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Simulations of Flooding on the Tennessee River in the Vicinity of U.S. Highway 231 near Huntsville, Alabama

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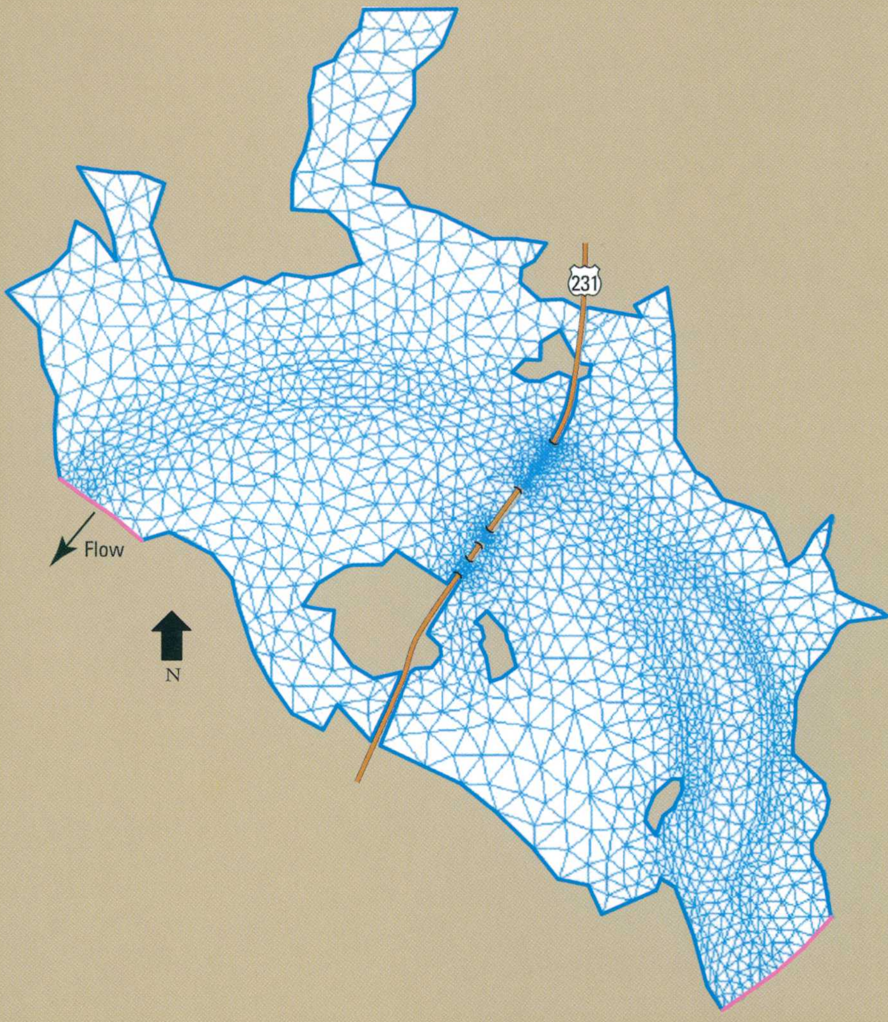
U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 01–4114



Prepared in cooperation with the
ALABAMA DEPARTMENT OF TRANSPORTATION

U.S. Department of the Interior
U.S. Geological Survey

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By T.S. Hedgecock

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Montgomery, Alabama
2001

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS and VERTICAL DATUM

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per second (ft/s)	0.3048	meter per second
foot squared per second (ft^2/s)	0.0929	meter squared per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD) of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

A two-dimensional finite-element surface-water model was used to study the effects of proposed modifications to the U.S. Highway 231 corridor on water-surface elevations and flow distributions during flooding in the Tennessee River Basin south of Huntsville, Madison County, Alabama. Flooding was first simulated for the March 19, 1973, flood for the existing conditions in order to calibrate the model to measured data collected by the U.S. Geological Survey (USGS) and the Tennessee Valley Authority (TVA) during and after the flood. After model calibration, the effects of flooding were simulated for two scenarios—existing and proposed conditions—for the 100-year and 500-year recurrence intervals. The first scenario was to simulate the existing bridge and highway configuration for the U.S. Highway 231 crossing of the Tennessee River flood plain. The second scenario was to simulate the proposed modifications to this bridge and highway configuration.

The simulation of floodflow for the Tennessee River flood of March 19, 1973, in the study reach compared closely to discharge measurement and flood profile data obtained during and after the flood. The flood of March 19, 1973, had an estimated peak discharge of 323,000 cubic feet per second and was estimated to be about a 50-year flood event.

Simulation of the 100-year floodflow for the Tennessee River for the existing conditions at U.S. Highway 231 indicates that of the peak flow, 92.1 percent (316,500 cubic feet per second) was conveyed by the main channel bridge, 4.0 percent (13,800 cubic feet per second) by the northernmost relief bridge, and 3.8 percent (13,200 cubic feet per second) by the southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 576.91 feet. No overtopping of U.S. Highway 231 occurred. For the 500-year flood, the simulation indicates that of the peak flow, 89.2 percent (359,000 cubic feet per second) was conveyed by the main channel bridge, 5.6 percent (22,600 cubic feet per second) by the northernmost relief bridge, and 5.2 percent (20,900 cubic feet per second) by the southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 580.91 feet. No overtopping of U.S. Highway 231 occurred; however, the girders of both relief bridges were partially submerged.

Simulation of the 100-year floodflow for the Tennessee River for the proposed conditions indicates that of the peak flow, 93.2 percent (319,800 cubic feet per second) was conveyed by the proposed main channel bridge, 3.3 percent (11,400 cubic feet per second) by the proposed northernmost relief bridge, and 3.4 percent (11,800 cubic feet per second) by the proposed southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 576.93 feet. No overtopping of U.S. Highway 231 occurred. For the 500-year flood, the simulation indicates that of the peak

flow, 90.9 percent (365,400 cubic feet per second) was conveyed by the proposed main channel bridge, 4.3 percent (17,300 cubic feet per second) by the proposed northernmost relief bridge, and 4.8 percent (19,400 cubic feet per second) by the proposed southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 580.93 feet. No overtopping of U.S. Highway 231 occurred; however, the girders of both relief bridges were partially submerged.

INTRODUCTION

The hydraulic performance of bridges during floods is a major concern when the opening and grade of drainage structures are designed. In the case of multiple bridge openings, it is important to know the distribution of discharge through the bridges for an efficient hydraulic design. The Alabama Department of Transportation (DOT) plans to replace the existing bridges on the U.S. Highway 231 crossing of the Tennessee River flood plain [Project Number BRF–310(17)]. U.S. Highway 231 presently crosses the Tennessee River flood plain at an average angle (skew) of less than 10 degrees and consists of three dual-bridge openings; one main channel bridge and two relief bridges (fig. 1). Although the crossing has a small skew, it occurs in a major river bend (fig. 2) that complicates the flood hydraulics at the site. Because of the complexity of this site and the two-dimensional nature of the flow, a two-dimensional flow model will best serve to determine the effects of the proposed modifications to the U.S. Highway 231 corridor on flooding. In 2000, the U.S. Geological Survey (USGS) in cooperation with the Alabama DOT, analyzed the flood hydraulics of the Tennessee River at the U.S. Highway 231 crossing. This study will serve as an aid to other States and municipalities that encounter complex flow hydraulics near bridges.

Purpose and Scope

This report presents results of simulated floods having 100-year and 500-year recurrence intervals for both the existing and proposed conditions, as well as results of the simulated March 19, 1973, flood. Discharge, discharge distribution, water-surface elevation, and velocity data are given at various locations of interest throughout the study reach. Other topics discussed include the following: evaluation of hydrology, collection of survey data, development of a computational grid, selection of flow model, simulation of floodflows, calibration, and validation of the model.

Acknowledgments

The assistance of Mr. Tom Flournoy, Alabama DOT Hydraulic Engineer, and personnel of the Location Section of the Alabama DOT Design Bureau is greatly appreciated. Also, the assistance of several Alabama District USGS personnel was very instrumental in the collection of survey data used for this project.

DESCRIPTION OF STUDY AREA

The study reach is located in southern Madison County and northeastern Morgan County (fig. 3) about 9 mi south of the city of Huntsville. The Tennessee River drains 25,610 mi^2 at U.S. Highway 231 (Pearman and others, 2000). The USGS has operated a gaging station (03575500 Tennessee River at Whitesburg; fig. 1) about 3,100 ft upstream of this crossing since 1924. The study reach includes approximately a 10-mi reach of the Tennessee River flood plain, extending from about 1.1 river miles upstream of the southern tip of Hobbs Island to about 6 river miles downstream of U.S. 231. The width of the flood plain ranges from about 2.5 mi in the vicinity of Hobbs Island to just under 0.5 mi at the downstream end of the study reach. The Tennessee River flows in a north-northwesterly direction from the upstream end of the study reach toward U.S. Highway 231 and bends to the west just past this crossing. About 2 mi downstream from U.S. Highway 231, the river continues to bend and flows to the southwest to the downstream end of the study reach.

The average slope of the basin in the study reach is about 0.5 ft/mi. The Tennessee River Basin is characterized as flat, mostly open land with minimal tree cover and vegetative undergrowth. The majority of the flood plain in the study reach is farm land used for row crops. However, part of the overbank area consists of thick, vegetated swamps and dense woodlands, especially in the downstream third of the study reach.

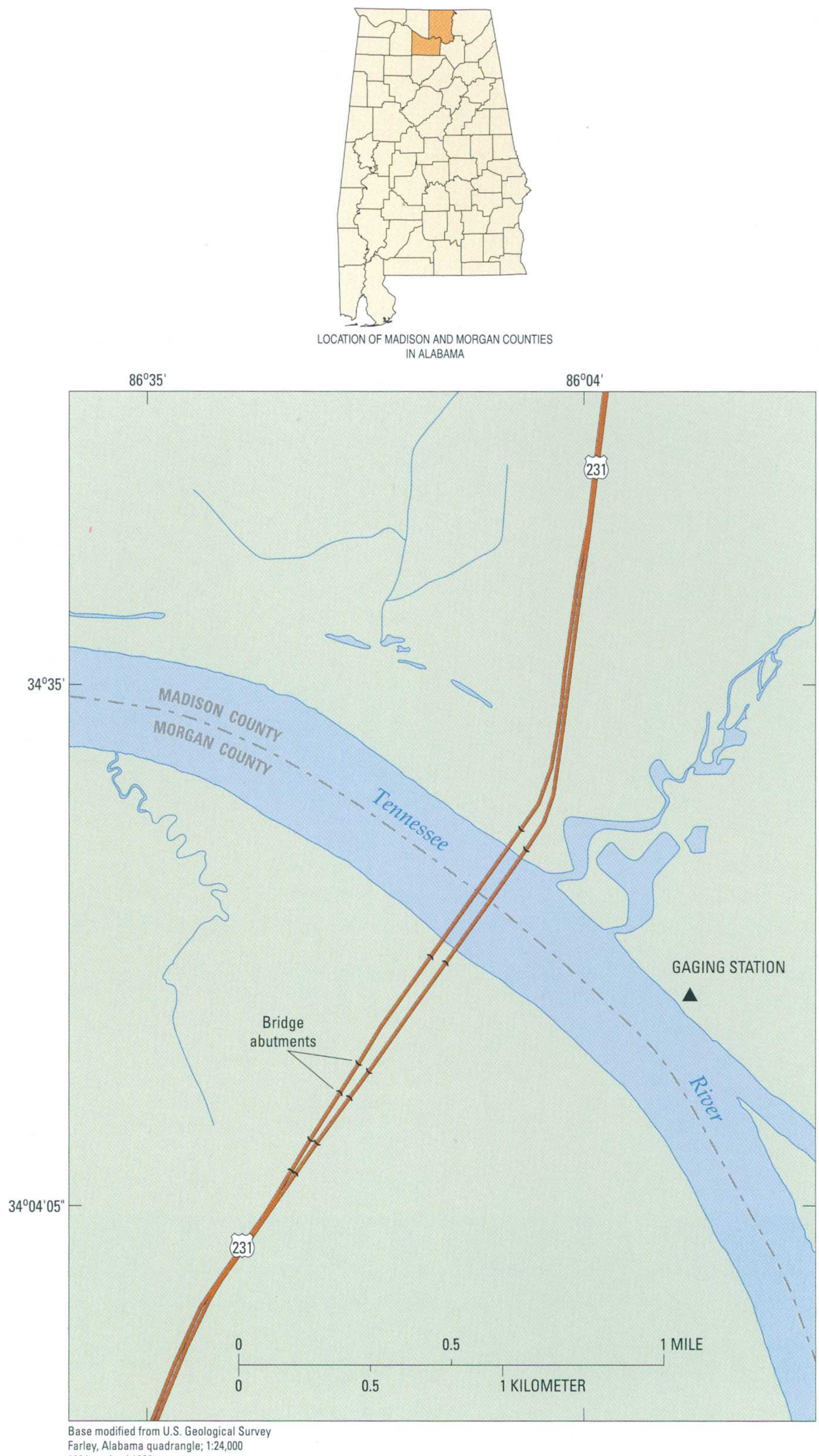
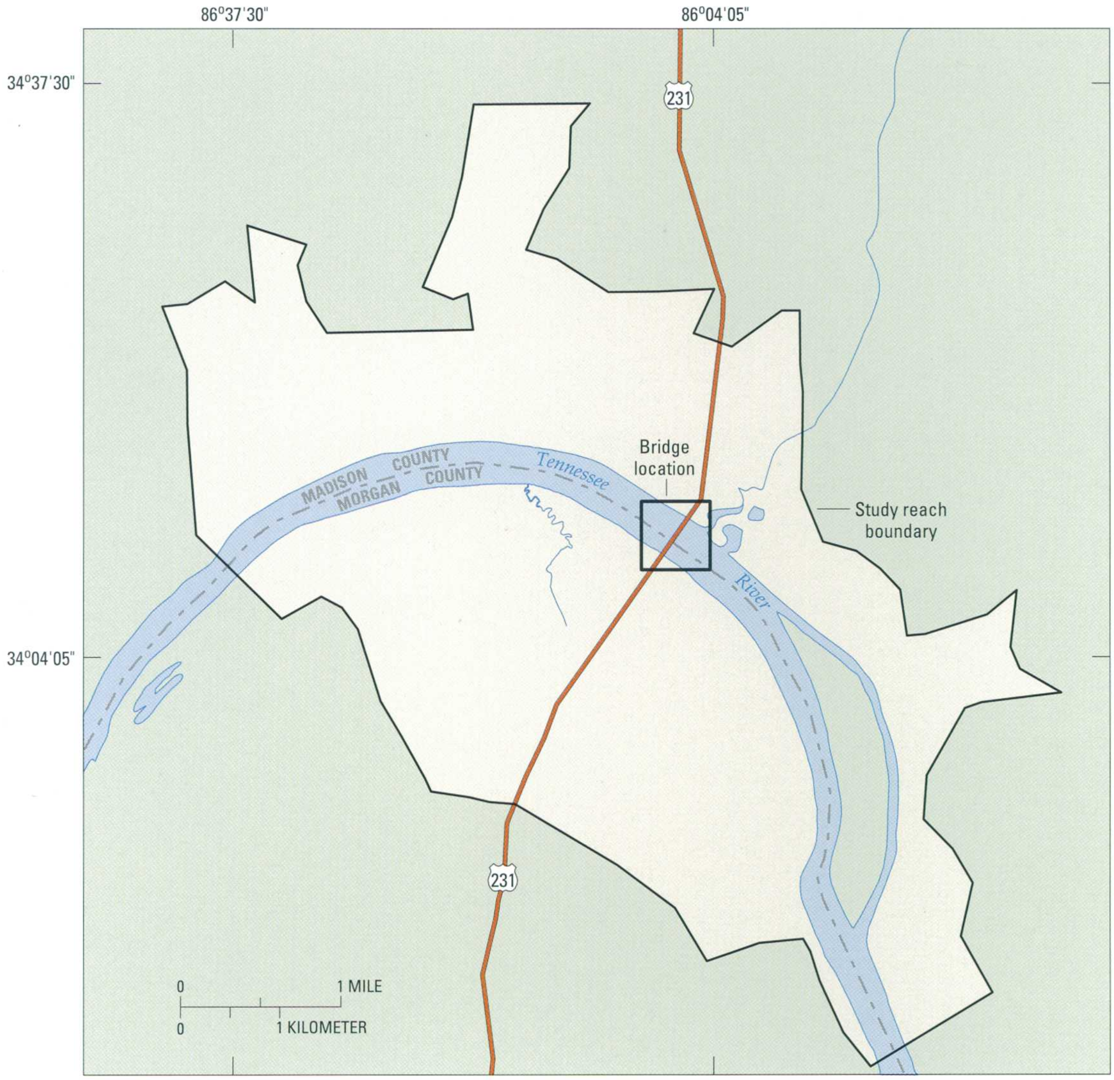


