TWO-DIMENSIONAL RELAXATION METHOD FLOW MODEL (RMFM) FOR HYDRAULIC STRUCTURES

By Braxtel L. Neely, Jr.

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 92-4021

Prepared in cooperation with the

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

Little Rock, Arkansas

1992

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
2301 Federal Office Building
700 West Capitol
Little Rock, Arkansas 72201

Copies of this report can
be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Federal Center
Box 25425
Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (continued)

Page

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
square foot (ft^2)	0.0929	square meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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.

TWO-DIMENSIONAL RELAXATION METHOD FLOW MODEL (RMFM) FOR HYDRAULIC STRUCTURES

By Braxtel L. Neely, Jr.

ABSTRACT

A two-dimensional streamflow model called the Relaxation Method Flow Model (RMFM) was developed for use in the design of hydraulic structures in Arkansas. This report describes how to use the model to simulate water-surface elevations, velocities, direction of flow, and distribution of flow on the flood plain for peak flow conditions.

In the application of RMFM, the geometry of the flood plain is described by a grid network. Ground elevations and roughness coefficients are identified at each element in the grid network.

The two-dimensional streamflow model, RMFM, is not as complex or as complicated to use as the U.S. Geological Survey's Finite Element Surface-Water Modeling System (FESWMS), but the water-surface elevations generated by both models for several test sites differed by only a few hundredths of a foot. Comparisons between RMFM and FESWMS were made by comparing the results of model runs using identical input data at three sites. Results were in good agreement and the computer time used to run RMFM was less than that used to run FESWMS.

A comparison also was made between the coefficient of discharge computed using RMFM and the coefficient determined using standard indirect methods of computing peak discharge. The coefficient of discharge determined using the results of RMFM was only 4 percent greater than that computed using indirect methods for computing peak discharge.

INTRODUCTION

Water-surface elevations, velocities, flow distribution, and backwater are primary factors in the design of bridges, culverts, streets, embankments, dams, levees, and other structures near streams. Where these data are not available, computer models are sometimes used to simulate hydrologic and hydraulic characteristics of streams at bridges and other sites of interest. Because many factors can affect streamflow, most streamflow models are fairly complex, require much data preparation and entry, and require considerable computational resources. For many applications, a simpler, more efficient model that might yield somewhat less accurate results would provide adequate estimates of the streamflow characteristics.

Recognizing the need for a simpler streamflow model, the U.S. Geological Survey, in cooperation with the Arkansas State Highway and Transportation Department, developed a two-dimensional streamflow model known as the Relaxation Method Flow Model (RMFM). The model is intended to be simple to use and to address the major factors that affect flow. The model does not consider the effects of wind and coriolis forces on flow and is not suited for use on large bodies of water where these forces are significant.

The purpose of this report is to describe the RMFM, and to describe the use of the model to simulate water-surface elevations, velocities, direction of flow, and discharges in a stream reach and to compare RMFM results with results from more complex streamflow models. The user does not need to be proficient in the details of the RMFM beyond the preparation of input data and the interpretation of results.

To use RMFM to model streamflow in a given reach of the stream, the geometry of the flood plain is defined by a grid network. The model then uses energy and continuity equations to balance heads at each element of the grid. The model should be used only at sites that have subcritical flow.

USING THE MODELING PROGRAM

Assembling the data and arranging it in a usable form are necessary for running the model. The data that describe the geometry must be accurate for the results to be accurate. Care must be taken to verify all of the data that will be used. The computer program for running the model is named "Two.D.Model" and is listed in Attachment A.

A grid network must be developed for the study site that describes the geometry of the flood plain and the drainage structures. The X and Y coordinates must be determined at each grid node. Ground elevations and Manning's roughness coefficients (Barnes, 1967) must be known at each element of the grid. The water-surface elevation at the downstream end of the study reach must be given and the total discharge flowing through the study reach must be known.

The following sections describe how to develop the grid network and assemble the input data. Most of the input data can be checked for accuracy by visually examining it. The grid network can be checked more easily if the grid is plotted graphically. A computer program for plotting the grid network is listed in Attachment B.

The water-surface elevations and velocity vectors generated by the model also can be plotted graphically. A computer program for plotting lines of equal water-surface elevations is listed in Attachment C. A computer program for plotting the velocity-vector lines is listed in Attachment D.

Grid Network

A grid network is used to describe the geometry of the flood plain and to establish points where flow definition is needed. A sketch of a grid measuring 150 ft in width and 200 ft in length is shown on figure 1. The grid network is an arrangement of rows and columns and each element or cell of the grid network has four sides. If the grid can be made to match the actual stream geometry and lines of equal stage reasonably well, the model will simulate flow conditions more accurately.

The grid network uses I and J coordinates to locate and identify each element or cell and each grid node. The I coordinates are numbered from 1 at the bottom (downstream end) to ITOPI at the top (upstream end). The J coordinates are numbered from 1 at the left side (looking upstream) to ISIDEI at right side (looking upstream). This arrangement is used for simplicity in locating each grid node. All data such as ground elevations, n values, and stationing are located by using the I and J subscripts. The X and Y stationing are the abscissa and ordinate values that define the distance from the horizontal and vertical baselines (figs. 1, 11, and 12). The X and Y stationing of the grid network are described as X (I,J) and Y (I,J). When I equals 4 and J equals 3 (example grid node in fig. 1), the horizontal stationing described as X(4,3) is the stationing (100 ft) of this point on the abscissa scale. The vertical stationing described as Y(4,3) is the stationing (150 ft) of this point on the ordinate scale. Other data such as ground- and water-surface elevations also are referenced by using the I and J coordinates, but they represent the midpoint of each element. The I and J coordinates that identify each element are at the lower left corner of the element. For example, element a on figure 1 has I and J coordinates of 1,1 and element b has coordinates of 2,3.

The number of elements in the grid network will vary from site to site depending on the amount of definition that is needed. An average or typical site might have 30 horizontal lines (ITOPI=30) and 25 vertical lines (ISIDEI=25). In describing the grid, the term vertical line means the line that goes from the upstream end of the grid network to the downstream end. The horizontal line means the line that goes from one edge of the flood plain to the other. Each vertical and horizontal line must go completely through the grid network so that each element has four sides.

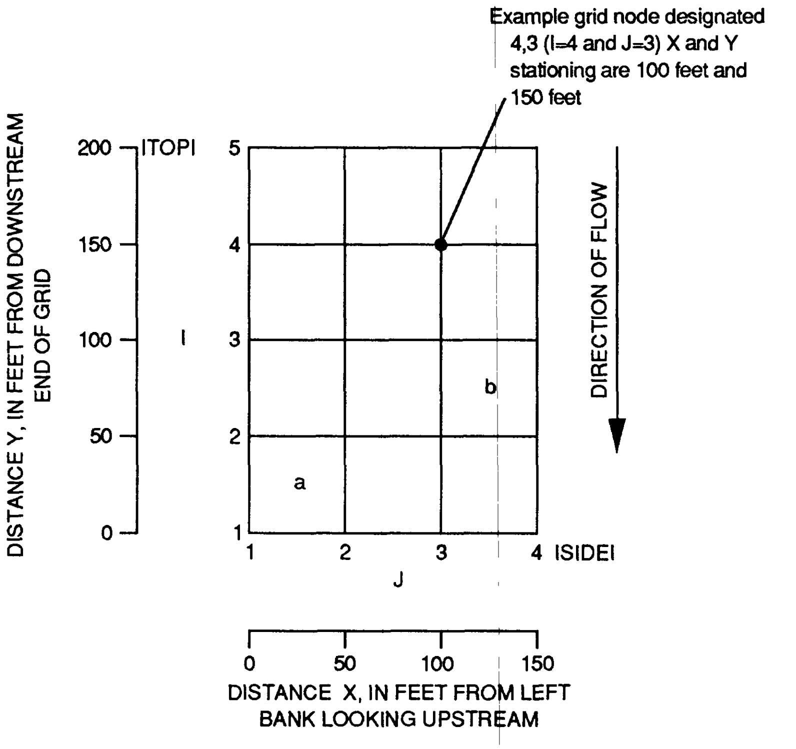
Consideration needs to be given to the fact that the larger the network, the more computer memory is required. If the network is too large, enough computer memory may not be available to run the model.

The grid network can be squeezed, spread, mashed, or bent, until it looks like a spider web, but if the vertical lines do not cross each other and the horizontal lines do not cross each other, then each element in the network will have four sides.

In laying out the grid network, the first things to be defined are usually the low-water channel and the water's edge on each bank. A sketch of the low-water channel and the water's edge at a typical highway crossing is shown on figure 2.

The lines describing the low-water channel define the top of each bank. The computations for flow are based on the assumption that the channel is rectangular in shape, but the channel probably resembles the example in figure 3.

The vertical lines at the top of figure 3 represent each edge of the channel. A channel-bottom elevation will be selected by the user so that the rectangular area used in the model equals the actual area. The depth of the rectangular area is determined by dividing the actual area by the width between the vertical lines. The channel-bottom elevation is determined by subtracting the depth from the elevation of land surface adjacent to the channel.



EXPLANATION

I HORIZONTAL LINES USED TO LOCATE AND IDENTIFY EACH ELEMENT OF CELL AND EACH GRID NODE--I is numbered from "1" at the bottom (downstream end) to "ITOPI" at the top (upstream end)

J VERTICAL LINES OF GRID USED TO LOCATE AND IDENTIFY EACH ELEMENT OR CELL AND EACH GRID NODE--J is numbered from "1" at the left side (looking upstream) to "ISIDEI" at the right side

X HORIZONTAL STATIONING OF GRID

Y VERTICAL STATIONING OF GRID

a b DESIGNATION FOR GRID CELLS DISCUSSED IN TEXT

Figure 1.-- Definition sketch of grid network.

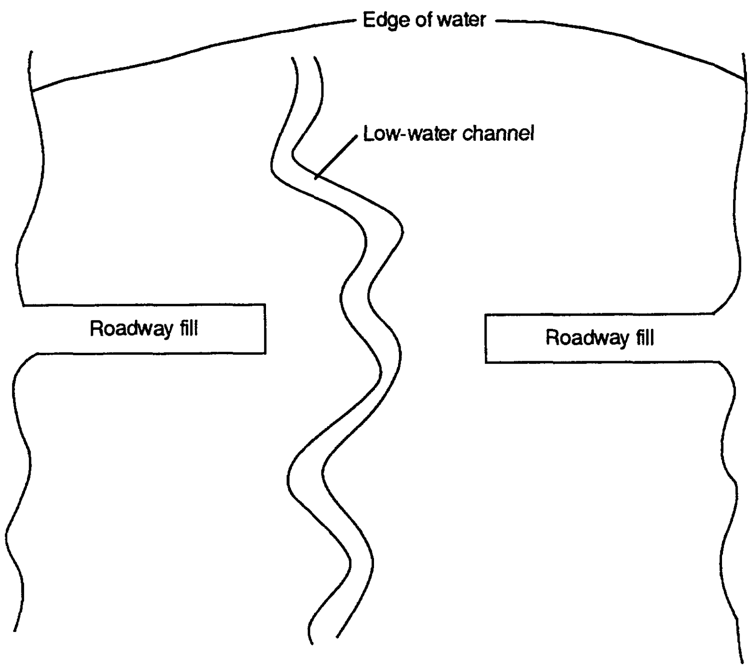


Figure 2.--Definition sketch of low-water channel.

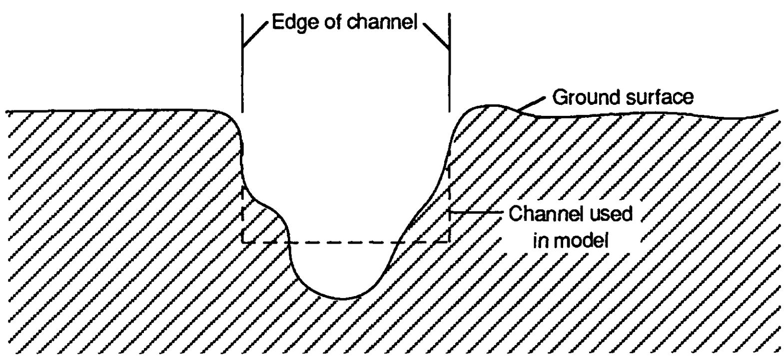


Figure 3.--Definition sketch of low-water channel cross section.

The next step is to define all other features that are related to changes in the shape of the flood plain. Lines are drawn at break points in the topography of the flood plain. If the remainder of the flood plain is reasonably flat, then the remaining vertical lines can be placed uniformly on the flood plain. The vertical lines do not represent streamlines and need not necessarily be parallel to flow lines, but should approximate flow lines as nearly as possible.

The next step is to draw in the horizontal lines. The most downstream line and the most upstream line are drawn normal to flow. The position of these lines is fairly subjective, but with the use of topographic maps, flow direction can be determined with reasonable accuracy. Also, minor errors at each end of the grid network probably will have little effect on the model results at the bridge.

A minimum of two horizontal lines is required in the bridge section. A convenient place for these is along the downstream side and upstream side of the bridge. If the remainder of the flood plain is reasonably flat, the remaining horizontal lines can be placed uniformly on the flood plain. A good general rule to follow is to place the horizontal lines normal to flow and the vertical lines parallel to flow. Another general rule to follow is to place the horizontal lines so that the changes in water-surface elevation from one to the other are about the same. This means that near the bridge, the horizontal lines will be closer together than they will be farther away from the bridge. The horizontal lines and the vertical lines should cross each other at angles reasonably close to 90 degrees. This, of course, may not always be possible, but should be considered when drawing in the grid network. The model program does not assume that horizontal lines are normal to flow or that vertical lines are parallel to flow or that the horizontal and vertical lines cross each other at 90 degree angles. These general rules are suggested to adequately describe the flood plain. The grid network that was started on figure 2 is completed on figure 4.

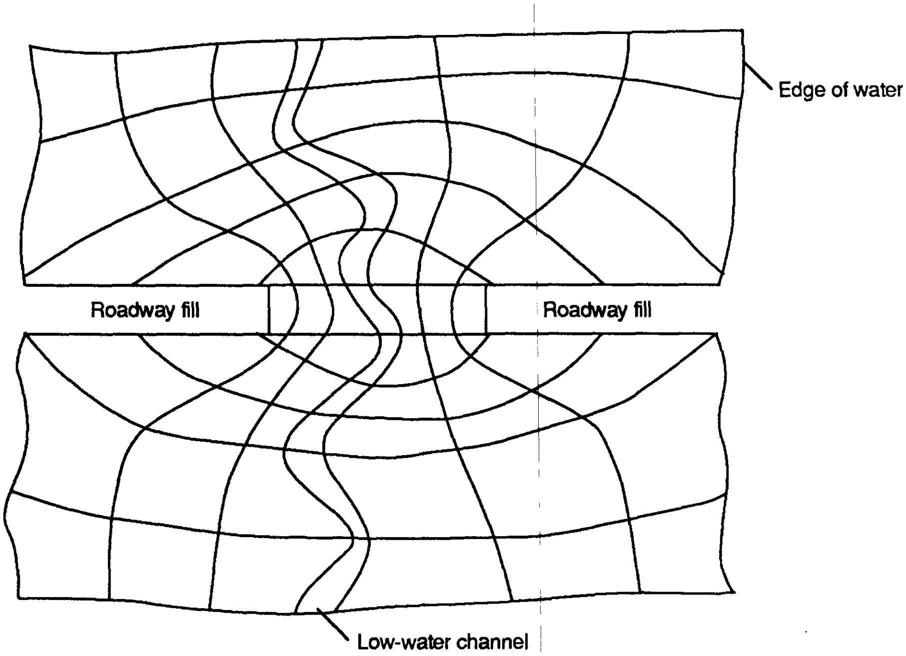


Figure 4.--Sketch showing example grid network.

The low-water channel does not have to be defined by vertical lines throughout. It can be defined by horizontal lines when necessary such as when the low-water channel meanders from one side of the flood plain to the other. An example of this is shown on figure 5. Care must be taken at the intersections to maintain the correct channel width.

The grid network for multiple bridges is the same as that for a single bridge except that the road fill between the bridges must be defined. Two vertical lines are used to define the road fill. An example of this is shown on figure 6. The model will not allow flow to pass from one vertical line through the road fill to the other vertical line. The remaining vertical lines are drawn in the same way as previously described for a single bridge.

The horizontal lines for multiple bridges are drawn in the same way as previously described except that the part that would go through the road fill is omitted. An example of horizontal lines at multiple bridges is shown on figure 7. Lines 3-6 are not drawn through the roadway fill.

The I and J coordinates of the two nodes shown as solid dots on figure 7 are used to identify the roadway fill. This identification is necessary so that the model will not allow flow to pass through the roadway fill. If the same grid shown on figure 7 were drawn with all elements being square, it would look like the example on figure 8.

On figure 8, the rectangular shaded area is the road fill. Note that lines 3-6 do not extend through the road fill. Additional bridges on the flood plain are handled the same way. This arrangement maintains the integrity of the system in that all grid nodes can be located using the I and J coordinates.

The output from the model such as water-surface elevations represent values at the midpoint of each element. Consequently if a water-surface elevation is needed at some particular point, then this point must be at the midpoint of an element.

At the downstream end of the grid network, an initial water-surface elevation must be given. The water-surface elevations at the midpoint of each element along the downstream end do not have to be equal. If they are equal, only one entry is required. If the water surface is sloping along the downstream end of the grid network, an elevation must be given for each element.

In drawing the grid network, consideration must be given to the possibility that flow over the road may occur. The computation of flow over the road is made using standard U.S. Geological Survey methods (Hulsing, 1968) and is not made using the equations for the two-dimensional flow model. For this reason, the grid network is always drawn as if water would not flow over the road. Horizontal lines should be directly across the road from each other because an upstream and a downstream water-surface elevation is needed in computing the flow over the road. An example of this is shown on figure 9.

The downstream water-surface elevation that is used should represent the water-surface elevation directly downstream from the point of the upstream water-surface elevation. The solid dots on figure 9 represent the location of the upstream and downstream water-surface elevations. The discharge that flows over the road is removed from the system at the upstream point and returns to the system at the downstream point. The I and J coordinates of the two elements (upstream and downstream) used in computing the flow must be identified.

Culverts also may exist at the highway crossing. As a general rule, culverts are small compared to the bridges at the crossing and usually are not defined by the grid network. Flow through culverts is handled the same way as flow over the road. An upstream and a downstream water-surface elevation are needed for the computation of flow. The two elements (upstream and downstream) that are used in computing the flow must be identified by the I and J coordinates. Flow through the culvert is computed using standard U.S. Geological Survey methods (Bodhaine, 1968). The discharge through the culvert is removed from the system at the upstream point and returned to the system at the downstream point. If the culvert is wide, it can be described with the grid network, but as a general rule it is not.

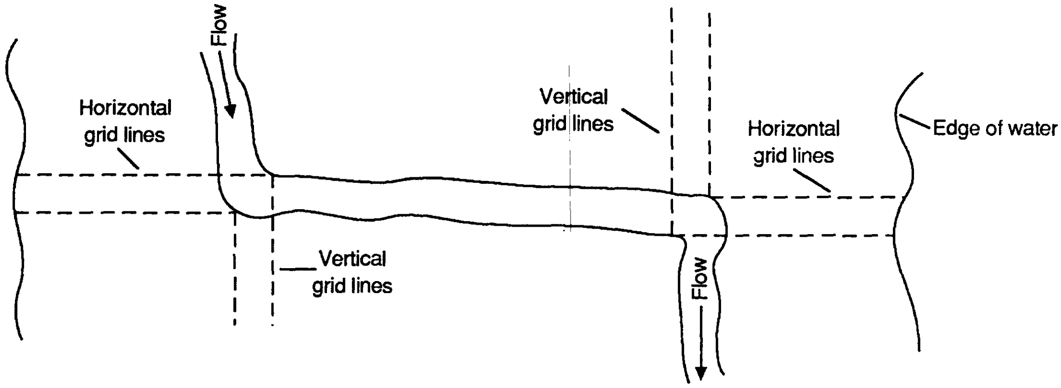


Figure 5.--Sketch showing use of grid lines to define horizontal and vertical reaches of the low-water channel.

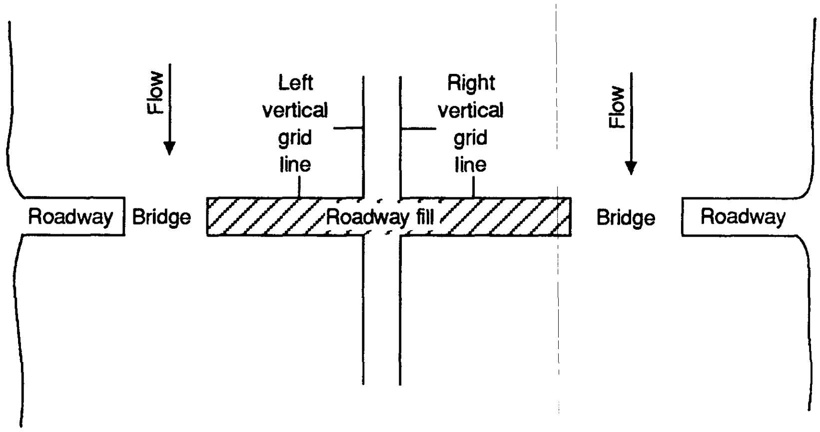
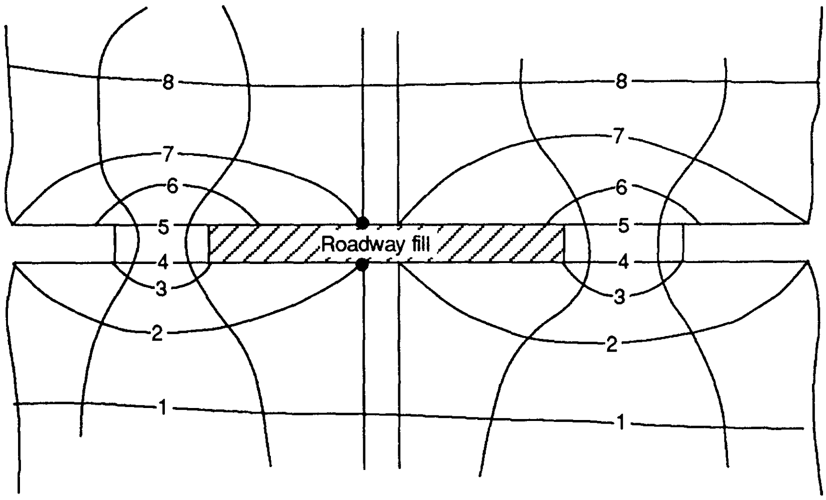


Figure 6.--Sketch showing use of vertical grid lines to define roadway fill between two bridges.

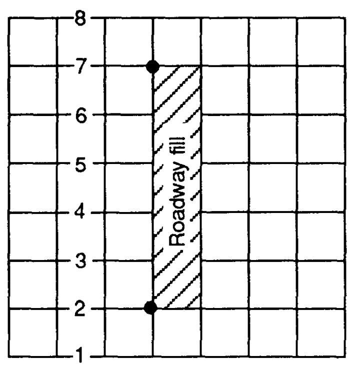


EXPLANATION

—1— I COORDINATE OF HORIZONTAL LINE OF GRID NETWORK

● GRID NODE THAT DEFINES ROADWAY FILL

Figure 7.--Sketch showing use of horizontal lines to define roadway fill between two bridges.



EXPLANATION

—1— I COORDINATE OF HORIZONTAL LINE OF GRID NETWORK

● GRID NODE THAT DEFINES ROADWAY FILL

Figure 8.--Sketch showing grid network for two openings when all grid elements are square.

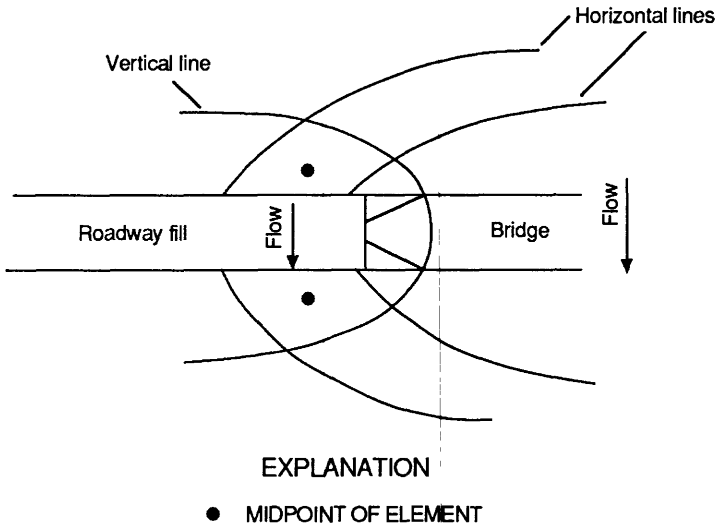


Figure 9.--Sketch showing use of horizontal grid lines to define flow over the road.

Input Data

The input data that are required to drive the model are described below by line and column numbers. Several lines may be required to hold certain types of data but for identification purposes, all data are considered to be on the same line.

The ground elevations and Manning's n values represent the midpoint of each element. In the grid network, there may be several large areas where the n value is the same for each element. An index number is entered for each element in that area rather than the actual n value. The n value that is associated with the index number is identified. This allows the user to assign or change n values over a large area by changing only one entry. The index numbers usually are assigned sequential numbers such as 1, 2, and so forth.

At sites with multiple bridges, flow must be allowed to move freely from one bridge to another bridge until a final solution is reached. This is provided by creating a large grid element where the vertical lines on each side of the element pass through adjoining bridges. An example is shown on figure 10. In the computational procedure, part of the discharge along the vertical line that passes through one bridge may be removed and assigned to the vertical line that passes through the other bridge.

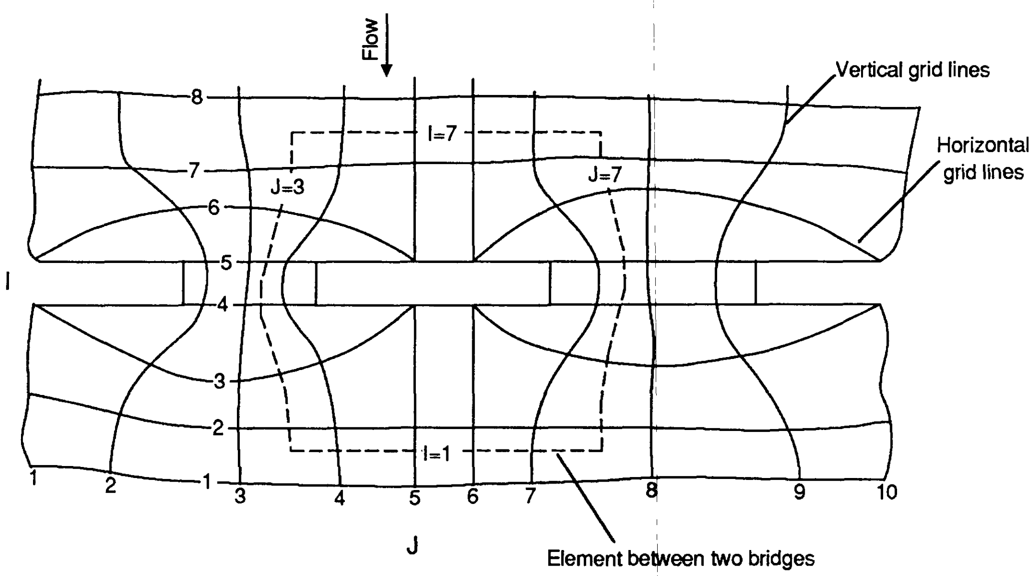


Figure 10.--Sketch showing grid network where there is a large element between two bridges.

The following input data are entered in a file named "TWO.D.DATA".

Line	Column	
1	1-80	Name of site. This line also may show other pertinent information.
2	1-10	Discharge. The total flow entering and leaving the system in cubic feet per second.
3	1-10	Water-surface elevation at downstream end of system, in feet.
4	1-10	Maximum number of iterations desired. This usually is set equal to 1 when verifying the input data. The model will make one run and print out all of the input data. After the input data are verified, this value should be set at 800. The number of iterations used will be printed out. If that value is less than 800, then a solution was reached. If the number of iterations used was 800, the model stopped before a solution was reached. If a solution is not reached in 800 iterations, then the grid should be checked for problem areas.
5	1-10	The number of horizontal lines used in defining the grid network.
6	1-10	The number of vertical lines used in defining the grid network.
7	1-10	Use "0", if this is an initial run. Use 1, if a solution was not reached after 800 iterations in a previous run and you want to use these computed values as initial values to continue the model run.
8	1-10	Total number of roadway fills between bridges. This number is always equal to the number of bridges minus one if only one roadway system is described. If more than one roadway system is described such as a highway and a railroad crossing, then the number is equal to the number of bridges minus one for each roadway system.
9	1-10	Number of element pairs where flow over the road computations will be made. Include culverts in this number. If a culvert and flow over the road occur at the same element, count it once.
10	1-10	Number of index numbers and Manning's n value sets to be used. This is used to assign or change n values for a given area with one entry.
11	1-10	Use "0" if water-surface elevations at the downstream end of the reach are the same. Use 1 if sloping water-surface conditions exist at the downstream end.
12		If line 11, columns 1-10 is equal to "0", skip line 12. If line 11, columns 1-10 is equal to 1, enter the water-surface elevations for each element at the downstream end of the reach.
12	1-10, 11-20, ... 71-80.	If there are more than 8 water-surface elevation values, use additional lines. The first value, columns 1-10, is for J equals 1. The second value, columns 11,20, is for J equals 2.
13	1-5	Index number for Manning's n values in an area.
	6-10	Manning's n value for that area. If there is more than one set, use additional lines.
14		If the number of road over-flow element pairs (line 9, columns 1-10) is equal to "0", skip line 14. If it is greater than "0", enter the following for each set of road over-flow elements.
14	1-4	I value for upstream element
	5-8	J value for upstream element
	9-12	I value for downstream element
	13-16	J value for downstream element

17-26 Elevation of roadway (highest point) between upstream and downstream elements, in feet

27-36 Width of flow over road section, normal to flow, in feet

37-46 Constant for culvert with type 4 flow. If there is no culvert, leave blank. The constant is multiplied by the square root of the fall to obtain the discharge. The constant can be computed from the following equation as described by Bodhaine (1968).

$$\text{The constant} = CA_0\sqrt{\frac{2g}{1+\frac{29\,C^2n^2L}{R_0^{4/3}}}} \qquad (1)$$

where A_0 is the area of culvert, in square feet,

C is the discharge coefficient,

L is the length of culvert barrel, in feet

n is Mannings roughness coefficient,

g is 32.2, in feet per square second, and

R_0 is the hydraulic radius, in feet.

If the culvert is not flowing full, the constant must be estimated.

15 If the number of roadway fills between bridges is equal to "0" (line 8, columns 1-10), skip line 15. If the number is greater than "0", enter the following for each roadway fill between bridges.

15 1-4 I value at the downstream side of the road where the vertical lines turn and run toward the bridges (fig. 7).

5-8 J value at the downstream side of the road where the vertical lines turn and run toward the bridges. At each roadway fill there are two vertical lines thatturn and run toward opposite bridges. The smaller of the two values is listed here.

9-12 I value at the upstream side of the road where the vertical lines leave the roadway fill to continue upstream.

At multiple bridges a large element must be created to allow flow to move between bridges. The position of this grid is left to the discretion of the user. Each vertical side is usually placed near the middle of each bridge. Each horizontal side is usually placed one or two grid units away from the roadway fill. The four sides of this element are entered in columns 13-28 as described below. An example of this is shown on figure 10.

15 13-16 J value at left side (looking upstream)

17-20 J value at right side (looking upstream)

21-24 I value at top of element

25-28 I value at bottom of element

16 The ground elevations are entered on line 16. They describe the midpoint of each element. Values are entered beginning with the most downstream horizontalelements where I=1 and J ranges from 1 to the last value on that horizontalline. Sixteen values can be entered on each line with each value using 5 columns.

16 1-5, 6-10, ... 76-80. If there are more than 16 values on each horizontal line, use additional lines. When each horizontal line is completed, the user moves upstream to the next horizontal line. The first value in each horizontal line must begin a new line and begin in columns 1-5. If the element is for a roadway fill, any value may be entered or it may be left blank.

17 The index numbers to Manning's n values are entered on line 17. These values also represent the midpoint of each element. These data are entered in exactly the same order that the ground elevations were entered.

17 1-5, 6-10, ... 76-80.

18 The X and Y stationing of the grid are entered on line 18. Values are entered beginning with the most downstream horizontal line where I=1 and J ranges from 1 to the last value. Each set (X and Y) uses 12 columns. The first 6 columns are for X and the next 6 columns are for Y.

18 X Y X Y X Y
(1-6,7-12),(13-18,19-24), ... (61-66,67-72)

Six sets can be entered on each line. If there are more than 6 sets on each horizontal line, use additional lines. When each horizontal line is completed, the user moves upstream to the next horizontal line. The first value in each horizontal line must begin a new line and begin in columns 1-6,7-12. The grid network may be oriented at the discretion of the user. The smallest values of X and Y may be at any of the four corners. If stationing is normally used from upstream to downstream and from left to right looking downstream, this is permissible. The only restriction is that data must be entered at the most downstream horizontal line first with the first value corresponding to the element on the left side looking upstream.

Example of Input Data

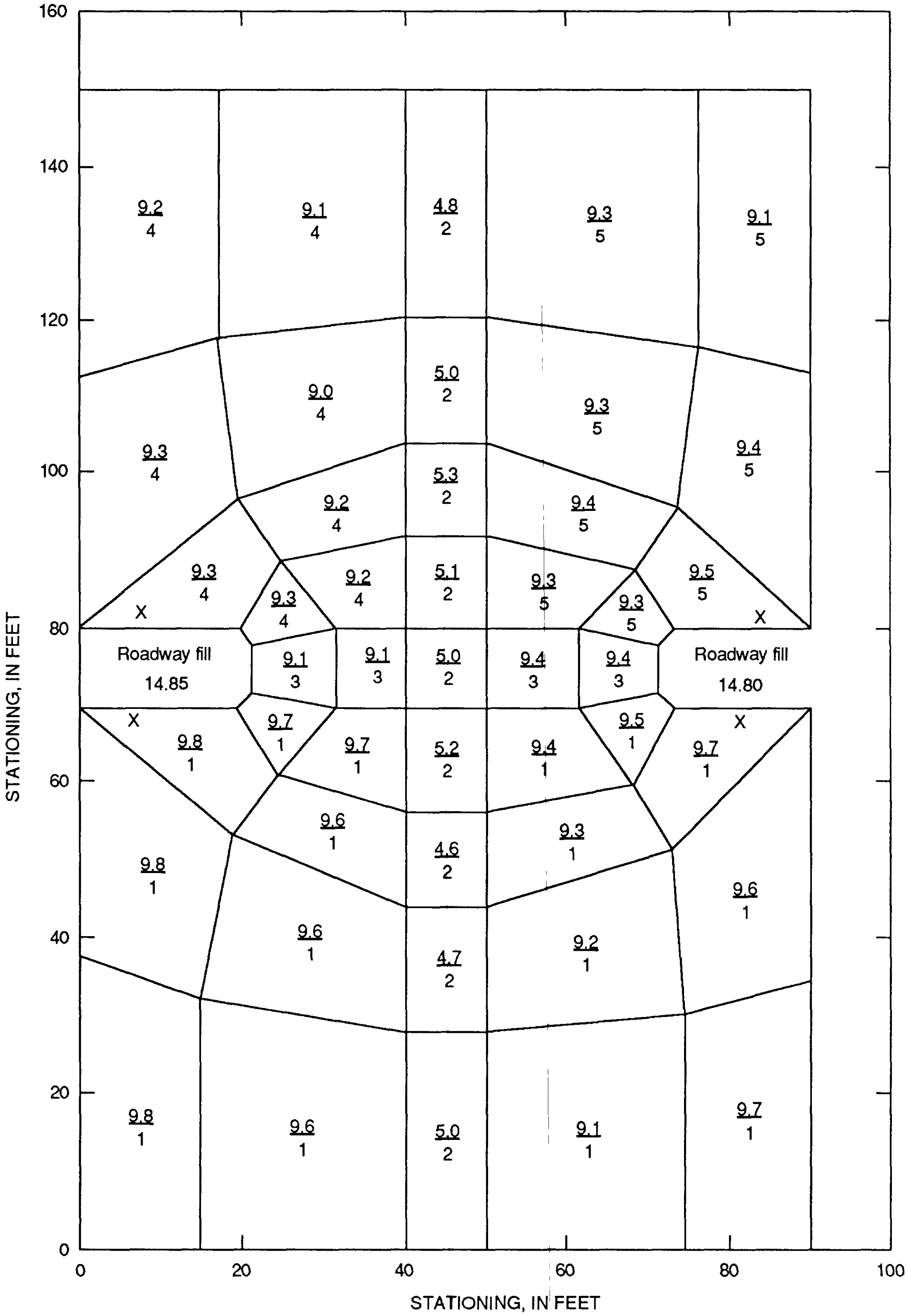
An example of how to input the data for the grid network shown on figure 11 is shown in Attachment E. The example is for a single bridge on one roadway crossing of Example.One Creek.

