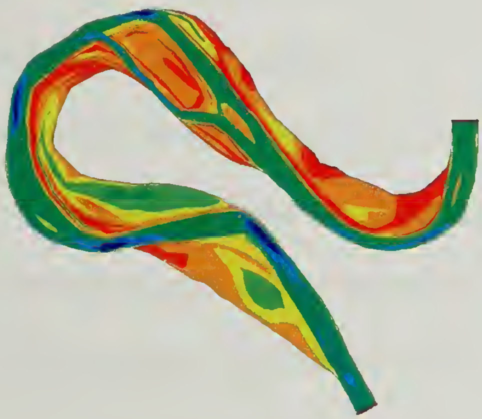
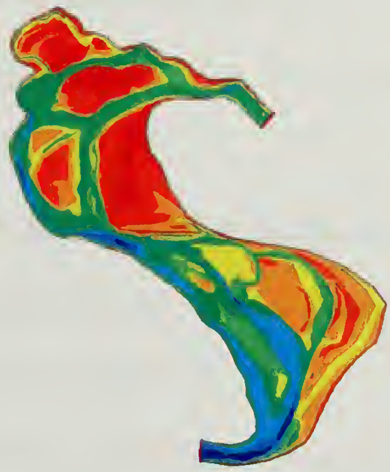
Two Dimensional Computer Modeling of Green River at Dinosaur National Monument and Canyonlands National Park

For:
Water Rights Branch
Water Resources Division
National Park Service





Dan Gessler, Colorado State University
Eric Moser, National Park Service

July 19, 2001

Executive Summary

The National Park Service (NPS) developed two dimensional numerical models (RMA2) for two reaches along the Green River in Utah to provide hydraulic information to resource experts. The models will be used by the NPS and resource experts to evaluate the impact of flow regimes on water-related resources in Dinosaur National Monument and Canyonlands National Park. The Island Park area was modeled in Dinosaur National Monument and the Fort Bottom area was modeled in Canyonlands National Park. Each model has approximately 10,000 computational cells with a typical cell size of 40 x 80 ft.

Five flow rates were modeled at Island Park , to determine stage and velocity. These flows were 18,000, 22,000, 26,000, 30,000, and 33,700 cfs. The model geometry remained constant for each flow.

Model results for the Island Park reach suggest that a channel around Bobby Island is probably aggrading and will continue disconnecting from the river system. The growth of vegetation in the channel will increase the rate of sediment deposition.

Two flows were modeled at Fort Bottom: 18,000 cfs and 24,000 cfs. The model was also used to evaluate the potential for breaching natural levees that have disconnected historical floodplains important for riparian vegetation and native fish species.

Model results indicate that it is possible to create 30 to 45 acres of aquatic habitat by breaching existing levees at Fort Bottom. Maximum depths in the inundated area would be 5 to 8 feet. It is anticipated that the area would disconnect from the system annually.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

The National Park Service (NPS) has developed two-dimensional numerical models of two reaches of the Green River. The uppermost reach (Island Park model), encompasses two miles of the Green River within Island Park, an alluvial valley located near the downstream end of Dinosaur National Park, as shown in Figure 1.1. The other (Fort Bottom model), is approximately four miles in length, within Stillwater Canyon and is near the upstream boundary of Canyonlands National Park as shown in Figure 1.2.

The models will be used by the NPS to assess the impact of river regulation (at Flaming Gorge Dam) on endangered fish, orchids, and other riparian species such as cottonwood. The models will help evaluate the hydrodynamic conditions at the noted flow rates with regards to native fish spawning and rearing, and the establishment of cottonwood and endangered orchids. New cottonwood trees appear to grow in areas which encounter periodic inundation by water. The model will help predict the water levels in the floodplain during periodic floods.

Floodplains along the Fort Bottom reach have been disconnected from the active channel by a near continuous levee that is vegetated predominately by salt cedar (Tamarix ramosissima). Since the 1930's the Green River has narrowed in response to climatic variation and decreased flood magnitudes caused by the Flaming Gorge dam. Salt cedar does not appear to initiate channel narrowing, but may stabilize river deposits and prevent scour (Allred and Schmidt, 1999). Cross sections of excavated salt cedar stems, growing on levees in Fort Bottom, indicated successive depositional events since the 1940's, of over six feet (Shafroth, 2000). Breaching the levees would allow the river, at higher stages, to inundate floodplains once again. One benefit would be creation of backwater habitat for Razorback

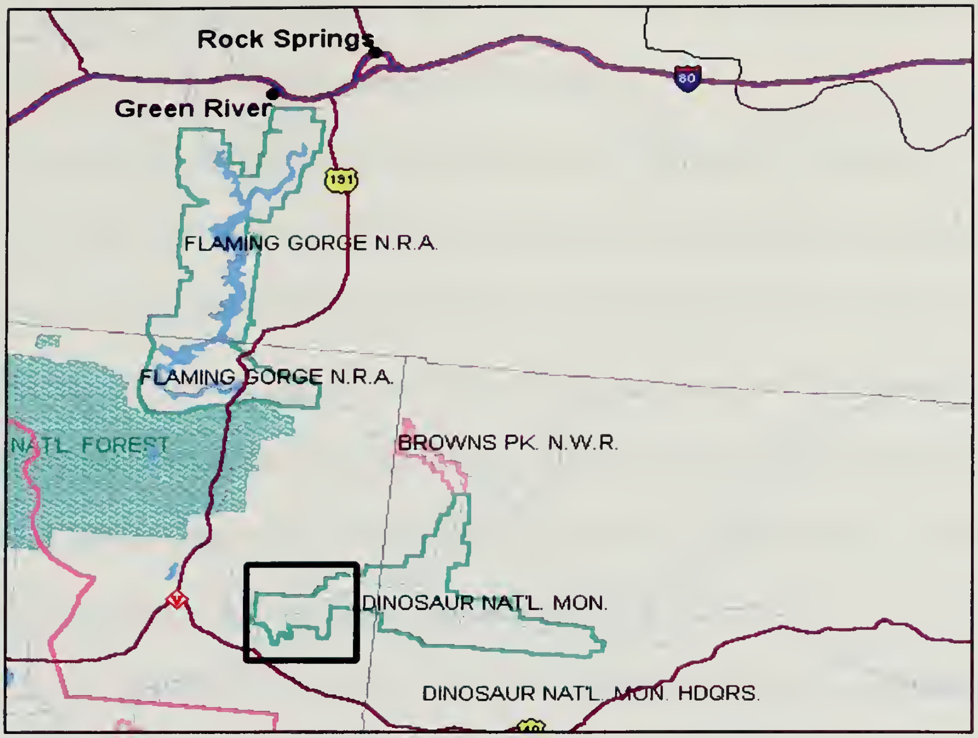


Figure 1.1: Site map showing location of Island Park model.

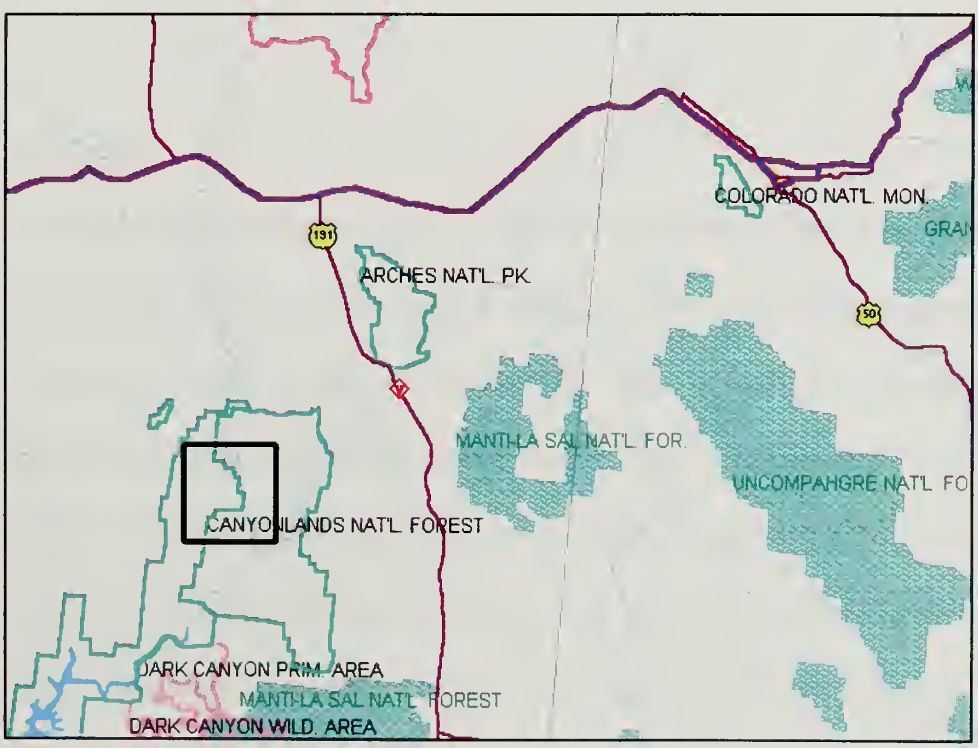


Figure 1.2: Site map showing location of Fort Bottom model.

sucker (Xyrauchen texanus) larvae. The Fort Bottom model was used to test two breaching scenarios and is available to simulate additional scenarios.

The NPS, Water Rights Branch (WRB), surveyed the Island Park and Fort Bottom reaches in 1998, using control points established by survey-grade GPS instruments. Floodplains and channel boundary topography was surveyed by transit traverses from the control points. The active channel was surveyed using an acoustic Doppler current profiler (ADCP) coupled with real-time position data provided by the GPS base station (Cluer and Hammack, 1998). The channel of the Island Park reach was surveyed twice. In June 1998, and again in June 1999, during flows of about 18,000 cfs.

WRB staff entered the survey data into the SMS computer model and a TIN (Triangular Irregular Network) was created. The TIN describes the topology of the region and provides a basis on which to build a mesh for hydraulic modeling. Due to staffing changes in the NPS, the models were finished under contract with Colorado State University in 2001.

1.1 Objectives

The objectives of the contract were to finish the model meshes and run two flow levels through each model. Results of each run are depth of flow and velocity magnitude and vector. Preliminary results precipitated an extension of the objectives for the Island Park model, and five flow rates were ultimately run; 18,000, 22,000, 26,000, 30,000 and 33,700 cfs. The flows for the Island Park model were selected on the following basis: First, 18,000 cfs was the flow at which the channel was surveyed in 1999, and was used to calibrate the model. The downstream boundary condition (water surface elevation), and water surface

profiles of other flows run in the Island Park model were determined from data collected at five cross-sections through the reach, during 1993-1996 (Grams and Schmidt, 1996). Relative elevations of water surface, and channel bottom were surveyed at the cross-sections at flows ranging from 1,600 to 18,000 cfs. From this data, stage-discharge relationships were developed using procedures established by the U.S. Geological Survey for stream gaging stations (Rantz, 1982). A flow of 33,700 cfs was selected as the high-end flow, and is the pre-Flaming Gorge dam 10-year recurrence peak flow, at the USGS stream gage on the Green River at Jensen. The USGS recommends that stage-discharge curves not be extrapolated beyond twice the highest measured flow value. The requirement is satisfied by flows less than 36,000 cfs. Three additional flows could be reasonably run under the contract, and were selected in equal increments (22,000, 26,000, 30,000 cfs).

Two flows were run in the Fort Bottom model. In contrast to Island Park, there are no previous surveys done on the reach. The channel was surveyed in 1998 during a flow rate of 18,000 cfs, which was used to calibrate the model. The second flow rate run, 24,000 cfs, is the two-year recurrence peak at the USGS stream gage at Green River, Utah, the closest gage to the reach. This was deemed a reasonable flow for the purpose of examining inundation of abandoned floodplains through levee breaches, because a downstream water surface elevation could be adequately determined assuming the water surface slope was the same at both flow rates.

1.2 Scope of Work

The mesh for the two models was completed and the model was calibrated (determine Manning's n). The Island Park model was run at 18,000, 22,000, 26,000, 30,000, and 33,700

cfs. For each flow rate, water surface profiles were matched to observed water surface profiles. Post processing and interpretation of the results was beyond the scope of this project.

The Fort Bottom model was run at 18,000 cfs and 24,000 cfs. Observed and predicted water surface profiles were compared at each flow rate. Two levee breaching scenarios were tested at each flow rate. For each levee breaching scenario, flow visualization was used to show predicted water velocities and the areas inundated by the breach.

The model used for the project was SMS version 7.0 (BYU, 2000). This was consistent with the version of the model currently used by the NPS. The approximate grid resolution was 40 x 80 foot rectangular cells. The maximum cell length was approximately 120 feet and the minimum cell length was approximately 40 feet.

The original schedule and scope of work required the project be completed in 3 months (January 1 to March 31). The scope of work was expanded and an additional month allowed for completion.

2.0 Background

Changes in the natural flow regime on the Green River are the result of the construction of the Flaming Gorge Dam in 1963. Background information is included about the dam and the two study reaches.

2.1 Flaming Gorge Dam

Flaming Gorge dam was constructed between 1958 and 1963. Power production started in 1963, with the final turbine starting to produce power in February 1964. Flaming Gorge reservoir was full for the first time in 1974, with a water surface elevation of 6,040 ft and a live storage of 3,749,000 acre feet of water. Selective withdrawal structures were installed during the winters of 1977 and 1978 to provide temperature control for the water released through the turbines. Generator upgrades were started in 1991 and completed in 1992. The present generator capacity is 151,950 kW. The U.S. Bureau of Reclamation operates 194 generating units with a total generating capacity of 14,692,930 kW. Flaming Gorge represents approximately 1 percent of the total generating capacity of all Reclamation power plants.

Flaming Gorge can release 4,600 cfs through the three turbines. In addition, 4,000 cfs can be released through two by-pass tubes. Water released through the turbines enters through a selective withdrawal structure which helps to regulate the water temperature. Water which is released through the bypass tubes does not appear to pass through the selective withdrawal structure. Finally, the reservoir is equipped with an overflow spillway. The rated capacity of the spillway is approximately 33,000 cfs. Figure 2.1 shows Flaming Gorge Dam.

Figure 2.1: Flaming Gorge Dam.

2.2 Island Park model

The NPS collected extensive survey information and river bathymetry, in June 1998, for the Island Park model. The survey data was entered into the SMS computer model and a TIN (Triangular Irregular Network) was created. The TIN describes the topology of the region and provides a basis on which to build a mesh for hydraulic modeling. The Island Park model is approximately two miles in length. A 2001 survey shows the 1998 to be in error +1.0 foot, although this does not affect the relative spatial orientation of the survey points or the accuracy of the model simulations.

Historic flow rates for the Island Park model were based on observations made at the Jensen stream gage (USGS station #9261000) downstream of the model reach. No significant inflow or diversions occur between the model reach and the gage. Figure 2.2 shows the flow frequency from 1947 to 1961 and the flow frequency from 1962 to 1998. The

pre-dam two-year recurrence peak flow is approximately 22,000 cfs while the post-dam two-year peak flow is approximately 18,000 cfs. Each data set was fit with a Log-Pearson Type III distribution.

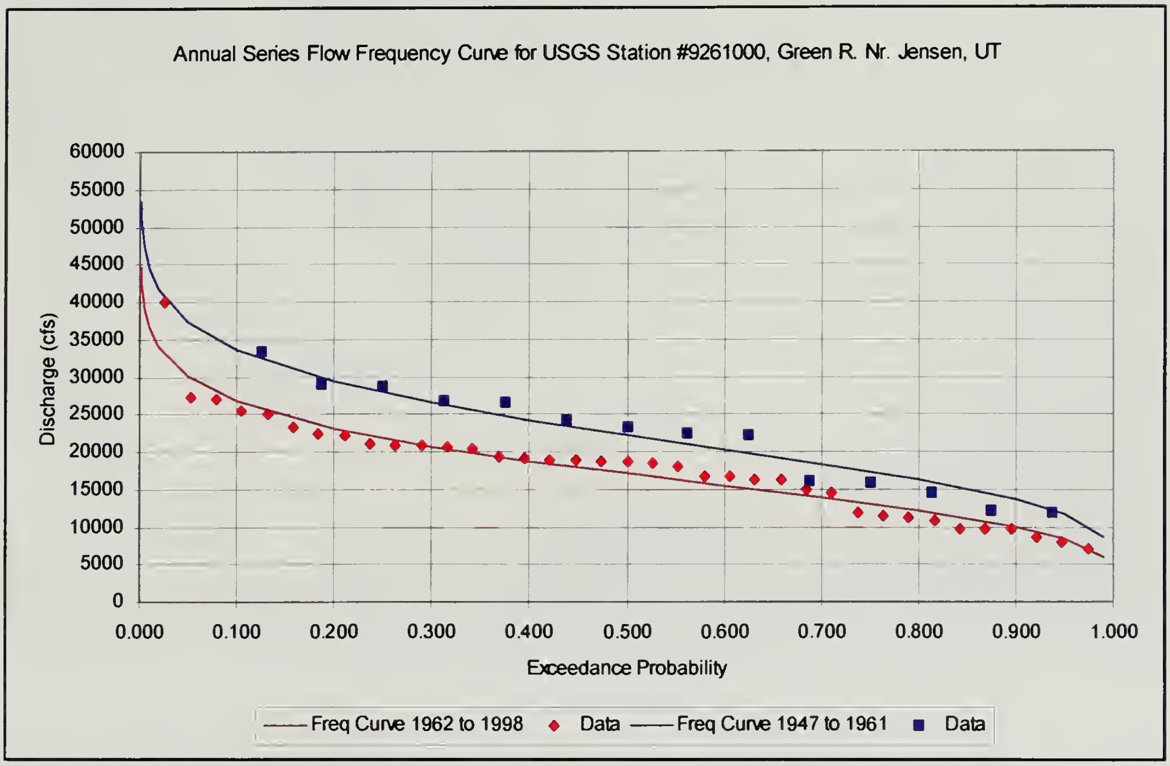


Figure 2.2: Flow frequency at Jensen, Utah USGS gage # 9261000 for pre- and post-Flaming Gorge dam construction.