Figure 1. Existing highway alignment and bridge scheme for the U.S. Highway 231 crossing of the Tennessee River flood plain.



Base modified from U.S. Geological Survey
Farley, Alabama quadrangle; 1:24,000
1964, revised 1982

Figure 2. Tennessee River two-dimensional model study reach.

Figure 3. Proposed bridge replacement project.

The river channel is well defined, clear, and varies in width from about 1,600 ft in the vicinity of U.S. Highway 231 to about 900 ft at the downstream end of the study reach. The Tennessee River is classified as a wide, perennial, regulated stream that is used for flood control, power generation, navigation, and recreation.

Existing Conditions

U.S. Highway 231 is a four-lane divided highway with northbound and southbound lanes that cross the Tennessee River flood plain at an average angle (skew) of less than 10 degrees (fig. 1). This crossing occurs in a river bend and consists of one main channel bridge and two relief bridges for each lane. The existing bridge openings have spillthrough-type abutments, sloping embankments, and no wingwalls. The bridge lengths are 1,850 ft for the main channel bridge, 442 ft for the northernmost of the two relief bridges, and 476 ft for the southernmost relief bridge. A major contraction naturally occurs in the channel and flood plain about 3 mi downstream from the bridge crossing. This contraction increases and controls water-surface elevations throughout the reach during high floodflows.

Proposed Conditions

The Alabama DOT plans to replace the existing bridges at the U.S. Highway 231 crossing of the Tennessee River flood plain. Proposed plans include a conversion to a six-lane divided highway constructed on approximately the same highway alignment. Each of the proposed bridge openings will have spillthrough-type abutments, sloping embankments, and no wingwalls. The proposed bridge lengths are 2,100 ft for the main channel bridge, 315 ft for the northernmost relief bridge, and 315 ft for the southernmost relief bridge.

Hydrology

A flood frequency relation was developed for the site by the Tennessee Valley Authority (TVA) for a Federal Emergency Management Agency (FEMA) flood study. Discharges from the FEMA study for the 100-year and 500-year floods were used for this study. Procedures used in the development of this flood frequency are outlined in "Flood Insurance Study: Madison County, Alabama and Incorporated Areas" (Federal Emergency Management Agency, 1998). The 100- and 500-year flood discharges used for this study were 346,000 ft^3/s and 400,000 ft^3/s, respectively. Floodflows from unnamed tributaries in the study reach along with flows from Aldridge Creek, Bartee Branch, Long Pond Slough, Dry Creek, and Hambrick Slough were ignored due to the small relative size of these streams as compared to the Tennessee River. It was assumed that each of these tributaries would peak and recede well before river flooding would occur. Because of the large magnitudes of the floods simulated, the large contributing drainage area, and the relatively short study reach, sustained peak discharges are probable; therefore, steady-flow conditions were simulated.

MODELING APPROACH

Floodflow simulations for the study were based on a two-dimensional finite-element surface-water model. First, a computational grid representing the flow system for the existing conditions was constructed using an automated grid generator, digital topographic data (W.F. Adams, Alabama Department of Transportation, written commun., 2000), and flood-plain cross sections surveyed during April and May of 2000. This grid was then used as input into the two-dimensional finite-element flow model, and simulations were performed for the peak of March 19, 1973, the 100-year flood, and 500-year flood. This process was repeated for the 100- and 500-year floodflows for the proposed conditions. A plot of land-surface elevation contours for the study reach is shown in figure 4.

Model Description

The Finite Element Surface-Water Modeling System for Two-Dimensional Flow in the Horizontal Plane (FESWMS-2DH) (Froehlich, 1989) was selected as an appropriate model for simulating the two-dimensional flows within the study reach. The model uses the Galerkin finite-element method to solve three partial-differential equations representing conservation of mass and momentum (Lee and Froehlich, 1989). A depth-averaged velocity is computed at each computational point (node) in the model domain. The model area is divided into triangular sections

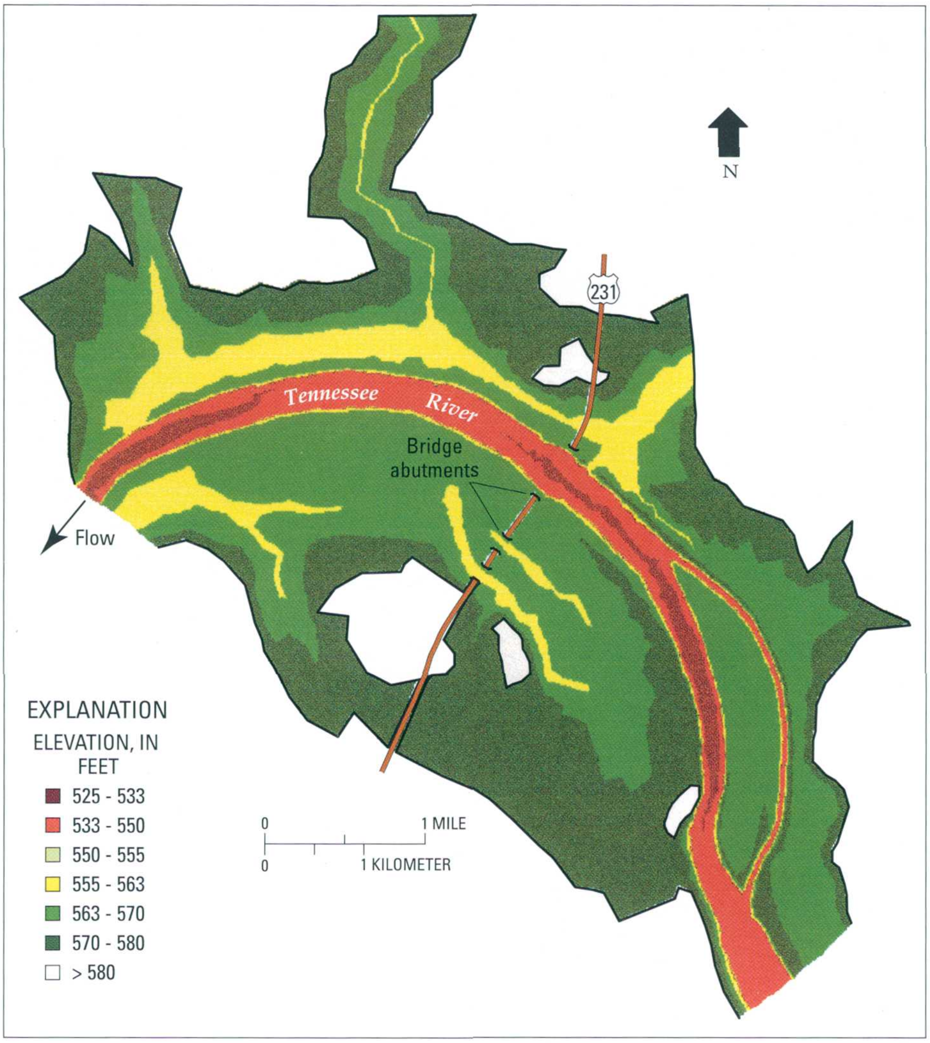


Figure 4. Land-surface elevations for study reach.

(elements) of variable size, which are better for fitting the model to physical features. Input data requirements can be put into three major categories:

1. **Geographical information.** Land-surface elevations for each element, and dimensions and locations of each element (as defined by the computational grid).
2. **Flow parameters.** Resistance coefficients for each element, possibly as a variable function of depth or velocity; also kinematic eddy viscosity.
3. **Boundary conditions.** Flow conditions at the edges of the model are either water-surface elevations or flux. Boundary conditions are required to execute the model.

The theory of the model is beyond the scope of this report; however, a detailed explanation of the theory is provided in the research report by Lee and Froehlich (1989).

Model Implementation

There are several steps involved in the application of a two-dimensional finite-element flow model. First, a finite-element grid representing the flow system must be constructed and tested for its integrity. Once a stable grid has been constructed, boundary conditions, such as water-surface elevation and(or) discharge, must be determined to execute the model. Finally, several model parameters and options must be considered before it can be determined which will produce the best results for floodflow simulations.

Computational Grid

The use of a finite-element model requires that the study reach be divided into elements that form a grid. In the case of a triangular grid, nodes are located at the corners and mid-sides of the elements and are assigned coordinates and elevations. A finite-element grid should be carefully designed so that mass is conserved within the system. The finite-element grid needs to be more refined (smaller elements) in areas where changes in velocity or bathymetry are substantial than in areas where changes are gradual. The software package GRIDGEN (R.R. McDonald, U.S. Geological Survey, oral commun., 1999) was used to construct the computational grids used to represent the flow system in this study. GRIDGEN is an automated grid generator that uses vertex triangulation methods in which vertices (nodes) are distributed through the model domain and then connected appropriately by a triangulation algorithm.The finite-element grid used for modeling the existing conditions consists of 3,193 elements and 6,688 nodes (fig. 5), while the grid for the proposed conditions has 3,290 elements and 6,891 nodes (fig. 6).

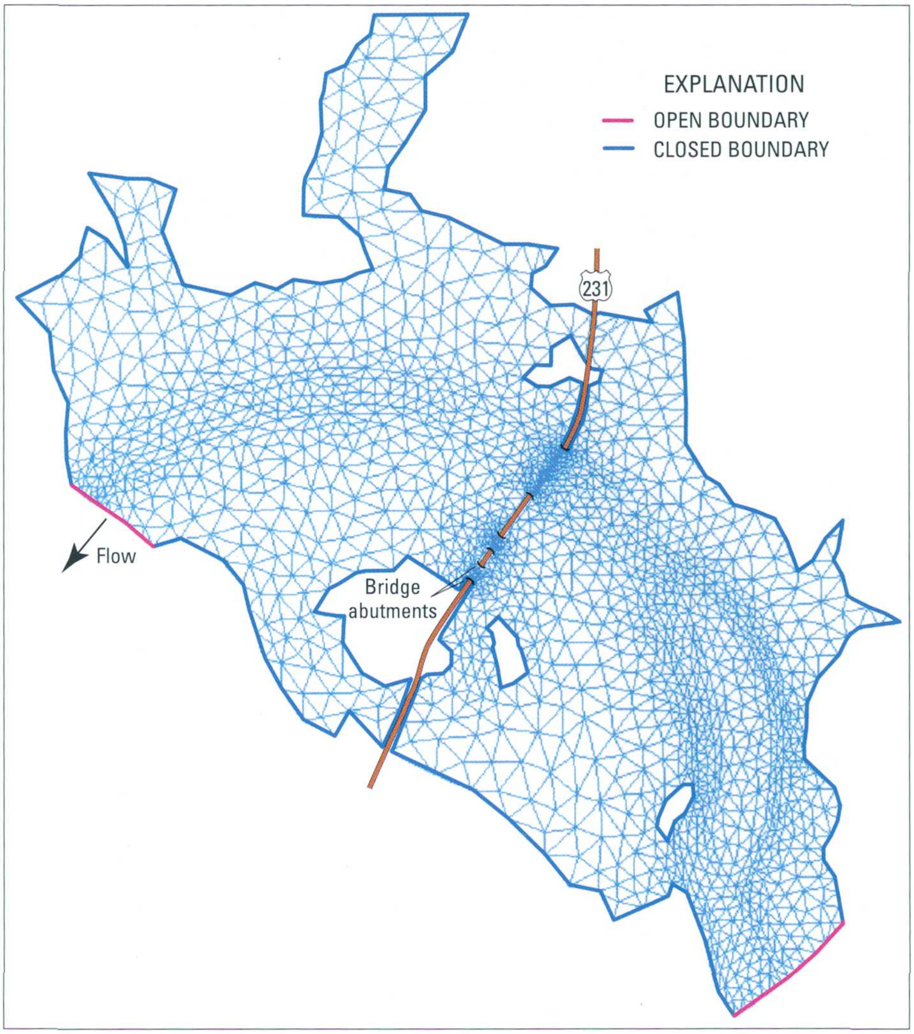


Figure 5. Finite-element grid used in flow simulations for existing conditions.

