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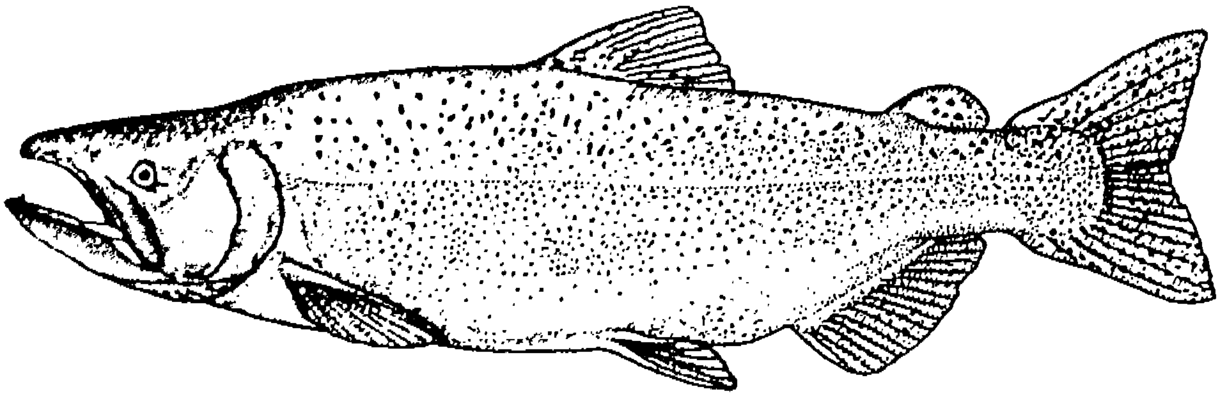
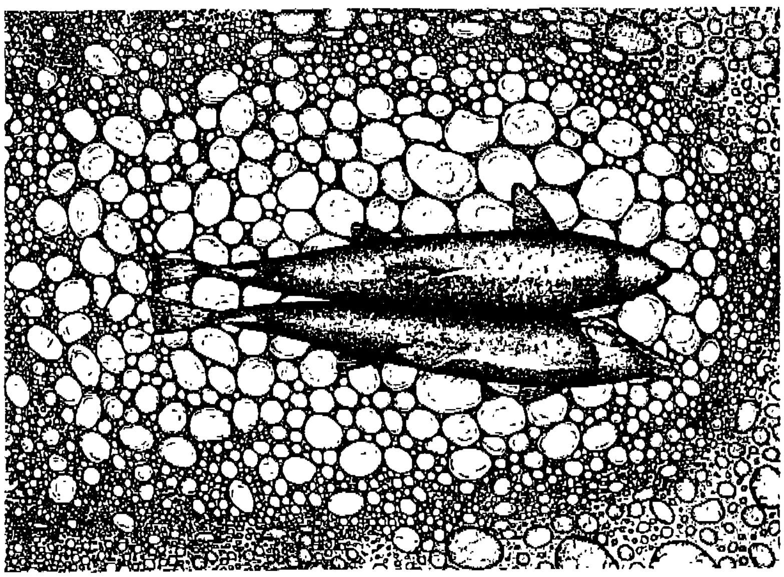
FLOW-HABITAT RELATIONSHIPS FOR FALL-RUN CHINOOK SALMON SPAWNING IN THE SACRAMENTO RIVER BETWEEN BATTLE CREEK AND DEER CREEK





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CVPIA INSTREAM FLOW INVESTIGATIONS SACRAMENTO RIVER BETWEEN BATTLE CREEK AND DEER CREEK FALL-RUN CHINOOK SPAWNING

PREFACE

The following is the final report for the U. S. Fish and Wildlife Service's investigations on salmonid spawning habitat in the Sacramento River between Battle Creek and the confluence of Deer Creek. These investigations are part of the Central Valley Project Improvement Act (CVPIA) Instream Flow Investigations, a 7-year effort which began in February, 1995[1]. Title 34, Section 3406(b)(1)(B) of the CVPIA, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U. S. Fish and Wildlife Service after consultation with the California Department of Fish and Game (CDFG). The purposes of these investigations are to provide scientific data to the U. S. Fish and Wildlife Service Central Valley Project Improvement Act Program to assist in developing such recommendations for Central Valley rivers.

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

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[1] This effort has continued with a 6-year effort, also titled the Central Valley Project Improvement Act Flow Investigations, which began in October, 2001.

ACKNOWLEDGMENTS

The field work for this study was conducted by Justin Ly, Ed Ballard, Elizabeth Hankins, Richard DeHaven, Mark Gard, John Kelly, Deborah Giglio, Jason Kent, Jeff Thomas, Erin Sauls, Jerry Big Eagle and Rick Williams. Data analysis and report preparation were performed by Ed Ballard and Mark Gard. Funding was provided by the Central Valley Project Improvement Act.

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INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act requires the doubling of the natural production of anadromous fish stocks, including the four races of chinook salmon (fall, late-fall, winter, and spring runs), steelhead, and white and green sturgeon. For the Sacramento River, the Central Valley Project Improvement Act Anadromous Restoration Plan calls for October through April flows ranging from 3,250 to 5,500 cfs, with the recommended flow varying with the October 1 carryover storage in Shasta Reservoir (U. S. Fish and Wildlife Service 1995). In December 1994, the U. S. Fish and Wildlife Service prepared a study proposal to identify the instream flow requirements for anadromous fish in certain streams within the Central Valley of California, including the Sacramento River. The purpose of this report is to produce models predicting the flow-habitat relationships of spawning fall-run chinook salmon in the Sacramento River between Battle Creek and Deer Creek over a range of streamflows.

A 2-dimensional hydraulic and habitat model (RIVER2D) was used for this modeling, instead of the Physical Habitat Simulation (PHABSIM[2]) component of the Instream Flow Incremental Methodology (IFIM). The 2-D model uses as inputs the bed topography and substrate of a site, total discharge at the upstream transect, and the water surface elevation at the downstream transect of the site, to predict the amount of habitat present in the site. The 2-D model avoids problems of transect placement, since the entire site can be modeled. The 2-D model also has the potential to model depths and velocities over a range of flows more accurately than PHABSIM because it takes into account upstream and downstream bed topography and bed roughness, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's n and a velocity adjustment factor.

Other advantages of 2-D modeling are that it can explicitly handle complex habitats, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions. The model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. The 2-D model does a better job of representing patchy microhabitat features, such as gravel patches. The data can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate. Bed topography and substrate mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the upstream and downstream transects of the site and flow and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

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

The results of this study are intended to support or revise the flow recommendations above.

METHODS

Study Site Selection

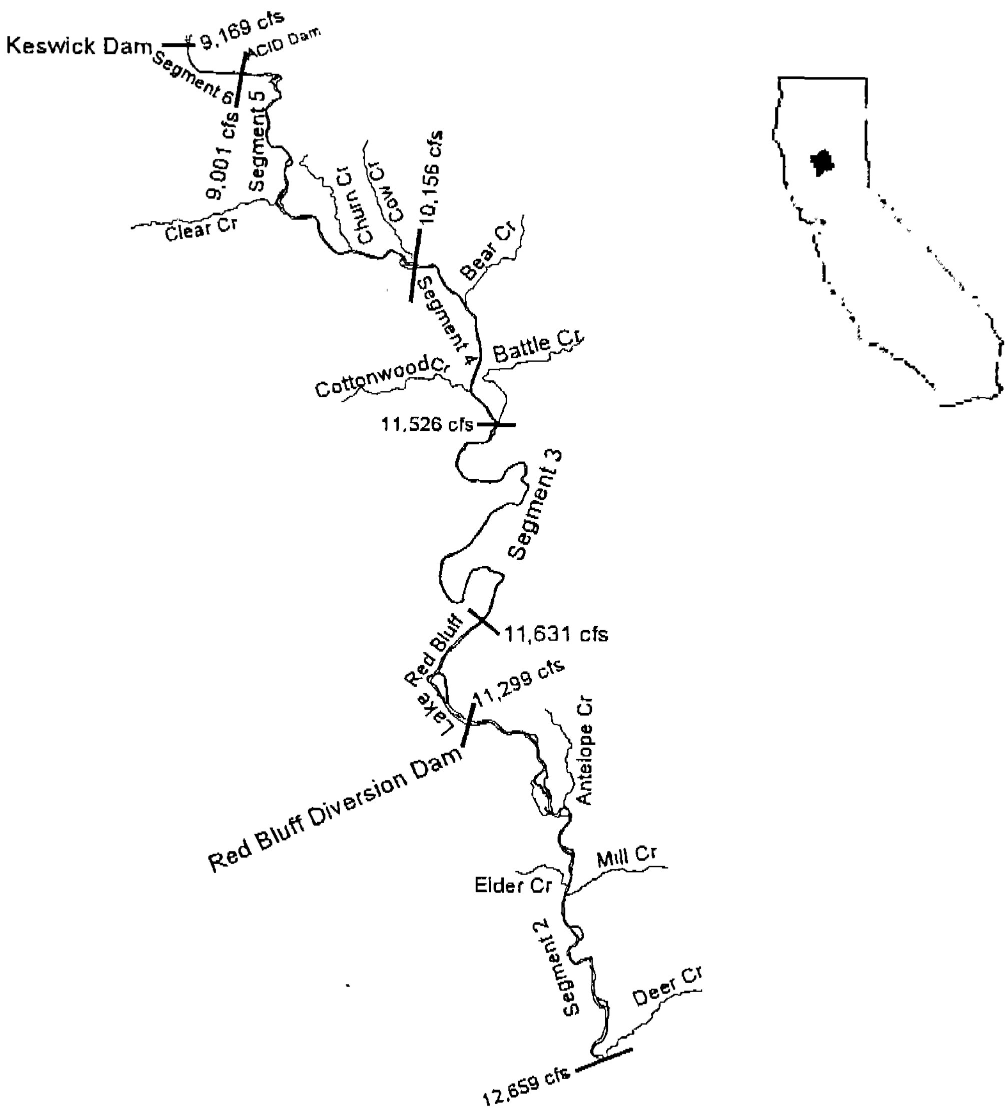
We have divided the Sacramento River study area into six stream segments (Figure 1), based on hydrology and other factors: Grimes to Colusa (Segment 1); Deer Creek to Red Bluff Diversion Dam (Segment 2); above Lake Red Bluff to Battle Creek (Segment 3); Battle Creek to Cow Creek (Segment 4); Cow Creek to ACID Dam (Segment 5); and ACID Dam to Keswick Dam (Segment 6). Segment 1 addresses green and white sturgeon, while the other segments address chinook salmon. The flow-habitat relationship for chinook salmon spawning in segments 4 to 6 are given in U.S. Fish and Wildlife Service (2003).

Aerial redd survey data for 1989-1994 collected by Frank Fisher (CDFG) for each of the four runs of chinook salmon were analyzed to determine the most heavily used spawning mesohabitat units (primarily riffles). Insufficient data were available for spring-run chinook salmon. This race is thought to be primarily a tributary spawner and it has proven impossible to differentiate those that do spawn in the mainstem from fall-run adults present at the same time. The mesohabitat units were ranked in Segments 2 and 3, to identify those areas which consistently received the heaviest spawning use by fall-run chinook salmon. Segments 2 and 3 were found to be primarily important for fall-run spawning with, respectively, 15% and 23% of the fall-run spawners.

In December 1998, we conducted a reconnaissance of the 10 top ranked sites in Segments 2 and 3 to determine their viability as study sites (Table 1). Each site was evaluated based on morphological and channel characteristics which facilitate the development of reliable hydraulic models. Also noted were riverbank and floodplain characteristics (e.g., steep, heavily vegetated berms or gradually sloping cobble benches) which might affect our ability to collect the necessary data to build these models. For sites selected for modeling, the landowners along both riverbanks were identified and temporary entry permits were sent, accompanied by a cover letter, to acquire permission for entry onto their property during the course of the study.

After reviewing the field reconnaissance notes and considering time and manpower constraints, six study sites were selected for modeling in Segments 2 and 3. The study sites (listed in order by segment and study site from downstream to upstream) were Segment 2: 1) Five Fingers; 2) Blackberry Island; 3) Osborne; Segment 3: 4) Bend Bridge; 5) Jellys Ferry; and 6) Mudball. These six sites were those receiving the heaviest use by spawning fall-run salmon in Segments 2 and 3.

Figure 1
Sacramento River Stream Segments[3]



1 in = 7.2 mi

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[3] Flows are the average flows for the period October 1974 to September 1993 at the upstream end of each segment. The figure is oriented north-south from the top of the page to the bottom of the page.

Table 1
Top-ranked Mesohabitat Units for Fall-run Chinook Salmon Spawning Based on Aerial Redd Survey Data

Stream Segment	River Mile	Location
3	270.2-270	Mud Ball Site
3	269.5-269.2	Laurence Riffle Site
3	268.7-268.4	Freitas Riffle Site
3	266.3-266.2	Jellys Ferry Site
3	257.9-258	Bend Bridge Site
2	240.3-240.7	Osborne Site
2	239.2-239.5	Blackberry Island Site
2	222.9-223.2	Five Fingers Site
2	241.5-241.8	Pipeline Riffle Site
2	2225	unnamed

Transect Placement (study site setup)

The study sites were established in August 1999. The study site boundaries (upstream and downstream) were generally selected to coincide with the upstream and downstream ends of the heavy spawning use areas. A PHABSIM transect was placed at the upstream and downstream end of each study site (in this report the terms transect and XS are synonymous, with transect 2 being the upstream transect and transect 1 being the downstream transect). The downstream transect was modeled with PHABSIM to provide water surface elevations as an input to the 2-D model.

The upstream transect was used in calibrating the 2-D model - bed roughnesses are adjusted until the water surface elevation at the upstream transect of the site matches the water surface elevation predicted by PHABSIM. For the Five Fingers study site, an additional transect was placed part-way down a side-channel. As a result, transect 3 was located at the upstream-most boundary of the site, transect 2 was the transect located in the side-channel, and transect 1 was located at the downstream boundary of the site. The portion of the side-channel upstream of this transect was considered part of the site. This transect was also modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. Transect pins (headpins and tailpins) were marked on each river bank above the 60,000 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Headpins were located on the left bank with relative to upstream, while tailpins were located on the right bank relative to upstream. Survey flagging was used to mark the locations of each pin.

Hydraulic and Structural Data Collection

Vertical benchmarks were established at each site to serve as the reference elevations to which all elevations (streambed and water surface) were tied. Vertical benchmarks consisted of lag bolts driven into trees. In addition, horizontal benchmarks (rebar driven into the ground) were established at each site to serve as reference locations to which all horizontal locations (northings and eastings) were tied.

The data collected on the upstream and downstream transect included: 1) water surface elevations (WSELs), measured to the nearest 0.01 foot at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate and cover classification at these same locations and also where dry ground elevations were surveyed. In between these transects, the following data were collected: 1) bed elevation; 2) horizontal location (northing and easting, relative to horizontal benchmarks); 3) substrate; and 4) cover. These parameters were collected at enough points to characterize the bed topography, substrate and cover of the site. Hydraulic and structural data collection began in August 1999 and was completed in October 2001.

Water surface elevations were measured at all sites at the following flow ranges: 6,000-11,000 cfs, 12,000-15,000 cfs, and 21,000-27,000 cfs. Water surface elevations were also collected at a range of 30,000-31000 cfs (Mudball and Jellys Ferry), and 53,000-60,000 cfs (Mudball, Osborne, and Blackberry Island). Depth and velocity measurements were collected at the Mudball, Jellys Ferry, and Bend Bridge transects at the flow range of 25,500-30,500 cfs. Depth and velocity measurements were collected at the Osborne, Blackberry Island, and Five Fingers transects at a flow range of 9,500-13,500 cfs.

Depth and velocity measurements in portions of the transects with depths greater than 3 feet were made with the Broad-Band Acoustic Doppler Current Profiler (ADCP) mounted on a boat, while depths and velocity measurements in shallower areas were made by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 or a Price AA velocity meter. Starting at the water's edge, water depths and velocities were made at measured intervals using the wading rod and Marsh-McBirney[R] model 2000 or Price AA velocity meter until the water became sufficiently deep to operate the ADCP (approximately 3 feet). The distance intervals of each depth and velocity measurement from the headpin or tailpin were measured using a hand held laser range finder[4]. 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

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

were collected across the transect up to the location near the opposite bank where water depths of approximately 3 feet 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 bank water's edge was reached.

Substrate and cover classification was accomplished using underwater video equipment along the deepwater portion of the transects and visually in shallow water. The underwater video equipment consists of two waterproof remote cameras mounted on an aluminum frame with two 30-lbs. bombs. One camera is mounted at a 45° angle to the frame and the second camera is mounted at a 90° angle to the frame. The camera mounted at a 45° angle was used for distinguishing changes in substrate size and cover types, while the camera mounted at 90° was used for assessing substrate size and cover type. The frame is attached to a cable/winch assembly, while a separate cable from the remote cameras is connected to two TV monitors on the boat. The two monitors are used by the winch operator to distinguish changes in substrate size and cover type and determine the substrate size and cover type.

Substrates and cover were visually assessed (using a calibrated grid[5] on the monitor connected to the 90° camera for the deep water substrates) for the dominant particle size range for substrate (e.g., range of 2-4 inches) and for cover type[6]. Table 2 gives the substrate codes and size classes used in this study, while Table 3 gives the cover codes and types used in this study. The substrate sizes and cover types were visually assessed from the headpin or tailpin to the location along the transect where the water became too deep for further visual assessment. At each change in substrate size class or cover type, the distance from the headpin or tailpin was measured using a hand held laser range finder. A buoy was placed at the location where visual assessment stopped and assessment from that point was continued across the transect by boat using the video camera assembly, with the distances where substrate size or cover type changed again measured with the hand held laser range finder. A buoy was again dropped at the location along the transect near the opposite shore where shallow water depth prevented further progress by boat. The substrate and cover over the remaining distance from the buoy to the end of the transect was assessed using the same visual methods used on the opposite bank. In between the upstream and downstream transect, the following data were collected: 1) bed elevation; 2) horizontal location (northing and easting, relative to horizontal benchmarks); 3) substrate; and 4) cover. These parameters were collected at enough points to characterize the bed topography, substrate and cover of the site.

There were two techniques used to collect the data within the site: 1) for areas that were dry or shallow (less than 3 feet), bed elevation and horizontal location of individual points were

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

[6] Cover types were only used to calculate bed roughnesses.

obtained by sighting from a total station to a stadia rod and prism, while the substrate and cover were visually assessed at each point; and 2) in portions of the site with depths greater than 3 feet, the ADCP was used in concert with the total station to obtain bed elevation and horizontal location. Specifically, the ADCP was run across the channel at 50 to 150 foot intervals, with the initial and final horizontal location of each traverse recorded by the total station (in this report, traverse refers to the path across the channel that the ADCP followed when collecting data and is not synonymous with the transects which delineated the upstream and downstream ends of the

Table 2
Substrate Descriptors and Codes

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

study sites). At each ADCP traverse, a WSEL was measured using differential leveling. Depths measured by the ADCP along these traverses were subtracted from the WSELs to obtain the bed elevation data.

Velocities at each point measured by the ADCP were used to validate the 2-D model. 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. The horizontal locations and bed elevations were determined by sighting from a total station to a 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. Velocity data collected on the PHABSIM transects in depths of approximately 3 feet or less where the ADCP could not be utilized were also used to validate the velocities predicted for shallow areas within the site.

Table 3
Cover Coding System

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

For the collection of the substrate and cover data on the ADCP traverses for the six sites, the initial and final locations of each deep bed elevation traverse were located using the previously-measured horizontal angle and slope distance, and marked with buoys. The underwater video and hand held laser range finder were then used to determine the substrate and cover along each traverse, so that substrate and cover values can be assigned to each point of the traverse.

[7] In addition to these cover codes, we have been using composite cover codes (3.7, 4.7, 5.7 and 9.7); for example, 4.7 would be branches plus overhead cover.

By determining the horizontal location of the head and tail pins of the transects at the spawning sites, we have used all of the points on these transects to determine at least part of the bed topography and cover/substrate of these sites. The number and density of data points collected for each site is given in Table 4.

Hydraulic Model Construction and Calibration

PHABSIM WSEL Calibration

The upstream and downstream transects were modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. By calibrating the upstream and downstream transects with PHABSIM using the collected calibration WSELs, we could then predict the WSELs for these transects for the various simulation flows that were to be modeled using RIVER2D. We then calibrated the RIVER2D models using the highest simulation flow. The highest simulation WSELs predicted by PHABSIM for the upstream and downstream transects could be used for the upstream boundary condition (in addition to flow) and the downstream boundary condition. The PHABSIM predicted WSEL for upstream transect at the highest simulation flow could also be used to ascertain calibration of the RIVER2D model at the highest simulation flow. Once calibration of the RIVER2D model was achieved at the highest simulation flow, the WSELs predicted by PHABSIM for the downstream transect for each simulation flow were used as an input for the downstream boundary condition when running the RIVER2D model production run files for the simulation flows. The following describes the PHABSIM WSEL calibration process for the upstream and downstream transects.

All data were compiled and checked before entry into PHABSIM 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 a QuattroPro spreadsheet and combined with the velocity, depth, and station data collected in shallow water. We 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].

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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.

Table 4
Number and Density of Data points Collected for Each Site

Site Name	Number of Points			Density of Points (points/100 m^2)
	Points on Transects	Points Between Transects Collected with Total Station	Points Between Transects Collected with ADCP	
Mudball	134	409	335	0.50
Jellys Ferry	108	362	279	0.95
Bend Bridge	120	361	318	2.21
Osborne	154	226	393	1.55
Blackberry Island	168	89	412	2.26
Five Fingers	147	250	407	2.44

R was calculated for each velocity where Vel_n, Vel_{n-1} and Vel_{n+1} were all greater than 1 ft/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 0.5-1.6.

All verticals with R values less than 0.5 or greater than 1.6 were deleted from each ADCP data set[11]. Flows were calculated for each ADCP traverse, including the data collected in shallow water. The traverse for each transect which had the flow closest to the gaged flow, determined from U.S. Geological Survey and U.S. Bureau of Reclamation gage readings (Table 5), was selected for use in the PHABSIM files.

The ADCP traverses selected for use are shown in Table 6 and the ADCP settings used for the ADCP traverses selected for use are shown in Table 7.

A table of substrate and cover ranges/values was created to determine the substrate and cover for each vertical/cell (e.g, if the substrate size class was 2-4 inches 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. RHABSIM was used rather than PHABSIM because the number of verticals per transect exceeded 100.

All of the measured WSELs were checked to make sure that water was not flowing uphill. No problems of this type were found for any of the six study sites A total of three to five sets of WSELs at widely spaced flows were used; if WSELs were available for several closely spaced flows, the WSEL that corresponded with the velocity set or the WSEL collected at the lowest flow was used in the PHABSIM files. Calibration flows in the PHABSIM files (Appendix A) were the flows calculated from gage readings or the flows calculated from gage readings and the regression equations in Table 8.

A separate PHABSIM file was constructed for each study site. Additional files were constructed for split channel sites (Mudball transect 2 and Bend Bridge transect 2) and for Five Fingers site (transects 1 and 2) which had a side channel.

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[11] We also deleted velocities where Vel_n was less than 1.00 ft/s and Vel_{n-1} and Vel_{n+1} were greater than 2.00 ft/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); these criteria were also based on the Lower American River data set.

Table 5
Gage Measured Calibration Flows for the Six Study Sites (cfs)

Date	Mudball	Jellys Ferry	Bend Bridge	Osborne	Blackberry Island	Five Fingers
8/9/99					9661	
8/10/99	10900	10900				
8/11/99			10600	9105		
8/12/99						8905
1/11/00	6820	6820	6820			
1/13/00				6379	6379	
1/25/00						25554
1/26/00				22179	22179	
2/1/00	26300					
2/2/00		21600	21600			
2/3/00		17800				
2/15/00				59879	59879	
2/16/00	53800					
3/14/00	30200	30200				
3/15/00		25800	25800			
3/21/00	14700	14700	14700			
4/3/00	8520		8520			
5/23/00				13424		
8/1/01						12285
8/2/01			13300			
10/23/01						5433

Table 6
ADCP Files Used in PHABSIM Files

Date	Site Name	XS Number	File Name	USFWS Measured Q	% Difference from Gage Measured Q
3/14/00	Mudball	1	MDE141	27360	9.4%
2/16/00	Mudball	2	MD4E135	54090	0.5%
3/15/00	Jellys Ferry	1	MD4E146	24589	4.7%
3/14/00	Jellys Ferry	2	MD4E143	27452	9.1%
3/15/00	Bend Bridge	1	MD4E152	24453	5.2%
3/15/00	Bend Bridge	2	MD4E151	24335	5.7%
5/23/00	Osborne	1	MD8A362	13407	0.1%
5/23/00	Osborne	2	MD8A366	13193	1.7%
8/9/99	Blackberry	1	D45D068	10512	8.8%
8/9/99	Blackberry	2	D45D069	10291	6.5%
8/1/01	Five Fingers	1	MD8A500	10452	3.3%
8/1/01	Five Fingers	2	MD4C267	2144	1.2%
7/31/01	Five Fingers	3	MD8A499	14493	15.2%

The water surface slope for each transect was computed at each gage measured calibration flow as the difference in WSELs between the two transects divided by the distance between the two. The water surface slope used for each transect was calculated by averaging the slopes computed for each flow. In the case of Five Fingers, the two averages for transects 1 and 2 were then averaged again to determine the final slope for transect 3 used in the velocity simulation.