The Island Park reach includes numerous islands and complex channel morphology. The river bed is primarily sand, however, numerous gravel bars exist. The maximum gravel size is approximately 4 to 6 inches. Figure 2.3 shows a 1996 aerial photograph of the reach. The primary concern in the Island Park reach is that the lower, post-dam construction, flow rates have reduced the amount of habitat available to native fish and plant species.

Figure 2.3: 1996 aerial photograph of Island Park model reach.

2.3 Fort Bottom model

The Fort Bottom model is approximately 4 miles in length. The NPS collected extensive bathymetry and ground survey data of the river reach and the surrounding area. The NPS generated a TIN for the model reach, showing area contours. The TIN was used as the basis for construction of the grid for numeric modeling.

The river is predominantly a sand bed river with local fine and coarse gravel deposits. The banks of the river are predominantly lined with salt cedar. In particular, salt cedar has lined the banks on the inside of the river bends. During large flow events which inundated the salt cedar, suspended sediment was deposited around the plants. Repeated cycles of flow and deposition have resulted in large levees along the banks of the river. The levees prevent

the inundation of land typically covered by slack water during large flow events. Figure 2.4 shows a 1996 aerial photograph of the Fort Bottom reach. The near-infrared image clearly shows the dense growth of vegetation along the banks of the river.

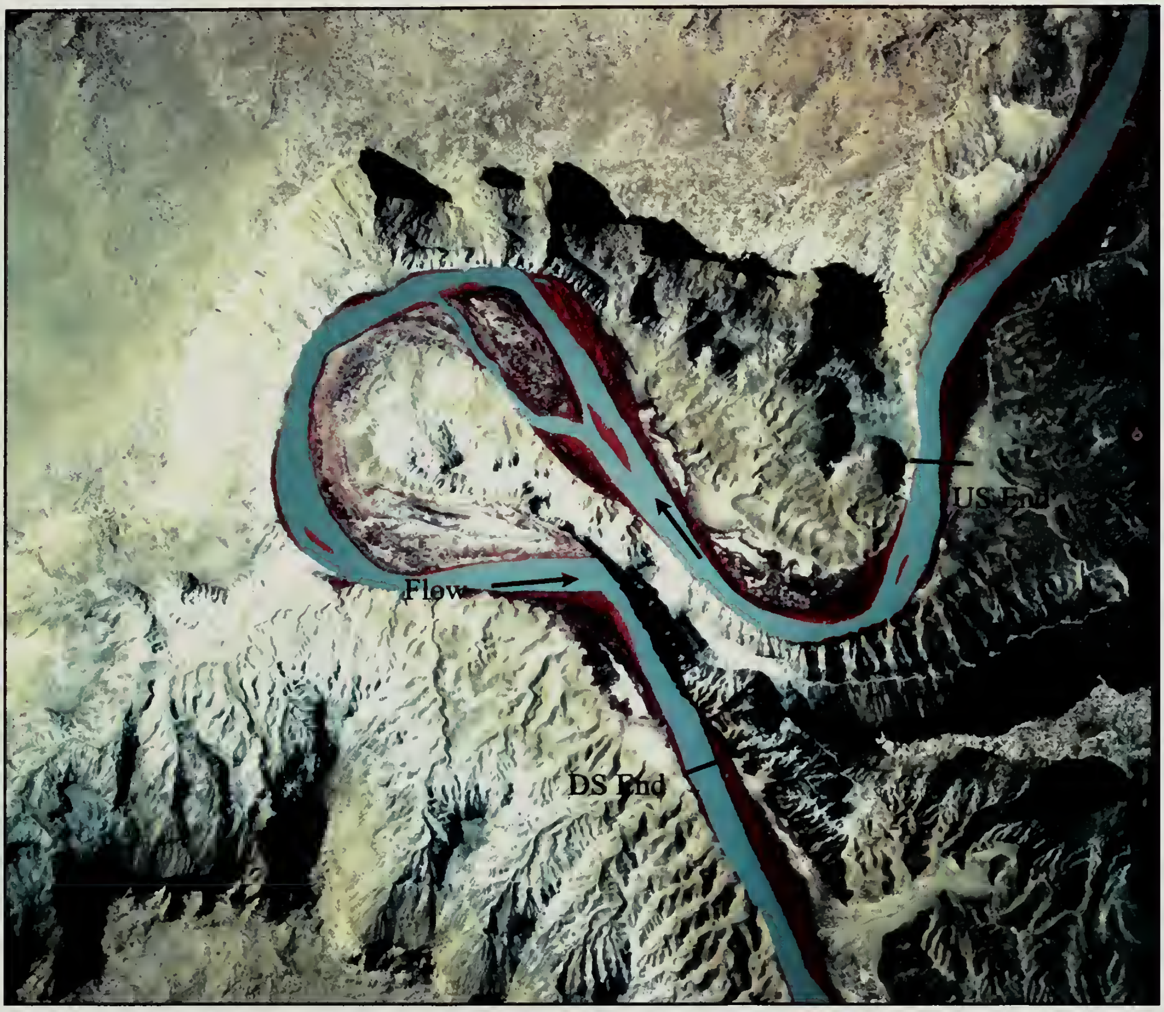


Figure 2.4: 1996 aerial photograph of Fort Bottom model reach.

The Green River gage (USGS station number 9315000) is the closest gage to the Fort Bottom reach. The San Rafael River joins the Green River between the gage and the Fort Bottom model reach, but is thought to contribute only a minimal flow to the Green River. Figure 2.5 shows the flow frequency at the gage from 1925 to 1961 and 1962 to 1998. The pre-dam two-year recurrence peak flow was approximately 27,000 cfs and the post-dam two-

year flow is approximately 23,000 cfs. The change in pre- and post-dam flows is larger at the ten-year recurrence peak with flow rates of approximately 43,000 and 36,000 cfs respectively.

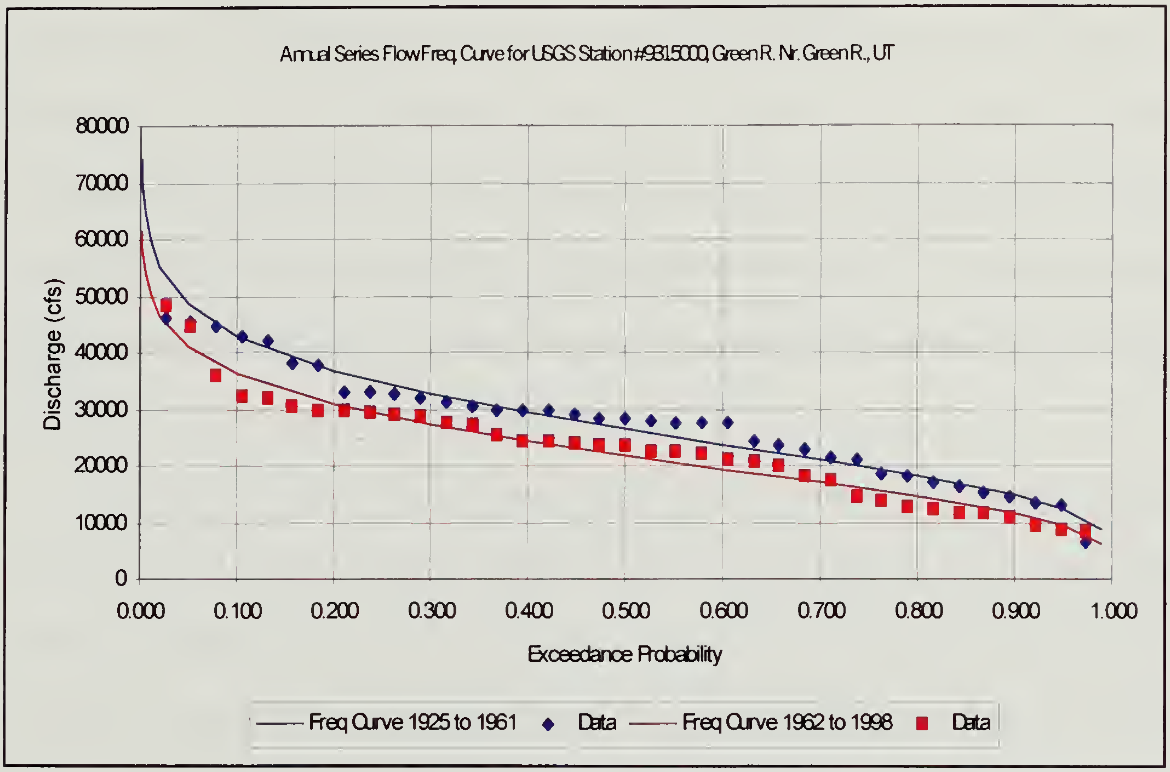


Figure 2.5: Flow frequency at Green River, Utah USGS gage # 9315000, pre-and post-Flaming Gorge dam construction

3.0 Island Park Model

The Island Park model has 10,564 elements and 29,973 nodes. Nodes are the corner points and mid-points of the element sides. To each node are attached xyz coordinates. Elements are either triangular or quadrilateral; there are 2,193 triangular elements and 8,371 quadrilaterals. Quadrilateral elements are typically more efficient (require fewer elements) than triangular elements. Triangular elements are necessary to more closely fit model boundaries and to add and subtract quadrilateral elements as the river width changes. Typical quadrilateral elements are 40 ft x 80 ft giving a typical aspect ratio of 2 to 1. Elements which are more than 120 feet long were split into two elements, and elements which were more than 60 feet wide were divided into two elements.

During a run, RMA-2 uses an iterative approach to determine the depth and velocity at the interior nodes (nodes that do not form the mesh boundary) based on the boundary conditions, and the existing, or initial, conditions of depth and velocity at the interior nodes. The initial conditions, for a run, at the interior nodes are usually results from a previous simulation. If values from a previous simulation are not available, all interior nodes are given a velocity of zero and a constant user specified water surface elevation. This solution scheme requires that solutions are found by gradually changing the boundary conditions from a flooded flat-water condition to the known values. Changing the boundary conditions from those used to compute the interior nodes will cause a change in the interior node values. Large changes in the boundary conditions can cause model instabilities. The Island Park model was initialized with a water elevation of 4,954 ft, a downstream stage of 4,954 ft and an inflow of 5,000 cfs. The inflow was gradually increased (ramped up) to the target values of 18,000, 22,000, 26,000, 30,000, and 33,700 cfs. Model settings and flow rates for the

ramp up are given in Appendix A, Table A.1. Following the ramp up, the downstream boundary (stage) was decreased to the known water level for the flow rate being modeled (ramp down). Model settings during the ramp down process are shown for each flow rate in Appendix A, Tables A.2 through A.6.

3.1 Island Park Model Calibration

Model calibration involves adjusting Manning's n and the eddy viscosity until predicted stage matches observed stage. Manning's n is used to specify the resistance to flow due to bed roughness. Values for Manning's n, for natural alluvial channels including floodplains and bank vegetation, range from 0.01-0.05 (Chow, 1964). Values used in the Island Park Model were from 0.026-0.042 (Table A.7 in Appendix A).

Eddy viscosity is used to specify the rate of turbulent energy diffusion and dissipation. Typical values for eddy viscosity range from 20 to 100 for river flow with some islands (RMA-2 Manual, 1997). Eddy viscosity significantly affects the formation of eddies in the flow field and consequently the stability of the model. In general, a low eddy viscosity will more readily allow the formation of eddies than a high eddy viscosity. The rate of turbulent energy dissipation is typically higher in faster moving flow fields, therefore the eddy viscosity is frequently higher at high flow rates than at low flow rates.

The model was divided into eight reaches, each with an assigned Manning's n value, Figure 3.1. After the ramp down was completed, Manning's n was adjusted until the predicted and observed water surface profiles matched. Values for Manning's n and eddy viscosity are reported by zone for each flow rate in Table A.7 in Appendix A. Water surface elevations were observed in the Island Park reach for flow rates up to18,000 cfs. The data

Figure 3.1: Map of Island Park showing material locations.

was used to develop a rating curve for the downstream end of the model and is given as follows:

$$Q = 8.65(WSE)^{2.979}$$

where Q = flow (cfs) and WSE = water surface elevation (ft). The rating curve was used to determine stage at the downstream end of the model for all flow rates. Extrapolation of the curve was within the guidelines set forth by the USGS, i.e. to flows less than twice the maximum observed flow. Observed water surface profiles for flows greater than 18,000 cfs are computed assuming a constant water surface slope. Figure 3.2 shows the observed and predicted water surface elevations. Solid lines indicate the predicted profile while points of the same color as the line indicate the observed water surface elevation.

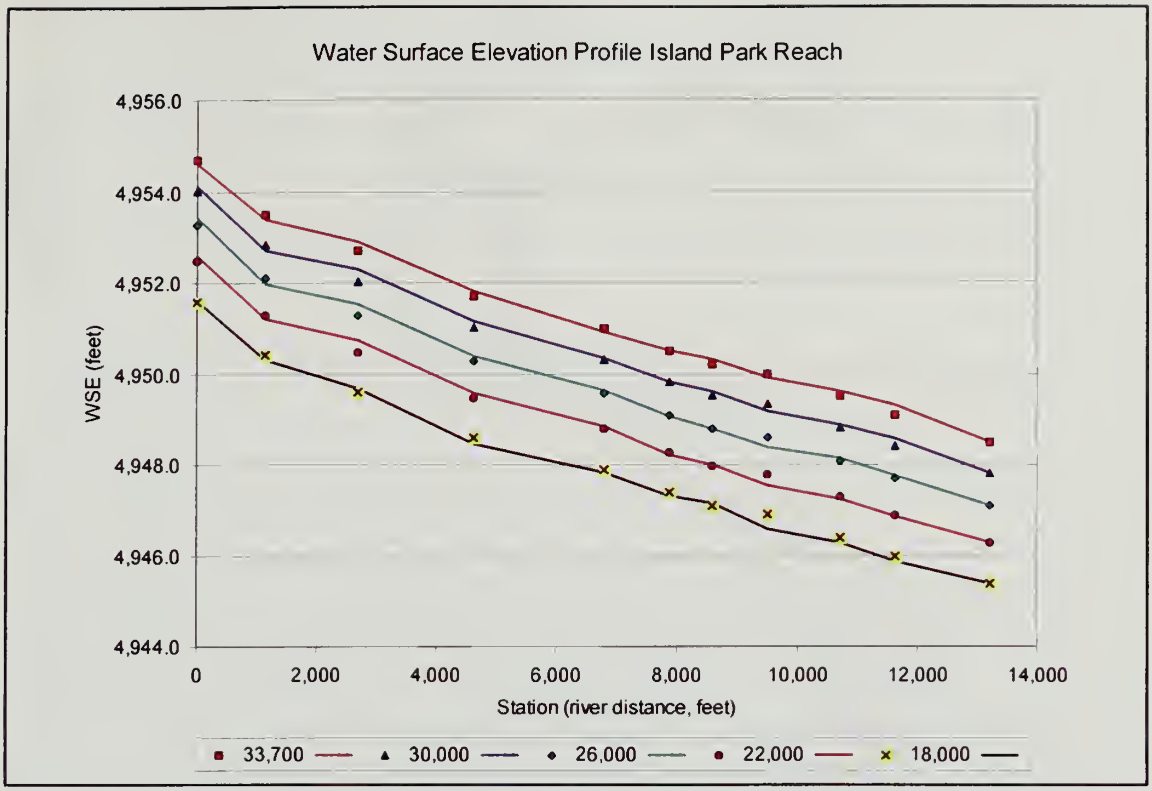


Figure 3.2: Observed and predicted water surface elevations for Island Park Model.

Validation of the eddy viscosity was accomplished by comparing observed and predicted water velocity profiles at a cross section. The NPS measured water velocity at 18,000 cfs during a channel survey in 1998. Velocity measurements were made at several cross sections within the reach, one was selected for comparison with the predicted velocities. The cross section selected is near the upstream end of an island, and has large differences in the two velocity components and magnitudes. The location is difficult to model and gives a worst case test of the model. Figure 3.3 shows velocity contours for the model at 18,000 cfs, and the location where the velocity comparison was made. Figure 3.4 shows the observed and predicted velocities.