An example of how to input the data for the grid network shown on figure 12 is shown in Attachment F. The example is for one roadway crossing with two bridges on Example.Two Creek. Most of the input data shown here is the same as the previous example except for describing the roadway fill between the bridges and the large element connecting the two bridges. These two features are shown in the grid network on figure 12.

Output from Model

When the computer program "TWO.D.MODEL" is run, three output files are generated. These files are OUTPUT.DATA, OP.TWO.D, and OP.ITER.

The OUTPUT.DATA file lists all the generated data. A heading identifies each set of data. The data are listed using the I and J coordinates. The data for the elements along the downstream end of the reach are listed first. The data for the element on the left side looking upstream is listed first. Data are then listed for the elements along each horizontal line progressing in an upstream order. This file must be renamed "INIT.DATA", if it is to be used as initial values for additional computations using the computer program "TWO.D.MODEL".



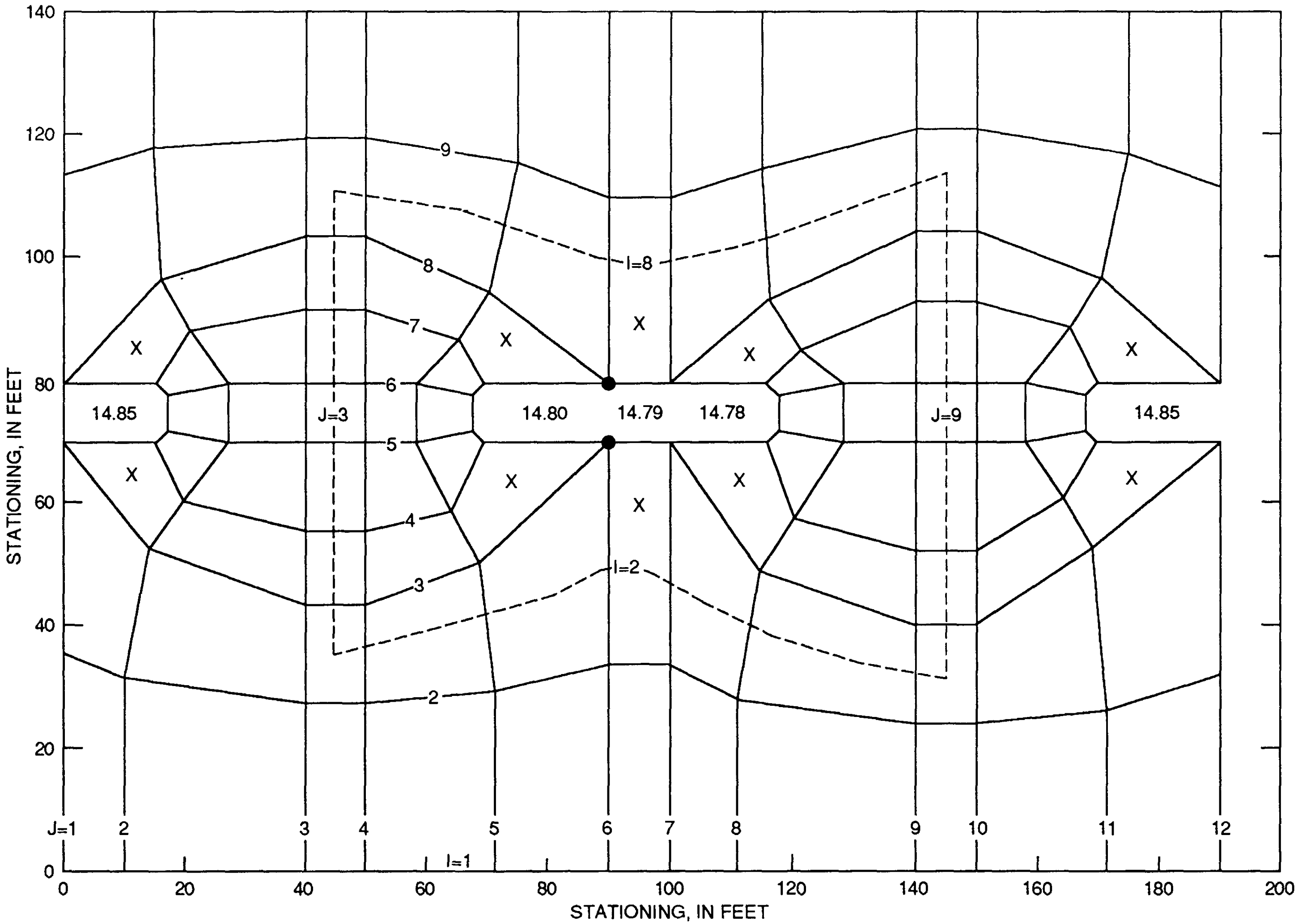
EXPLANATION

9.8 GROUND ELEVATION AT MIDPOINT, IN FEET ABOVE SEA LEVEL
1 INDEX NUMBER TO MANNING'S "N" VALUE

14.85 ELEVATION OF ROADWAY, IN FEET ABOVE SEA LEVEL

X ELEMENTS THAT ARE USED IN COMPUTING FLOW OVER ROAD

Figure 11.--Grid network for Example.One Creek.



EXPLANATION

- ● GRID NODE THAT DEFINES ROADWAY FILL
- X ELEMENTS USED IN COMPUTING FLOW OVER ROAD
- – – – – LARGE ELEMENT CONNECTING THE TWO BRIDGES
- 14.85 ELEVATION OF ROADWAY, IN FEET ABOVE SEA LEVEL

Figure 12.--Grid network for Example.Two Creek.

The OP.TWO.D file lists all the input data. This file also lists computations of grid lengths and angles. The computation of grid lengths and angles are discussed in the Method of Solution section.

The OP.ITER file lists the total error in balancing heads around each element, the total error in discharge adjustment, and the water-surface elevation at the upstream end of the reach. The flow over the road and through the culverts and the water-surface and road elevations also are listed. The three output files for the TWO.D MODEL run for Example.One Creek are listed in Attachments G-I.

COMPARISON OF RELAXATION METHOD FLOW MODEL AND FINITE ELEMENT SURFACE-WATER MODELING SYSTEM RESULTS

The Finite Element Surface-Water Modeling System (FESWMS) was developed by the U.S. Geological Survey for the Federal Highway Administration to analyze flow at highway bridge crossings where complicated hydraulic conditions exist (Froehlich, 1988).

Comparisons were made between the RMFM and FESWMS models by comparing the results of three model runs using identical input data. The first comparison is for a hypothetical site, symmetrical on both flood plains with one bridge in the middle. The second is a site in Mississippi where the shape of the flood plain and the crossing are similar to those at the hypothetical site and where observed discharge data are available. The other is a complicated highway crossing in Arkansas where additional evaluations of the crossing were needed and where evaluations using standard hydraulic methods might be questionable.

Less time was required to prepare and assemble the input data for the RMFM than for the FESWMS. Each node in the grid network had to be numbered and all the nodes that define each element had to be entered using FESWMS whereas RMFM did not require that effort. Entering the ground elevations and Manning's roughness coefficients required about the same amounts of effort for both models.

Hypothetical Site

A hypothetical site was used for purposes of comparing results from RMFM and FESWMS runs. The flood plain of the hypothetical site was assumed to be 1,000 ft wide and the length of the reach was 2,100 ft. A 200-ft bridge was centered on the flood plain near the middle of the reach. The distance through the bridge (highway fill) was 100 ft.

The grid network used in both models is shown in figure 13. For modeling purposes, the ground elevation and n value at each element were assumed to be 0.0 and 0.035, respectively. The starting water-surface elevation at the downstream end of the reach was assumed to be 4.00 ft and the discharge was assumed to be 4,000 ft^3/s.

Lines of equal water-surface elevation generated by each model are shown on figures 14 and 15. The water-surface elevation at the upstream end of the reach and the average elevation under the bridge are the same using both models.

The distribution of velocity along the upstream side of the bridge is similar for both models. This velocity distribution is shown on figure 16. The velocities are high near the abutment and decrease away from the abutment toward the middle of the stream. This confirms the current-meter measurement data used by Colson (1974) in his evaluation of earthen spur dikes. The water-surface elevations, velocity, and discharge data generated by each model for points along the upstream side of the bridge are listed in table 1.

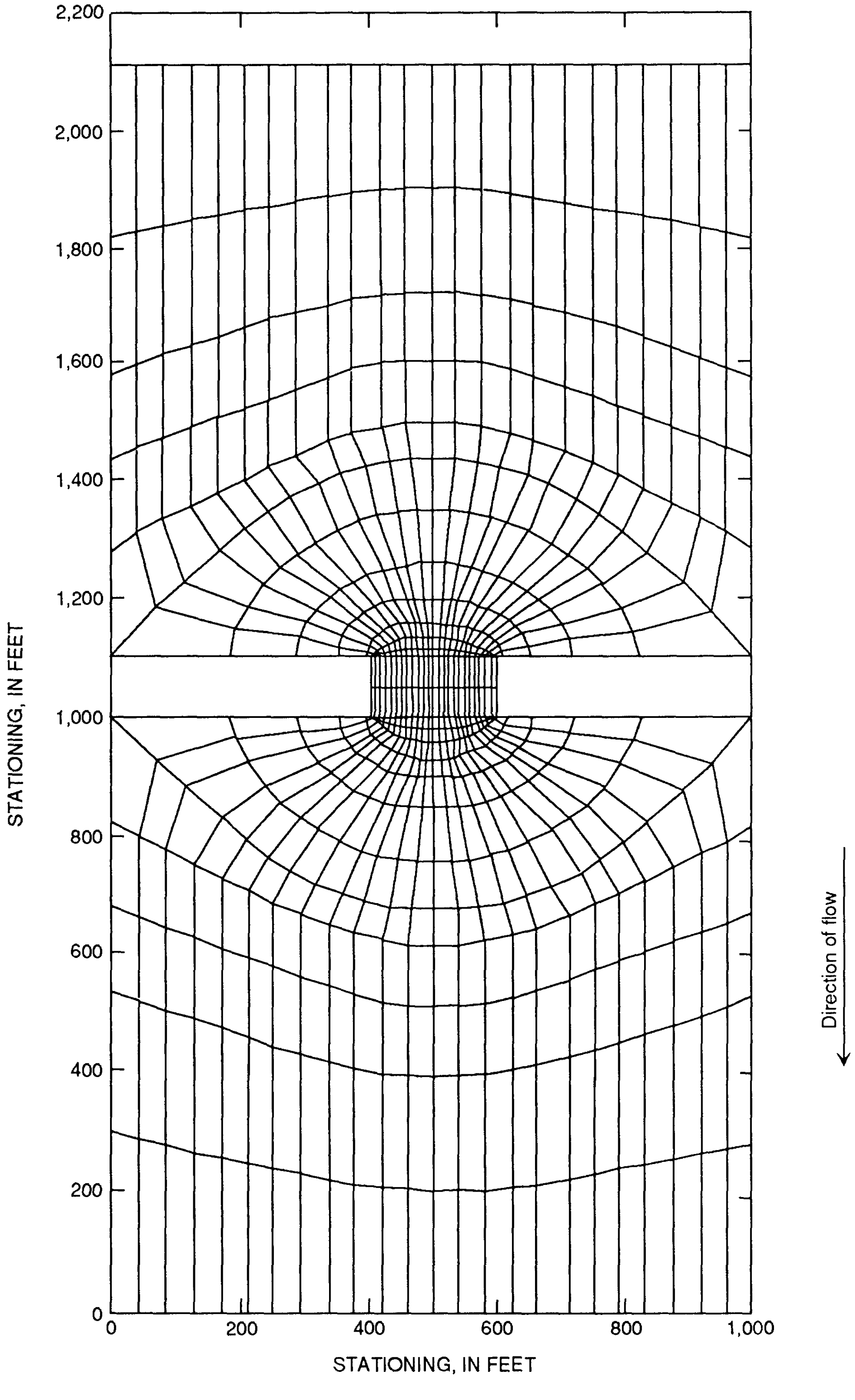


Figure 13.--Grid network for hypothetical site.

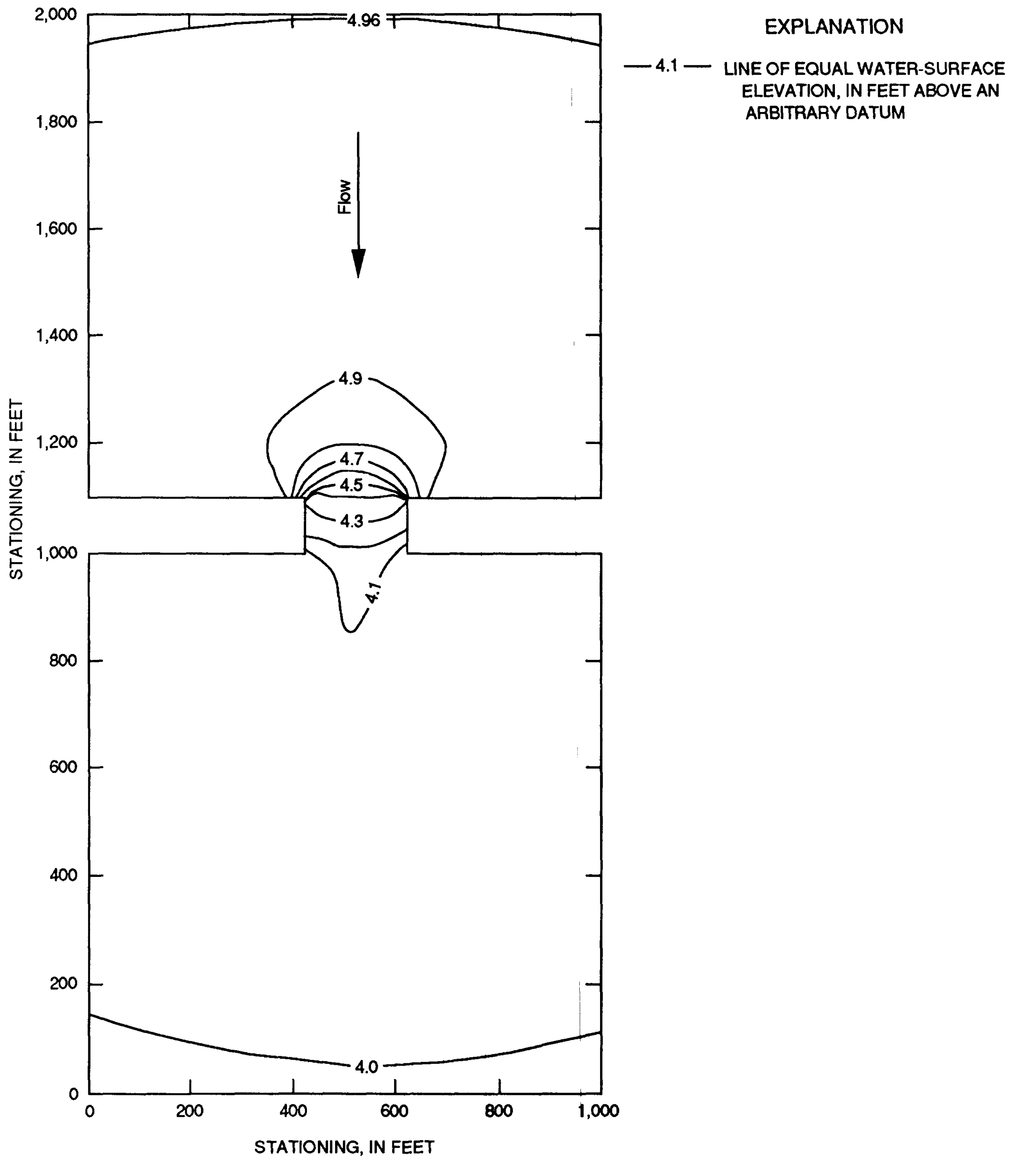


Figure 14.--Lines of equal water-surface elevation for hypothetical site using the Relaxation Method Flow Model (RMFM).

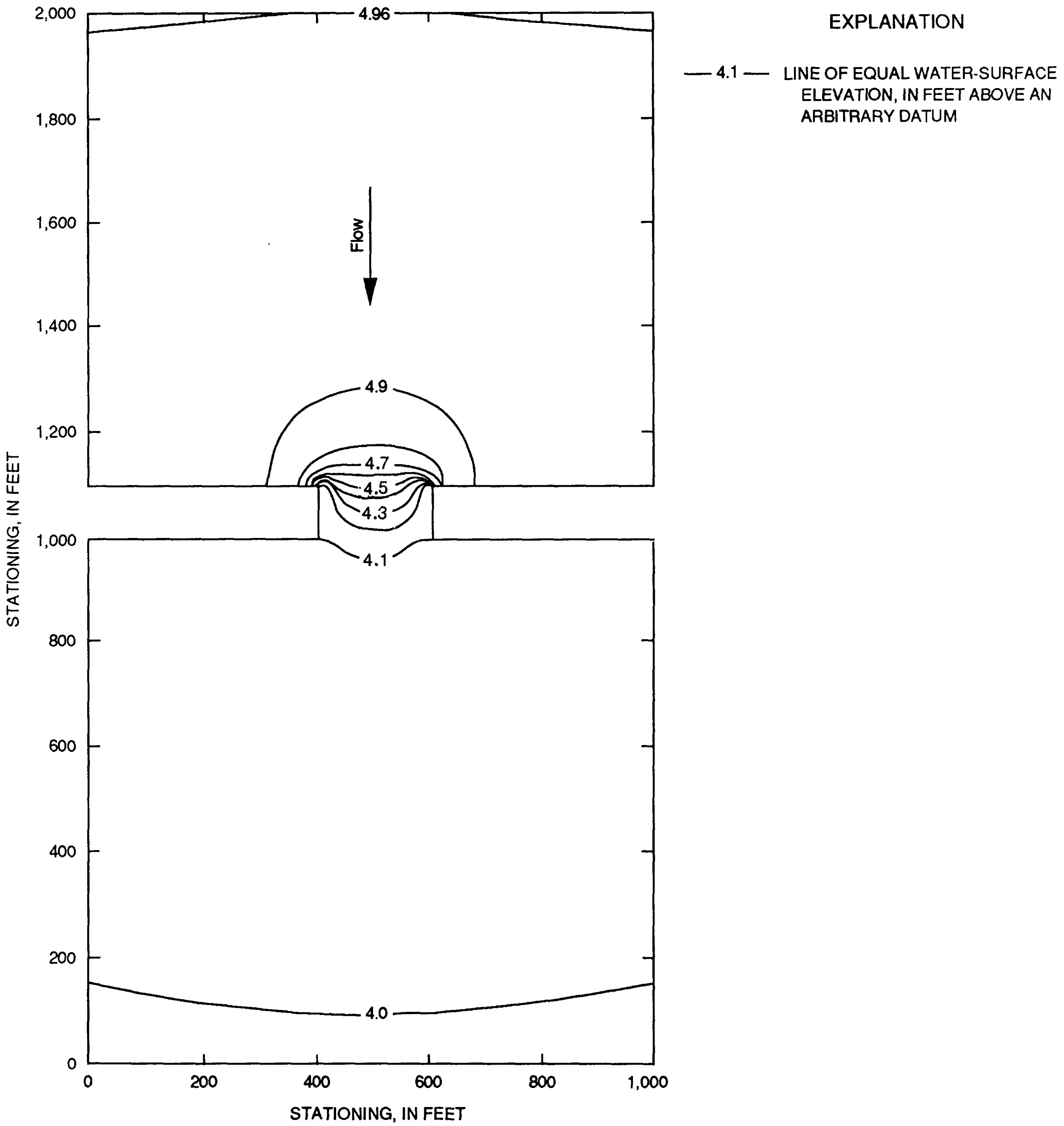


Figure 15.--Line of equal water-surface elevation for hypothetical site using Finite Element Surface-Water Modeling System (FESWMS).

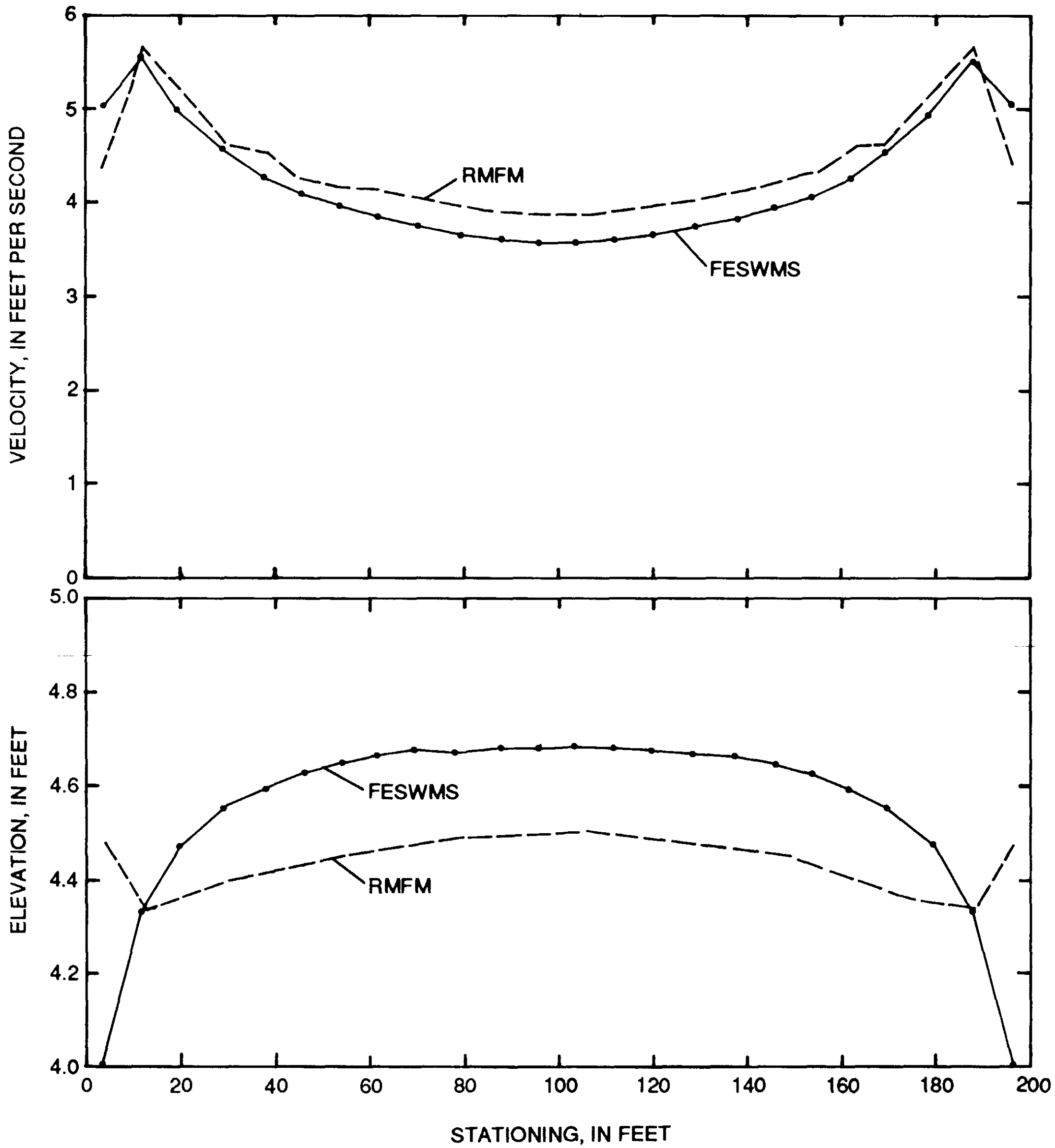


Figure 16.--Distribution of velocity and water-surface elevation along upstream side of bridge for hypothetical site, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water Modeling System (FESWMS) models.

Table 1.--*Water-surface elevations, velocity, and discharge data generated by models at upstream side of the bridge for hypothetical site*

[ft, feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Bridge stationing (ft)	Grid network coordinates I	Grid network coordinates J	Relaxation Method Flow Model (RMFM) Stage (ft)	RMFM Velocity (ft/s)	RMFM Discharge (ft^3/s)	RMFM Flow angle (degrees)	Finite Element Surface-Water Modeling System (FESWMS) Stage (ft)	FESWMS Velocity (ft/s)	FESWMS Discharge (ft^3/s)	FESWMS Flow angle (degrees)
400 (abutment)										
404	16	1	4.47	4.39	167	177	3.99	5.04	140	137
412	16	2	4.34	5.62	205	177	4.33	5.51	173	136
421	16	3	4.36	5.20	196	177	4.48	4.99	177	143
429	16	4	4.39	4.62	173	173	4.55	4.57	177	149
438	16	5	4.42	4.52	170	173	4.59	4.27	175	153
446	16	6	4.44	4.25	157	172	4.62	4.06	163	157
454	16	7	4.45	4.19	153	173	4.64	3.92	161	161
462	16	8	4.46	4.12	132	174	4.66	3.81	161	165
470	16	9	4.48	4.05	166	174	4.67	3.72	170	168
479	16	10	4.49	3.98	160	175	4.68	3.65	169	172
487	16	11	4.49	3.90	152	176	4.68	3.60	167	175
496	16	12	4.50	3.89	169	178	4.68	3.56	167	178
504	16	16	4.50	3.89	169	180	4.68	3.56	167	182
513	16	14	4.49	3.90	152	184	4.68	3.60	167	185
521	16	15	4.49	3.98	160	185	4.68	3.65	169	189
530	16	16	4.47	4.05	166	186	4.67	3.72	170	192
538	16	17	4.46	4.12	132	186	4.66	3.81	161	195
546	16	18	4.45	4.21	153	187	4.64	3.92	161	199
554	16	19	4.44	4.26	157	187	4.62	4.06	163	202
562	16	20	4.42	4.53	170	187	4.59	4.27	175	207
571	16	21	4.39	4.63	173	187	4.55	4.58	177	212
579	16	22	4.36	5.22	196	183	4.48	4.99	177	217
588	16	23	4.34	5.64	205	182	4.33	5.52	173	224
596	16	24	4.47	4.40	167	183	3.99	5.04	140	223
600 (abutment)	16									
Total					4,000				4,000	
At downstream end of reach	1	11	4.00				4.00			
At upstream end of reach	26	11	4.96				4.96			

The distribution of velocity along the downstream side of the bridge differs between the two model runs (fig. 17). The RMFM results had higher velocities near the abutment and lower velocities near the middle of the channel than did the FESWMS results. Eddies at each downstream abutment were generated by FESWMS. Eddies were not generated by RMFM. Because actual velocity data are not available, it is difficult to determine which model gives more reasonable results.

A center line water-surface profile computed from a direct application of one-dimensional theory and computed by use of WSPRO, a water-surface profile computation model, is shown on figure 18. The one-dimensional plot assumes an entrance loss coefficient of 0.5 and the value of alpha to be unity everywhere, so there is a discontinuity in water-surface elevation at the upstream end of the bridge.

Center line water-surface profiles developed by using the water-surface elevations generated by RMFM and FESWMS are also shown on figure 18. The one-dimensional profile computed by WSPRO shows that RMFM provides a good approximation of the water-surface profile. The water-surface elevation at the upstream end of the reach computed by WSPRO is 0.15 ft higher than the water-surface elevation computed by RMFM and FESWMS. An entrance loss coefficient of 0.80 in WSPRO would have matched the 4.96 ft value obtained by RMFM and FESWMS.

The CPU (central processing unit) time for running RMFM was much less than that required to run FESWMS. The RMFM run used 3 minutes of CPU time and FESWMS used 62 minutes.

The 100-ft distance through the bridge (highway fill) that was used may be longer than a typical two-lane highway fill, but it may be typical of a four-lane interstate highway. To examine the effects of a shorter bridge width on model results, the grid network was modified so that the distance through the bridge was equal to 30 ft. Both models were run using this network. The velocity distribution along the downstream side of the bridge generated by both models is shown on figure 19. Both distributions have the same shape between stations 50 and 150, but RMFM computed velocities near the abutment that were higher than those computed by FESWMS.

Okatoma Creek at State Highway 28 near Magee, Mississippi

A prototype site with observed data was included in the study in an effort to explain the differences in the velocity distribution generated by the two models for the downstream side of the bridge at the hypothetical site (fig. 17). An actual bridge site was needed that was similar to the hypothetical site and for which current-meter measurement data were available for the downstream side of the bridge. A bridge site in Arkansas with those conditions could not be found. A site on Okatoma Creek at State Highway 28 near Magee, Mississippi, was used for the comparison.

The bridge across Okatoma Creek at this site is 202 ft long and the length through the bridge (highway fill) is 115 ft. The downstream side of the bridge is 90 ft downstream from the upstream edge of the highway fill. The current-meter measurement made along the downstream side of the bridge showed an average velocity of 8.42 ft/s. This measurement was made during the April 12, 1974, flood at an elevation 0.26 ft below the crest. Numerous high-water marks and several cross sections were recovered after the flood and tied in with level surveys.

A grid network was developed to describe the geometry of the site (fig. 20). Because the accuracy of the abutment geometry is critical, the abutment geometry was surveyed March 21, 1990. The grid network near the abutments was developed using this survey. Ground elevations were estimated for each element based on the cross sections determined during the 1974 survey. Manning's roughness coefficient values were originally selected in 1974 based on engineering judgement. Roughness coefficients originally selected for the main channel ranged from 0.04 to 0.08. Roughness coefficients selected for the overbank pasture ranged from 0.08 to 0.11.

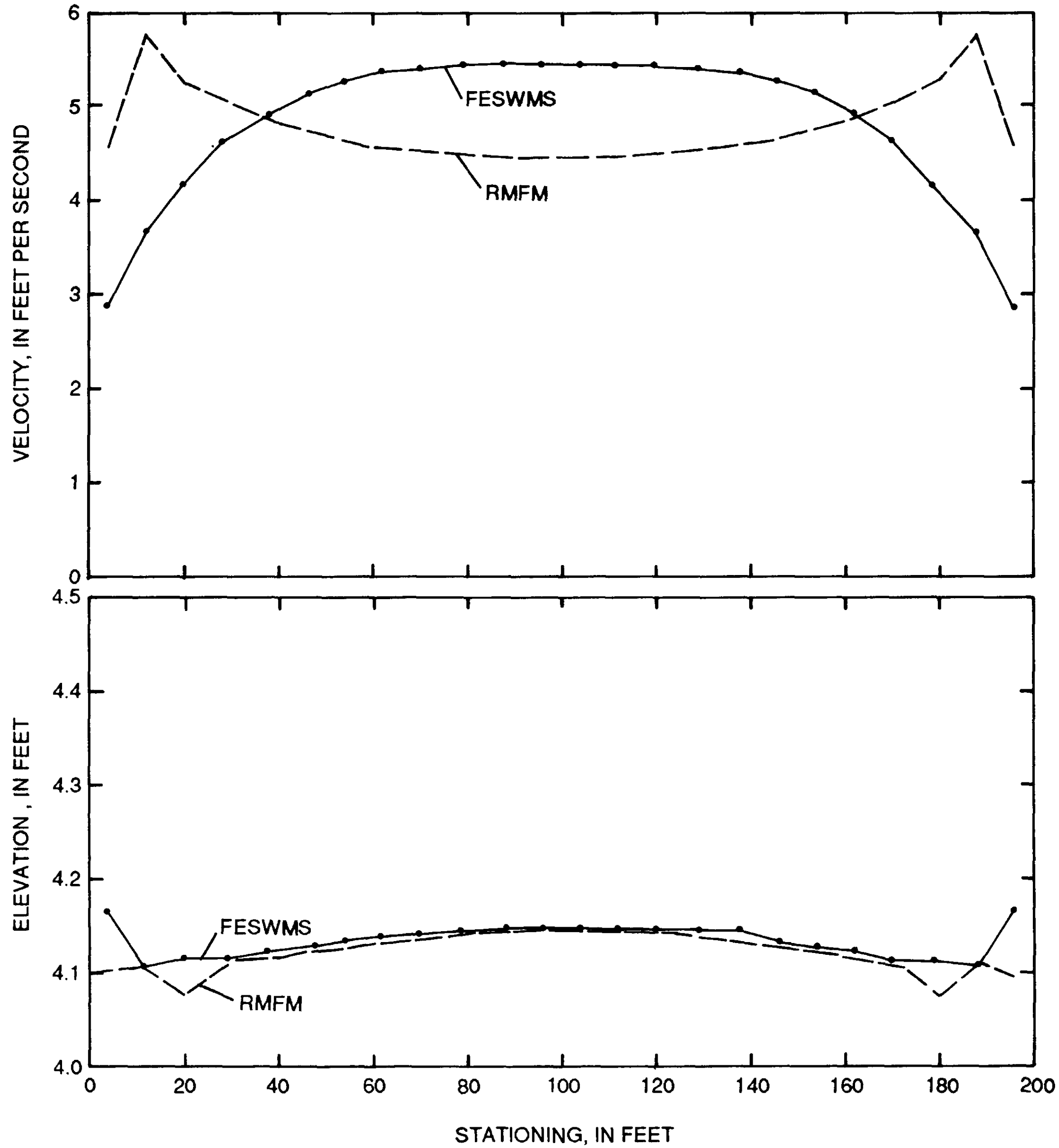


Figure 17.--Distribution of velocity and water-surface elevation along downstream side of bridge for hypothetical site, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water Modeling System (FESWMS) models.

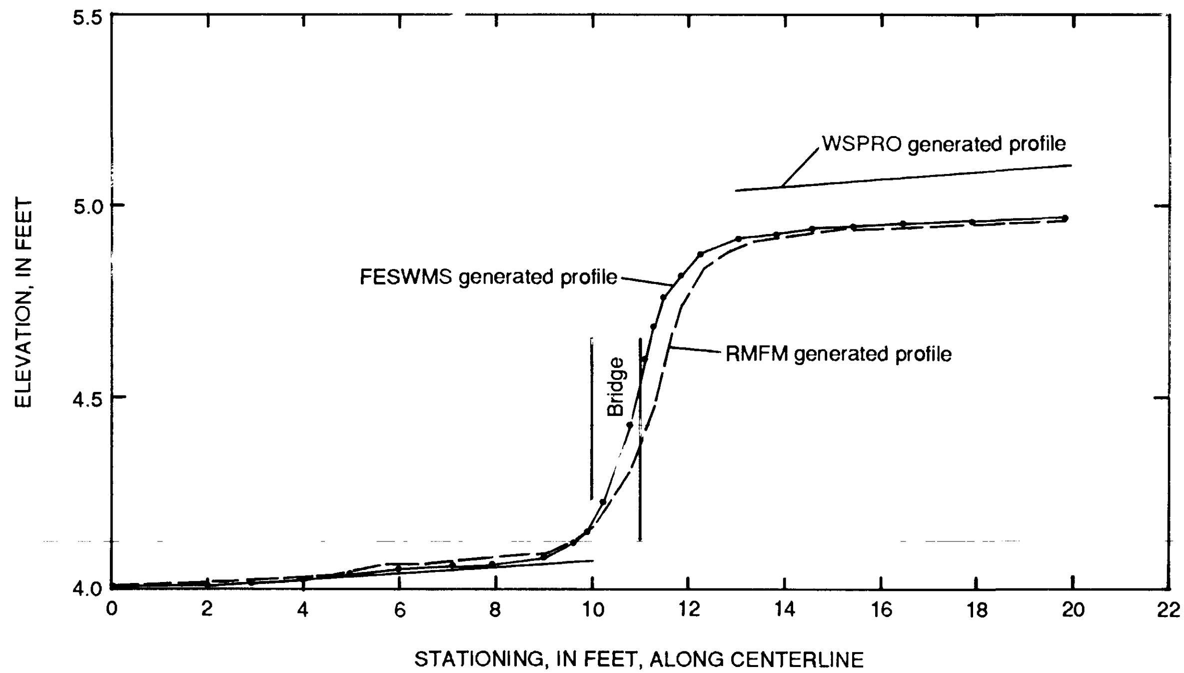


Figure 18.--Water-surface profile of hypothetical site, as simulated using Relaxation Method Flow Model (RMFM), and Finite Element Surface-Water Modeling System (FESWMS), and Water-Surface Profile (WSPRO) models.