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 the upstream transect. The SZFs used for each transect are given in Appendix A, Table 1.

Table 7
CFG Files[12] Used for ADCP Data

CFG File	Mode	Depth Cell Size (cm)	Depth Cell Number	Max Bottom Track (ft)	Pings	WT	First Depth Cell (ft)	Blanking Dist. (cm)
MD8A	8	20	15	26	4	5	1.61	10
MD4C	4	10	30	26	4	5	1.51	10
MD4E	4	20	30	26	4	5	1.84	10
MD4G	4	20	50	39	4	5	1.84	10
D45D	8	20	30	26	4	5	1.94	20

Table 8
Flow/Flow Regression Equations

Study Site	XS #	Flow Range	Regression Equations
Mudball	2 RC[13]	3250-31000	Mudball XS2 RC Q = -1153 + 0.4040 x Q
Mudball	2 LC	3250-31000	Mudball XS2 LC Q = Q - Mudball XS2 RC Q
Bend Bridge	2 RC	3250-31000	Bend Bridge XS2 RC Q = 10 ^(-1.65 + 1.308 x log (Q - 4150))
Bend Bridge	2 LC	3250-31000	Bend Bridge XS2 LC Q = Q - Bend Bridge XS2 RC Q
Five Fingers	2	3250-31000	Five Fingers XS2 Q = 10 ^(-0.79 + 0.878 x log (Q - 4500))
Five Fingers	1	3250-31000	Five Fingers XS1 Q = Q - Five Fingers XS2 Q

[12] The first four characters of the ADCP traverses designates which CFG file (containing the ADCP settings) was used for the traverses.

[13] RC and LC refer to right channel and left channel from the perspective of looking upstream.

The first step in the calibration procedure was to determine the best approach for WSEL simulation. Initially, the *IFG4* hydraulic model (Milhous *et al.*, 1989) was run on each 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 condition of the channel and the nature of the streambed controls WSELs; and 2) *WSP*, the water surface profile model, which calculates the energy loss between transects to determine WSELs. *MANSQ*, like *IFG4*, evaluates each transect independently. *WSP* must, by nature, link at least two adjacent transects.

IFG4, the most versatile of these models, is considered to have worked well if the following criteria are met: 1) the beta value (a measure of the change in channel roughness with changes in streamflow) is between 2.0 and 4.5; 2) the mean error in calculated versus given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot difference between measured and simulated WSELs[14]. *MANSQ* is considered to have worked well if the second through fourth of the above criteria are met, and if the beta value parameter used by *MANSQ* is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier and flow; and 3) there is no more than a 0.1 foot difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*. For a majority of the transects for at least a portion of the gage measured calibration flows, *IFG4* met the above criteria for *IFG4* (Appendix A, Table 2). *MANSQ* worked successfully for a number of transects, meeting the above criteria for *MANSQ* (Appendix A, Table 2). *WSP* worked successfully for the remaining transect, meeting the above criteria for *WSP*.

For most of the transects, we needed to simulate low and high flows with different sets of calibration WSELs (Appendix A, Table 2) to meet the above criteria. For transects where we had measured five sets of WSELs, *IFG4* could be run for low flows using the three lowest calibration WSELs, and run for high flows using the three highest calibration WSELs. For transects where we had only measured four sets of WSELs, we typically used *IFG4* with the three highest or three lowest flows to simulate, respectively, the high or low flows, and used *MANSQ* or *WSP* with the two lowest or two highest flows to simulate the remaining flows.

For those transects/flow ranges modeled with *IFG4*, the mean error and calculated-given discharge criteria were met in all cases, and the measured-simulated WSEL difference criterion for *IFG4* was met in all cases except for Mudball transect 2, right channel (3,250-31,000 cfs), Bend Bridge transect 2, left channel (3,250-21,000 cfs), Bend Bridge transect 2, right channel

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

(10,000-31,000 cfs), and Five Fingers transect 1 (3,250-31,000 cfs). We still used *IFG4* for these transects because *MANSQ* gave much greater errors and *WSP* could not be used because the Mudball and Bend Bridge transects were split channels and the Five Fingers transect was the downstream-most transect in the site; in addition, the difference between measured and simulated WSELs for the Bend Bridge and Five Fingers transects was 0.12 foot or less.

Mudball transect 2, right channel had the worst differences of 0.21 foot for 8,520 cfs and 0.15 foot for 6,820 cfs. As shown in Appendix A, Table 3, the beta coefficient values were less than 2.0 for the following transects calibrated with *IFG4*: 1) Mudball transect 2, left channel (3,250-31,000 cfs) and Mudball transect 2, right channel (3,250-31,000 cfs); 2) Bend Bridge transect 2, left channel (3,250-21,000 cfs) and Bend Bridge transect 2, right channel (10,000-31,000 cfs); and 3) Osborne transect 2 (3,250-21,000 cfs). The potential cause for the low beta coefficient values for the above transects is given below in the discussion of VAFs. The beta coefficient value was greater than 4.5 for Five Fingers transect 1 (3,250-31,000 cfs). The high beta coefficient value for Five Fingers transect 1 likely was due to the presence of a hydraulic control downstream of this transect that was not surveyed in. As a result, we underestimated the SZF for this transect, resulting in the high beta coefficient value.

Another factor that may have played a significant role in the deviations in the calibration criteria and the difficulties we experienced in the calibration process was the likely significant changes in bed topography within the six study sites that resulted from high flows that occurred from February 12, 2000, until March 11, 2000. During this period the flows in the Sacramento River averaged 53,800 cfs and peaked at 72,600 cfs at the Bend gauge. Comparison of bed elevations of data points collected in some study sites prior to the high flows to nearby points collected after the high flows within those sites suggest that the bed topography may have been altered dramatically during the course of the month- long high flows. For all six sites, WSELs were collected on the transects at several flows prior to or at the beginning of the high flows, with the rest of the WSELs collected afterward. The changes in the bed topography may have introduced errors into stage-discharge calibration and the flow-flow regressions we later developed for generating the simulation flows and WSELs used in calibrating and running the 2-D models.

The final step in simulating WSELs was to check whether water was going uphill at any of the simulated WSELs. No problems of this type were found for any of the six study sites.

Velocity Adjustment Factors (VAFs) were examined for all of the simulated flows as a potential indicator of problems with the stage-discharge relationship (Appendix B). The following transects that deviated significantly from the expected pattern of VAFs were Mudball transect 2, left channel, Mudball transect 2, right channel, Jellys Ferry transect 1, Bend Bridge transect 2, left channel, Bend Bridge transect 2, right channel, and Osborne transect 2. Five Fingers transect 2 had minor deviations from the expected pattern of VAFs.

In the cases of Mudball transect 2, left and right channels, Bend Bridge transect 2, left and right channels, the deviations were likely due to split channel dynamics. Examination of the VAFs also gives an indication of what may have been causing the lower beta coefficient values described previously for those transects. In those instances, the VAFs show a significant decrease with increasing flow (Appendix B). VAFs typically increase monotonically with increasing flows as higher flows produced higher water velocities. The model, in mass balancing, was obviously decreasing water velocities as flows increased so that the known discharge would pass through the increased cross sectional area. We concluded that, particularly for the split channel transects, the low beta coefficient values were caused by a combination of downstream controls on water surface elevations and upstream controls on split channel discharge.

For the remaining transects (Jellys Ferry transect 1 and Osborne transect 2), the deviations may have been due to discrepancies in bed topography between data collected prior to the February-March 2000 high flows and afterward or the presence of compound controls. In addition, the VAF values were all within an acceptable range (0.426-3.776), except for Bend Bridge transect 2, right channel at the lowest calibration flow (8.221).[15] The high VAF value for this site is likely due to an inaccuracy at low flows in the flow-flow regression used for determining the calibration flows. We did not regard the atypical VAF patterns as problematic since RHABSIM was only used to simulate WSELs and not velocities.

RIVER2D Model Construction

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 a QuattroPro spreadsheet in the same manner described above for the ADCP data on the 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 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 was 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 QuattroPro with the dry/shallow total station data and the PHABSIM transect data to create the input files (bed and substrate) for the 2-D modeling program. An artificial one channel-width-long extension was added upstream of the upstream transect of the site to enable the flow to be distributed by the model when it reached the study area, thus minimizing boundary conditions influencing the flow distribution at the upstream transect and within the study site.

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

In the case of the Blackberry Island site, artificial bed topography data that simulated the presence of an island that was a short distance upstream of transect 2 was added to the upstream extension to create flow and velocity conditions that would more closely approximate those found in the study site below this island. This data was added to the model after it was realized that the velocities were substantially different in the model compared to those measured in the field on transect 2. We resorted to using artificial bed topography points that delineated the island since we had not collected data on the island topography because of its location outside of the study site. The placement of the points that delineated the island within the upstream extension was based on the location of the island relative to transect 2 in aerial photos. For the Osborne and Blackberry Island sites, we also had to add an artificial extension one channel-width-long downstream of the downstream transect of the site to enable a stable solution.

The bed files contain the horizontal location (northing and easting), bed elevation and initial bed roughness value for each point, while the substrate files contain the horizontal location, bed elevation and substrate code for each point. The initial bed roughness value for each point was determined from the substrate and cover codes for that point and the corresponding bed roughness values in Table 9, 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 9 were computed as five times the average particle size. The bed roughness values in for cover in Table 9 were computed as five times the average cover size, where the cover size was measured in the field on a representative sample of cover elements of each cover type. The bed and substrate files were exported from QuattroPro as ASCII files.

A utility program, R2D_BED (Steffler 2001b), was used to define the study area boundary and to refine the raw topographical data TIN (triangulated irregular network) for the bed files by defining breaklines[16] following longitudinal features such as thalwegs, tops of bars and bottoms of banks. Breaklines were also added along lines of constant elevation. The bed topographies of the sites are shown in Appendix C.

An additional utility program, R2D_MESH (Steffler 2001a), was used to define the inflow and outflow boundaries and create the finite element computational mesh for the RIVER2D model. R2D_MESH uses the final R2D_BED built bed files as an input. The mesh files of the sites are shown in Appendix D. The first stage in creating the computational mesh was to define mesh

[16] Breaklines are a feature of the R2D_Bed program which force the TIN of the bed nodes to linearly interpolate bed elevation and bed roughness values between the nodes on each breakline and force the TIN to fall on the breaklines (Steffler 2001b).

Table 9
Initial Bed Roughness Values[17]

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

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

breaklines[18] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and additional nodes were added as needed to improve the fit between the mesh and the final bed file and to improve the quality of the mesh, as measured by the Quality Index (QI) value. The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Steffler 2001a). As shown in Appendix E, Table 1, the meshes for all sites had QI values of at least 0.30.

The percentage of the original bed nodes for which the mesh differed by less than 0.1 foot (0.03 m) from the elevation of the original bed nodes ranged from 75% to 90% (Appendix E, Table 1). In most cases, the areas of the mesh where there was greater than a 0.1 foot (0.03 m) difference between the mesh and final bed file were in steep areas; in these areas, within 1 foot (0.30 m) horizontally of the bed file location, the mesh would be within 0.1 foot (0.03 m) vertically of the bed file. 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. The final step with the R2D_MESH software was to generate the computational (cdg) files.

It should again be noted that the collection of bed topography data for the six study sites occurred over a relatively lengthy period of time (August 1999-October 2001). We found there were significant (>3 feet) differences in the bed topography for data collected with the ADCP early on in the study compared to overlapping data collected later with the total station, apparently the result of changes in bed topography that occurred within the study sites during the high February-March 2000 flows. Initially, for the first three study sites that were modeled (Mudball, Jellys Ferry, and Bend Bridge), we determined that it was best just to keep all the data and not attempt to judge which points to delete. Later, after further discussion, we determined that bed topography data that was collected using the total station was considered to have a more reliable elevation relative to data collected using ADCP, where the bed elevations are derived by subtracting depths measurements from the WSELs made on each traverse. This conclusion was partly based on examinations of the water surface elevations for the two study sites where water surface elevations were collected on both sides of the channel due to the presence of a split channel (Mudball and Bend Bridge). These examinations showed that there was, at minimum, several tenths of a foot difference in the water surface elevation across the channel.

It became apparent that some of the differences in bed topography that we observed between overlapping ADCP and total station collected data points could likely be attributed to differences in the WSELs that existed from one side of the river to the other. Since we measured only one WSEL for each ADCP traverse for some transects and all traverses between transects, this added

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

further uncertainty to the accuracy of the bed elevations collected using ADCP. As a result, where bed topography data collected using the total station overlapped with data collected using ADCP, the ADCP data were deleted for the Osborne, Blackberry Island, and Five Fingers study sites. Since all of the bed topography data collected using the total station were collected only out to a depth of 2-3 feet, this resulted in the deletion of ADCP data points at the beginning and ending of the traverses. We did not delete overlapping data points for Mudball, Jellys Ferry, and Bend Bridge because we had already completed building the 2-D models and had completed or nearly completed the process of running those models. Regardless, the observed notable discrepancy in the bed elevations collected using the total station compared with those collected using ADCP indicates that the bed topography in the 2-D models was likely a mix between the bed topography that existed prior to the high flows and that which existed afterward, introducing a significant level of uncertainty into the 2-D model results.

RIVER2D Model Calibration

The cdg files were opened in the RIVER2D software, where the computational bed topography mesh was used together with the WSEL at the downstream transect 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 (31,000 cfs), and the WSELs predicted by RIVER2D at the upstream end of the site were compared to the WSELs predicted by PHABSIM at the upstream transect. The bed roughnesses of the computational mesh elements were then modified by multiplying them by a constant bed roughness multiplier (BR Mult) until the WSELs predicted by RIVER2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the upstream transect.

The calibration of the Mudball and Bend Bridge study sites were exceptions to the above protocols for 2-D model calibration. For Mudball site transect 2, as a result of the left channel calibration measured-simulated WSEL difference criterion for *IFG4* being so poor for the low flow (0.15 foot) and middle flow (0.21 foot), we determined that the best approach for calibrating the 2-D model was to use the WSEL measured at 30,200 cfs for the highest simulation flow of 31,000 cfs. In the case of Bend Bridge, we could not get the model to calibrate using the PHABSIM simulated WSEL for 31,000 cfs. We determined that the stage-discharge relationship for transect 2, left and right channels developed using PHABSIM was unreliable, given the low beta coefficient values and the measured-simulated WSEL difference criterion being off by 0.11 foot for the middle flow of 8,520 cfs for the *IFG4* calibration for both channels. We decided it was better to use the WSELs measured for transect 2, right and left channels, at the highest flow at which WSELs were measured at the Bend Bridge site (25,800 cfs).

For the Mudball and Jellys Ferry sites, we resorted to adjusting the Eddy Viscosity Coefficient Parameter of epsilon 3 to 0.3 from the default setting of 0.1 as a result of the calibration models' inability to reach a stable solution. Within the RIVER2D model, there are three Eddy Viscosity Coefficient Parameters that can be adjusted, epsilon 1, 2, and 3. The inability of RIVER2D models to reach a stable solution often results from turbulent changes in the flow field that produce eddies that may or may not be real. Increasing the eddy viscosity helps stabilize the solution, perhaps artificially. Epsilon 3 was considered the appropriate parameter to adjust since it is the most physically justified and focused on eddies (Dr. Peter Steffler, personal communication 2003). After achieving calibration, the subsequent production runs for the various simulation flows for these sites also used this increased epsilon 3 setting.

An additional calibration step was needed for the two sites which had downstream extensions. This step involved the development of a relationship between the WSEL at the downstream boundary and the WSEL predicted by PHABSIM at the downstream-most transect (transect 1) for the calibration flows. For these sites, we initially took the WSEL predicted by PHABSIM at the downstream-most transect for the highest simulation flow and subtracted the slope used to determine the change in bed elevation used in creating the downstream extension.

After running the model to a stable solution, we then checked the WSEL predicted by the 2-D model on the downstream-most transect to see if it was within 0.1 foot (0.03 m) of the WSEL predicted by PHABSIM for that transect. If not, we adjusted the WSEL on the downstream boundary up or down according to the results and repeated this process until we found a WSEL for the downstream boundary that resulted in a WSEL predicted by RIVER2D at the downstream end of the site which matched the WSELs measured at the downstream transect. The same process was repeated at flows of 15,000 and 3,250 cfs, with the WSEL predicted by RIVER2D at the downstream end of the site 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 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 2001). In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than 1[19]. Finally, the WSEL predicted by the 2-D model should be within 0.1 foot (0.031 m) of the WSEL measured at the upstream transect[20]. The calibrated cdg files all had a solution change of less than 0.00001, with the net Q for all sites less than 1% (Appendix E, Table 1). The calibrated cdg file for all six sites, with the exception of Blackberry Island, had a maximum Froude Number of greater than 1 (Appendix E, Table 1). We considered the solutions for all the five study sites with Froude Numbers greater than 1 to be acceptable since the Froude Number was only greater

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

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

than 1 at a few nodes, with the vast majority of the site having Froude Numbers less than 1. Furthermore, these nodes were located either at water's edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water's edge or in very shallow depths would be expected to have an insignificant effect on the model results.

Five of the six sites had calibrated cdg files with WSELs that differed by more than 0.1 foot (0.031 m) from the measured WSELs (Appendix E, Table 2). For all six of the sites, the predicted WSELs near the water's edge, where the WSELs were measured, were all within 0.1 foot (0.031 m) of the PHABSIM simulated calibration WSELs. For much of the Sacramento River, the WSEL going across the river will differ by more than 0.1 foot (0.031 m), with up to a 1 foot (0.31 m) measured difference in WSEL between the two banks in some areas, such as the Mudball site. Accordingly, we conclude that the calibration for these five sites was acceptable.

RIVER2D Model Velocity Validation

Velocity validation is the final step in the preparation of the hydraulic models for use in habitat simulation. Velocities predicted by RIVER2D were compared with measured velocities to determine the accuracy of the model's predictions of mean water column velocities. The measured velocities used were the velocities measured on the upstream and downstream transects, the velocities measured during collection of the deep bed topography with the ADCP (otherwise known as deep beds in this report), and the 50 velocities per site measured in between the upstream and downstream transects. See Appendix F, Tables 1 and 2 , for velocity validation statistics.

Although there was a strong correlation between predicted and measured velocities, there were significant differences between individual measured and predicted velocities. In general, the simulated and measured velocities profiles at the upstream and downstream transects and deep bed ADCP traverses (Appendix F) were relatively similar in shape. Differences in magnitude in most cases are likely due to: (1) operator error during data collection, i.e., the probe was not facing precisely into the direction of current; (2) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the velocity range averaged in the model simulations; (3) aspects of the bed topography of the site that were not captured in our data collection or aspects of the bed topography being erroneous due to the mix of data collected before and after the February-March 2000 high flows; (4) the effect of the velocity distribution at the upstream boundary of the site[21]; and (5) the measured velocities being

[21] RIVER2D distributes velocities across the upstream boundary in proportion to depth, so that the fastest velocities are at the thalweg. In contrast, the bed topography of a site may be such that the fastest measured velocities may be located in a different part of the channel. Since we did not measure the bed topography above a site, this may result in RIVER2D improperly distributing the flow across the upstream end of the site. As discussed above, we added artificial upstream extensions to the sites to try to address this issue.

the component of the velocity in the downstream direction, while the velocities predicted by the 2-D model were the absolute magnitude of the velocity[22]. As shown in the figures in Appendix F, 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.

Unless noted as follows, the simulated velocities for the six 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 F, 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.

For Mudball transects 1 and 2 and Deep Beds A-F (Appendix F), RIVER2D over-predicted the velocities in approximately the middle to north side of the channel. The higher simulated velocities in the middle and north side of the channel were likely an artifact of the flow distribution from the upstream extension. The RIVER2D model acts to increase velocities with depth. At the location of the higher simulated velocities on transect 2, the channel was at its deepest. The use of the upstream extension longitudinally extended the deep area upstream of transect 2. The increased length of this deep area above transect 2 likely acted to increase the water velocities more than actually occurred at transect 2, with this increase in water velocities in the middle and north side of the channel extending down through the channel. For Mudball Deep Beds D-F, RIVER2D under-predicted the velocities near the bank on the south side of the channel. In examining the bed topography between Deep Beds C and D, we found that there was a mix of deep bed data, collected prior to the February-March 2000 high flows, and total station bed topography data collected later. The total station bed topography was higher in elevation and appears to have resulted in a artificial higher bed elevation feature protruding into the channel upstream of Deep Bed D that likely was not present when deep bed runs were done. This almost certainly affected the flow distribution in this side of the channel in RIVER2D for the south ends of Deep Beds D-F.

For Jellys Ferry transect 2 (Appendix F), RIVER2D over-predicted the velocities on the south side of the channel. The lower measured velocities on this side of the channel were most likely due to the presence of something upstream of the study site that was not accounted for in the model. A bridge was present upstream of the Jellys Ferry study site. The presence of a bridge pillar in the south side of the channel likely acted to reduce velocities at transect 2. Another explanation is that there was a protrusion of the south bank upstream of transect 2 that reduced

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

the velocities downstream.

For Jellys Ferry Deep Beds A-D (Appendix F), the velocities simulated by RIVER2D in the middle of the channel were significantly less than the measured velocities. We attribute this to errors in the ADCP velocity measurements (being too high). For example, the ADCP measured discharge for Jellys Ferry Deep Bed A, which did not include the total river discharge, was 20,460 cfs, versus the gage measured total river discharge of 17,800 cfs. To further verify this, we compared the discharge of Jellys Ferry Deep Bed G, where the RIVER2D predicted velocities were relatively similar to the measured velocities, to the gage measured discharge. The ADCP measured discharge for Jellys Ferry Deep Bed G (which did not include all of the total river discharge) was slightly lower at 20,344 cfs compared to the gage measured discharge of 21,600 cfs.

For Jellys Ferry Deep Beds A-H (Appendix F), RIVER2D under-predicted the velocities at the far north side of the channel. After examining the bed-file used to construct the RIVER2D model, it was apparent that the cause of this can be attributed to the mix of bed topography data collected prior to the February-March 2000 high flows and data collected afterward. The deep bed traverses were conducted prior to the high flow event and the bed topography on those traverses was lower than the total station data upstream and downstream of each deep bed in the bed file. This higher bed topography upstream of the locations of the north ends of the deep bed traverses was likely higher than that present at the time the velocities were measured and acted to reduce the velocities in RIVER2D.

For Bend Bridge transect 2 (Appendix F), RIVER2D over-predicted the velocities on the north side of the channel. This can attributed to the presence of a finger of land that protruded into the channel on that side of the river just upstream of transect 2. This protrusion of land acted to slow the velocities along the north side of the channel but is not accounted for in RIVER2D. This also likely accounts for the velocities being over-predicted on the north side of the channel for Deep Beds A-F.

For Bend Bridge Deep Beds A-H (Appendix F), particularly A-C, RIVER2D under-predicted the velocities on the south side of the channel. After examining the bed file used in constructing the RIVER2D model for this site, we attribute these under-predicted velocities to errors in the bed topography resulting from the mix of data collected prior to the change in bed topography caused by the February-March 2000 high flows with bed topography data collected afterward. In addition, further error may have been introduced given that the water surface elevations that were measured for each deep bed traverse were only measured on one side of the river. This likely resulted in bed elevation calculations that were inaccurate due to the nature of the water surface elevations varying from one side of the river to the other. The resulting bed topography errors on the south side of the river appear to have slowed the simulated velocities below those that were measured.

For Osborne transect 1 (Appendix F), the velocities simulated by RIVER2D on the north side of the channel were higher than the measured velocities. We attribute these differences to errors in the bed topography that resulted when constructing the bed file, producing a bed topography that was lacking some feature that likely slowed the velocities on that side of the channel. The bed elevations in portions of the bed topography upstream of the portions of transect 1 where RIVER2D was over-predicting the velocities appear low compared with the adjacent deep bed topography and on transects 1 and 2. We suspect that these lower bed elevations likely resulted from errors that occurred during data collection and that the actual elevations were higher in this area of the channel. By the bed elevations being lower, this had the effect of increasing the simulated velocities at transect 1.

For Blackberry transects 1 and 2 (Appendix F), along with Deep Beds A-G, RIVER2D over-predicted the velocities on the south side of the channel and under-predicted the velocities on the north side of the channel. In each case, this velocity pattern is the result of errors made when constructing the bed file and the RIVER2D model. As described previously in this report, there was an island located on the north side of the channel immediately upstream of transect 2. Since we did not collect data for this island, we added artificial data points to approximate this feature in the upstream extension because we recognized that this would have an affect on the velocities with the study site. Based on the velocity predictions of RIVER2D, it appears that we did not create an accurate representation of the island topography in the upstream extension. Most likely, the width of the island extended further out into the channel. In reality, the greater actual width of the island forced more of the flow toward the south side and resulted in higher velocities on that side of the channel and lower velocities on the north side of the channel.

