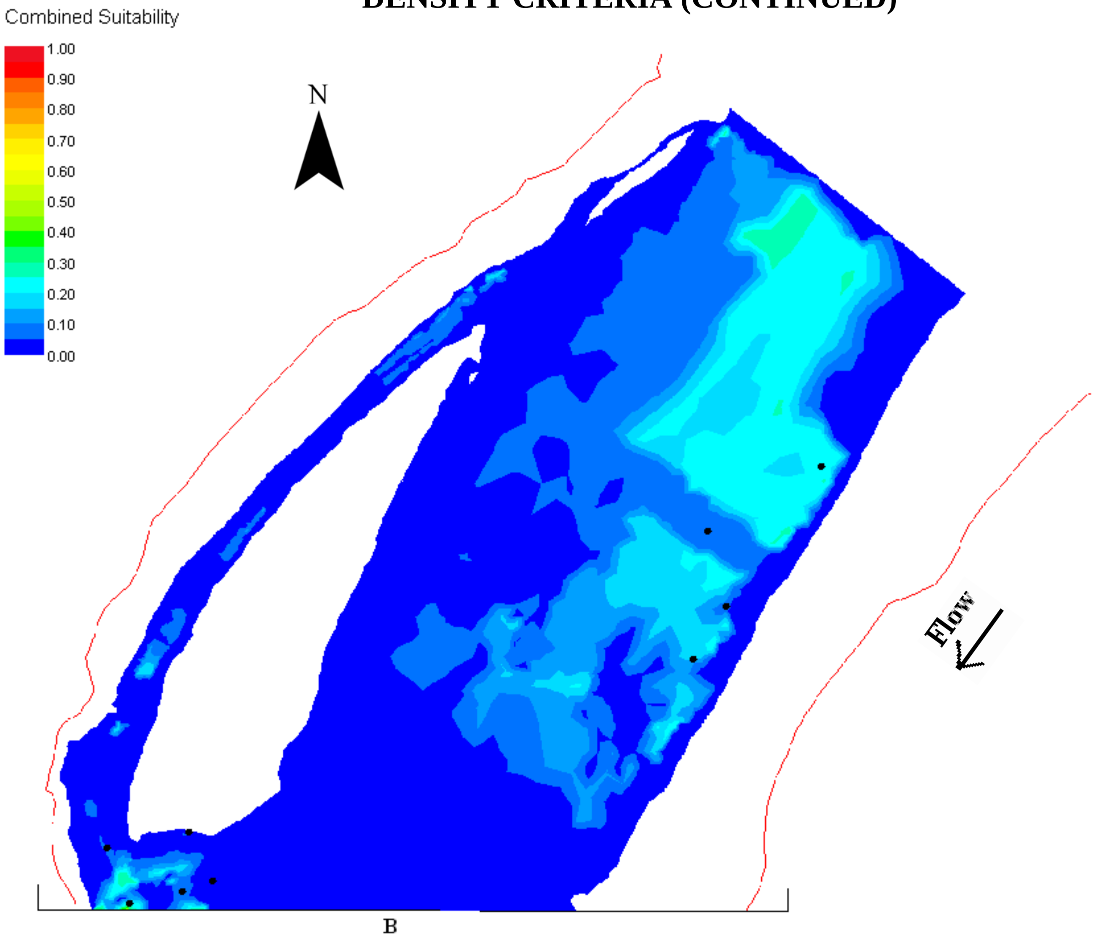


**Scale: 1:2490**

Redd locations: ●

**Scale: 1:2075**

# TIMBUCTOO STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS DENSITY CRITERIA (CONTINUED)

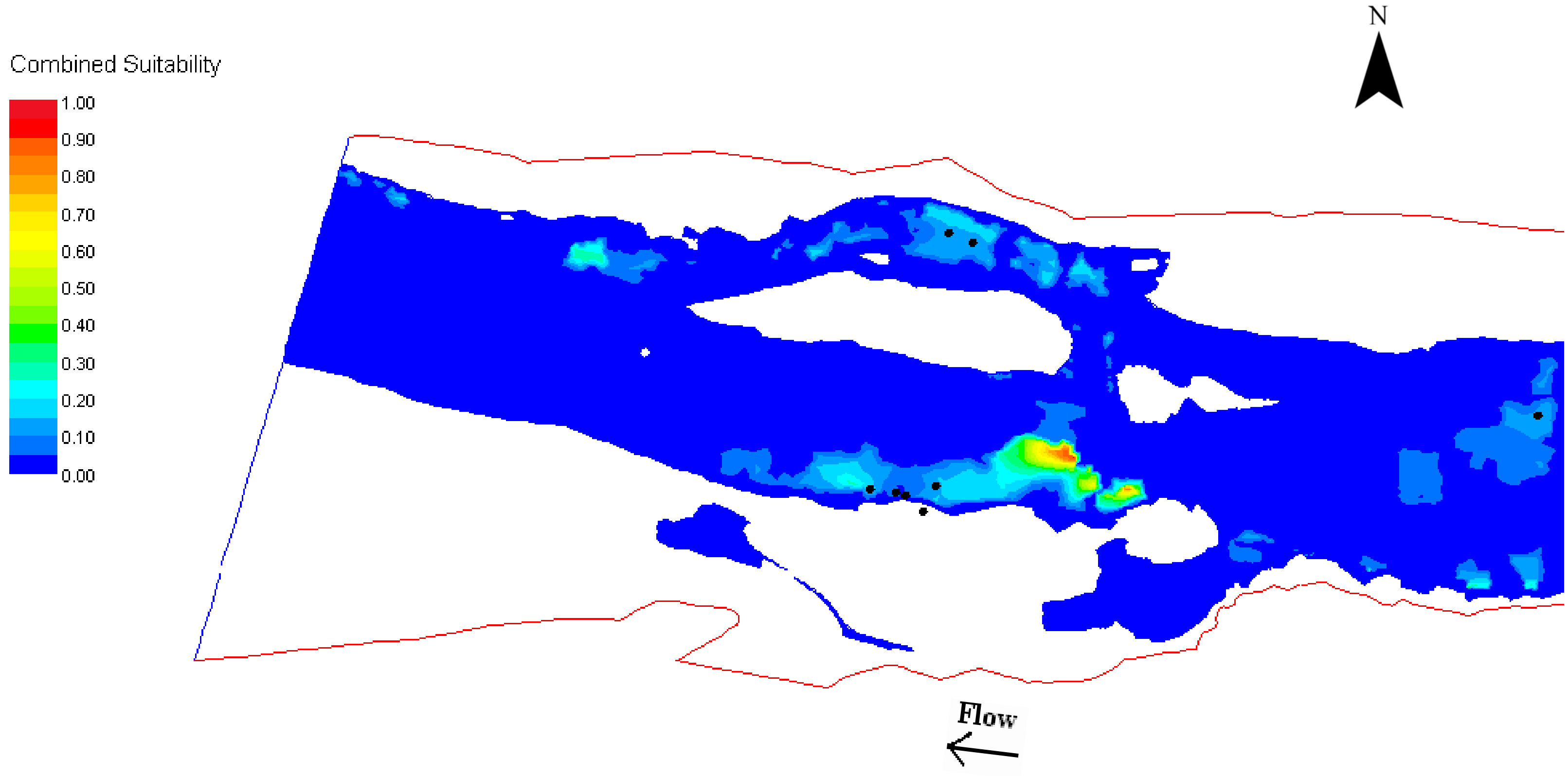


**Scale: 1:1334**

Redd locations: ●

Appendix D

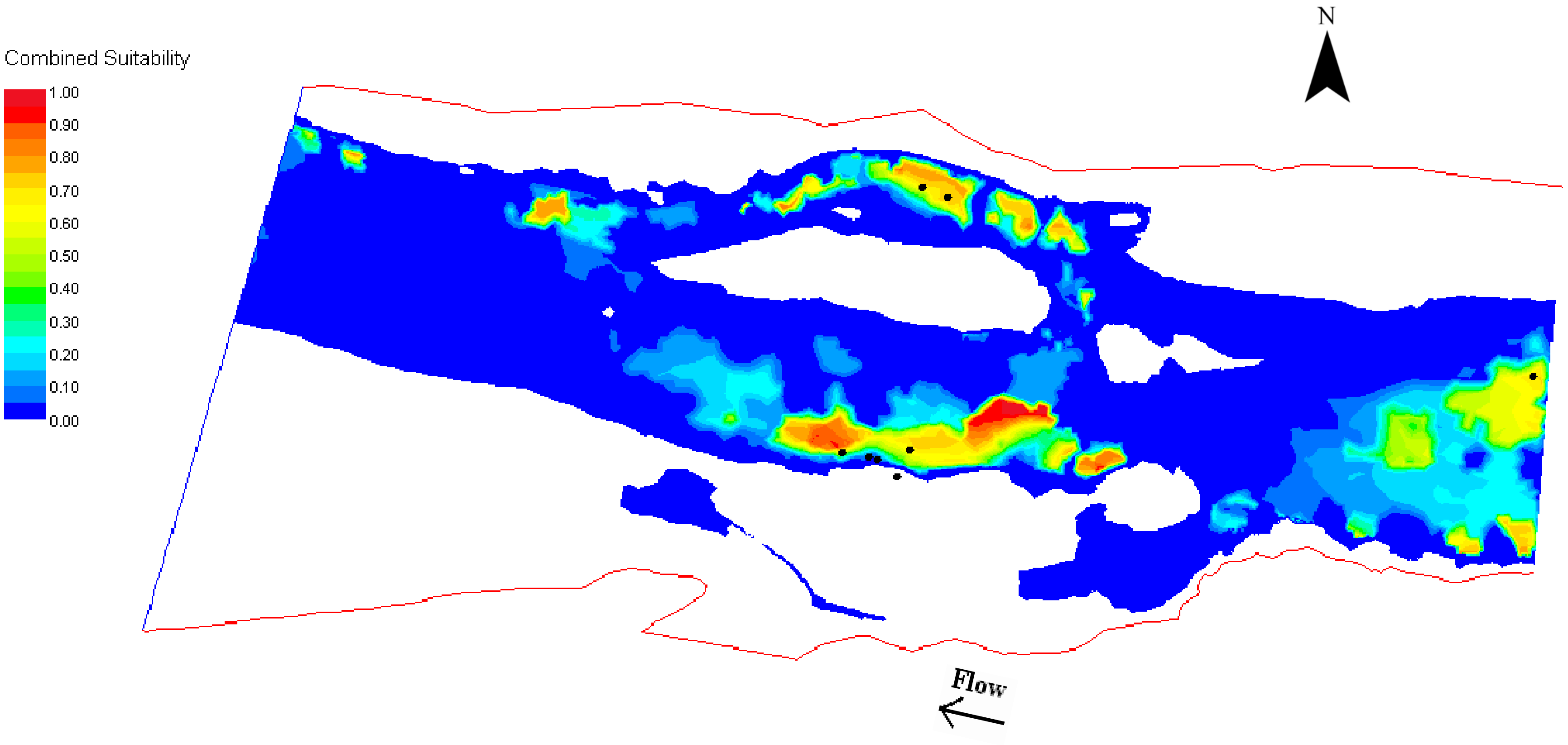
## HIGHWAY 20 STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008)