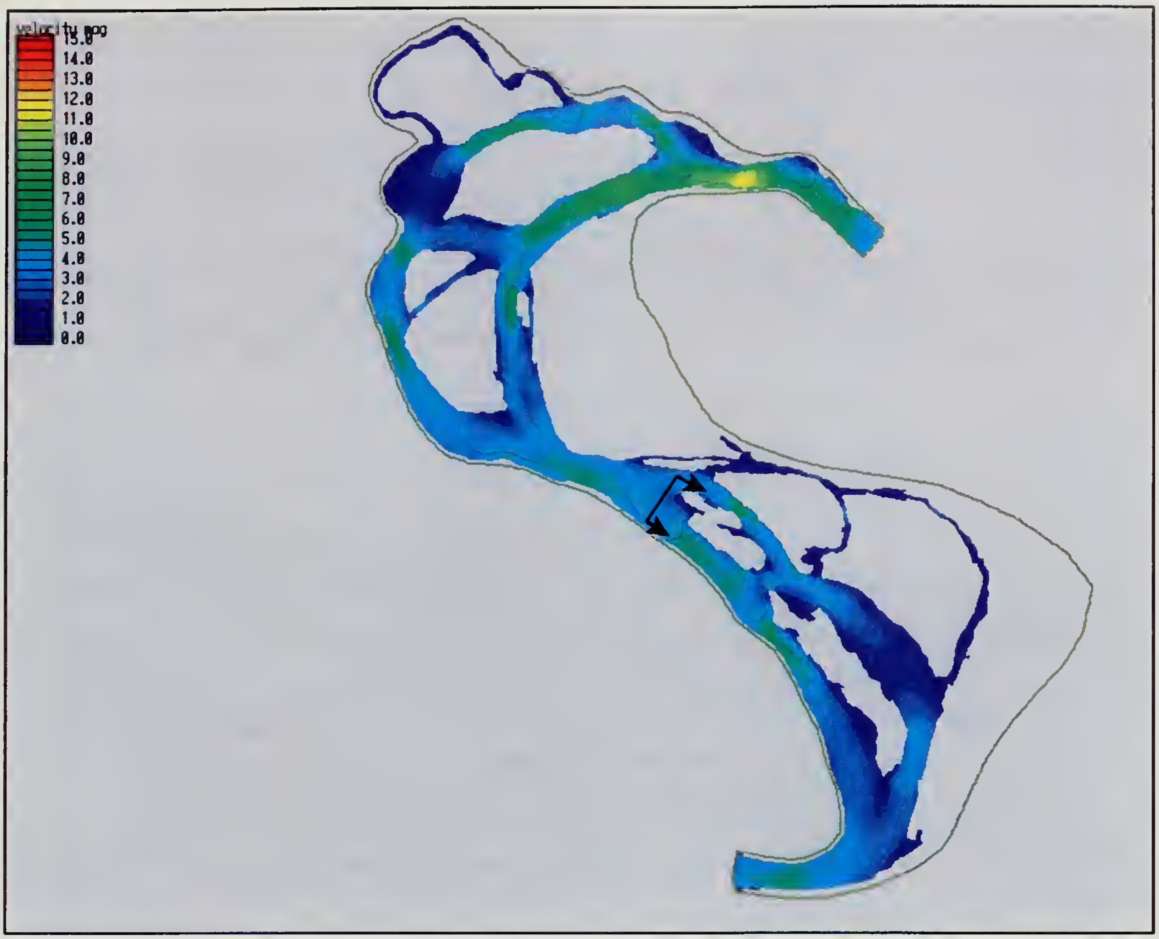


Figure 3.3: Velocity contours at 18,000 cfs, and location of velocity comparison cross section in Island Park model. Units are in feet per second.

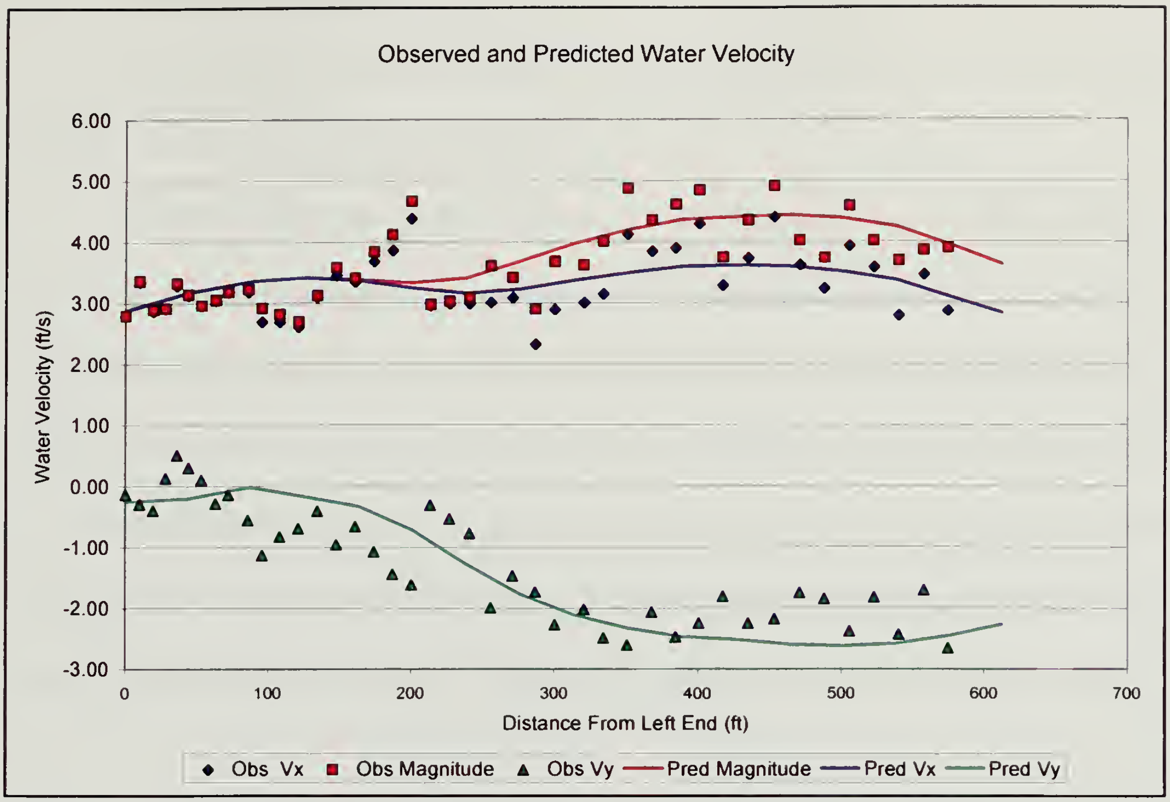


Figure 3.4: Observed and predicted water velocity at cross section in Island Park model.

3.2 Island Park Simulations

A range of flows between 18,000 cfs and 33,700 cfs was simulated. The depth of flow and water velocity in the channel around Bobby Island was of particular interest, because it could provide backwater habitat for young-of-the-year native fish. Flow rates of 18,000, 22,000, 26,000, 30,000, and 33,700 were run, and water depth and velocity were mapped.

4.0 Fort Bottom Model

The Fort Bottom model has 10,673 elements and 31,664 nodes. There are 982 triangular elements and 9691 quadrilateral elements.

A single water surface profile, from the 1998 NPS survey, was available at 18,000 cfs. The Fort Bottom model was initialized with a water surface elevation of 3, 945 ft, a downstream stage of 3,948 ft, and a flow of 1,000 cfs. The flow rate was gradually ramped up to 18,000 cfs with increments of 2000 to 5000 cfs. Manning's n value was adjusted until the water surface profile matched the observed profile. The model was then run at 14,000, 16,000, 18,000, 20,000, and 22,000 cfs. In each case, the downstream boundary was adjusted until the slope of the water surface profile paralleled the observed slope at 18,000 cfs.

4.1 Fort Bottom Model Calibration

Model calibration for the Fort Bottom reach was similar to that for the Island Park reach. Figure 4.1 shows the observed and predicted water surface elevations at 18,000 cfs. The second point from the downstream end is clearly an outlier and physically impossible when compared to the next two upstream points. The point is included in the graph because there is no basis for correcting the point. Furthermore, by including all of the points collected the variability in the field data is apparent. Figure 4.2 shows the model reach, Manning's n values and eddy viscosity determined in the calibration process.

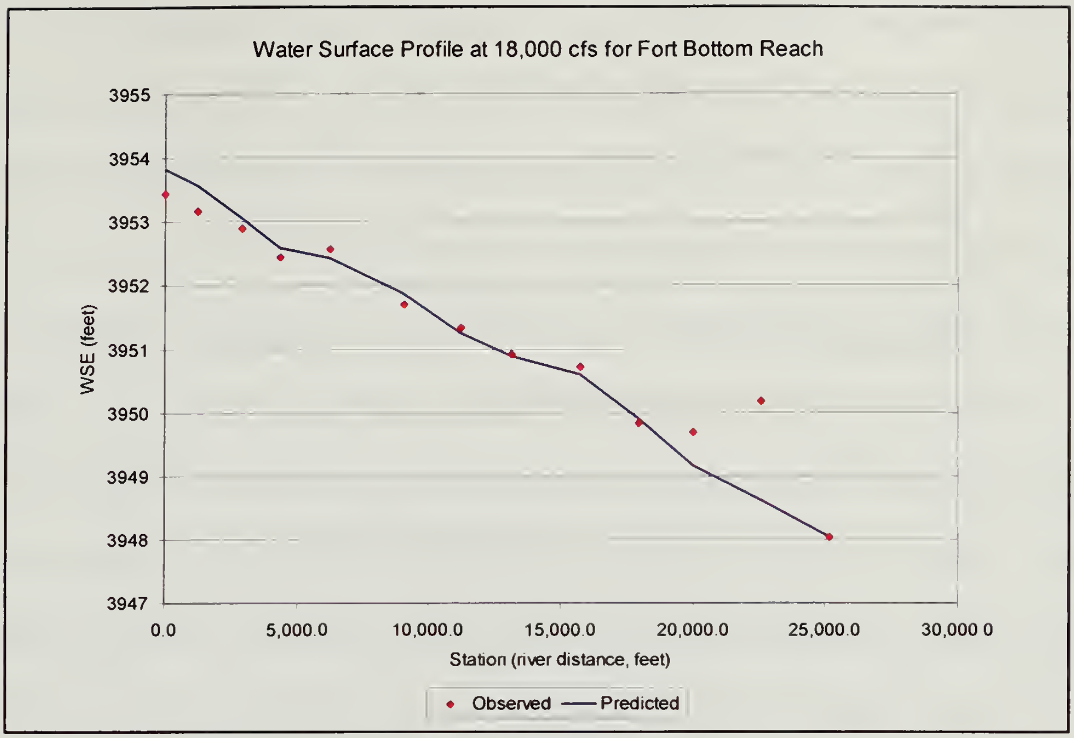


Figure 4.1: Fort Bottom water surface profile at 18,000 cfs.

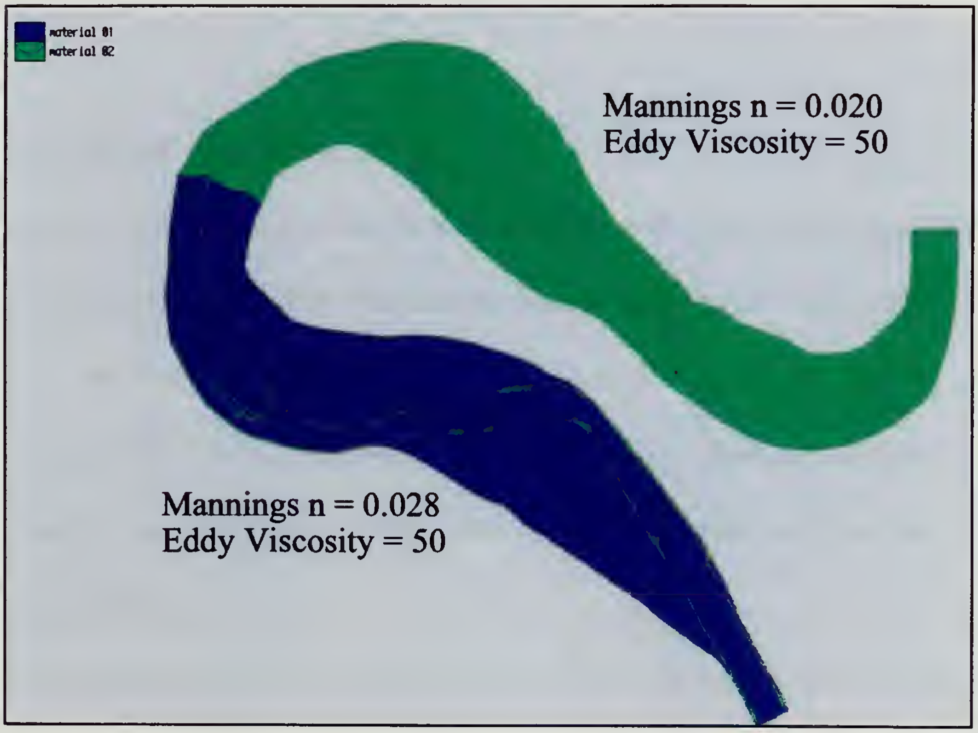


Figure 4.2: Manning's n and eddy viscosity in Fort Bottom model.

Since a stage-discharge relationship was not available at the downstream end of the model, one was developed making the assumption that the water surface slope was constant from 14,000 cfs to 24,000 cfs. Therefore, the observed water surface profile at 18,000 cfs was used in conjunction with the model to develop a rating curve. Developing the rating curve required assuming that the values of Manning's n, determined from the observed water surface profile at 18,000 cfs, remained constant over the range of flows to be modeled. For flow rates other than 18,000 cfs, the downstream boundary condition (stage) was adjusted until the water surface slope matched the observed slope as closely as possible. In this manner, a range of flows was run and the corresponding downstream water surface elevation was determined. The resulting set of discharges and downstream boundary conditions was used to develop a rating curve, shown in Figure 4.3, and in the following relationship:

$$Q = 852.132 * (WSE - 3939)^{1.395}$$

where Q = flow (cfs) and WSE is water surface elevation in feet.

4.2 Fort Bottom Simulations

Two flow rates were modeled for the Fort Bottom reach, 18,000 and 24,000 cfs. The banks of the river are steep and well defined, resulting in little change in channel width as flow is increased within the range of interest. The final solution for 18,000 cfs was gradually adjusted to reach 24,000 cfs. The downstream boundary was raised in 0.25 ft intervals. The inflow boundary was adjusted in 1000 to 2000 cfs intervals while increasing the flow from 18,000 to 24,000 cfs.

Simulations using the Fort Bottom model were designed to assess the effectiveness of breaching a naturally occurring levee to create fish and plant habitat. Two breaching

scenarios were tested at 18,000 and 24,000 cfs. A total of six simulations were required: two at the existing conditions (without levee breaching), for flows of 18,000 and 24,000 cfs, and two at each of the two proposed breaching scenarios.

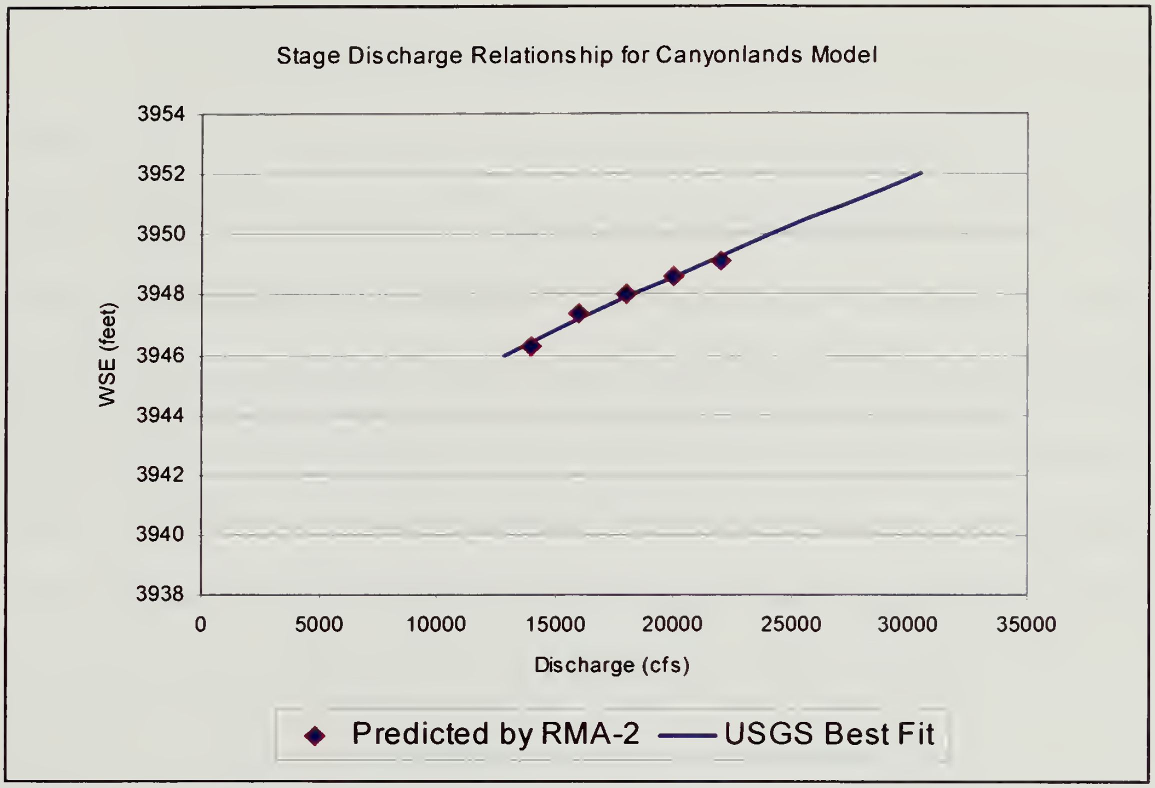


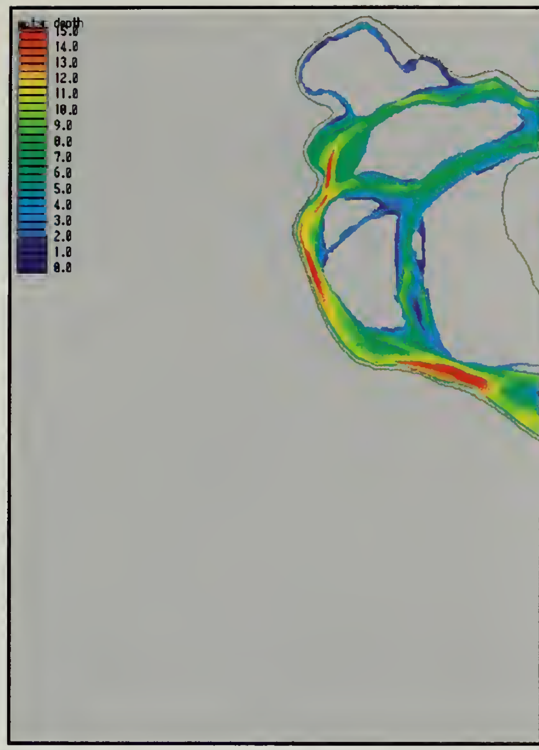
Figure 4.3: Fort Bottom rating curve at the downstream end of the model.