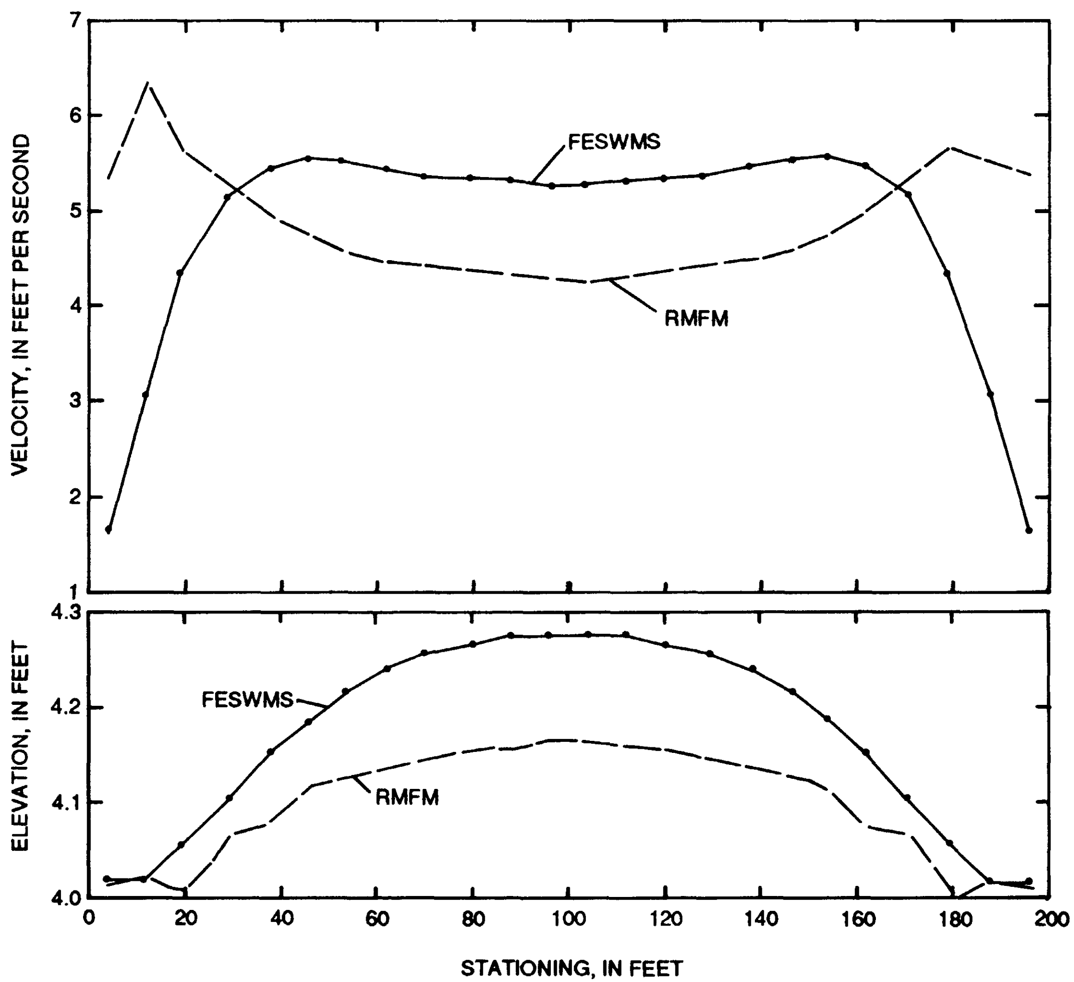


Figure 19.--Distribution of velocity and water-surface elevation along downstream side of bridge for hypothetical site with abutment length equal to 30 feet, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water Modeling System (FESWMS) models.

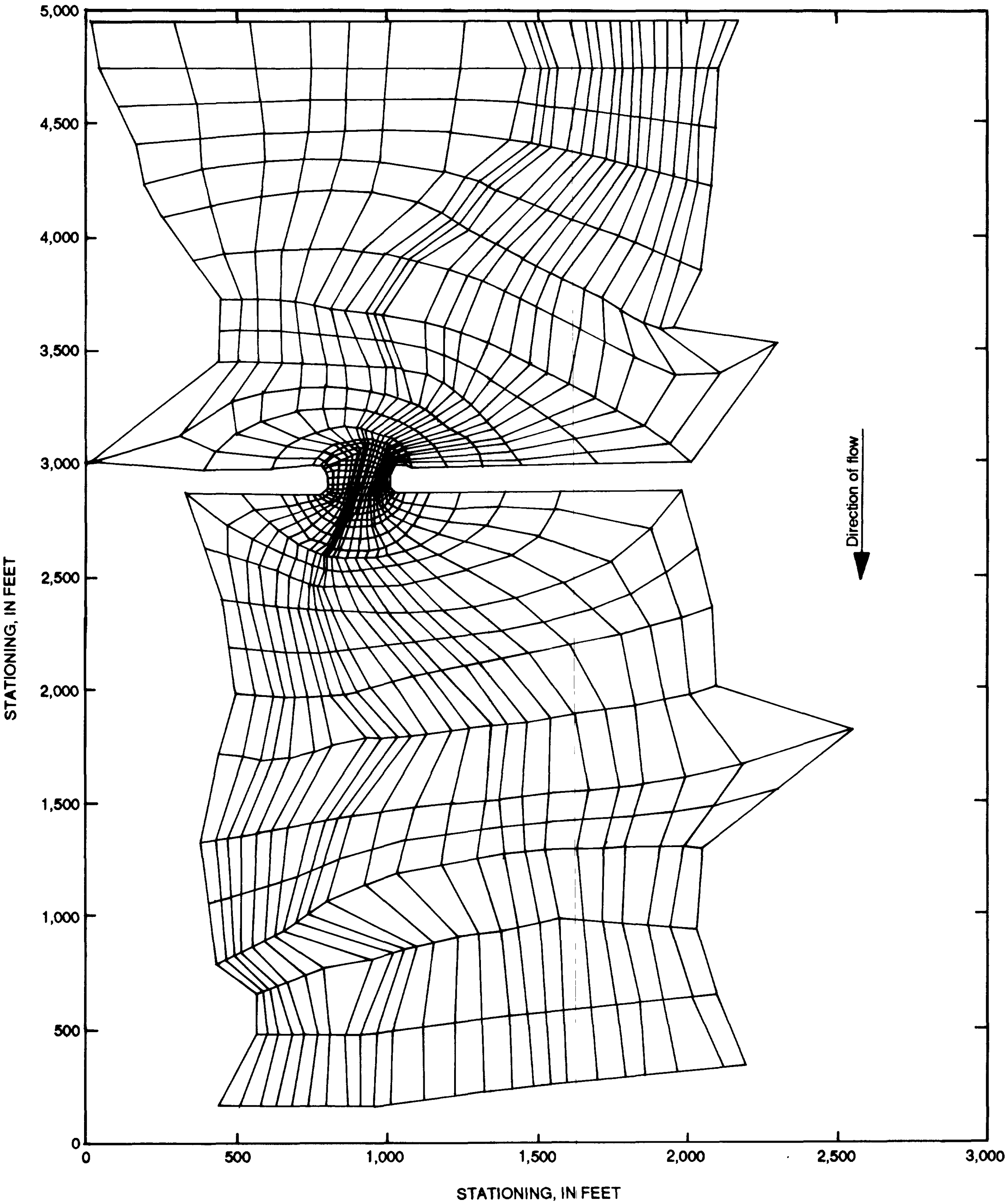


Figure 20.--Grid network for Okatoma Creek at State Highway 28 near Magee, Mississippi.

Roughness coefficients selected for the wooded area on the flood plain ranged from 0.11 to 0.18. Roughness coefficients for the bridge section were selected March 21, 1990, as 0.03 for the main channel and 0.02 for the overbank. The final roughness coefficients were calibrated for the RMFM using known high-water elevations recovered at the site and the measured discharge. The calibrated roughness coefficients used in RMFM were 0.06 for the main channel, 0.09 for the pasture, 0.17 for the wooded area, 0.03 for the main channel at the bridge, and 0.02 for the overbank at the bridge. The coefficients that were calibrated fell within the limits originally selected. Roughness coefficients also were calibrated for FESWMS using known high-water elevations recovered at the site and the measured discharge. The calibrated roughness coefficients used in FESWMS were 0.06 for the main channel, 0.11 for the pasture, 0.19 for the wooded area, 0.03 for the main channel at the bridge and 0.02 for the overbank at the bridge. The coefficient calibrated for the wooded area falls outside the limits originally selected. This is not alarming because the selection of roughness coefficients is subjective. The water-surface elevations generated by FESWMS at the upstream end of the reach are 0.20 ft lower than those generated by RMFM. The water-surface elevations under the bridge generated by FESWMS are 0.05 ft higher than those generated by RMFM.

Both computer models were run using identical input data. The velocities and elevations computed by each model and the measured velocities along the downstream side of the bridge are shown on figure 21. The measured velocity along the downstream side of the bridge changes abruptly from measuring section to measuring section (fig. 21). The computed velocities using RMFM tend to follow the abrupt changes in velocity slightly better than FESWMS. The velocities generated by FESWMS are smooth without abrupt changes. Velocities generated by both models, however, agree reasonably well with the measured velocities except between bridge stations 140 and 180, where the measured velocities are higher. One n value was arbitrarily used for the entire overbank section. However, it is possible that at the time of the flood, n values varied substantially across the overbank section.

The primary reason for including this site in the report was to resolve the question generated by the data on figure 17 as to which model gives more reasonable results along the downstream side of bridges when the distance through the bridge (highway fill) is large. The data shown on figure 21 do not indicate that either model is better, although RMFM tends to follow the abrupt changes in velocity better than FESWMS. It should be noted, however, that the maximum computed velocities are less and in different locations for model runs than the observed maximum velocities.

Water-surface profiles were developed for the main channel using the water-surface elevations generated by RMFM and FESWMS. These profiles are shown on figure 22. The elevations of the high-water marks recovered at the site were lowered by 0.26 ft and plotted on figure 22. The current-meter measurement during the April 12, 1974, flood was made 0.26 ft below the crest elevation. The profiles generated by both models agree reasonably well with the high-water marks recovered.

The CPU time for running RMFM was 4 minutes and the time required to run FESWMS was 9.5 hours. FESWMS required 22 iterations before it converged. The water-surface elevations, velocities, and discharge data generated by RMFM, FESWMS, and the measured velocity and discharge for points along the downstream side of the bridge are listed in table 2. The velocity vectors generated by RMFM are shown in figure 23. The length of the vector indicates the velocity and the arrow shows the direction of flow.

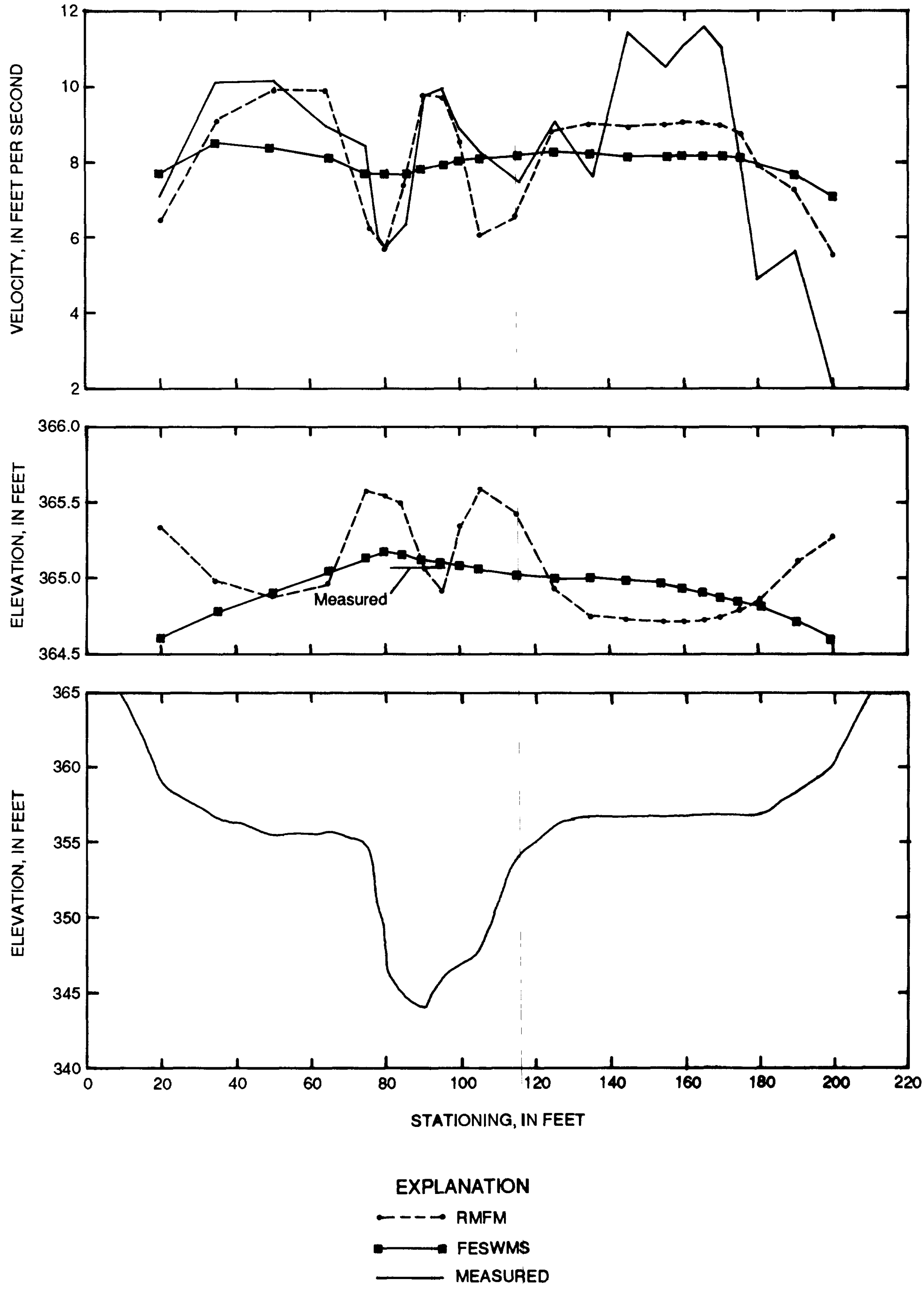


Figure 21.--Distribution of velocity, water-surface elevation, and cross-section along downstream side of bridge for Okatoma Creek at State Highway 28 near Magee, Mississippi, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water Modeling System (FESWMS) models and as measured on April 12, 1974.

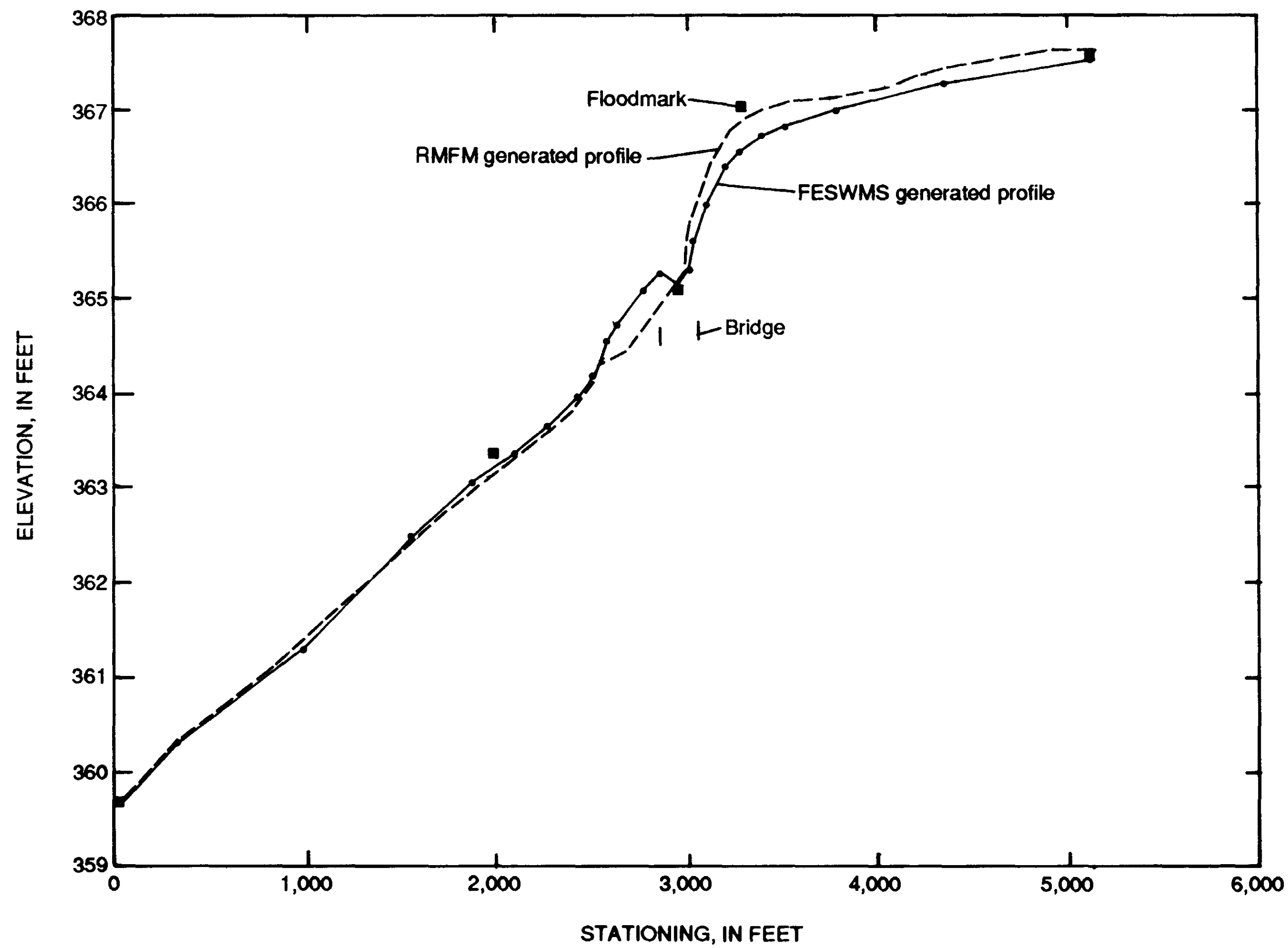


Figure 22.--Water-surface profile along main channel for flood of April 12, 1974, on Okatoma Creek at State Highway 28 near Magee, Mississippi, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water Modeling System (FESWMS) models.

Table 2.--*Water-surface elevations, velocity, and discharge data generated by models and measured April 12, 1974, at Okatoma Creek at State Highway 28 near Magee, Mississippi*

[ft, feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Bridge stationing (ft)	Grid network coordinates I	J	Measured: Stage (ft)	Measured: Depth (ft)	Measured: Velocity (ft/s)	Measured: Discharge (ft^3/s)	Measured: Flow angle (degrees)	Relaxation Method Flow Model (RMFM): Stage (ft)	RMFM: Velocity (ft/s)	RMFM: Flow angle (degrees)	Finite Element Surface-Water Modeling System (FESWMS): Stage (ft)	FESWMS: Velocity (ft/s)	FESWMS: Flow angle (degrees)
212 (abutment)				0									
200	22	1		6.3	7.16	609	180	365.34	6.54	178	364.59	7.70	186
185	22	2		8.4	10.13	1,276	180	364.98	9.10	179	364.77	8.52	186
170	22	3		9.5	10.13	1,438	180	364.88	9.85	181	364.92	8.38	185
155	22	4		9.2	8.98	1,033	180	364.98	9.95	181	365.06	8.17	185
145	22	5		10.0	8.54	640	180	365.58	6.33	180	365.14	7.74	185
140	22	6		18.6	5.38	500	180	365.57	5.71	181	365.17	7.74	185
135	22	7		20.2	6.40	646	180	365.51	7.24	179	365.15	7.73	185
130	22	8	365.06	21.0	9.57	1,005	180	365.09	9.71	179	365.12	7.83	185
125	22	9		18.8	9.90	931	180	364.94	9.75	179	365.10	7.95	185
120	22	10		18.0	8.82	794	180	365.35	8.57	179	365.09	8.11	185
115	22	11		17.5	8.29	1,086	180	365.60	6.10	175	365.06	8.16	184
105	22	12		11.0	7.56	832	180	365.45	6.59	175	365.03	8.21	183
95	22	13		8.5	9.07	771	180	364.94	8.86	176	365.01	8.27	181
85	22	14		8.0	5.76	461	180	364.75	9.01	175	365.01	8.23	180
75	22	15		8.2	11.49	942	180	364.74	8.99	175	364.99	8.18	179
65	22	16		8.0	10.56	634	180	364.72	9.01	175	364.97	8.20	179
60	22	17		8.0	11.11	444	180	364.71	9.06	175	364.94	8.20	178
55	22	18		8.1	11.60	464	180	364.71	9.02	176	364.91	8.20	178
50	22	19		8.0	11.04	442	180	364.76	9.05	176	364.88	8.18	178
45	22	20		8.0	8.17	327	180	364.80	8.87	177	364.85	8.10	177
40	22	21		8.0	4.96	298	180	364.89	7.83	176	364.81	7.99	177
30	22	22		6.2	5.40	335	164	365.12	7.36	176	364.73	7.66	175
20	22	23		4.6	1.88	86	180	365.28	5.51	176	364.60	7.16	176
10 (abutment)				0									
Total						16,100							
At downstream end of reach	1	1	359.66					359.66			359.66		
At bridge	22	7	365.06					365.07			365.12		
At upstream end of reach	43	11	367.58					367.68			367.48		

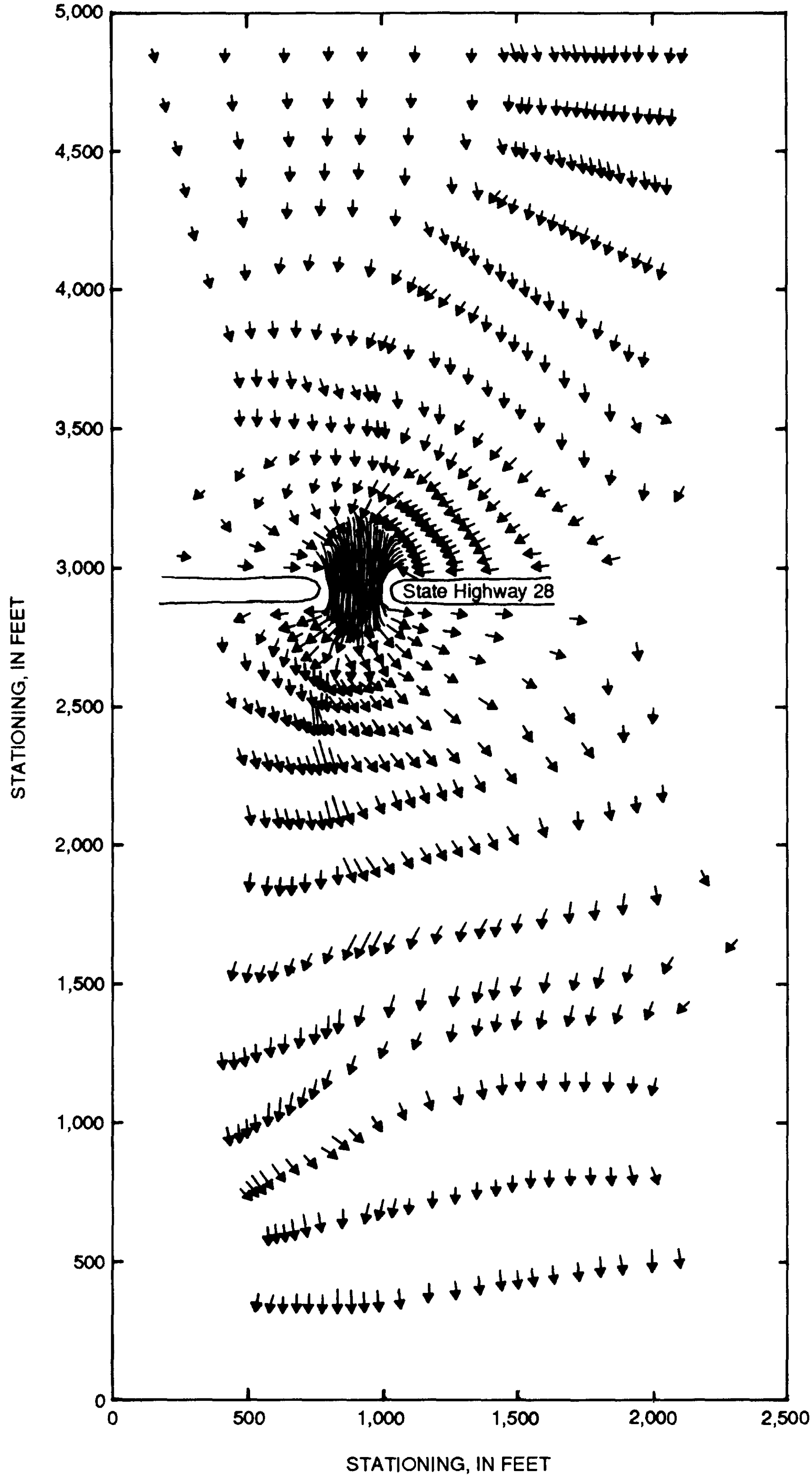


Figure 23.--Velocity vectors for flood of April 12, 1974, at Okatoma Creek at State Highway 28 near Magee, Mississippi.

Saline River at State Highway 160 near Johnsville, Arkansas

The State Highway 160 crossing of Saline River has a main channel bridge and two relief bridges on the east flood plain (fig. 24). A grid network was developed to describe the geometry of this site (fig. 25). Ground elevations were estimated for each element based on highway cross sections at and near the highway and topographic maps of the area. Manning's roughness coefficient values were originally selected based on engineering judgement. The final roughness coefficients were calibrated for both models using known high-water elevations recovered at the site and an estimated discharge based on the peak discharge of the December 1987 flood at the gaging station 38 miles upstream. The calibrated roughness coefficients were the same for both models. A roughness coefficient of 0.030 was used for the main channel. Roughness coefficients of 0.035 and 0.150 were used for the pasture and wooded areas of the flood plain, respectively. These roughness coefficients were calibrated for both models.

The results of both model runs are for present conditions using the discharge of the December 1987 flood. Lines of equal water-surface elevations generated by RMFM and FESWMS are shown in figures 26 and 27, respectively.

Water-surface profiles shown on figure 28 were developed for the main channel by using the water-surface elevations generated by RMFM and FESWMS. The elevations of high-water marks recovered at the site also are plotted on figure 28. The profiles generated by both models agree reasonably well with the high-water marks recovered.

The distribution of velocity along the downstream side of the main channel bridge generated by both models is shown on figure 29. A current-meter measurement is not available at this site for comparison.

The water-surface elevations, velocity, and discharge data, generated by each model for points along the bridges are listed in table 3. The average water-surface elevation under the main channel bridge is the same using both models. The water-surface elevations at the upstream end of the reach generated by FESWMS are 0.01 ft higher than those generated using RMFM. The distribution of discharge among the bridges is similar for both models. More discharge over the highway was computed using FESWMS than was computed using RMFM because a higher upstream water-surface elevation was also computed using FESWMS.

Less CPU time was required to run RMFM than was required to run FESWMS. The RMFM run used 9 minutes of CPU time and the FESWMS run used 120 minutes.

INFLUENCE OF GRID LAYOUT

The grid layout that is used to define the geometry of the flood plain will influence the results generated by the model. Different model users who draw different grids will get different answers. If, however, the users draw the vertical lines of the grid reasonably parallel to flow lines and draw the horizontal lines reasonably normal to flow then the answers will be similar.

To test the effect of grid layout, the grid for a hypothetical site was deliberately drawn in violation of the general rules for drawing the grid (fig. 30). In this example, the flow at each abutment crosses the vertical and horizontal lines. Also, the flow crosses the vertical lines as it approaches the bridge and as it leaves the bridge to be distributed on the flood plain. This grid layout incorporates most of the grid layout problems that a user might make.

The geometry of this site is identical to the hypothetical site used in a previous section. The flood plain of the hypothetical site was assumed to be 1,000 ft wide and the length of the reach was 2,100 ft. A 200-ft bridge was centered on the flood plain near the middle of the reach. The distance through the bridge (highway fill) was 100 ft. The discharge, ground elevations, and "n" values are identical to those used in the previous example at the hypothetical site.

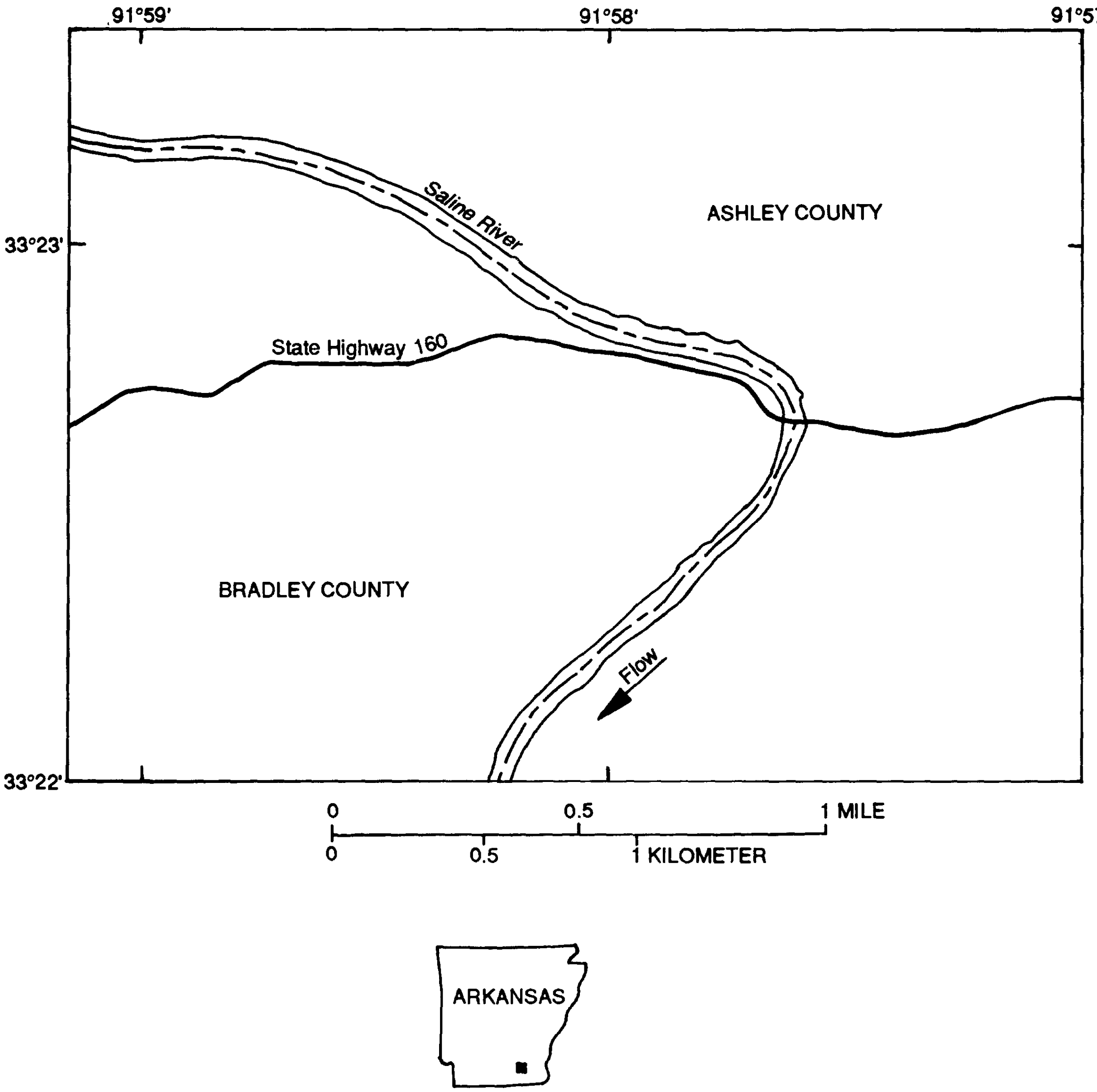


Figure 24.-- Saline River at State Highway 160 near Johnsville, Arkansas.

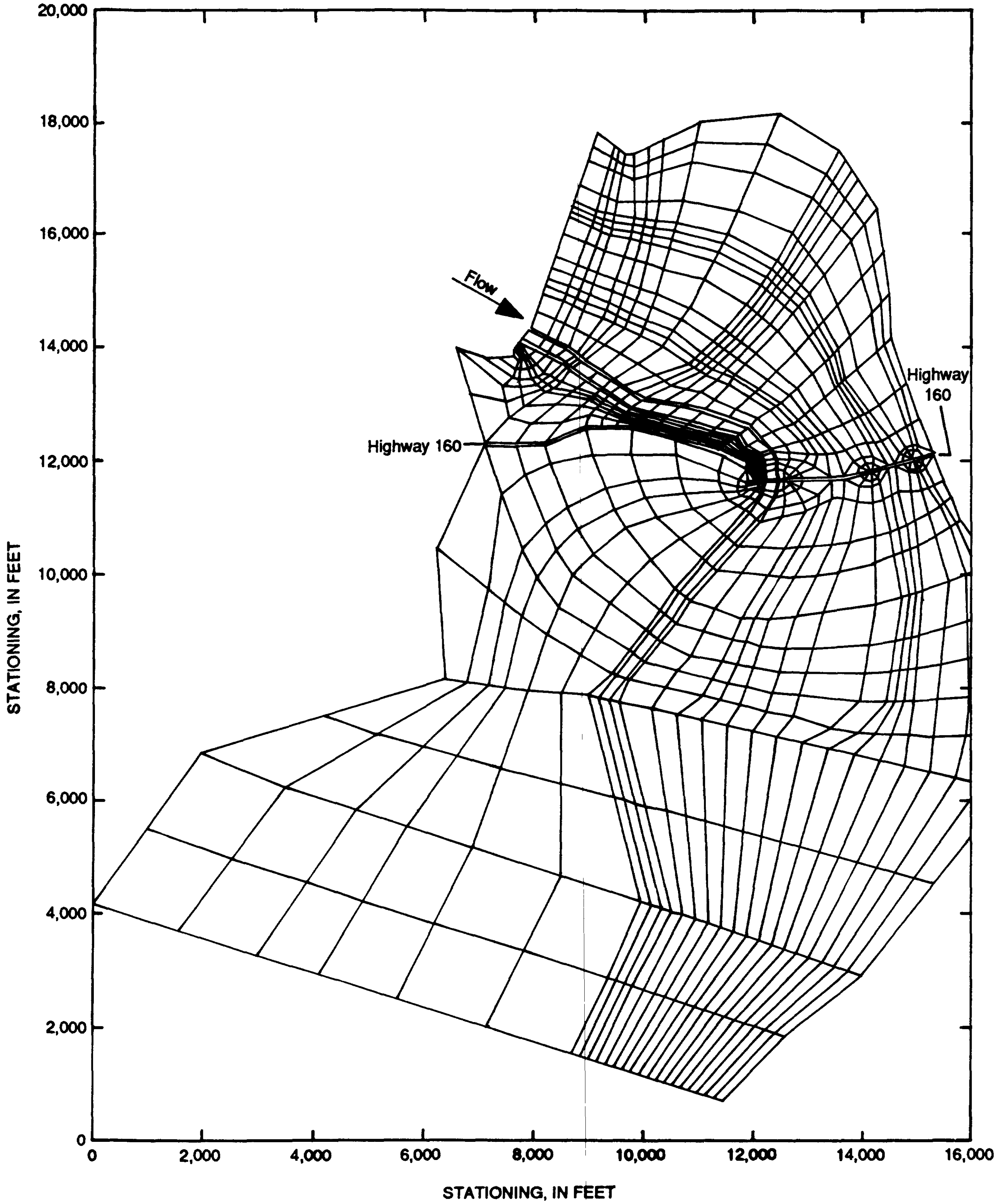


Figure 25.--Grid network for the Saline River at State Highway 160 near Johnsville, Arkansas.