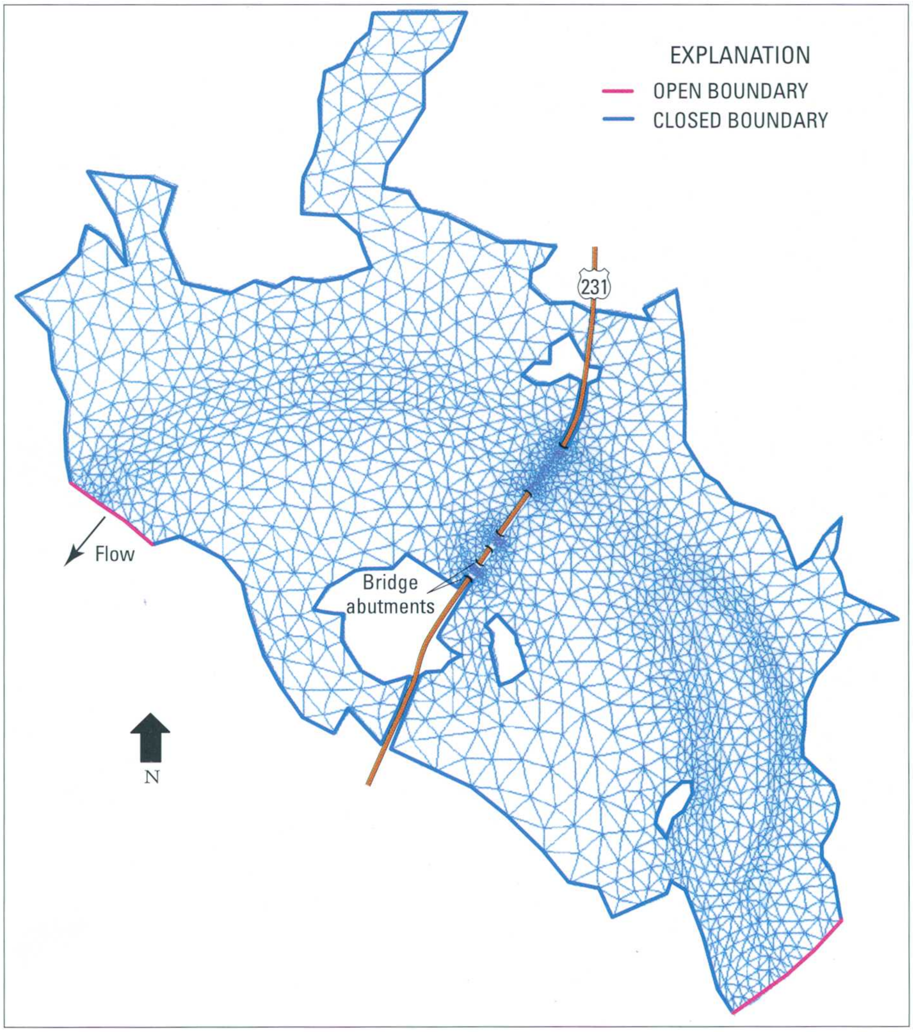


Figure 6. Finite-element grid used in flow simulations for proposed conditions.

Boundary Conditions

Boundary conditions are established around the perimeter of a finite-element network and are identified as either closed or open. Closed boundaries represent obstructions, such as shorelines, embankments, and levees, that do not allow flow to pass through. The locations of the closed boundaries representing the shorelines in this study were estimated using water-surface profiles surveyed by the TVA for the flood of March 19, 1973, and profiles determined from WSPRO [a one-dimensional step-backwater model used for computing water-surface profiles (Shearman, 1990)]. For the simulations in this study, all closed boundaries were set up for tangential slip condition, which forces all flow adjacent to the closed boundaries to flow parallel to the boundaries.

Open boundaries allow flow to enter or leave the finite-element network. In this study, open boundaries are located at the upstream and downstream ends of the Tennessee River study reach. The open boundary conditions at the upstream boundary are the discharges for the different flows being simulated. The open boundary conditions for the downstream end of the study reach are normal water-surface elevations estimated from either surveyed flood profiles or step-backwater computations. A downstream boundary condition of 573.0 ft was estimated from flood profiles furnished by the TVA for the flood of March 19, 1973.

The downstream boundary conditions computed using WSPRO are 574.9 ft and 579.0 ft for the 100- and 500-year floods, respectively. The WSPRO model used to compute these boundary conditions was first calibrated to match the flood profile for the 1973 flood for a flood-peak discharge of 323,000 ft^3/s. Once the one-dimensional flow model was calibrated, the 100- and 500-year floods were modeled in the step-backwater reach using the same energy slope and Manning's roughness coefficients. The step-backwater portion of the study reach was approximately 14,000 ft long (fig. 3).

Model Parameters

Several modeling parameters and options were considered and varied throughout the modeling process to ensure that the best simulation of floodflows was achieved. Manning's roughness coefficient (*n*) and base kinematic eddy viscosity (eq. 4–19, Froehlich, 1989) were the two primary model parameters varied throughout the modeling process. Manning's roughness coefficients were selected based on field investigations made during the spring of 2000 (fig. 7). Default values for all other modeling parameters were used for floodflow simulations. These parameters included the following: water density, air density, dimensionless turbulence coefficient, relaxation factor, depth tolerance, and coefficients used to compute the momentum correction coefficient. Additionally, a low-order numerical integration technique was performed for each simulation. Wind effects were ignored and a constant density was assumed (assumed flow was well mixed vertically). Any unsteady effects of the floodflow were ignored. Some of the modeling options that were considered were (1) steady-state versus time-dependent solution, (2) elements being "turned on" and "off" during a run versus elements being left "on" (Froehlich, 1989), and (3) varying the number of iterations to be performed to reach a converged solution.

Model Calibration and Validation

Calibration is the process of adjusting model input parameters so that model results closely compare to actual measured data. Data from the flood of March 19, 1973, were used as the calibration data for this study. These data include a flood profile furnished by the TVA, the recorded peak gage height upstream of the crossing, and a discharge measurement made at the site by the USGS just prior to the peak. The model input parameters adjusted during model simulation were Manning's roughness coefficients and base kinematic eddy viscosity. These parameters were adjusted until the computed water-surface elevations and flow distributions closely matched the measured data from the 1973 flood. The proper technique for validating a calibrated model is to simulate a separate hydraulic event for which the discharge and water-surface elevations are known independent of the original event. If no model parameters are adjusted to reach a solution comparable to the recorded data for the independent event, the model is commonly considered well calibrated for a limited range of discharges. Since there was no other recorded event with sufficient data for comparison, it was not possible to validate the model.

Sensitivity Analysis

The sensitivity of model results to changes in model parameters was observed. Mannings roughness coefficients and base kinematic eddy viscosity were adjusted from the original values used in the initial convergence of the model. Changes in Mannings *n* for elements in the overbank areas had minimal effects on the model results. Manning's *n* for overbank elements was varied by 25 percent, resulting in less than 0.1 ft change in computed water-surface elevations at the bridge openings and upstream end of the study reach. Changes in Manning's *n* in the channel, however, had a more significant effect. Mannings *n* was varied between 0.022 and 0.027, resulting in an increase of about 0.7 ft in computed water-surface elevations at the bridge openings and upstream end of the study reach. Changes in base kinematic eddy viscosity had somewhat significant effects on the solution. For each floodflow simulation, a beginning base kinematic eddy viscosity of 150 ft^2/s was used. Once a converged solution was reached for the targeted boundary conditions, the base kinematic eddy viscosity was lowered in a series of steps to a value of 10 ft^2/s. For base eddy viscosities between 150 and 30 ft^2/s, significant changes were observed in the solution (about 0.9 ft) at the upstream end of the study reach. For base eddy viscosities between 30 and 10 ft^2/s, however, no significant changes were observed in the solution (less than 0.1 ft) at the upstream boundary. Finally, the sensitivity of model output to grid density (spatial convergence) was analyzed. Grid refinement

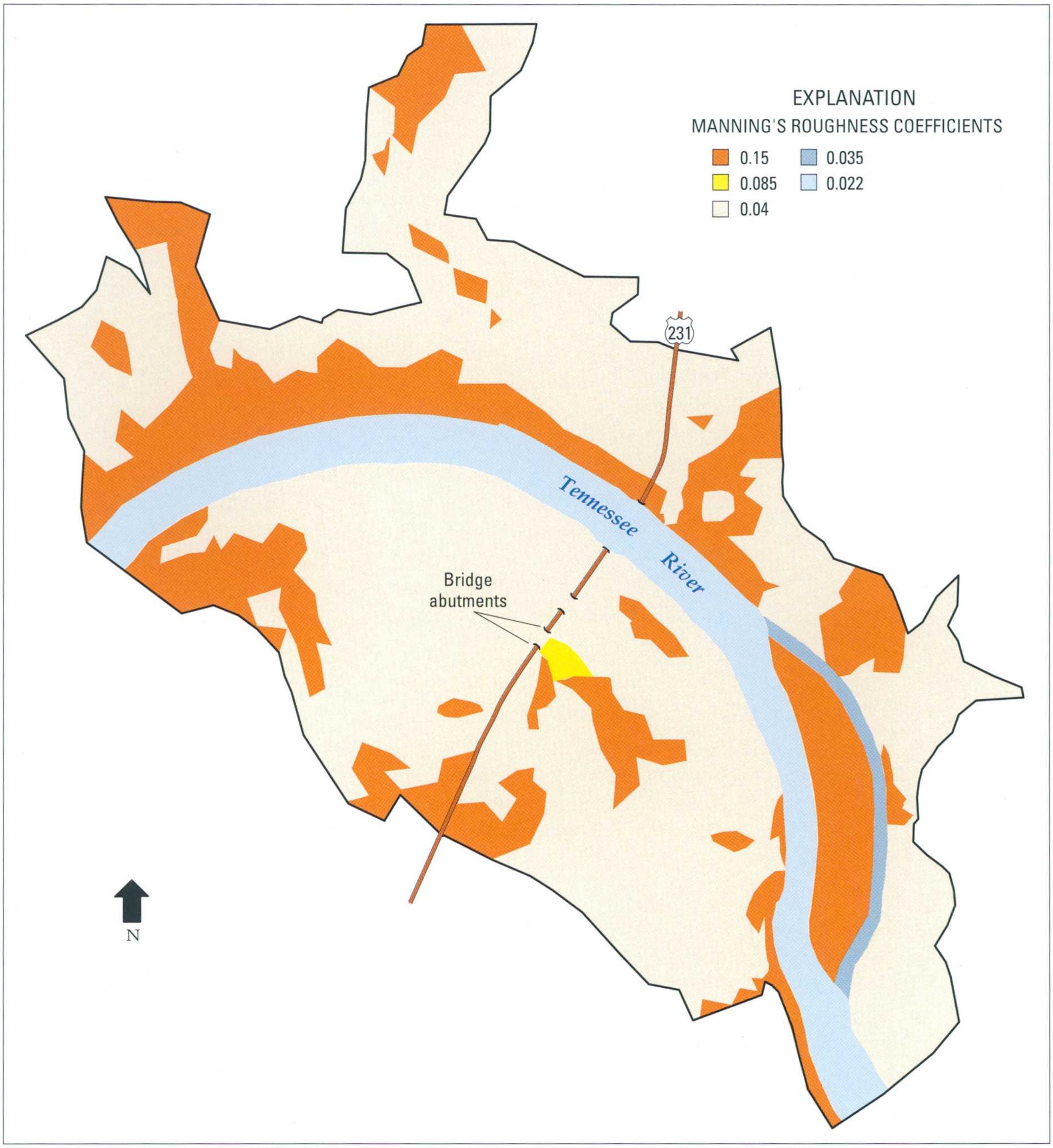


Figure 7. Manning's roughness coefficients used in Tennessee River study reach.

was performed by subdividing each triangular element into four similar elements. The 1973 flood simulation utilized 12,816 elements and 26,214 nodes with the refined grid. On average, the simulated discharges computed for each of the U.S. Highway 231 bridges agreed within 7.5 percent of the results obtained when using the original grid. When using the refined grid, the computed water-surface elevations agreed within 0.03 ft of the water-surface elevations computed at the bridge openings using the original grid. Because the results obtained when using the refined grid agreed reasonably close to those obtained when using the original grid, it was concluded that the original grid was adequate for flow simulations in this study.

SIMULATION OF FLOODFLOWS

Floodflows for the 100- and 500-year floods were simulated for both the existing and proposed conditions. The 100- and 500-year flood discharges were simulated because hydraulic structures are designed by the Alabama DOT to meet Federal, State, and local guidelines. These guidelines require the design of a hydraulic structure to adequately pass the 100-year flood such that backwater is not excessively increased. Additionally, these guidelines require that theoretical scour be computed for the proposed hydraulic structures for the 100- and 500-year floods. Prior to the simulation of the 100- and 500-year floodflows, the flood of March 19, 1973, was simulated for existing conditions to calibrate the model to an actual recorded event.