5.0 Results

Model results are summarized separately for the Island Park and Fort Bottom models.

5.1 Island Park

The Island Park model was used to determine areas inundated and associated water depths and velocities over a range of flow rates. Figures 5.1 through 5.5 show the predicted depth of flow at the five flow rates. Figures 5.6 through 5.10 show the predicted water velocity at the five flow rates. It should be noted that depths of flow greater than 15 feet are all shown in red. The change in water surface elevation between 18,000 cfs and 33,700 cfs is approximately 3 feet. The increase in water level results in the inundation of two islands, and partial inundation of two additional islands. It is noteworthy that the islands inundated are mid-channel islands. The total width of the river did not increase significantly with the flow rates modeled, indicating that overland flow or out-of-bank flow is rare.



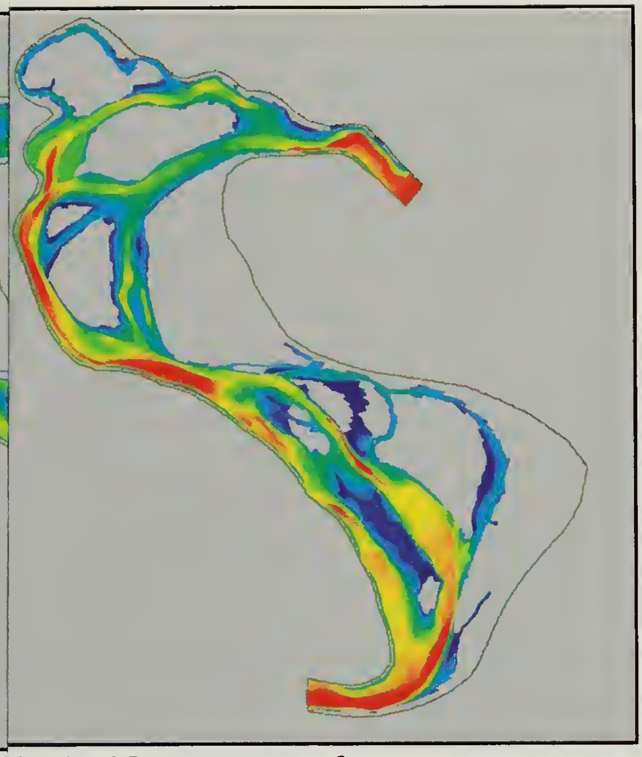


Figure 5.1: Predicted depth of flow at 18depth of flow at 26,000 cfs.

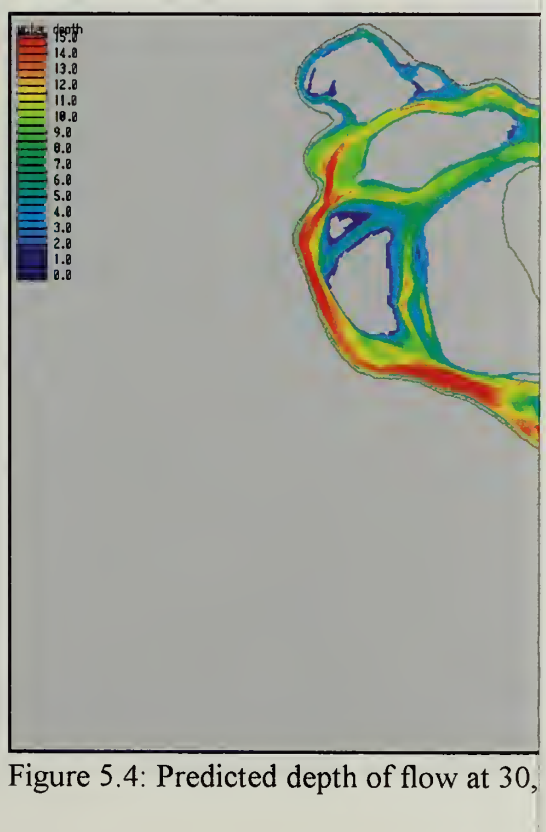


Figure 5.4: Predicted depth of flow at 30,

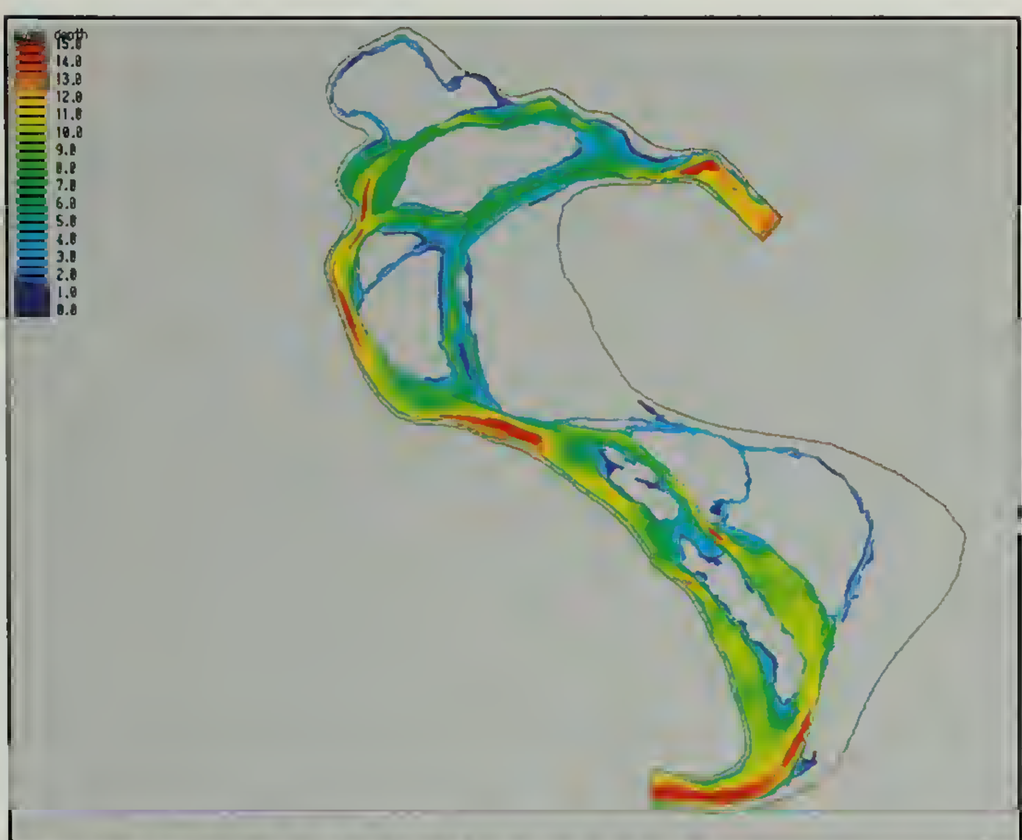


Figure 5.1: Predicted depth of flow at 18,000 cfs.

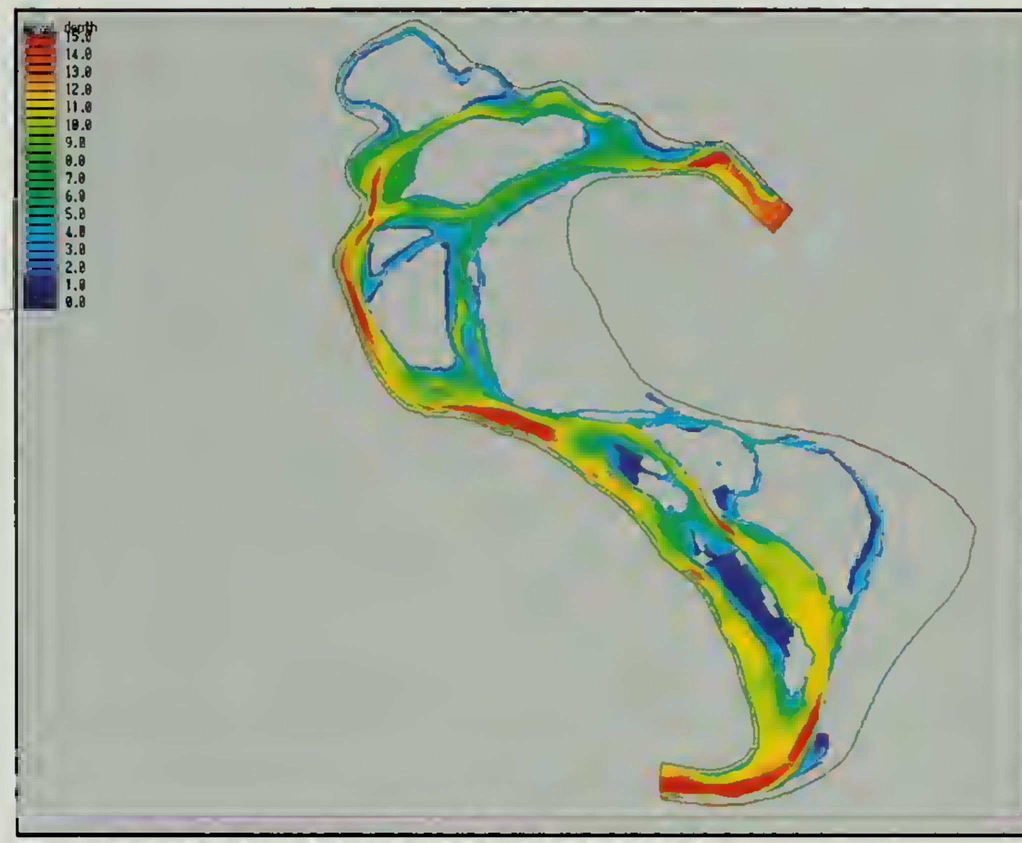


Figure 5.2: Predicted depth of flow at 22,000 cfs.

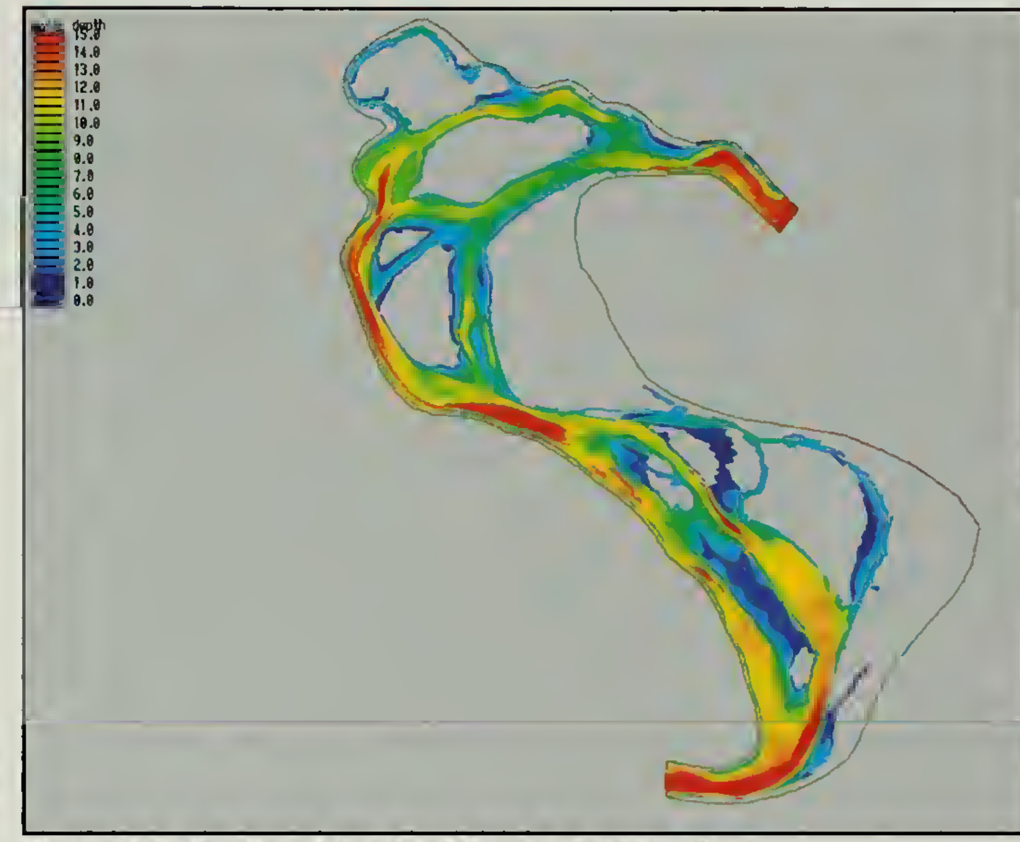


Figure 5.3: Predicted depth of flow at 26,000 cfs.

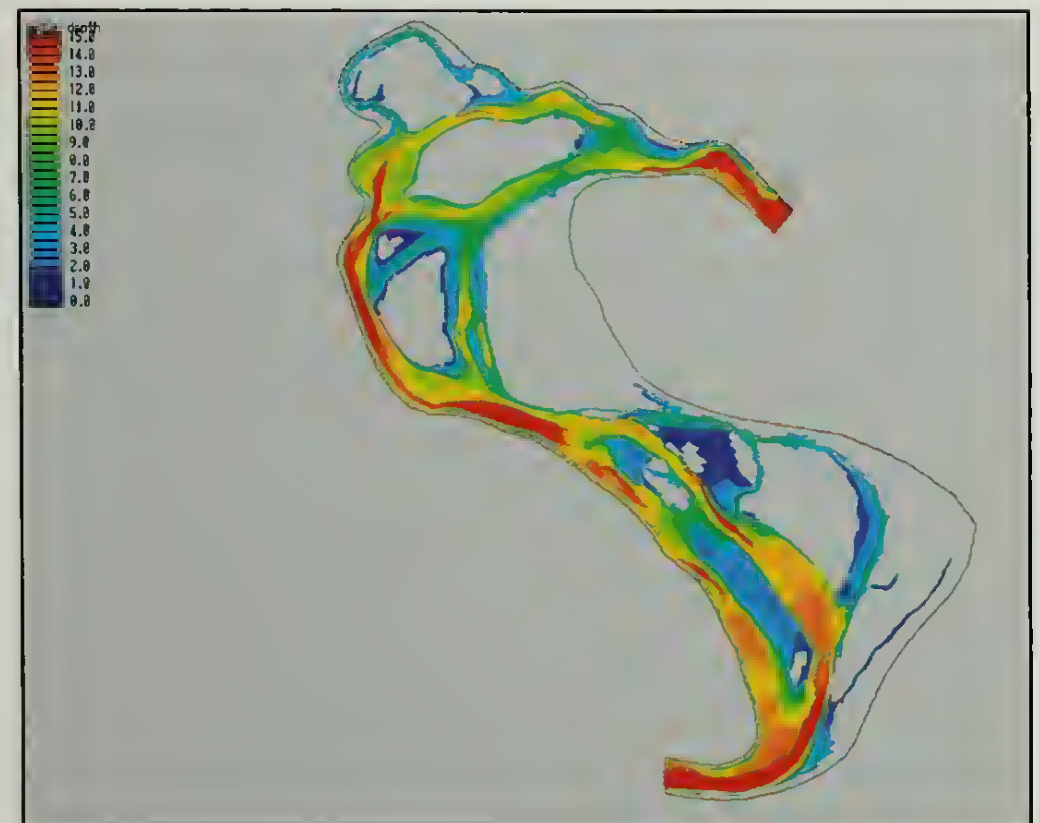


Figure 5.4: Predicted depth of flow at 30,000 cfs.

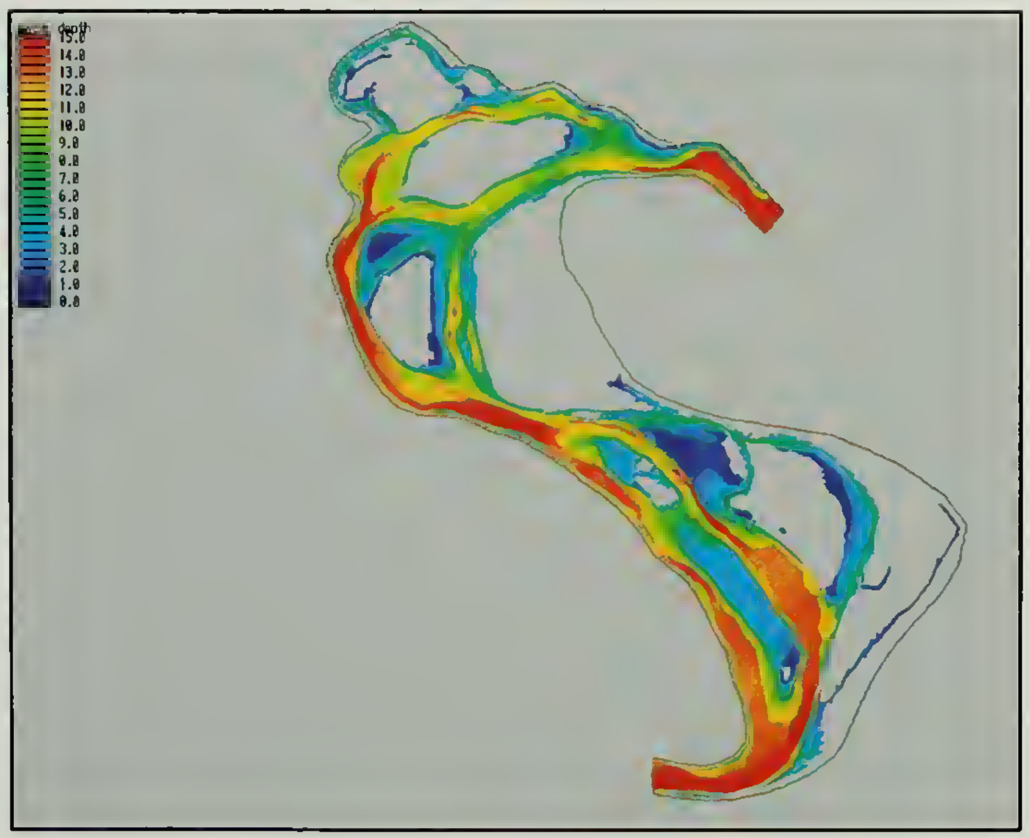


Figure 5.5: Predicted depth of flow at 33,700 cfs.