**Scale: 1:2254**

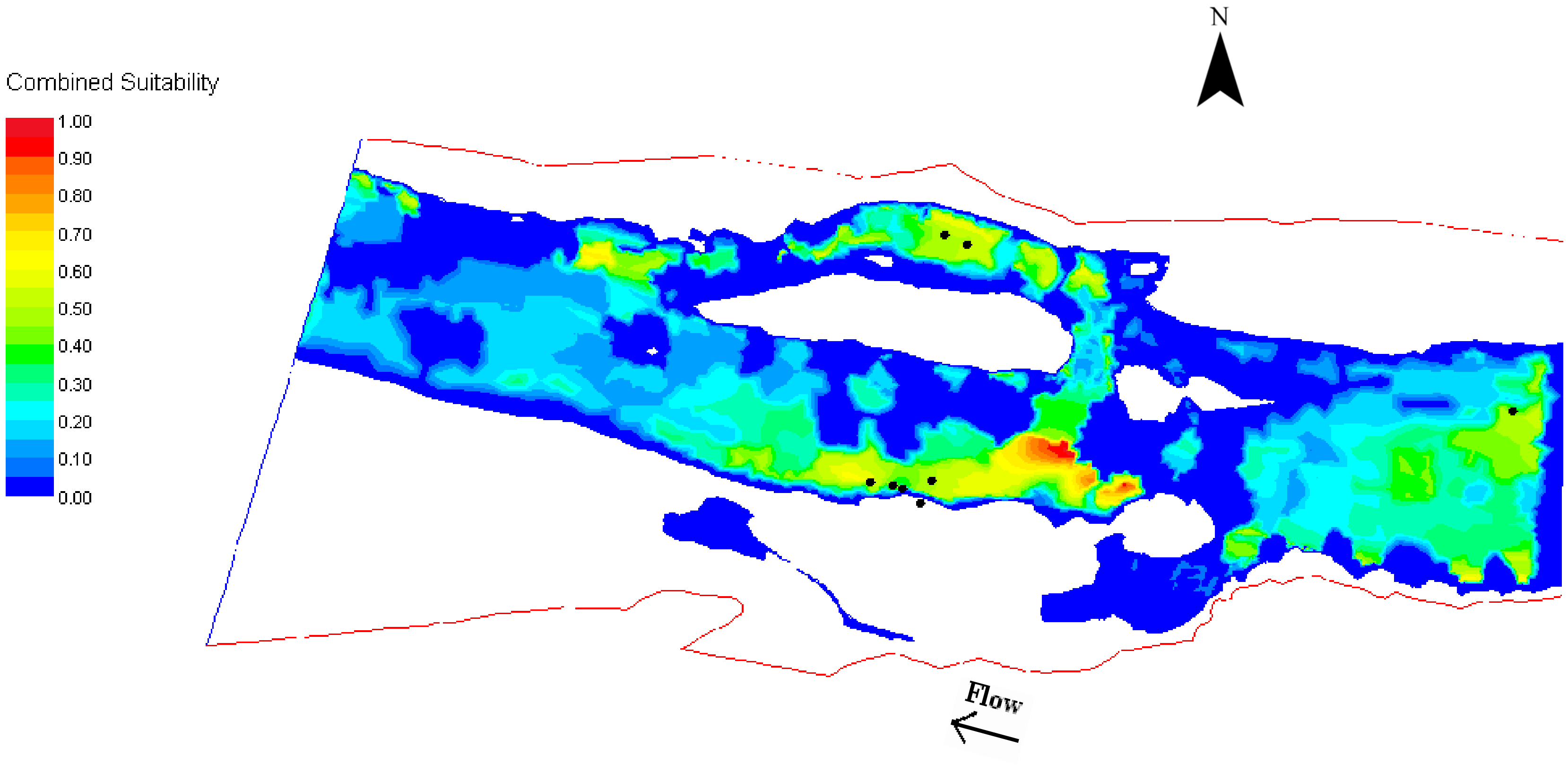
Redd locations: ●

## HIGHWAY 20 STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20



**Scale: 1:1994**
Redd locations: ●

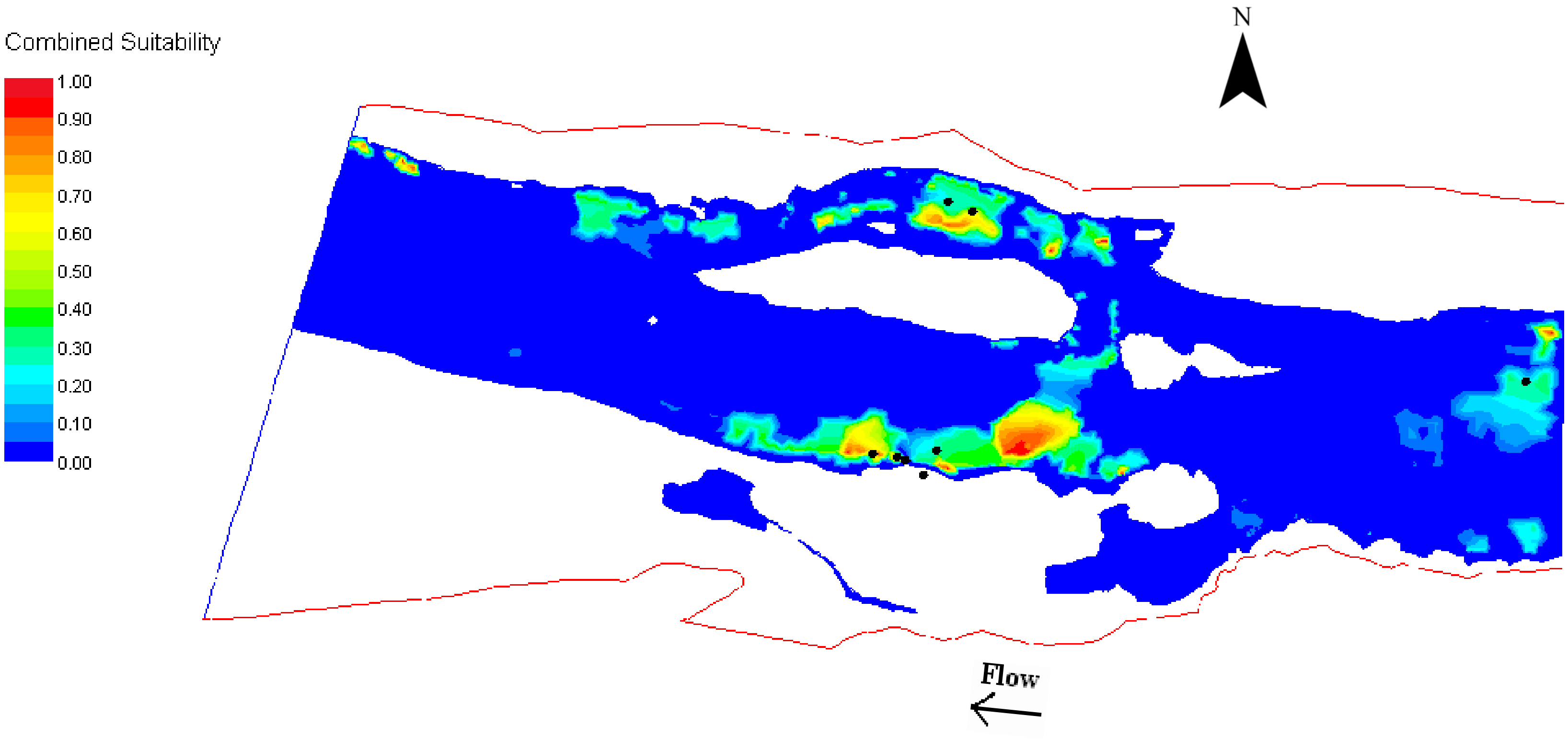