For Five Fingers transect 1 (Appendix F), there is a dramatic spike in the measured velocities toward the north side of the channel compared to the velocities predicted by RIVER2D. After reviewing the depth and velocity data for that portion of the channel and recalling the flow conditions in that area, we believe that the spike in measured velocities is not real, but rather is an error in the ADCP readings, perhaps due to the shallow depths. The spike in the velocities occurred for each traverse at the very end of the runs. The velocity data for the remainder of the north side of the channel was collected by hand. The depths for the portion of the channel where the readings spiked were approximately 3 feet or less. The ADCP's ability to make accurate velocity reading degrades at depths of 3 feet or less, so this is the likely explanation. The fact that the velocities measured immediately adjacent to the end of ADCP traverses do not show this spike further supports this conclusion.

For Five Fingers transect 2 (Appendix F), RIVER2D under-predicted the velocities. We attribute this to errors in the ADCP velocity measurements (being too high). For example, the lowest calculated discharge for this side channel when combined with the calculated discharge on transect 1 was 12,502 cfs, versus the gage measured total river discharge of 12,285 cfs. The calculated discharge of 12,502 cfs was computed using the lowest discharge ADCP traverses for transects 1 and 2. The other traverse combinations resulted in even higher values, with the highest being 13,477 cfs. Furthermore, for each transect 1 traverse, the previously described spike in velocities erroneously measured by the ADCP were all negative values, which resulted in a lower discharge value for each traverse.

For Five Fingers transect 3 (Appendix F), RIVER2D over-predicted the velocities on the south and north ends of the channel and under-predicted the velocities in the middle to northern portion of the channel. We attribute under-prediction of the velocity in the middle to northern portion of the channel to errors in the ADCP measurements as we traversed the channel. In the vicinity of that portion of the channel there were difficulties running the ADCP due to fallen trees in the water which likely resulted in erroneous measurements. The over-prediction of the velocities on the south and north sides of the channel may have been due to the fact that RIVER2D model makes assumptions about how to distribute the total flow across the upstream boundary that will likely result in a distribution of flow that differs from the actual distribution at the location of the upstream boundary. The upstream boundary conditions will have an influence on the flow for some distance downstream of the boundary. The discrepancies between the simulated velocities and the measured velocities at transect 3 may have been due to the influence of the upstream boundary conditions. Another possible explanation for the higher simulated velocities on the north side of the channel was the presence of trees and other brush in the water upstream of transect 3 on that side of the channel which acted to slow the measured velocities on the transect but was not present in the model.

For Five Fingers Deep Beds A-D (Appendix F), RIVER2D over-predicted the velocities on the south and north sides of the channel and under-predicted the velocities in the middle of the channel. We attribute the under-prediction of the velocities in the middle of the channel to the mix of data from before and after the February-March 2000 high flows. The deep bed traverses were conducted prior to changes that resulted from the high flows, while the data collected using the total station was collected afterward. The data collected using the total station included a bar that was located approximately mid-channel down through the study site. We deleted the deep bed points over the bar and used the total station points for the bar itself. This resulted in a bed topography that was likely higher in the middle than existed at the time the deep bed traverses were done. As a result, the higher mid-channel bed elevations in RIVER2D likely acted to divert water toward the deeper north and south sides of the channel, increasing the velocities on those sides of the channel down through the site and reducing the predicted velocities in the middle of the channel. These higher predicted velocities on the north and south sides of the channel may have also been enhanced as a result of the upstream boundary conditions. As described above, if the location in question is within the region of influence of the upstream boundary conditions, then the velocities could be influenced by the upstream boundary conditions (Julia Blackburn, Personal Communication 2005).

For Five Fingers Deep Beds E-F (Appendix F), RIVER2D over-predicted the velocities on the south side of the channel and generally under-predicted the velocities for the middle and north side of the channel (with the exception of a over-predictive spike approximately mid-channel for Deep Bed F). We attribute the over-prediction of the velocities on the south side of the channel and the under-prediction of the velocities mid-channel to the same factors described for Deep

Beds A-D. However, starting with Deep Bed E, the bar in the middle of the channel was high enough in bed elevation that the deep bed traverses ended at the south side of the bar, whereas the traverses for Deep Beds A-D actually passed over the bar. Examination of the bed topography in the bed file for this site suggests that use of the total station data collected after the February-March 2000 high flows for the bar resulted in a bed topography along the south side of the bar (north end of the deep bed traverses) that was higher than existed at the time the deep bed traverses were conducted. These higher bed elevations along the south side of the bar likely acted to reduce the predicted velocities in this portion of the channel compared to the measured velocities.

Examination of the RIVER2D velocity vectors on the middle and north side of the main channel in the vicinity of Five Fingers Deep Bed F and transect 1 showed that there was an eddy that resulted in an upstream direction of flow at the location of the velocity spike at approximately mid-channel and affected the downstream flow on either side. Comparison with the measured velocities in this area of the Deep Bed F traverse showed that there was no apparent eddy at that flow when the Deep Bed F traverse was done at the start of the February-March high flows. It appears that the mix of bed topography collected prior to the high flows with the bed topography data collected on transect 1 immediately downstream and on the bar after the high flows resulted in an inaccurate representation of the bed topography that 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 transect 1 may have caused the eddy. Use of a downstream extension might have eliminated the eddy.

RIVER2D Model Simulation Flow Runs

The flow and downstream WSEL in the calibrated cdg file were changed to simulate the hydrodynamics of the sites at the simulation flows (3,250 cfs to 5,500 cfs by 250 cfs increments, 5,500 cfs to 8,000 cfs by 500 cfs increments, 8,000 cfs to 15,000 cfs by 1,000 cfs increments, and 15,000 cfs to 31,000 cfs by 2,000 cfs increments). The cdg file for each flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow. Each discharge was run in RIVER2D to steady state. Again, a stable solution will generally have a Sol Δ of less than 0.00001 and a Net Q of less than 1%. In addition, solutions will usually have a Max F of less than 1. The production cdg files all had a solution change of less than 0.00001, but the Net Q was greater than 1% for two flows for Bend Bridge Site (Appendix G). We still considered these two production cdg files for this site to have a stable solution since the net Q was not changing and the net Q in both cases was less than 5% (1.41% and 1.03%). In comparison, the accepted level of accuracy for USGS gages is generally 5%. Thus, the difference between the flows at the upstream and downstream boundary (net Q) is greater than the accuracy for USGS gages, and is considered acceptable. The maximum Froude Number was greater than 1 for 26 simulated flows for Mudball, 9 simulated flows for Jellys Ferry, 26 simulated flows for Bend Bridge, 30 simulated flows for Osborne, 11 simulated flows for Blackberry Island, and 22 simulated flows for Five Fingers (Appendix G); however, we considered these production runs to be acceptable since the maximum Froude Number was only greater than 1 at a few nodes, with the vast majority of the area within the site having maximum Froude Numbers less than 1. Also, as described previously, these nodes were located either at water's edge or where water depth was extremely shallow, typically approaching zero and would be expected to have an insignificant effect on the model results.

Habitat Suitability Criteria (HSC) Development

Fall-run chinook salmon HSC for depth and velocity were developed from Sacramento River spawning data collected in 1995, 1996, 1997 and 1999 between Keswick Dam and Battle Creek. For details on how the HSC were developed, see U. S. Fish and Wildlife Service 2003.

Habitat Simulation

The final step was to simulate available habitat for each site. A preference curve file was created containing the digitized HSC developed for the Sacramento River fall-run chinook salmon (Appendix H). RIVER2D was used with the final cdg production files, the substrate file and the preference curve file to compute WUA for each site over the desired range of 30 flows (3,250 cfs to 5,500 cfs by 250 cfs increments, 5,500 cfs to 8,000 cfs by 500 cfs increments, 8,000 cfs to 15,000 cfs by 1,000 cfs increments, and 15,000 cfs to 31,000 cfs by 2,000 cfs increments) for all six sites. The WUA values calculated for each site are contained in Appendix I, Tables 1 and 2. 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 (Segment 3 = 8.95, Segment 2 = 4.16)[23], from the aerial redd survey data for 1989-1994 collected by Frank Fisher (CDFG), to produce the total WUA per reach.

In the case of the Blackberry and Five Fingers sites (both sites in Segment 2), the amount of suitable spawning habitat present during the period of our study had decreased substantially from what was present during the 1989-1994 redd surveys. We attribute this decrease in the amount of suitable spawning habitat to the high flows that occurred during the winter of 1997 (prior to the high flows that occurred in February-March 2000). As a result of this decrease in suitable spawning habitat, after initially calculating the WUA values, the values were modified to correct for the decrease in suitable spawning habitat. To modify the initial WUA values for each of these two sites, we divided the total number of redds counted between 1989-1994 for the site in question by the total number of redds counted between 1989-1994 for Osborne site (the one study site in Segment 2 where the amount of suitable spawning habitat had not changed substantially after the 1997 high flows). We then divided the average WUA value for the 30 simulation flows for Osborne site by the initial average WUA value for the 30 simulation flows for the site in question. The two ratios were then multiplied times the initial WUA values for the site in question to arrive at the modified WUA values for the 30 simulation flows.

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[23]These ratios are equivalent to the spawning sites having, respectively, 11% and 24% of the redds in Segments 3 and 2.

RESULTS

The flow-habitat relationships for fall-run chinook salmon in Segments 3 and 2 are shown in Figures 2 and 3 and Appendix I. In Segment 3, the 2-D model predicts the highest total WUA at the flow of 4,750 cfs. For Segment 2, the total WUA peaks at 5,500 cfs.

We suggest that the results of this study should be regarded with considerable caution. Considering the many errors and difficulties with the model calibration and the many discrepancies in the validation velocities, it is clear that the mix of bed topography, WSEL, and validation velocity data collected before and after the changes in bed topography caused by the February-March 2000 high flows resulted in a considerable level of uncertainty about the reliability of the calibration and performance of the models and their results. In addition, the modifications of the WUA values made for two of the three sites in Segment 2 in order to compensate for the reductions in the amount of suitable spawning habitat following the 1997 high flows further detracts from the reliability of the study results.

Figure 2
Fall-run Chinook Salmon Flow-Habitat Relationships, Segment 3

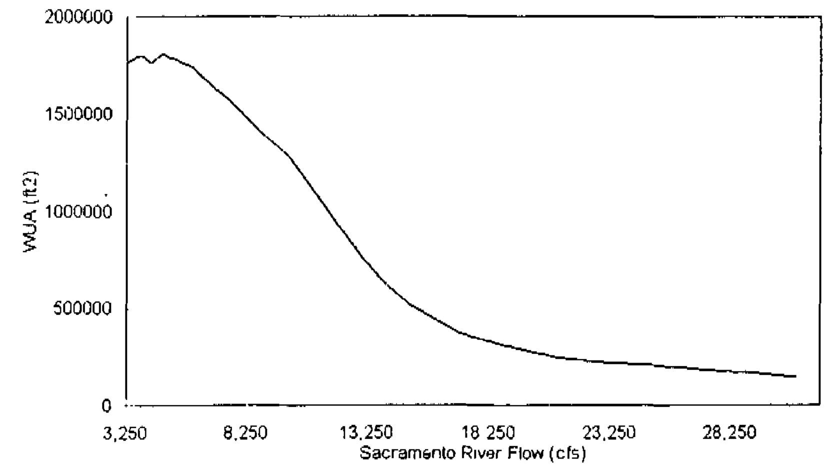
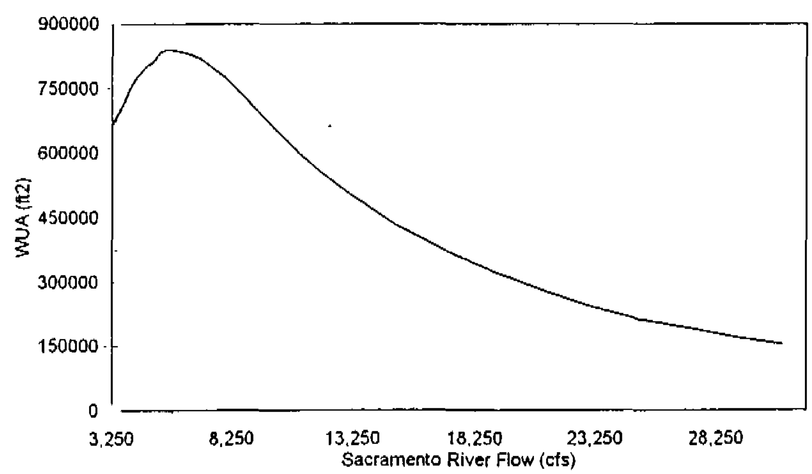


Figure 3
Fall-run Chinook Salmon Flow-Habitat Relationships, Segment 2



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APPENDIX A
PHABSIM WSEL CALIBRATION

Table 1
Stage of Zero Flow Values

Study Site	XS #	SZF (feet)
Mudball	1	83.80
Mudball	2 LC	88.20
Mudball	2 RC	93.70
Jellys Ferry	1, 2	83.00
Bend Bridge	1	75.00
Bend Bridge	2 LC	81.70
Bend Bridge	2 RC	86.70
Osborne	1	78.70
Osborne	2	87.70
Blackberry Island	1, 2	75.00
Five Fingers	1	86.40
Five Fingers	2	91.10
Five Fingers	3	87.30

Table 2
Calibration Methods and Parameters Used

Study Site	XS #	Flow Range (cfs)	Calibration Flows (cfs)	Method	Parameters
Mudball	1	3250-12000	6820, 10900, 14700	IFG4	—
Mudball	1	13000-31000	14700, 26300, 30200	IFG4	—
Mudball	2 LC	3250-31000	6820, 10900, 14700, 30200, 53800	IFG4	—
Mudball	2 RC	3250-31000	6820, 8520, 30200	IFG4	—
Jellys Ferry	1	3250-14000	6820, 10900, 14700	IFG4	—
Jellys Ferry	1	15000-31000	14700, 21600, 25800	IFG4	—
Jellys Ferry	2	3250-14000	6820, 10900, 14700	IFG4	—
Jellys Ferry	2	15000-31000	14700, 17800, 30200	IFG4	—
Bend	1	3250-9000	6820, 8520, 10600	IFG4	—
Bend	1	10000-31000	10600, 14700, 25800	IFG4	—
Bend	2 LC	3250-21000	6820, 8520, 21600	IFG4	—
Bend	2 LC	23000-31000	21600, 25800	MANSQ	β = 0.00, CALQ = 21600 cfs
Bend	2 RC	3250-9000	6820, 8520, 10600	IFG4	—
Bend	2 RC	10000-31000	10600, 13300, 25800	IFG4	—
Osborne	1	3250-15000	6379, 9105	MANSQ	β = 0.50, CALQ = 6379 cfs
Osborne	1	17000-31000	13424, 22179, 59879	IFG4	—
Osborne	2	3250-21000	6379, 9105, 22179	IFG4	—
Osborne	2	23000-31000	22179, 59879	WSP	n = 0.0457, RM = 0.6664
Blackberry Island	1	3250-23000	6379, 9661, 22179	IFG4	—
Blackberry Island	1	25000-31000	22179, 59879	MANSQ	β = 0.405, CALQ = 22179 cfs
Blackberry Island	2	3250-23000	6379, 9661, 22179	IFG4	—

Study Site	XS#	Flow Range (cfs)	Calibration Flows (cfs)	Method	Parameters
Blackberry Island	2	25000-31000	22179, 59879	MANSQ	$\beta = 0.342$, CALQ = 22179 cfs
Five Fingers	1	3250-31000	5433, 12285, 25554	IFG4	—
Five Fingers	2	3250-14000	5433, 8905, 12285	IFG4	—
Five Fingers	2	15000-31000	12285, 25554	MANSQ	$\beta = 0.00$, CALQ = 12285 cfs
Five Fingers	3	3250-31000	5433, 8905, 25554	MANSQ	$\beta = 0.45$, CALQ = 5433 cfs

Table 3
Mudball

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6820 cfs	10900 cfs	14700 cfs	Difference (measured vs. pred. WSELs, feet) 6820 cfs	10900 cfs	14700 cfs
1	3.34	2.02	1.0	3.0	2.1	0.03	0.10	0.07

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 14700 cfs	26300 cfs	30200 cfs	Difference (measured vs. pred. WSELs, feet) 14700 cfs	26300 cfs	30200 cfs
1	3.61	1.56	0.3	2.3	2.0	0.01	0.09	0.08

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6820 cfs	8520 cfs	30200 cfs	Difference (measured vs. pred. WSELs, feet) 6820 cfs	8520 cfs	30200 cfs
2 LC	2.40	4.58	5.4	6.6	1.5	0.15	0.19	0.07

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6820 cfs	10900 cfs	14700 cfs	30200 cfs	53800 cfs	Difference (measured vs. pred. WSELs, feet) 6820 cfs	10900 cfs	147000 cfs	30200 cfs	53800 cfs
2 RC	1.79	1.52	2.6	3.7	0.2	0.4	0.19	0.03	0.07	None	0.01	0.04

Jellys Ferry

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6820 cfs	10900 cfs	14700 cfs	Difference (measured vs. pred. WSELs, feet) 6820 cfs	10900 cfs	14700 cfs
1	3.04	2.36	1.6	3.6	1.9	0.04	0.10	0.06

Jellys Ferry

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 14700 cfs	21600 cfs	25800 cfs	Difference (measured vs. pred. WSELs, feet) 14700 cfs	21600 cfs	25800 cfs
1	2.14	0.93	0.4	1.4	1.0	0.02	0.07	0.06

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6820 cfs	10900 cfs	14700 cfs	Difference (measured vs. pred. WSELs, feet) 6820 cfs	10900 cfs	14700 cfs
2	4.18	0.49	0.8	0.7	0.4	0.01	0.02	0.01

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 14700 cfs	17800 cfs	30200 cfs	Difference (measured vs. pred. WSELs, feet) 14700 cfs	17800 cfs	30200 cfs
2	2.64	0.58	0.7	0.9	0.2	0.03	0.04	0.01

Bend Bridge

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6820 cfs	8520 cfs	10600 cfs	Difference (measured vs. pred. WSELs, feet) 6820 cfs	8520 cfs	10600 cfs
1	2.93	1.12	0.9	0.7	1.7	0.04	0.07	0.04

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 10600 cfs	14700 cfs	25800 cfs	Difference (measured vs. pred. WSELs, feet) 10600 cfs	14700 cfs	25800 cfs
1	3.50	1.45	2.2	1.5	0.7	0.06	0.10	0.04

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6820 cfs	8520 cfs	21600 cfs	Difference (measured vs. pred. WSELs, feet) 6820 cfs	8520 cfs	21600 cfs
2 LC	1.30	1.35	1.5	2.0	0.5	0.07	0.11	0.04

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 21600 cfs	25800 cfs	Difference (measured vs. pred. WSELs, feet) 21600 cfs	25800 cfs
2 LC	—	—	—	—	None	0.06

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6820 cfs	8520 cfs	10600 cfs	Difference (measured vs. pred. WSELs, feet) 6820 cfs	8520 cfs	10600 cfs
2 RC	1.39	4.82	3.8	7.6	3.3	0.04	0.11	0.07

Bend Bridge

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 10600 cfs	13300 cfs	25800	Difference (measured vs. pred. WSELs, feet) 10600 cfs	13300 cfs	25800
2 RC	1.87	1.01	1.1	1.5	0.4	0.02	0.03	0.02

Osborne

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6379 cfs	9105 cfs	Difference (measured vs. pred. WSELs, feet) 6379 cfs	9105 cfs
1	—	—	—	—	None	0.05

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 13424 cfs	22179 cfs	59879	Difference (measured vs. pred. WSELs, feet) 13424 cfs	22179 cfs	59879
1	3.52	0.07	0.07	0.10	0.00	0.00	0.01	0.00

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6379 cfs	9105 cfs	22179 cfs	Difference (measured vs. pred. WSELs, feet) 6379 cfs	9105 cfs	22179 cfs
2	2.24	2.13	6.1	11.3	4.3	0.05	0.09	0.04

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 22179 cfs	59879 cfs	Difference (measured vs. pred. WSELs, feet) 22179 cfs	59879 cfs
2	—	—	—	—	None	None

Blackberry Island

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6379 cfs	9661 cfs	22179 cfs	Difference (measured vs. pred. WSELs, feet) 6379 cfs	9661 cfs	22179 cfs
1	4.07	0.86	0.8	1.3	0.5	0.02	0.04	0.02

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 22179 cfs	59879 cfs	Difference (measured vs. pred. WSELs, feet) 22179 cfs	59879 cfs
1	—	—	—	—	None	None

Blackberry Island

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 6379 cfs	9661 cfs	22179 cfs	Difference (measured vs. pred. WSELs, feet) 6379 cfs	9661 cfs	22179 cfs
2	4.03	1.57	1.5	2.3	0.9	0.04	0.07	0.03

Blackberry Island

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 22179 cfs	59879 cfs	Difference (measured vs. pred. WSELs, feet) 22179 cfs	59879 cfs
2	—	—	—	—	None	None

Five Fingers

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 5433 cfs	12285 cfs	25554 cfs	Difference (measured vs. pred. WSELs, feet) 5433 cfs	12285 cfs	25554 cfs
1	4.69	3.35	2.8	5.2	2.2	0.06	0.12	0.06

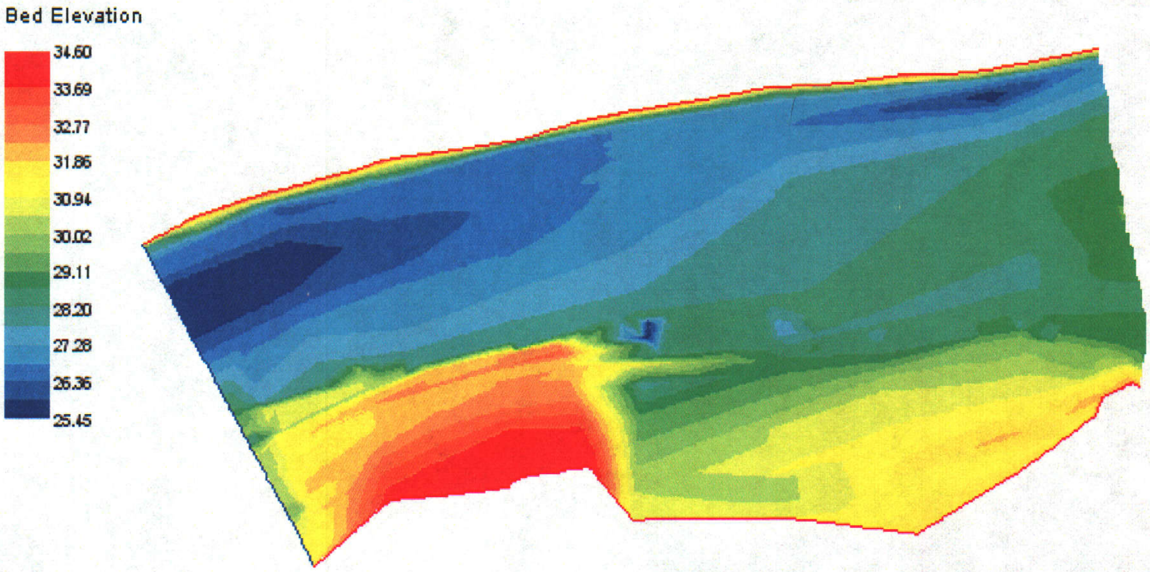
XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 5433 cfs	8905 cfs	12285 cfs	Difference (measured vs. pred. WSELs, feet) 5433 cfs	8905 cfs	12285 cfs
2	3.02	3.78	1.8	5.9	3.8	0.02	0.08	0.07

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 12285 cfs	25554 cfs	Difference (measured vs. pred. WSELs, feet) 12285 cfs	25554 cfs
2	—	—	—	—	None	0.01

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs. Given Disch. (%) 5433 cfs	8905 cfs	25554 cfs	Difference (measured vs. pred. WSELs, feet) 5433 cfs	8905 cfs	25554 cfs
3	—	—	—	—	—	None	0.06	0.03

APPENDIX B
VELOCITY ADJUSTMENT FACTORS

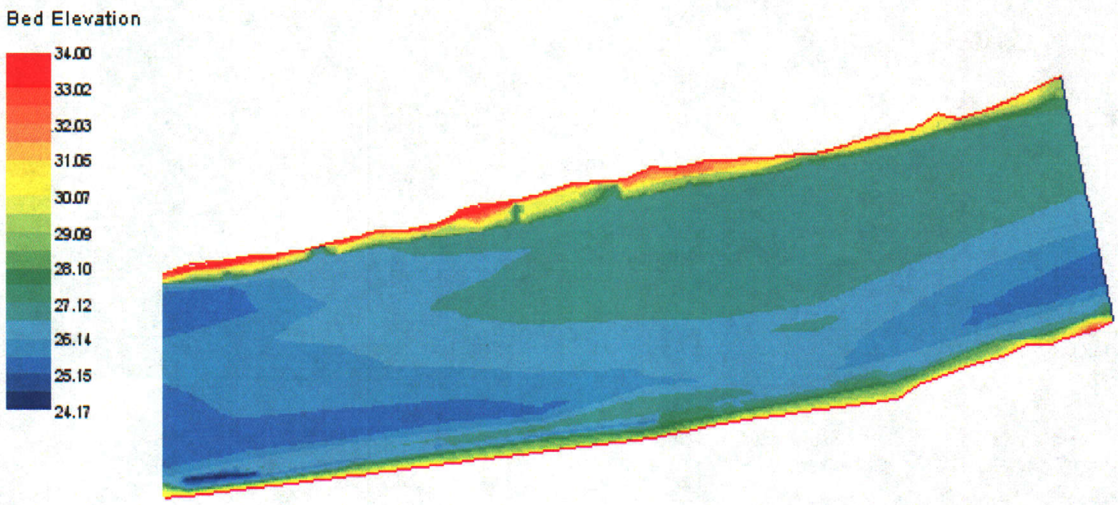
Mudball Study Site



Units of bed elevation are meters.