Flood of March 19, 1973

Floodflow was simulated depicting the Tennessee River flood of March 19, 1973, in the study reach. This simulation was performed with the present land and highway configuration in place, including the present embankments and bridge openings for the U.S. Highway 231 corridor. The estimated flood discharge for the 1973 flood at the gage was 323,000 ft^3/s, which is very close to the 50-year flood (325,000 ft^3/s) published in the FEMA study. This flood has a 2 percent chance of being equaled or exceeded in any given year. During the March 1973 flood, the average depth in the channel in the vicinity of U.S. Highway 231 was about 36 ft, whereas the average depth in the overbank areas was about 8 ft. No overtopping of U.S. Highway 231 occurred.

Simulation of the March 1973 floodflow indicates that of the peak flow, 93.4 percent (299,000 ft^3/s) was conveyed by the main channel bridge, 3.4 percent (11,000 ft^3/s) by the northernmost relief bridge, and 3.2 percent (10,200 ft^3/s) by the southernmost relief bridge. This flow distribution compares closely to the distribution measured at a discharge of 313,000 ft^3/s just prior to the peak. From these discharge measurement records, 93 percent of the flow (291,000 ft^3/s) was conveyed by the main channel bridge, 3.8 percent (11,800 ft^3/s) by the northernmost relief bridge, and 3.2 percent (10,200 ft^3/s) by the southernmost relief bridge. The water-surface elevation predicted by the flow model for the March 1973 flood in the vicinity of the USGS gaging station (approximately 3,100 ft upstream of U.S. Highway 231) was 575.09 ft. This compares closely to the recorded peak gage height of 575.06 ft. Finally, the maximum point velocities predicted for the bridges were 7.9 ft/s for the main channel bridge, 2.9 ft/s for the northernmost relief bridge, and 2.4 ft/s for the southernmost relief bridge. From the discharge measurement records, the maximum point velocities measured just prior to the peak were 7.7 ft/s for the main channel bridge, 3.3 ft/s for the northernmost relief bridge, and 3.0 ft/s for the southernmost relief bridge. A complete tabulation of the hydraulic data for the March 1973 flood for the existing bridges is presented in table 1. A plot of computed water-surface elevations for the March 1973 flood for existing conditions is

Table 1. Simulation of March 1973 flood

[Input discharge=323,000 cubic feet per second (ft^3/s); peak stage recorded was 575.06 feet (ft) at gage; measured discharge=313,000 (ft^3/s) at gage height of 574.53 ft for the March 1973 flood; peak gage height predicted by finite-element surface-water modeling system (FESWMS)=575.09 ft; VMAX, maximum point velocity in feet per second (ft/s)]

Bridge	FESWMS discharge (ft^3/s)	Percent of total FESWMS flow	Measured[a] discharge (ft^3/s)	Percent of total measured flow	FESWMS downstream stage (ft)	VMAX FESWMS (ft/s)	VMAX measured (ft/s)
Main channel	299,000	93.4	291,000	93.0	574.86	7.9	7.7
Northernmost relief	11,000	3.4	11,800	3.8	574.79	2.9	3.3
Southernmost relief	10,200	3.2	10,200	3.2	574.79	2.4	3.0
Total	320,200[b]		313,000				

[a]Measured prior to peak.

[b]Difference between total bridge discharge and total input discharge is due to small, local mass conservation errors (Lee and Froehlich, 1989).

shown in figure 8. A plot of corresponding velocity contours is shown in figure 9, and plots of computed velocity contours and velocity vectors in the vicinity of U.S. Highway 231 are shown in figures 10–13.

100-Year Flood

Floodflows were simulated depicting the Tennessee River 100-year flood for the existing and proposed conditions. The estimated 100-year flood discharge at the site is 346,000 ft^3/s (Federal Emergency Management Agency, 1998). This flood has a 1 percent chance of being equaled or exceeded in any given year. During the 100-year flood, the average depth in the channel in the vicinity of U.S. Highway 231 was about 38 ft, whereas the average depth in the overbank areas was about 10 ft. No overtopping of U.S. Highway 231 occurred.

Existing Conditions

Simulation of the 100-year floodflow for the Tennessee River for the existing conditions at U.S. Highway 231 indicates that of the peak flow, 92.1 percent (316,500 ft^3/s) was conveyed by the main channel bridge, 4.0 percent (13,800 ft^3/s) by the northernmost relief bridge, and 3.8 percent (13,200 ft^3/s) by the southernmost relief bridge. The water-surface elevation predicted near the USGS gaging station was 576.91 ft and plots within 3 percent of a linear extension of the rating curve for the gage

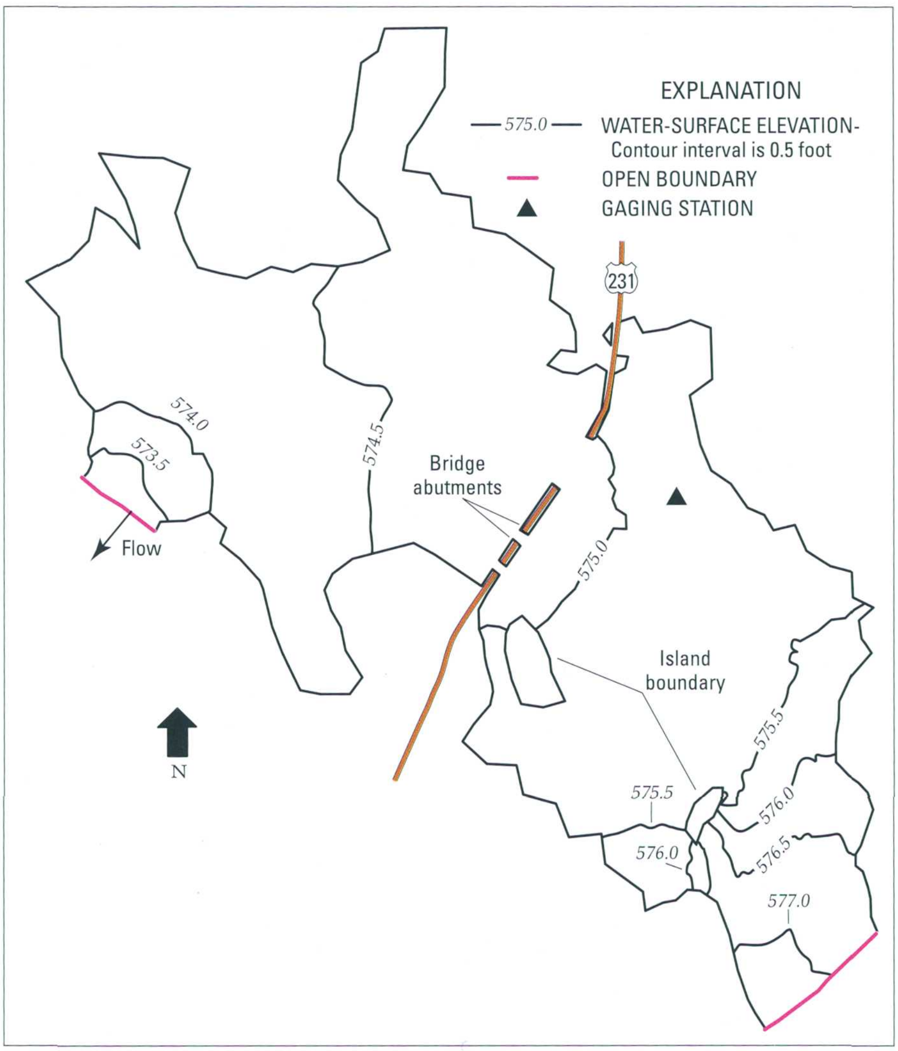


Figure 8. Computed water-surface elevations for March 1973 flood.

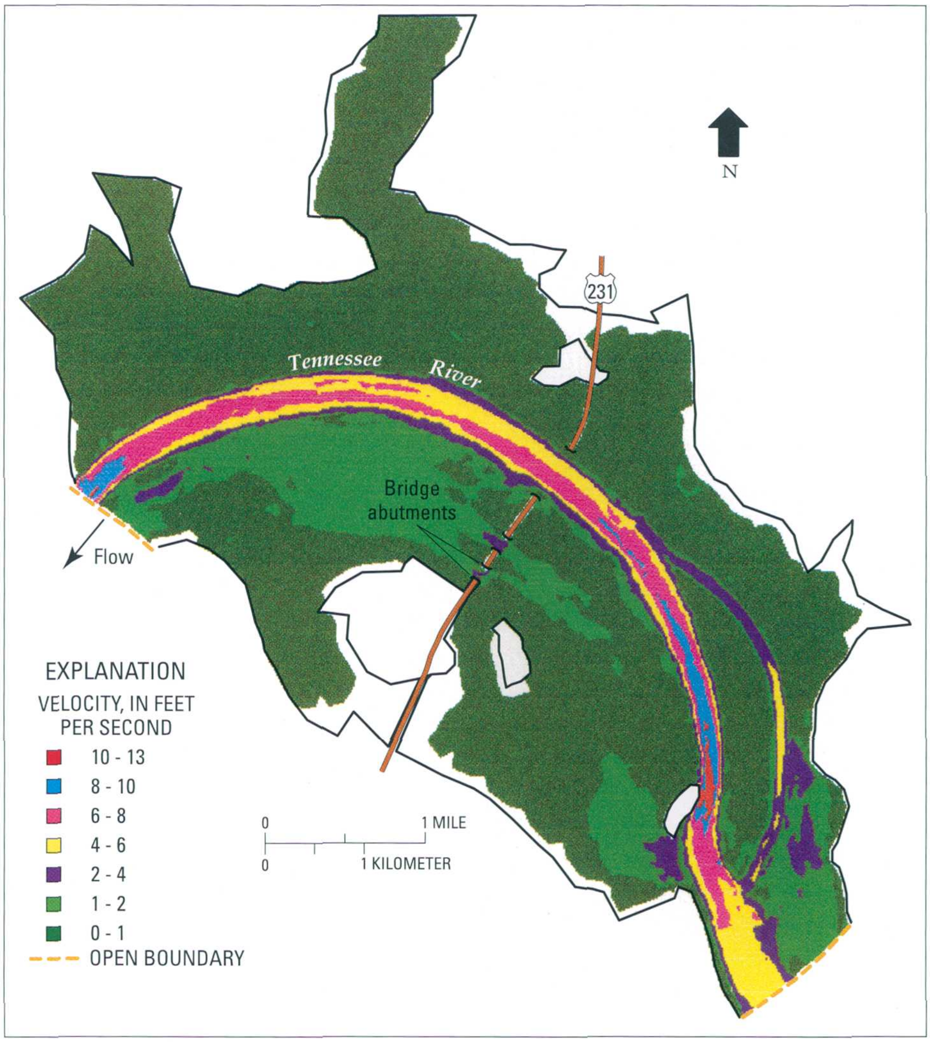


Figure 9. Computed velocity contours for March 1973 flood.

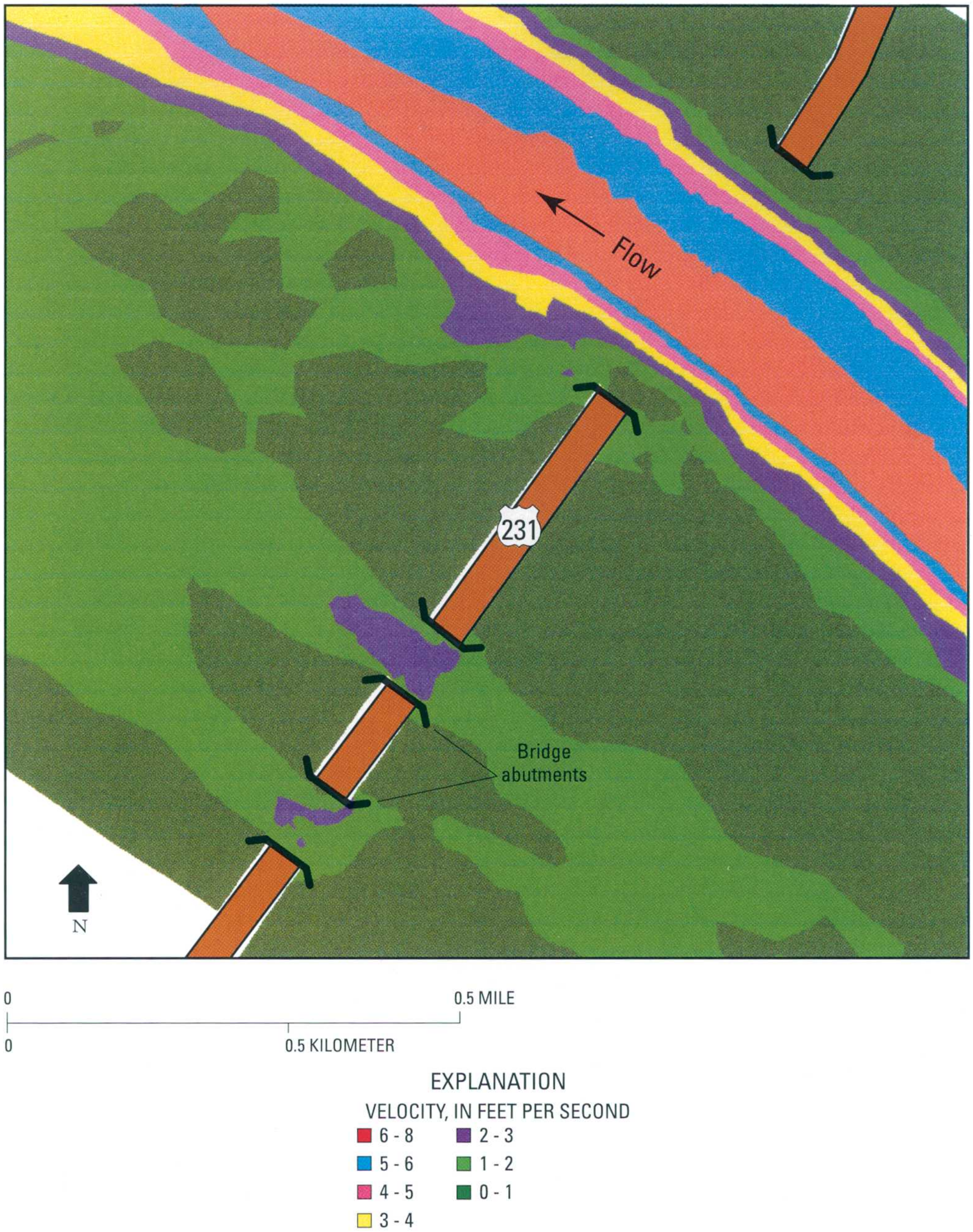


Figure 10. Computed velocity contours for March 1973 flood for existing bridge crossing.