## HIGHWAY 20 STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## GEOMETRIC MEAN CRITERIA



**Scale: 1:2254**

Redd locations: ●

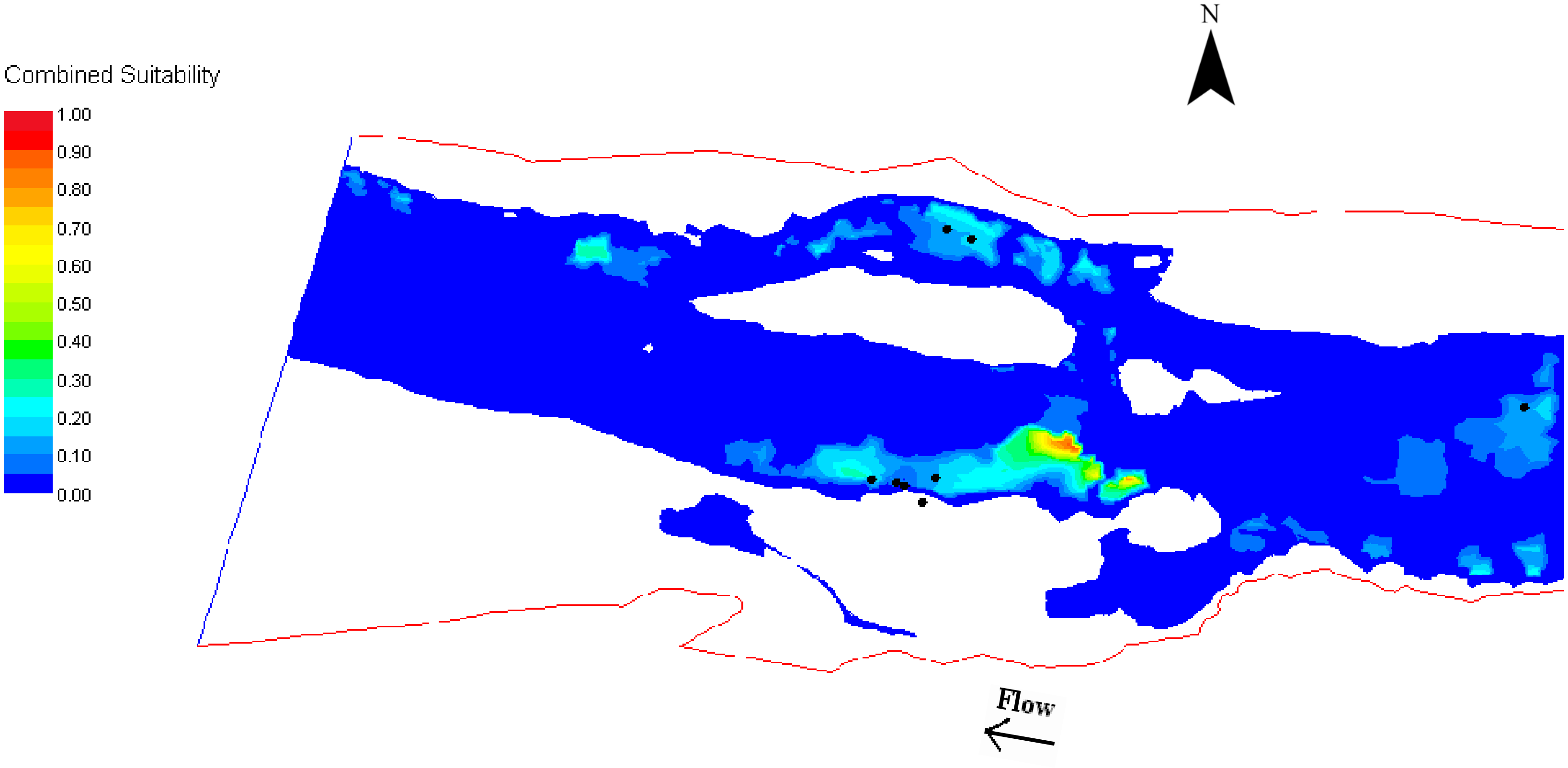
# HIGHWAY 20 STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
# CLEAR CREEK CRITERIA