Upstream extension not displayed.

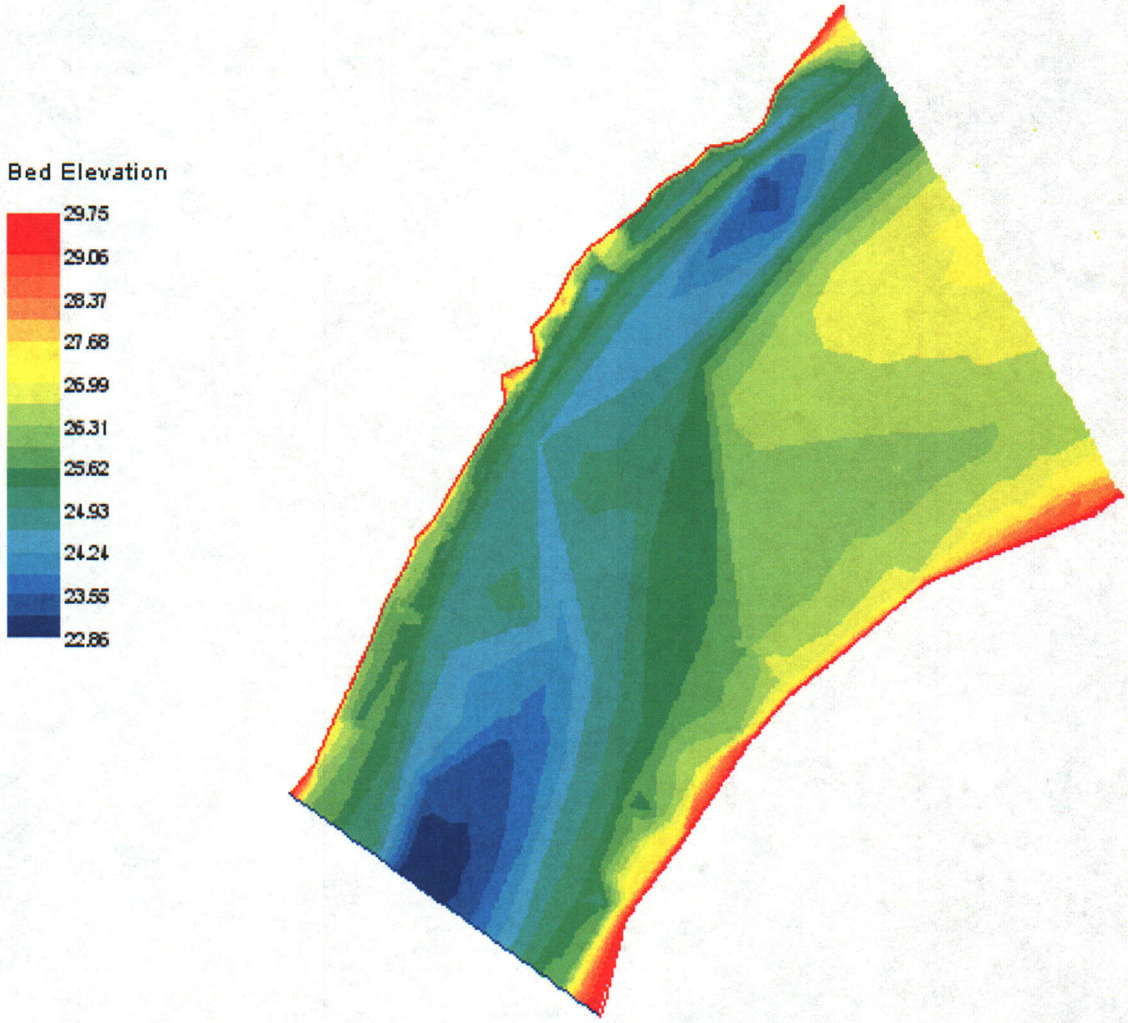
Jellys Ferry Study Site



Units of bed elevation are meters.

Upstream extension not displayed.

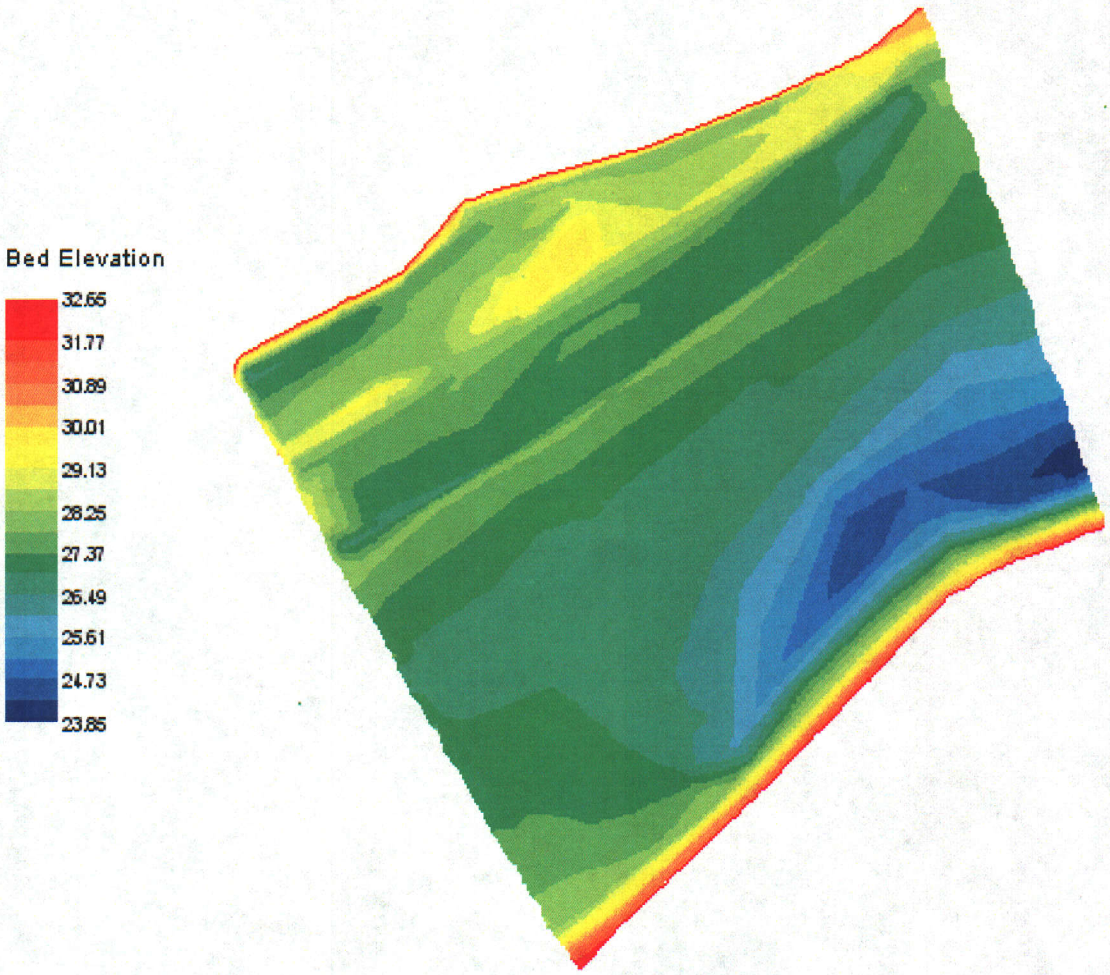
Bend Bridge Study Site



Units of bed elevation are meters.

Upstream extension not displayed.

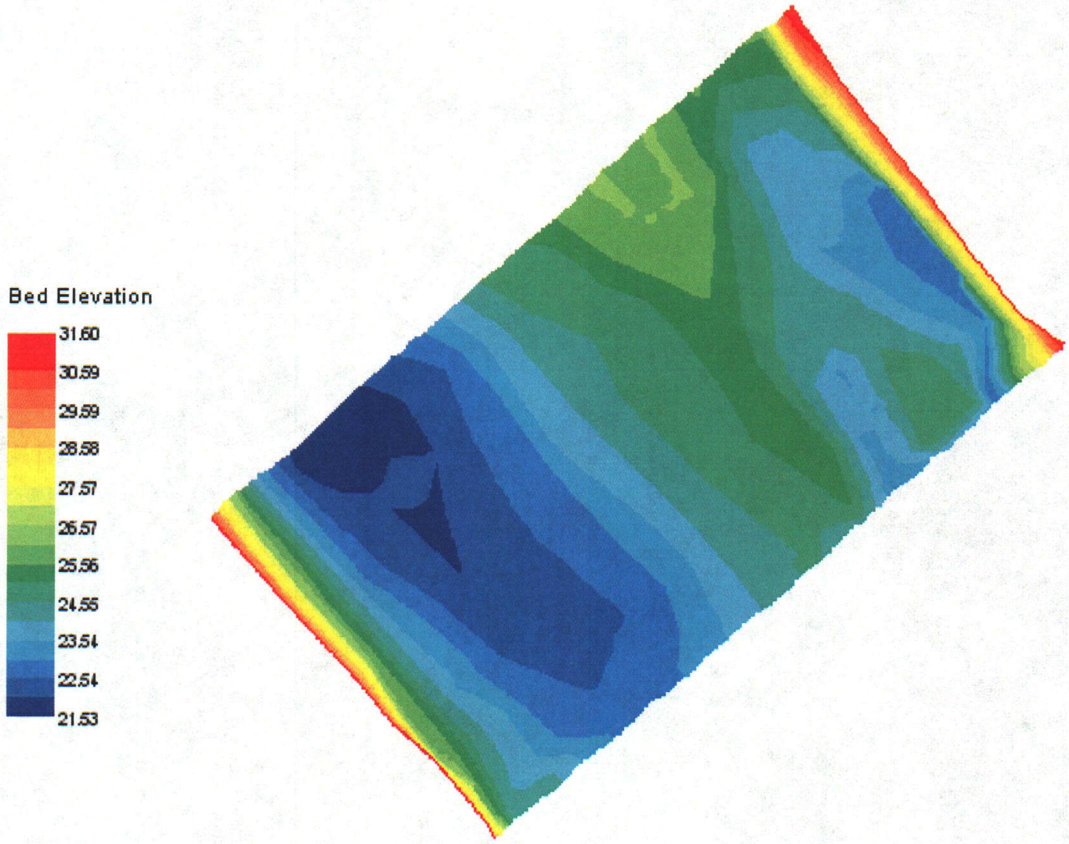
Osborne Study Site



Units of bed elevation are meters.

Upstream and downstream extensions not displayed.

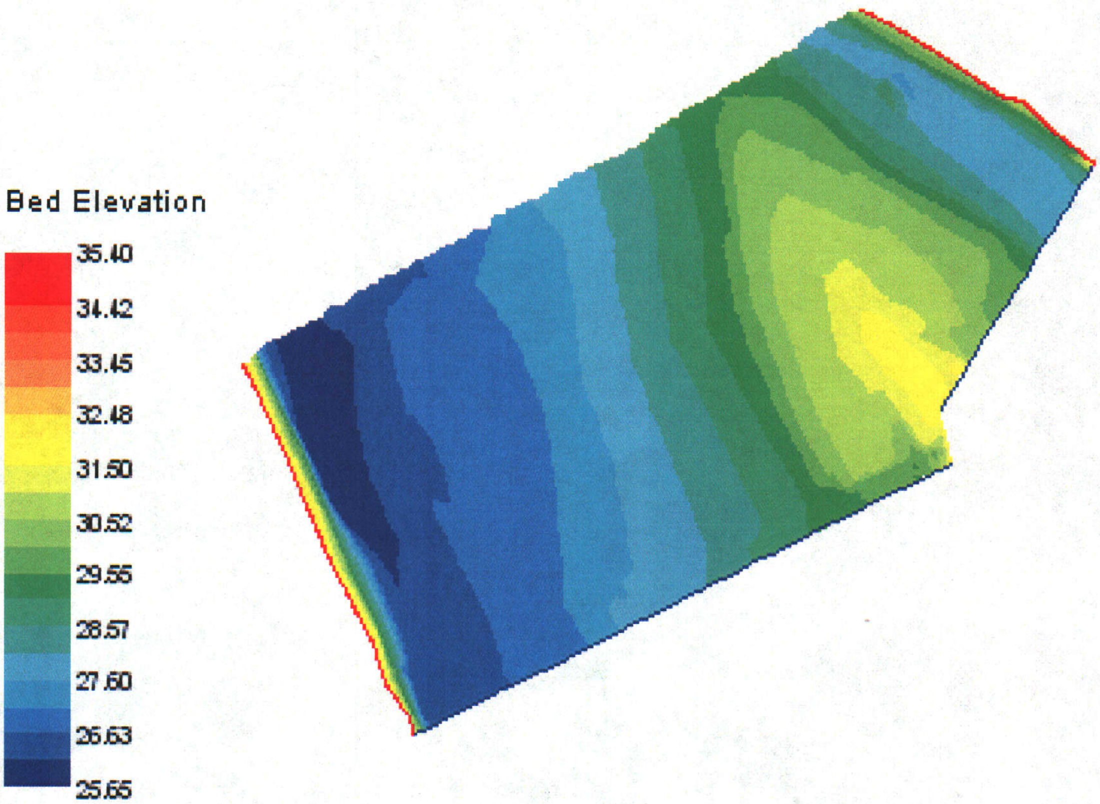
Blackberry Island Study Site



Units of bed elevation are meters.

Upstream and downstream extensions not displayed.

Five Fingers Study Site

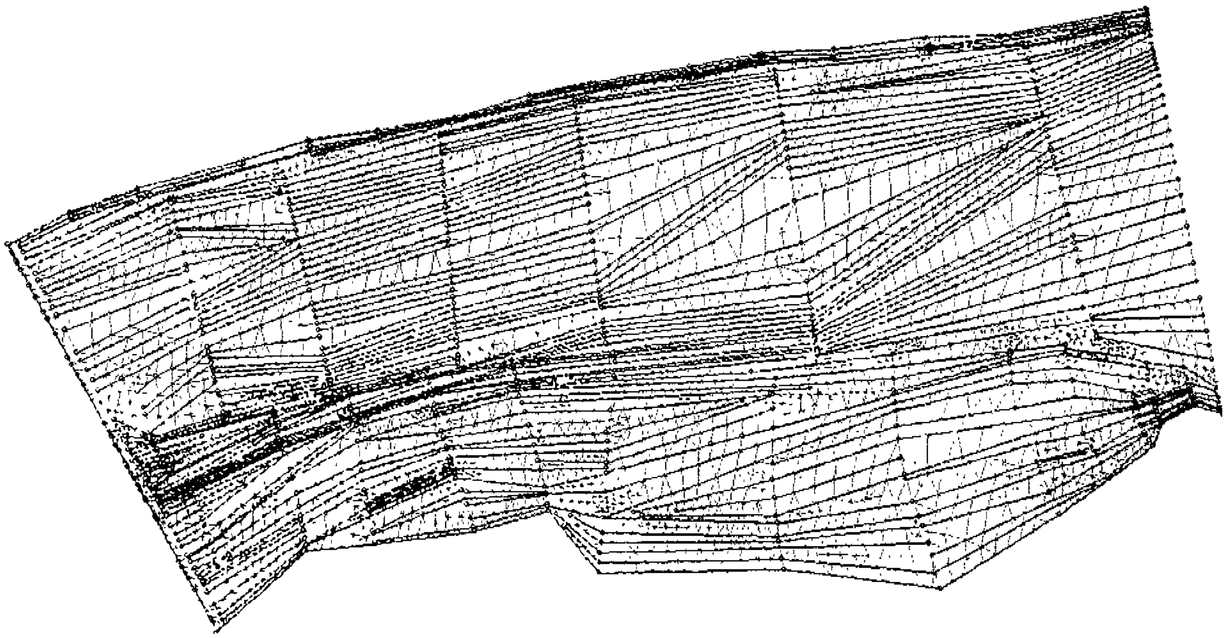


Units of bed elevation are meters.

Upstream extension not displayed.

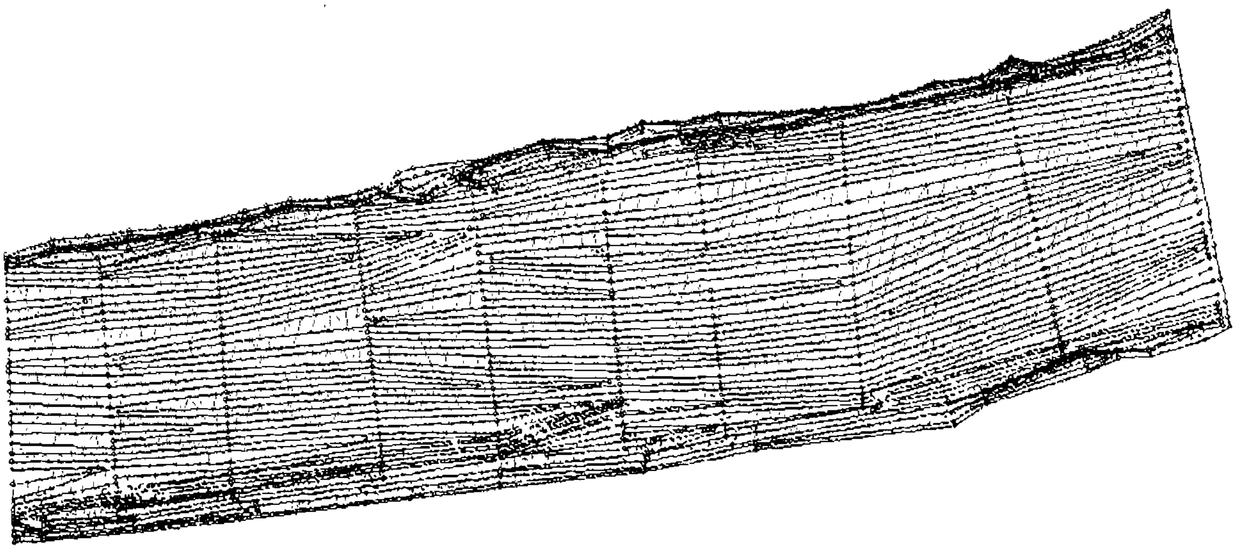
APPENDIX D
STUDY SITE MESH FILES

Mudball Study Site



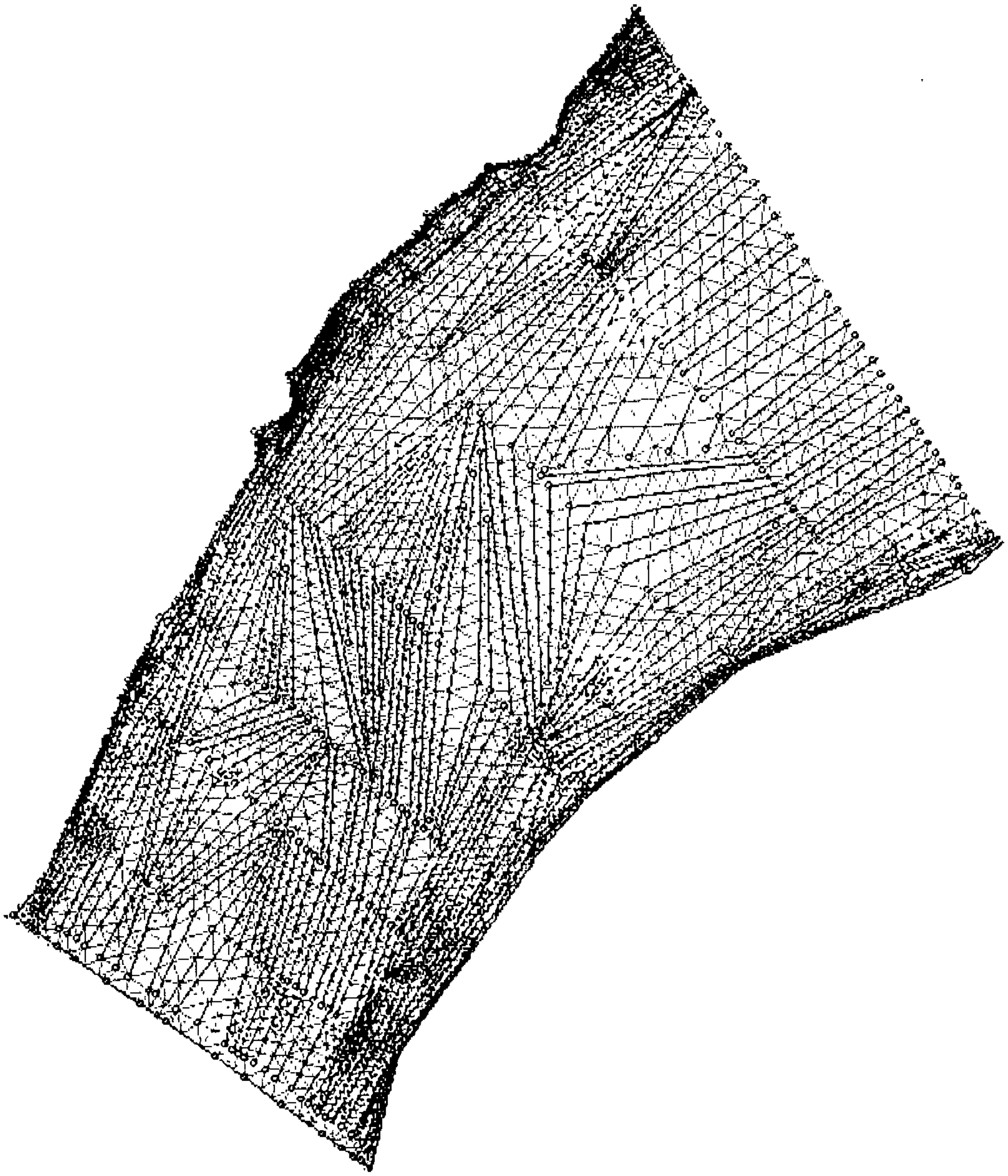
Upstream extension not displayed.

Jellys Ferry Study Site



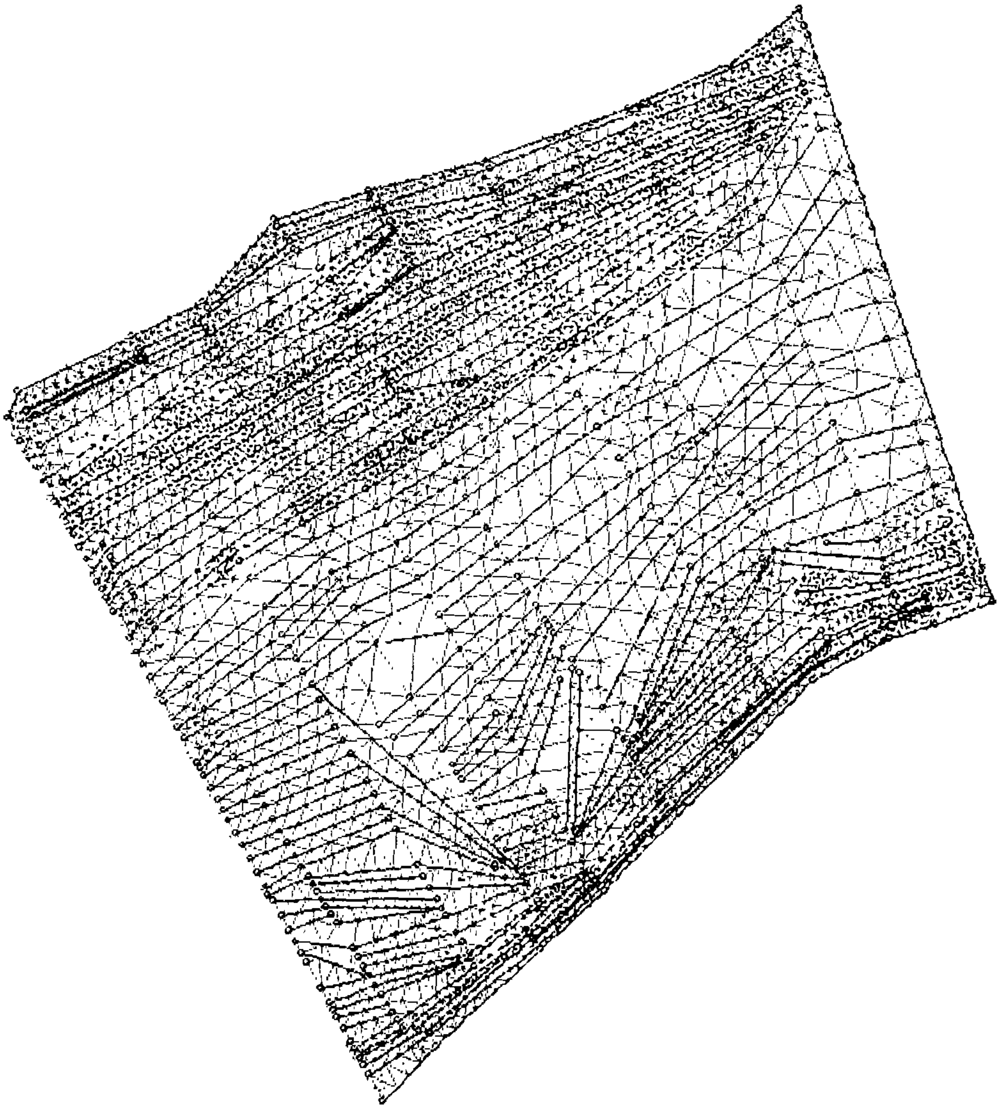
Upstream extension not displayed.