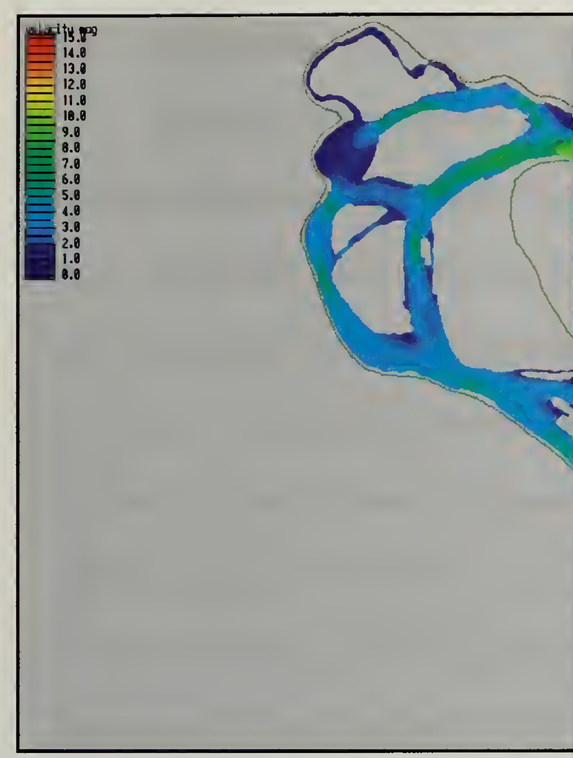
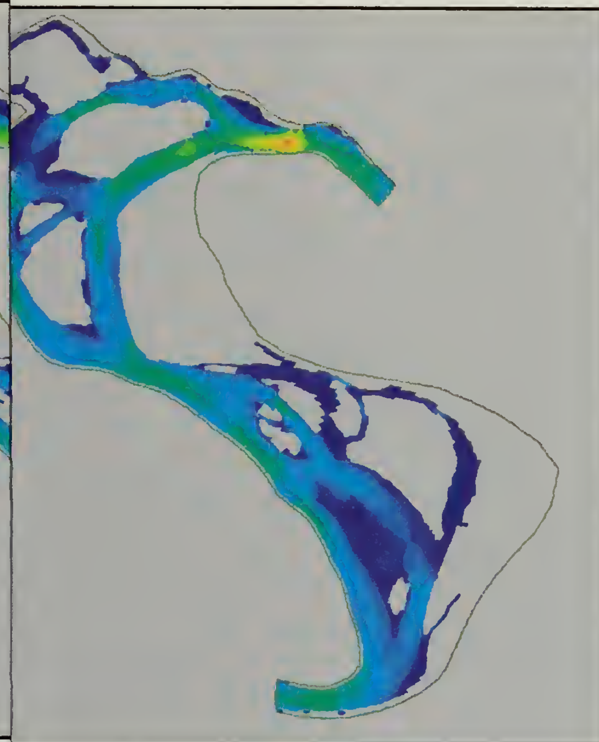


Figure 5.6: Predicted velocity at 18,000 cfs.



ocity at 26,000 cfs.

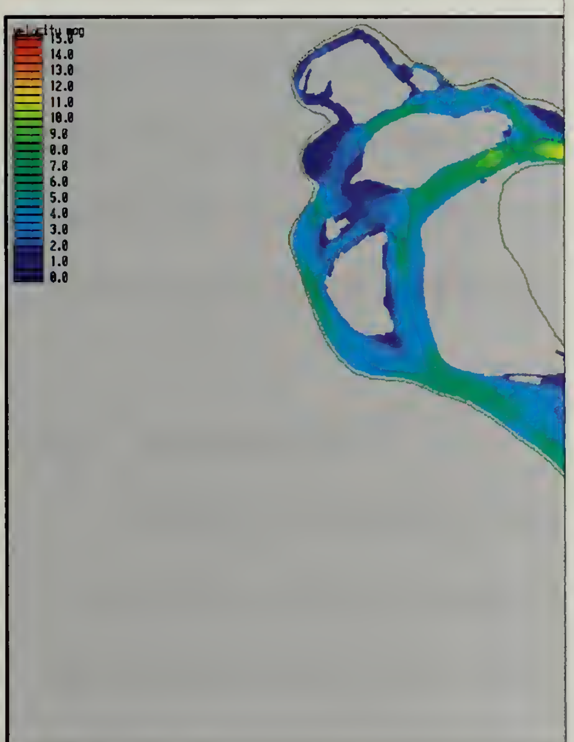


Figure 5.9: Predicted velocity at 30,000 cfs.

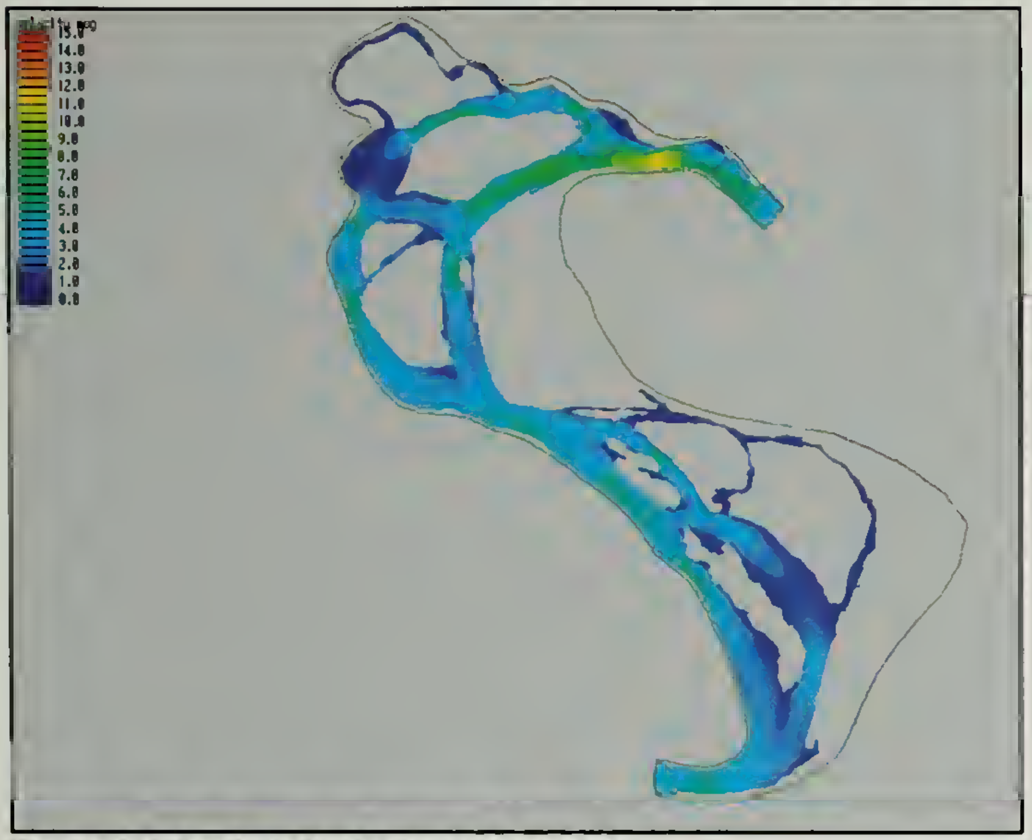


Figure 5.6: Predicted velocity at 18,000 cfs.

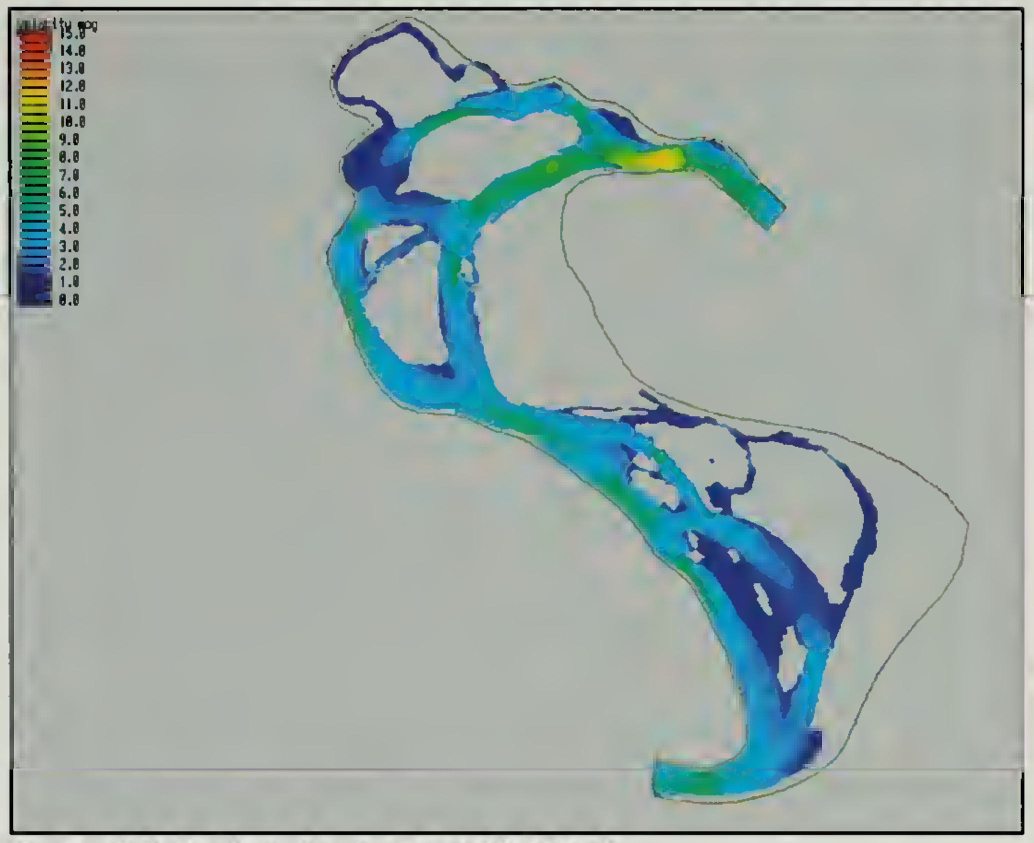


Figure 5.7: Predicted velocity at 22,000 cfs.

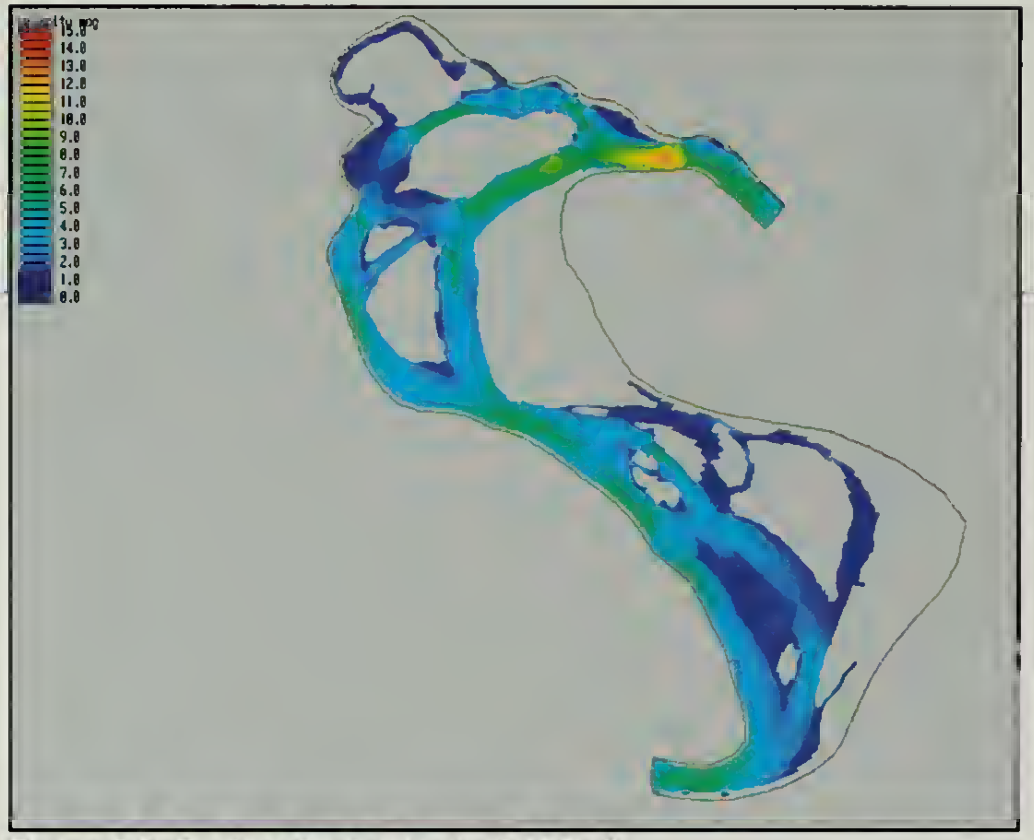


Figure 5.8: Predicted velocity at 26,000 cfs.

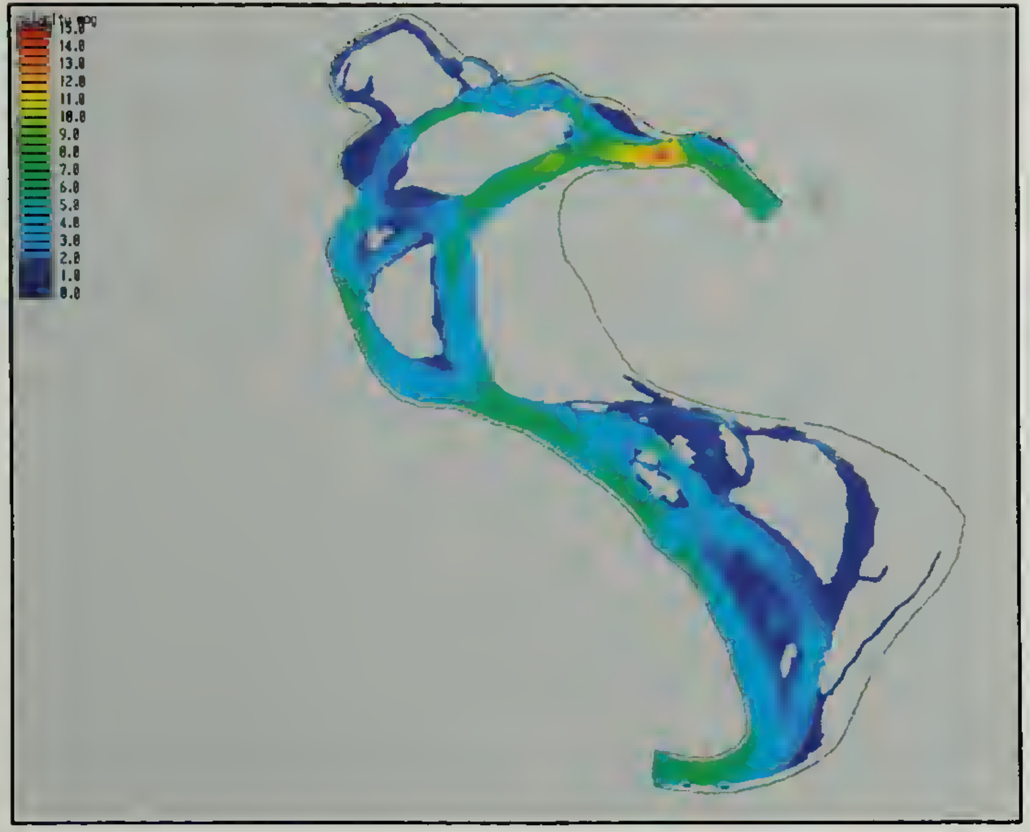


Figure 5.9: Predicted velocity at 30,000 cfs.