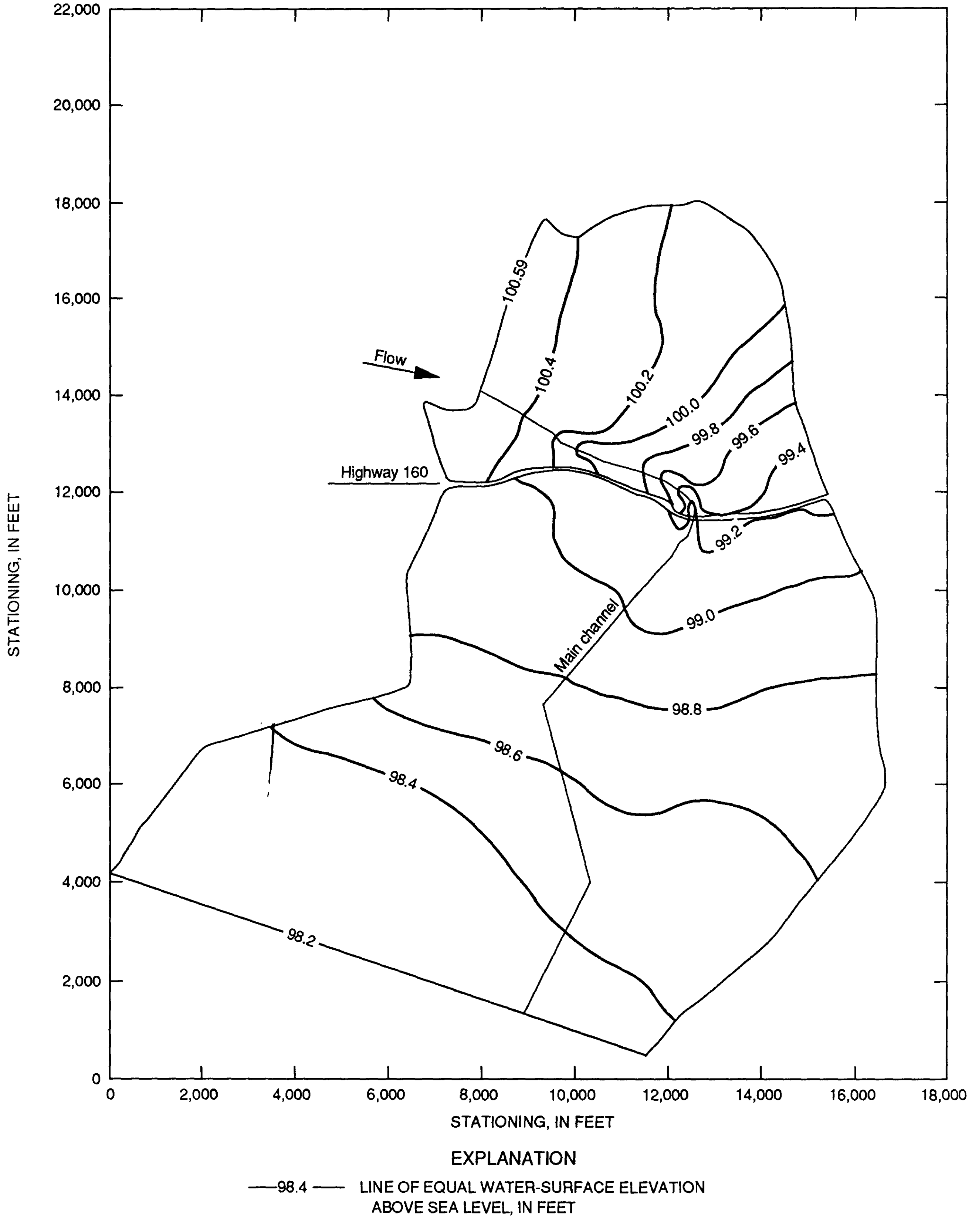
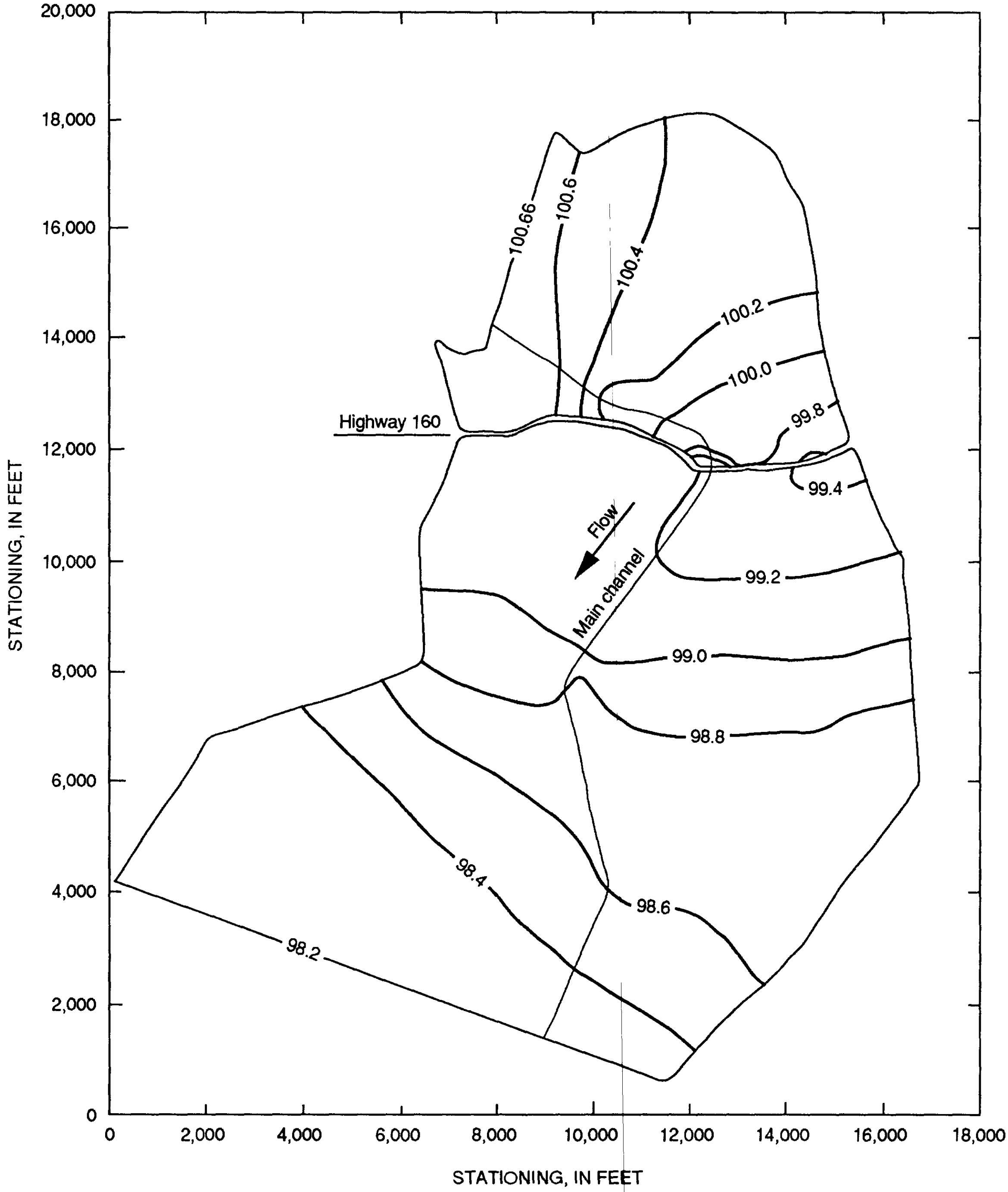


Figure 26.--Lines of equal water-surface elevation for the December 1987 flood on the Saline River at State Highway 160 near Johnsville, Arkansas, generated using the Relaxation Method Flow Model (RMFM).



EXPLANATION

—98.4— LINE OF EQUAL WATER-SURFACE ELEVATION ABOVE SEA LEVEL, IN FEET

Figure 27.--Lines of equal water-surface elevations for the December 1987 flood on the Saline River at State Highway 160 near Johnsville, Arkansas, generated using the Finite Element Surface-Water Modeling System (FESWMS).

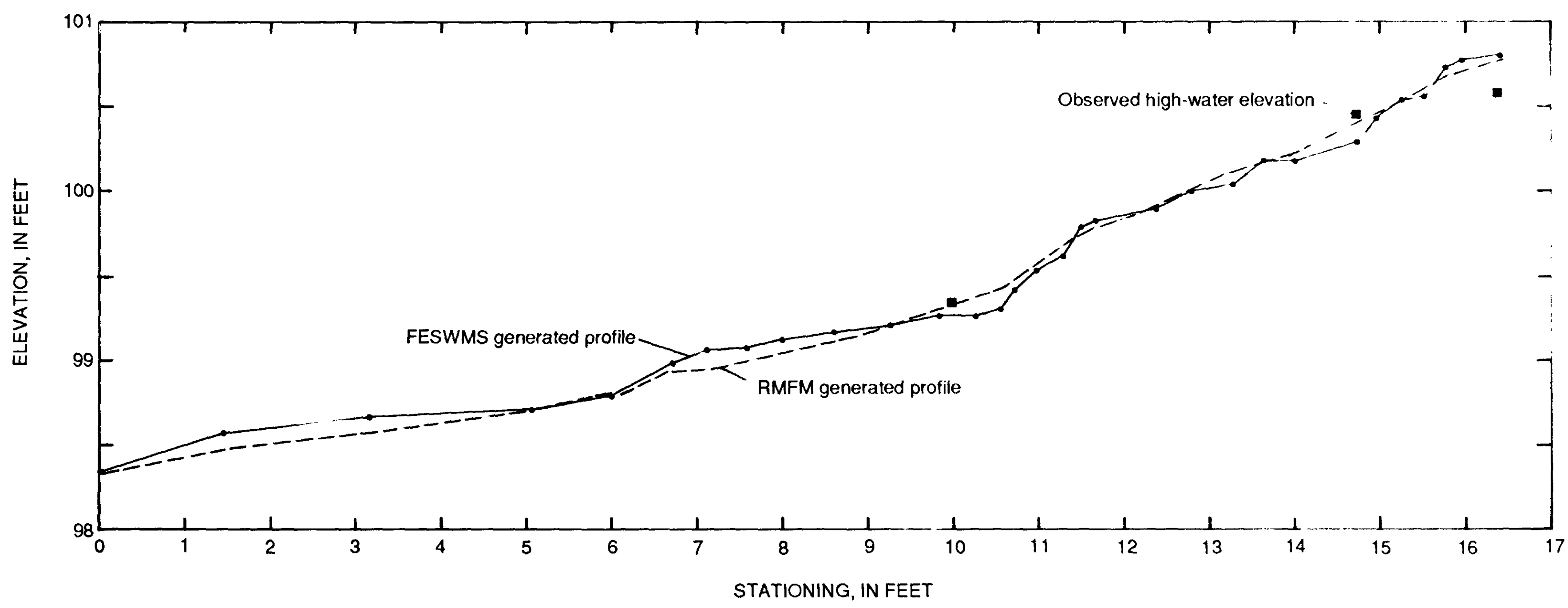


Figure 28.--Water-surface profile for flood of December 1987 of the Saline River at State Highway 160 near Johnsville, Arkansas, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water Modeling System (FESWMS) models.

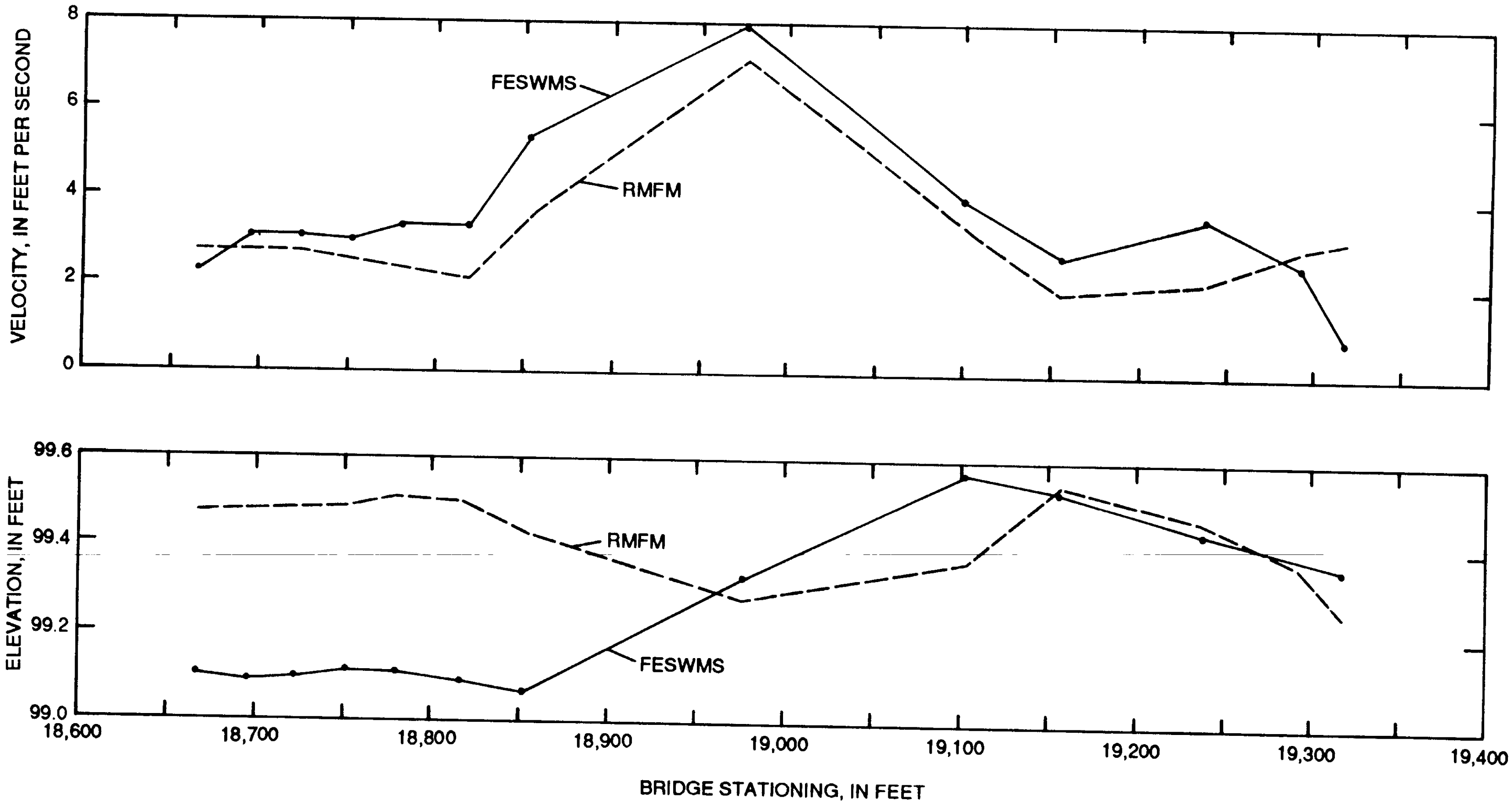


Figure 29.--Distribution of velocity and water-surface elevation along downstream side of main channel bridge for flood of December 1987 on the Saline River at State Highway 160 near Johnsville, Arkansas, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water Modeling System (FESWMS) models.

Table 3.--*Water-surface elevations, velocity, and discharge data generated by models for December 31, 1987, flood on Saline River at State Highway 160 near Johnsville, Arkansas*

[ft, feet; ft/s, feet per second; ft^3/s, cubic feet per second]

Bridge stationing (ft)	Grid network coordinates I	Grid network coordinates J	Relaxation Method Flow Model (RMFM) Stage (ft)	RMFM Velocity (ft/s)	RMFM Discharge (ft^3/s)	RMFM Flow angle (degrees)	Finite Element Surface-Water Modeling System (FESWMS) Stage (ft)	FESWMS Velocity (ft/s)	FESWMS Discharge (ft^3/s)	FESWMS Flow angle (degrees)
18,654 (abutment)										
18,668	17	1	99.47	2.71	340	178	99.10	2.19	380	169
18,696	17	2	99.48	2.77	370	179	99.08	2.88	320	164
18,724	17	3	99.48	2.74	360	189	99.10	2.89	390	167
18,752	17	4	99.49	2.52	340	198	99.11	2.85	370	167
18,780	17	5	99.51	2.33	330	202	99.11	3.20	450	167
18,819	17	6	99.50	2.05	520	201	99.08	3.27	660	171
18,854	17	7	99.43	3.43	1,570	181	99.06	5.10	1,790	183
18,979	17	8	99.28	7.04	65,970	180	99.33	7.60	63,390	184
19,104	17	9	99.37	3.24	1,440	178	99.57	3.89	2,040	179
19,155	17	10	99.56	1.87	590	160	99.53	2.67	730	200
19,238	17	11	99.47	2.16	770	166	99.44	3.47	1,140	199
19,292	17	12	99.37	2.85	320	169	99.38	2.49	320	196
19,317	17	16	99.26	3.51	320	168	99.36	0.84	130	187
19,329 (abutment)										
Subtotal					73,240				72,110	
20,700 (abutment)										
20,712	17	15	99.27	2.73	560	166	99.41	1.42	240	172
20,750	17	16	99.30	2.11	1,190	168	99.48	2.80	1,590	166
20,795	17	17	99.28	2.30	1,020	168	99.50	2.49	1,130	164
20,828	17	18	99.23	2.16	430	165	99.47	1.10	190	152
20,840 (abutment)										
Subtotal					3,200				3,150	
21,555 (abutment)										
21,567	17	20	99.22	.39	60	176	99.54	.38	40	191
21,605	17	21	99.20	.27	130	192	99.57	.66	360	182
21,642	17	22	99.19	.35	90	183	99.58	.59	190	166
21,665	17	23	99.17	.26	60	171	99.58	.48	120	158
21,685	17	24	99.18	.19	20	166	99.58	.34	40	156
21,695 (abutment)										
Subtotal					360				750	
Flow over highway					4,600				5,390	
Total flow					81,400				81,400	
At downstream end of reach	1	1	98.20				98.20			
At upstream end of reach	41	1	100.78				100.79			
1,200 feet upstream from Highway 160 and 150 west of river	33	6	100.42				100.54			

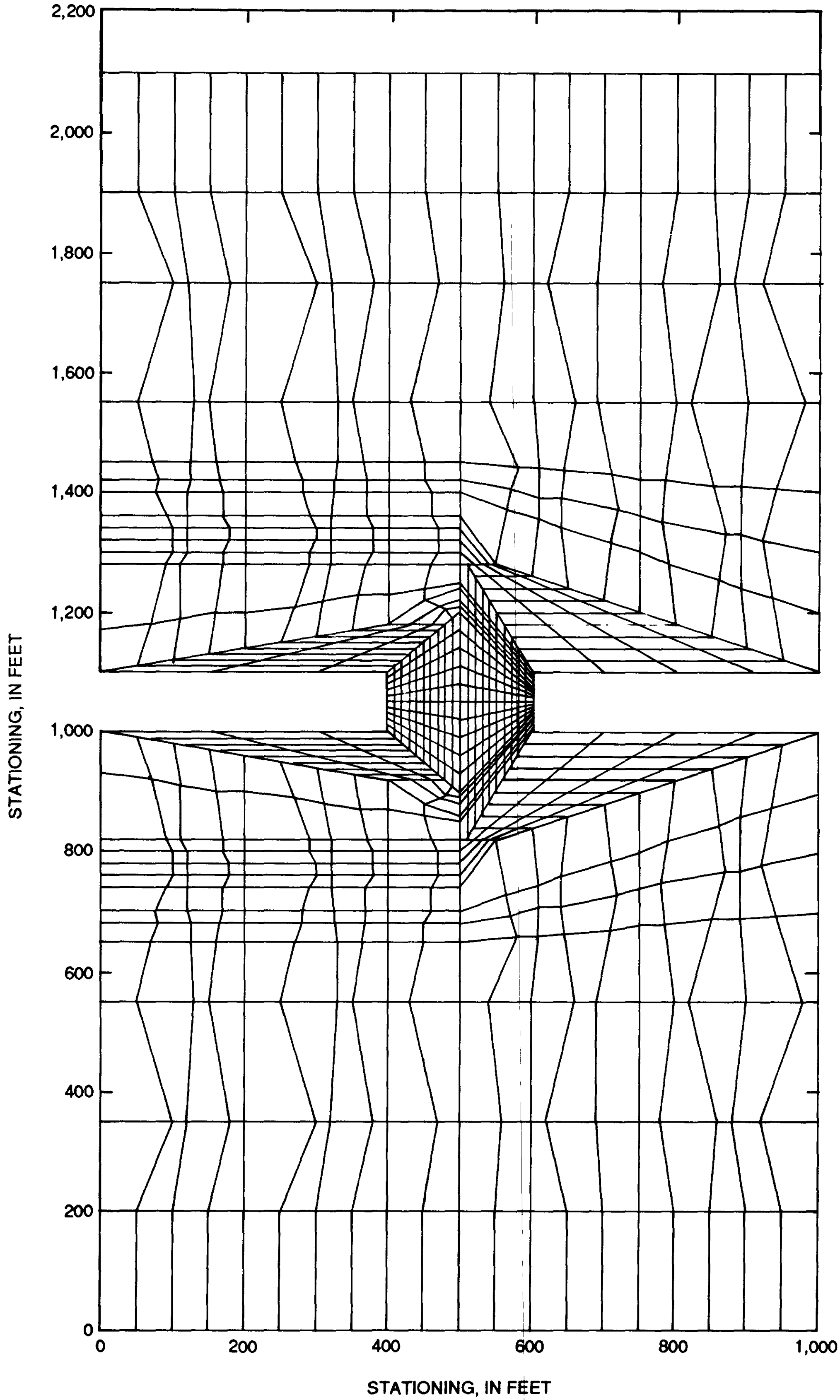


Figure 30.--Incorrectly drawn grid network for hypothetical site.

The models RMFM and FESWMS were run using the grid layout. The flow lines generated by both models are shown in figure 31, for selected flow increments of 10, 20, 50, 80, and 90 percentiles.

Theoretically the 50 percent flow should be in the middle throughout the reach and the flow lines on either side of the midline should be a mirror image of the other. The flow lines in figure 31 show the model results for both RMFM and FESWMS are influenced by the grid layout.

The distribution of velocity along the downstream side of the bridge generated by RMFM and FESWMS are shown in figure 32. The velocities for RMFM are higher near the right abutment (looking upstream) than they are near the left abutment.

The water-surface elevations along the downstream side of the bridge are shown in figure 32. The elevations near the left abutment are higher than those near the right abutment. The water-surface elevations and velocities in figure 32 can be compared with those in figure 17, which were generated using the grid in figure 13. The water-surface elevation at the upstream end of the reach from RMFM was 5.08 ft, which is 0.12 ft higher than the 4.96 ft computed using the grid in figure 13. The water-surface elevation at the upstream end of the reach from FESWMS was 5.02 ft, which is 0.06 ft higher than the 4.96 ft computed using the grid in figure 13.

The distortion of the grid layout in this simple example did not greatly affect the RMFM model results. Comparison of RMFM model runs using the original and the distorted grids, indicate that the flow patterns were similar, surface elevations generally differed by no more than about 0.2 foot, and velocities generally differed by less than about 10 percent. The effect of a badly drawn grid, however, could be greater in more complex systems.

COMPARISON OF RELAXATION METHOD FLOW MODEL RESULTS WITH PEAK DISCHARGE COMPUTED USING INDIRECT METHODS

The U.S. Geological Survey has a procedure for indirectly computing peak discharge at width contractions (Matthai, 1967). This procedure uses the difference in water-surface elevations between a section located one bridge-width upstream (referred to as Section 1) and a section located at the contracted opening (Section 3), normally at the downstream side of the bridge. The equation for computing discharge is as follows:

$$Q = CA_3\sqrt{2g\left(\Delta h + \frac{\alpha_1 v_1^2}{2g} - hf_{1.3}\right)} \qquad (2)$$

where Q is discharge, in cubic feet per second,

C is the coefficient of discharge,

A_3 is the area at section 3, in square feet,

Δh is the difference in elevation of the water surface between sections 1 and 3, in feet,

g is the gravitational acceleration, 32.2 ft/s^2,

$\frac{\alpha_1 v_1^2}{2g}$ is the weighted average velocity head at section 1, in feet,

v_1 is the velocity at section 1, in feet per second, and

$hf_{1.3}$ is the friction loss between sections 1 and 3, in feet.

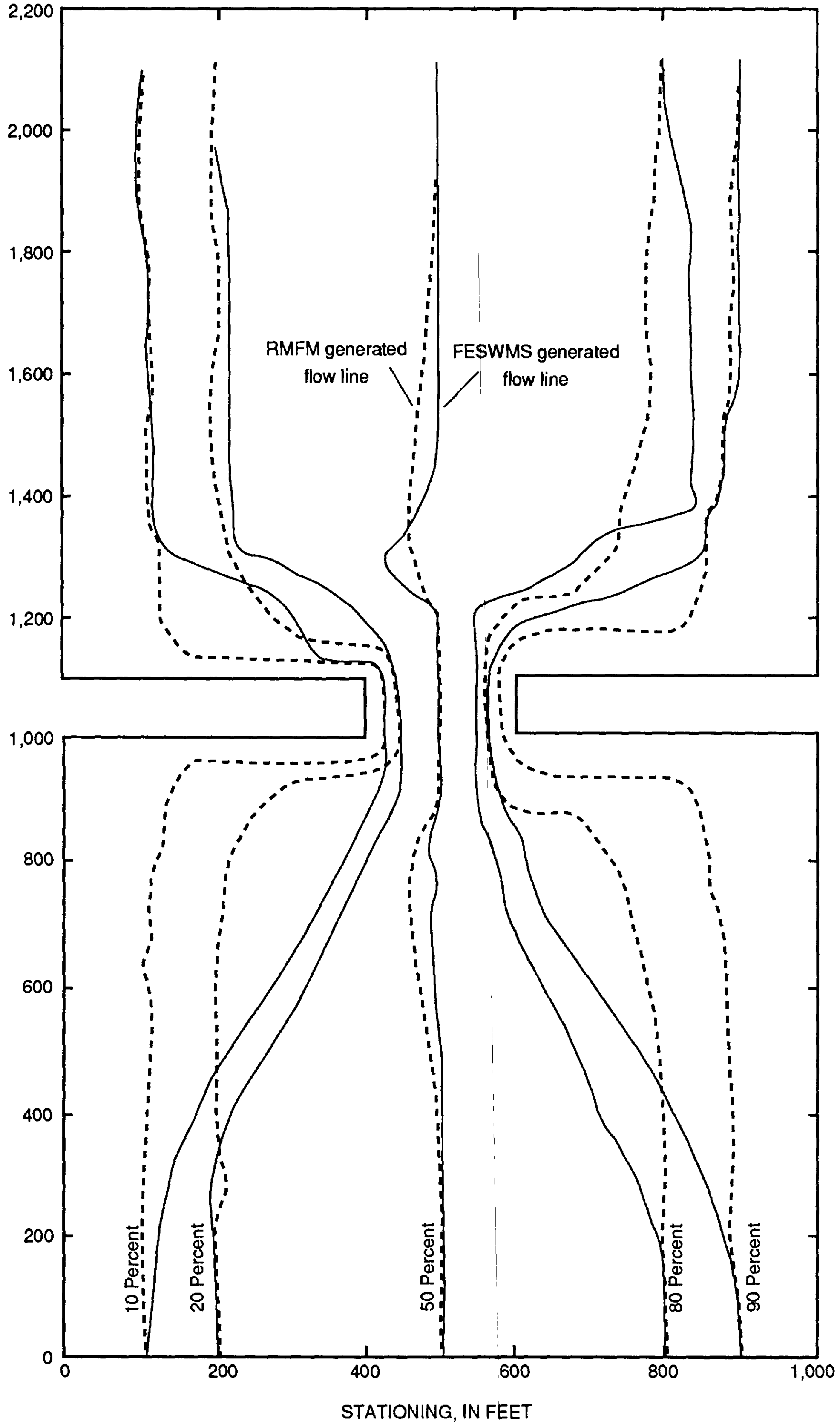


Figure 31.--Distribution of flow for selected flow lines for hypothetical site, for which the grid was incorrectly drawn, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water Modeling System (FESWMS) models.

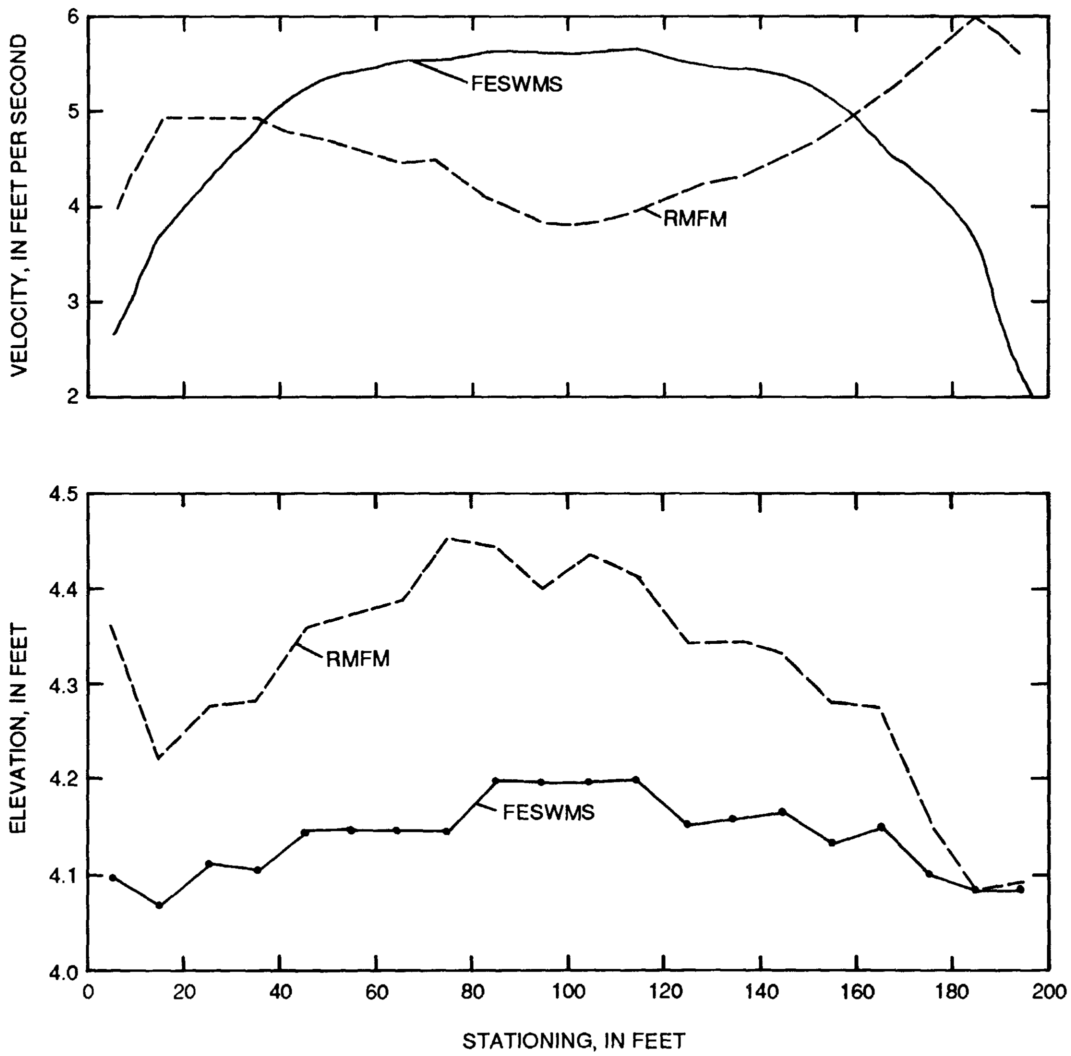


Figure 32.--Distribution of velocity and water-surface elevation along downstream side of bridge for hypothetical site, as simulated using Relaxation Method Flow Model (RMFM) and Finite Element Surface-Water System (FESWMS) models.

In order to compare RMFM results with peak discharges computed using indirect methods, a model run was made using the hypothetical site described in an earlier section. Water-surface elevations generated by the model were used to define the water surface for sections 1 and 3. Conveyance and area computations were made based on the water-surface elevations.

The friction loss through the bridge opening from section 2 located at the upstream side of the bridge to section 3 was computed by the equation LQ^2/K_3^2, where L is the distance through the bridge and K_3 is the conveyance at section 3. The friction loss between sections 1 and 2 was computed by the equation LwQ^2/K_1K_3, where Lw is the average distance from the bridge to the approach section (Schneider and others, 1977) and K_1 and K_3 are conveyances at sections 1 and 3, respectively. The velocity head coefficient, α_1, was assumed to equal 1.00.

The values listed in the table below are needed in the computation.

$Q = 4{,}000\ ft^3/s$	$F = 0.47$ = Froude number
$A_3 = 782\ ft^3$	$K_1 = 621{,}000\ ft^3/s$ = conveyance at section 1
$\Delta h = 1.09$ ft	$K_3 = 82{,}400\ ft^3/s$ = conveyance at section 3
$v_1^2/2g = 0.01$ ft	$b = 200$ ft = bridge width
$hf_{1.2} = 0.13$ ft	Lw= 424 ft = 200 * 2.12
$hf_{2.3} = 0.23$ ft	m = 0.87
$2g = 64.3\ ft/s^2$	L = 100 ft = bridge length

A coefficient of discharge, C, of 0.74 was determined from equation 2 by substituting in the equation the values that were generated by RMFM. A coefficient of discharge of 0.71 was determined by using standard indirect computation methods (Matthai, 1967). The two coefficients of discharge differ by 4 percent.

GOVERNING EQUATIONS

The energy equation used in the RMFM computations is written as:

$$WS_2 - WS_1 = \frac{\alpha_1 V_1^2 X_4}{2g} + \frac{LQ^2}{K_1 K_2 X_1 X_2} - \frac{\alpha_2 V_2^2 X_3}{2g} \qquad (3)$$

where WS_2 is the water surface at center of element 2,
WS_1 is the water surface at center of element 1,
V_1 is the velocity at center of element 1,
V_2 is the velocity at center of element 2,
K_1 is the conveyance of element 1 to flow,
K_2 is the conveyance of element 2 to flow,
Q is the discharge leaving element 2 and entering element 1,
L is the distance from center of element 1 to center of element 2,
X_1 and X_2 is the sine of angle between the direction of flow and the direction of the grid line between elements 1 and 2 (fig. 33),
X_3 and X_4 is the cosine of angle between the direction of flow and the direction between midpoints of adjacent elements (fig. 33)
α_1 and α_2 is alpha 1 and alpha 2 that are assumed to equal unity, and
g is $32.2\ ft/s^2$.

A sketch of the elements is shown on figure 33.

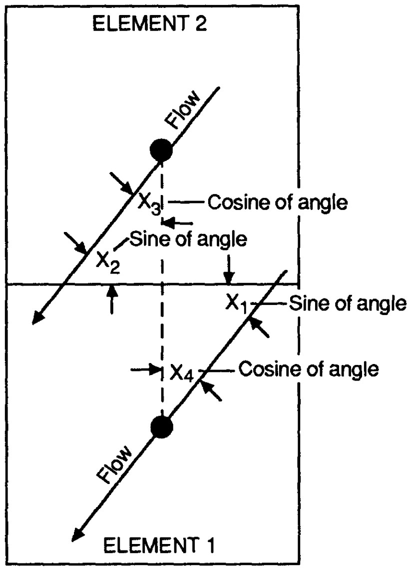


Figure 33.--Sketch showing angle of flow with respect to alignment of element.

The direction of flow between elements in the RMFM grid is designated by positive and negative signs. Positive flow is when flow enters the horizontal face of an element moving from upstream to downstream. Negative flow at the horizontal face of an element is when flow is moving in an upstream direction. Positive flow at the vertical face of an element is when flow is moving from left to right looking upstream. Negative flow at the vertical face of an element is when flow is moving from right to left looking upstream. In equation 3, Q^2 is equal to Q times the absolute value of Q. This shows the direction of the friction slope. The terms V_1^2 and V_2^2 are always positive.

The energy lost in expanding reaches is somewhere between 0 and 100 percent. In expanding reaches, two-thirds of the energy is assumed lost and the terms V_1^2 and V_2^2 are multiplied by 0.33. Expanding reaches are identified when the velocity at the downstream end is less than the velocity at the upstream end. In contracting reaches, the terms V_1^2 and V_2^2 are multiplied by 1.45. The contraction coefficient for different bridge abutments depend on several conditions at the bridge site (Matthai, 1967). For a type I abutment, the coefficient is equal to 0.86 for maximum contractions with length to width ratios greater than 2.0. An average condition has a bridge coefficient of about 0.83. The constant 1.45 is computed as $1/(0.83)^2$. When V_1 and V_2 are equal, the difference in velocity heads is equal to 0. When V_1 and V_2 are equal, multiplying both by 1.45 or 0.33 will not effect the change in water-surface elevation. These constants have a greater effect on the water surface when the change in velocity is large.