Bend Bridge Study Site



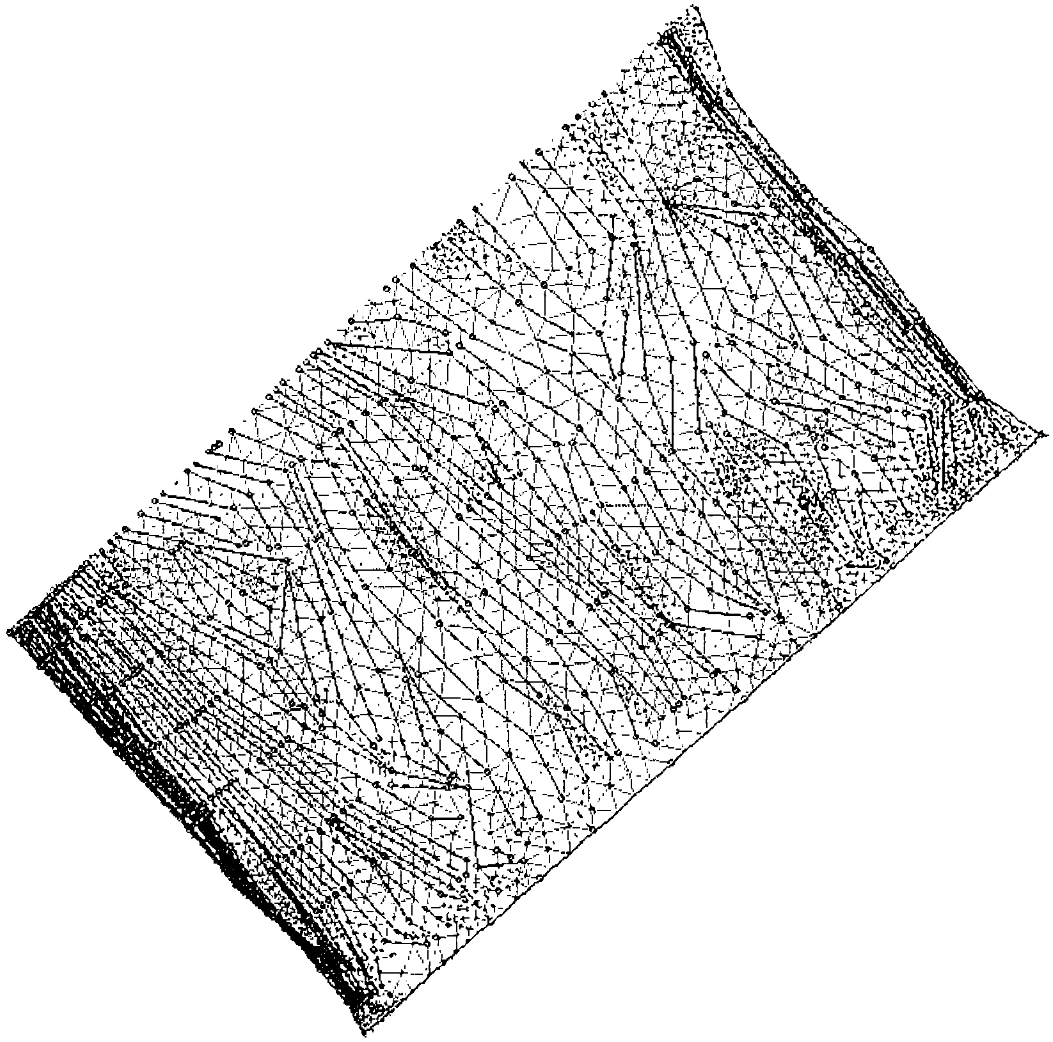
Upstream extension not displayed.

Osborne Study Site



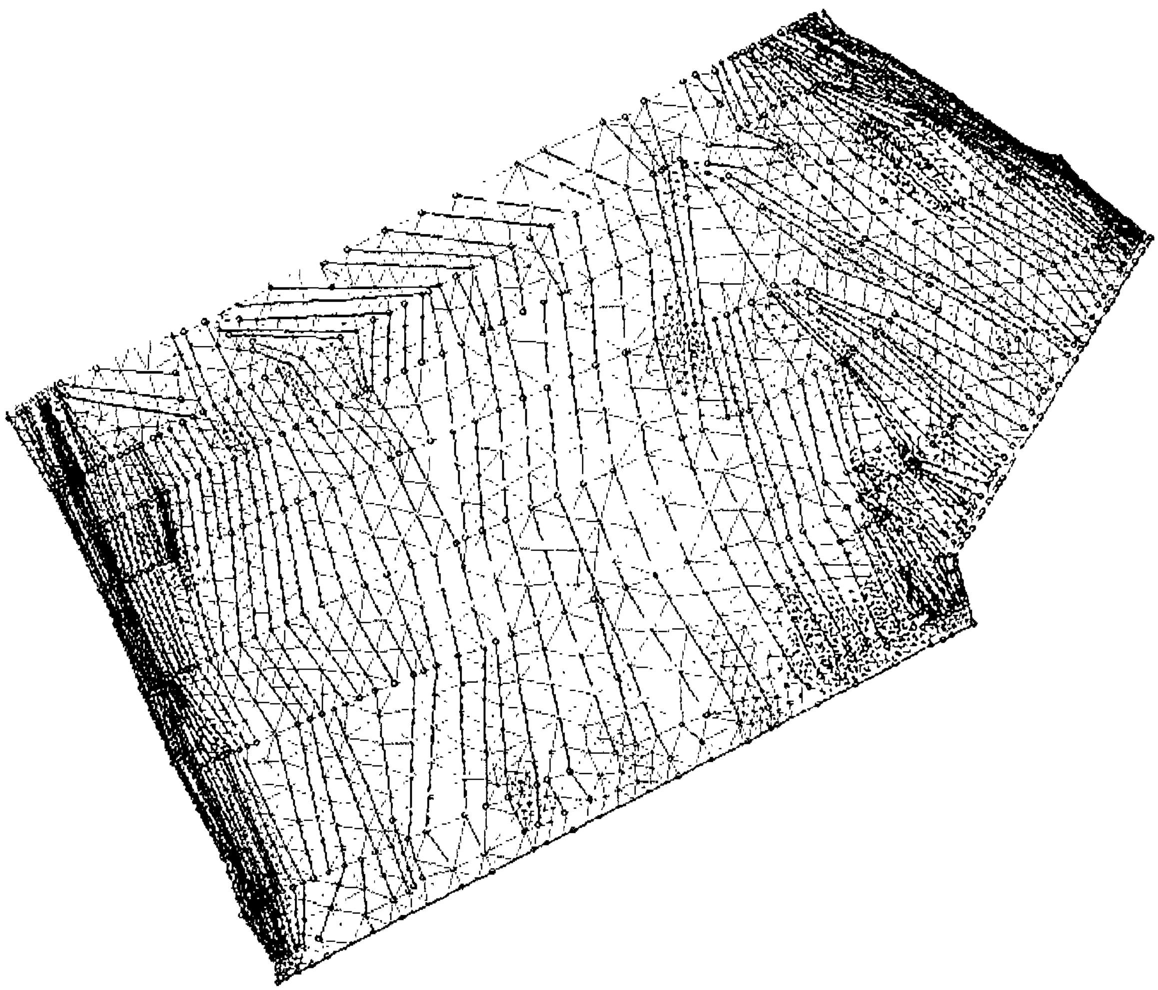
Upstream and downstream extensions not displayed.

Blackberry Island Study Site



Upstream and downstream extensions not displayed.

Five Fingers Study Site



Upstream extension not displayed.

APPENDIX E
2-D WSEL CALIBRATION

Table 1
Calibration Statistics

Site Name	% Nodes within 0.1'	Nodes	QI	Net Q	Sol Δ	Max F
Mudball	83%	11678	0.30	0.03%	9×10^{-7}	1.95
Jellys Ferry	84%	11233	0.30	0.02%	7×10^{-10}	2.71
Bend Bridge	75%	11867	0.30	0.001%	9×10^{-16}	1.04
Osborne	85%	7851	0.31	0.004%	6×10^{-13}	1.92
Blackberry Island	85%	13196	0.32	0.04%	6×10^{-7}	0.52
Five Fingers	90%	11433	0.31	0.02%	1×10^{-7}	1.23

Table 2
Mudball

XSEC	BR Mult	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
2 LC	0.35	0.10	0.06	0.16
2 RC	0.35	0.19	0.29	0.62

Jellys Ferry

XSEC	BR Mult	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
2	0.3	0.01	0.03	0.08

Bend Bridge

XSEC	BR Mult	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
2 LC	0.8	0.99	0.12	1.25
2 RC	0.8	0.94	0.09	1.05

Osborne

XSEC	BR Mult	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
1	3.0	0.11	0.09	0.24
2	3.0	0.23	0.20	0.68

Blackberry Island

XSEC	BR Mult	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
1	3	0.03	0.01	0.05
2	3	0.10	0.03	0.15

Five Fingers

XSEC	BR Mult	Difference (measured vs. pred. WSELs, feet) Average	Standard Deviation	Maximum
3	1.5	0.23	0.32	1.04

APPENDIX F
VELOCITY VALIDATION STATISTICS

Table 1
Measured Velocities less than 3 ft/s

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

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Mudball	102	1.58	1.45	6.04
Jellys Ferry	95	1.70	0.97	4.38
Bend Bridge	97	1.59	1.67	6.68
Osborne	147	1.22	0.94	3.79
Blackberry Island	268	0.93	1.10	4.62
Five Fingers	127	2.27	2.27	7.39

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

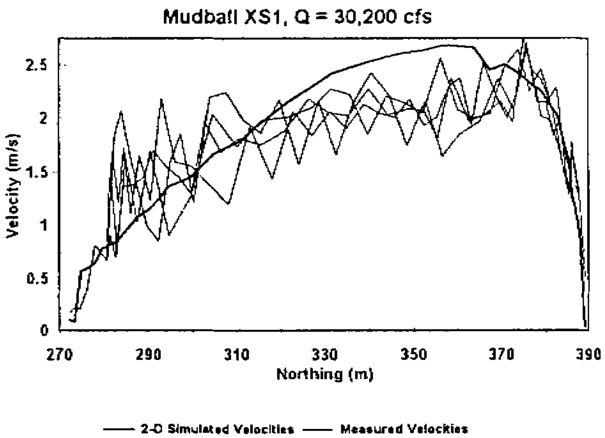
Table 2
Measured Velocities greater than 3 ft/s

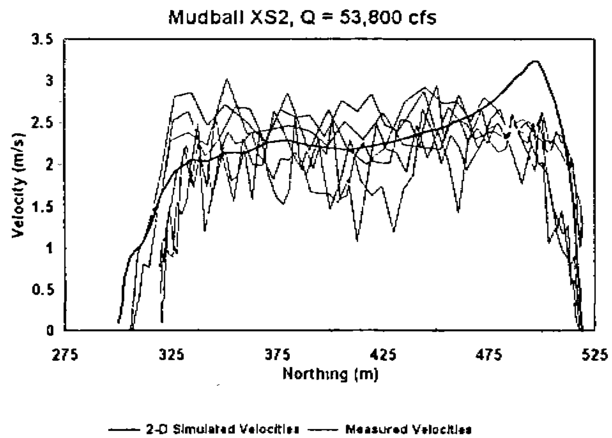
Percent Difference (measured vs. pred. velocities)

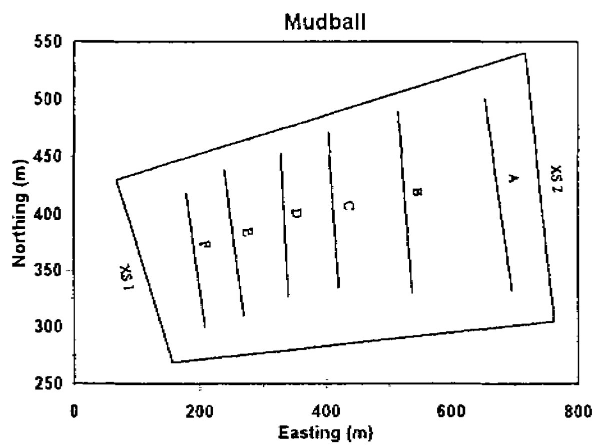
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Mudball	347	22%	25%	179%
Jellys Ferry	383	22%	23%	100%
Bend Bridge	347	20%	18%	111%
Osborne	355	17%	13%	76%
Blackberry Island	223	21%	16%	114%
Five Fingers	353	46%	34%	171%

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

Mudball Study Site

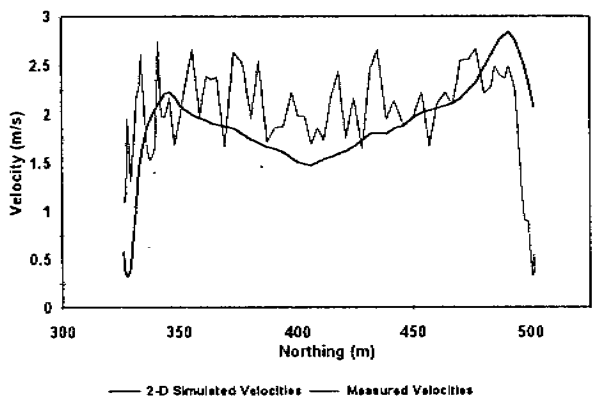






Mudball Study Site

Mudball Deep Beds A
Q = 26,300 cfs



Mudball Deep Beds B
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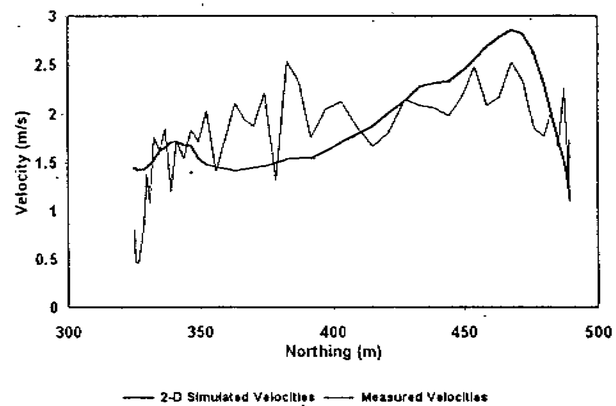
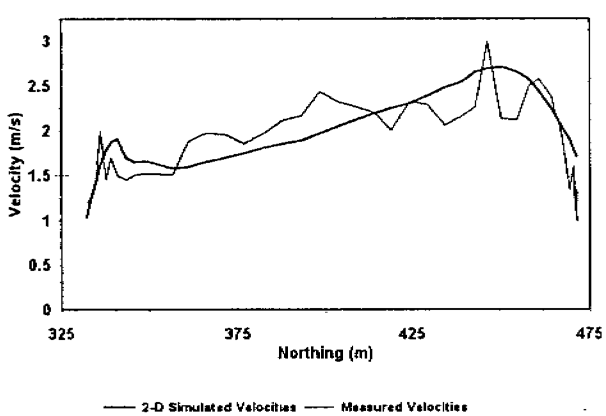
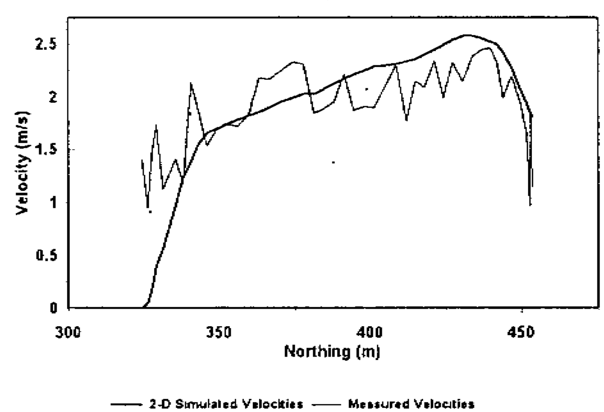


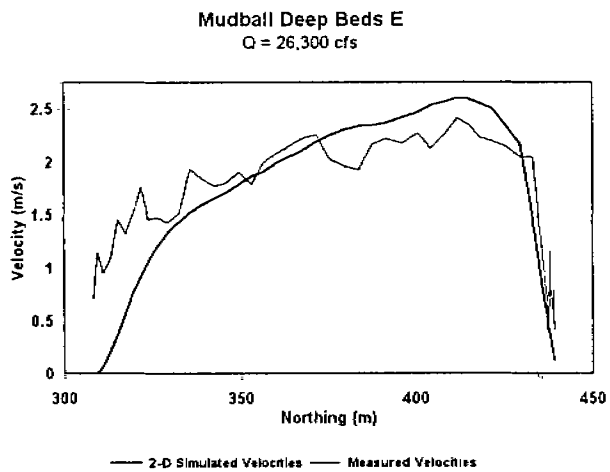
Mudball Deep Beds C
Q = 26,300 cfs

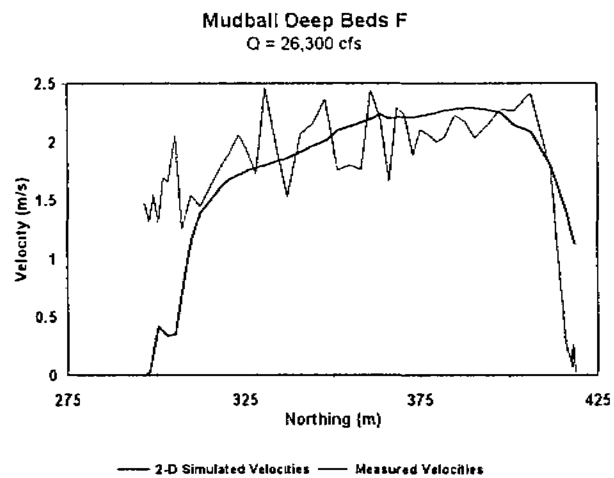


Mudball Deep Beds D
Q = 26,300 cfs



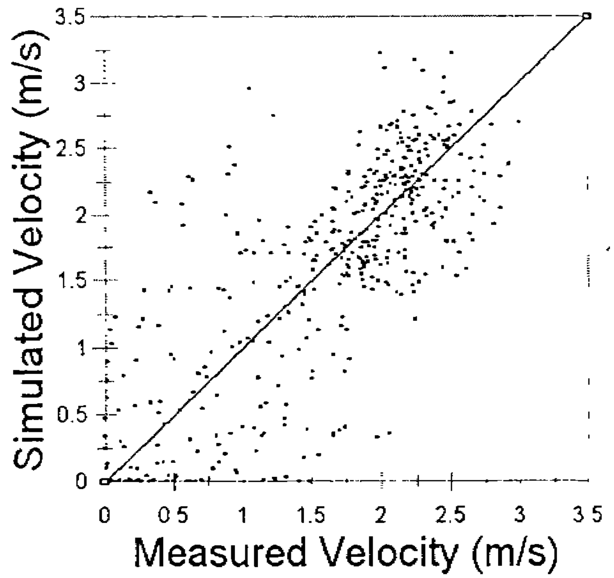
Mudball Study Site



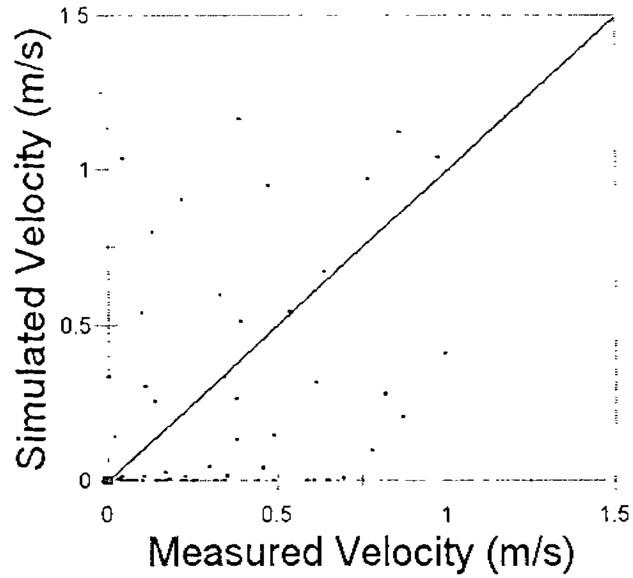


Mudball Study Site

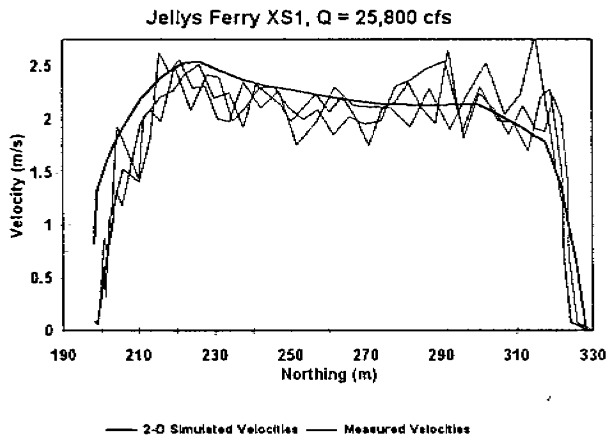
Mudball
All Validation Velocities

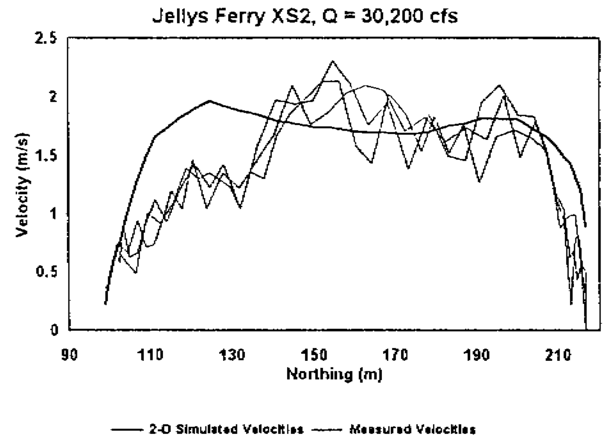


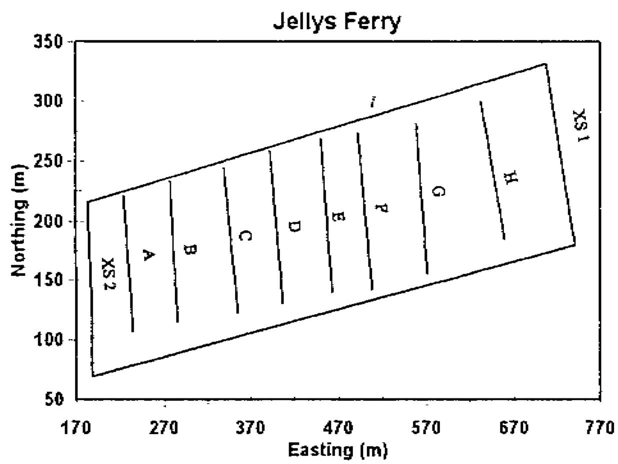
Mudball
Between Transect Non-ADCP Velocities



Jellys Ferry Study Site







Jellys Ferry Study Site

Jellys Ferry Deep Beds A
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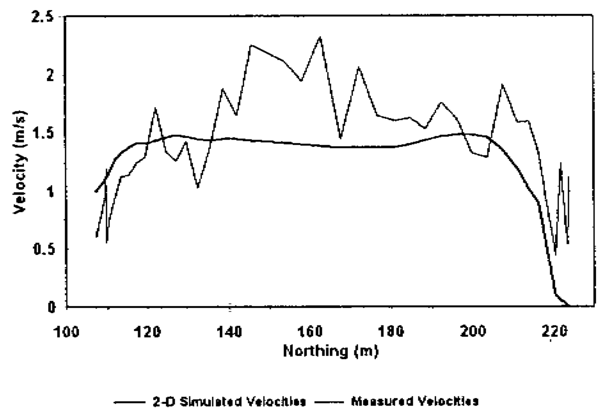
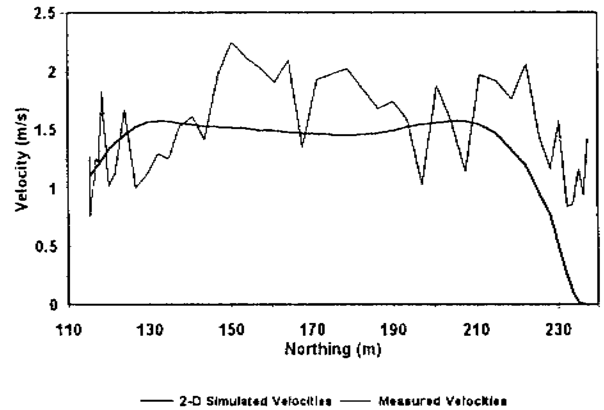
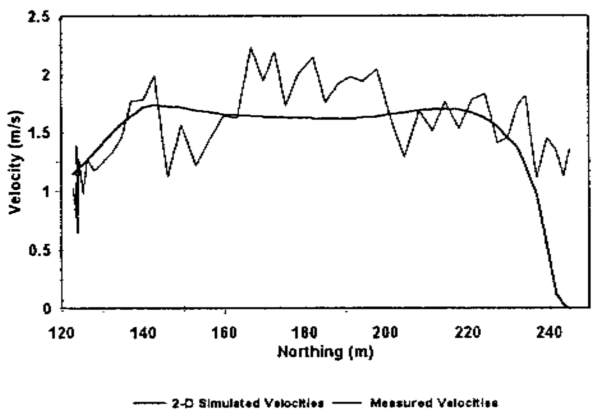