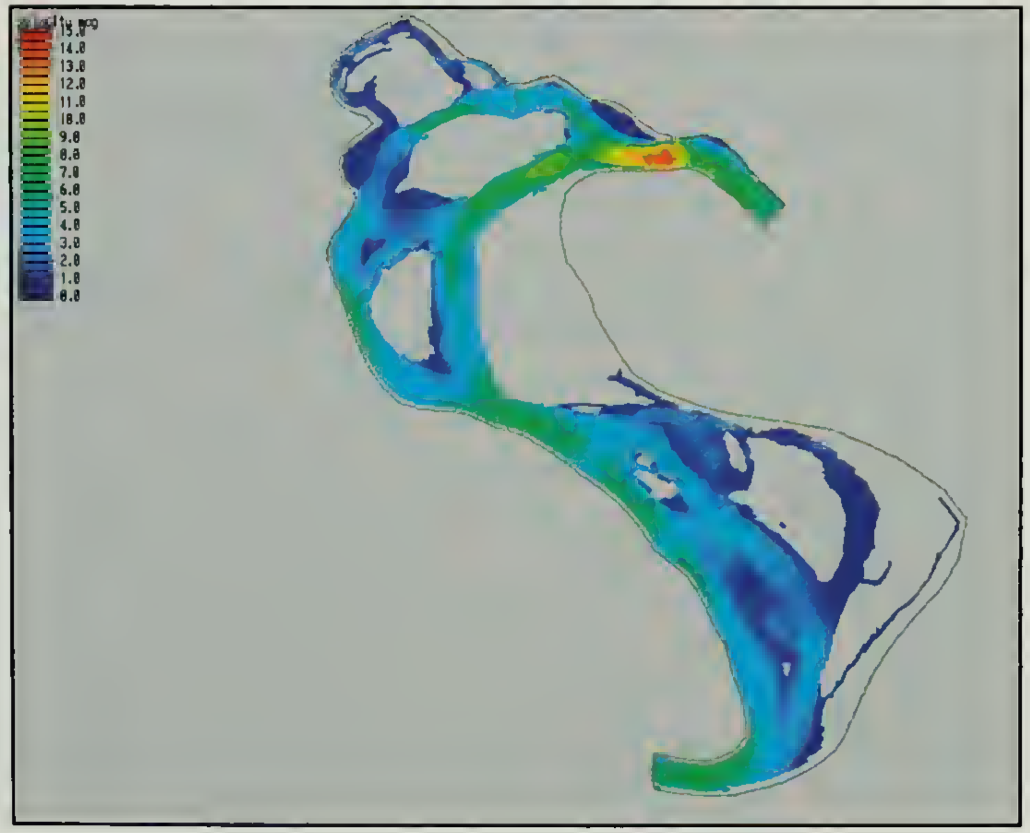


Figure 5.10: Predicted velocity at 33,700 cfs.

5.2 Fort Bottom

The Fort Bottom model was used to assess the viability of breaching natural levees that have formed along the channel. Two breaching scenarios were tested on the inside of a bend. Each scenario had a total breach length of 1,000 feet and was evaluated at a flow rate of 18,000 cfs and 24,000 cfs. A flow rate of 18,000 cfs is the post-dam average annual peak, and 24,000 cfs is the approximate two year recurrence peak flow. A breach length of 1,000 ft allows a reasonable chance of ingress for drifting larvae into the floodplain, and also for efficient filling of the floodplain area. Alternative one has four, 250 foot wide openings spaced at 250 foot intervals to spread the total breaching over a longer length of bank. Alternative two was a continuous 1,000 foot breach. Figure 5.11 shows a contour map of a portion of the Fort Bottom model. The flow direction is as shown in the figure and the area to be inundated is indicated.

The amount of land inundated is independent of breach geometry, but dependant on stage. At 18,000 cfs, 1,327,038 square feet (30 acres) will be inundated. At 24,000 cfs, 1,958,685 square feet (45 acres) will be inundated. The total volume of water in the inundated area is 3,590,163 cubic feet (82 acre-ft) and 7,653,696 cubic feet (176 acre-ft) at 18,000 cfs and 24,000 cfs respectively.

5.2.1 Alternative One

Alternative One was four 250 foot wide openings spaced at 250 foot intervals. Figures 5.12 and 5.13 show the water depth at 18,000 and 24,000 cfs for Alternative One. At 18,000 cfs the maximum depth in the inundated area is approximately five feet, while at 24,000 cfs the approximate maximum depth is seven feet. Figures 5.14 and 5.15 show the water velocity

for Alternative One. Water velocities through the breach openings are typically less than 2 feet per second. Water velocity is an indication of the potential for erosion. Velocities in the inundated area are less than one foot per second.

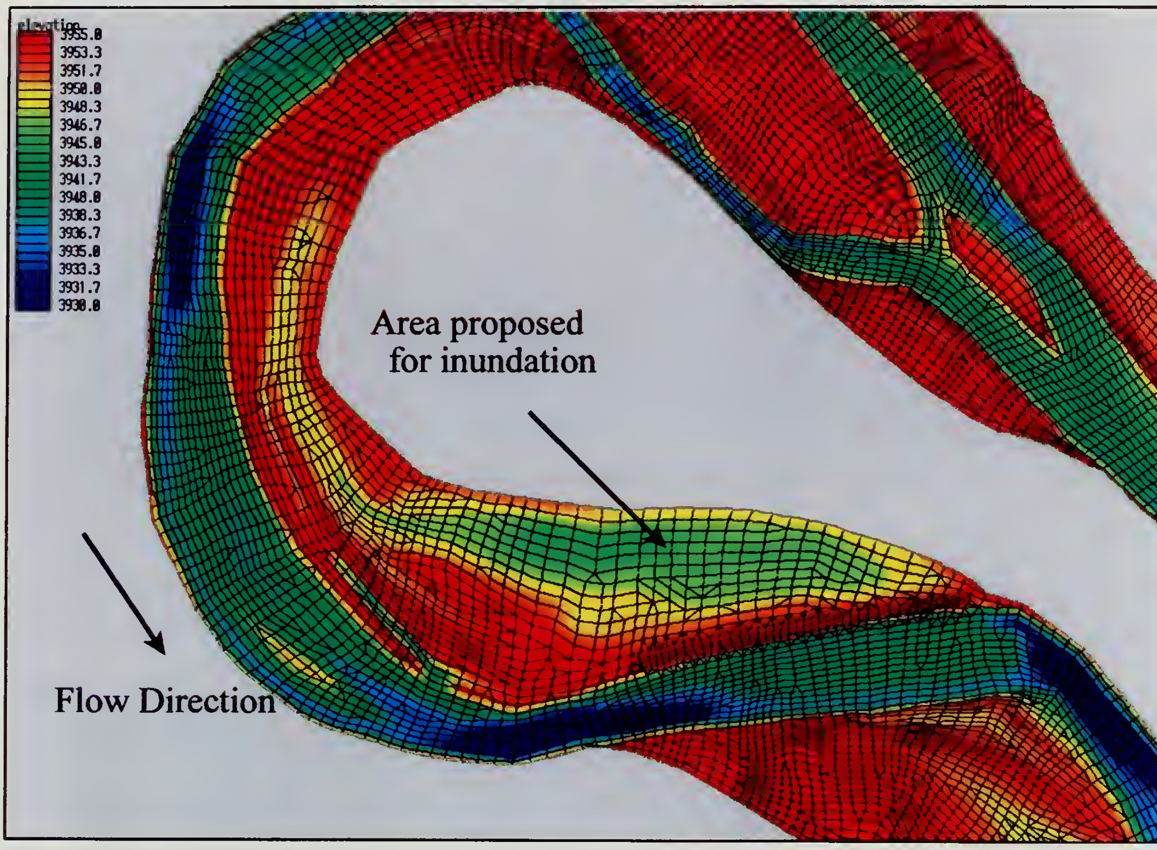


Figure 5.11: Contour map showing area of Fort Bottom proposed for inundation.

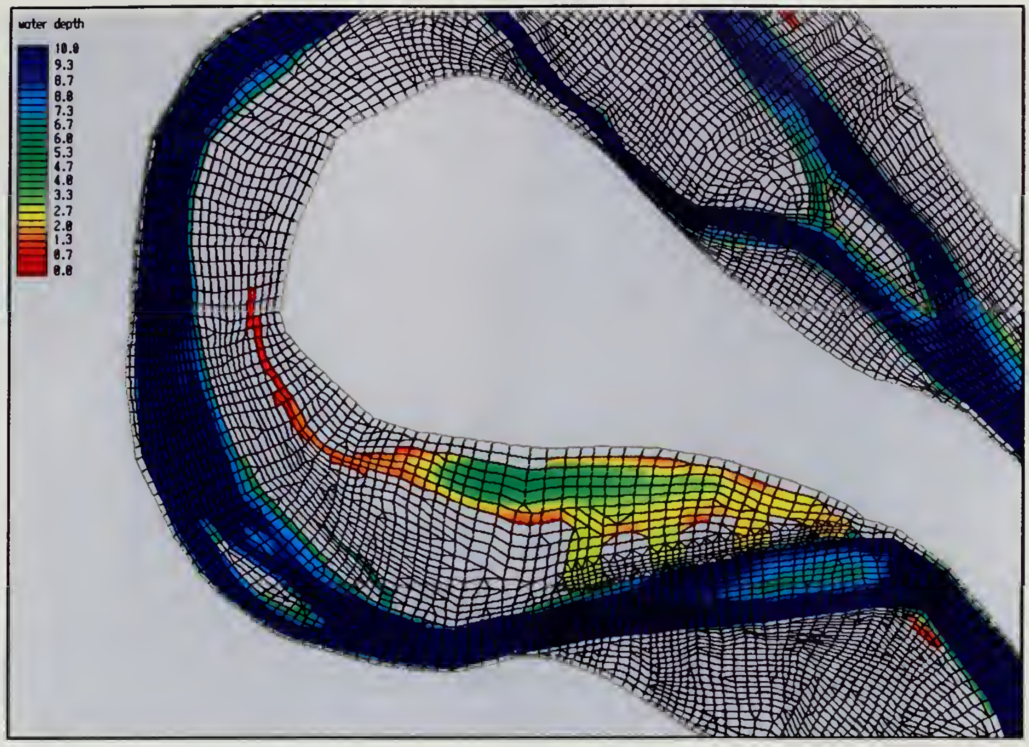


Figure 5.12: Predicted water depth for Alternative One at 18,000 cfs.

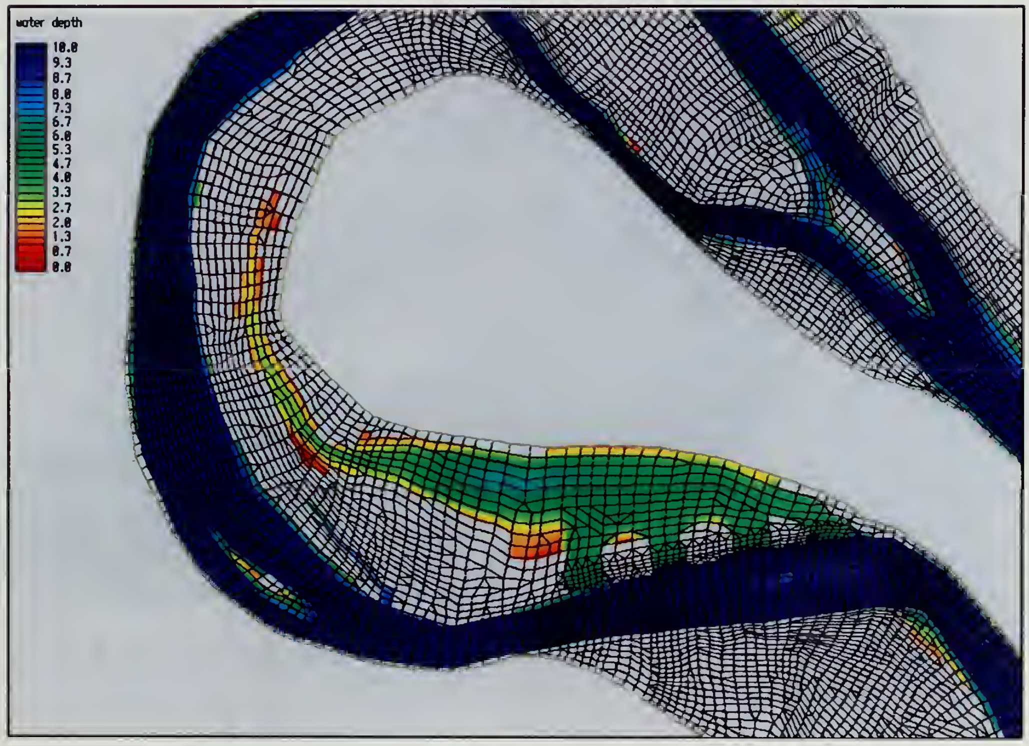


Figure 5.13: Predicted water depth for Alternative One at 24,000 cfs.

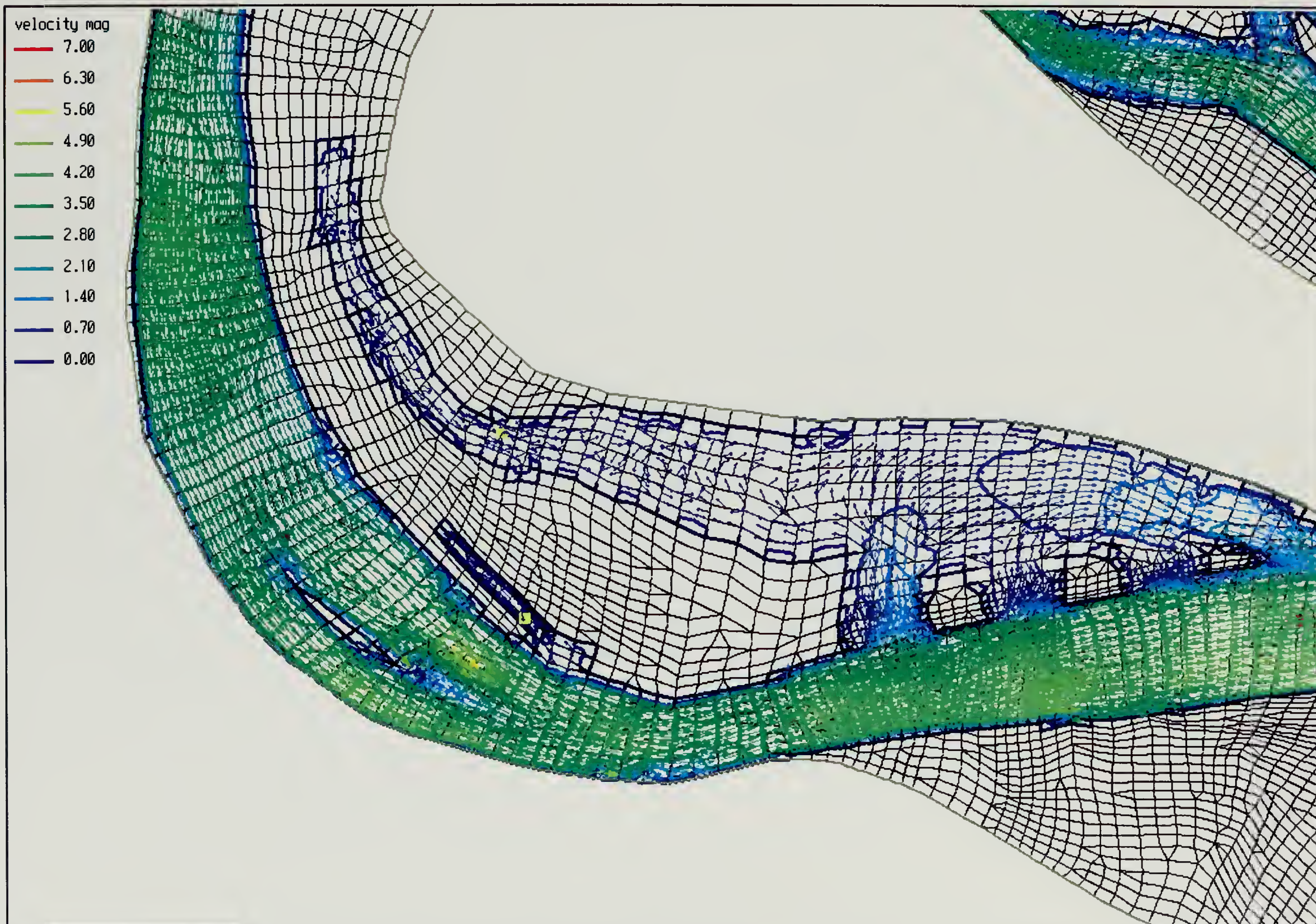


Figure 5.14: Computed velocity vectors for Alternative One at 18,000 cfs.