**Scale: 1:2254**

Redd locations: ●

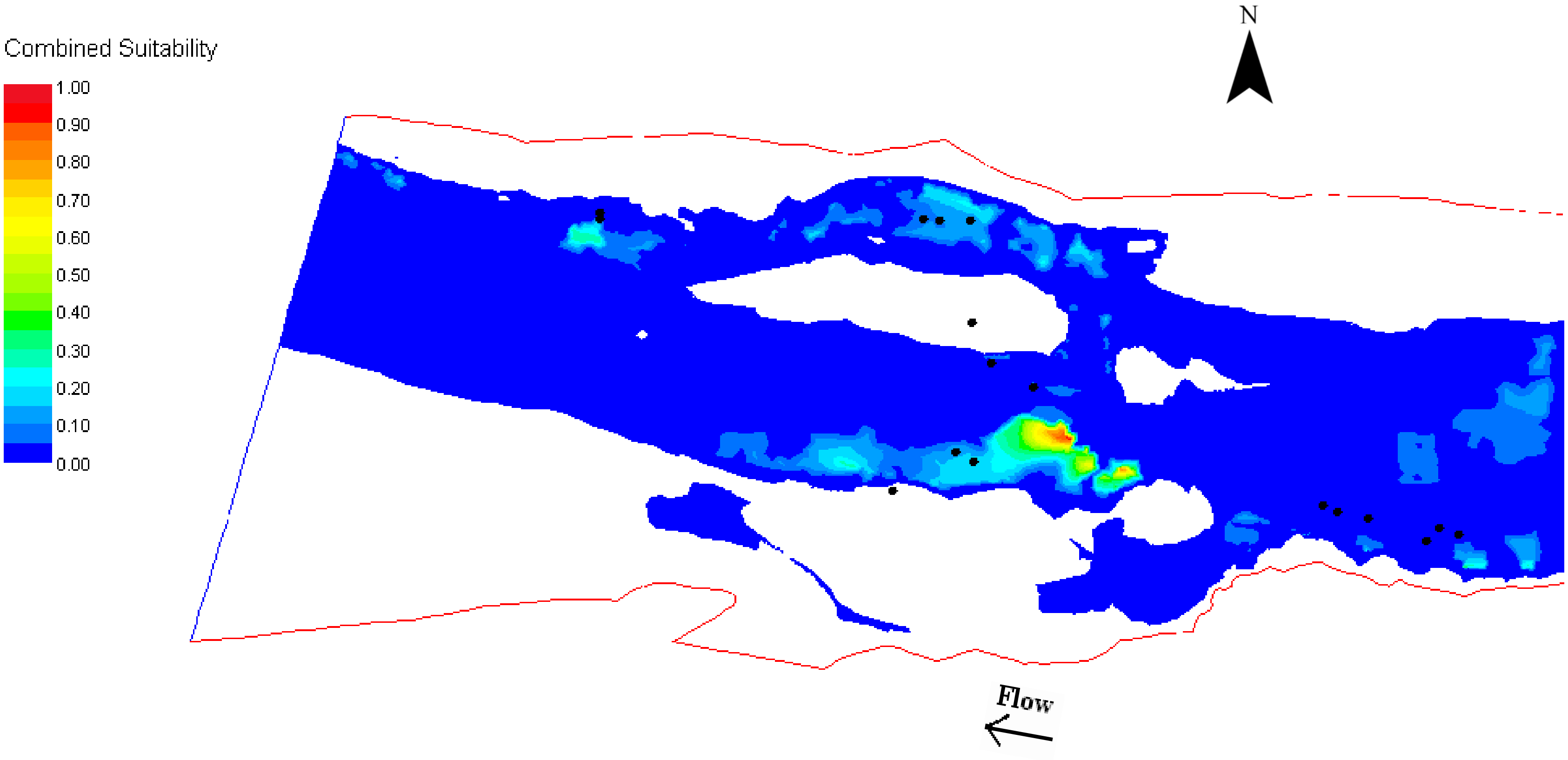
## HIGHWAY 20 STUDY SITE, MARCH 12 - APRIL 11, 2002, FLOW = 2,353 CFS
## DENSITY CRITERIA



**Scale: 1:2254**

Redd locations: ●

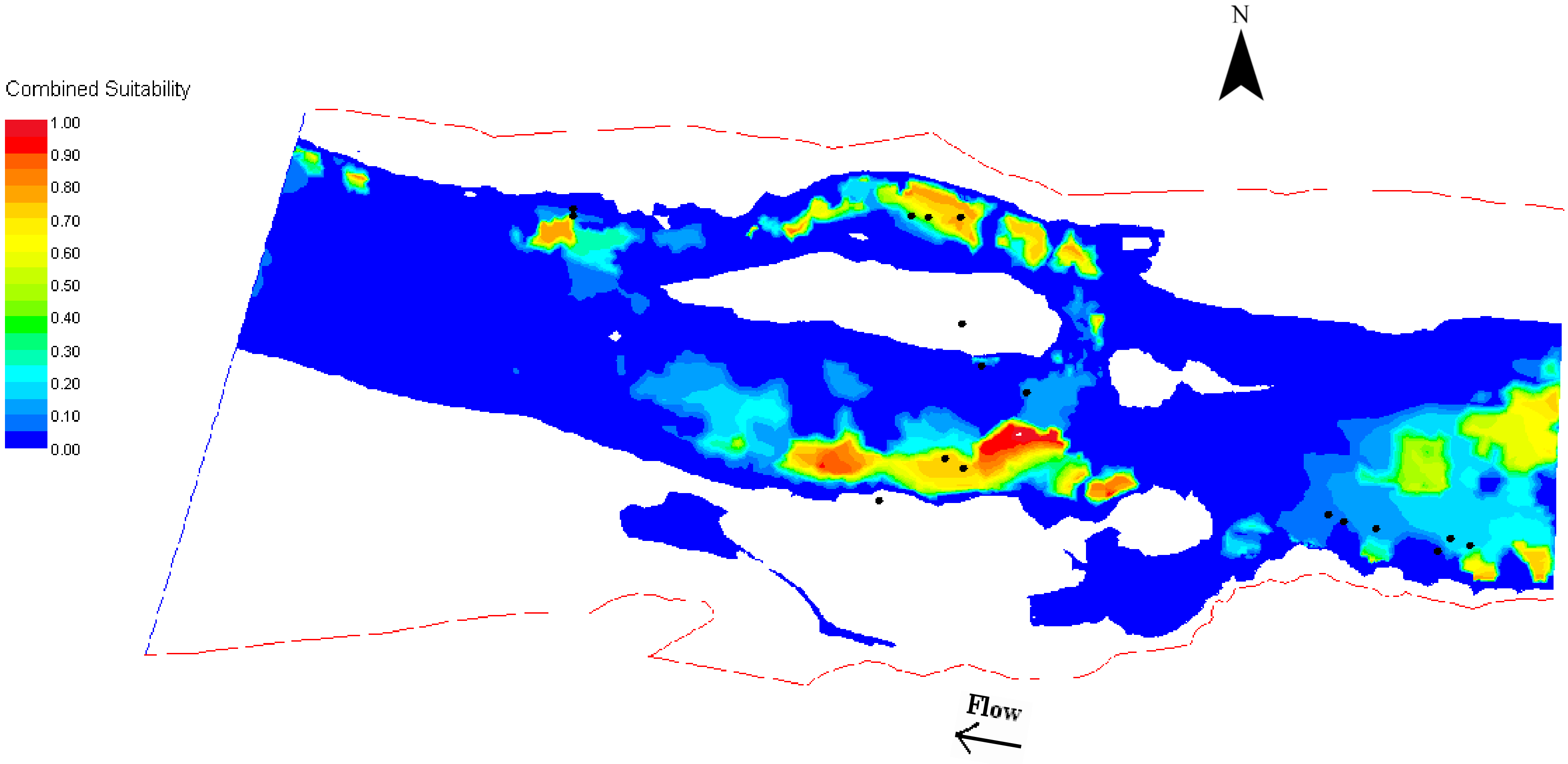
## HIGHWAY 20 STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008)