METHOD OF SOLUTION

The modeling program loads the system with initial estimated values before computations begin. The discharge flowing through the system and the water-surface elevation at the center of each element along the downstream end of the grid network is known. A water-surface elevation is estimated for the midpoint of each element in the grid network. This is done by estimating a water-surface slope between the upstream and downstream end of the grid network. This slope is used to estimate water-surface elevations at each element by multiplying the slope by the distance from a downstream element and adding this value to the elevation of the downstream element. The slope is computed by subtracting the average ground elevation at the downstream end of the grid network from the average ground elevation at the upstream end of the grid network divided by the length of the grid network.

The depth of water is computed for each element by subtracting the ground elevation from the water-surface elevation. The length of the horizontal or vertical grid line between adjoining elements is used as the width of the section. The area of the element cross section is computed by multiplying the depth times the appropriate width. Conveyance is computed for each of the four sides of the elements as:

$$K = \frac{1.486}{n} A d^{\frac{2}{3}} \qquad (4)$$

where n is Manning's roughness coefficient,
A is the area of element in square feet, and
d is the depth of water in element, in feet.

The total discharge in the system is equal to the summation of all the discharges entering each element along a given horizontal plane. An example of this is shown in figure 34. Initial values of discharge on the horizontal face of each element are estimated by assuming that discharge is proportional to conveyance. The total conveyance along a horizontal plane is the summation of the conveyances for each element in the plane. The discharge at each element is estimated by dividing the conveyance at each element by the total conveyance and multiplying this ratio by the total discharge.

After the discharge is estimated for the horizontal face of each element in the grid network, discharges are computed for the vertical face of each element. This computation maintains continuity by assuring that the discharge entering each element is equal to the discharge leaving each element. An example of this is shown in figure 35.

The computed horizontal discharge of 10 ft^3/s in figure 35 is equal to 80 ft^3/s entering the horizontal face of the element minus the 70 ft^3/s leaving the horizontal face of the element. The horizontal discharge of 20 ft^3/s is equal to 100+10 ft^3/s entering the element minus 90 ft^3/s leaving the element.

After discharges are estimated for all horizontal and vertical faces of each element, the velocity and angle of flow are computed for each element.

The angle of flow is computed by using the following procedure. The maximum vertical or horizontal discharge entering or leaving an element is determined. If the maximum discharge is entering an element, the flow line of the discharge leaving the element across the adjacent grid line crosses the grid line that has the maximum discharge entering the element (fig. 36). The point where the flow line crosses the horizontal grid line at the top of the cell needs to be determined for computing the direction of flow. The ratio of the distance from the flow line to the end of the horizontal grid line to the total length of the horizontal grid line is equal to the ratio of the discharge leaving the element across the vertical grid line to the discharge entering the element. In figure 36, 100 ft^3/s is the maximum discharge entering the element. The ratio of the distances a to b is equal to the ratio of the discharges 30 ft^3/s to 100 ft^3/s. This ratio was used to locate point A in figure 36. The direction of flow is along the flow line AB. If the maximum discharge is flowing out of an element, the discharge entering the element across the adjacent grid line are used to compute the direction of flow in the same manner.

The velocity is determined for the side of the element where the maximum discharge is entering or leaving the element and for the opposite side of the element. The average of these two velocities is used as the velocity of the element. Each velocity is computed by dividing the discharge crossing the grid line by the area. The area is equal to the depth of the element times the length of the grid line times the sine of the angle that the flow line makes with the grid line.

The slope of the energy gradient is equal to the friction loss between midpoints of adjacent grid cells. The friction loss is computed by the equation:

$$\frac{LQ^2}{K_1K_2X_1X_2} \tag{5}$$

where terms are the same as defined in equation 3.

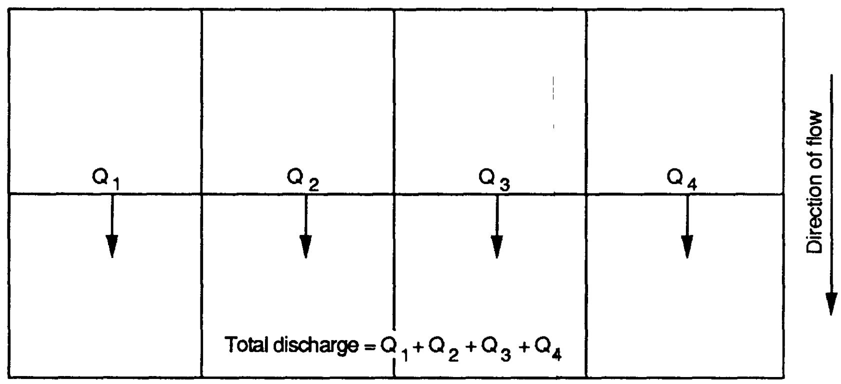


Figure 34.--Sketch showing computation of total discharge of grid system.

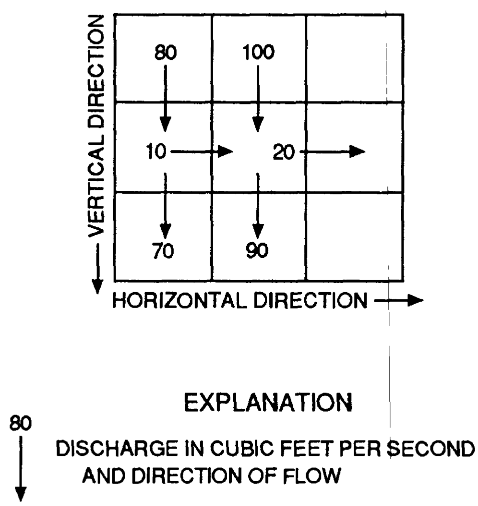


Figure 35.--Sketch showing continuity of discharge between grid cells.

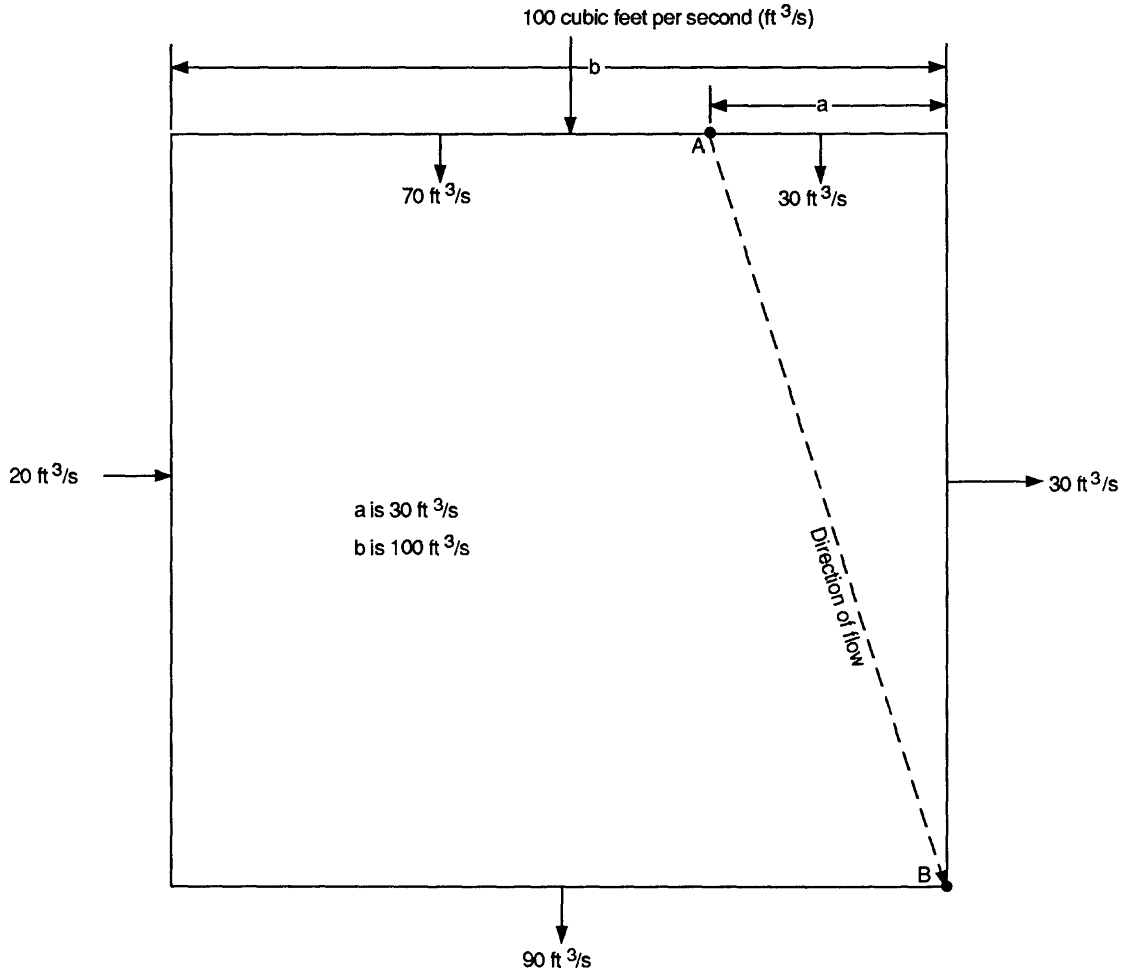


Figure 36.--Sketch showing example computation of velocity and direction of flow.

A relaxation method is used to obtain a solution for balancing heads around the midpoints of four adjacent elements (fig. 37). The change in the energy gradient along each of the four sides must add to 0 for the heads to balance. If the heads do not balance, the discharge is adjusted to obtain a balance. Adjustments are made using equation 6. The equation for the friction loss with the discharge adjustment, dq, is:

$$hf = \frac{L(Q-dq)^2}{K_1K_2X_1X_2} = \frac{LQ^2}{K_1K_2X_1X_2} - \frac{2LQdq}{K_1K_2X_1X_2} + \frac{Ldq^2}{K_1K_2X_1X_2} \quad (6)$$

where dq is the discharge adjustment factor. Other terms are the same as those defined in equation 3.

Equation 6 is written for each of the four sides shown in figure 37 to obtain a balance.

$$O = \frac{L_1 Q_1^2}{K^2} - \frac{2L_1 Q_1 dq}{K^2} + \frac{L_1 dq^2}{K^2} + \frac{L_2 Q_2^2}{K^2} - \frac{2L_2 Q_2 dq}{K^2} + \frac{L_2 dq^2}{K^2} - \frac{L_4 Q_4^2}{K^2} - \frac{2L_4 Q_4 dq}{K^2} - \frac{L_4 dq^2}{K^2} - \frac{L_3 Q_3^2}{K^2} - \frac{2L_3 Q_3 dq}{K^2} - \frac{L_3 dq^2}{K^2} \quad (7)$$

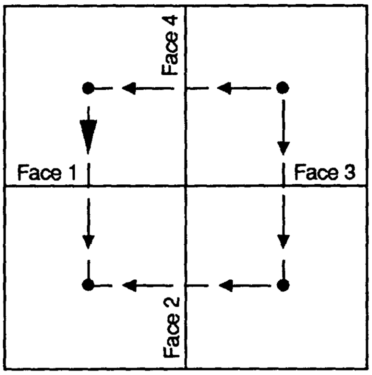
The K^2 term in equation 7 is for the appropriate side with adjustments for angularity. The, dq^2, terms in equation 7 prevent solving directly for dq. The, dq^2 terms are replaced with the term, dqZ, where Z is equal to an estimated value for dq. The terms in equation 7 are rearranged to solve for the discharge adjustment, dq, in equation 8.

$$dq = \frac{\frac{L_1 Q_1^2}{K^2} + \frac{L_2 Q_2^2}{K^2} - \frac{L_4 Q_4^2}{K^2} - \frac{L_3 Q_3^2}{K^2}}{\frac{2L_1 Q_1}{K^2} + \frac{2L_2 Q_2}{K^2} + \frac{2L_4 Q_4}{K^2} + \frac{2L_3 Q_3}{K^2} - \frac{L_1 Z}{K^2} - \frac{L_2 Z}{K^2} + \frac{L_4 Z}{K^2} + \frac{L_3 Z}{K^2}} \quad (8)$$

Equation 8 is solved by a relaxation method. The term, Z, is initially set equal to zero and used in equation 8. Equation 8 is used to solve for dq. The term, Z, is set equal to the computed value of dq and used in equation 8. This procedure is repeated until the computed value, dq, is equal to the assumed value of Z.

The value of dq is subtracted from the discharge at face 1 and face 2 in figure 37 and added to the discharge at face 3 and face 4. This maintains continuity in the system. After each iteration, all discharge values are adjusted. Adjustments made to each flow element affect each adjoining flow element. For this reason, several iterations are required before the heads balance around each flow element in the network. After the energy gradient is balanced around each flow element, the change in water-surface elevation between midpoints are determined using equation 3. New water-surface elevations are computed for each element by starting with the water-surface elevation at the downstream end and adding each computed change between midpoints progressing in an upstream direction. With new water-surface elevations, new depths and conveyances are computed. This relaxation method is repeated until the discharge adjustment, dq, and the change in water-surface elevations reach acceptable minimum values. In this model, the acceptable minimum value of dq is when the total dq along a given horizontal plane is less than 0.0002 times the total discharge. The water-surface elevations along the upstream end of the grid network must be within 0.004 ft of that computed in a previous run.

The midpoint of each element is determined by dividing each element into two triangles. The centroid of each triangle is determined as one-third of the height from each base. The X and Y coordinates of each element is determined by taking moments about each axis using the area and centroid of each triangle.



EXPLANATION

DIRECTION OF FLOW

MIDPOINT OF ELEMENT

Figure 37.--Sketch of discharge on each of the four sides of a flow element.

SUMMARY

Comparisons were made between the results of simulations of hydraulic conditions at stream contractions (bridges) made using the Relaxation Method Flow Model (RMFM) and the Finite Element Surface-Water Modeling System (FESWMS). Using identical input data for three runs of each model, the generated velocities, water-surface elevations, and discharges simulated by each model were in reasonably good agreement.

For a hypothetical site, the velocity distribution along the upstream side of the bridge was about the same using both models, but the velocity distribution along the downstream side of the bridge was not the same. The RMFM run indicated higher velocities near the abutments but lower velocities near the middle of the stream than did the FESWMS run.

At a site on Okatoma Creek in Mississippi, where observed data were available for comparison, the velocities generated by both models for the downstream side of the bridge agree reasonably well with the measured data. The computed velocities using RMFM tend to follow the measured abrupt change in velocity slightly better than FESWMS but the peak velocities generated by both models were lower than measured peak velocities at the site.

The grid layout that defines the geometry of the flood plain will influence the model results. A grid layout for a hypothetical site was drawn according to the general rules for drawing a grid. Another grid layout for the hypothetical site was deliberately drawn in violation of the general rules for drawing a grid. The models RMFM and FESWMS were run using both grid layouts to measure the effects of a badly drawn grid. The computed water-surface elevation at the upstream end of the reach using the badly drawn grid was higher than the elevation computed using the grid drawn according to the rules. FESWMS generally was less affected by a poor grid than RMFM.

Less time was required to prepare and assemble the input data for RMFM than for FESWMS. Each node in the grid network had to be numbered using FESWMS whereas it did not using RMFM. Entry of the data for the ground elevations and for Manning's roughness coefficient values was about the same for both models.

Less computer time was required using RMFM than was required using FESWMS. For the hypothetical site, 3 minutes of CPU time were used to run RMFM and 62 minutes were used to run FESWMS. The CPU time used to run RMFM for a site on the Saline River in Arkansas was 9 minutes and the CPU time used to run FESWMS was 120 minutes. The CPU time used to run RMFM for a site on Okatoma Creek in Mississippi was 4 minutes and the CPU time used to run FESWMS was 9.5 hours.

The Relaxation Method Flow Model (RMFM) is not as complex as FESWMS in that it does not consider every force that affects the flow. Energy and continuity equations are the only equations used in RMFM. The effects of wind and coriolis forces are not considered. The results of RMFM may not be as accurate as FESWMS, but they may be sufficiently accurate for most highway system design needs. If the time of data preparation and the computer time for running the model are important considerations, and the accuracy is adequate for the intended use, RMFM may be a simpler, more efficient alternative to FESWMS.

A comparison was made between the results of the RMFM model run for a hypothetical site and peak discharges computed for the sites using indirect discharge computation methods. A discharge coefficient of 0.74 was computed using the results of the model run. A discharge coefficient of 0.71 was determined using standard procedures for making indirect measurements of peak discharge. The two coefficients of discharge differ by 4 percent.

REFERENCES

Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Bodhaine, G.L., 1968, Measurement of peak discharge at culverts by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, chapter A3, 60 p.

Colson, B.E. and Wilson, K.V., 1974, Hydraulic performance of bridges, efficiency of earthen spur dikes in Mississippi: Mississippi State Highway Department, MSHD-RD-73-15-SD, 33 p.

Froehlich, D.C., 1988, Finite element surface-water modeling system in Two dimensional flow in a horizontal plane: U.S. Department of Transportation, v. I., Users Manual.

Hulsing, Harry, 1968, Measurement of peak discharge at dams by indirect method: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, chapter A5, 29 p.

Matthai, H.F., 1967, Measurement of peak discharge at width contractions by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, chapter A4, 44 pg.

Schneider, V.R., and others, 1977, Computation of backwater and discharge at width constrictions of heavily vegetated flood plains: U.S. Geological Survey Water-Resources Investigations Report 76-129, 64 p.

Shearman, J.O., 1990, User's manual for WSPRO--A computer model for water surface profile computations: U.S. Department of Transportation, Federal Highway Administration Publication No. FHWA-IP-89-027, 177 p.