Jellys Ferry Deep Beds B
Q = 17,800 cfs



Jellys Ferry Deep Beds C
Q = 17,800 cfs



Jellys Ferry Deep Beds D
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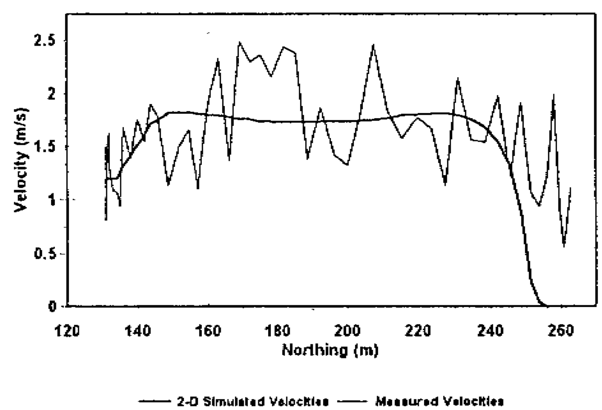
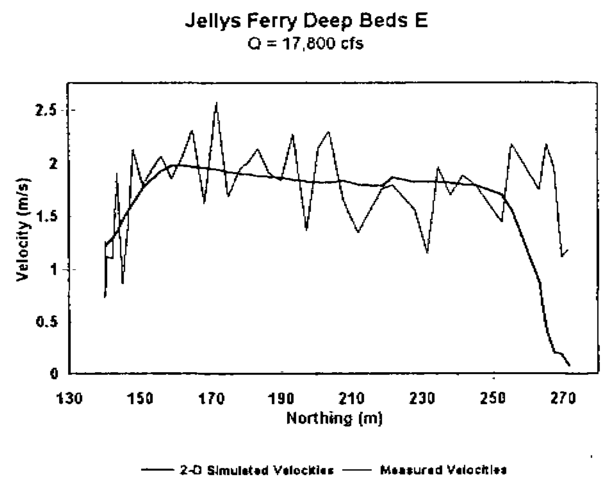
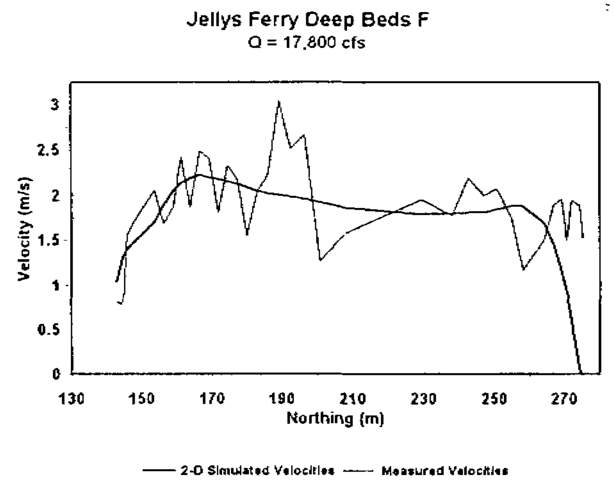
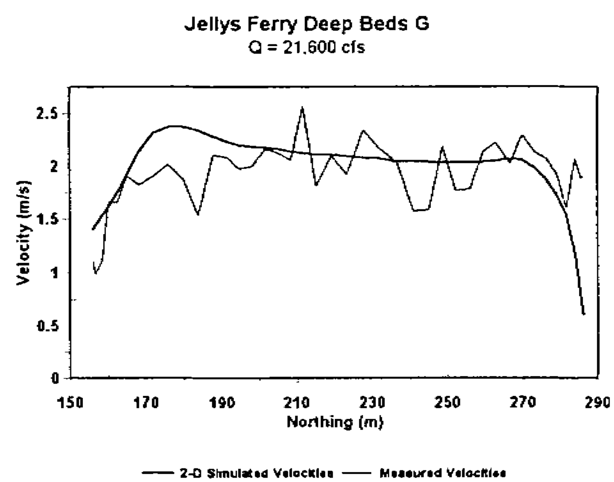
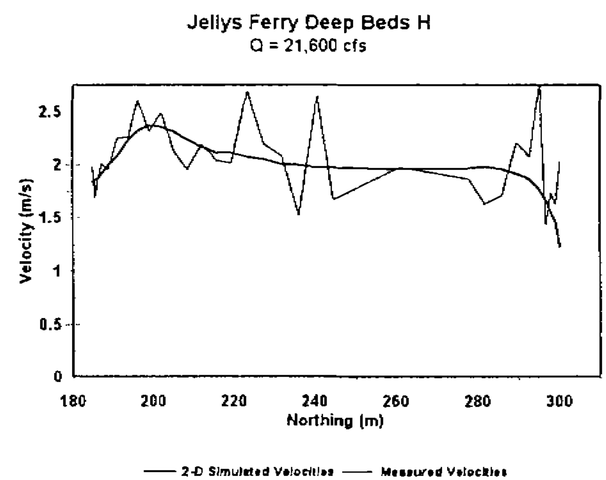


Jellys Ferry Study Site

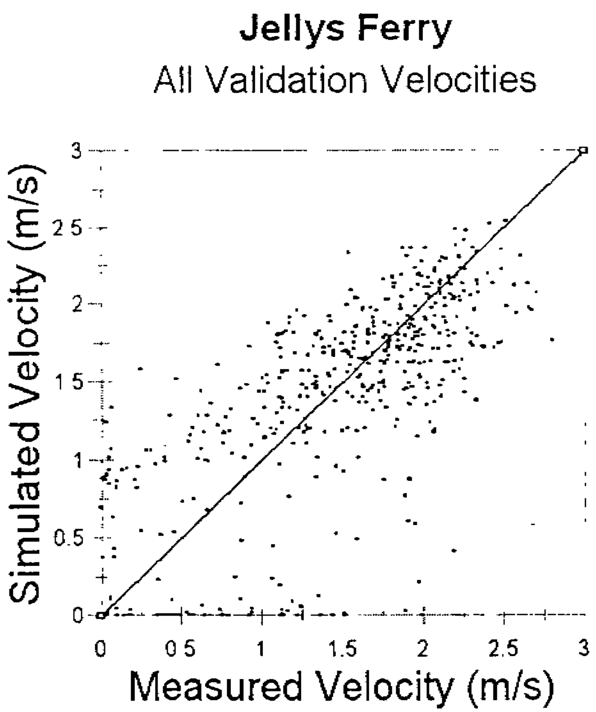


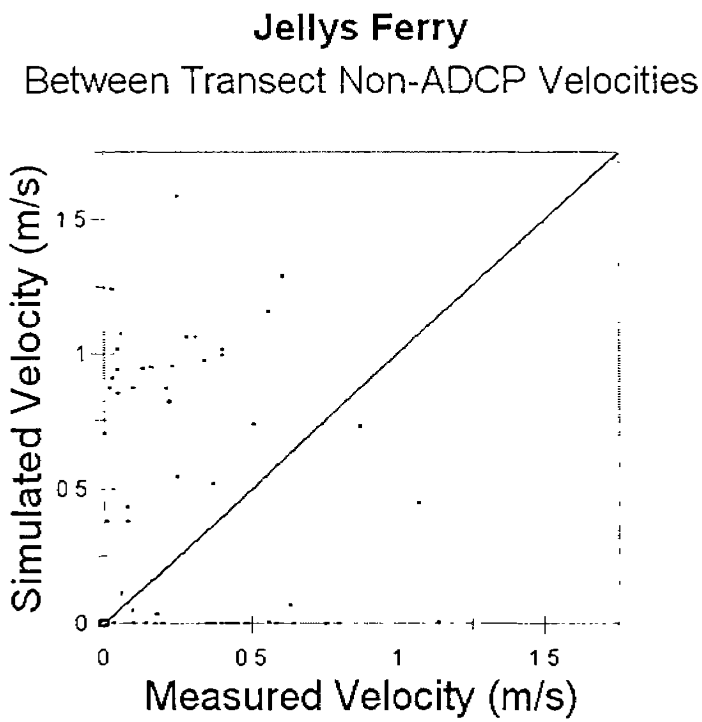




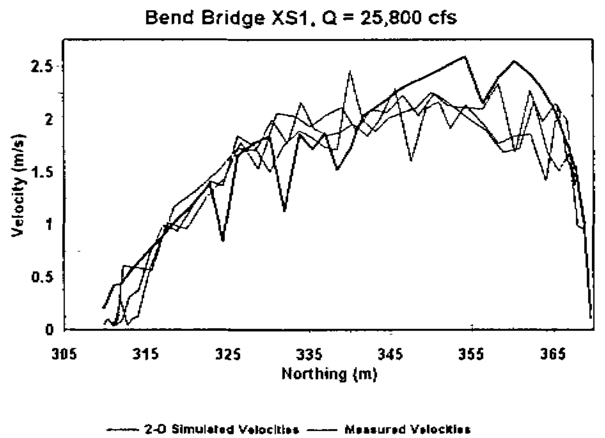


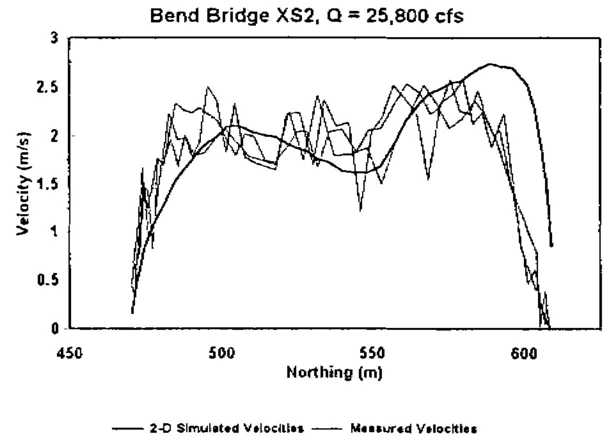
Jellys Ferry Study Site

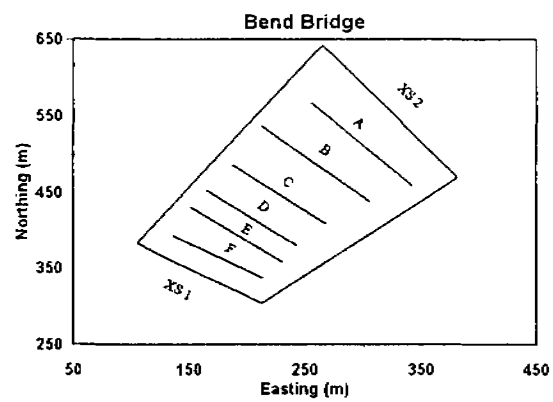




Bend Bridge Study Site

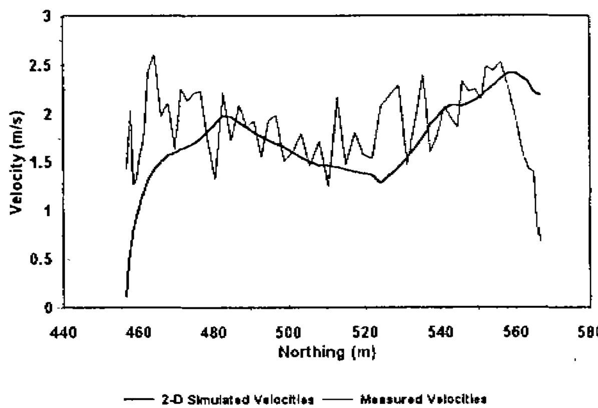






Bend Bridge Study Site

Bend Bridge Deep Beds A
Q = 21,600 cfs



Bend Bridge Deep Beds B
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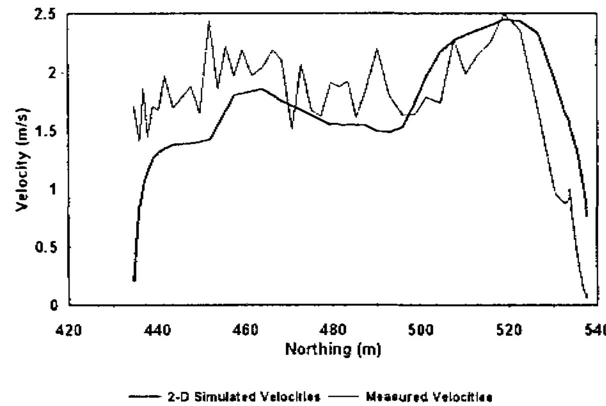

Bend Bridge Deep Beds C
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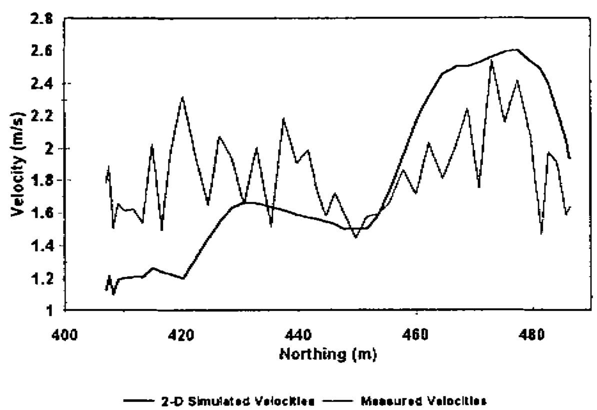

Bend Bridge Deep Beds D
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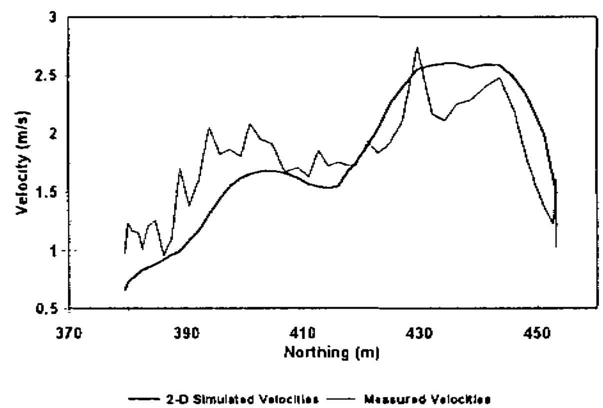

Bend Bridge Study Site

Bend Bridge Deep Beds E
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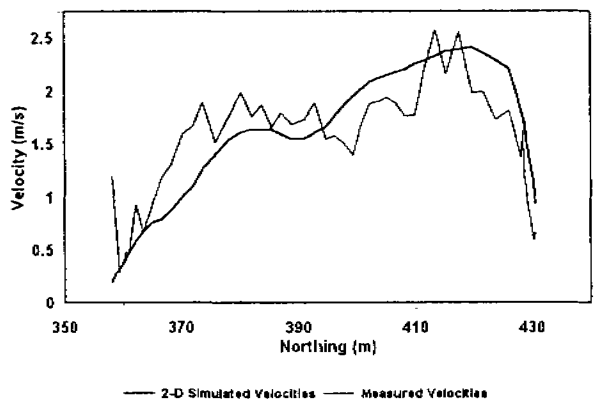

Bend Bridge Deep Beds F
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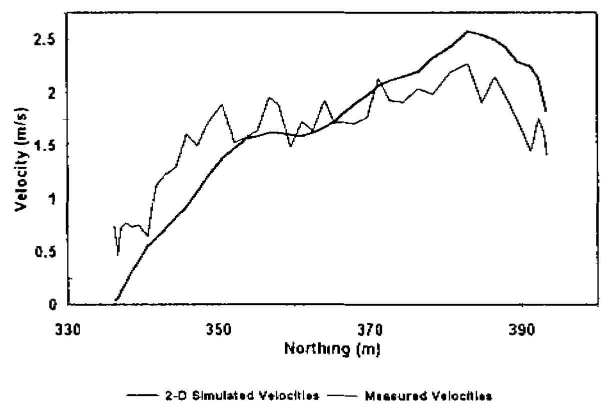
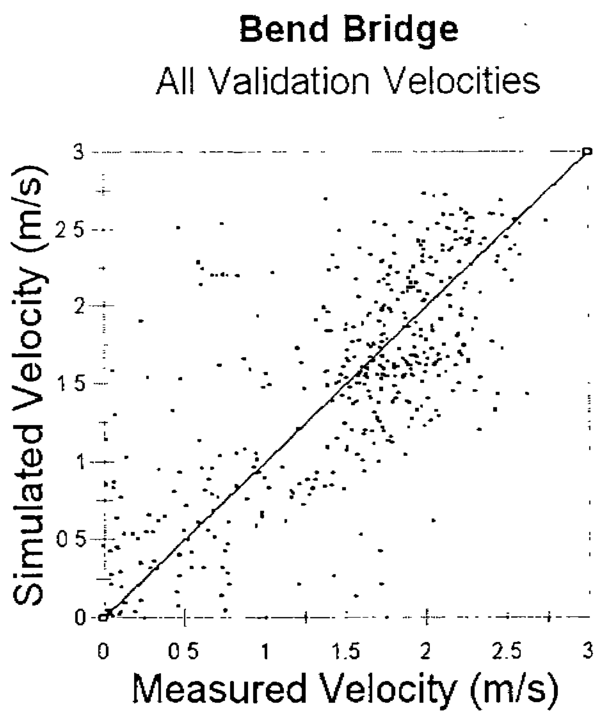
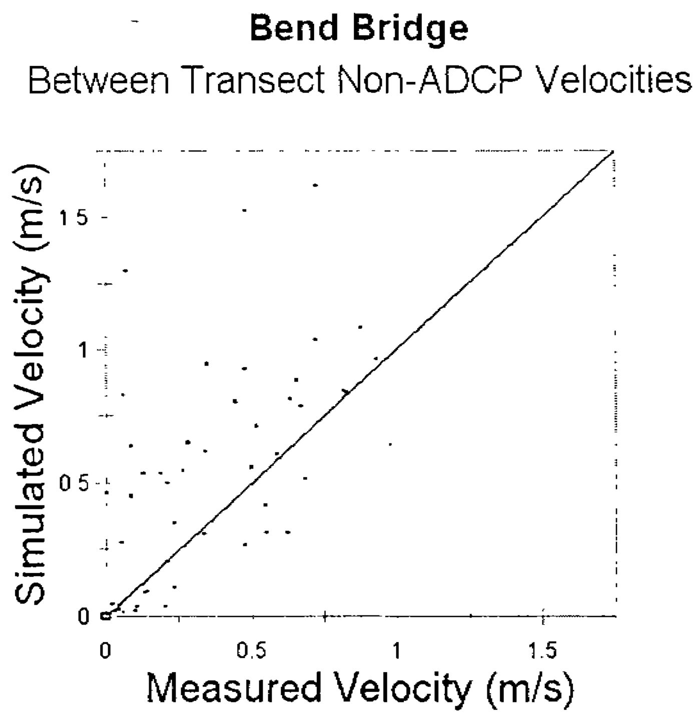
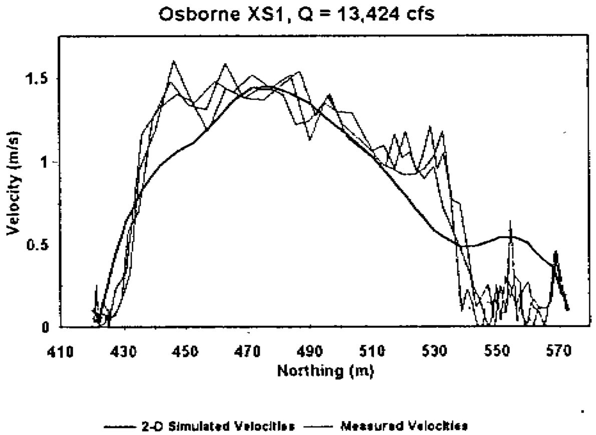


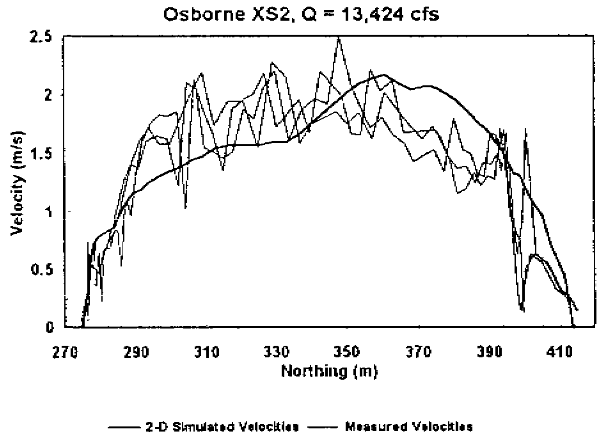
Bend Bridge Study Site

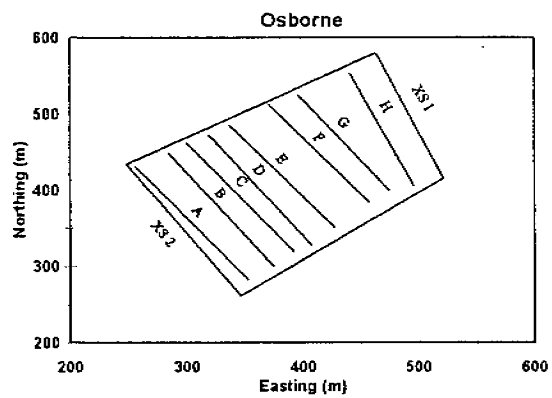




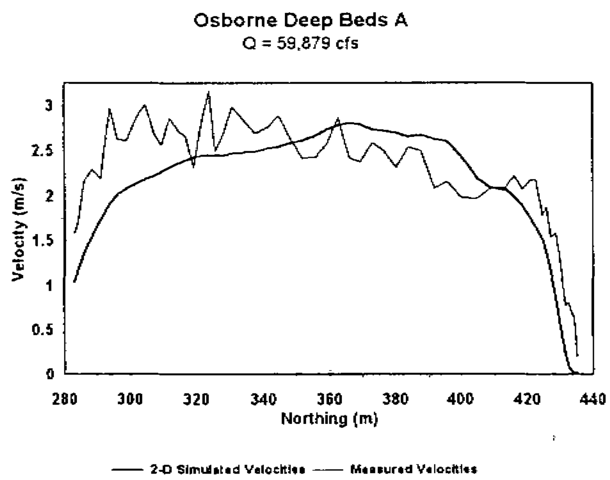
Osborne Study Site

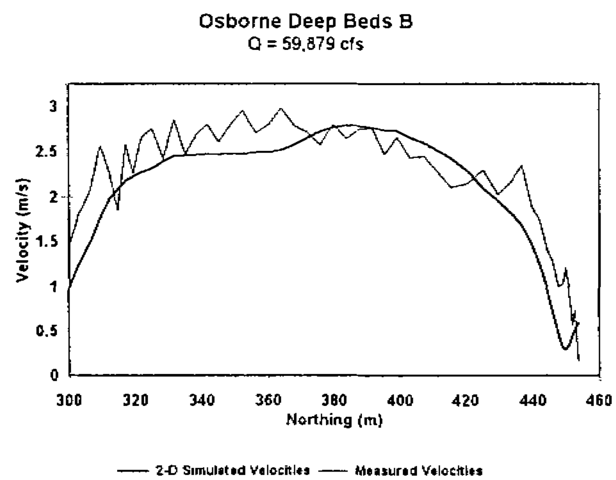


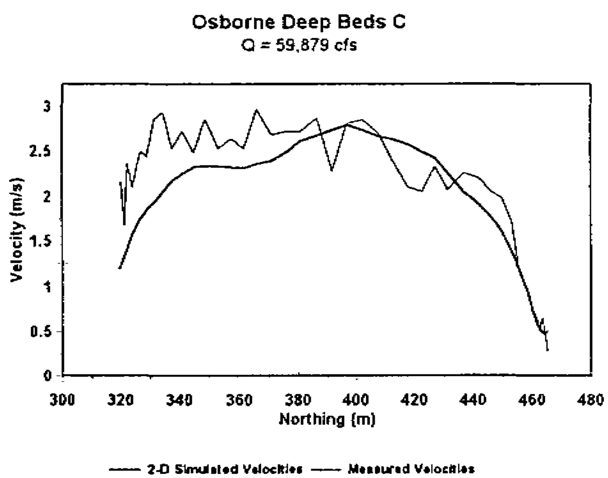


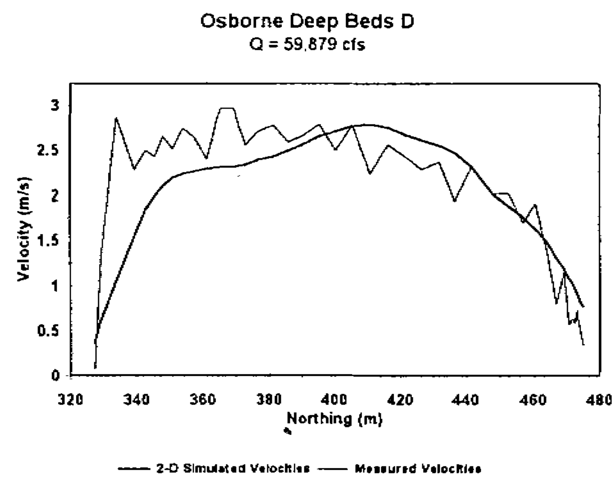


Osborne Study Site



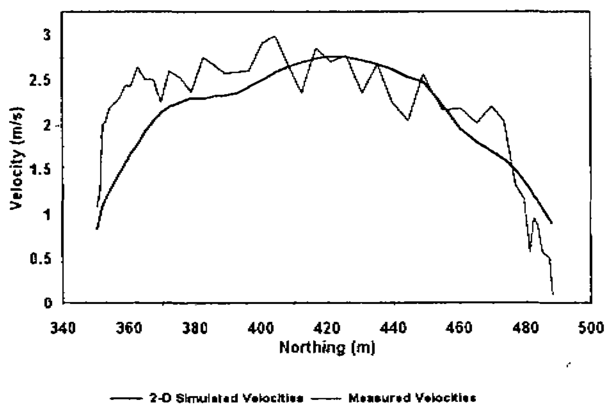




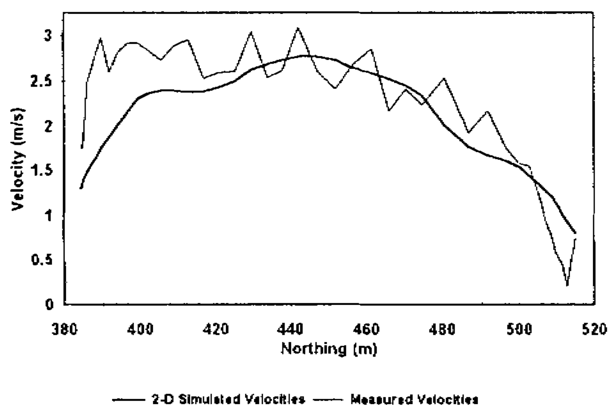


Osborne Study Site

Osborne Deep Beds E
Q = 59,879 cfs



Osborne Deep Beds F
Q = 59,879 cfs



Osborne Deep Beds G
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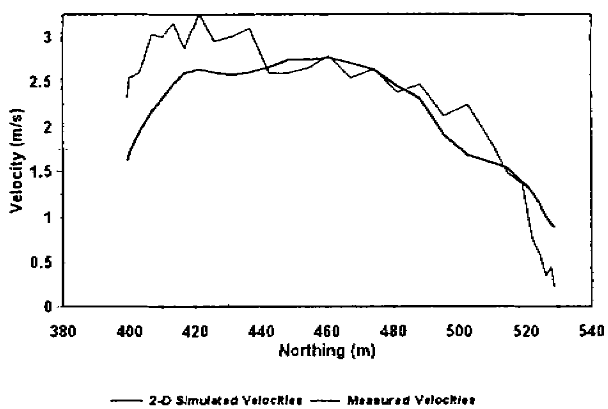