**Scale: 1:2116**
Redd locations: ●

Appendix D

## HIGHWAY 20 STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20

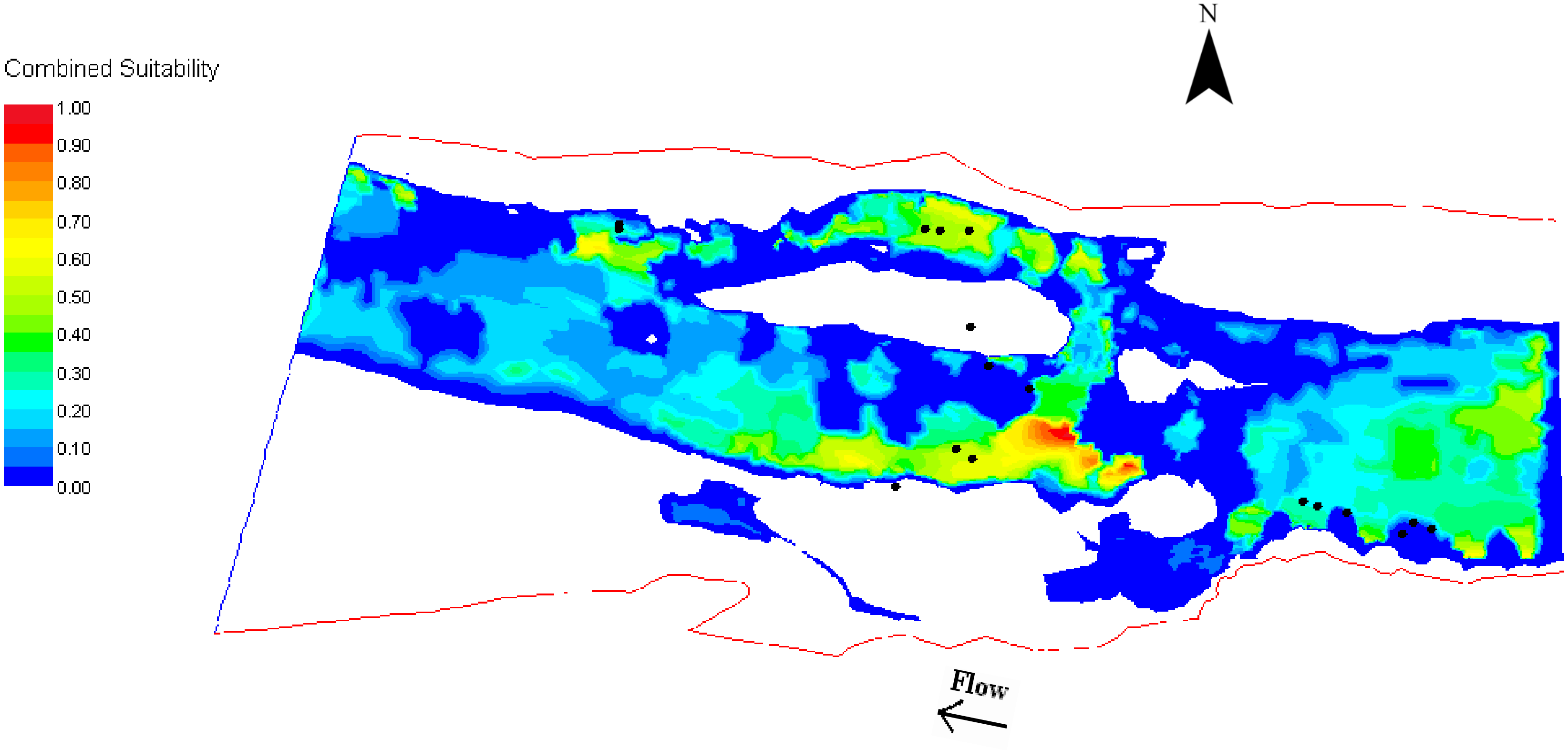


**Scale: 1:1994**

Redd locations: ●

Appendix D

## HIGHWAY 20 STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## GEOMETRIC MEAN CRITERIA

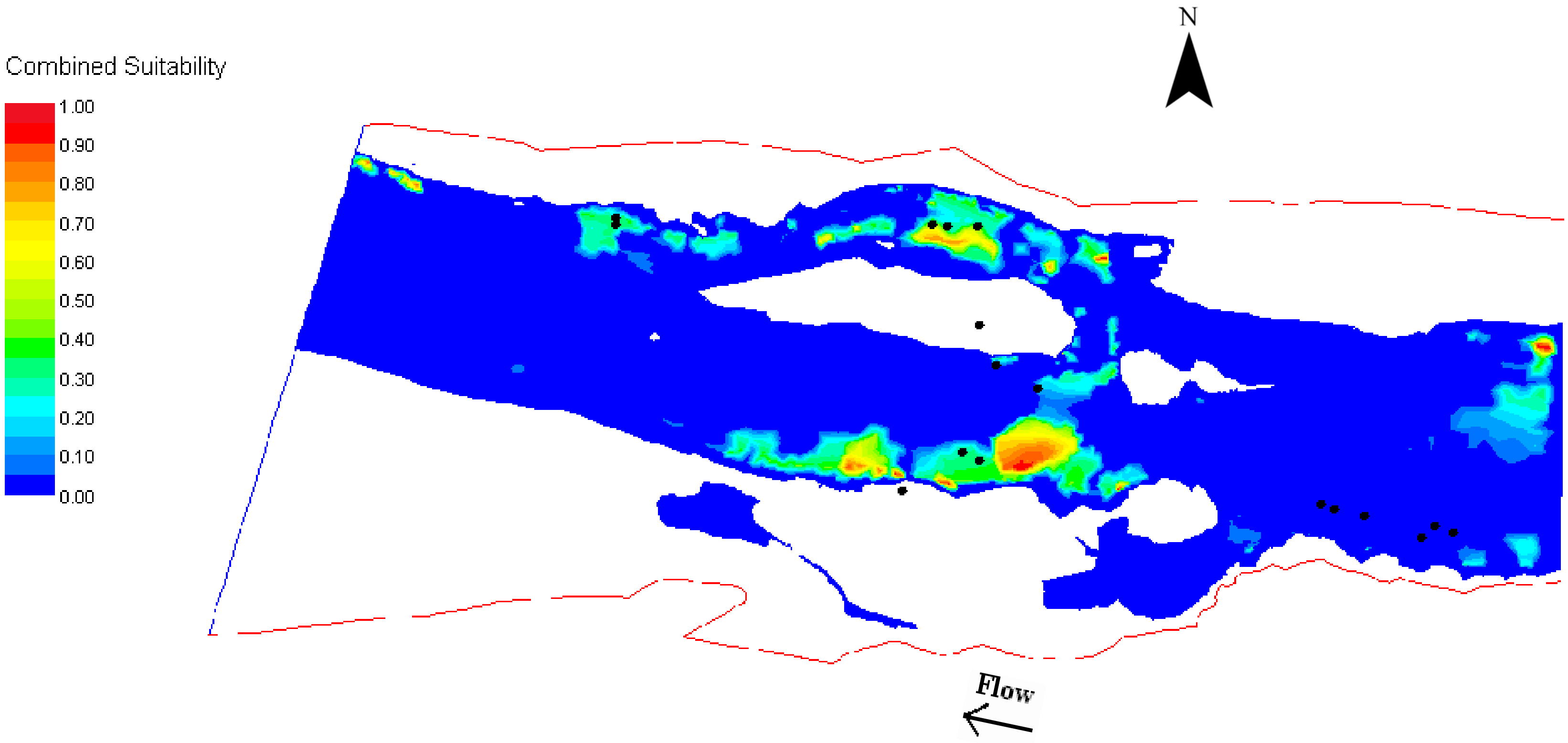