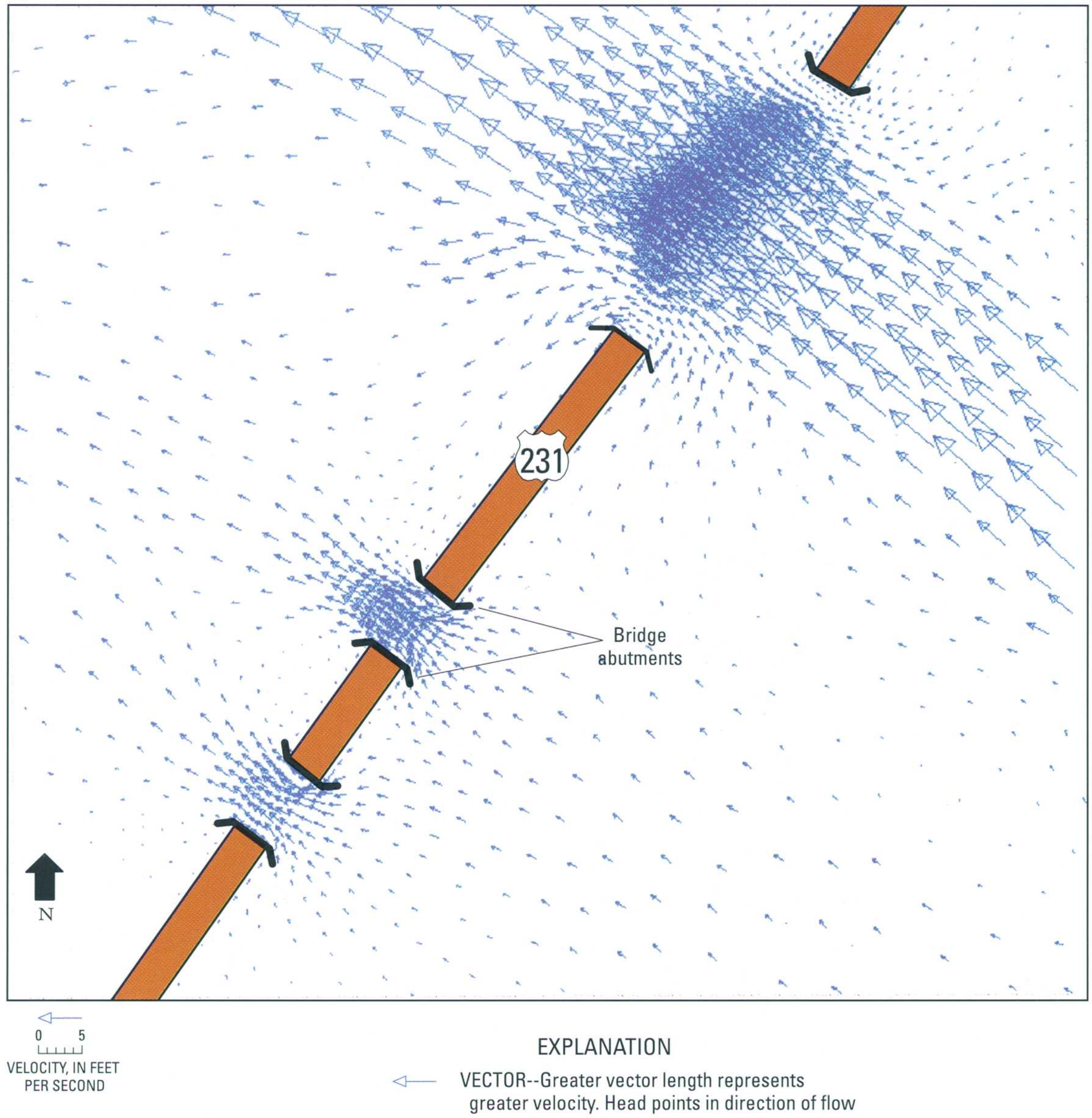


Figure 11. Computed velocity vectors for March 1973 flood for existing bridge crossing.

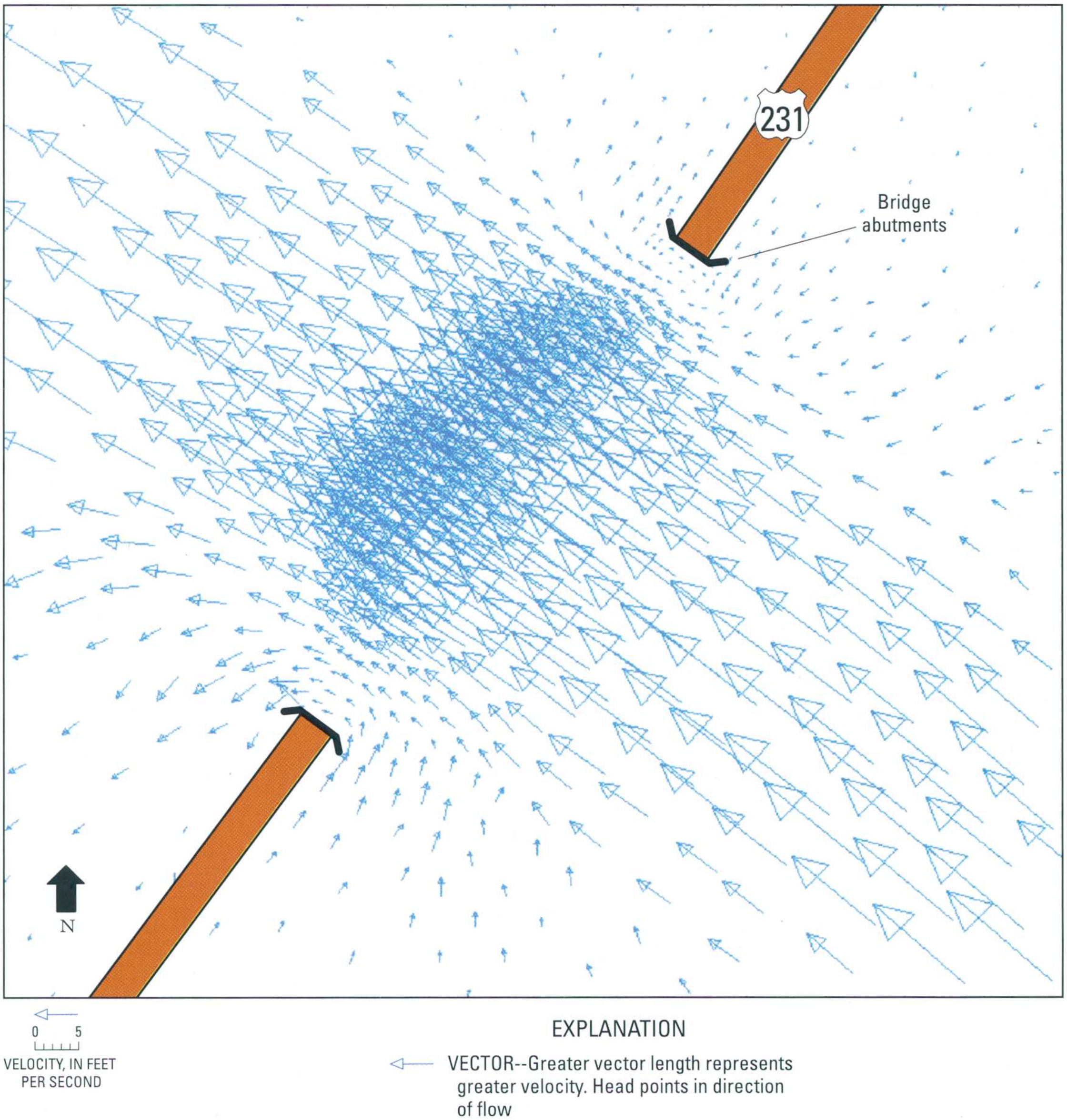


Figure 12. Computed velocity vectors for March 1973 flood for the existing main channel bridge.

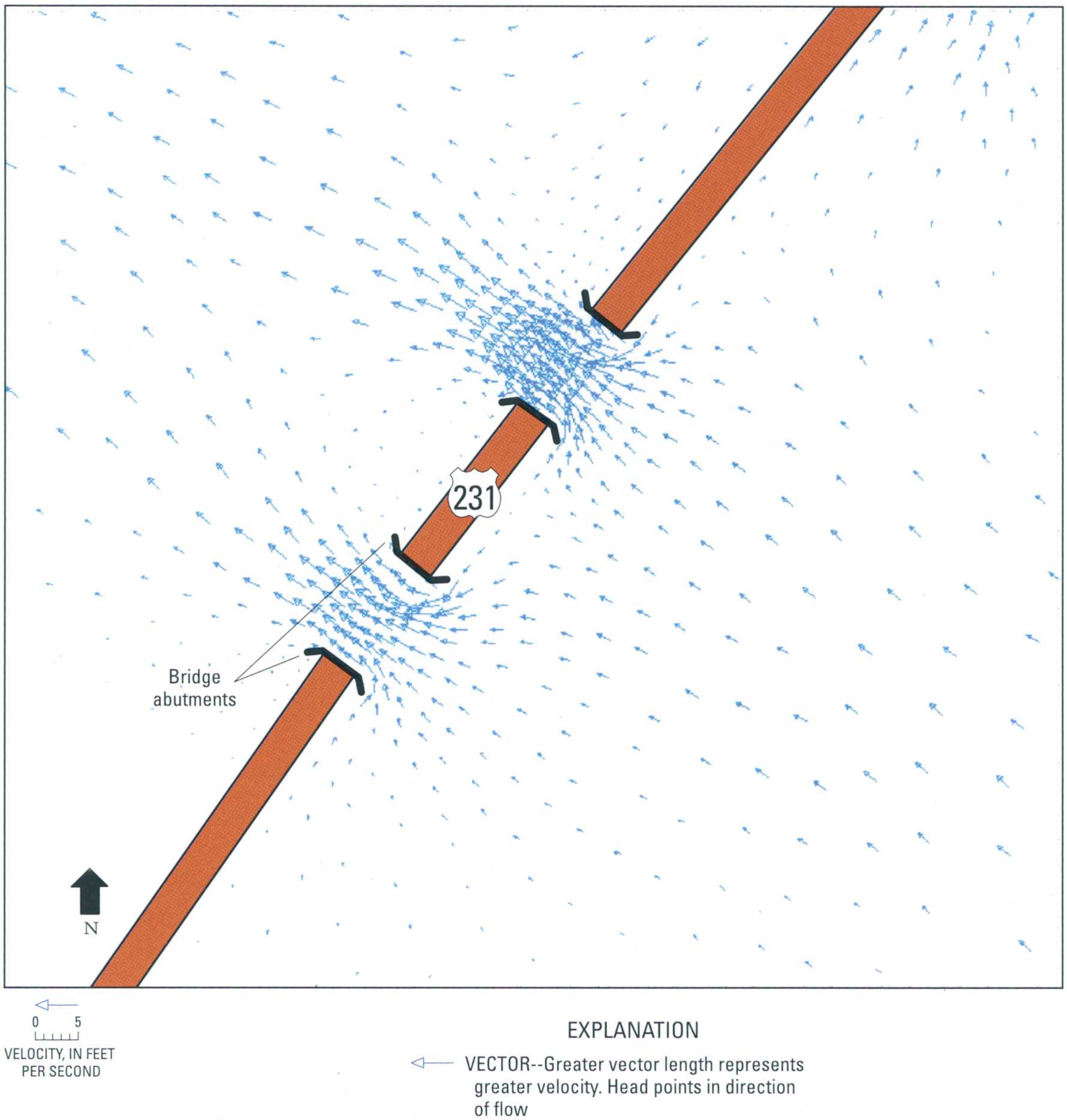


Figure 13. Computed velocity vectors for March 1973 flood for the existing relief bridges.

(fig. 14). The maximum point velocities predicted for the bridges were 7.8 ft/s for the main channel bridge, 3.2 ft/s for the northernmost relief bridge, and 2.7 ft/s for the southernmost relief bridge. No overtopping of U.S. Highway 231 occurred. A plot of computed water-surface elevations for the 100-year flood for the existing conditions is shown in figure 15. A plot of corresponding velocity contours is shown in figure 16, and a plot of computed velocity contours in the vicinity of U.S. Highway 231 is shown in figure 17.

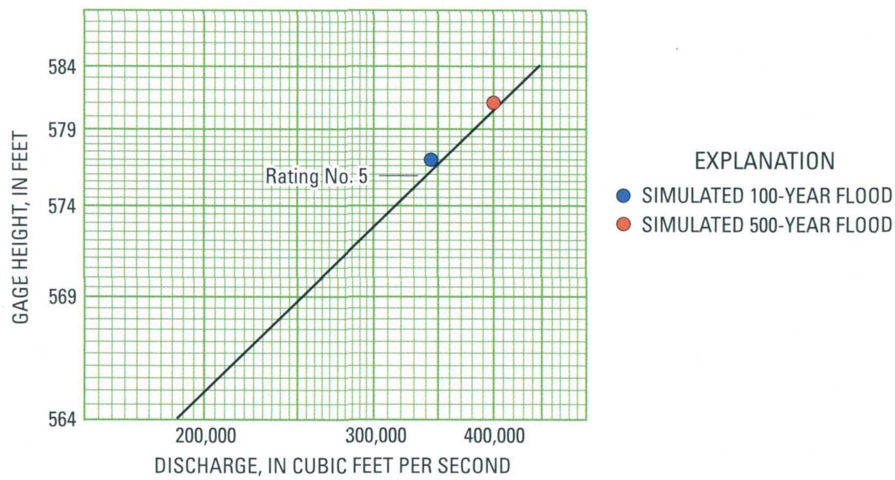


Figure 14. Rating curve for 03575500 Tennessee River at Whitesburg.