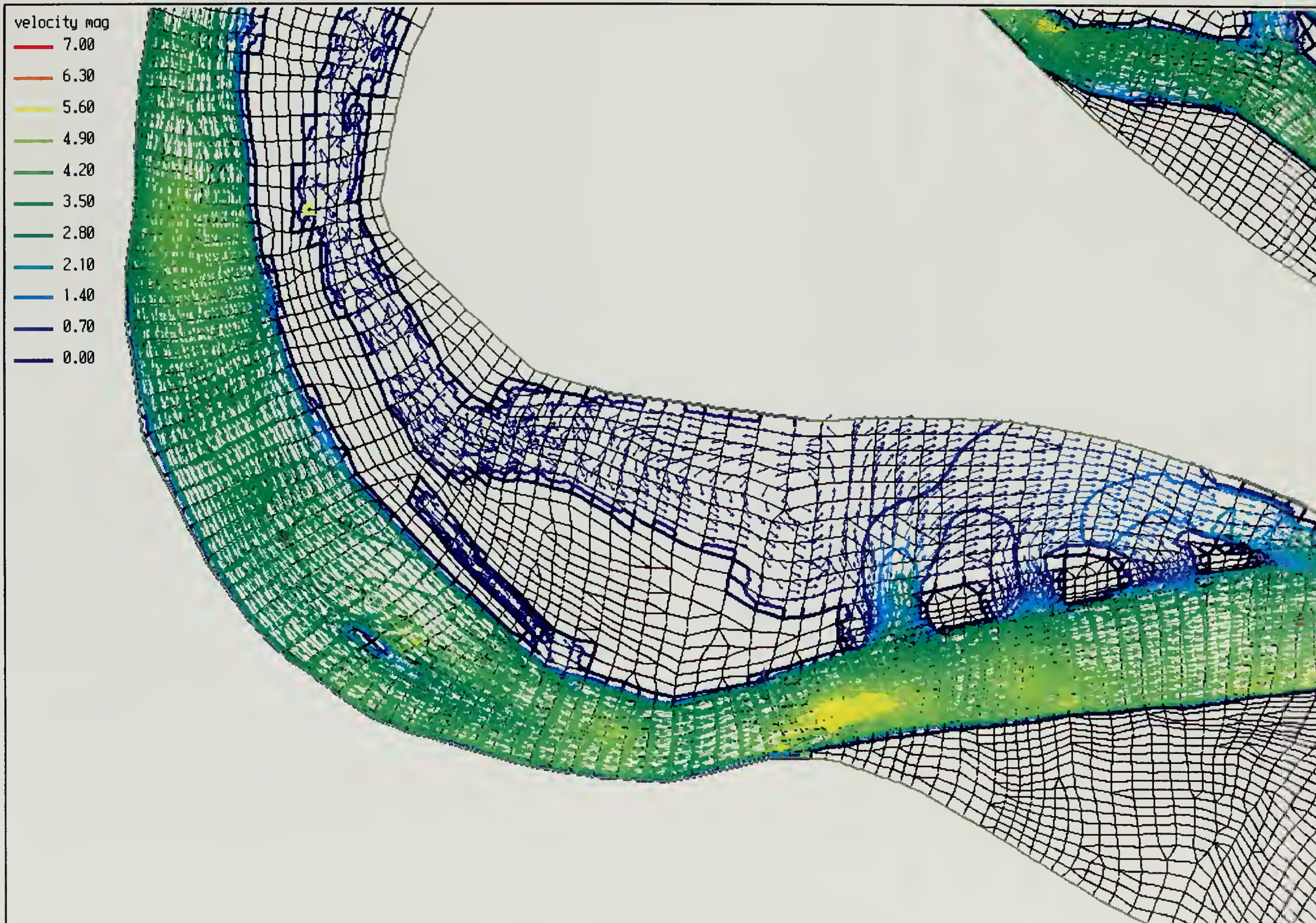


Figure 5.15: Computed velocity vectors for Alternative One at 24,000 cfs.

5.2.1 Alternative Two

Alternative Two was a single 1,000 foot wide breach at the downstream end of the levee. Figures 5.16 and 5.17 show that the maximum water depths in the inundated area at 18,000 and 24,000 cfs for Alternative Two, which are the same as for Alternative One; five and seven feet, respectively. Figures 5.18 and 5.19 show the water velocity for Alternative Two. Water velocities over 3 feet per second are noted in front of the opening running parallel to the opening. Water velocities passing through the opening are approximately 2 feet per second or less. Velocities in the inundated area are less than one foot per second. Water velocities are significant because they provide an indication of the potential for erosion.

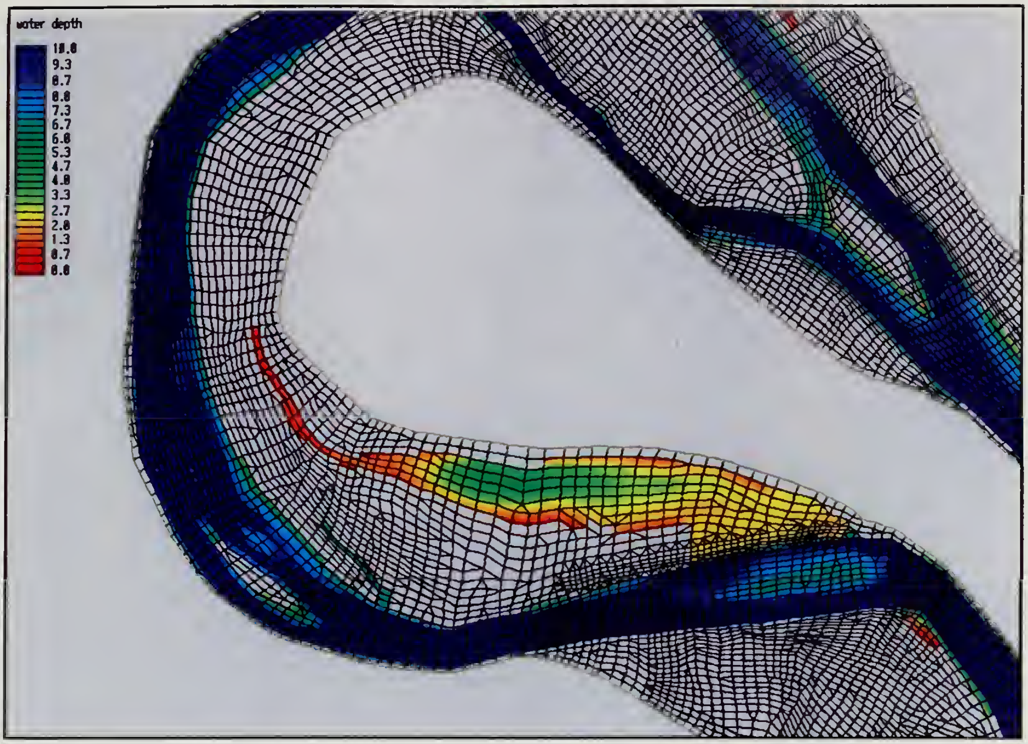


Figure 5.16: Predicted water depth for Alternative Two at 18,000 cfs.

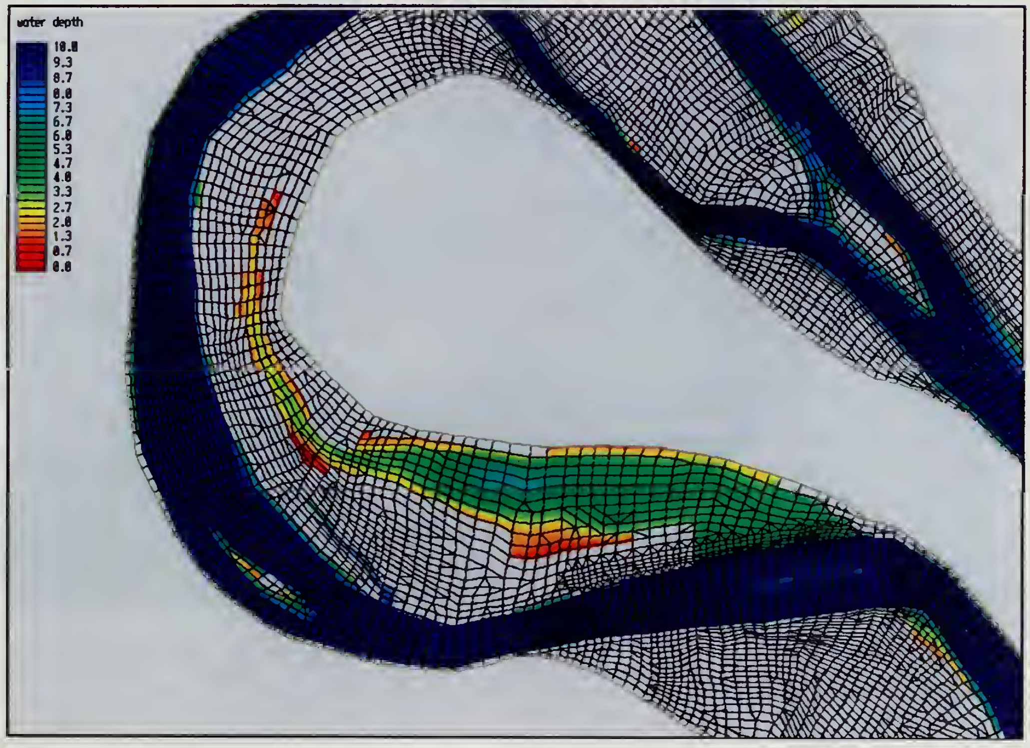


Figure 5.17: Predicted water depth for Alternative Two at 24,000 cfs.

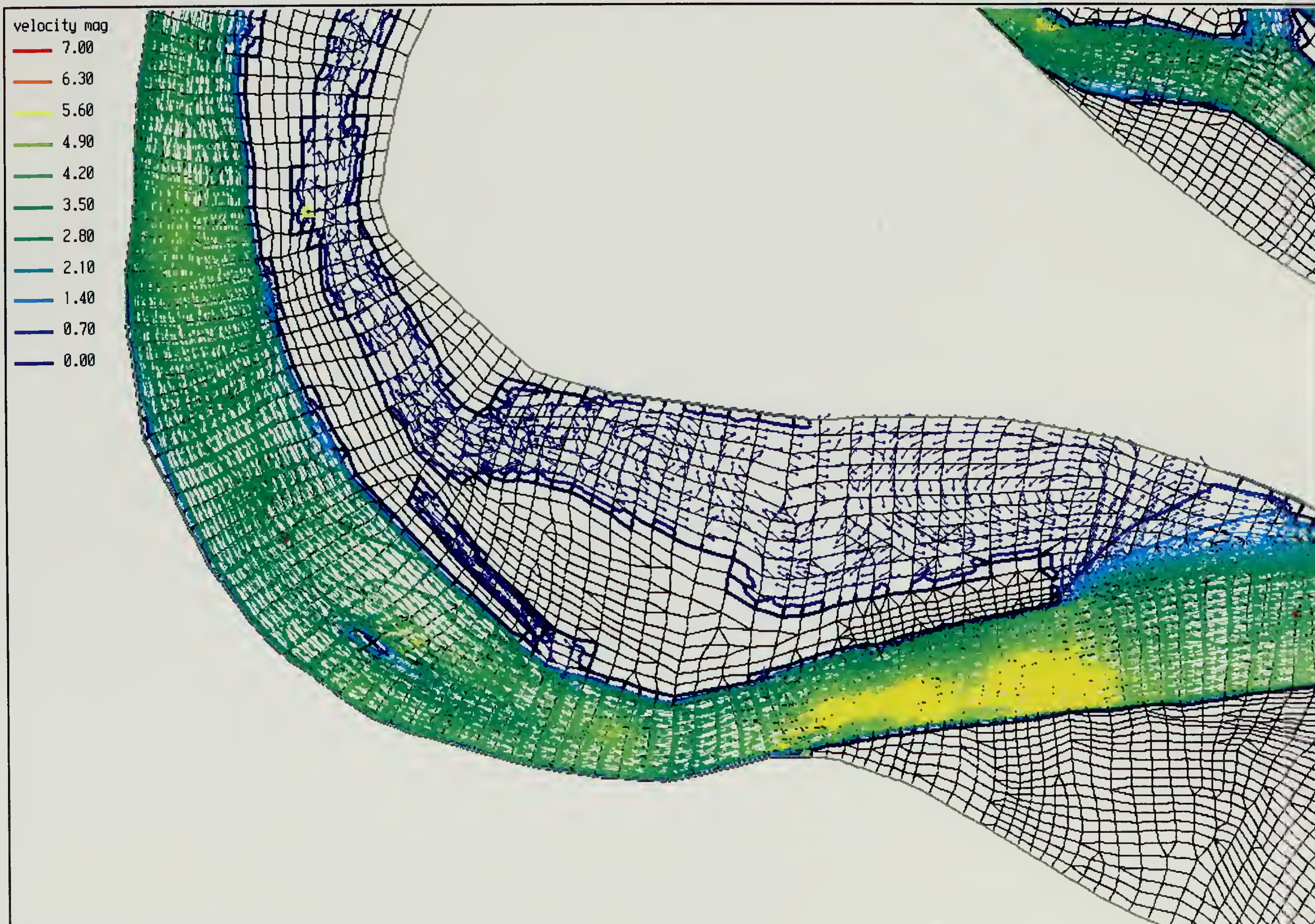


Figure 5.18: Computed velocity vectors for Alternative Two at 18,000 cfs.

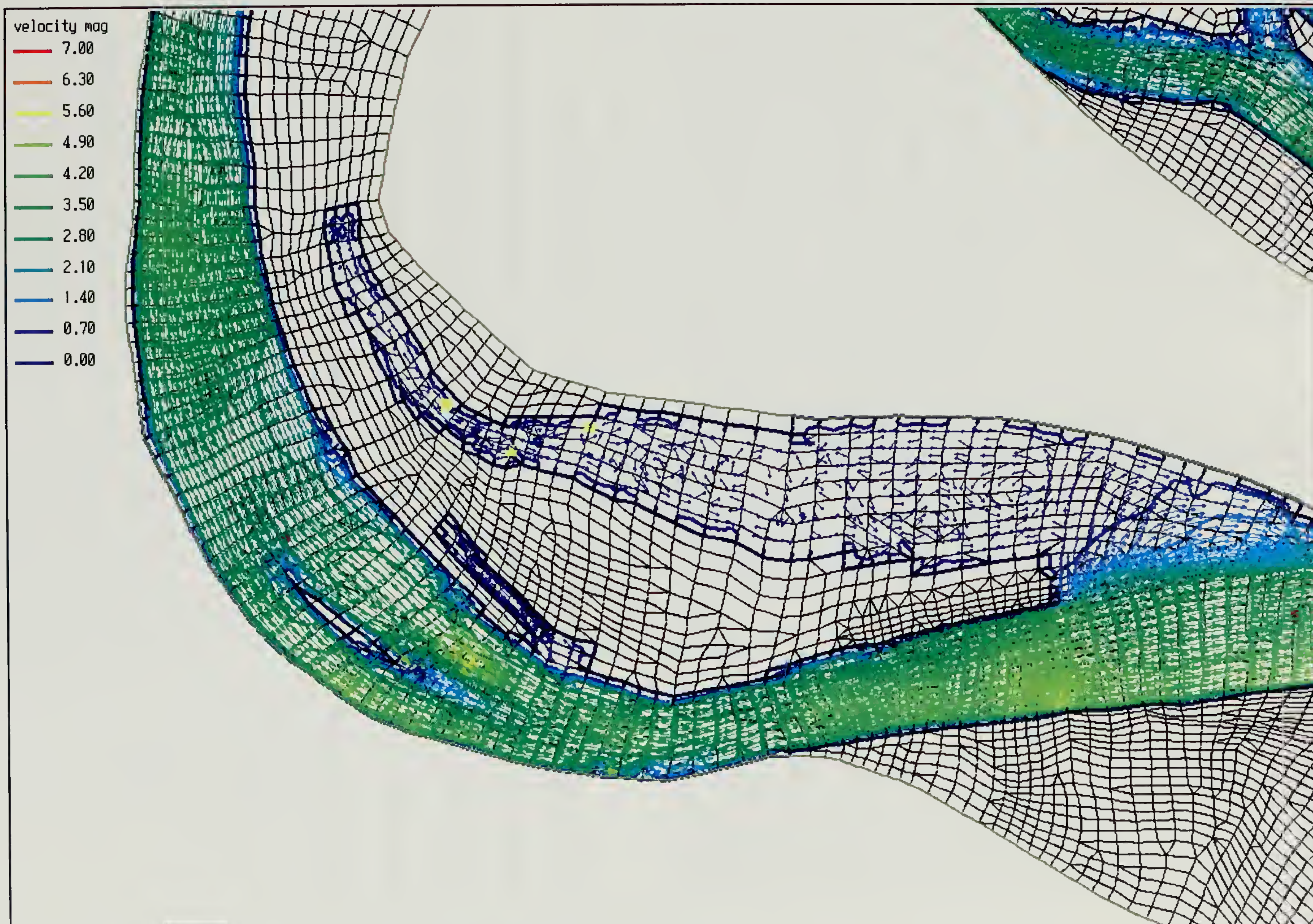


Figure 5.19: Computed velocity vectors for Alternative Two at 24,000 cfs.

6.0 Discussion

6.1 Island Park

The Island Park model suggests that the area behind Bobby Island is gradually filling with sediment. The channel length behind Bobby Island is significantly longer than the channel length in front of the island. This results in a lower energy gradient and less sediment transport capacity behind the island. Field observations indicate that cottonwood trees and willows are growing in the channel behind the island. The increase in channel roughness due to the vegetation further reduces the sediment transport capacity, again reducing the sediment transport rate. Figure 6.1 shows an oblique view of the channel looking upstream. (Additional photos are included in Appendix B.) The vegetation is several years old and may be difficult to remove with a flow event within the range modeled. Therefore, it is thought that the vegetation will continue to cause sediment deposition in the channel.

Historical photographic evidence further suggests that the channel behind Bobby Island is disconnecting from the main channel. Figures 6.2 and 6.3 show aerial photographs taken in 1954 at a flow rate of 1,300 cfs and 1993 at a flow rate of 1,600 cfs. In the 1954 photograph, the channel behind Bobby Island is clearly inundated while in the 1993 photograph, at a higher flow rate, the channel is dry. Figure 6.2 shows that in 1953 a flow rate of 1,300 cfs was sufficient to inundate the channel.

Figure 6.1: Looking upstream at Bobby Island, Island Park, (April, 2001).

6.2 Fort Bottom

The levees in Canyonlands began forming in the 1930's. There is no indication that the levees are eroding or will be removed by natural processes in the near future. The rating curve developed for the model, at its downstream end, shows that a flow of 40,000 cfs is required to generally overtop the levees in the Fort Bottom area, which represents a stage of nearly five feet greater than the 24,000 cfs flow that was simulated. The largest post-dam peak flow at the Green River gage is less than 50,000 cfs, suggesting that natural removal of the levees is not probable.