**Scale: 1:2304**

Redd locations: ●

Appendix D

## HIGHWAY 20 STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## CLEAR CREEK CRITERIA

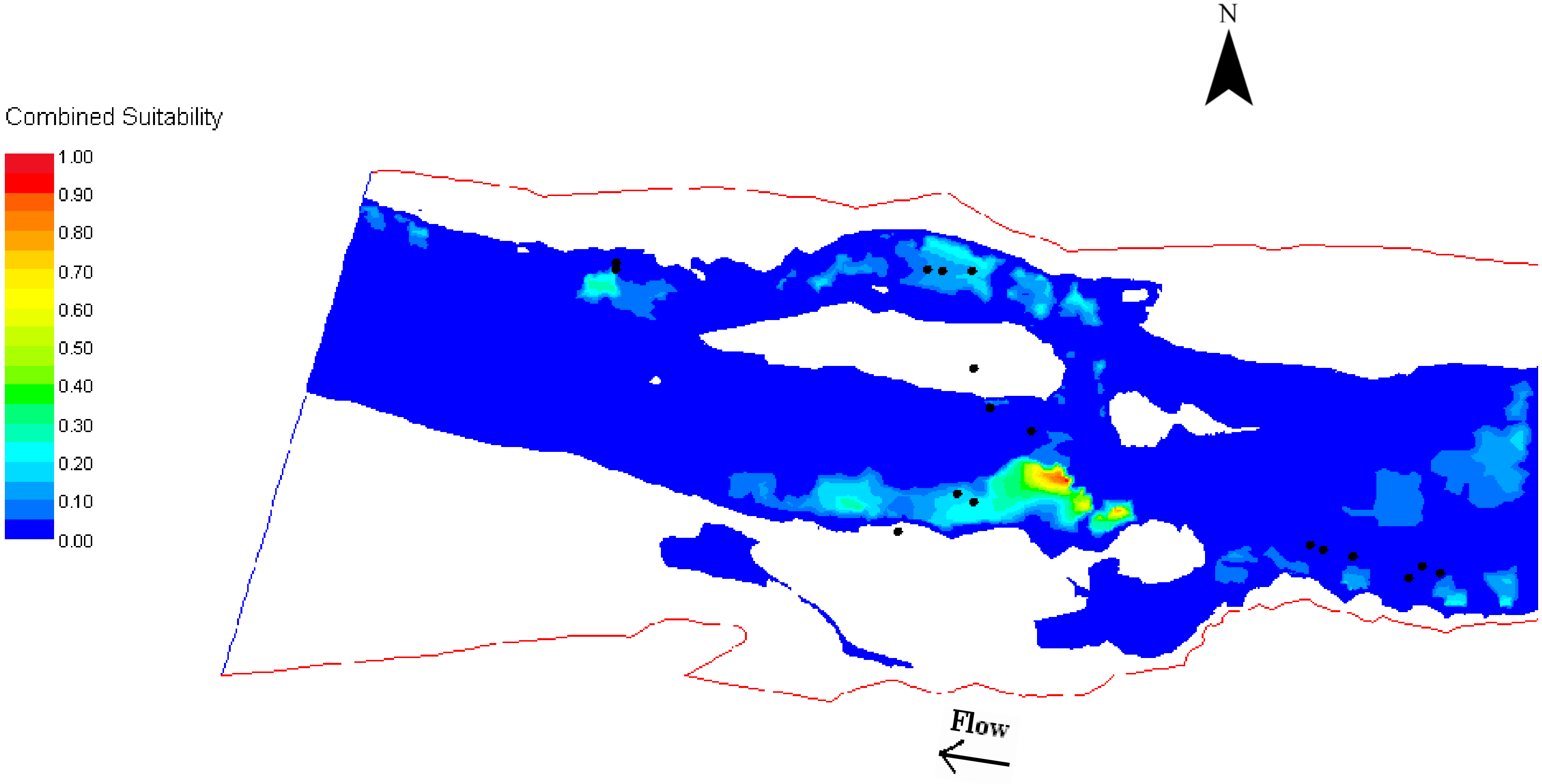


**Scale: 1:2254**

Redd locations: ●

Appendix D

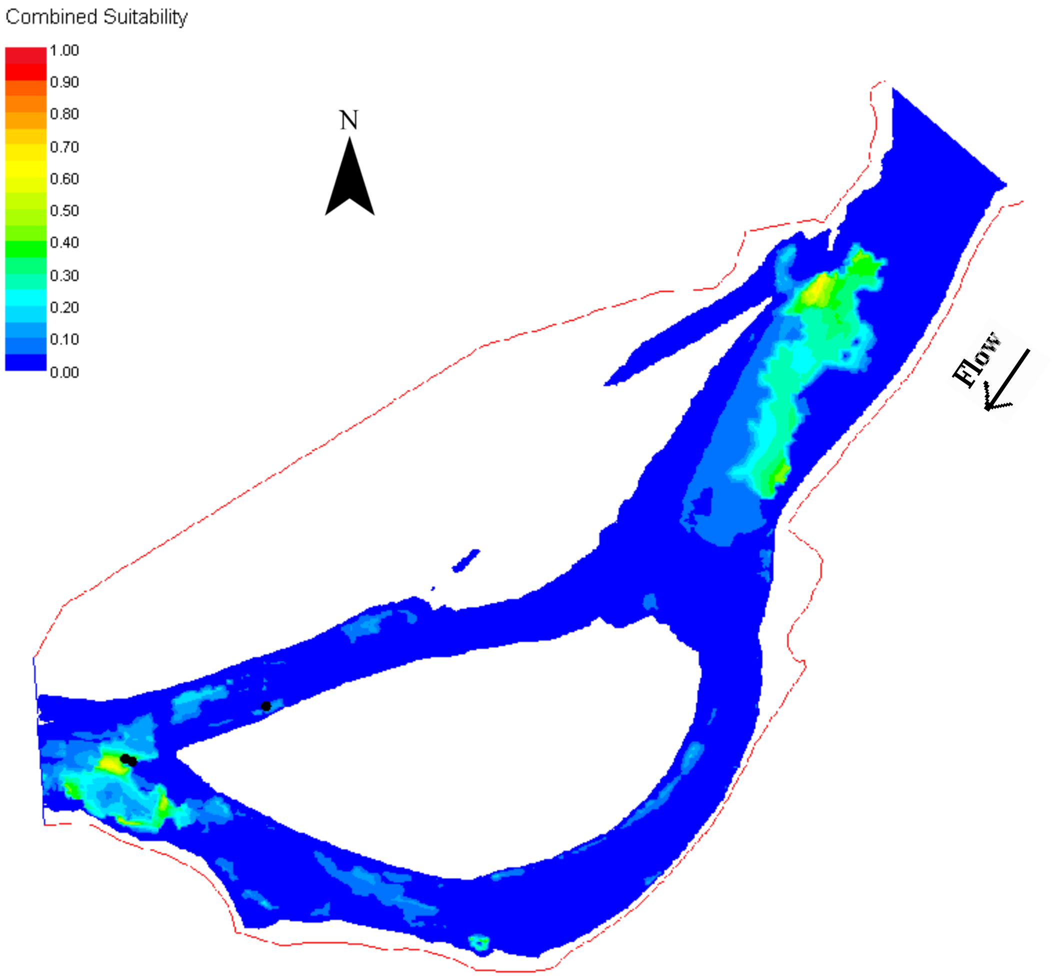
## HIGHWAY 20 STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## DENSITY CRITERIA