ATTACHMENT A

FORTRAN IV TWO.D.MODEL PROGRAM LISTING

```
      COMMON /NAME1/ X,Y,DISTJ,DISTI,ANGLEI,ANGLEJ,QRD,GR,CM,WS,CONV
      COMMON /NAME2/ QV,QH,XM,YM,ANGLE,V,E,TFV,TFH,HFH,HFV,DQ,DP
      COMMON /NAME3/ DST,DX1,DX2
      COMMON /NAME4/ ANGLEJ2,ANGLEI2
      DIMENSION X(44,25),Y(44,25),DISTJ(44,25),DISTI(44,25)
      DIMENSION ANGLEI(44,25),ANGLEJ(44,25),INAME(20),QRD(44,25)
      DIMENSION GR(44,25),CM(44,25),WS(44,25),CONV(44,25),QV(44,25)
      DIMENSION QH(44,25),XM(44,25),YM(44,25),ANGLE(44,25)
      DIMENSION V(44,25), E(44,25),TFV(44,25),TFH(44,25),HFH(44,25)
      DIMENSION HFV(44,25),DQ(44,25),DP(44,25)
      DIMENSION ADM(30),DX1(44,25), IBLANK(20),DST(44,25),DX2(44,25)
      DIMENSION QADJ(50),KUI(50),KUJ(50),KDI(50),RE(50),KDJ(50)
      DIMENSION LLJ(10),LRJ(10),LTI(10),LBI(10),KIBI(10),KIBJ(10)
      DIMENSION KITI(10),CULC(50),FLW(50),QA1(50)
      DIMENSION NUB(20),ANV(20)
      DIMENSION ANGLEI2(44,25),ANGLEJ2(44,25)
      OPEN (UNIT=7,FILE='TWO.D.DATA',STATUS='OLD')
      OPEN (UNIT=8,FILE='OP.TWO.D',STATUS='NEW')
      OPEN (UNIT=6,FILE='OUTPUT.DATA',STATUS='NEW')
      OPEN (UNIT=9,FILE='INIT.DATA',STATUS='OLD')
      OPEN (UNIT=5,FILE='OP.ITER',STATUS='NEW')
C     THIS IS A TWO-D FLOW MODEL WRITTEN BY BRAXTEL NEELY.
C     A GRID IS ESTABLISHED TO DEFINE THE FLOODPLAIN CHARACTERISTICS.
C     THE GRID USES 'I' AND 'J' COORDINATES.  'I' IS NUMBERED FROM
C     1 AT THE BOTTOM TO ITOP AT THE UPSTREAM END.  'J' IS NUMBERED
C     FROM 1 AT THE LEFT SIDE, LOOKING UPSTREAM, TO ISIDE AT THE
C     RIGHT SIDE.
C     INAME -- IDENTIFICATION CARD. NAME OF SITE, FLOOD DATE, ETC.
C     DISCH -- DISCHARGE IN FT3/S IN SYSTEM.
C     WSINT -- WATER-SURFACE ELEVATION AT DOWNSTREAM END OF GRID.
C     KSTOP -- MAXIMUM NUMBER OF ITERATIONS ACCEPTED. USUALLY 800.
C     ITOPI -- NUMBER OF LATERAL GRID LINES.
C     ISIDEI -- NUMBER OF LONGITUDINAL GRID LINES.
C     IRERUN -- 0 IF STARTING NEW, 1 IF STARTING WITH RESULTS OF
C               PREVIOUS RUN.
C     IBR -- NUMBER OF HIGHWAY FILLS BETWEEN BRIDGES.
C     NROP -- NUMBER OF ROAD OVERFLOW POINTS.
C     NV -- NUMBER OF ROUGHNESS VALUES
C     KUI(I),KUJ(I) -- 'I' AND 'J' VALUES FOR UPSTREAM OVERFLOW POINT.
C     KDI(I),KDJ(I) -- 'I' AND 'J' VALUES FOR DOWNSTREAM OVERFLOW
C                      POINT. WATER FLOWS FROM UPSTREAM I AND J POINT
C                      TO DOWNSTREAM I AND J POINT.
C     RE(I) -- ELEVATION OF ROAD, IN FEET, BETWEEN UPSTREAM AND
C              DOWNSTREAM OVERFLOW POINTS.
C     FLW(I) -- WIDTH OF OVERFLOW SECTION, IN FEET.
C     CULC(I) -- CONSTANT FOR CULVERT WITH TYPE 4 FLOW. THIS CONSTANT
C                IS MULTIPLIED BY DH**.5 TO OBTAIN DISCHARGE.
C     THE FOLLOWING SEVEN VALUES ARE USED ONLY WHEN MULTIPLE
C     BRIDGES ARE AT SITE.
C     KIBI -- 'I' VALUE AT DOWNSTREAM SIDE OF ROAD WHERE GRID TURNS
C             AND RUNS TOWARD BRIDGE.
C     KIBJ -- 'J' VALUE AT DOWNSTREAM SIDE OF ROAD WHERE GRID TURNS
C             AND RUNS TOWARD BRIDGE.
C     KITI -- 'I' VALUE AT UPSTREAM SIDE ROAD WHERE GRID RETURNS.
C     THE FOLLOWING FOUR VALUES ARE CORNER POINTS THAT DEFINE THE
C       GRID THAT WILL BALANCE HEADS THROUGH TWO BRIDGES.
C     LLJ -- LEFT MOST VALUE OF 'J'.
C     LRJ -- RIGHT MOST VALUE OF 'J'.
C     LTI -- TOP MOST VALUE OF 'I'.
C     LBI -- BOTTOM MOST VALUE OF 'I'.
```

```
C       GR(I,J) -- GROUND ELEVATION, IN FEET.
C       CM(I,J) -- INDEX TO ROUGHNESS COEFFICIENT.
C       X(I,J),Y(I,J) -- X AND Y COORDINATES.
C       KM INCREMENTS EACH TIME MOMENTUM IS USED
C       KKOUNT IS INITIALIZED EACH TIME WS IS COMPUTED
C       IPHASE INCREMENTS AFTER EACH WS ELEV COMPUTATION AFTER FLOW OVER
C        ROAD HAS BEEN COMPUTED 8 TIMES
C       KOR INCREMENTS EACH TIME FLOW OVER ROAD IS COMPUTED
C       KMD=1, AFTER WS AT UPSTR END IS COMPUTED WITHIN 0.01 OF PREVIOUS
C        WS 6 TIMES.
         TOPLAST=0.0
        KOUNT=0
        KMD=0
        KKOUN=0
        KWS=0
        KSTAGE=0
        IPHASE=0
        KOR=0
        SUMDZ=0.0
        KM=0
        KSW=0
        TFLOR=0.0
        TFAJ=1.0
        READ(7,29)(INAME(I),I=1,20)
   29   FORMAT(20A4)
        WRITE(8,19)(INAME(I),I=1,20)
   19   FORMAT(1X,20A4)
        WRITE(8,2517)
        READ(7,2500)DISCH
 2500   FORMAT(F10.0)
        READ(7,2500)WSINT
        READ(7,2501)KSTOP
 2501   FORMAT(I10)
        IF(KSTOP.GT.1200)KSTOP=1200
        READ(7,2501)ITOPI
        ITOP=ITOPI-1
        READ(7,2501)ISIDEI
        ISIDE=ISIDEI-1
        READ(7,2501)IRERUN
        READ(7,2501)IBR
        READ(7,2501)NROP
        READ(7,2501)NV
        READ(7,2501)NDSEL
        WRITE(8,2502)DISCH
 2502   FORMAT(1X,'DISCHARGE =',F10.2)
        WRITE(8,2517)
 2517   FORMAT(/)
        IF(NDSEL.GT.0)GO TO 2503
        WRITE(8,2504)WSINT
 2504   FORMAT(1X,'WATER SURFACE ELEVATION AT DOWNSTREAM END =',F10.3)
        WRITE(8,2517)
 2503   WRITE(8,2505)KSTOP
 2505   FORMAT(1X,'MAXIMUM NUMBER OF ITERATIONS =',I5)
        WRITE(8,2517)
        WRITE(8,2506)ITOPI
 2506   FORMAT(1X,'NUMBER OF HORIZONTAL LINES =',I5)
        WRITE(8,2517)
        WRITE(8,2507)ISIDEI
 2507   FORMAT(1X,'NUMBER OF VERTICAL LINES =',I5)
        WRITE(8,2517)
        IF(IRERUN.EQ.0)WRITE(8,2508)
 2508   FORMAT(1X,'INITIAL RUN')
```

```
      IF(IRERUN.EQ.1)WRITE(8,2509)
 2509 FORMAT(1X,'INITIAL DATA REQUESTED TO CONTINUE RUN')
      WRITE(8,2517)
      WRITE(8,2510)IBR
 2510 FORMAT(1X,'NUMBER OF ROADWAY FILLS BETWEEN BRIDGES =',I5)
      WRITE(8,2517)
      WRITE(8,2511)NROP
 2511 FORMAT(1X,'NUMBER OF ROAD OVERFLOW POINTS =',I5)
      WRITE(8,2517)
      WRITE(8,2512)NV
 2512 FORMAT(1X,'NUMBER OF N VALUES =',I5)
      WRITE(8,2517)
      IF(NDSEL.LT.1)WRITE(8,2513)
 2513 FORMAT(1X,'WATER SURFACE IS NOT READ FOR EACH DOWNSTREAM ELEMENT'
     1)
      IF(NDSEL.EQ.1)WRITE(8,2514)
 2514 FORMAT(1X,'THE FOLLOWING WATER SURFACES ARE READ FOR EACH DOWNSTR
     1EAM ELEMENT')
      ISIDE=ISIDEI-1
      DO 1513 J=1,ISIDE
      WS(1,J)=WSINT
 1513 E(1,J)=WSINT
      IF(NDSEL.LT.1)GO TO 1512
      READ(7,1051)(WS(1,J),J=1,ISIDE)
 1051 FORMAT(8F10.0)
      DO 1514 J=1,ISIDE
 1514 E(1,J)=WS(1,J)
      WRITE(8,2515)(WS(1,J),J=1,ISIDE)
 2515 FORMAT(1X,8F9.3)
      WRITE(8,2517)
 1512 CONTINUE
      IF(IRERUN.EQ.1)KOR=5
      IF(IRERUN.EQ.1)KWS=4
      IF(NROP.EQ.0)KOR=10
C     READ INDEX NUMBER AND ASSOCIATED ROUGHNESS VALUE
      DO 620 I=1,NV
      READ(7,621)NUB(I),ANV(I)
  621 FORMAT(8(I5,F5.0))
  620 CONTINUE
      WRITE(8,2516)
 2516 FORMAT(1X,'INDEX NUMBER AND ASSOCIATED N VALUE')
      WRITE(8,1501)(NUB(I),ANV(I),I=1,NV)
 1501 FORMAT(1X,(6(I5,F7.3)))
      WRITE(8,2517)
   22 FORMAT(2F10.0,8I5)
      IF(NROP.EQ.0)GO TO 443
      DO 911 I=1,NROP
  911 QA1(I)=0.0
      WRITE(8,2518)
 2518 FORMAT(4X,'FLOW OVER ROADWAY ELEMENTS')
      WRITE(8,2519)
 2519 FORMAT(4X,'UPSTREAM DOWNSTREAM   ROADWAY   FLOW    CULVERT')
      WRITE(8,2520)
 2520 FORMAT(5X,'I    J    I    J      ELEV     WIDTH   CONSTANT')
C     READ ROAD OVER FLOW POINTS
      DO 445 N=1,NROP
      READ(7,444)KUI(N),KUJ(N),KDI(N),KDJ(N),RE(N),FLW(N),CULC(N)
  445 QADJ(N)=0.0
      DO 2521 N=1,NROP
 2521 WRITE(8,2522)KUI(N),KUJ(N),KDI(N),KDJ(N),RE(N),FLW(N),CULC(N)
 2522 FORMAT(1X,4I5,3F10.2)
  444 FORMAT(4I4,3F10.0)
```

```
  443   CONTINUE
        IF(IBR.LT.1)GO TO 447
C       READ DATA DEFINING ROADWAY FILL AND FLOW ELEMENT
        DO 448 M=1,IBR
  448   READ(7,449)KIBI(M),KIBJ(M),KITI(M),LLJ(M),LRJ(M),LTI(M),LBI(M)
        WRITE(8,2517)
        WRITE(8,2523)
 2523   FORMAT(1X,'DEFINING ROADWAY FILL WITH I AND J COORDINATES')
        DO 2524 M=1,IBR
 2524   WRITE(8,2526)KIBI(M),KIBJ(M),KITI(M)
 2526   FORMAT(1X,'LOWER HORIZ LINE =',I3,2X,'VERTICAL LINE =',I3,2X,
     1'UPPER HORIZ LINE =',I3)
        WRITE(8,2517)
        WRITE(8,2527)
 2527   FORMAT(1X,'DEFINING GRID SIDES THROUGH BRIDGES WITH I AND J COORD
     1NINATES')
        DO 2528 M=1,IBR
 2528   WRITE(8,2529)LLJ(M),LRJ(M),LTI(M),LBI(M)
 2529   FORMAT(1X,'LEFT VERT LINE =',I3,2X,'RIGHT VERT LINE =',I3,2X,
     1'UPPER HORIZ LINE =',I3,2X,'LOWER HORIZ LINE =',I3)
  449   FORMAT(7I4)
  447   CONTINUE
        PREDQ=0.0
        SUMDQ=0.0
        ITOP=ITOPI-1
        ISIDE=ISIDEI-1
        XPRE=1.0
        X1=FLOAT(ISIDE)
        X2=FLOAT(ITOP)
        DSUP=DISCH/(X1*1000.0)
        DQMAX=DISCH/(X1*8.0)
        DQMIN=DQMAX*(-1.0)
        ITOPY=ITOP-1
        ISIDEE=ISIDE-1
        ITOP2=ITOP-2
        ISIDE2=ISIDE-2
        DQWS=X1*X2*0.10
        DSMAX=X1*X2*0.003
        DQQ=DISCH*X2*0.002
        DO 114 I=1,ITOP
        DO 114 J=1,ISIDE
        DST(I,J)=0.0
        DX1(I,J)=1.0
        DX2(I,J)=1.0
        QRD(I,J)=0.0
        V(I,J)=0.0
        ANGLE(I,J)=0.0
        DISTJ(I,J)=0.0
  114   DQ(I,J)=0.0
        DO 24 I=1,ITOP
   24   READ(7,51)(GR(I,J),J=1,ISIDE)
        DO 25 I=1,ITOP
   25   READ(7,623)(CM(I,J),J=1,ISIDE)
  623   FORMAT(16F5.0)
   51   FORMAT(16F5.0)
C       ASSIGNING ROUGHNESS COEFFICIENTS
        DO 127 I=1,ITOP
        DO 127 J=1,ISIDE
        KK=IFIX(CM(I,J))
        DO 622 K=1,NV
        IF(KK.EQ.NUB(K))CM(I,J)=ANV(K)
  622   CONTINUE
```

```
  127  CONTINUE
       WRITE(8,2517)
       WRITE(8,2530)
 2530  FORMAT(1X,'ALL OF THE FOLLOWING DATA, GROUND ELEVATIONS,MANNINGS
     1N, ETC, ARE LISTED STARTING WITH THE')
       WRITE(8,2531)
 2531  FORMAT(1X,'DOWNSTREAM HORIZONTAL LINE AND GOING TO THE UPSTREAM H
     1ORIZONTAL LINE.  THE FIRST VALUE ON EACH')
       WRITE(8,2532)
 2532  FORMAT(1X,'LINE IS THE LEFT MOST VALUE LOOKING UPSTREAM.')
       WRITE(8,2517)
       WRITE(8,162)
  162  FORMAT(1X,'GROUND ELEVATIONS')
       DO 52 I=1,ITOP
   52  WRITE(8,14)(GR(I,J),J=1,ISIDE)
       WRITE(8,15)
       WRITE(8,163)
  163  FORMAT(1X,'MANNINGS N')
       DO 53 I=1,ITOP
   53  WRITE(8,54)(CM(I,J),J=1,ISIDE)
       WRITE(8,15)
   54  FORMAT(1X,16F8.4)
       DO 4 I=1,ITOPI
    4  READ(7,3)(X(I,J),Y(I,J),J=1,ISIDEI)
    3  FORMAT(12F6.0)
       WRITE(8,164)
  164  FORMAT(1X,'X-Y COORDINATES')
       DO 18 I=1,ITOPI
   18  WRITE(8,14)(X(I,J),Y(I,J),J=1,ISIDEI)
C       COMPUTING VERTICAL DISTANCES BETWEEN GRID POINTS AND ANGLE OF LINE
       DO 1 I=1,ITOP
       DO 1 J=1,ISIDEI
       Y1=Y(I+1,J)-Y(I,J)
       X1=X(I+1,J)-X(I,J)
       Z=((Y1*Y1)+(X1*X1))**.5
       IF(Z.LT.0.1)Z=0.1
       DISTI(I,J)=Z
       X2=ABS(X1)
       Z2=X2/Z
       IF(Z2.GT.1.0)Z2=0.9999999
       Z1=ASIN(Z2)
       Z1=Z1*57.296
   20  FORMAT(1X,3F10.2)
       IF(X1.GE.0.0.AND.Y1.GE.0.0)ANGLEI(I,J)=Z1+180.0
       IF(X1.GE.0.0.AND.Y1.LE.0.0)ANGLEI(I,J)=360.0-Z1
       IF(X1.LE.0.0.AND.Y1.GE.0.0)ANGLEI(I,J)=180.0-Z1
       IF(X1.LE.0.0.AND.Y1.LE.0.0)ANGLEI(I,J)=Z1
    1  CONTINUE
C      COMPUTING HORIZONTAL DISTANCE BETWEEN GRID POINTS AND ANGLE OF LINE
       DO 2 I=1,ITOPI
       DO 2 J=1,ISIDE
       Y1=Y(I,J+1)-Y(I,J)
       X1=X(I,J+1)-X(I,J)
       Z=((Y1*Y1)+(X1*X1))**.5
       IF(Z.LT.0.1)Z=0.1
       DISTJ(I,J)=Z
       X2=ABS(X1)
       Z2=X2/Z
       IF(Z2.GT.1.0)Z2=0.999999
       Z1=ASIN(Z2)
       Z1=Z1*57.3
       IF(X1.GE.0.0.AND.Y1.GE.0.0)ANGLEJ(I,J)=Z1
```

```
      IF(X1.GE.0.0.AND.Y1.LE.0.0)ANGLEJ(I,J)=180.0-Z1
      IF(X1.LE.0.0.AND.Y1.GE.0.0)ANGLEJ(I,J)=360.0-Z1
      IF(X1.LE.0.0.AND.Y1.LE.0.0)ANGLEJ(I,J)=180.0+Z1
    2 CONTINUE
C     COMPUTE MIDPOINT OF EACH ELEMENT.  DIVIDE EACH ELEMENT INTO TRIANGLES.
C     COMPUTE MIDPOINT AND AREA OF EACH TRIANGLE.  WEIGHT FOR MIDPOINT OF
ELEMENT.
      DO 1800 I=1,ITOP
      DO 1800 J=1,ISIDE
      A1=Y(I,J)*(X(I+1,J)-X(I+1,J+1))
      A2=Y(I+1,J)*(X(I+1,J+1)-X(I,J))
      A3=Y(I+1,J+1)*(X(I,J)-X(I+1,J))
      A4=A1+A2+A3
      A4=ABS(A4)
      IF(A4.LT.0.01)A4=0.01
      A5=Y(I,J)*(X(I+1,J+1)-X(I,J+1))
      A6=Y(I+1,J+1)*(X(I,J+1)-X(I,J))
      A7=Y(I,J+1)*(X(I,J)-X(I+1,J+1))
      A8=A5+A6+A7
      A8=ABS(A8)
      A9=A8/(A4+A8)
      X1=((X(I+1,J)+X(I+1,J+1)-X(I,J)-X(I,J))*0.333)+X(I,J)
      Y1=((Y(I+1,J)+Y(I+1,J+1)-Y(I,J)-Y(I,J))*0.333)+Y(I,J)
      X2=((X(I+1,J+1)+X(I,J+1)-X(I,J)-X(I,J))*0.333)+X(I,J)
      Y2=((Y(I+1,J+1)+Y(I,J+1)-Y(I,J)-Y(I,J))*0.333)+Y(I,J)
      XM(I,J)=((X2-X1)*A9)+X1
 1800 YM(I,J)=((Y2-Y1)*A9)+Y1
C     COMPUTING VERTICAL ANGLE BETWEEN MIDPOINTS OF ELEMENTS
      DO 1001 I=1,ITOPY
      DO 1001 J=1,ISIDE
      Y1=YM(I+1,J)-YM(I,J)
      X1=XM(I+1,J)-XM(I,J)
      Z=((Y1*Y1)+(X1*X1))**.5
      IF(Z.LT.0.1)Z=0.1
      X2=ABS(X1)
      Z2=X2/Z
      IF(Z2.GT.1.0)Z2=0.9999999
      Z1=ASIN(Z2)
      Z1=Z1*57.296
      IF(X1.GE.0.0.AND.Y1.GE.0.0)ANGLEI2(I,J)=Z1+180.0
      IF(X1.GE.0.0.AND.Y1.LE.0.0)ANGLEI2(I,J)=360.0-Z1
      IF(X1.LE.0.0.AND.Y1.GE.0.0)ANGLEI2(I,J)=180.0-Z1
      IF(X1.LE.0.0.AND.Y1.LE.0.0)ANGLEI2(I,J)=Z1
 1001 CONTINUE
C     COMPUTING HORIZONTAL ANGLE BETWEEN MIDPOINTS OF ELEMENTS
      DO 1002 I=1,ITOP
      DO 1002 J=1,ISIDEE
      Y1=YM(I,J+1)-YM(I,J)
      X1=XM(I,J+1)-XM(I,J)
      Z=((Y1*Y1)+(X1*X1))**.5
      IF(Z.LT.0.1)Z=0.1
      X2=ABS(X1)
      Z2=X2/Z
      IF(Z2.GT.1.0)Z2=0.999999
      Z1=ASIN(Z2)
      Z1=Z1*57.3
      IF(X1.GE.0.0.AND.Y1.GE.0.0)ANGLEJ2(I,J)=Z1
      IF(X1.GE.0.0.AND.Y1.LE.0.0)ANGLEJ2(I,J)=180.0-Z1
      IF(X1.LE.0.0.AND.Y1.GE.0.0)ANGLEJ2(I,J)=360.0-Z1
      IF(X1.LE.0.0.AND.Y1.LE.0.0)ANGLEJ2(I,J)=180.0+Z1
 1002 CONTINUE
      WRITE(8,1801)
```

```
 1801   FORMAT(1X,'X-Y MIDPOINT')
        DO 1802 I=1,ITOP
 1802   WRITE(8,14)(XM(I,J),YM(I,J),J=1,ISIDE)
        WRITE(8,15)
        WRITE(8,165)
  165   FORMAT(1X,'VERTICAL DISTANCE')
        DO 12 I=1,ITOP
   12   WRITE(8,14)(DISTI(I,J),J=1,ISIDEI)
   14   FORMAT(1X,16F8.1)
        WRITE(8,15)
   15   FORMAT(/)
        WRITE(8,166)
  166   FORMAT(1X,'HORIZONTAL DISTANCE')
        DO 16 I=1,ITOPI
   16   WRITE(8,14)(DISTJ(I,J),J=1,ISIDE)
        WRITE(8,15)
        WRITE(8,167)
  167   FORMAT(1X,'VERTICAL ANGLE')
        DO 10 I=1,ITOP
   10   WRITE(8,14)(ANGLEI(I,J),J=1,ISIDEI)
        WRITE(8,15)
        WRITE(8,168)
  168   FORMAT(1X,'HORIZONTAL ANGLES')
        DO 11 I=1,ITOPI
   11   WRITE(8,14)(ANGLEJ(I,J),J=1,ISIDE)
        WRITE(8,1805)
 1805   FORMAT(1X,'VERTICAL ANGLE BETWEEN MIDPOINTS')
        DO 1806 I=1,ITOPY
 1806   WRITE(8,14)(ANGLEI2(I,J),J=1,ISIDE)
        WRITE(8,15)
        WRITE(8,1807)
 1807   FORMAT(1X,'HORIZONTAL ANGLE BETWEEN MIDPOINTS')
        DO 1808 I=1,ITOP
 1808   WRITE(8,14)(ANGLEJ2(I,J),J=1,ISIDEE)
C       COMPUTE INITIAL WATER SURFACE AT EACH GRID
        IF(IBR.LT.1)GO TO 820
        DO 450 I=1,IBR
        KB=KIBI(I)+1
        KJ=KIBJ(I)
        KT=KITI(I)-1
        X1=WSINT+100.0
        KX=KIBI(I)
        IF(GR(KX,KJ).LT.X1)GR(KX,KJ)=X1
        DO 451 J=KB,KT
        X1=WSINT+100.0
        IF(GR(J,KJ).LT.X1)GR(J,KJ)=X1
  451   DISTJ(J,KJ)=0.01
  450   CONTINUE
  820   CONTINUE
        IF(IRERUN.EQ.1)GO TO 172
        MJ=ISIDE/2
        X1=FLOAT(ISIDE)
        TTOP=0.0
        TBOT=0.0
        DO 624 J=1,ISIDE
        TTOP=TTOP+GR(ITOP,J)
  624   TBOT=TBOT+GR(1,J)
        TTOP=TTOP/X1
        TBOT=TBOT/X1
        TDIS=0.0
        DO 625 I=1,ITOP
  625   TDIS=TDIS+DISTI(I,MJ)
```

```
      SLOPE=(TTOP-TBOT)/TDIS
      IF(SLOPE.LT.0.0)SLOPE=0.0
      DO 21 I=2,ITOP
      DO 21 J=1,ISIDE
   21 WS(I,J)=WS(I-1,MJ)+(DISTI(I-1,MJ)*SLOPE)
      TOPLAST=WS(ITOP,1)
      WRITE(8,15)
      WRITE(8,15)
      DO 26 I=1,ITOP
      DO 26 J=1,ISIDE
      D=WS(I,J)-GR(I,J)
      IF(D.LT.0.50)D=0.50
      DP(I,J)=D
      IF(CM(I,J).LT.0.001)WRITE(8,1900)I,J
 1900 FORMAT(1X,'CHECK N VALUE AT',2X,2I4)
   26 CONV(I,J)=(1.486*(D**1.667))/CM(I,J)
C     ESTIMATE INITIAL Q
      DO 28 I=1,ITOPY
      X1=0.0
      DO 815 J=1,ISIDE
      X2=DISTJ(I,J)*CONV(I,J)
      X3=DISTJ(I+1,J)*CONV(I+1,J)
  815 X1=X1+X2+X3
      DO 816 J=1,ISIDE
      X2=DISTJ(I,J)*CONV(I,J)
      X3=DISTJ(I+1,J)*CONV(I+1,J)
  816 QV(I,J)=((X2+X3)*DISCH)/X1
   28 CONTINUE
      DO 614 I=2,ITOPY
  614 QH(I,1)=QV(I,1)-QV(I-1,1)
      DO 615 I=2,ITOPY
      DO 615 J=2,ISIDEE
      QH(I,J)=QV(I,J)-QV(I-1,J)+QH(I,J-1)
      IF(DISTJ(I,J).LT.0.02.OR.DISTJ(I+1,J).LT.0.02)QV(I,J)=QV(I,J)
     1-QH(I,J)
      IF(DISTJ(I,J).LT.0.02)QH(I,J)=0.0
      IF(J.EQ.ISIDEE)QV(I,ISIDE)=QV(I-1,ISIDE)-QH(I,J)
  615 CONTINUE
      DO 30 J=1,ISIDEE
      QH(ITOP,J)=0.0
   30 QH(1,J)=0.0
      GO TO 175
  172 CONTINUE
      KWS=4
      READ(9,29)(IBLANK(I),I=1,20)
      READ(9,29)(IBLANK(I),I=1,20)
      READ(9,29)(IBLANK(I),I=1,20)
      READ(9,29)(IBLANK(I),I=1,20)
      READ(9,29)(IBLANK(I),I=1,20)
      READ(9,29)(IBLANK(I),I=1,20)
      DO 173 I=1,ITOPY
  173 READ(9,300)(QV(I,J),J=1,ISIDE)
      READ(9,29)(IBLANK(I),I=1,20)
      DO 174 I=1,ITOP
  174 READ(9,300)(QH(I,J),J=1,ISIDEE)
      WRITE(8,15)
      WRITE(8,311)
  311 FORMAT(1X,'VERTICAL DISCHARGE')
      DO 278 I=1,ITOPY
  278 WRITE(8,300)(QV(I,J),J=1,ISIDE)
  179 FORMAT(1X,12F6.0)
      WRITE(8,15)
```

```
      WRITE(8,312)
  312 FORMAT(1X,'HORIZONTAL DISCHARGE')
      DO 280 I=1,ITOP
  280 WRITE(8,300)(QH(I,J),J=1,ISIDEE)
  300 FORMAT(1X,8F9.2)
      READ(9,29)(IBLANK(I),I=1,20)
      DO 177 I=1,ITOP
  177 READ(9,182)(DP(I,J),J=1,ISIDE)
      READ(9,29)(IBLANK(I),I=1,20)
      DO 194 I=1,ITOP
  194 READ(9,182)(WS(I,J),J=1,ISIDE)
      TOPLAST=WS(ITOP,1)
      READ(9,29)(IBLANK(I),I=1,20)
      DO 1195 I=1,ITOP
 1195 READ(9,182)(V(I,J),J=1,ISIDE)
      READ(9,29)(IBLANK(I),I=1,20)
      DO 1196 I=1,ITOP
 1196 READ(9,300)(ANGLE(I,J),J=1,ISIDE)
      READ(9,29)(IBLANK(I),I=1,20)
      DO 195 I=1,ITOP
  195 READ(9,179)(CONV(I,J),J=1,ISIDE)
  182 FORMAT(1X,11F7.3)
      WRITE(8,711)
  711 FORMAT(1X,'DEPTH')
      DO 283 I=1,ITOP
  283 WRITE(8,182)(DP(I,J),J=1,ISIDE)
      WRITE(8,712)
  712 FORMAT(1X,'WATER SURFACE ELEVATIONS')
      DO 292 I=1,ITOP
  292 WRITE(8,182)(WS(I,J),J=1,ISIDE)
      WRITE(8,713)
  713 FORMAT(1X,'UNIT CONVEYANCE')
      DO 293 I=1,ITOP
  293 WRITE(8,179)(CONV(I,J),J=1,ISIDE)
      READ(9,356)KMD
      IF(KMD.EQ.1)KM=1
      READ(9,356)KOR
      READ(9,29)(IBLANK(I),I=1,20)
      DO 452 I=1,ITOP
  452 READ(9,300)(QRD(I,J),J=1,ISIDE)
      WRITE(8,453)
      DO 454 I=1,ITOP
  454 WRITE(8,300)(QRD(I,J),J=1,ISIDE)
      IF(NROP.EQ.0)GO TO 3004
      DO 3003 I=1,NROP
      KI=KUI(I)
      KJ=KUJ(I)
 3003 QA1(I)=QRD(KI,KJ)
 3004 CONTINUE
      READ(9,29)(IBLANK(I),I=1,20)
      DO 954 I=1,ITOPY
  954 READ(9,182)(DX1(I,J),J=1,ISIDE)
      READ(9,29)(IBLANK(I),I=1,20)
      DO 955 I=1,ITOP
  955 READ(9,182)(DX2(I,J),J=1,ISIDEE)
  175 CONTINUE
      WRITE(8,15)
  456 FORMAT(1X,'KOUNT =',I4)
C     BEGIN ITERATION LOOPS
   71 CONTINUE
      IF(IPHASE.EQ.0)GO TO 929
      DO 924 I=2,ITOPY
```

```
  924   QH(I,1)=QV(I,1)-QV(I-1,1)-QRD(I,1)
        DO 317 I=2,ITOPY
        DO 317 J=2,ISIDEE
        X1=1.0
        IF(DISTJ(I,J+1).LT.0.02.OR.DISTJ(I+1,J+1).LT.0.02)X1=0.01
        Z=1.0
        IF(DISTJ(I,J).LT.0.02.OR.DISTJ(I+1,J).LT.0.02)Z=0.01
        QH(I,J)=QV(I,J)-QV(I-1,J)+QH(I,J-1)-QRD(I,J)
        IF(X1.LT.0.02)QV(I,J)=QV(I,J)-QH(I,J)
        IF(X1.LT.0.02.AND.J.LT.ISIDEE)QV(I,J+2)=QV(I,J+2)+QH(I,J)
        IF(X1.LT.0.02)QH(I,J)=0.0
        IF(Z.LT.0.02)QH(I,J)=0.0
  317   CONTINUE
  929   CONTINUE
C       COMPUTING FALL USING FRICTION LOSS ONLY
C       ADJUST Q BALANCING HEADS AROUND ENERGY LINE
        DO 45 I=1,ITOPY
        DO 45 J=1,ISIDE
        X3=XM(I,J)-XM(I+1,J)
        X4=YM(I,J)-YM(I+1,J)
        X1=(X3*X3)+(X4*X4)
        X1=X1**.5
        IF(J.GT.1)X3=GR(I,J-1)-GR(I,J)
        IF(X3.GT.DP(I,J))X3=DP(I,J)
        IF(J.EQ.1)X3=DP(I,J)
        IF(X3.LT.0.0)X3=0.0
        IF(J.LT.ISIDE)X4=GR(I,J+1)-GR(I,J)
        IF(X4.GT.DP(I,J))X4=DP(I,J)
        IF(J.EQ.ISIDE)X4=DP(I,J)
        IF(X4.LT.0.0)X4=0.0
        IF(J.GT.1)X5=GR(I+1,J-1)-GR(I+1,J)
        IF(X5.GT.DP(I+1,J))X5=DP(I+1,J)
        IF(J.EQ.1)X5=DP(I+1,J)
        IF(X5.LT.0.0)X5=0.0
        IF(J.LT.ISIDE)X6=GR(I+1,J+1)-GR(I+1,J)
        IF(X6.GT.DP(I+1,J))X6=DP(I+1,J)
        IF(J.EQ.ISIDE)X6=DP(I+1,J)
        IF(X6.LT.0.0)X6=0.0
        X7=(X3+X4+X5+X6)/2.0
        X8=DISTJ(I+1,J)/(DISTJ(I+1,J)+X7)
        X8=X8**1.667
        X2=CONV(I,J)*CONV(I+1,J)*DISTJ(I+1,J)*DISTJ(I+1,J)*X8
   45   TFV(I,J)=X1/X2
        DO 46 I=1,ITOP
        DO 46 J=1,ISIDEE
        X3=XM(I,J)-XM(I,J+1)
        X4=YM(I,J)-YM(I,J+1)
        X1=(X3*X3)+(X4*X4)
        X1=X1**.5
        X3=0.0
        X4=0.0
        IF(I.GT.1)X3=GR(I-1,J)-GR(I,J)
        IF(X3.GT.DP(I,J))X3=DP(I,J)
        IF(X3.LT.0.0)X3=0.0
        IF(I.LT.ITOP)X4=GR(I+1,J)-GR(I,J)
        IF(X4.GT.DP(I,J))X4=DP(I,J)
        IF(X4.LT.0.0)X4=0.0
        X5=0.0
        X6=0.0
        IF(I.GT.1)X5=GR(I-1,J+1)-GR(I,J+1)
        IF(X5.GT.DP(I,J+1))X5=DP(I,J+1)
        IF(X5.LT.0.0)X5=0.0
```

```
      IF(I.LT.ITOP)X6=GR(I+1,J+1)-GR(I,J+1)
      IF(X6.GT.DP(I,J+1))X6=DP(I,J+1)
      IF(X6.LT.0.0)X6=0.0
      X7=(X3+X4+X5+X6)/2.0
      X8=DISTI(I,J+1)/(DISTI(I,J+1)+X7)
      X8=X8**1.667
      X2=CONV(I,J)*CONV(I,J+1)*DISTI(I,J+1)*DISTI(I,J+1)*X8
   46 TFH(I,J)=X1/X2
      DO 47 I=1,ITOPY
      DO 47 J=1,ISIDE
      Z6=QV(I,J)
      Z3=ABS(Z6)
      X1=DX1(I,J)
      IF(X1.GE.0.0.AND.X1.LT.0.001)X1=0.001
      IF(X1.LE.0.0.AND.X1.GT.(-0.001))X1=(-0.001)
      HFV(I,J)=(TFV(I,J)*Z6*Z3)/X1
      TFV(I,J)=TFV(I,J)/X1
C     TFV(I,J)=ABS(TFV(I,J))
   47 CONTINUE
      DO 48 I=1,ITOP
      DO 48 J=1,ISIDEE
      Z4=QH(I,J)
      Z3=ABS(Z4)
      X1=DX2(I,J)
      IF(X1.GE.0.0.AND.X1.LT.0.001)X1=0.001
      IF(X1.LE.0.0.AND.X1.GT.(-0.001))X1=(-0.001)
      HFH(I,J)=(TFH(I,J)*Z4*Z3)/X1
      TFH(I,J)=TFH(I,J)/X1
C     TFH(I,J)=ABS(TFH(I,J))
   48 CONTINUE
      IF(PREDQ.LT.1.0)PREDQ=1.0
      X2=SUMDQ/PREDQ
      TFAJ=(((X2/0.99)*TFAJ)+TFAJ)/2.0
      IF(TFAJ.GT.4.0)TFAJ=4.0
      IF(TFAJ.LT.1.00)TFAJ=1.00
      IF(KWS.LT.4)TFAJ=1.0
C     COMPUTE DELTA Q
      DO 49 I=1,ITOPY
      DO 49 J=1,ISIDEE
      Z1=QV(I,J)
      Z1=ABS(Z1)
      Z2=QH(I,J)
      Z2=ABS(Z2)
      Z3=QV(I,J+1)
      Z3=ABS(Z3)
      Z4=QH(I+1,J)
      Z4=ABS(Z4)
      X1=((TFV(I,J)*Z1)+(TFH(I,J)*Z2)+(TFV(I,J+1)*Z3)+(TFH(I+1,J)*Z4))
     1*2.0*TFAJ
      Y1=TFV(I,J)*Z1
      Y1=ABS(Y1)
      Y2=TFH(I,J)*Z2
      Y2=ABS(Y2)
      Y3=TFV(I,J+1)*Z3
      Y3=ABS(Y3)
      Y4=TFH(I+1,J)*Z4
      Y4=ABS(Y4)
      Y5=(Y1+Y2+Y3+Y4)*2.0*TFAJ
      Y6=Y5*(-1.0)
      IF(X1.GE.0.0)X1=Y5
      IF(X1.LE.0.0)X1=Y6
      IF(X1.LT.0.0001.AND.X1.GE.0.0)X1=0.0001
```

```
      IF(X1.LE.0.0.AND.X1.GT.(-0.0001))X1=(-0.0001)
      DST(I,J)=HFV(I,J)+HFH(I,J)-HFV(I,J+1)-HFH(I+1,J)
      X8=DST(I,J)
      X9=X8/X1
      X99=X9
      DO 745 K=1,20
      X3=ABS(X9)
      X2=X1+((TFV(I,J)+TFH(I,J)-TFV(I,J+1)-TFH(I+1,J))*X3)
      IF(X2.LT.Y5.AND.X2.GE.0.0)X2=Y5
      IF(X2.LE.0.0.AND.X2.GT.Y6)X2=Y6
      X9=X8/X2
      X98=X99-X9
      IF(X98.LT.(0.1).AND.X98.GT.(-0.1))GO TO 746
      X99=X9
  745 CONTINUE
  746 CONTINUE
   49 DQ(I,J)=(X9+DQ(I,J))/2.0
      IF(IBR.LT.1)GO TO 420
C     BALANCE HEADS THROUGH BRIDGES
      DO 421 I=1,IBR
      KB=KIBI(I)-1
      KJ=KIBJ(I)
      KJB=KJ-1
      KT=KITI(I)-1
      DO 422 J=KB,KT
      DST(J,KJ)=0.0
      DST(J,KJB)=0.0
      DQ(J,KJB)=0.0
      QV(J,KJ)=0.0
      IF(J.LT.KT)QH(J+1,KJ)=0.0
      IF(J.LT.KT)QH(J+1,KJB)=0.0
  422 DQ(J,KJ)=0.0
  421 CONTINUE
      DO 414 K=1,IBR
      M1=LLJ(K)
      M2=LTI(K)
      M3=LRJ(K)
      M4=LBI(K)
      M33=M3-1
      M22=M2-1
      SUM=0.0
      TUM=0.0
      DO 410 I=M4,M22
      Z1=QV(I,M1)
      Z1=ABS(Z1)
      Z2=QV(I,M3)
      Z2=ABS(Z2)
      TUM=TUM+(TFV(I,M1)*Z1)+(TFV(I,M3)*Z2)
  410 SUM=SUM+HFV(I,M1)-HFV(I,M3)
      DO 411 J=M1,M33
      Z1=QH(M4,J)
      Z1=ABS(Z1)
      Z2=QH(M2,J)
      Z2=ABS(Z2)
      SUM=SUM+HFH(M4,J)-HFH(M2,J)
  411 TUM=TUM+(TFH(M4,J)*Z1)+(TFH(M2,J)*Z2)
      X9=SUM/(TUM*4.00)
      IF(X9.GT.DQMAX)X9=DQMAX
      IF(X9.LT.DQMIN)X9=DQMIN
      DO 412 I=M4,M22
      QV(I,M1)=QV(I,M1)-X9
  412 QV(I,M3)=QV(I,M3)+X9
```

```
      DO 413 J=M1,M33
      QH(M4,J)=QH(M4,J)-X9
  413 QH(M2,J)=QH(M2,J)+X9
  414 CONTINUE
  420 CONTINUE
      PREDQ=SUMDQ
      SUMDS=0.0
      SUMDQ=0.0
      DO 430 I=1,ITOPY
      DO 430 J=1,ISIDEE
      X8=DST(I,J)
      CC=ABS(X8)
      SUMDS=SUMDS+CC
      A=ABS(DQ(I,J))
  430 SUMDQ=SUMDQ+A
      DO 330 I=1,ITOPY
      DO 330 J=1,ISIDEE
      IF(DQ(I,J).GT.DQMAX)DQ(I,J)=DQMAX
      IF(DQ(I,J).LT.DQMIN)DQ(I,J)=DQMIN
  330 CONTINUE
  772 FORMAT(1X,'DELTA STAGE')
      DO 50 I=1,ITOPY
      DO 50 J=1,ISIDEE
      QV(I,J)=QV(I,J)-DQ(I,J)
      QH(I,J)=QH(I,J)-DQ(I,J)
      QV(I,J+1)=QV(I,J+1)+DQ(I,J)
      QH(I+1,J)=QH(I+1,J)+DQ(I,J)
   50 CONTINUE
      DO 141 J=1,ISIDEE
      QH(1,J)=0.0
  141 QH(ITOP,J)=0.0
      IF(KWS.LT.4)GO TO 80
C     COMPUTING VELOCITY AND ANGLE OF FLOW
      DO 740 I=2,ITOPY
      DO 740 J=2,ISIDEE
      X5=ABS(QV(I-1,J))
      X2=ABS(QV(I,J))
      X3=ABS(QH(I,J-1))
      X4=ABS(QH(I,J))
      IF(X5.LT.0.01)X5=0.01
      IF(X2.LT.0.01)X2=0.01
      IF(X3.LT.0.01)X3=0.01
      IF(X4.LT.0.01)X4=0.01
      IF(X4.GE.X5.AND.X4.GE.X2.AND.X4.GE.X3)GO TO 742
      IF(X3.GE.X5.AND.X3.GE.X2.AND.X3.GE.X4)GO TO 743
      IF(X2.GE.X5.AND.X2.GE.X3.AND.X2.GE.X4)GO TO 744
      IF(QV(I-1,J).LT.0.0)GO TO 762
      IF(QH(I,J-1).LT.0.0)GO TO 761
      IF(X5.LT.0.001)X5=0.001
      Z4=X3/X5
      XX1=((X(I,J+1)-X(I,J))*Z4)+X(I,J)
      YY1=((Y(I,J+1)-Y(I,J))*Z4)+Y(I,J)
      Y1=Y(I+1,J)-YY1
      X1=X(I+1,J)-XX1
      GO TO 770
  761 Z4=X4/X5
      XX1=X(I,J+1)-((X(I,J+1)-X(I,J))*Z4)
      YY1=Y(I,J+1)-((Y(I,J+1)-Y(I,J))*Z4)
      Y1=Y(I+1,J+1)-YY1
      X1=X(I+1,J+1)-XX1
      GO TO 770
  762 IF(QH(I,J-1).GE.0.0)GO TO 747
```

```
      Z4=X3/X5
      XX1=((X(I,J+1)-X(I,J))*Z4)+X(I,J)
      YY1=((Y(I,J+1)-Y(I,J))*Z4)+Y(I,J)
      Y1=YY1-Y(I+1,J)
      X1=XX1-X(I+1,J)
      GO TO 770
747   Z4=X4/X5
      XX1=X(I,J+1)-((X(I,J+1)-X(I,J))*Z4)
      YY1=Y(I,J+1)-((Y(I,J+1)-Y(I,J))*Z4)
      Y1=YY1-Y(I+1,J+1)
      X1=XX1-X(I+1,J+1)
      GO TO 770
744   IF(QV(I,J).LT.0.0)GO TO 748
      IF(QH(I,J-1).GE.0.0)GO TO 749
      Z4=X3/X2
      XX1=((X(I+1,J+1)-X(I+1,J))*Z4)+X(I+1,J)
      YY1=((Y(I+1,J+1)-Y(I+1,J))*Z4)+Y(I+1,J)
      Y1=YY1-Y(I,J)
      X1=XX1-X(I,J)
      GO TO 770
749   Z4=X4/X2
      XX1=X(I+1,J+1)-((X(I+1,J+1)-X(I+1,J))*Z4)
      YY1=Y(I+1,J+1)-((Y(I+1,J+1)-Y(I+1,J))*Z4)
      Y1=YY1-Y(I,J+1)
      X1=XX1-X(I,J+1)
      GO TO 770
748   IF(QH(I,J-1).LT.0.0)GO TO 750
      Z4=X3/X2
      XX1=((X(I+1,J+1)-X(I+1,J))*Z4)+X(I+1,J)
      YY1=((Y(I+1,J+1)-Y(I+1,J))*Z4)+Y(I+1,J)
      Y1=Y(I,J)-YY1
      X1=X(I,J)-XX1
      GO TO 770
750   Z4=X4/X2
      XX1=X(I+1,J+1)-((X(I+1,J+1)-X(I+1,J))*Z4)
      YY1=Y(I+1,J+1)-((Y(I+1,J+1)-Y(I+1,J))*Z4)
      Y1=Y(I,J+1)-YY1
      X1=X(I,J+1)-XX1
      GO TO 770
743   IF(QH(I,J-1).LT.0.0)GO TO 751
      IF(QV(I-1,J).LT.0.0)GO TO 752
      Z4=X5/X3
      XX1=((X(I+1,J)-X(I,J))*Z4)+X(I,J)
      YY1=((Y(I+1,J)-Y(I,J))*Z4)+Y(I,J)
      X1=XX1-X(I,J+1)
      Y1=YY1-Y(I,J+1)
      GO TO 770
752   Z4=X2/X3
      XX1=X(I+1,J)-((X(I+1,J)-X(I,J))*Z4)
      YY1=Y(I+1,J)-((Y(I+1,J)-Y(I,J))*Z4)
      X1=XX1-X(I+1,J+1)
      Y1=YY1-Y(I+1,J+1)
      GO TO 770
751   IF(QV(I-1,J).GT.0.0)GO TO 753
      Z4=X5/X3
      XX1=((X(I+1,J)-X(I,J))*Z4)+X(I,J)
      YY1=((Y(I+1,J)-Y(I,J))*Z4)+Y(I,J)
      X1=X(I,J+1)-XX1
      Y1=Y(I,J+1)-YY1
      GO TO 770
753   Z4=X2/X3
      XX1=X(I+1,J)-((X(I+1,J)-X(I,J))*Z4)
```

```
      YY1=Y(I+1,J)-((Y(I+1,J)-Y(I,J))*Z4)
      X1=X(I+1,J+1)-XX1
      Y1=Y(I+1,J+1)-YY1
      GO TO 770
742   IF(QH(I,J).GT.0.0)GO TO 754
      IF(QV(I-1,J).LT.0.0)GO TO 755
      Z4=X5/X4
      XX1=((X(I+1,J+1)-X(I,J+1))*Z4)+X(I,J+1)
      YY1=((Y(I+1,J+1)-Y(I,J+1))*Z4)+Y(I,J+1)
      X1=XX1-X(I,J)
      Y1=YY1-Y(I,J)
      GO TO 770
755   Z4=X2/X4
      XX1=X(I+1,J+1)-((X(I+1,J+1)-X(I,J+1))*Z4)
      YY1=Y(I+1,J+1)-((Y(I+1,J+1)-Y(I,J+1))*Z4)
      X1=XX1-X(I+1,J)
      Y1=YY1-Y(I+1,J)
      GO TO 770
754   IF(QV(I-1,J).GE.0.0)GO TO 756
      Z4=X5/X4
      XX1=((X(I+1,J+1)-X(I,J+1))*Z4)+X(I,J+1)
      YY1=((Y(I+1,J+1)-Y(I,J+1))*Z4)+Y(I,J+1)
      X1=X(I,J)-XX1
      Y1=Y(I,J)-YY1
      GO TO 770
756   Z4=X2/X4
      XX1=X(I+1,J+1)-((X(I+1,J+1)-X(I,J+1))*Z4)
      YY1=Y(I+1,J+1)-((Y(I+1,J+1)-Y(I,J+1))*Z4)
      X1=X(I+1,J)-XX1
      Y1=Y(I+1,J)-YY1
770   Z=((Y1*Y1)+(X1*X1))**.5
      IF(Z.LT.0.01)Z=0.01
      X2=ABS(X1)
      Z2=X2/Z
      IF(Z2.GE.1.0)Z2=0.999999
      Z1=ASIN(Z2)
      Z1=Z1*57.3
      IF(X1.GE.0.0.AND.Y1.GE.0.0)ANGLE(I,J)=Z1+180.0
      IF(X1.GE.0.0.AND.Y1.LE.0.0)ANGLE(I,J)=360.0-Z1
      IF(X1.LE.0.0.AND.Y1.GE.0.0)ANGLE(I,J)=180.0-Z1
      IF(X1.LE.0.0.AND.Y1.LE.0.0)ANGLE(I,J)=Z1
740   CONTINUE
      DO 757 I=2,ITOPY
      X2=ABS(QV(I-1,1))
      X3=ABS(QV(I,1))
      IF(X2.LT.0.01)X2=0.01
      IF(X3.LT.0.01)X3=0.01
      IF(X3.GT.X2)GO TO 758
      Z4=X3/X2
      XX1=((X(I,2)-X(I,1))*Z4)+X(I,1)
      YY1=((Y(I,2)-Y(I,1))*Z4)+Y(I,1)
      X1=X(I+1,2)-XX1
      Y1=Y(I+1,2)-YY1
      IF(QV(I-1,1).LE.0.0)X1=X1*(-1.0)
      IF(QV(I-1,1).LE.0.0)Y1=Y1*(-1.0)
      GO TO 769
758   Z4=X2/X3
      XX1=((X(I+1,2)-X(I+1,1))*Z4)+X(I+1,1)
      YY1=((Y(I+1,2)-Y(I+1,1))*Z4)+Y(I+1,1)
      X1=XX1-X(I,2)
      Y1=YY1-Y(I,2)
      IF(QV(I,J).LE.0.0)X1=X1*(-1.0)
```

```
      IF(QV(I,J).LE.0.0)Y1=Y1*(-1.0)
769   Z=((Y1*Y1)+(X1*X1))**.5
      IF(Z.LT.0.01)Z=0.01
      X2=ABS(X1)
      Z2=X2/Z
      IF(Z2.GE.1.0)Z2=0.999999
      Z1=ASIN(Z2)
      Z1=Z1*57.3
      IF(X1.GE.0.0.AND.Y1.GE.0.0)ANGLE(I,1)=Z1+180.0
      IF(X1.GE.0.0.AND.Y1.LE.0.0)ANGLE(I,1)=360.0-Z1
      IF(X1.LE.0.0.AND.Y1.GE.0.0)ANGLE(I,1)=180.0-Z1
      IF(X1.LE.0.0.AND.Y1.LE.0.0)ANGLE(I,1)=Z1
      X2=ABS(QV(I-1,ISIDE))
      X3=ABS(QV(I,ISIDE))
      IF(X2.LT.0.01)X2=0.01
      IF(X3.LT.0.01)X3=0.01
      IF(X3.GT.X2)GO TO 759
      Z4=X3/X2
      XX1=X(I,ISIDEI)-((X(I,ISIDEI)-X(I,ISIDE))*Z4)
      YY1=Y(I,ISIDEI)-((Y(I,ISIDEI)-Y(I,ISIDE))*Z4)
      X1=X(I+1,ISIDE)-XX1
      Y1=Y(I+1,ISIDE)-YY1
      IF(QV(I-1,ISIDE).LE.0.0)X1=X1*(-1.0)
      IF(QV(I-1,ISIDE).LE.0.0)Y1=Y1*(-1.0)
      GO TO  768
759   Z4=X2/X3
      XX1=X(I+1,ISIDEI)-((X(I+1,ISIDEI)-X(I+1,ISIDE))*Z4)
      YY1=Y(I+1,ISIDEI)-((Y(I+1,ISIDEI)-Y(I+1,ISIDE))*Z4)
      X1=XX1-X(I,ISIDE)
      Y1=YY1-Y(I,ISIDE)
      IF(QV(I,ISIDE).LE.0.0)X1=X1*(-1.0)
      IF(QV(I,ISIDE).LE.0.0)Y1=Y1*(-1.0)
768   Z=((Y1*Y1)+(X1*X1))**.5
      IF(Z.LT.0.01)Z=0.01
      X2=ABS(X1)
      Z2=X2/Z
      IF(Z2.GE.1.0)Z2=0.999999
      Z1=ASIN(Z2)
      Z1=Z1*57.3
      IF(X1.GE.0.0.AND.Y1.GE.0.0)ANGLE(I,ISIDE)=Z1+180.0
      IF(X1.GE.0.0.AND.Y1.LE.0.0)ANGLE(I,ISIDE)=360.0-Z1
      IF(X1.LE.0.0.AND.Y1.GE.0.0)ANGLE(I,ISIDE)=180.0-Z1
      IF(X1.LE.0.0.AND.Y1.LE.0.0)ANGLE(I,ISIDE)=Z1
757   CONTINUE
      DO 760 J=1,ISIDE
      ANGLE(1,J)=ANGLE(2,J)
760   ANGLE(ITOP,J)=ANGLE(ITOPY,J)
      DO 767 I=2,ITOPY
      DO 767 J=2,ISIDEE
      X1=ABS(QV(I-1,J))
      X2=ABS(QV(I,J))
      X3=ABS(QH(I,J))
      X4=ABS(QH(I,J-1))
      IF(X3.GT.X1.AND.X3.GT.X2)GO TO 763
      IF(X4.GT.X1.AND.X4.GT.X2)GO TO 763
      XX1=ANGLE(I,J)-ANGLEJ(I,J)
      XX1=XX1/57.3
      XX1=SIN(XX1)
      XX1=ABS(XX1)
      IF(XX1.LT.0.01)XX1=0.01
      V1=QV(I-1,J)/(DISTJ(I,J)*(DP(I,J)+DP(I-1,J))*0.5*XX1)
      V1=ABS(V1)
```

```
      XX2=ANGLE(I,J)-ANGLEJ(I+1,J)
      XX2=XX2/57.3
      XX2=SIN(XX2)
      XX2=ABS(XX2)
      IF(XX2.LT.0.01)XX2=0.01
      V2=QV(I,J)/(DISTJ(I+1,J)*(DP(I,J)+DP(I+1,J))*0.5*XX2)
      V2=ABS(V2)
      V(I,J)=(V1+V2)/2.0
      GO TO 764
763   XX1=ANGLE(I,J)-ANGLEI(I,J)
      XX1=XX1/57.3
      XX1=SIN(XX1)
      XX1=ABS(XX1)
      IF(XX1.LT.0.01)XX1=0.01
      V1=QH(I,J-1)/(DISTI(I,J)*XX1*0.5*(DP(I,J)+DP(I,J-1)))
      V1=ABS(V1)
      XX2=ANGLE(I,J)-ANGLEI(I,J+1)
      XX2=XX2/57.3
      XX2=SIN(XX2)
      XX2=ABS(XX2)
      IF(XX2.LT.0.01)XX2=0.01
      V2=QH(I,J)/(DISTI(I,J+1)*XX2*0.5*(DP(I,J)+DP(I,J+1)))
      V2=ABS(V2)
      V(I,J)=(V1+V2)/2.0
764   CONTINUE
767   CONTINUE
      DO 765 I=2,ITOPY
      XX1=ANGLE(I,1)-ANGLEJ(I,1)
      XX1=XX1/57.3
      XX1=SIN(XX1)
      XX1=ABS(XX1)
      IF(XX1.LT.0.01)XX1=0.01
      V1=QV(I-1,1)/(DISTJ(I,1)*(DP(I,1)+DP(I-1,1))*XX1*0.5)
      XX2=ANGLE(I,1)-ANGLEJ(I+1,1)
      XX2=XX2/57.3
      XX2=SIN(XX2)
      XX2=ABS(XX2)
      IF(XX2.LT.0.01)XX2=0.01
      V2=QV(I,1)/(DISTJ(I+1,1)*(DP(I,1)+DP(I+1,1))*XX2*0.5)
      V(I,1)=(V1+V2)/2.0
      XX3=ANGLE(I,ISIDE)-ANGLEJ(I,ISIDE)
      XX3=XX3/57.3
      XX3=SIN(XX3)
      XX3=ABS(XX3)
      IF(XX3.LT.0.01)XX3=0.01
      V3=QV(I-1,ISIDE)/(DISTJ(I,ISIDE)*(DP(I,ISIDE)+DP(I-1,ISIDE))*XX3*
     10.5)
      XX4=ANGLE(I,ISIDE)-ANGLEJ(I+1,ISIDE)
      XX4=XX4/57.3
      XX4=SIN(XX4)
      XX4=ABS(XX4)
      IF(XX4.LT.0.01)XX4=0.01
      V4=QV(I,ISIDE)/(DISTJ(I+1,ISIDE)*(DP(I,ISIDE)+DP(I+1,ISIDE))*XX4
     1*0.5)
765   V(I,ISIDE)=(V3+V4)/2.0
      DO 766 J=1,ISIDE
      XX1=ANGLE(1,J)-ANGLEJ(2,J)
      XX1=XX1/57.3
      XX1=SIN(XX1)
      XX1=ABS(XX1)
      IF(XX1.LT.0.01)XX1=0.01
      V(1,J)=QV(1,J)/(DISTJ(2,J)*DP(1,J)*XX1)
```

```
      XX2=ANGLE(ITOP,J)-ANGLEJ(ITOP,J)
      XX2=XX2/57.3
      XX2=SIN(XX2)
      XX2=ABS(XX2)
      IF(XX2.LT.0.01)XX2=0.01
  766 V(ITOP,J)=QV(ITOPY,J)/(DISTJ(ITOP,J)*DP(ITOP,J)*XX2)
  500 CONTINUE
C     IF(KMD.EQ.1)GO TO 80
C     COMPUTING ADJUSTMENT FOR ANGULARITY
      DO 961 I=1,ITOPY
      DO 961 J=1,ISIDE
      X11=ANGLEI2(I,J)
      X1=ANGLE(I,J)-ANGLE(I+1,J)
      X2=ANGLE(I,J)+ANGLE(I+1,J)
      IF(X1.GT.180.0)X2=X2+360.0
      IF(X1.LT.(-180.0))X2=X2+360.0
      X2=X2/2.0
      IF(X2.GT.360.0)X2=X2-360.0
      X6=X2-X11
      IF(X6.LT.0.0)X6=X6+180.0
      IF(X6.LT.0.0)X6=X6+180.0
      IF(X6.GT.180.0)X6=X6-180.0
      X61=X6
      X6=X6/57.3
      X6=COS(X6)
      X6=ABS(X6)
      IF(X6.LT.0.01)X6=0.01
      X12=ANGLEJ(I+1,J)
      X14=X2-X12
      IF(X14.GT.180.0)X14=X14-180.0
      IF(X14.LT.0.0)X14=X14+180.0
      IF(X14.LT.0.0)X14=X14+180.0
      X141=X14
      X14=X14/57.3
      X14=SIN(X14)
      X14=ABS(X14)
      X9=X14*X14/X6
      IF(X9.GT.3.0)X9=3.0
      IF(X9.LT.0.01)X9=0.01
C     IF(X61.LT.90.0.AND.X141.LT.90.0.AND.IPHASE.GT.2)X9=0.01
C     IF(X61.GT.90.0.AND.X141.GT.90.0.AND.IPHASE.GT.2)X9=0.01
      DX1(I,J)=((DX1(I,J)*49.0)+X9)/50.0
  961 CONTINUE
      DO 962 I=2,ITOPY
      DO 962 J=1,ISIDEE
      X11=ANGLEJ2(I,J)
      X1=ANGLE(I,J)-ANGLE(I,J+1)
      X2=ANGLE(I,J)+ANGLE(I,J+1)
      IF(X1.GT.180.0)X2=X2+360.0
      IF(X1.LT.(-180.0))X2=X2+360.0
      X2=X2/2.0
      IF(X2.GT.360.0)X2=X2-360.0
      X6=X2-X11
      IF(X6.LT.0.0)X6=X6+180.0
      IF(X6.LT.0.0)X6=X6+180.0
      IF(X6.GT.180.0)X6=X6-180.0
      X61=X6
      X6=X6/57.3
      X6=COS(X6)
      X6=ABS(X6)
      IF(X6.LT.0.01)X6=0.01
      X12=ANGLEI(I,J+1)
```

```
      X14=X2-X12
      IF(X14.GT.180.0)X14=X14-180.0
      IF(X14.LT.0.0)X14=X14+180.0
      IF(X14.LT.0.0)X14=X14+180.0
      X141=X14
      X14=X14/57.3
      X14=SIN(X14)
      X14=ABS(X14)
      X9=X14*X14/X6
      IF(X9.GT.3.0)X9=3.0
      IF(X9.LT.0.01)X9=0.01
C     IF(X61.GT.90.0.AND.X141.GT.90.0.AND.IPHASE.GT.2)X9=0.01
C     IF(X61.LT.90.0.AND.X141.LT.90.0.AND.IPHASE.GT.2)X9=0.01
      DX2(I,J)=((DX2(I,J)*49.0)+X9)/50.0
  962 CONTINUE
   80 CONTINUE
      KOUNT=KOUNT+1
      KKOUN=KKOUN+1
      IF(KKOUN.GT.30.AND.KMD.EQ.0)GO TO 862
      IF(KKOUN.GT.30.AND.KMD.GT.0)GO TO 691
C     WS IS COMPUTED AT LEAST EVERY 50 ITERATIONS
      X2=FLOAT(ITOP)
      IF(IPHASE.GT.0)DQQ=DISCH*X2*0.0002
      IF(IPHASE.GT.0)DSMAX=DQWS*0.03
      IF(KKOUN.GT.30.AND.IPHASE.GT.0)DQQ=DQQ*1.1
      IF(KKOUN.GT.30.AND.IPHASE.GT.0)DSMAX=SUMDS*1.1
      IF(IPHASE.GT.0.AND.SUMDS.GT.DSMAX)GO TO 143
      IF(SUMDS.GT.DQWS)GO TO 143
      IF(SUMDQ.GT.DQQ)GO TO 143
      IF(KMD.EQ.0)GO TO 862
C     GO TO 862
C     COMPUTING FALL BASED ON ENERGY EQUATION
C     THIS INCLUDES COMPUTING SUPERELEVATION
  691 CONTINUE
      KM=KM+1
C     IF(IPHASE.LT.100)GO TO 862
      DO 661 I=1,ITOPY
      DO 661 J=1,ISIDE
      X6=ANGLE(I,J)-ANGLEI2(I,J)
      IF(X6.LT.-180.0)X6=X6+360.0
      IF(X6.GT.180.0)X6=360.0-X6
      X6=X6/57.3
      X6=COS(X6)
      X6=ABS(X6)
      X7=ANGLE(I+1,J)-ANGLEI2(I,J)
      IF(X7.LT.-180.0)X7=X7+360.0
      IF(X7.GT.180.0)X7=360.0-X7
      X7=X7/57.3
      X7=COS(X7)
      X7=ABS(X7)
      X8=(X7+X6)/2.0
      VU=V(I+1,J)
      VU=VU*VU/64.3
      X1=(DP(I+1,J)*0.32)
      IF(VU.GT.X1)VU=X1
      VD=V(I,J)
      VD=VD*VD/64.3
      X2=DP(I,J)*0.32
      IF(VD.GT.X2)VD=X2
      EP=0.33*X8
      CC=1.45*X8
      IF(QV(I,J).GE.0.0.AND.VU.LE.VD)HFV(I,J)=HFV(I,J)+(VD*CC)
```

```
     1-(VU*CC)
       IF(QV(I,J).GE.0.0.AND.VU.GE.VD)HFV(I,J)=HFV(I,J)+(VD*EP)
     1-(VU*EP)
       IF(QV(I,J).LE.0.0.AND.VU.GE.VD)HFV(I,J)=HFV(I,J)+(VD*CC)
     1-(VU*CC)
       IF(QV(I,J).LE.0.0.AND.VU.LE.VD)HFV(I,J)=HFV(I,J)+(VD*EP)
     1-(VU*EP)
       FALL=0.0
       IF(J.EQ.1)GO TO 1720
       IF(QH(I,J-1).LE.0.0.OR.QH(I+1,J-1).LE.0.0)GO TO 1720
       OX1=(X(I,J)-X(I+2,J)+X(I,J+1)-X(I+2,J+1))/4.0
       OY1=(Y(I,J)-Y(I+2,J)+Y(I,J+1)-Y(I+2,J+1))/4.0
       OH=(OX1*OX1)+(OY1*OY1)
       IF(OH.GT.0.1)OH=OH**0.5
       OX1=(X(I+2,J-1)+X(I+1,J-1)-X(I+2,J+1)-X(I+1,J+1))/4.0
       OY1=(Y(I+2,J-1)+Y(I+1,J-1)-Y(I+2,J+1)-Y(I+1,J+1))/4.0
       OV1=(OX1*OX1)+(OY1*OY1)
       IF(OV1.GT.0.1)OV1=OV1**0.5
       OX1=(X(I,J-1)+X(I+1,J-1)-X(I,J+1)-X(I+1,J+1))/4.0
       OY1=(Y(I,J-1)+Y(I+1,J-1)-Y(I,J+1)-Y(I+1,J+1))/4.0
       OV2=(OX1*OX1)+(OY1*OY1)
       IF(OV2.GT.0.1)OV2=OV2**0.5
       IF(OH.GT.OV1)OH=OV1
       IF(OH.GT.OV2)OH=OV2
       X8=ANGLE(I+1,J-1)-ANGLE(I+1,J)
       IF(X8.LT.-180.0)X8=X8+360.0
       IF(X8.GT.180.0)X8=360.0-X8
       X8=X8/114.6
       X8=SIN(X8)
       R1=(X8*2.0)/OV1
       X9=ANGLE(I,J-1)-ANGLE(I,J)
       IF(X9.LT.-180.0)X9=X9+360.0
       IF(X9.GT.180.0)X9=360.0-X9
       X9=X9/114.6
       X9=SIN(X9)
       R2=(X9*2.0)/OV2
       R3=(R1+R2)/2.0
       Z1=(V(I,J)+V(I,J-1)+V(I+1,J)+V(I+1,J-1))/4.0
       FALL=(Z1*Z1*R3*OH*X3)/32.2
       GO TO 1721
1720   CONTINUE
       IF(J.EQ.ISIDE)GO TO 1721
       IF(QH(I,J).GE.0.0.OR.QH(I+1,J).GE.0.0)GO TO 1721
       OX1=(X(I,J)+X(I,J+1)-X(I+2,J)-X(I+2,J+1))/4.0
       OY1=(Y(I,J)+Y(I,J+1)-Y(I+2,J)-Y(I+2,J+1))/4.0
       OH=(OX1*OX1)+(OY1*OY1)
       IF(OH.GT.0.1)OH=OH**0.5
       OX1=(X(I+1,J)+X(I+2,J)-X(I+1,J+2)-X(I+2,J+2))/4.0
       OY1=(Y(I+1,J)+Y(I+2,J)-Y(I+1,J+2)-Y(I+2,J+2))/4.0
       OV1=(OX1*OX1)+(OY1*OY1)
       IF(OV1.GT.0.1)OV1=OV1**0.5
       OX1=(X(I,J)+X(I+1,J)-X(I,J+2)-X(I+1,J+2))/4.0
       OY1=(Y(I,J)+Y(I+1,J)-Y(I,J+2)-Y(I+1,J+2))/4.0
       OV2=(OX1*OX1)+(OY1*OY1)
       IF(OV2.GT.0.1)OV2=OV2**0.5
       IF(OH.GT.OV1)OH=OV1
       IF(OH.GT.OV2)OH=OV2
       X8=ANGLE(I+1,J)-ANGLE(I+1,J+1)
       IF(X8.LT.-180.0)X8=X8+360.0
       IF(X8.GT.180.0)X8=360.0-X8
       X8=X8/114.6
       X8=SIN(X8)
```

```
      R1=(X8*2.0)/OV1
      X9=ANGLE(I,J)-ANGLE(I,J+1)
      IF(X9.LT.-180.0)X9=X9+360.0
      IF(X9.GT.180.0)X9=360.0-X9
      X9=X9/114.6
      X9=SIN(X9)
      R2=(X9*2.0)/OV2
      R3=(R1+R2)/2.0
      Z1=(V(I,J)+V(I+1,J)+V(I,J+1)+V(I+1,J+1))/4.0
      FALL=(Z1*Z1*OH*R3*X3)/32.2
 1721 CONTINUE
C     HFV(I,J)=HFV(I,J)-FALL
  661 CONTINUE
      DO 662 I=2,ITOPY
      DO 662 J=1,ISIDEE
      X6=ANGLE(I,J+1)-ANGLEJ2(I,J)
      IF(X6.GT.180.0)X6=360.0-X6
      IF(X6.LT.-180.0)X6=X6+360.0
      X6=X6/57.3
      X6=COS(X6)
      X6=ABS(X6)
      X7=ANGLE(I,J)-ANGLEJ2(I,J)
      IF(X7.GT.180.0)X7=360.0-X7
      IF(X7.LT.-180.0)X7=X7+360.0
      X7=X7/57.3
      X7=COS(X7)
      X7=ABS(X7)
      X8=(X7+X6)/2.0
      EP=0.33*X8
      CC=1.45*X8
      VU=V(I,J)
      VU=VU*VU/64.3
      X1=DP(I,J)*0.32
      IF(VU.GT.X1)VU=X1
      VD=V(I,J+1)
      VD=VD*VD/64.3
      X2=DP(I,J+1)*0.32
      IF(VD.GT.X2)VD=X2
      IF(QH(I,J).GE.0.0.AND.VU.LE.VD)HFH(I,J)=HFH(I,J)+(VD*CC)
     1-(VU*CC)
      IF(QH(I,J).GE.0.0.AND.VU.GE.VD)HFH(I,J)=HFH(I,J)+(VD*EP)
     1-(VU*EP)
      IF(QH(I,J).LE.0.0.AND.VU.GE.VD)HFH(I,J)=HFH(I,J)+(VD*CC)
     1-(VU*CC)
      IF(QH(I,J).LE.0.0.AND.VD.GE.VU)HFH(I,J)=HFH(I,J)+(VD*EP)
     1-(VU*EP)
      FALL=0.0
      IF(QV(I,J).LE.0.0.OR.QV(I,J+1).LE.0.0)GO TO 1710
      OX1=(X(I,J)+X(I+1,J)-X(I,J+2)-X(I+1,J+2))/4.0
      OY1=(Y(I,J)+Y(I+1,J)-Y(I,J+2)-Y(I+1,J+2))/4.0
      OH=(OX1*OX1)+(OY1*OY1)
      IF(OH.GT.0.1)OH=OH**0.5
      OX1=(X(I,J)+X(I,J+1)-X(I+2,J)-X(I+2,J+1))/4.0
      OY1=(Y(I,J)+Y(I,J+1)-Y(I+2,J)-Y(I+2,J+1))/4.0
      OV1=(OX1*OX1)+(OY1*OY1)
      IF(OV1.GT.0.1)OV1=OV1**0.5
      OX1=(X(I,J+1)+X(I,J+2)-X(I+2,J+1)-X(I+2,J+2))/4.0
      OY1=(Y(I,J+1)+Y(I,J+2)-Y(I+2,J+1)-Y(I+2,J+2))/4.0
      OV2=(OX1*OX1)+(OY1*OY1)
      IF(OV2.GT.0.1)OV2=OV2**0.5
      IF(OH.GT.OV1)OH=OV1
      IF(OH.GT.OV2)OH=OV2
```

```
      X8=ANGLE(I,J)-ANGLE(I+1,J)
      IF(X8.LT.-180.0)X8=X8+360.0
      IF(X8.GT.180.0)X8=360.0-X8
      X8=X8/114.6
      X8=SIN(X8)
      R1=(X8*2.0)/OV1
      X9=ANGLE(I,J+1)-ANGLE(I+1,J+1)
      IF(X9.LT.-180.0)X9=X9+360.0
      IF(X9.GT.180.0)X9=360.0-X9
      X9=X9/114.6
      X9=SIN(X9)
      R2=(X9*2.0)/OV2
      R3=(R1+R2)/2.0
      Z1=(V(I,J)+V(I+1,J)+V(I,J+1)+V(I+1,J+1))/4.0
      FALL=(Z1*Z1*R3*OH*X3)/32.2
      GO TO 1711
 1710 CONTINUE
      IF(QV(I-1,J).GE.0.0.OR.QV(I-1,J+1).GE.0.0)GO TO 1711
      OX1=(X(I,J)+X(I+1,J)-X(I,J+2)-X(I+1,J+2))/4.0
      OY1=(Y(I,J)+Y(I+1,J)-Y(I,J+2)-Y(I+1,J+2))/4.0
      OH=(OX1*OX1)+(OY1*OY1)
      IF(OH.GT.0.1)OH=OH**0.5
      OX1=(X(I-1,J)+X(I-1,J+1)-X(I+1,J)-X(I+1,J+1))/4.0
      OY1=(Y(I-1,J)+Y(I-1,J+1)-Y(I+1,J)-Y(I+1,J+1))/4.0
      OV1=(OX1*OX1)+(OY1*OY1)
      IF(OV1.GT.0.1)OV1=OV1**0.5
      OX1=(X(I-1,J+1)+X(I-1,J+2)-X(I+1,J+1)-X(I+1,J+2))/4.0
      OY1=(Y(I-1,J+1)+Y(I-1,J+2)-Y(I+1,J+1)-Y(I+1,J+2))/4.0
      OV2=(OX1*OX1)+(OY1*OY1)
      IF(OV2.GT.0.1)OV2=OV2**0.5
      IF(OH.GT.OV1)OH=OV1
      IF(OH.GT.OV2)OH=OV2
      X8=ANGLE(I-1,J)-ANGLE(I,J)
      IF(X8.LT.-180.0)X8=X8+360.0
      IF(X8.GT.180.0)X8=360.0-X8
      X8=X8/114.6
      X8=SIN(X8)
      R1=(X8*2.0)/OV1
      X9=ANGLE(I-1,J+1)-ANGLE(I,J+1)
      IF(X9.LT.-180.0)X9=X9+360.0
      IF(X9.GT.180.0)X9=360.0-X9
      X9=X9/114.6
      X9=SIN(X9)
      R2=(X9*2.0)/OV2
      R3=(R1+R2)/2.0
      Z1=(V(I,J)+V(I-1,J)+V(I,J+1)+V(I-1,J+1))/4.0
      FALL=(Z1*Z1*R3*OH*X3)/32.2
 1711 CONTINUE
C     HFH(I,J)=HFH(I,J)-FALL
  662 CONTINUE
      DO 1430 J=1,ISIDE
      VU=(V(1,J)*V(1,J))/64.3
      X1=DP(1,J)*0.32
      IF(VU.GT.X1)VU=X1
      VD=(V(1,J+1)*V(1,J+1))/64.3
      X2=DP(1,J+1)*0.32
      IF(VD.GT.X2)VD=X2
C     HFH(1,J)=HFH(1,J)+VD-VU
      VU=(V(ITOP,J)*V(ITOP,J))/64.3
      X3=DP(ITOP,J)*0.32
      IF(VU.GT.X3)VU=X3
      VD=(V(ITOP,J+1)*V(ITOP,J+1))/64.3
```

```
      X4=DP(ITOP,J+1)*0.32
      IF(VD.GT.X4)VD=X4
C     HFH(ITOP,J)=HFH(ITOP,J)+VD-VU
 1430 CONTINUE
      DO 798 I=1,ITOPY
      DO 798 J=1,ISIDEE
      DST(I,J)=HFV(I,J)+HFH(I,J)-HFV(I,J+1)-HFH(I+1,J)
  798 CONTINUE
  776 FORMAT(1X,'DELTA-STAGE-MOMENTUM')
      SUMDZ=0.0
      DO 902 I=1,ITOPY
      DO 902 J=1,ISIDEE
      X9=DST(I,J)
      CC=ABS(X9)
      SUMDZ=SUMDZ+CC
  735 CONTINUE
  902 CONTINUE
      IF(KOUNT.GT.KSTOP)GO TO 111
  862 CONTINUE
C     ADJUSTING HFV FOR VALUES OF DST
      KKOUN=0
      KWS=KWS+1
      DO 774 I=1,ITOPY
      Z1=ABS(QV(I,1))
      Z9=ABS(QV(I,2))
      Z2=ABS(QH(I,1))
      Z3=ABS(QH(I+1,1))
      Z4=(Z1+Z9)/((Z1+Z9+Z2+Z3)*2.0)
      Z5=ABS(QV(I,ISIDE))
      Z10=ABS(QV(I,ISIDEE))
      Z6=ABS(QH(I,ISIDEE))
      Z7=ABS(QH(I+1,ISIDEE))
      Z8=(Z5+Z10)/((Z5+Z10+Z6+Z7)*2.0)
      X1=DST(I,1)
      IF(X1.GT.0.1)X1=0.1
      IF(X1.LT.(-0.1))X1=(-0.1)
      HFV(I,1)=HFV(I,1)-(X1*Z4)
      X2=DST(I,ISIDEE)
      IF(X2.GT.0.1)X2=0.1
      IF(X2.LT.(-0.1))X2=(-0.1)
      HFV(I,ISIDE)=HFV(I,ISIDE)+(X2*Z8)
      X3=WS(I+1,1)-WS(I,1)
      X4=X3+0.1
      X5=X3-0.1
      IF(HFV(I,1).GT.X4)HFV(I,1)=X4
      IF(HFV(I,1).LT.X5)HFV(I,1)=X5
      X6=WS(I+1,ISIDE)-WS(I,ISIDE)
      X7=X6+0.1
      X8=X6-0.1
      IF(HFV(I,ISIDE).GT.X7)HFV(I,ISIDE)=X7
      IF(HFV(I,ISIDE).LT.X8)HFV(I,ISIDE)=X8
C     IF(HFV(I,1).GT.2.0)HFV(I,1)=2.0
C     IF(HFV(I,1).LT.(-2.0))HFV(I,1)=(-2.0)
C     IF(HFV(I,ISIDE).GT.2.0)HFV(I,ISIDE)=2.0
C     IF(HFV(I,ISIDE).LT.(-2.0))HFV(I,ISIDE)=(-2.0)
  774 CONTINUE
      DO 775 I=1,ITOPY
      DO 775 J=2,ISIDEE
      Z1=ABS(QV(I,J))
      Z2=ABS(QV(I,J-1))
      Z3=ABS(QH(I,J-1))
      Z4=ABS(QH(I+1,J-1))
```

```
      Z5=(Z1+Z2)/((Z1+Z2+Z3+Z4)*2.0)
      Z6=ABS(QV(I,J+1))
      Z7=ABS(QH(I,J))
      Z8=ABS(QH(I+1,J))
      Z9=(Z1+Z6)/((Z1+Z6+Z7+Z8)*2.0)
      X1=DST(I,J)
      IF(X1.GT.0.1)X1=0.1
      IF(X1.LT.(-0.1))X1=(-0.1)
      X2=DST(I,J-1)
      IF(X2.GT.0.1)X2=0.1
      IF(X2.LT.(-0.1))X2=(-0.1)
      HFV(I,J)=HFV(I,J)-(X1*Z9)+(X2*Z5)
      X3=WS(I+1,J)-WS(I,J)
      X4=X3+0.1
      X5=X3-0.1
      IF(HFV(I,J).GT.X4)HFV(I,J)=X4
      IF(HFV(I,J).LT.X5)HFV(I,J)=X5
C     IF(HFV(I,J).GT.2.0)HFV(I,J)=2.0
C     IF(HFV(I,J).LT.(-2.0))HFV(I,J)=(-2.0)
  775 CONTINUE
      DO 6000 J=1,ISIDE
 6000 E(1,J)=WS(1,J)
      DO 144 I=2,ITOP
      DO 144 J=1,ISIDE
  144 E(I,J)=E(I-1,J)+HFV(I-1,J)
C     WATER SURFACE ELEVATIONS AT UPSTREAM END ARE ARRAYED
      DO 875 J=1,ISIDE
  875 ADM(J)=E(ITOP,J)
      DO 876 I=1,ISIDEE
      IP1=I+1
      DO 876 J=IP1,ISIDE
      IF(ADM(I).GE.ADM(J))GO TO 876
      TEMP=ADM(I)
      ADM(I)=ADM(J)
      ADM(J)=TEMP
  876 CONTINUE
C     LOWEST 2 OR 3 AND HIGHEST 2 OR 3 WS AT UPSTR END ARE DROPPED
C     AND THE REMAINDER ARE AVERAGED TO GIVE UPSTR WS (TOP).
      K=(ISIDE/11)+1
      K1=ISIDE-K
      K2=ISIDE-K-K
      AX=FLOAT(K2)
      K3=K+1
      IF(ISIDE.LT.5)K1=ISIDE
      IF(ISIDE.LT.5)K3=1
      IF(ISIDE.LT.5)AX=FLOAT(ISIDE)
      SUM=0.0
      DO 877 I=K3,K1
  877 SUM=SUM+ADM(I)
      SUM=SUM/AX
      TOP=SUM
      TOP=(TOP+TOPLAST)/2.0
      X1=TOPLAST+1.0
      X2=TOPLAST-1.0
      IF(TOP.GT.X1)TOP=X1
      IF(TOP.LT.X2)TOP=X2
C     EACH HFV IS ADJUSTED SO THAT WS LEVEL AT UPSTR END WILL BE EQUAL
      X9=FLOAT(ITOPY)
      DO 400 J=1,ISIDE
      DO 402 I=1,ITOPY
  402 HFV(I,J)=HFV(I,J)+((TOP-E(ITOP,J))/X9)
  400 CONTINUE
```

```
      DO 148 I=2,ITOP
      DO 148 J=1,ISIDE
  148 E(I,J)=E(I-1,J)+HFV(I-1,J)
      DO 401 I=2,ITOP
      DO 401 J=1,ISIDE
      E(I,J)=(E(I,J)+WS(I,J))/2.0
  401 CONTINUE
      DW2=0.0
C     COMPUTE CHANGE IN WS ELEV AT UPSTR END
      DW2=TOP-TOPLAST
      DW2=ABS(DW2)
      TOPLAST=TOP
C     COMPUTE NEW WS ELEVATIONS
      DO 149 I=2,ITOP
      DO 149 J=1,ISIDE
  149 WS(I,J)=E(I,J)
      IF(DW2.GT.0.03)GO TO 446
C     COMPUTATION OF FLOW OVER ROAD,  THIS IS DONE ONLY WHEN WS AT
C     UPSTR END IS LESS THAN 0.03 OF PREVIOUS WS AT UPSTR END
      TFLOR=ABS(TFLOR)
      IF(NROP.EQ.0)GO TO 446
      DO 910 I=1,ITOP
      DO 910 J=1,ISIDE
  910 QRD(I,J)=0.0
      KOR=KOR+1
      TFLOR=0.0
      DO 441 I=1,NROP
      KI=KUI(I)
      KI1=KI-1
      KJ=KUJ(I)
      LI=KDI(I)
      LI1=LI-1
      LJ=KDJ(I)
      H4=WS(KI,KJ)-RE(I)
      D4=WS(LI,LJ)-RE(I)
      IF(H4.LT.0.02)H4=0.02
      IF(D4.LT.0.01)D4=0.01
      H1=D4/H4
      IF(D4.GT.H4)H1=H4/D4
      IF(D4.GT.H4)H4=D4
      ADJ=1.0
C     COMPUTE ADJUSTMENT FOR NON FREEFALL
      IF(H1.GE.0.66.AND.H1.LE.0.8)ADJ=1.0-(((H1-0.66)/0.14)*0.12)
      IF(H1.GE.0.8.AND.H1.LE.0.9)ADJ=0.88-(((H1-0.8)/0.1)*0.18)
      IF(H1.GE.0.9.AND.H1.LE.0.98)ADJ=0.7-(((H1-0.9)/0.08)*0.3)
      IF(H1.GT.0.98)ADJ=0.4-(((H1-0.98)/0.02)*0.4)
      IF(H1.GT.0.995)ADJ=0.0
      H2=H4**1.5
      IF(H2.LT.0.005)H2=0.0
      QA=3.0*H2*ADJ*FLW(I)
      F1=WS(KI,KJ)-WS(LI,LJ)
      CI=CULC(I)
      F2=ABS(F1)
      IF(F2.GT.0.01)F2=F2**0.5
      QA=QA+(F2*CI)
      TFLOR=TFLOR+QA
      QADJ(I)=((F2*CI)+(QADJ(I)*3.0))/4.0
      IF(F1.LT.0.0)QA=QA*(-1.0)
      IF(F1.LT.0.0)QA=0.0
      IF(KOR.EQ.0)QA=QA*0.2
      IF(KOR.EQ.1)QA=QA*0.4
      IF(KOR.EQ.2)QA=QA*0.7
```

```
      IF(H4.LT.0.011)QA=0.0
      IF(IPHASE.EQ.0)QA=(QA+QA1(I))/2.0
      IF(IPHASE.GE.1)QA=(QA+(QA1(I)*3.0))/4.0
      QRD(KI,KJ)=QRD(KI,KJ)+QA
      QRD(LI,LJ)=QRD(LI,LJ)-QA
  441 QA1(I)=QA
      WRITE(5,3005)
 3005 FORMAT(2X,'DISCHARGE',4X,'UPS WS',3X,'DSTR WS',2X,'HWY ELEV')
      DO 940 I=1,NROP
      KI=KUI(I)
      KJ=KUJ(I)
      LI=KDI(I)
      LJ=KDJ(I)
  940 WRITE(5,941)QA1(I),WS(KI,KJ),WS(LI,LJ),RE(I)
  941 FORMAT(1X,F10.0,3F10.2)
      TFLOR=ABS(TFLOR)
  446 CONTINUE
C     END OF COMPUTATION OF FLOW OVER ROAD
      RUN=0.0
      DO 403 I=1,ITOPY
      TUM=0.0
      DO 404 J=1,ISIDE
  404 TUM=TUM+QV(I,J)
      DO 442 J=1,ISIDE
  442 RUN=RUN+QRD(I,J)
      DO 405 J=1,ISIDE
  405 QV(I,J)=(QV(I,J)*(DISCH+RUN))/TUM
  923 FORMAT(1X,3F10.0)
 2000 FORMAT(1X,2F10.0)
  403 CONTINUE
C     IF(KMD.EQ.1)GO TO 934
      DO 150 I=1,ITOP
      DO 150 J=1,ISIDE
      D=WS(I,J)-GR(I,J)
      X1=DP(I,J)+1.0
      X2=DP(I,J)-1.0
      IF(D.GT.X1)D=X1
      IF(D.LT.X2)D=X2
      IF(D.LT.0.50)D=0.50
      DP(I,J)=D
  150 CONV(I,J)=(1.486*(D**1.667))/CM(I,J)
  934 CONTINUE
  895 FORMAT(1X,5F10.4)
      X8=FLOAT(ISIDE)
      WRITE(5,732)DW2,TOP,IPHASE
  732 FORMAT(4X,'CHANGE IN STAGE AT UPSTR END =',F5.2,3X,'AVERAGE STAGE
     1 =',F6.2,2X,'IPHASE =',I3)
      X1=(WS(ITOP,1)-WS(1,1))/200.0
      IF(X1.LT.0.02)X1=0.02
      IF(DW2.LT.X1.AND.KM.GE.8)GO TO 111
      IF(KOR.GT.8.AND.DW2.LT.X1)IPHASE=IPHASE+1
C     WS AT UPSTR END IS COMPUTED WITHIN 0.01 OF PREVIOUS WS 6 TIMES
C     BEFORE ENERGY EQUATION IS USED
      IF(IPHASE.GT.5.AND.DW2.LT.X1)KMD=1
  143 CONTINUE
      WRITE(5,731)KOUNT,SUMDZ,SUMDQ,SUMDS,TFAJ
  731 FORMAT(1X,'ITERATION =',I4,3X,'SUMDZ =',F7.1,4X,'SUMDQ =',F8.1,
     12X,'SUMDS=',F7.1,2X,'TFAJ =',F4.2)
      N=KSTOP
      IF(KOUNT.GE.2)N=KSTOP+100
      IF(KOUNT.LT.N)GO TO 71
  111 CONTINUE
```

```
 305  FORMAT(1X,16F8.2)
 828  FORMAT(1X,26F5.2)
      WRITE(6,2540)
2540  FORMAT(1X,'ALL OF THE FOLLOWING DATA, VERTICAL DISCHARGE, WATER S
     1URFACE ELEVATIONS, ETC, ARE')
      WRITE(6,2541)
2541  FORMAT(1X,'LISTED STARTING WITH THE DOWNSTREAM HORIZONTAL LINE AN
     1D GOING TO THE UPSTREAM HORIZONTAL')
      WRITE(6,2542)
2542  FORMAT(1X,'LINE.  THE FIRST VALUE ON EACH LINE IS THE LEFT MOST V
     1ALUE LOOKING UPSTREAM.  POSITIVE')
      WRITE(6,2543)
2543 FORMAT(1X,' VERTICAL DISCHARGES ARE GOING FROM UPSTREAM TO DOWNSTR
     1EAM.  POSITIVE HORIZONTAL DISCHARGES')
      WRITE(6,2544)
2544 FORMAT(1X,'ARE GOING FROM LEFT TO RIGHT LOOKING UPSTREAM.  NEGATIV
     1E DISCHARGES ARE IN OPPOSITE DIRECTIONS')
      WRITE(6,311)
      DO 178 I=1,ITOPY
 178  WRITE(6,300)(QV(I,J),J=1,ISIDE)
      WRITE(6,312)
      DO 180 I=1,ITOP
 180  WRITE(6,300)(QH(I,J),J=1,ISIDEE)
      WRITE(6,711)
      DO 183 I=1,ITOP
 183  WRITE(6,182)(DP(I,J),J=1,ISIDE)
      WRITE(6,712)
      DO 192 I=1,ITOP
 192  WRITE(6,182)(WS(I,J),J=1,ISIDE)
      WRITE(6,720)
 720  FORMAT(1X,'VELOCITY')
      DO 730 I=1,ITOP
 730  WRITE(6,182)(V(I,J),J=1,ISIDE)
      WRITE(6,721)
 721  FORMAT(1X,'ANGLE OF FLOW')
      DO 722 I=1,ITOP
 722  WRITE(6,300)(ANGLE(I,J),J=1,ISIDE)
      WRITE(6,713)
      DO 193 I=1,ITOP
 193  WRITE(6,179)(CONV(I,J),J=1,ISIDE)
 894  FORMAT(1X,10F8.4)
      WRITE(6,356)KMD
 356  FORMAT(1X,I3)
      WRITE(6,356)KOR
      WRITE(6,453)
 453  FORMAT(1X,'FLOW OVER ROAD')
      DO 455 I=1,ITOP
 455  WRITE(6,300)(QRD(I,J),J=1,ISIDE)
      WRITE(6,950)
 950  FORMAT(1X,'THESE VALUES ARE CORRECTIONS FOR ANGULARITY')
      DO 951 I=1,ITOPY
 951  WRITE(6,182)(DX1(I,J),J=1,ISIDE)
      WRITE(6,952)
 952  FORMAT(1X,'THESE VALUES ARE CORRECTIONS FOR ANGULARITY')
      DO 953 I=1,ITOP
 953  WRITE(6,182)(DX2(I,J),J=1,ISIDEE)
      WRITE(6,423)
 423  FORMAT(1X,'ERROR IN BALANCING WATER SURFACE HEADS AT EACH ELEMENT
     1, IN FEET')
      DO 424 I=1,ITOPY
 424  WRITE(6,54)(DST(I,J),J=1,ISIDEE)
      WRITE(6,2001)
```

```
2001  FORMAT(1X,'FLOW THROUGH CULVERT.  THESE ARE FOR EACH OF THE FLOW
    1OVER ROAD POINTS')
      WRITE(6,300)(QADJ(I),I=1,NROP)
9999  CONTINUE
      CLOSE (8)
      CLOSE (6)
      CLOSE (7)
      STOP
      END
```