Osborne Deep Beds H
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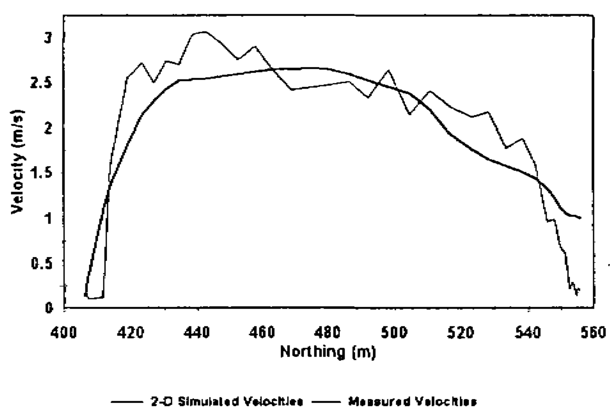
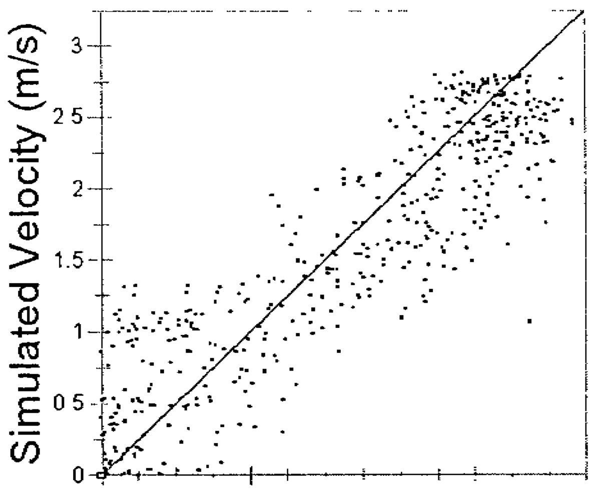


Osborne Study Site

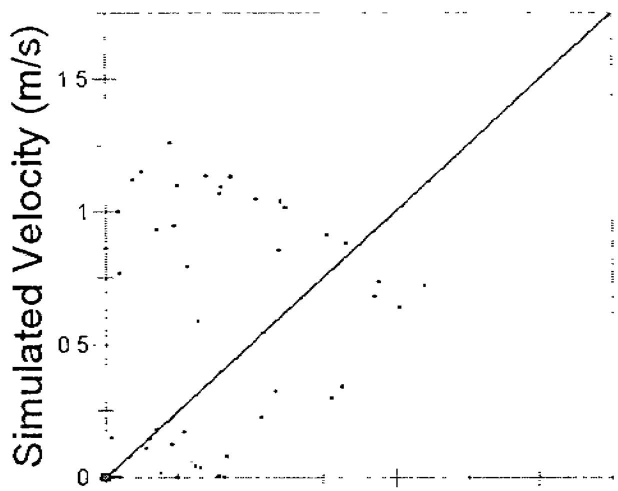
Osborne

All Validation Velocities

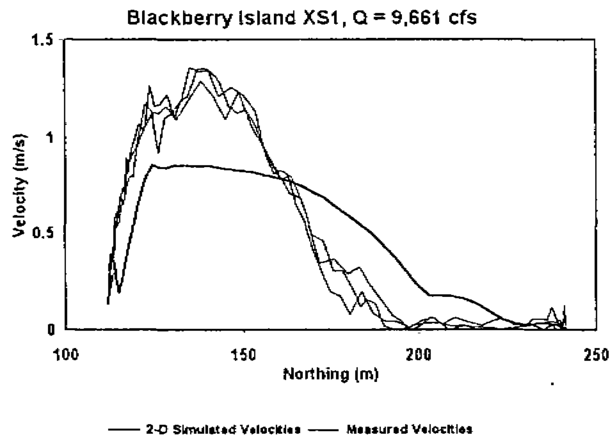


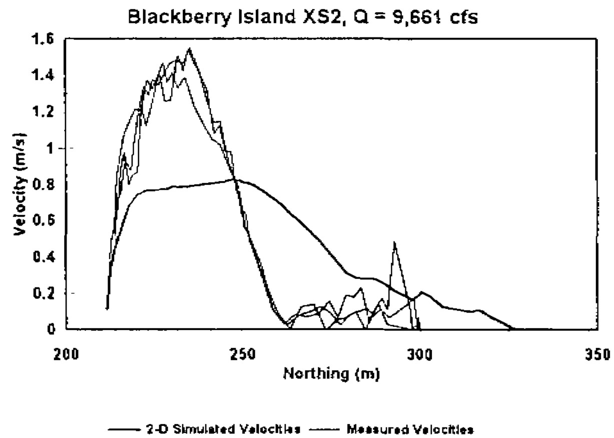
Osborne

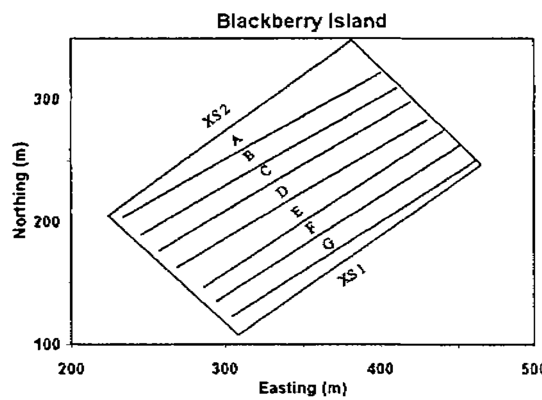
Between Transect Non-ADCP Velocities



Blackberry Island Study Site







Blackberry Island Study Site

Blackberry Island Deep Beds A
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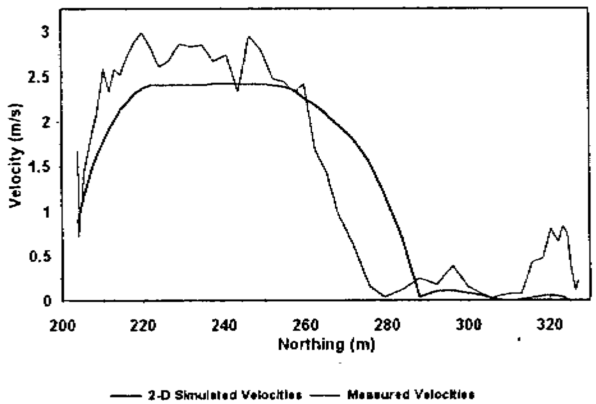
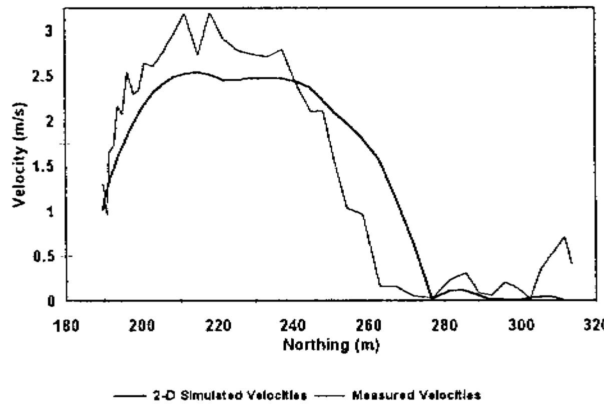


Blackberry Island Deep Beds B
Q = 59,879 cfs



Blackberry Island Deep Beds C
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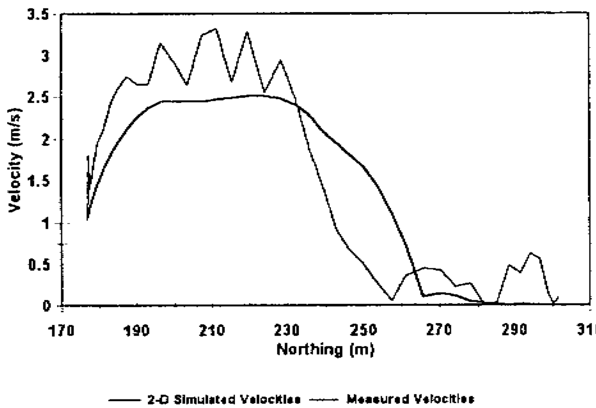

Blackberry Island Deep Beds D
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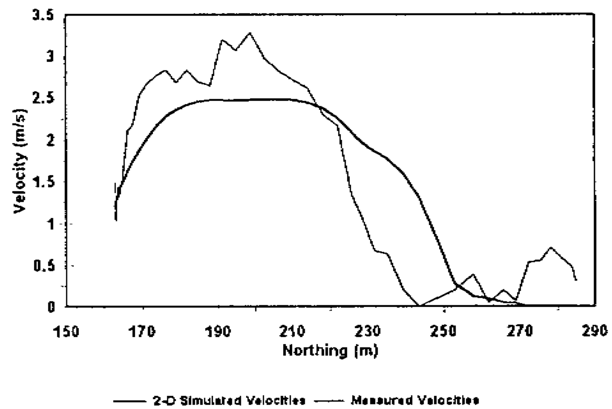
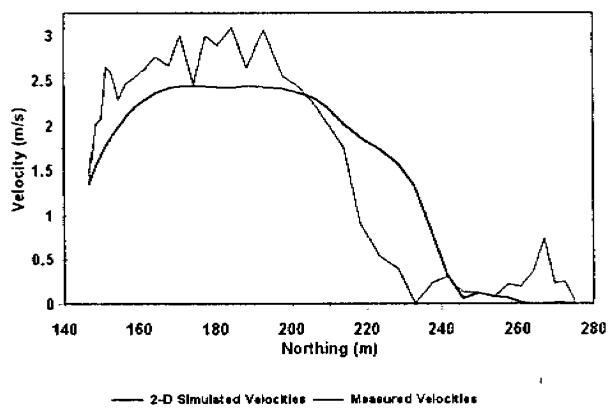
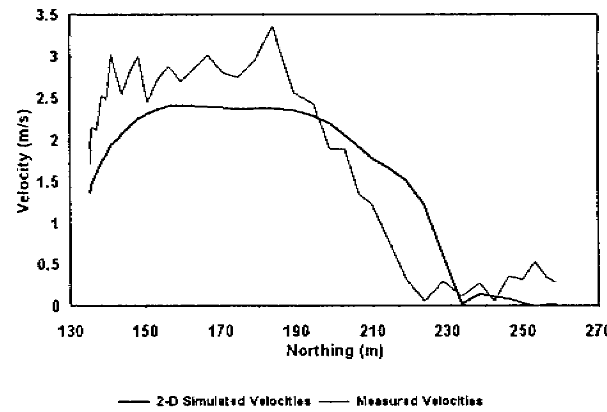


Blackberry Island Study Site

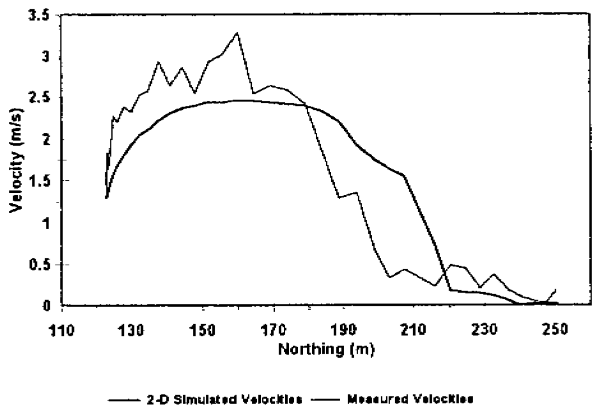
Blackberry Island Deep Beds E
Q = 59,879 cfs



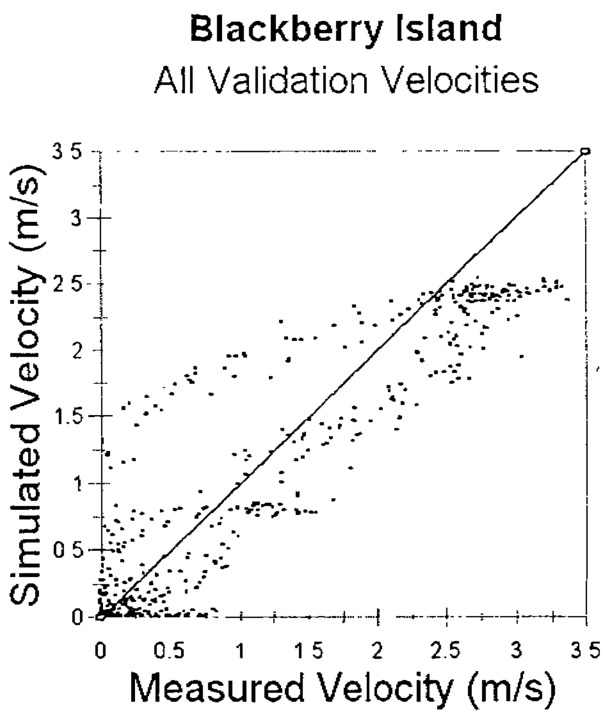
Blackberry Island Deep Beds F
Q = 59,879 cfs