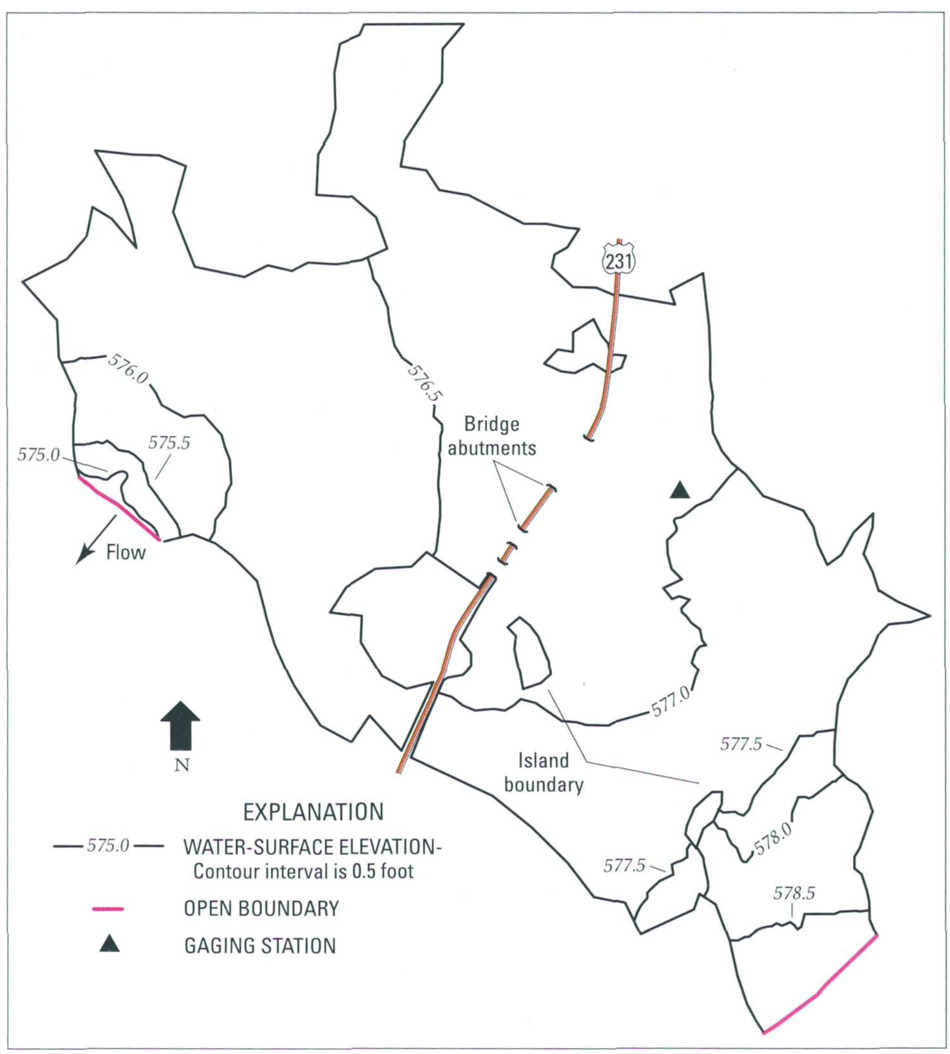


Figure 15. Computed water-surface elevations for 100-year flood for existing conditions.

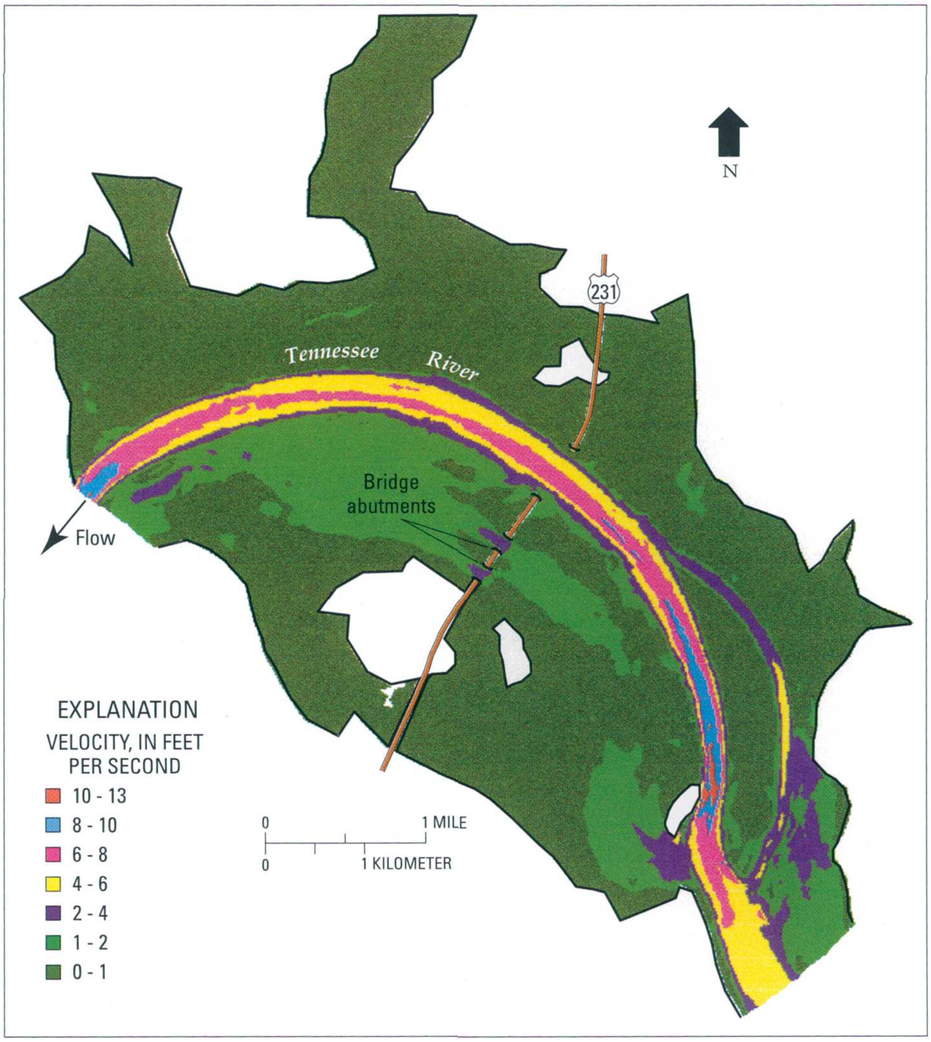


Figure 16. Computed velocity contours for 100-year flood for existing conditions.

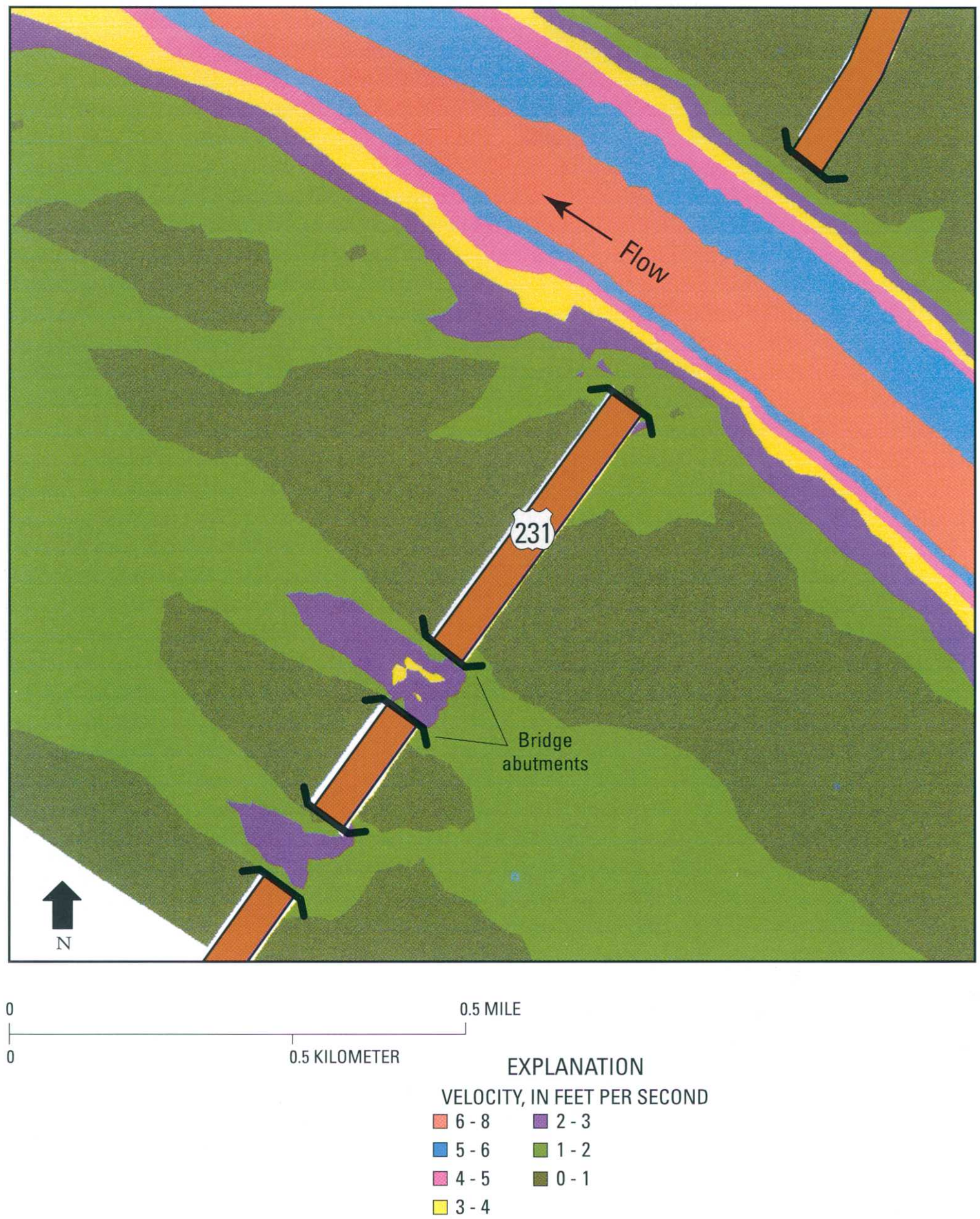


Figure 17. Computed velocity contours for 100-year flood for existing bridge crossing.

Proposed Conditions

Simulation of the 100-year floodflow for the Tennessee River for the proposed conditions indicates that of the peak flow, 93.2 percent (319,800 ft^3/s) was conveyed by the proposed main channel bridge, 3.3 percent (11,400 ft^3/s) by the proposed northernmost relief bridge, and 3.4 percent (11,800 ft^3/s) by the proposed southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 576.93 ft, about 0.02 ft higher than that computed for the existing conditions. The maximum point velocities predicted for the bridges were 7.8 ft/s for the main channel bridge, 3.5 ft/s for the northernmost relief bridge, and 3.5 ft/s for the southernmost relief bridge. For each bridge mentioned above, average downstream and approach water-surface elevations were estimated by taking the average of the water-surface elevations at a group of nodes on a line at the location of interest. Approach elevations were selected from nodes about one bridge length upstream from each bridge. The average water-surface elevation about one bridge length upstream from the proposed bridges was about 0.04 ft higher than that computed for the existing conditions. No overtopping of U.S. Highway 231 occurred. A complete tabulation of the hydraulic data for the 100-year flood for the bridges mentioned above is presented in tables 2–4. A plot of computed velocity contours in the vicinity of U.S. Highway 231 is shown in figure 18.

Table 2. Simulation of 100-year flood for existing conditions

[Input discharge=346,000 cubic feet per second (ft^3/s); gage height predicted by finite-element surface-water modeling system (FESWMS)=576.91 feet (ft); VMAX, maximum point velocity in feet per second (ft/s)]

Bridge	Length (ft)	FESWMS discharge (ft^3/s)	Percent of total FESWMS flow	FESWMS downstream stage (ft)	VMAX FESWMS (ft/s)
Main channel	1,850	316,500	92.1	576.63	7.8
Northernmost relief	442	13,800	4.0	576.58	3.2
Southernmost relief	476	13,200	3.8	576.58	2.7
Total		343,500[a]			

[a]Difference between total bridge discharge and total input discharge is due to small, local mass conservation errors (Lee and Froehlich, 1989).

Table 3. Simulation of 100-year flood for proposed conditions

[Input discharge=346,000 cubic feet per second (ft^3/s); gage height predicted by finite-element surface-water modeling system (FESWMS)=576.93 feet (ft); VMAX, maximum point velocity in feet per second (ft/s)]

Bridge	Length (ft)	FESWMS discharge (ft^3/s)	Percent of total FESWMS flow	FESWMS downstream stage (ft)	VMAX FESWMS (ft/s)
Main channel	2,100	319,800	93.2	576.62	7.8
Northernmost relief	315	11,400	3.3	576.56	3.5
Southernmost relief	315	11,800	3.4	576.56	3.5
Total		343,000[a]			

[a]Difference between total bridge discharge and total input discharge is due to small, local mass conservation errors (Lee and Froehlich, 1989).