**Scale: 1:2304**

Redd locations: ●

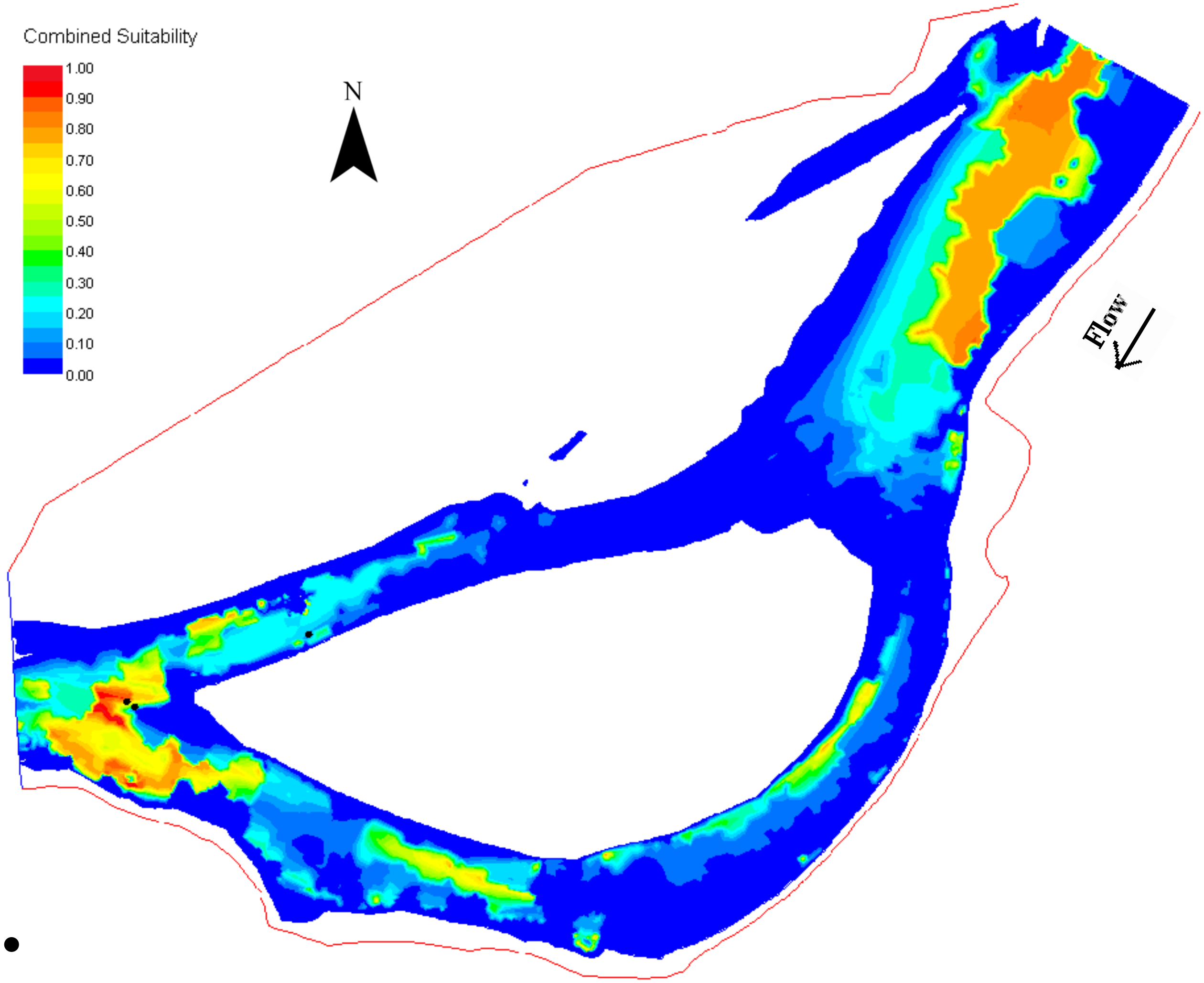
## ISLAND STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## CRITERIA FROM U.S. FISH AND WILDLIFE SERVICE (2008)



**Scale: 1:4210**

Redd locations: ●

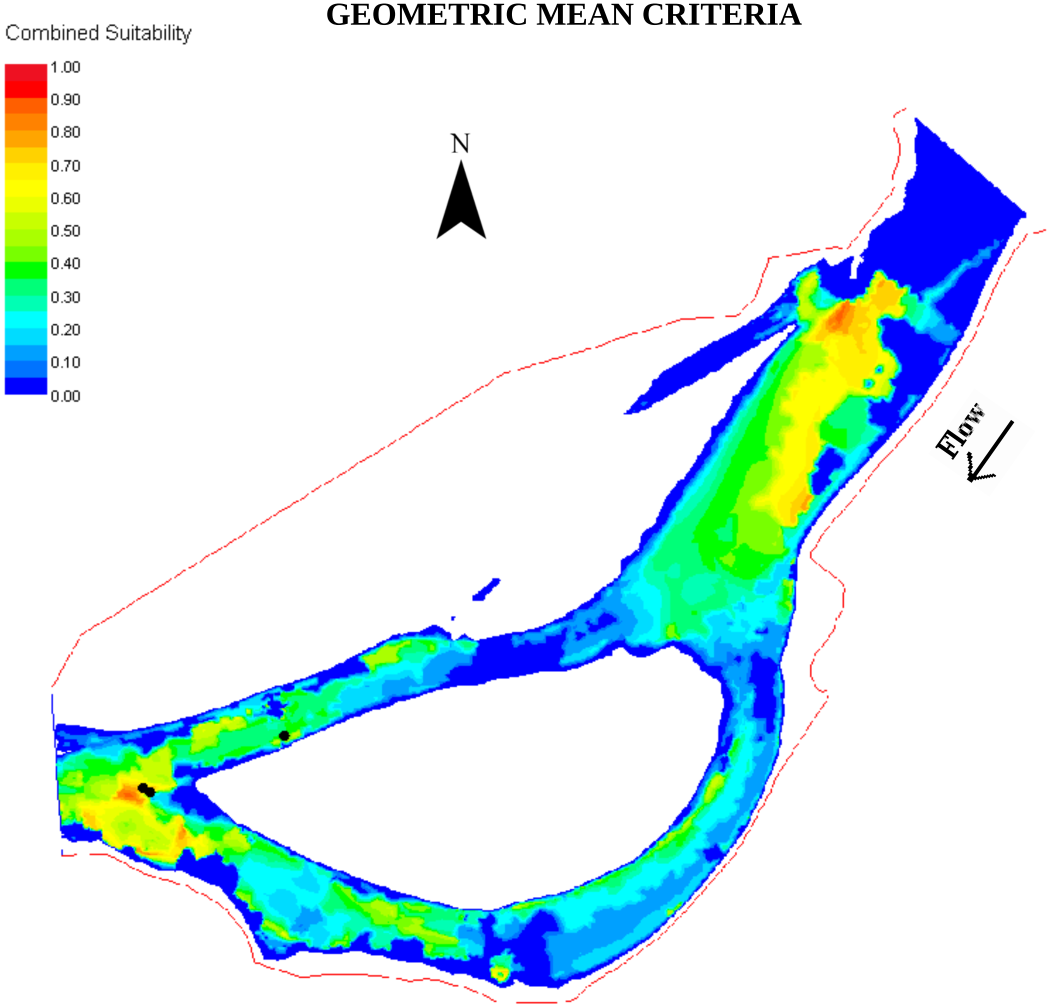
# ISLAND STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
# CRITERIA USING ONLY DATA FROM UPSTREAM OF HIGHWAY 20