Figure 6.2: Aerial photograph 1954, Island Park, (1,300 cfs).

Figure 6.3: Aerial photograph 1993, Island Park, (1,600 cfs).

References

Allred, T. M. 1997. Thesis. Channel Narrowing of the Green River near Green River, Utah: Rates, and Processes of Narrowing. Utah State University, Logan, Utah. 115 p.

Chow, Ven Te, ed. 1964. Handbook of Applied Hydrology. McGraw-Hill, New York.

Cluer, B.C. and Hammack, L. A. 1998. Data Collection and High-Flow Modeling of the Green River in Dinosaur NM and Canyonlands NP, Utah. National Park Service, Water Rights Branch, Water Resources Division, Fort Collins, Colorado. 33p.

Grams, P. E and Schmidt, J. C. 1996. Unpublished data.

Rantz, S.E. 1982. Measurement and Computation of Streamflow. U.S. Geological Survey Water-Supply Paper 2175. Washington. 630 p.

RMA-2 WES Version 4.3 Users Guide. 1997. Waterways Experiment Station, US Army Corps of Engineering, Vicksburg, MS.

Shafroth, P. B. 2000. Riparian Vegetation Age and Deposition History along the Green River in Canyonlands National Park: Results of an Exploratory Data Collection Effort, September 23-27, 1999. US Geological Survey, Midcontinent Ecological Science Center, Fort Collins, Colorado. 12 p.

SMS Tutorials Version 7.0. 2000. Brigham Young University, Environmental Modeling Research Laboratory, Provo, Utah 84601.

Appendix A: Model Controls for Island Park model

Table A.1: Model Settings for Ramp Up.

Flow	D.S. B.C.	Iterations	Dry Elem. Update	Nodal Dry	Nodal Active	file name
10,000	4,954.00	40	10	.275	0.9	10K.hot
18,000	4,953.50	40	10	.275	0.9	18K.hot
22,000	4,953.25	40	10	.275	0.9	22K.hot
26,000	4,953.25	40	10	.275	0.9	26K.hot
30,000	4,953.00	40	10	.275	0.9	30K.hot
33,700	4,952.50	40	10	.275	0.9	33K.hot

Note: D.S.B.C. is an abbreviation for Down Stream Boundary Condition.

Table A.2: Model Settings for Ramp Down at 18,000 cfs

Adjust Manning's n?	D.S. B.C.	Iterations	Dry Elem. Update	Nodal Dry	Nodal Active	file name
no	4,953.50	40	10	.275	0.8	18K1.hot
no	4,953.00	40	10	.275	0.8	18K2.hot
no	4,952.75	40	10	.275	0.8	18K3.hot
no	4,952.50	40	10	.275	0.8	18K4.hot
no	4,952.25	40	10	.275	0.8	18K5.hot
no	4,952.00	40	10	.275	0.8	18K6.hot
no	4,951.75	40	10	.275	0.8	18K7.hot
no	4,951.50	40	10	.275	0.8	18K8.hot
no	4,951.25	40	10	.275	0.8	18K9.hot
no	4,951.00	40	10	.275	0.8	18K10.hot
no	4,950.75	40	10	.275	0.8	18K11.hot
no	4,950.50	40	10	.275	0.8	18K12.hot
no	4,950.25	40	10	.275	0.8	18K13.hot
no	4,950.00	40	10	.275	0.8	18K14.hot
no	4,949.75	40	10	.275	0.8	18K15.hot
no	4,949.50	40	10	.275	0.8	18K16.hot
no	4,949.25	40	10	.275	0.8	18K17.hot
no	4,949.00	40	10	.275	0.8	18K18.hot
no	4,948.75	40	10	.275	0.8	18K19.hot
no	4,948.50	40	10	.275	0.8	18K20.hot
no	4,948.25	40	10	.275	0.8	18K21.hot
no	4,948.00	40	10	.275	0.8	18K22.hot
no	4,947.75	40	10	.275	0.8	18K23.hot
no	4,947.50	40	10	.275	0.8	18K24.hot
no	4,947.25	40	10	.275	0.8	18K25.hot

no	4,947.00	40	10	.275	0.8	18K26.hot
no	4,947.00	40	10	.275	0.8	18K27.hot
no	4,946.85	40	10	.275	0.8	18K28.hot
no	4,946.75	40	10	0.275	0.8	18K29.hot
no	4,946.60	40	10	.275	1.5	18K30.hot
no	4,946.25	40	10	.275	1.5	18K31.hot
no	4,946.00	40	10	.275	1.5	18K32.hot
no	4,945.75	40	10	.275	1.5	18K33.hot
no	4,945.40	40	10	.275	1.5	18Kfinal.hot

Table A.3: Model Settings for Ramp Down at 22,000 cfs

Adjust Manning's n?	D.S. B.C.	Iterations	Dry Elem. Update	Nodal Active	Nodal Dry	file name
no	4,953.00	40	10	.275	0.8	22K1.hot
no	4,952.75	40	10	.275	0.8	22K2.hot
no	4,952.50	40	10	.275	0.8	22K3.hot
no	4,952.25	40	10	.275	1.5	22K4.hot
no	4,952.00	40	10	.275	1.5	22K5.hot
no	4,951.75	40	10	.275	1.5	22K6.hot
no	4,951.50	40	10	.275	1.5	22K7.hot
no	4,951.25	40	10	.275	1.5	22K8.hot
no	4,951.00	40	10	.275	1.5	22K9.hot
no	4,950.75	40	10	.275	1.5	22K10.hot
no	4,950.50	40	10	.275	1.5	22K11.hot
no	4,950.25	40	10	.275	1.5	22K12.hot
no	4,950.00	40	10	.275	1.5	22K13.hot
no	4,949.75	40	10	.275	1.5	22K14.hot
no	4,949.50	40	10	.275	1.5	22K15.hot
no	4,949.25	40	10	.275	1.5	22K16.hot
no	4,949.00	40	10	.275	1.5	22K17.hot
no	4,948.75	40	10	.275	1.5	22K18.hot
no	4,948.50	40	10	.275	1.5	22K19.hot
no	4,948.25	40	10	.275	1.5	22K20.hot
no	4,948.00	40	10	.275	1.5	22K21.hot
no	4,947.75	40	10	.275	1.5	22K22.hot
no	4,947.50	40	10	.275	1.5	22K23.hot
no	4,947.25	40	10	.275	1.5	22K24.hot
no	4,947.00	40	10	.275	1.5	22K25.hot

no	4,946.75	40	10	.275	1.5	22K26.hot
no	4,946.50	40	10	.275	1.5	22K27.hot
no	4,946.28	40	10	.275	1.5	22K28.hot
no	4,946.28	40	10	.275	1.5	22Kfinal.hot

Table A.4: Model Settings for Ramp Down at 26,000 cfs

Adjust Manning's n?	D.S. B.C.	Iterations	Dry Elem. Update	Nodal Active	Nodal Dry	file name
no	4,953.00	40	10	.275	2	26K1.hot
no	4,952.75	40	10	.275	1.5	26K2.hot
no	4,952.50	40	10	.275	1.5	26K3.hot
no	4,952.25	40	10	.275	1.5	26K4.hot
no	4,952.00	40	10	.275	1.5	26K5.hot
no	4,951.75	40	10	.275	1.5	26K6.hot
no	4,951.50	40	10	.275	1.5	26K7.hot
no	4,951.25	40	10	.275	1.5	26K8.hot
no	4,951.00	40	10	.275	1.5	26K9.hot
no	4,950.75	40	10	.275	1.5	26K10.hot
no	4,950.50	40	10	.275	1.5	26K11.hot
no	4,950.25	40	10	.275	1.5	26K12.hot
no	4,950.00	40	10	.275	1.5	26K13.hot
no	4,949.75	40	10	.275	1.5	26K14.hot
no	4,949.50	40	10	.275	1.5	26K15.hot
no	4,949.25	40	10	.275	1.5	26K16.hot
no	4,949.00	40	10	.275	1.5	26K17.hot
no	4,948.75	40	10	.275	1.5	26K18.hot
no	4,948.50	40	10	.275	1.5	26K19.hot
no	4,948.25	40	10	.275	1.5	26K20.hot
no	4,948.00	40	10	.275	1.5	26K21.hot
no	4,947.75	40	10	.275	1.5	26K22.hot
no	4,947.50	40	10	.275	1.5	26K23.hot
no	4,947.25	40	10	.275	1.5	26K24.hot
no	4,947.09	40	10	.275	1.5	26K25.hot
no	4,947.09	40	10	.275	1.5	26Kfinal.hot

Table A.5: Model Settings for Ramp Down at 30,000 cfs

Adjust Manning's n?	D.S. B.C.	Iterations	Dry Elem. Update	Nodal Active	Nodal Dry	file name
no	4,952.50	40	10	.275	1.5	30K1.hot
no	4,952.25	40	10	.275	1.5	30K2.hot
no	4,952.00	40	10	.275	1.5	30K3.hot
no	4,951.75	40	10	.275	1.5	30K4.hot
no	4,951.50	40	10	.275	1.5	30K5.hot
no	4,951.25	40	10	.275	1.5	30K6.hot
no	4,951.00	40	10	.275	1.5	30K7.hot
no	4,950.75	40	10	.275	1.5	30K8.hot
no	4,950.50	40	10	.275	1.5	30K9.hot
no	4,950.25	40	10	.275	1.5	30K10.hot
no	4,950.00	40	10	.275	1.5	30K11.hot
no	4,949.75	40	10	.275	1.5	30K12.hot
no	4,949.50	40	10	.275	1.5	30K13.hot
no	4,949.25	40	10	.275	1.5	30K14.hot
no	4,949.00	40	10	.275	1.5	30K15.hot
no	4,948.75	40	10	.275	1.5	30K16.hot
no	4,948.50	40	10	.275	1.5	30K17.hot
no	4,948.25	40	10	.275	1.5	30K18.hot
no	4,948.00	40	10	.275	1.5	30K19.hot
no	4,947.82	40	10	.275	1.5	30K20.hot
no	4,947.82	40	10	.275	1.5	30Kfinal.hot

Table A.6: Model Settings for Ramp Down at 33,700 cfs

Adjust Manning's n?	D.S. B.C.	Iterations	Dry Elem. Update	Nodal Dry	Nodal Active	file name
no	4,952.00	40	10	.275	0.9	33K1.hot
no	4,951.75	40	10	.275	0.9	33K2.hot
no	4,951.50	40	10	.275	0.8	33K3.hot
no	4,951.25	40	10	.275	0.8	33K4.hot
no	4,951.00	40	10	.275	0.8	33K5.hot
no	4,950.75	40	10	.275	0.8	33K6.hot
no	4,950.50	40	10	.275	0.8	33K7.hot
no	4,950.00	40	10	.275	0.8	33K8.hot
no	4,949.75	40	10	.275	0.8	33K9.hot
no	4,949.50	40	10	.275	0.8	33K10.hot
no	4,949.25	40	10	.275	0.8	33K11.hot
no	4,949.25	40	10	.275	0.8	33K12.hot
no	4,949.25	40	10	.275	0.8	33K13.hot
no	4,949.00	40	10	.275	0.8	33K14.hot
no	4,948.75	40	10	.275	0.8	33K15.hot
no	4,948.50	40	10	.275	0.8	33K16.hot
yes	4,948.50	40	10	.275	0.8	33K17.hot
yes	4,948.50	50	10	.275	0.8	33Kfinal.hot

Table A.7: Manning's n and Eddy Viscosity for Island Park model

zone	18,000 cfs	22,000 cfs	26,000 cfs	30,000 cfs	33,700 cfs
1	0.027* 75**	0.028 50	0.030 50	0.031 50	0.031 75
2	0.024 50	0.023 50	0.022 50	0.021 50	0.021 50
3	0.041 50	0.041 50	0.041 50	0.041 50	0.040 50
4	0.042 50	0.042 50	0.042 50	0.042 50	0.042 50
5	0.032 50	0.032 50	0.032 50	0.032 50	0.033 50
6	0.028 50	0.028 50	0.028 50	0.028 50	0.027 50
7	0.027 50	0.027 50	0.027 50	0.027 50	0.027 50
8	0.029 75	0.029 50	0.029 50	0.029 50	0.029 75
9	0.026 50	0.026 50	0.026 50	0.026 50	0.026 50
D.S. B.C.	4945.4	4946.28	4947.09	4947.82	4948.5

* Manning's n
** eddy viscosity

Table A.7 gives the Manning's n value and eddy viscosity by zone, for each flow rate in the Island Park model. Figure A.1 on the following page shows the zones into which the model was divided. Each column in the table above gives the Manning's n and the eddy viscosity for each model zone. Manning's n is the top number (less than 1) and eddy viscosity is the bottom number (greater than 20). D.S.B.C. is the abbreviation for Down Stream Boundary Condition and gives the water surface elevation at the downstream end of the model.

Appendix B: Field Photos for Island Park model

Photographs of the Island Park model were taken from an overlook approximately 5,000 feet downstream from the upstream end of the reach. Figure B.1 shows the point from which the photographs were taken and the direction the camera was pointed. The letter number designation at the end of each arrow corresponds to the figure caption number the photo was given on the following pages. All photographs were taken March 21, 2001. Stream flow at the time of the photographs is approximately 1900 cfs, from USGS, Water Resource Division, provisional data posted on the internet.

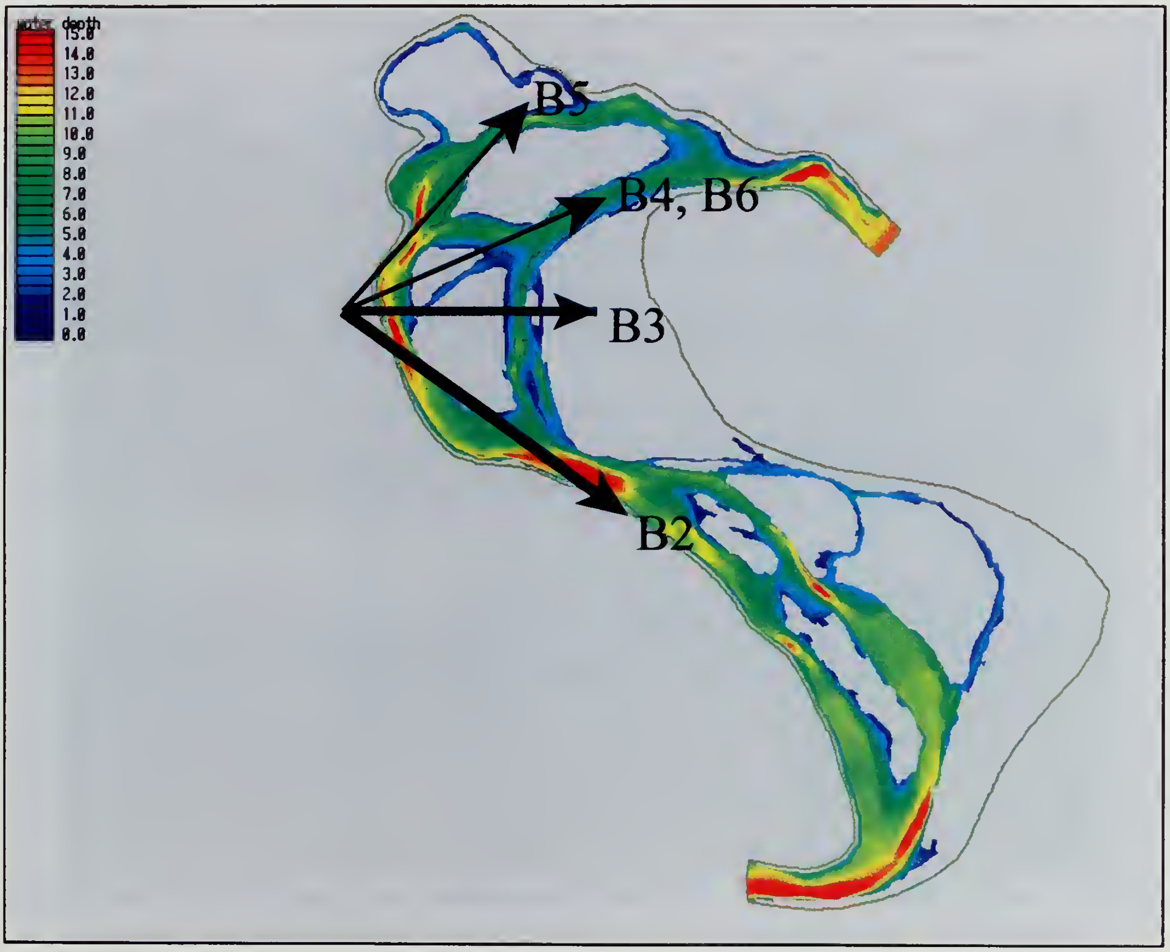


Figure B.1: Site map showing direction of photos B.2 to B.6.

Figure B.2: Looking downstream (SE), March 21, 2001. Unnamed Island in foreground, Tree Island in middle background. Flow approx. 1,900 cfs.

Figure B.3: Looking across stream to left bank (E), March 21, 2001. Upper Meadow is in middle background, unnamed island with sandy cutoff channel in foreground Flow is approx. 1,900 cfs.

Figure B.4: Looking upstream (ENE), March 21, 2001. Ford Island is upper left, unnamed island lower right with sandy cutoff channel. Flow is approx. 1,900 cfs.

Figure B.5: Looking upstream (NE), March 21, 2001. Ford Island in middle right of photo, Bobby Island in middle left. Flow is approx. 1,900 cfs..

Figure B.6: Looking downstream (ENE), march 21, 2001. Ford Island in middle of photo. Flow approx. 1,900 cfs.