ATTACHMENT B

FORTRAN IV GRID NETWORK PLOTTING PROGRAM LISTING

```
      DIMENSION X(52,38),Y(52,38),INAME(20),KUI(40),KUJ(40),RE(40)
      DIMENSION GR(52,38),CM(52,38),WS(52,38),KDI(40),KIBI(10)
      DIMENSION KIBJ(10),KITI(10),NUB(20),ANV(20)
      OPEN (UNIT=7,FILE='TWO.D.DATA',STATUS='OLD')
      OPEN (UNIT=8,FILE='PL.DATA',STATUS='NEW')
      READ(7,9)(INAME(I),I=1,20)
    9 FORMAT(20A4)
      WRITE(8,19)(INAME(I),I=1,20)
   19 FORMAT(1X,20A4)
      READ(7,2500)DISCH
 2500 FORMAT(F10.0)
      READ(7,2500)WSINT
      READ(7,2501)KSTOP
 2501 FORMAT(I10)
      READ(7,2501)ITOPI
      READ(7,2501)ISIDEI
      READ(7,2501)IRERUN
      READ(7,2501)IBR
      READ(7,2501)NROP
      READ(7,2501)NV
      READ(7,2501)NDSEL
      ITOP=ITOPI-1
      ISIDE=ISIDEI-1
      IF(NDSEL.LT.1)GO TO 1512
      READ(7,1051)(WS(1,J),J=1,ISIDE)
 1051 FORMAT(8F10.0)
 1512 CONTINUE
   22 FORMAT(2F10.0,7I5)
      DO 620 I=1,NV
      READ(7,621)NUB(I)
  621 FORMAT(F5.0)
  620 CONTINUE
      IF(NROP.EQ.0)GO TO 443
      DO 445 N=1,NROP
  445 READ(7,444)KUI(N),KUJ(N),KDI(N),RE(N)
  444 FORMAT(3I4,F10.0)
  443 CONTINUE
      IF(IBR.LT.1)GO TO 447
      DO 448 M=1,IBR
  448 READ(7,449)KIBI(M),KIBJ(M),KITI(M)
  449 FORMAT(3I4)
  447 CONTINUE
      DO 24 I=1,ITOP
   24 READ(7,51)(GR(I,J),J=1,ISIDE)
      DO 25 I=1,ITOP
   25 READ(7,51)(CM(I,J),J=1,ISIDE)
   51 FORMAT(16F5.0)
      DO 4 I=1,ITOPI
    4 READ(7,3)(X(I,J),Y(I,J),J=1,ISIDEI)
    3 FORMAT(12F6.0)
      DO 5 I=1,ITOPI
      WRITE(8,2) I
    2 FORMAT(3X,'"',I2,'"')
      DO 14 J=1,ISIDEI
      WRITE(8,11)X(I,J),Y(I,J)
      KCAT=0
      DO 15 K=1,IBR
      KB=KIBI(K)
      KJ=KIBJ(K)
      KT=KITI(K)
```

```
15   IF(KJ.EQ.J.AND.I.GT.KB.AND.I.LT.KT)KCAT=1
     IF(KCAT.EQ.1)WRITE(8,2)I
14   CONTINUE
 5   CONTINUE
11   FORMAT(1X,8F9.1)
     DO 10 J=1,ISIDEI
     WRITE(8,2) J
10   WRITE(8,11)(X(I,J),Y(I,J),I=1,ITOPI)
     CLOSE(8)
     CLOSE(7)
     STOP
     END
```