**Scale: 1:3275**

Redd locations: ●

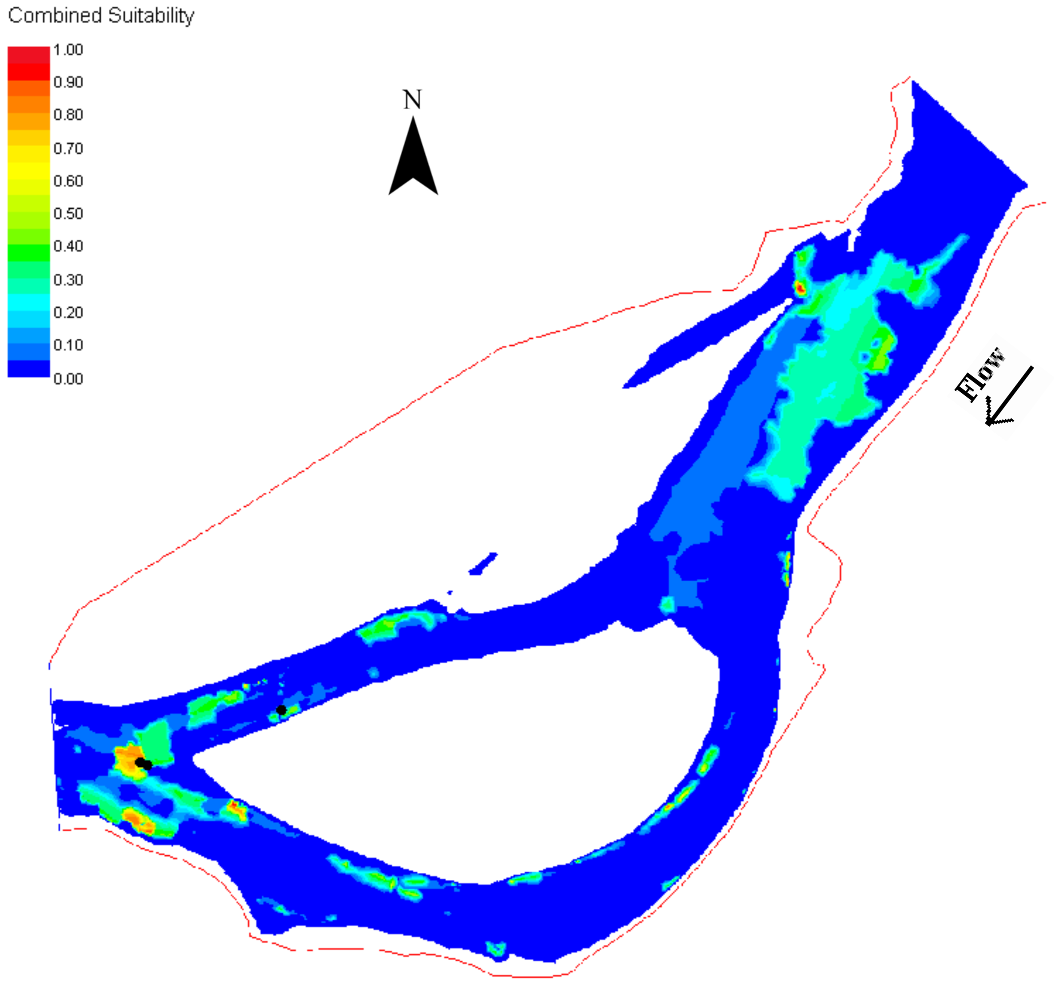
## ISLAND STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## GEOMETRIC MEAN CRITERIA



**Scale: 1:4210**

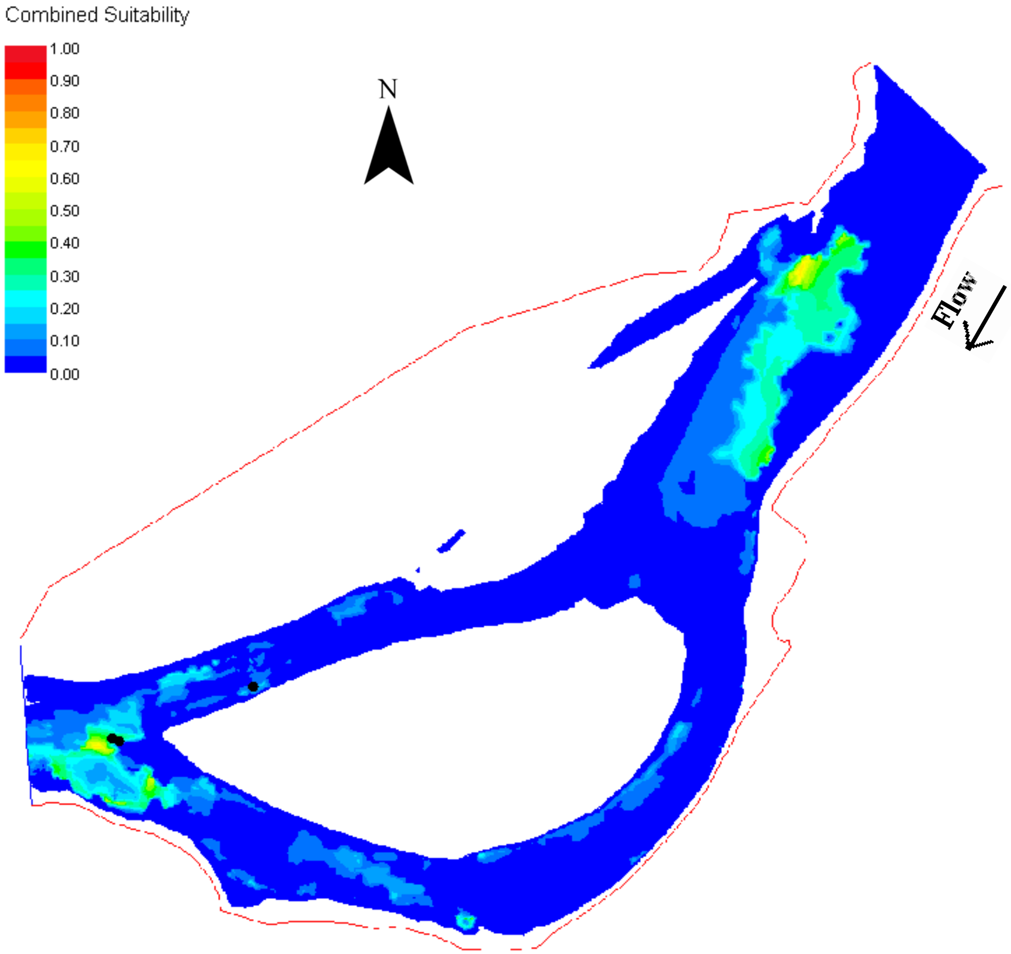
Redd locations: ●

## ISLAND STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
## CLEAR CREEK CRITERIA



**Scale: 1:4210**
Redd locations: ●

# ISLAND STUDY SITE, MARCH 6 – APRIL 5, 2004, FLOW = 2,546 CFS
# DENSITY CRITERIA



**Scale: 1:4210**

Redd locations: ●