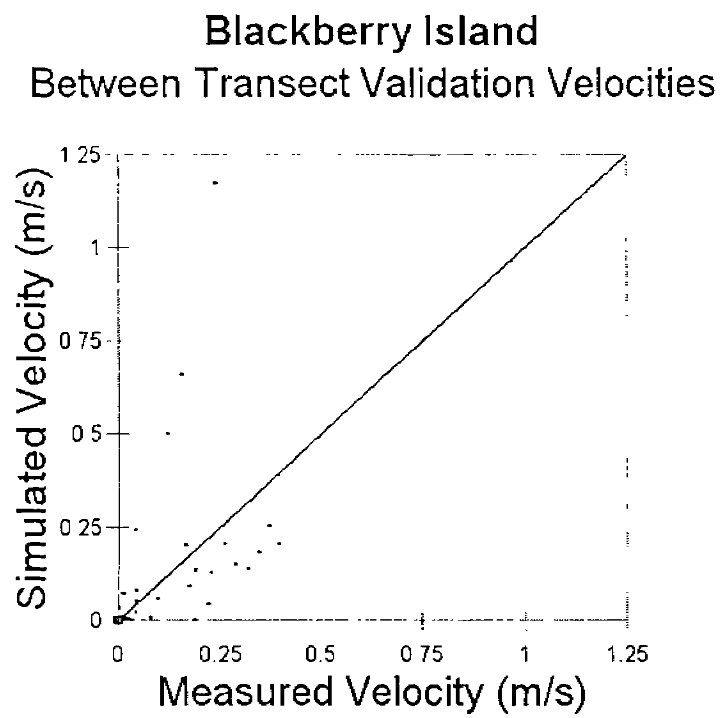


Blackberry Island Deep Beds G
Q = 59,879 cfs

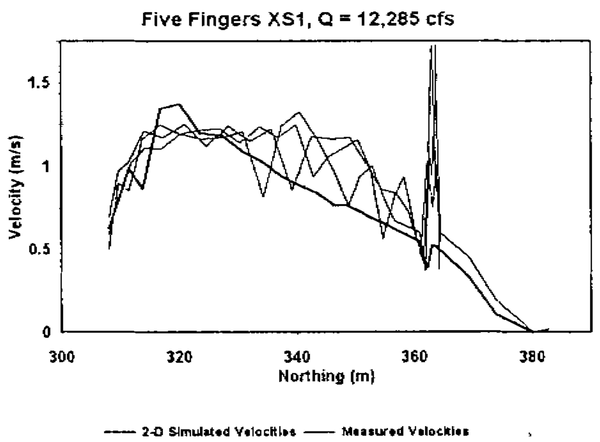


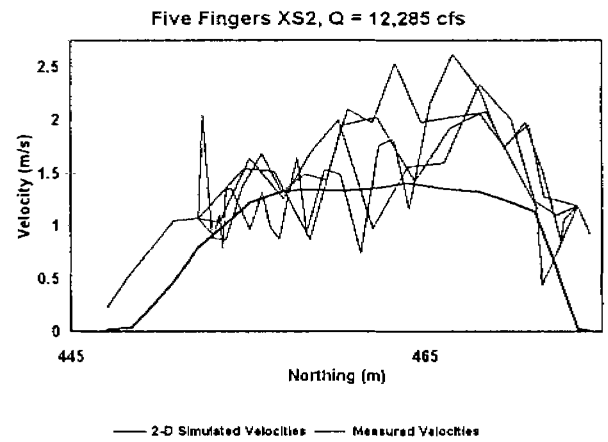
Blackberry Island Study Site

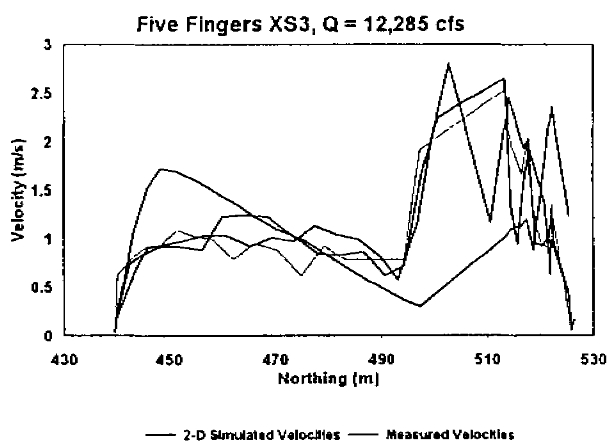


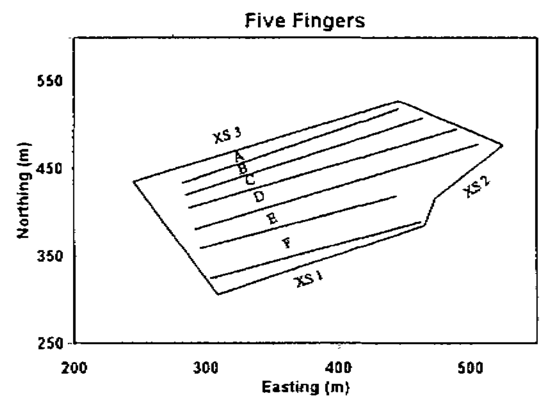


Five Fingers Study Site

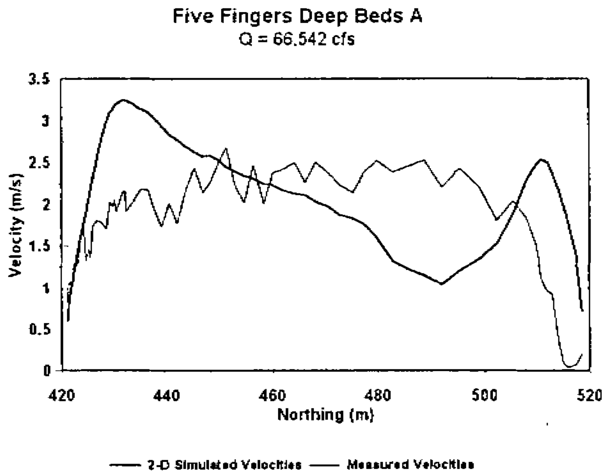


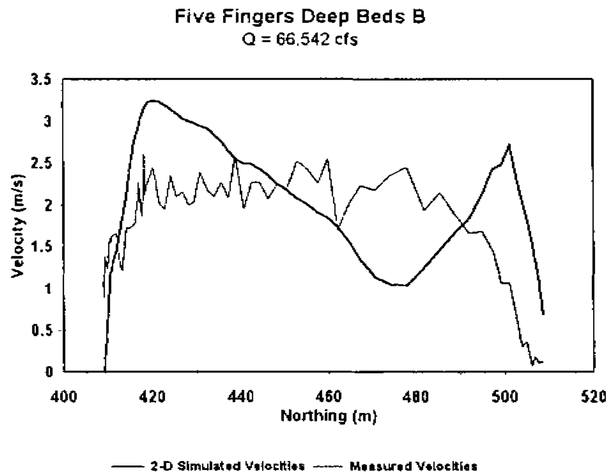


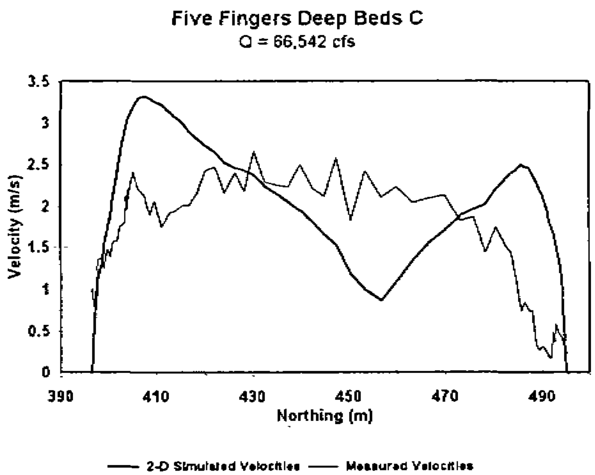


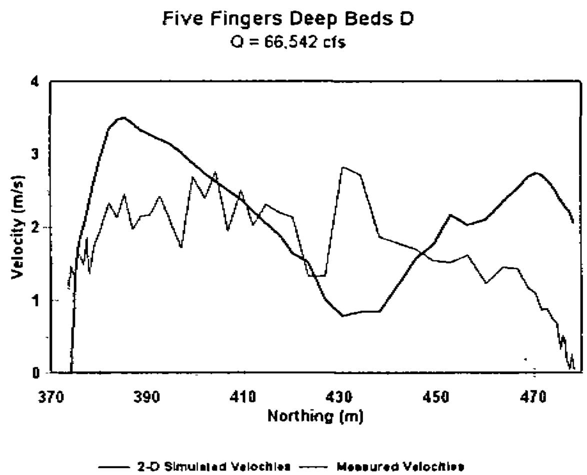


Five Fingers Study Site

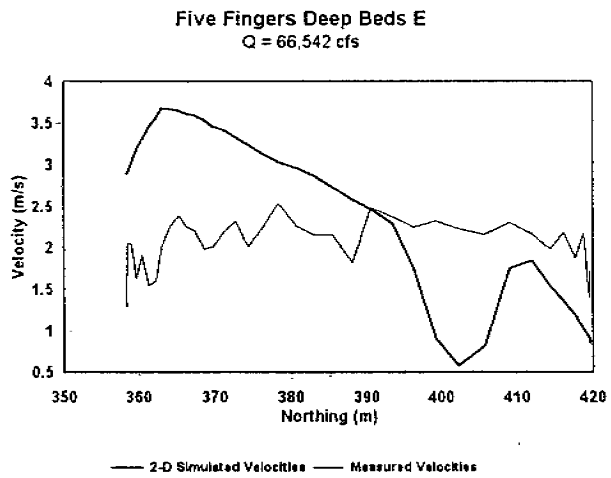


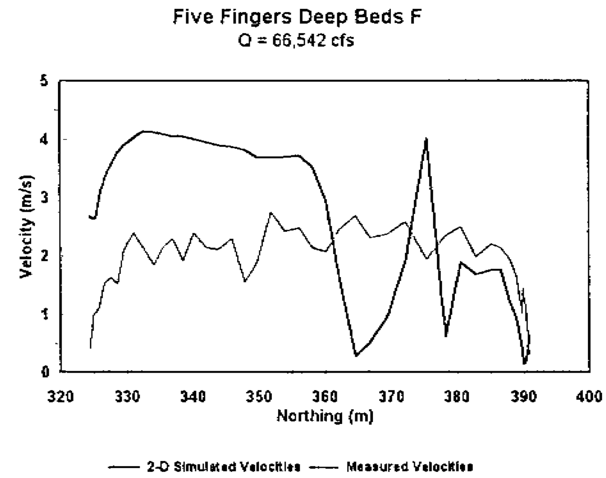




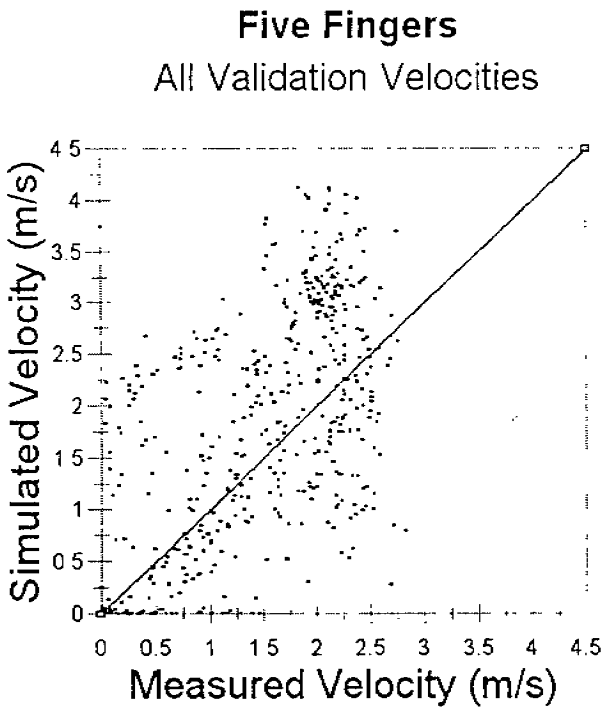


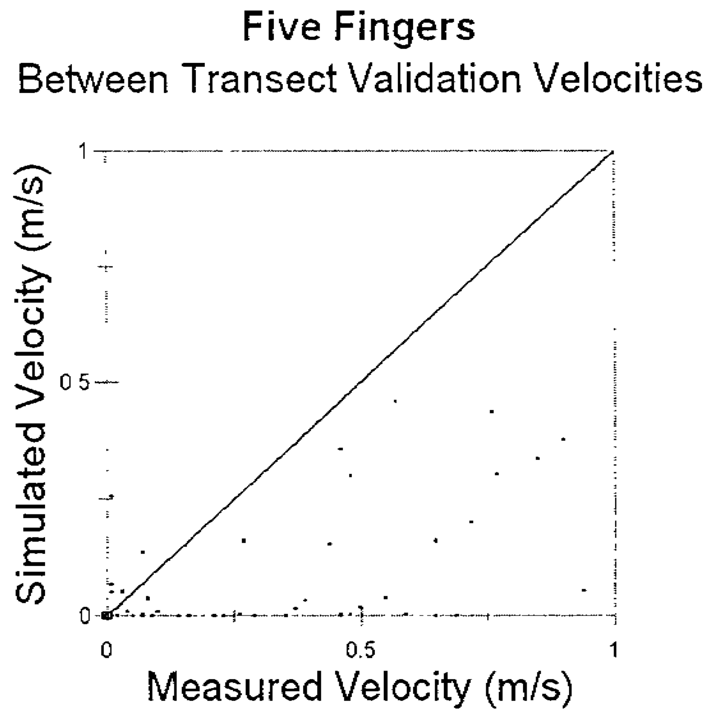
Five Fingers Study Site





Five Fingers Study Site





APPENDIX G
SIMULATION STATISTICS

Mudball

Flow (cfs)	Net Q	Sol	Max F
3250	0.022%	.000001	1.68
3500	0.010%	.000003	1.57
3750	0.028%	.000003	1.58
4000	0.035%	.000005	1.40
4250	0.058%	.000007	1.42
4500	0.157%	.000005	1.46
4750	0.022%	.000002	1.50
5000	0.028%	.000001	1.53
5250	0.047%	.000002	1.55
5500	0.064%	.000001	1.56
6000	0.065%	.000007	1.57
6500	0.054%	< .000001	1.57
7000	0.055%	.000007	1.57
7500	0.056%	.000007	2.04
8000	0.053%	.000008	1.91
9000	0.035%	.000006	1.62
10000	0.014%	.000004	1.59
11000	0.022%	.000005	1.27
12000	0.018%	.000005	0.95
13000	0.016%	.000005	0.89
14000	0.018%	.000006	0.94
15000	0.024%	.000007	0.95
17000	0.012%	.000006	1.48
19000	0.006%	.000006	1.25
21000	0.002%	.000006	1.67
23000	0.005%	.000004	1.56
25000	0.004%	.000005	1.42
27000	0.013%	.000003	1.55
29000	0.037%	.000009	2.14
31000	0.026%	< .000001	1.95

Jellys Ferry

Flow (cfs)	Net Q	Sol Δ	Max F
3250	0.005%	< .000001	0.69
3500	0.020%	< .000001	0.69
3750	0.019%	< .000001	0.67
4000	0.018%	< .000001	0.65
4250	0.050%	< .000001	0.70
4500	0.047%	< .000001	0.68
4750	0.052%	< .000001	0.68
5000	0.056%	< .000001	0.77
5250	0.061%	< .000001	0.74
5500	0.051%	< .000001	0.71
6000	0.018%	< .000001	0.66
6500	0.001%	< .000001	0.64
7000	0.001%	< .000001	0.67
7500	0.080%	< .000001	0.70
8000	0.075%	< .000001	0.64
9000	0.047%	< .000001	0.57
10000	0.039%	< .000001	0.55
11000	0.003%	< .000001	0.63
12000	0.006%	< .000001	1.22
13000	0.008%	< .000001	1.08
14000	0.010%	< .000001	0.94
15000	0.009%	< .000001	0.84
17000	0.002%	< .000001	0.89
19000	0.004%	< .000001	1.62
21000	0.003%	< .000001	4.29
23000	0.008%	< .000001	1.78
25000	0.018%	< .000001	1.23
27000	0.056%	< .000001	2.20
29000	0.022%	< .000001	2.11
31000	0.014%	< .000001	2.71

Bend Bridge

Flow (cfs)	Net Q	Sol Δ	Max F
3250	0.630%	< .000001	2.83
3500	0.807%	.000001	2.79
3750	0.753%	.000001	3.23
4000	0.697%	< .000001	2.82
4250	0.632%	< .000001	2.93
4500	0.377%	< .000001	3.65
4750	0.357%	.000006	4.31
5000	0.028%	.000008	3.68
5250	0.182%	.000002	3.28
5500	0.064%	.000001	2.94
6000	0.071%	.000007	3.55
6500	0.027%	.000007	6.72
7000	0.045%	.000003	1.88
7500	1.412%	.000004	1.38
8000	1.029%	.000003	1.30
9000	0.004%	< .000001	1.50
10000	0.004%	< .000001	3.38
11000	0.003%	< .000001	3.88
12000	0.003%	< .000001	3.16
13000	0.000%	< .000001	1.53
14000	0.000%	< .000001	1.65
15000	0.009%	< .000001	1.14
17000	0.035%	< .000001	0.90
19000	0.046%	< .000001	0.75
21000	0.044%	< .000001	1.42
23000	0.032%	< .000001	0.85
25000	0.001%	< .000001	1.15
27000	0.001%	< .000001	0.99
29000	0.006%	< .000001	1.16
31000	0.011%	< .000001	8.13

Osborne

Flow (cfs)	Net Q	Sol Δ	Max F
3250	0.022%	< .000001	1.65
3500	0.020%	< .000001	1.62
3750	0.019%	.000002	1.58
4000	0.018%	< .000001	1.66
4250	0.017%	.000002	1.50
4500	0.016%	.000001	1.46
4750	0.015%	< .000001	1.41
5000	0.014%	< .000001	1.35
5250	0.013%	< .000001	1.29
5500	0.013%	.000001	1.22
6000	0.012%	< .000001	1.05
6500	0.001%	< .000001	2.43
7000	0.001%	< .000001	1.98
7500	0.000%	< .000001	1.35
8000	0.000%	< .000001	1.60
9000	0.027%	< .000001	1.63
10000	0.053%	< .000001	1.34
11000	0.074%	< .000001	1.22
12000	0.085%	< .000001	1.80
13000	0.087%	< .000001	2.49
14000	0.078%	< .000001	2.99
15000	0.049%	< .000001	3.20
17000	0.000%	< .000001	2.82
19000	0.001%	< .000001	2.11
21000	0.001%	< .000001	1.36
23000	0.002%	< .000001	1.28
25000	0.004%	< .000001	1.74
27000	0.007%	< .000001	2.09
29000	0.004%	< .000001	2.13
31000	0.005%	< .000001	1.92

Blackberry Island

Flow (cfs)	Net Q	Sol Δ	Max F
3250	0.010%	.000009	0.19
3500	0.003%	.000001	0.19
3750	0.028%	.000001	0.20
4000	0.044%	.000008	0.20
4250	0.058%	.000001	0.21
4500	0.078%	< .000001	0.21
4750	0.082%	.000001	0.21
5000	0.092%	.000003	0.22
5250	0.094%	.000006	0.22
5500	0.096%	< .000001	0.23
6000	0.100%	< .000001	0.24
6500	0.054%	< .000001	11.68
7000	0.066%	< .000001	10.39
7500	0.071%	.000004	9.22
8000	0.066%	.000008	8.12
9000	0.082%	.000001	8.62
10000	0.088%	.000004	7.46
11000	0.083%	.000008	4.85
12000	0.074%	.000004	4.49
13000	0.057%	.000003	2.41
14000	0.035%	.000003	2.59
15000	0.000%	.000003	0.38
17000	0.044%	.000004	0.40
19000	0.043%	.000002	0.43
21000	0.037%	.000003	0.45
23000	0.032%	.000003	0.47
25000	0.004%	.000002	0.49
27000	0.008%	.000008	1.46
29000	0.028%	.000004	0.51
31000	0.038%	< .000001	0.52

Five Fingers

Flow (cfs)	Net Q	Sol Δ	Max F
3250	0.022%	.000002	0.36
3500	0.010%	.000004	0.36
3750	0.009%	.000003	0.37
4000	0.009%	.000005	0.37
4250	0.025%	.000002	0.38
4500	0.110%	.000003	0.38
4750	0.119%	.000005	0.38
5000	0.106%	.000008	0.38
5250	0.195%	< .000001	1.45
5500	0.231%	.000002	1.38
6000	0.230%	.000001	1.28
6500	0.234%	.000001	1.44
7000	0.237%	.000001	1.16
7500	0.231%	.000001	1.47
8000	0.230%	.000001	1.64
9000	0.231%	.000001	2.40
10000	0.247%	< .000001	2.57
11000	0.125%	.000001	2.86
12000	0.118%	.000001	3.12
13000	0.111%	< .000001	3.19
14000	0.103%	.000004	2.90
15000	0.106%	< .000001	2.05
17000	0.114%	< .000001	2.09
19000	0.102%	< .000001	2.23
21000	0.066%	< .000001	1.72
23000	0.055%	< .000001	1.38
25000	0.045%	< .000001	1.19
27000	0.035%	< .000001	1.17
29000	0.040%	< .000001	1.09
31000	0.025%	< .000001	1.23

APPENDIX H
HABITAT SUITABILITY CRITERIA

FALL-RUN CHINOOK SALMON SPAWNING HSC

Water Depth (ft)	SI Value
0.00	0
0.40	0
0.50	0.22
0.62	0.30
0.78	0.41
0.93	0.54
1.08	0.67
1.24	0.79
1.39	0.89
1.54	0.96
1.70	1.00
1.85	1.00
48	0
100	0

Water Velocity (ft/s)	SI Value
0.00	0
0.31	0
0.32	0.08
0.40	0.11
0.52	0.17
0.72	0.30
0.85	0.41
0.97	0.54
1.23	0.78
1.36	0.88
1.55	0.98
1.68	1.00
1.75	1.00
1.88	0.97
1.94	0.95
2.07	0.89
2.33	0.73
2.58	0.55
2.84	0.39
3.10	0.27
3.29	0.20
3.36	0.19
3.48	0.15
3.93	0.08
4.32	0.05
4.51	0.05
4.58	0.04
5.79	0.04
5.8	0
100	0

Substrate Composition	SI Value
0.1	0
1	0
1.2	0.33
1.3	0.91
2.3	0.96
2.4	1.00
3.4	0.76
3.5	0.53
4.5	0.35
4.6	0.16
6.8	0
100	0

APPENDIX I
HABITAT MODELING RESULTS

Table 1
Fall-run chinook salmon spawning WUA (ft^2) in Segment 3

Flow	Mudball	Jellys Ferry	Bend Bridge	Total
3250	91310	93904	12292	1767681
3500	98780	88533	11786	1781938
3750	107348	81752	12066	1800435
4000	114657	74755	11593	1798990
4250	117735	68523	10872	1764309
4500	128047	60687	10559	1783672
4750	133946	55746	12927	1813440
5000	138197	49600	12626	1793788
5250	142664	44229	12486	1784443
5500	145818	39546	12443	1770378
6000	150027	32227	12303	1741284
6500	149198	26468	11700	1676931
7000	147594	22464	11237	1622598
7500	144279	20893	11184	1578379
8000	139026	19235	10742	1512581
9000	127272	16210	12012	1391679
10000	115712	15080	13358	1290140
11000	98500	13089	12787	1113170
12000	81547	11797	10753	931671
13000	66553	10398	8137	761541
14000	54584	9009	6028	623105
15000	45736	7685	4585	519158
17000	34401	4413	3154	375616
19000	28029	3649	2540	306254
21000	22400	3423	2099	246867
23000	19655	3132	1744	219551
25000	18944	2820	1496	208183
27000	176061	2530	1604	189687
29000	15489	1981	1442	169263
31000	13283	1819	1206	145950

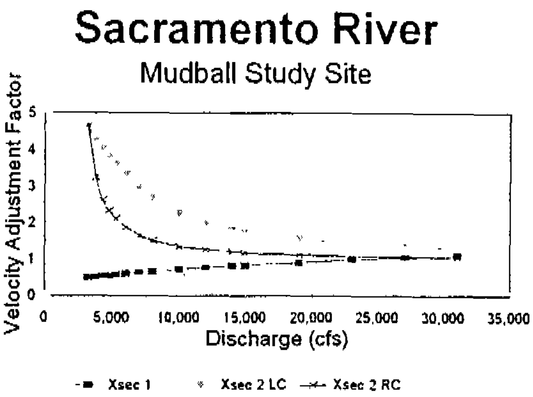
Table 2
Fall-run chinook salmon spawning WUA (ft^2) in Segment 2

Flow	Osborne	Blackberry	Five Fingers	Total
3250	59352	50833	49546	664478
3500	60633	54689	50656	690470
3750	62549	58143	51585	716672
4000	66575	61149	52418	749389
4250	68652	64038	53118	772961
4500	69739	66296	53504	788484
4750	71009	68320	53987	804195
5000	71429	69896	54174	813277
5250	71720	71062	57856	834650
5500	71677	71912	58338	840017
6000	70729	72448	58109	837349
6500	69233	71612	58115	827673
7000	68028	69434	58700	816034
7500	65337	66531	59111	794469
8000	63302	63429	59020	772727
9000	56952	57028	57874	714911
10000	52129	50803	55230	657959
11000	47275	44095	52726	599437
12000	43669	37386	51543	551608
13000	40946	31425	49811	508277
14000	38449	26219	48604	471211
15000	36037	21255	46969	433729
17000	32528	15192	42062	373496
19000	30612	10477	36915	324499
21000	27577	7354	32256	279498
23000	24143	5426	28834	242958
25000	21000	4289	26016	213431
27000	18029	3622	24779	193150
29000	15177	3233	22805	171458
31000	12583	3006	21025	152315

Mudball

Velocity Adjustment Factors

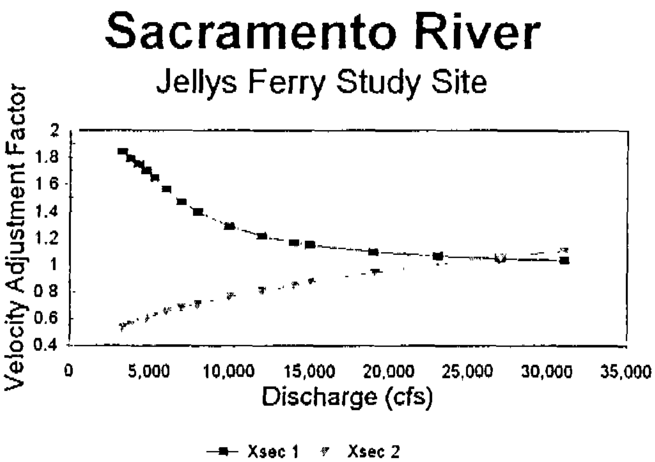
Discharge (cfs)	Xsec 1	Xsec 2 LC	Xsec 2 RC
3250	0.490	4.462	4.686
3750	0.514	4.238	3.242
4250	0.536	4.024	2.629
4750	0.556	3.817	2.340
5250	0.575	3.616	2.120
6000	0.602	3.323	1.872
7000	0.635	2.972	1.646
8000	0.662	2.679	1.505
10000	0.712	2.264	1.343
12000	0.756	1.998	1.252
14000	0.803	1.818	1.194
15000	0.824	1.748	1.173
19000	0.902	1.552	1.114
23000	0.970	1.433	1.079
27000	1.031	1.353	1.055
31000	1.088	1.296	1.038



Jellys Ferry

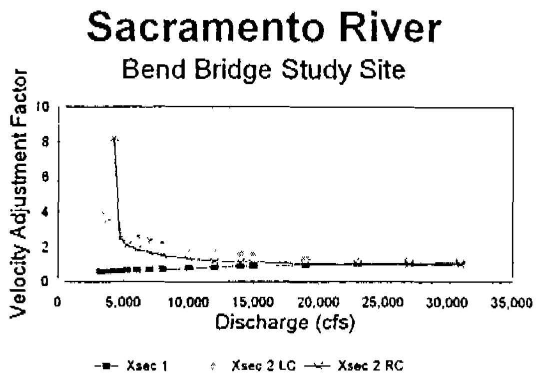
Velocity Adjustment Factors

Discharge (cfs)	Xsec 1	Xsec 2
3250	1.841	0.534
3750	1.792	0.558
4250	1.750	0.580
4750	1.702	0.600
5250	1.646	0.620
6000	1.564	0.647
7000	1.470	0.679
8000	1.395	0.709
10000	1.289	0.762
12000	1.218	0.809
14000	1.170	0.851
15000	1.151	0.871
19000	1.098	0.942
23000	1.068	1.004
27000	1.048	1.060
31000	1.036	1.110



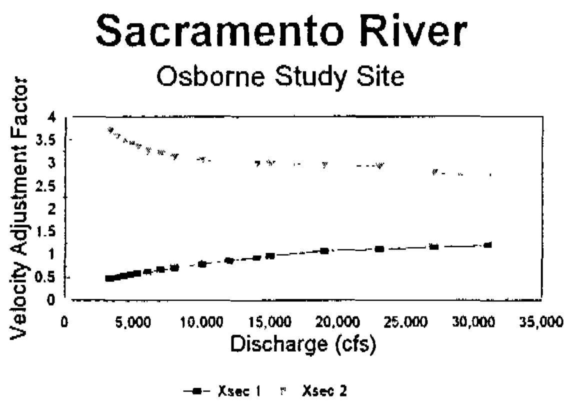
Bend Bridge

Velocity Adjustment Factors			
Discharge (cfs)	Xsec 1	Xsec 2 LC	Xsec 2 RC
3250	0.572	3.776	—
3750	0.595	3.400	—
4250	0.615	3.119	8.221
4750	0.634	2.921	2.510
5250	0.651	2.761	2.098
6000	0.675	2.570	1.845
7000	0.705	2.359	1.664
8000	0.732	2.181	1.525
10000	0.782	1.886	1.315
12000	0.827	1.675	1.197
14000	0.868	1.524	1.129
15000	0.887	1.463	1.105
19000	0.960	1.286	1.047
23000	1.025	1.165	1.019
27000	1.084	1.162	1.003
31000	1.139	1.161	0.995



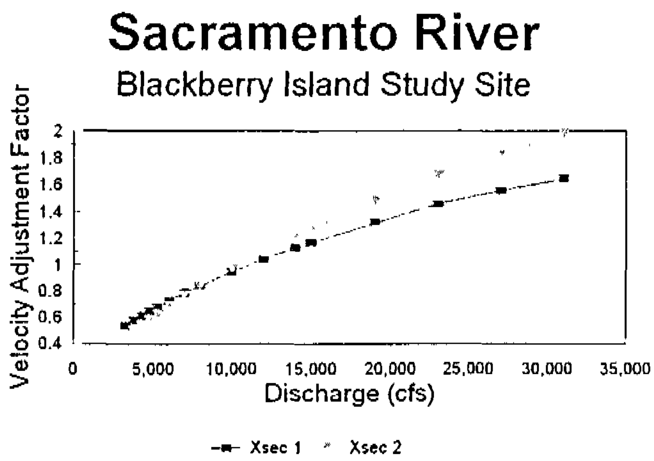
Osborne

Velocity Adjustment Factors		
Discharge (cfs)	Xsec 1	Xsec 2
3250	0.463	3.696
3750	0.495	3.570
4250	0.524	3.474
4750	0.551	3.400
5250	0.578	3.341
6000	0.615	3.270
7000	0.660	3.197
8000	0.704	3.142
10000	0.785	3.068
12000	0.858	3.022
14000	0.926	2.991
15000	0.957	2.979
19000	1.064	2.948
23000	1.109	2.930
27000	1.151	2.796
31000	1.192	2.700



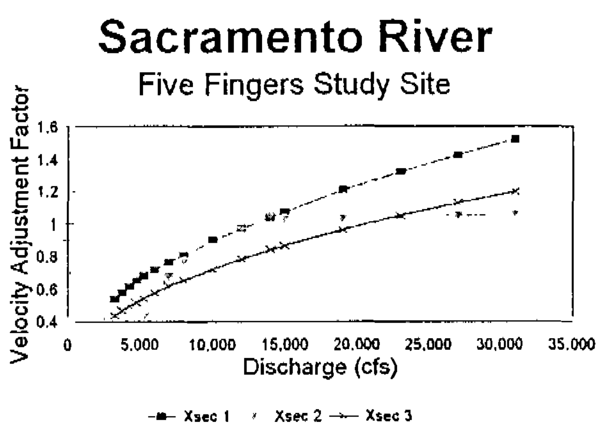
Blackberry Island

Discharge (cfs)	Velocity Adjustment Factors Xsec 1	Xsec 2
3250	0.536	0.457
3750	0.576	0.503
4250	0.612	0.548
4750	0.647	0.590
5250	0.681	0.631
6000	0.728	0.691
7000	0.787	0.766
8000	0.842	0.838
10000	0.945	0.972
12000	1.038	1.097
14000	1.124	1.214
15000	1.165	1.271
19000	1.319	1.484
23000	1.457	1.681
27000	1.558	1.840
31000	1.652	1.988



Five Fingers

Discharge (cfs)	Velocity Adjustment Factors Xsec 1	Xsec 2	Xsec 3
3250	0.538	—	0.437
3750	0.578	—	0.467
4250	0.616	—	0.495
4750	0.652	—	0.519
5250	0.679	0.426	0.543
6000	0.716	0.565	0.575
7000	0.764	0.675	0.617
8000	0.805	0.773	0.653
10000	0.897	0.848	0.722
12000	0.969	0.959	0.783
14000	1.037	1.046	0.840
15000	1.069	1.031	0.866
19000	1.210	1.032	0.963
23000	1.320	1.039	1.049
27000	1.424	1.048	1.129
31000	1.521	1.057	1.200



APPENDIX C
BED TOPOGRAPHY OF STUDY SITES