Table 4. Approach water-surface elevations for 100-year flood for existing and proposed bridge lengths

[ft, foot]

Bridge	Existing bridge length (ft)	Approach[a] water-surface elevation (ft)	Proposed bridge length (ft)	Approach[a] water-surface elevation (ft)
Main channel	1,850	576.81	2,100	576.84
Northernmost relief	442	576.76	315	576.80
Southernmost relief	476	576.76	315	576.80

[a]Approach water-surface elevation located one bridge length upstream from bridge opening.

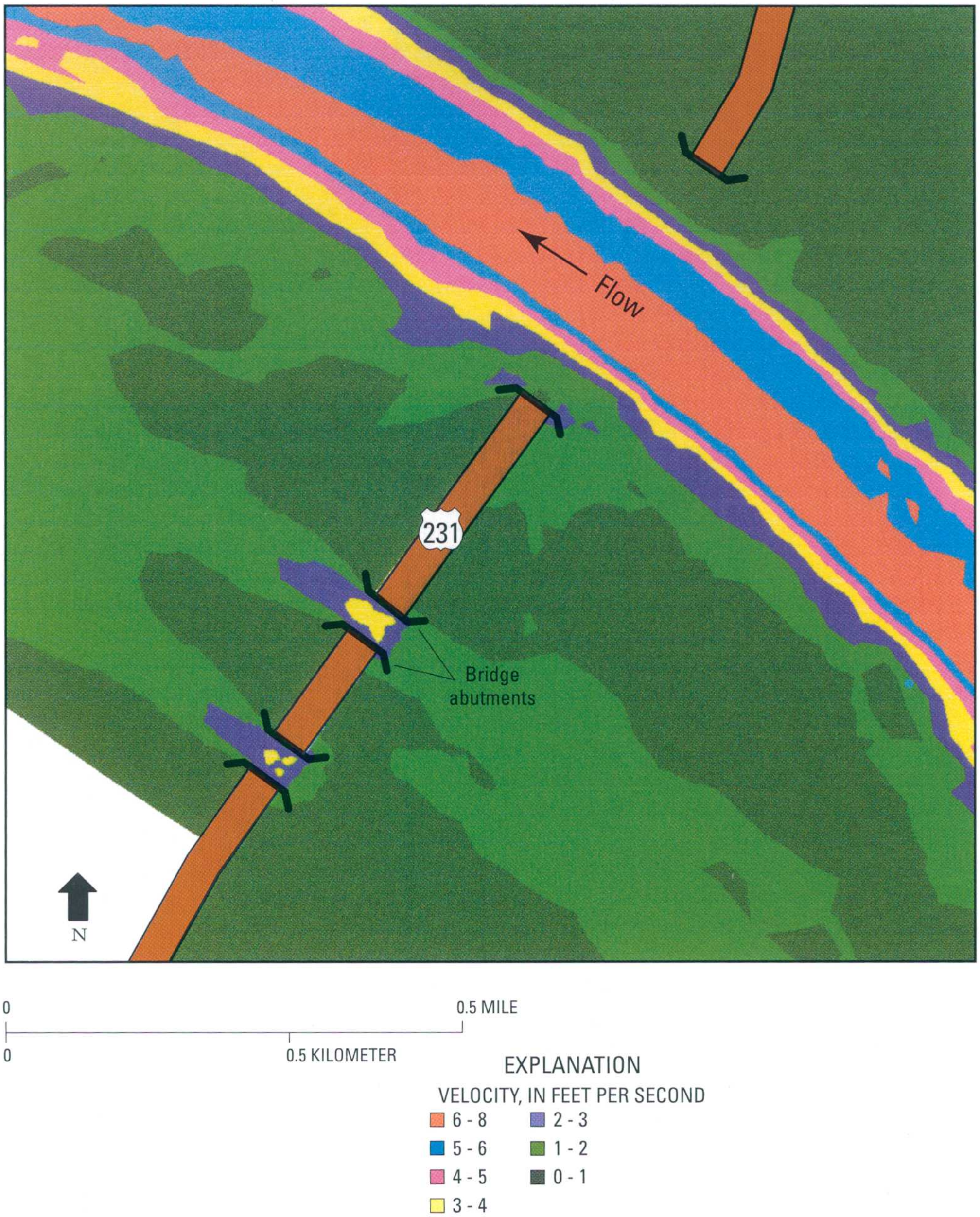


Figure 18. Computed velocity contours for 100-year flood for proposed bridge crossing.

500-Year Flood

Floodflows were simulated depicting the Tennessee River 500-year flood for the existing and proposed conditions. The estimated 500-year flood discharge at the site is 400,000 ft^3/s (Federal Emergency Management Agency, 1998). This flood has a 0.2 percent chance of being equaled or exceeded in any given year. During the 500-year flood, the average depth in the channel in the vicinity of U.S. Highway 231 was about 42 ft, whereas the average depth in the overbank areas was about 14 ft. No overtopping of U.S. Highway 231 occurred; however, the girders of both relief bridges were partially submerged.

Existing Conditions

Simulation of the 500-year floodflow for the Tennessee River for the existing conditions at

U.S. Highway 231 indicates that of the peak flow, 89.2 percent (359,000 ft^3/s) was conveyed by the main channel bridge, 5.6 percent (22,600 ft^3/s) by the northernmost relief bridge, and 5.2 percent (20,900 ft^3/s) by the southernmost relief bridge. The water-surface elevation predicted near the USGS gaging station was 580.91 ft and plots within 3 percent of a linear extension of the rating curve for the gage (fig. 14). The maximum point velocities predicted for the bridges were 7.8 ft/s for the main channel bridge, 3.7 ft/s for the northernmost relief bridge, and 4.1 ft/s for the southernmost relief bridge. No overtopping of U.S. Highway 231 occurred. A plot of computed water-surface elevations for the 500-year flood for the existing conditions is shown in figure 19. A plot of corresponding velocity contours is shown in figure 20, and a plot of computed velocity contours in the vicinity of U.S. Highway 231 is shown in figure 21.

Proposed Conditions

Simulation of the 500-year floodflow for the Tennessee River for the proposed conditions indicates that of the peak flow, 90.9 percent (365,400 ft^3/s) was conveyed by the proposed main channel bridge, 4.3 percent (17,300 ft^3/s) by the proposed northernmost relief bridge, and 4.8 percent (19,400 ft^3/s) by the proposed southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 580.93 ft, about 0.02 ft higher than that computed for the existing conditions. The maximum point velocities predicted

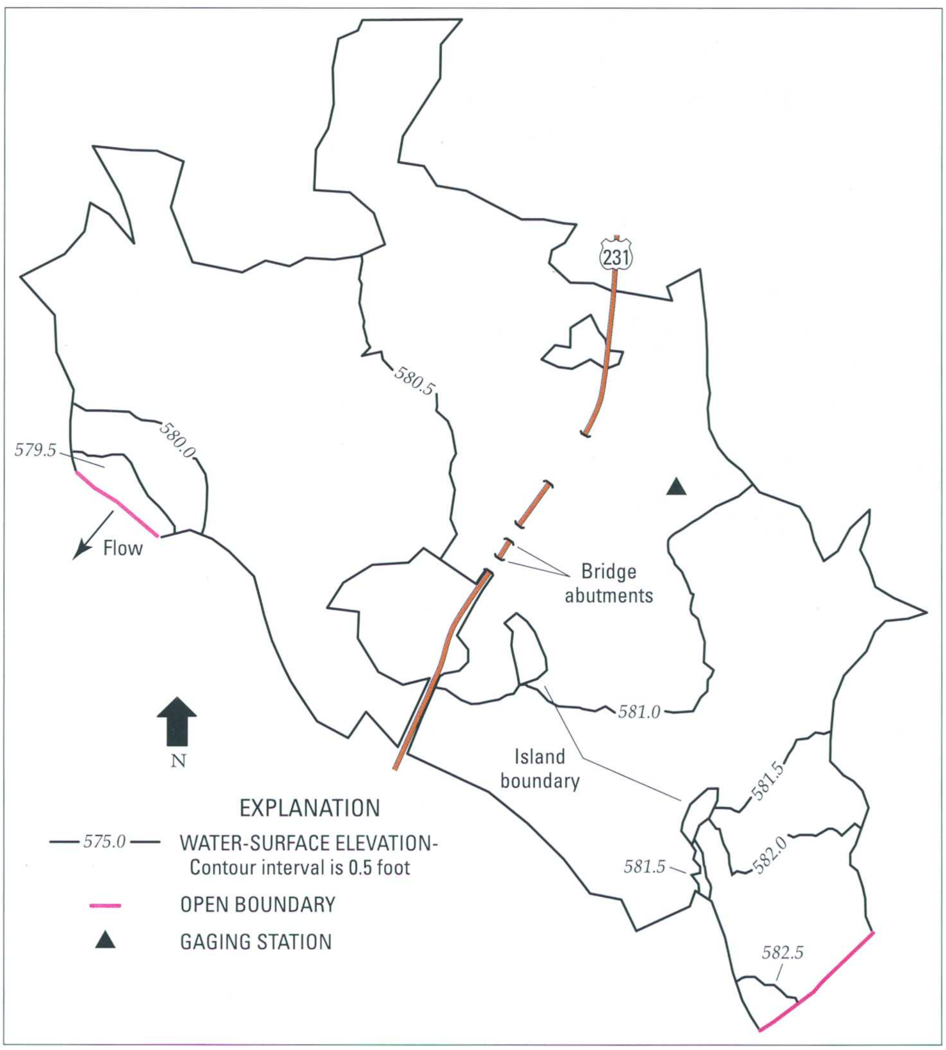


Figure 19. Computed water-surface elevations for 500-year flood for existing conditions.

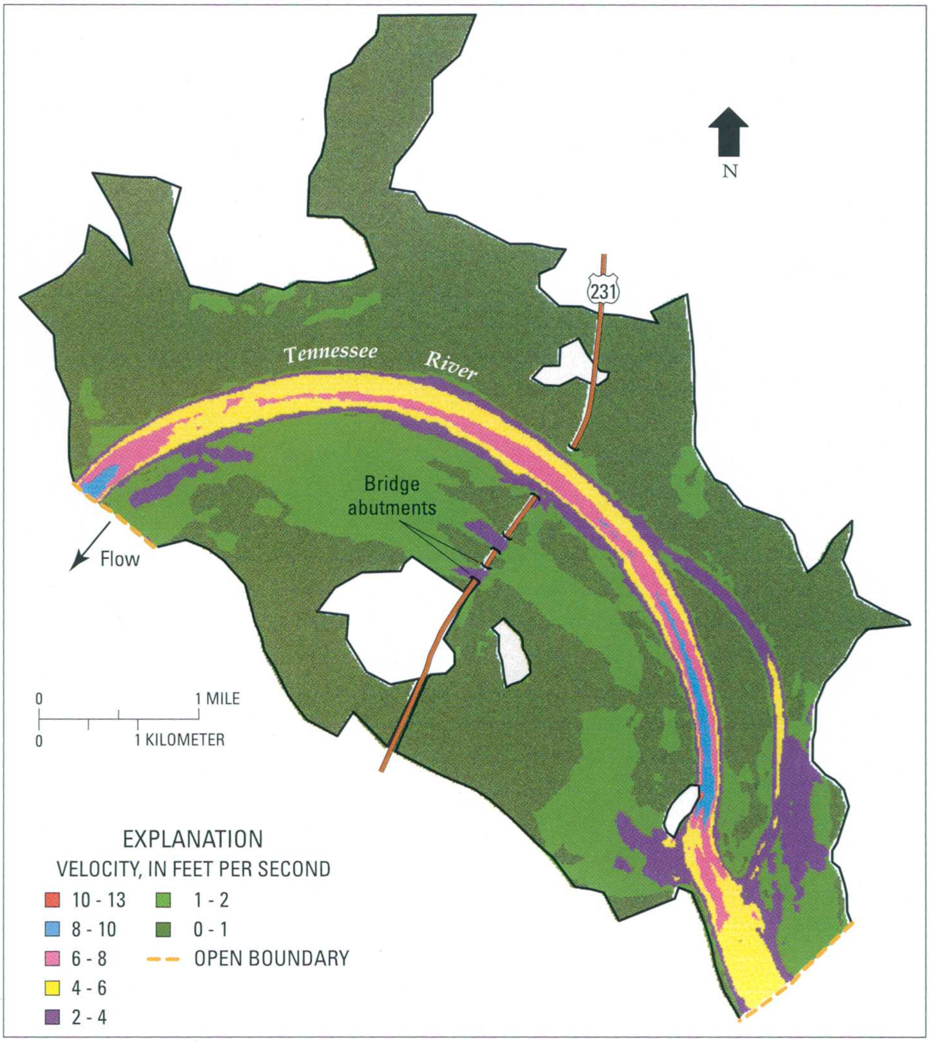


Figure 20. Computed velocity contours for 500-year flood for existing conditions.

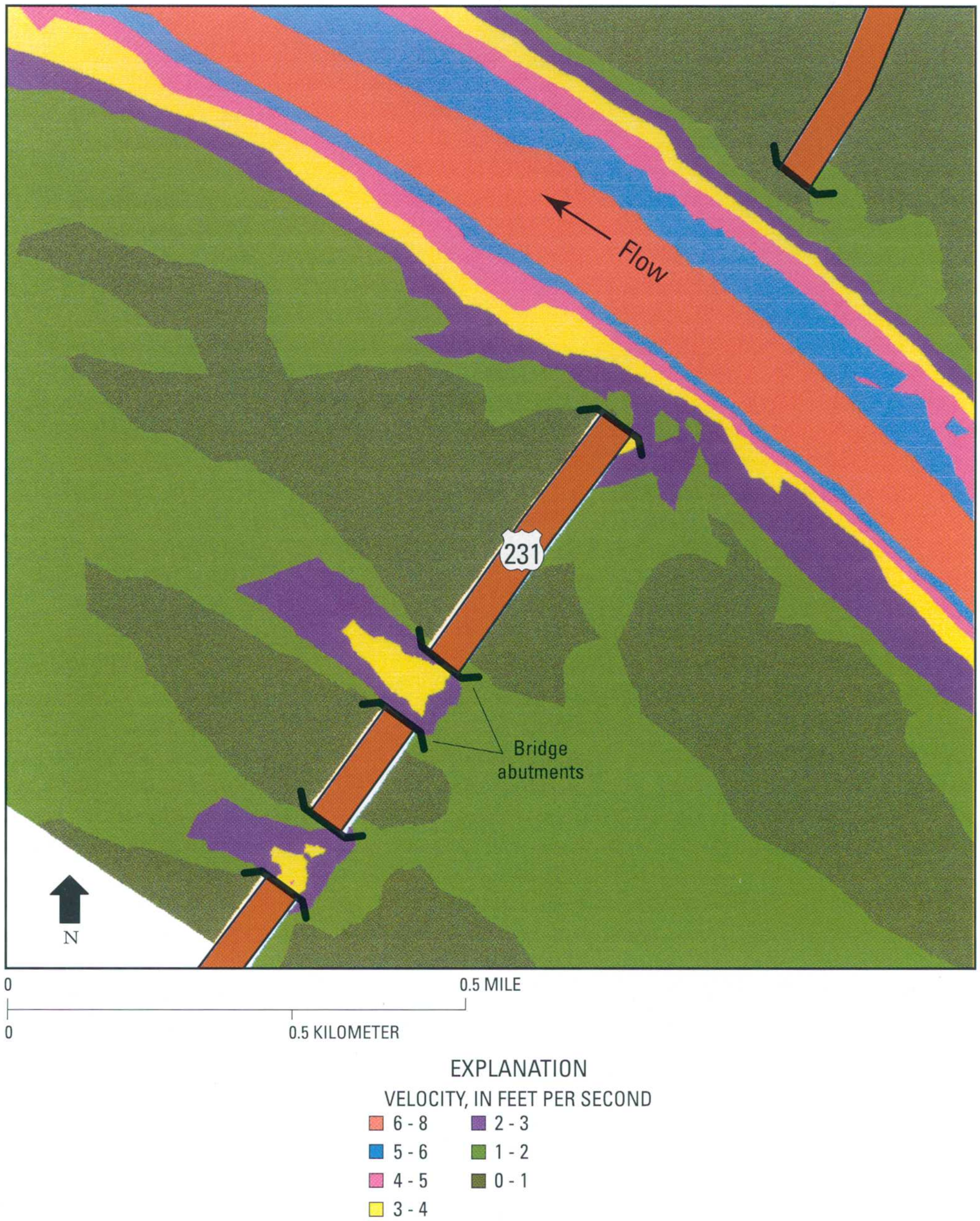


Figure 21. Computed velocity contours for 500-year flood for existing bridge crossing.

for the bridges were 7.8 ft/s for the main channel bridge, 4.5 ft/s for the northernmost relief bridge, and 4.3 ft/s for the southernmost relief bridge. No overtopping of U.S. Highway 231 occurred. A complete tabulation of the hydraulic data for the 500-year flood for the bridges mentioned above is presented in tables 5 and 6. A plot of computed velocity contours in the vicinity of U.S. Highway 231 is shown in figure 22.

Table 5. Simulation of 500-year flood for existing conditions

[Input discharge=400,000 cubic feet per second (ft^3/s); gage height predicted by finite-element surface-water modeling system (FESWMS)=580.91 feet (ft); VMAX, maximum point velocity in feet per second (ft/s)]

Bridge	Length (ft)	FESWMS discharge (ft^3/s)	Percent of total FESWMS flow	FESWMS downstream stage (ft)	VMAX FESWMS (ft/s)
Main channel................	1,850	359,000	89.2	580.58	7.8
Northernmost relief.......	442	22,600	5.6	580.52	3.7
Southernmost relief.......	476	20,900	5.2	580.52	4.1
Total		402,500[a]			

[a]Difference between total bridge discharge and total input discharge is due to small, local mass conservation errors (Lee and Froehlich, 1989).

Table 6. Simulation of 500-year flood for proposed conditions

[Input discharge=400,000 cubic feet per second (ft^3/s); gage height predicted by finite-element surface-water modeling system (FESWMS)=580.93 feet (ft); VMAX, maximum point velocity in feet per second (ft/s)]

Bridge	Length (ft)	FESWMS discharge (ft^3/s)	Percent of total FESWMS flow	FESWMS downstream stage (ft)	VMAX FESWMS (ft/s)
Main channel	2,100	365,400	90.9	580.57	7.8
Northernmost relief........	315	17,300	4.3	580.50	4.5
Southernmost relief........	315	19,400	4.8	580.50	4.3
Total		402,100[a]			

[a]Difference between total bridge discharge and total input discharge is due to small, local mass conservation errors (Lee and Froehlich, 1989).

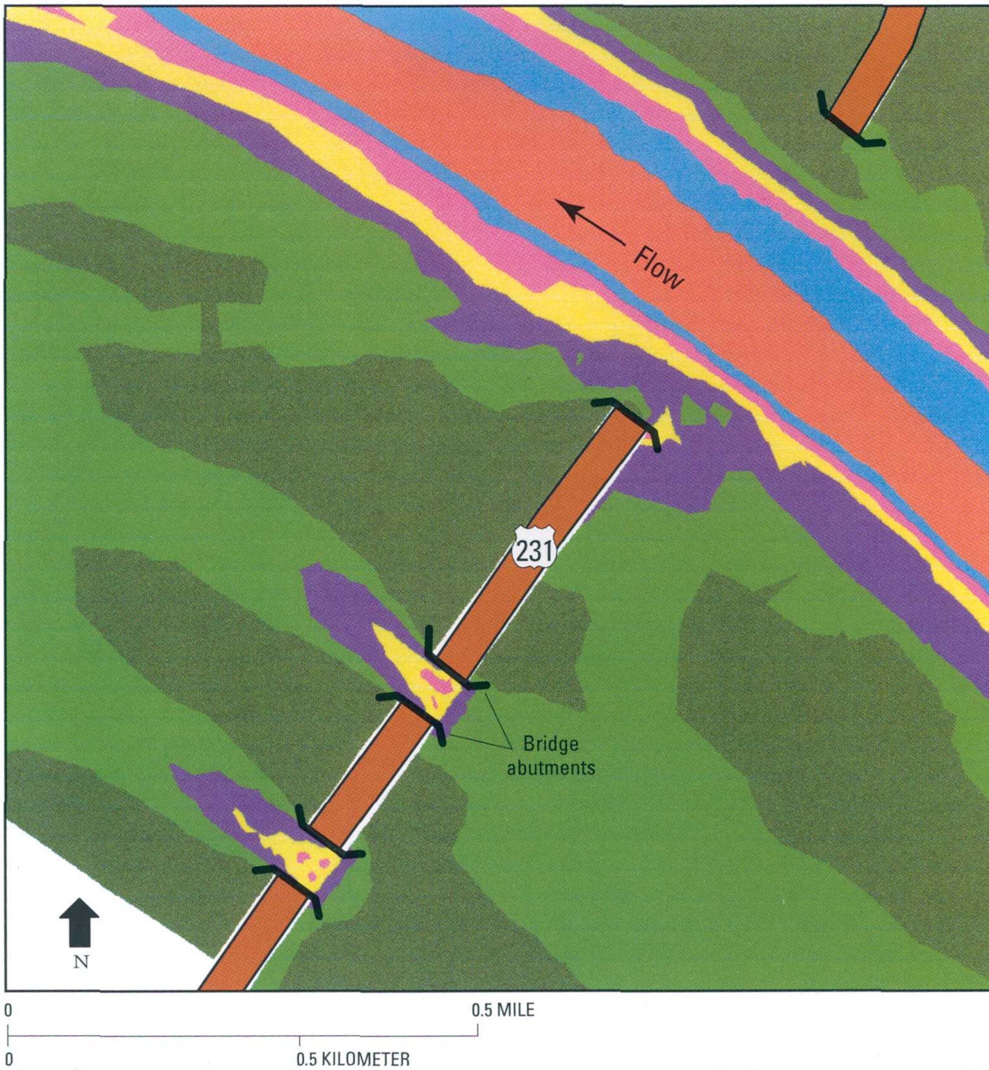


Figure 22. Computed velocity contours for 500-year flood for proposed bridge crossing.

SUMMARY

A two-dimensional finite-element surface-water model was used to study the effects of proposed modifications to the U.S. Highway 231 corridor on water-surface elevations and flow distributions during flooding in the Tennessee River Basin south of Huntsville, Madison County, Alabama. Flooding was first simulated for the March 19, 1973, flood for the existing conditions in order to calibrate the model to measured data collected by the U.S. Geological Survey (USGS) and the Tennessee Valley Authority (TVA) during and after the flood. After model calibration, the effects of flooding were simulated for two scenarios—existing and proposed conditions—for the 100-year and 500-year recurrence intervals. The first scenario simulated existing bridge and highway configuration for the U.S. Highway 231 crossing of the Tennessee River flood plain. The second scenario

simulated proposed modifications to this bridge and highway configuration.

The simulation of floodflow for the Tennessee River flood of March 19, 1973, in the study reach compared closely to discharge measurement and flood profile data obtained during and after the flood. The flood of March 19, 1973, had an estimated peak discharge of 323,000 cubic feet per second and was estimated to be about a 50-year flood event.

Simulation of the 100-year floodflow for the Tennessee River for the existing conditions at U.S. Highway 231 indicates that of the peak flow, 92.1 percent (316,500 cubic feet per second) was conveyed by the main channel bridge, 4.0 percent (13,800 cubic feet per second) by the northernmost relief bridge, and 3.8 percent (13,200 cubic feet per second) by the southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 576.91 feet. No overtopping of U.S. Highway 231 occurred. For the 500-year flood, the simulation indicates that of the peak flow, 89.2 percent (359,000 cubic feet per second) was conveyed by the main channel bridge, 5.6 percent (22,600 cubic feet per second) by the northernmost relief bridge, and 5.2 percent (20,900 cubic feet per second) by the southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 580.91 feet. No overtopping of U.S. Highway 231 occurred; however, the girders of both relief bridges were partially submerged.

Simulation of the 100-year floodflow for the Tennessee River for the proposed conditions indicates that of the peak flow, 93.2 percent (319,800 cubic feet per second) was conveyed by the proposed main channel bridge, 3.3 percent (11,400 cubic feet per second) by the proposed northernmost relief bridge, and 3.4 percent (11,800 cubic feet per second) by the proposed southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 576.93 feet, about 0.02 feet higher than that computed for the existing conditions. No overtopping of U.S. Highway 231 occurred. For the 500-year flood, the simulation indicates that of the peak flow, 90.9 percent (365,400 cubic feet per second) was conveyed by the proposed main channel bridge, 4.3 percent (17,300 cubic feet per second) by the proposed northernmost relief bridge, and 4.8 percent (19,400 cubic feet per second) by the proposed southernmost relief bridge. The water-surface elevation predicted in the vicinity of the USGS gaging station was 580.93 feet, about 0.02 feet higher than that computed for the existing conditions. No overtopping of U.S. Highway 231 occurred; however, the girders of both relief bridges were partially submerged.

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Appendix—Name, size, and description of input and output files used in two-dimensional flood simulation model for Tennessee River flood study*

File name	Size (bytes)	Description
1973.dat	3,000	ASCII-format file containing FESWMS input data for March 1973 flood.
1973.grd	533,000	ASCII-format file containing finite-element grid for existing conditions.
1973.out	471,000	ASCII-format file containing output flow file for March 1973 flood.
1973.prt	2,286,000	ASCII-format file containing complete FESWMS output for March 1973 flood.
tn100.dat	3,000	ASCII-format file containing FESWMS input data for 100-year flood or existing conditions.
tn100.grd	533,000	ASCII-format file containing finite-element grid for existing conditions.
tn100.out	471,000	ASCII-format file containing output flow file for 100-year flood for existing conditions.
tn100.prt	2,286,000	ASCII-format file containing complete FESWMS output for 100-year flood for existing conditions.
tn500.dat	3,000	ASCII-format file containing FESWMS input data for 500-year flood for existing conditions.
tn500.grd	533,000	ASCII-format file containing finite-element grid for existing conditions.
tn500.out	471,000	ASCII-format file containing output flow file for 500-year flood for existing conditions.
tn500.prt	2,286,000	ASCII-format file containing complete FESWMS output for 500-year flood for existing conditions.
p100.dat	3,000	ASCII-format file containing FESWMS input data for 100-year flood for proposed conditions.
p100.grd	550,000	ASCII-format file containing finite-element grid for proposed conditions.
p100.out	485,000	ASCII-format file containing output flow file for 100-year flood for proposed conditions.
p100.prt	2,352,000	ASCII-format file containing complete FESWMS output for 100-year flood for proposed conditions.
p500.dat	3,000	ASCII-format file containing FESWMS input data for 500-year flood for proposed conditions.
p500.grd	550,000	ASCII-format file containing finite-element grid for proposed conditions.
p500.out	485,000	ASCII-format file containing output flow file for 500-year flood for proposed conditions.
p500.prt	2,352,000	ASCII-format file containing complete FESWMS output for 500-year flood for proposed conditions.
refined.dat	4,000	ASCII-format file containing FESWMS input data for March 1973 flood using refined grid.
refined.grd	2,109,000	ASCII-format file containing refined finite-element grid for existing conditions.
refined.out	1,846,000	ASCII-format file containing output flow file for March 1973 flood for the refined grid.
refined.prt	11,016,000	ASCII-format file containing complete FESWMS output for March 1973 flood for the refined grid.

*To obtain the supplemental documentation on diskette or by electronic transfer, please contact the U.S. Geological Survey, Water Resources Division, Alabama District, at (334) 213-2332.

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USGS Hedgecock

Simulations of Flooding on the Tennessee River in the Vicinity of U.S. Highway 231 near Huntsville, Alabama

USGS WRIR-01–4114