ATTACHMENT C

FORTRAN IV WATER-SURFACE CONTOURS PLOTTING PROGRAM LISTING

```
      DIMENSION X(47,30),Y(47,30),INAME(20),IBLANK(20),M(90),MI(90)
      DIMENSION GR(47,30),CM(47,30),WS(47,30),XWS(50,90),YWS(50,90)
      DIMENSION QV(47,30), QH(47,30),DP(47,30),QADJ(40),QRD(47,30)
      DIMENSION KUI(40),KUJ(40),KDI(40),KDJ(40),RE(40),KIBI(40)
      DIMENSION KIBJ(40),KITI(40),LLJ(40),LRJ(40),LTI(40),LBI(40)
      DIMENSION NUB(30),ANV(30),E(1,30)
      OPEN (UNIT=7,FILE='TWO.D.DATA',STATUS='OLD')
      OPEN (UNIT=8,FILE='PL.DATA',STATUS='NEW')
      OPEN (UNIT=6,FILE='INIT.DATA',STATUS='OLD')
      READ(7,9)(INAME(I),I=1,20)
    9 FORMAT(20A4)
      WRITE(8,19)(INAME(I),I=1,20)
   19 FORMAT(1X,20A4)
      READ(7,2500)DISCH,DH
 2500 FORMAT(2F10.0)
      READ(7,2500)WSINT
      READ(7,2501)KSTOP
 2501 FORMAT(I10)
      READ(7,2501)ITOPI
      READ(7,2501)ISIDEI
      READ(7,2501)IRERUN
      READ(7,2501)IBR
      READ(7,2501)NROP
      READ(7,2501)NV
      READ(7,2501)NDSEL
      ISIDE=ISIDEI-1
      IF(NDSEL.LT.1)GO TO 1513
      READ(7,1051)(E(1,J),J=1,ISIDE)
 1513 CONTINUE
 1051 FORMAT(8F10.0)
      ITOP=ITOPI-1
      ISIDE=ISIDEI-1
      ISIDEE=ISIDE-1
      ITOPY=ITOP-1
      DO 622 I=1,NV
      READ(7,621)NUB(I),ANV(I)
  621 FORMAT(I5,F5.0)
  622 CONTINUE
   22 FORMAT(2F10.0,8I5,F5.0)
      IF(NROP.EQ.0)GO TO 443
      DO 445 I=1,NROP
      READ(7,444)KUI(I),KUJ(I),KDI(I),KDJ(I),RE(I)
  445 QADJ(I)=0.0
  444 FORMAT(4I4,F10.0)
  443 CONTINUE
      IF(IBR.LT.1)GO TO 447
      DO 448 I=1,IBR
  448 READ(7,449)KIBI(I),KIBJ(I),KITI(I),LLJ(I),LRJ(I),LTI(I),LBI(I)
  449 FORMAT(7I4)
  447 CONTINUE
      DO 24 I=1,ITOP
   24 READ(7,51)(GR(I,J),J=1,ISIDE)
  100 FORMAT(1X,F8.3)
      DO 25 I=1,ITOP
   25 READ(7,51)(CM(I,J),J=1,ISIDE)
   51 FORMAT(16F5.0)
      DO 4 I=1,ITOPI
    4 READ(7,3)(X(I,J),Y(I,J),J=1,ISIDEI)
    3 FORMAT(12F6.0)
      READ(6,9)(IBLANK(I),I=1,20)
```

```
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 173 I=1,ITOPY
  173 READ(6,300)(QV(I,J),J=1,ISIDE)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 174 I=1,ITOP
  174 READ(6,300)(QH(I,J),J=1,ISIDEE)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 177 I=1,ITOP
  177 READ(6,182)(DP(I,J),J=1,ISIDE)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 194 I=1,ITOP
  194 READ(6,182)(WS(I,J),J=1,ISIDE)
  300 FORMAT(1X,8F9.0)
  182 FORMAT(1X,11F7.3)
   50 FORMAT(1X,'WS 9,9 =',F8.3)
      K=1
      DH1=WSINT
      DO 67 J=1,ISIDE
      XWS(1,J)=X(1,J)
   67 YWS(1,J)=Y(1,J)
      MI(1)=ISIDE
C     IF(TWS.GT.WS(ITOP,9))TWS=WS(ITOP,9)
      TWS=WS(ITOP,9)
   65 K=K+1
      DH1=DH1+DH
      IF(DH1.GT.TWS)GO TO 66
      DO 35 J=1,ISIDE
      DO 39 I=2,ITOP
      M(J)=1
      IF(DH1.GT.WS(I,J))GO TO 40
      M(J)=I
      GO TO 41
   40 CONTINUE
   39 CONTINUE
   41 CONTINUE
   35 CONTINUE
C     WRITE(8,43)K
   43 FORMAT(1X,'K =',I2)
C     WRITE(8,44)(M(J),J=1,ISIDE)
   44 FORMAT(1X,19I4)
      M3=0
      I=M(1)
      Z=(DH1-WS(I-1,1))/(WS(I,1)-WS(I-1,1))
C     XWS(K,1)=((X(I,1)-X(I-1,1))*Z)+X(I-1,1)
C     YWS(K,1)=((Y(I,1)-Y(I-1,1))*Z)+Y(I-1,1)
      A1=(X(I,1)+X(I,2)+X(I+1,1)+X(I+1,2))/4.0
      A2=(X(I-1,1)+X(I-1,2)+X(I,1)+X(I,2))/4.0
      XWS(K,1)=((A1-A2)*Z)+A2
      A3=(Y(I,1)+Y(I,2)+Y(I-1,1)+Y(I-1,2))/4.0
      A4=(Y(I-1,1)+Y(I-1,2)+Y(I,1)+Y(I,2))/4.0
      YWS(K,1)=((A3-A4)*Z)+A4
      DO 61 J=2,ISIDE
      I=M(J)
      IF(M(J).EQ.M(J-1))GO TO 1
      M1=M(J)
      M2=M(J-1)
      M4=M1-1
      IF(M(J).LT.M(J-1))GO TO 32
```

```
      DO 33 I=M2,M4
      IF(DH1.GT.WS(I,J-1))GO TO 34
      J1=J+M3
      Z=(WS(I,J-1)-DH1)/(WS(I,J-1)-WS(I,J))
C     XWS(K,J1)=((X(I,J)-X(I,J-1))*Z)+X(I,J-1)
C     YWS(K,J1)=((Y(I,J)-Y(I,J-1))*Z)+Y(I,J-1)
      A1=(X(I,J)+X(I,J+1)+X(I+1,J)+X(I+1,J+1))/4.0
      A2=(X(I,J-1)+X(I,J)+X(I+1,J-1)+X(I+1,J))/4.0
      XWS(K,J1)=((A1-A2)*Z)+A2
      A3=(Y(I,J)+Y(I,J+1)+Y(I+1,J)+Y(I+1,J+1))/4.0
      A4=(Y(I,J-1)+Y(I,J)+Y(I+1,J-1)+Y(I+1,J))/4.0
      YWS(K,J1)=((A3-A4)*Z)+A4
      M3=M3+1
C     WRITE(8,11)XWS(K,J1),YWS(K,J1)
C     WRITE(8,46)M3,J1
   46 FORMAT(1X,'M3 =',I4,'    J1 =',I4)
   34 CONTINUE
   33 CONTINUE
      I=M(J)
      GO TO 1
   32 CONTINUE
      M5=M2-1
   37 IF(DH1.GT.WS(M5,J))GO TO 38
      J1=J+M3
      Z=(DH1-WS(M5,J-1))/(WS(M5,J)-WS(M5,J-1))
C     XWS(K,J1)=((X(M5,J)-X(M5,J-1))*Z)+X(M5,J-1)
C     YWS(K,J1)=((Y(M5,J)-Y(M5,J-1))*Z)+Y(M5,J-1)
      A1=(X(M5,J)+X(M5,J+1)+X(M5+1,J)+X(M5+1,J+1))/4.0
      A2=(X(M5,J-1)+X(M5,J)+X(M5+1,J-1)+X(M5+1,J))/4.0
      XWS(K,J1)=((A1-A2)*Z)+A2
      A3=(Y(M5,J)+Y(M5,J+1)+Y(M5+1,J)+Y(M5+1,J+1))/4.0
      A4=(Y(M5,J-1)+Y(M5,J)+Y(M5+1,J-1)+Y(M5+1,J))/4.0
      YWS(K,J1)=((A3-A4)*Z)+A4
      M3=M3+1
C     WRITE(8,11)XWS(K,J1),YWS(K,J1)
C     WRITE(8,46)M3,J1
   38 CONTINUE
      M5=M5-1
      IF(M5.GE.M1)GO TO 37
    1 CONTINUE
      I=M(J)
      J1=J+M3
      Z=(DH1-WS(I-1,J))/(WS(I,J)-WS(I-1,J))
C     XWS(K,J1)=((X(I,J)-X(I-1,J))*Z)+X(I-1,J)
C     YWS(K,J1)=((Y(I,J)-Y(I-1,J))*Z)+Y(I-1,J)
      A1=(X(I,J)+X(I,J+1)+X(I+1,J)+X(I+1,J+1))/4.0
      A2=(X(I-1,J)+X(I,J)+X(I,J+1)+X(I-1,J+1))/4.0
      XWS(K,J1)=((A1-A2)*Z)+A2
      A3=(Y(I,J)+Y(I,J+1)+Y(I+1,J)+Y(I+1,J+1))/4.0
      A4=(Y(I-1,J)+Y(I,J)+Y(I,J+1)+Y(I-1,J+1))/4.0
      YWS(K,J1)=((A3-A4)*Z)+A4
C     WRITE(8,46)M3,J1
   61 CONTINUE
      MI(K)=J1
C     WRITE(8,45)J1,MI(K)
   45 FORMAT(1X,'NUMBER =',I4,I6)
      GO TO 65
   66 CONTINUE
      K=K-1
      DO 5 I=1,K
      MT=MI(I)
      WRITE(8,2)I
```

```
  2   FORMAT(3X,'"',I2,'"')
  5   WRITE(8,11)(XWS(I,J),YWS(I,J),J=1,MT)
 11   FORMAT(1X,10F7.0)
      K=K+1
      WRITE(8,2)K
      WRITE(8,11)(X(I,1),Y(I,1),I=1,ITOP)
      WRITE(8,2)K
      WRITE(8,11)(X(I,ISIDEI),Y(I,ISIDEI),I=1,ITOPI)
      CLOSE(8)
      CLOSE(7)
      STOP
      END
```

ATTACHMENT D

FORTRAN IV VELOCITY VECTOR PLOTTING PROGRAM LISTING

```
      DIMENSION X(47,30),Y(47,30),INAME(20),IBLANK(20),M(90),MI(90)
      DIMENSION GR(47,30),DP(47,30),QV(47,30)
      DIMENSION KUI(40),KUJ(40),KDI(40),KDJ(40),RE(40),KIBI(40)
      DIMENSION KIBJ(40),KITI(40),LLJ(40),LRJ(40),LTI(40),LBI(40)
      DIMENSION NUB(30),ANV(30),E(1,30),XM(47,30),YM(47,30)
      DIMENSION XP(47,30),YP(47,30),V(47,30),ANGLE(47,30)
      DIMENSION XP3(47,30),YP3(47,30),XP4(47,30),YP4(47,30)
      OPEN (UNIT=7,FILE='TWO.D.DATA',STATUS='OLD')
      OPEN (UNIT=8,FILE='PL.DATA',STATUS='NEW')
      OPEN (UNIT=6,FILE='INIT.DATA',STATUS='OLD')
C     THIS PROGRAM PLOTS VELOCITY VECTORS.  THE INPUT DATA FILES ARE
C     'TWO.D.DATA' AND 'INIT.DATA'.  'INIT.DATA' IS EQUAL TO 'OUTPUT.DATA'
C     FROM THE TWO.D.MODEL RUN.  THE 'TWO.D.DATA' FILE NEEDS TO BE
C     MODIFIED BEFORE RUNNING THIS PROGRAM.  ON THE SECOND LINE, THE
C     DISCHARGE VALUE IS IN COLUMNS 1-10.  IN COLUMNS 21-30, ADD A
C     VECTOR SCALE WHICH DETERMINES THE LENGTH OF THE VECTOR LINE,
C     AND IN COLUMNS 31-40, ADD AN ARROW SCALE WHICH DETERMINES THE SIZE
C     OF THE ARROW.  BOTH OF THESE VALUES ARE APPROXIMATELY EQUAL TO 10.0.
C     THESE VALUES CAN BE CHANGED TO ACCOMADATE THE SIZE OF THE PLOT.
      READ(7,9)(INAME(I),I=1,20)
    9 FORMAT(20A4)
      WRITE(8,19)(INAME(I),I=1,20)
   19 FORMAT(1X,20A4)
      READ(7,2500)DISCH,DH,AL,SA
 2500 FORMAT(4F10.0)
      READ(7,2500)WSINT
      READ(7,2501)KSTOP
 2501 FORMAT(I10)
      READ(7,2501)ITOPI
      READ(7,2501)ISIDEI
      READ(7,2501)IRERUN
      READ(7,2501)IBR
      READ(7,2501)NROP
      READ(7,2501)NV
      READ(7,2501)NDSEL
      ISIDE=ISIDEI-1
      IF(NDSEL.LT.1)GO TO 1513
      READ(7,1051)(E(1,J),J=1,ISIDE)
 1513 CONTINUE
 1051 FORMAT(8F10.0)
      ITOP=ITOPI-1
      ISIDE=ISIDEI-1
      ISIDEE=ISIDE-1
      ITOPY=ITOP-1
      DO 622 I=1,NV
      READ(7,621)NUB(I),ANV(I)
  622 CONTINUE
  621 FORMAT(8(I5,F5.0))
   22 FORMAT(2F10.0,8I5,F5.0)
      IF(NROP.EQ.0)GO TO 443
      DO 445 I=1,NROP
  445 READ(7,444)KUI(I),KUJ(I),KDI(I),KDJ(I),RE(I)
  444 FORMAT(4I4,F10.0)
  443 CONTINUE
      IF(IBR.LT.1)GO TO 447
      DO 448 I=1,IBR
  448 READ(7,449)KIBI(I),KIBJ(I),KITI(I),LLJ(I),LRJ(I),LTI(I),LBI(I)
  449 FORMAT(7I4)
  447 CONTINUE
      DO 24 I=1,ITOP
   24 READ(7,51)(GR(I,J),J=1,ISIDE)
  100 FORMAT(1X,F8.3)
      DO 25 I=1,ITOP
```

```
 25   READ(7,51)(GR(I,J),J=1,ISIDE)
 51   FORMAT(16F5.0)
      DO 4 I=1,ITOPI
  4   READ(7,3)(X(I,J),Y(I,J),J=1,ISIDEI)
  3   FORMAT(12F6.0)
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 173 I=1,ITOPY
173   READ(6,300)(QV(I,J),J=1,ISIDE)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 174 I=1,ITOP
174   READ(6,300)(QV(I,J),J=1,ISIDEE)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 177 I=1,ITOP
177   READ(6,182)(DP(I,J),J=1,ISIDE)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 194 I=1,ITOP
194   READ(6,182)(DP(I,J),J=1,ISIDE)
300   FORMAT(1X,8F9.0)
182   FORMAT(1X,11F7.3)
      READ(6,9)(IBLANK(I),I=1,20)
      DO 400 I=1,ITOP
400   READ(6,182)(V(I,J),J=1,ISIDE)
      READ(6,9)(IBLANK(I),J=1,20)
      DO 401 I=1,ITOP
401   READ(6,300)(ANGLE(I,J),J=1,ISIDE)
      DO 402 I=1,ITOP
      DO 402 J=1,ISIDE
      XP(I,J)=(X(I,J)+X(I+1,J)+X(I+1,J+1)+X(I,J+1))/4.0
      YP(I,J)=(Y(I,J)+Y(I+1,J)+Y(I+1,J+1)+Y(I,J+1))/4.0
402   CONTINUE
      DO 403 I=1,ITOP
      DO 403 J=1,ISIDE
      Z=ANGLE(I,J)
      Z=Z/57.3
      XM(I,J)=XM(I,J)-((SIN(Z))*V(I,J)*AL)
      YM(I,J)=YM(I,J)-((COS(Z))*V(I,J)*AL)
      Z23=ANGLE(I,J)+165.0
      IF(Z23.GT.360.0)Z23=Z23-360.0
      Z42=ANGLE(I,J)+15.0
      IF(Z42.GT.360.0)Z42=Z42-360.0
      Z23=Z23/57.3
      Z42=Z42/57.3
      XP3(I,J)=XP(I,J)+((SIN(Z23))*SA)
      YP3(I,J)=YP(I,J)+((COS(Z23))*SA)
      XP4(I,J)=XP(I,J)-((SIN(Z42))*SA)
      YP4(I,J)=YP(I,J)-((COS(Z42))*SA)
403   CONTINUE
      DO 404 I=1,ITOP
      DO 404 J=1,ISIDE
      WRITE(8,2)I
  2   FORMAT(3X,'"',I2,'"')
      WRITE(8,11)XM(I,J),YM(I,J),XP(I,J),YP(I,J),XP3(I,J),YP3(I,J)
     1,XP4(I,J),YP4(I,J),XP(I,J),YP(I,J)
404   CONTINUE
 11   FORMAT(1X,10F7.0)
      CLOSE(8)
      CLOSE(7)
      STOP
      END
```

ATTACHMENT E

INPUT DATA FOR EXAMPLE.ONE CREEK

```
         COLUMNS
        1        10        20        30        40        50        60        70
LINE
 1      EXAMPLE.ONE CREEK,  25-YEAR FLOOD,  DISCHARGE= 1000 FT3/S
 2            1000
 3            15.0
 4             800
 5              10
 6               6
 7               0
 8               0
 9               2
10               5
11               0
13          1 .050
13          2 .030
13          3 .035
13          4 .100
13          5 .120
14         7   1   3   1     14.85      20.0            0
14         7   5   3   5     14.80      20.0            0
16        9.8  9.6  5.0  9.1  9.7
16        9.8  9.6  4.7  9.2  9.6
16        9.8  9.6  4.6  9.3  9.7
16        9.7  9.7  5.2  9.4  9.5
16        9.1  9.1  5.0  9.4  9.4
16        9.3  9.2  5.1  9.3  9.3
16        9.3  9.2  5.3  9.4  9.5
16        9.3  9.0  5.0  9.3  9.4
16        9.2  9.1  4.8  9.3  9.1
17          1    1    2    1    1
17          1    1    2    1    1
17          1    1    2    1    1
17          1    1    2    1    1
17          3    3    2    3    3
17          4    4    2    5    5
17          4    4    2    5    5
17          4    4    2    5    5
17          4    4    2    5    5
18           0     0    15     0    40     0    50     0    75     0    90     0
18           0    37    15    32    40    29    50    29    75    32    90    37
18           0    70    18    53    40    45    50    45    72    53    90    70
18          18    70    23    61    40    57    50    57    67    61    72    70
18          20    72    30    70    40    70    50    70    60    70    70    72
18          20    78    30    80    40    80    50    80    60    80    70    78
18          18    80    23    89    40    93    50    93    67    89    72    80
18           0    80    18    97    40   105    50   105    72    97    90    80
18           0   113    15   118    40   121    50   121    75   118    90   113
18           0   150    15   150    40   150    50   150    75   150    90   150

        1        10        20        30        40        50        60        70
```

ATTACHMENT F

INPUT DATA FOR EXAMPLE.TWO CREEK

```
          COLUMNS
        1        10        20        30        40        50        60        70
LINE
 1      EXAMPLE.TWO CREEK,  25-YEAR FLOOD,  DISCHARGE= 2000 FT3/S
 2            2000
 3            15.0
 4             800
 5              10
 6              12
 7               0
 8               1
 9               5
10               5
11               0
13          1 .050
13          2 .030
13          3 .035
13          4 .100
13          5 .120
14         7   1   3   1     14.85      20.0         0
14         7   5   3   5     14.80      20.0         0
14         8   6   2   6     14.79      10.0         0
14         7   7   3   7     14.78      20.0         0
14         7  11   3  11     14.85      20.0         0
15         3   6   8   3   9   8   2
16        9.8  9.6  5.0  9.1  9.7  9.7  9.7  9.1  9.5  9.6  9.8
16        9.8  9.6  4.7  9.2  9.6  9.6  9.6  9.2  9.5  9.6  9.8
16        9.8  9.6  4.6  9.3  9.7  9.7  9.7  9.3  9.5  9.6  9.8
16        9.7  9.7  5.2  9.4  9.5  9.5  9.5  9.4  9.5  9.7  9.7
16        9.1  9.1  5.0  9.4  9.4  9.4  9.4  9.4  9.5  9.1  9.1
16        9.3  9.2  5.1  9.3  9.3  9.3  9.3  9.3  9.5  9.2  9.3
16        9.3  9.2  5.3  9.4  9.5  9.5  9.5  9.4  9.5  9.2  9.3
16        9.3  9.0  5.0  9.3  9.4  9.4  9.4  9.3  9.5  9.0  9.3
16        9.2  9.1  4.8  9.3  9.1  9.1  9.1  9.3  9.5  9.1  9.2
17          1    1    2    1    1    1    1    1    1    1    1
17          1    1    2    1    1    1    1    1    1    1    1
17          1    1    2    1    1    1    1    1    1    1    1
17          1    1    2    1    1    1    1    1    1    1    1
17          3    3    2    3    3    3    3    3    3    3    3
17          4    4    2    5    5    5    5    5    5    5    5
17          4    4    2    5    5    5    5    5    5    5    5
17          4    4    2    5    5    5    5    5    5    5    5
17          4    4    2    5    5    5    5    5    5    5    5
18           0     0    15     0    40     0    50     0    75     0    90     0
18         100     0   115     0   140     0   150     0   175     0   190     0
18           0    37    15    32    40    29    50    29    75    32    90    37
18         100    37   115    32   140    29   150    29   175    32   190    37
18           0    70    18    53    40    45    50    45    72    53    90    70
18         100    70   118    53   140    45   150    45   172    53   190    70
18          18    70    23    61    40    57    50    57    67    61    72    70
18         118    70   123    61   140    57   150    57   167    61   172    70
18          20    72    30    70    40    70    50    70    60    70    70    72
18         120    72   130    70   140    70   150    70   160    70   170    72
18          20    78    30    80    40    80    50    80    60    80    70    78
18         120    78   130    80   140    80   150    80   160    80   170    78
18          18    80    23    89    40    93    50    93    67    89    72    80
18         118    80   123    89   140    93   150    93   167    89   172    80
18           0    80    18    97    40   105    50   105    72    97    90    80
18         100    80   118    97   140   105   150   105   172    97   190    80
18           0   113    15   118    40   121    50   121    75   118    90   113
18         100   113   115   118   140   121   150   121   175   118   190   113
18           0   150    15   150    40   150    50   150    75   150    90   150
18         100   150   115   150   140   150   150   150   175   150   190   150

        1        10        20        30        40        50        60        70
```

ATTACHMENT G

LISTING OF OUTPUT.DATA FILE

ALL OF THE FOLLOWING DATA, VERTICAL DISCHARGE, WATER SURFACE ELEVATIONS, ETC, ARE LISTED STARTING WITH THE DOWNSTREAM HORIZONTAL LINE AND GOING TO THE UPSTREAM HORIZONTAL LINE. THE FIRST VALUE ON EACH LINE IS THE LEFT MOST VALUE LOOKING UPSTREAM. POSITIVE VERTICAL DISCHARGES ARE GOING FROM UPSTREAM TO DOWNSTREAM. POSITIVE HORIZONTAL DISCHARGES ARE GOING FROM LEFT TO RIGHT LOOKING UPSTREAM. NEGATIVE DISCHARGES ARE IN OPPOSITE DIRECTIONS

VERTICAL DISCHARGE

99.40	241.98	281.61	273.60	103.41
137.91	215.97	263.88	237.45	144.79
99.35	217.72	323.85	236.79	102.21
142.90	168.72	362.59	166.53	139.18
128.15	157.51	445.49	138.00	110.77
86.63	189.88	479.53	152.94	70.94
124.64	201.10	413.84	157.21	103.21
89.57	222.50	439.59	173.82	74.52

HORIZONTAL DISCHARGE

0.00	0.00	0.00	0.00
38.52	12.50	-5.23	-41.38
-29.98	-28.09	32.07	31.55
43.58	-5.45	33.31	-36.99
-14.76	-25.98	56.97	28.42
-41.54	-9.16	24.90	39.85
29.43	40.54	-25.43	-21.25
-35.07	-13.67	12.08	28.69
0.00	0.00	0.00	0.00

DEPTH

5.200	5.400	10.000	5.900	5.300
5.214	5.423	10.293	5.819	5.414
5.209	5.424	10.399	5.722	5.309
5.301	5.320	9.793	5.614	5.501
5.912	5.923	9.991	5.621	5.614
5.767	5.852	9.955	5.762	5.782
5.844	5.933	9.765	5.746	5.647
5.854	6.158	10.144	5.861	5.755
5.979	6.079	10.379	5.879	6.079

WATER SURFACE ELEVATIONS

15.000	15.000	15.000	15.000	15.000
15.014	15.023	14.993	15.019	15.014
15.009	15.024	14.999	15.022	15.009
15.001	15.020	14.993	15.014	15.001
15.012	15.023	14.991	15.021	15.014
15.067	15.052	15.055	15.062	15.082
15.144	15.133	15.065	15.146	15.147
15.154	15.158	15.144	15.161	15.155
15.179	15.179	15.179	15.179	15.179

VELOCITY

1.313	1.804	2.817	1.864	1.342
1.452	1.821	2.664	1.887	1.481
1.545	2.295	2.887	2.080	1.574
2.449	2.768	3.439	2.709	2.404
2.384	2.873	4.076	2.851	2.267
2.035	2.338	4.669	2.013	1.770
1.253	1.649	4.524	1.343	1.057
1.162	1.501	4.222	1.225	0.977
1.029	1.473	4.236	1.192	0.842

ANGLE OF FLOW

175.50	177.39	178.41	182.08	184.74
175.50	177.39	178.41	182.08	184.74
252.03	224.58	184.13	164.78	106.29
202.36	200.17	180.66	169.12	155.50

```
    186.02    188.75    183.34    161.12    167.99
    158.71    161.61    180.84    194.37    199.31
    105.06    156.88    175.97    198.39    255.78
    184.58    182.51    181.11    177.00    175.55
    184.58    182.51    181.11    177.00    175.55
UNIT CONVEYANCE
   464.  494. 2301.  573.  479.
   466.  498. 2415.  560.  496.
   466.  498. 2456.  544.  480.
   479.  482. 2222.  527.  510.
   821.  824. 2297.  755.  753.
   276.  283. 2284.  229.  231.
   282.  289. 2212.  228.  222.
   283.  308. 2356.  236.  229.
   293.  301. 2448.  237.  251.
   1
  21
FLOW OVER ROAD
      0.00      0.00      0.00      0.00      0.00
      0.00      0.00      0.00      0.00      0.00
     -8.80      0.00      0.00      0.00    -11.29
      0.00      0.00      0.00      0.00      0.00
      0.00      0.00      0.00      0.00      0.00
      0.00      0.00      0.00      0.00      0.00
      8.80      0.00      0.00      0.00     11.29
      0.00      0.00      0.00      0.00      0.00
      0.00      0.00      0.00      0.00      0.00
 THESE VALUES ARE CORRECTIONS FOR ANGULARITY
   0.925  0.987  1.000  0.988  0.924
   0.996  1.007  1.000  1.002  1.000
   1.005  0.964  1.000  0.982  1.006
   0.998  0.970  1.000  0.969  0.993
   1.002  0.997  1.000  1.008  1.000
   1.005  0.993  1.000  0.997  1.004
   1.003  0.987  1.000  0.981  1.004
   0.925  0.987  1.000  0.987  0.926
 THESE VALUES ARE CORRECTIONS FOR ANGULARITY
   1.000  1.000  1.000  1.000
   0.538  0.498  0.498  0.536
   0.711  0.852  0.802  0.697
   1.992  0.610  0.568  1.644
   0.560  0.548  0.563  0.632
   2.014  0.596  0.587  1.552
   0.634  0.964  0.774  0.618
   0.537  0.498  0.498  0.537
   1.000  1.000  1.000  1.000
 ERROR IN BALANCING WATER SURFACE HEADS AT EACH ELEMENT, IN FEET
  -0.0145 -0.0355  0.0320  0.0160
   0.0142  0.0083 -0.0117 -0.0127
   0.0017  0.0081 -0.0036 -0.0012
   0.0091  0.0207 -0.0145 -0.0184
  -0.0260  0.0781 -0.1107  0.0400
  -0.0235 -0.0207  0.0503  0.0199
   0.0020  0.0022 -0.0145 -0.0017
   0.0069  0.0174 -0.0168 -0.0050

 FLOW THROUGH CULVERT.  THESE ARE FOR EACH OF THE FLOW OVER ROAD POINTS
      0.00      0.00
```

ATTACHMENT H

LISTING OF OP.TWO.D FILE

INPUT DATA FOR EXAMPLE.ONE CREEK

DISCHARGE = 1000.00

WATER SURFACE ELEVATION AT DOWNSTREAM END = 15.000

MAXIMUM NUMBER OF ITERATIONS = 800

NUMBER OF HORIZONTAL LINES = 10

NUMBER OF VERTICAL LINES = 6

INITIAL RUN

NUMBER OF ROADWAY FILLS BETWEEN BRIDGES = 0

NUMBER OF ROAD OVERFLOW POINTS = 2

NUMBER OF N VALUES = 5

WATER SURFACE IS NOT READ FOR EACH DOWNSTREAM ELEMENT

INDEX NUMBER AND ASSOCIATED N VALUE

1	0.050	2	0.030	3	0.035	4	0.100	5	0.120

FLOW OVER ROADWAY ELEMENTS

UPSTREAM		DOWNSTREAM		ROADWAY	FLOW	CULVERT
I	J	I	J	ELEV	WIDTH	CONSTANT
7	1	3	1	14.85	20.00	0.00
7	5	3	5	14.80	20.00	0.00

ALL OF THE FOLLOWING DATA, GROUND ELEVATIONS,MANNINGS N, ETC, ARE LISTED STARTING WITH THE DOWNSTREAM HORIZONTAL LINE AND GOING TO THE UPSTREAM HORIZONTAL LINE. THE FIRST VALUE ON EACH LINE IS THE LEFT MOST VALUE LOOKING UPSTREAM.

GROUND ELEVATIONS

9.8	9.6	5.0	9.1	9.7
9.8	9.6	4.7	9.2	9.6
9.8	9.6	4.6	9.3	9.7
9.7	9.7	5.2	9.4	9.5
9.1	9.1	5.0	9.4	9.4
9.3	9.2	5.1	9.3	9.3
9.3	9.2	5.3	9.4	9.5
9.3	9.0	5.0	9.3	9.4
9.2	9.1	4.8	9.3	9.1

MANNINGS N

0.0500	0.0500	0.0300	0.0500	0.0500
0.0500	0.0500	0.0300	0.0500	0.0500
0.0500	0.0500	0.0300	0.0500	0.0500
0.0500	0.0500	0.0300	0.0500	0.0500
0.0350	0.0350	0.0300	0.0350	0.0350
0.1000	0.1000	0.0300	0.1200	0.1200
0.1000	0.1000	0.0300	0.1200	0.1200
0.1000	0.1000	0.0300	0.1200	0.1200
0.1000	0.1000	0.0300	0.1200	0.1200

X-Y COORDINATES

0.0	0.0	15.0	0.0	40.0	0.0	50.0	0.0	75.0	0.0	90.0	0.0
0.0	37.0	15.0	32.0	40.0	29.0	50.0	29.0	75.0	32.0	90.0	37.0
0.0	70.0	18.0	53.0	40.0	45.0	50.0	45.0	72.0	53.0	90.0	70.0
18.0	70.0	23.0	61.0	40.0	57.0	50.0	57.0	67.0	61.0	72.0	70.0
20.0	72.0	30.0	70.0	40.0	70.0	50.0	70.0	60.0	70.0	70.0	72.0
20.0	78.0	30.0	80.0	40.0	80.0	50.0	80.0	60.0	80.0	70.0	78.0
18.0	80.0	23.0	89.0	40.0	93.0	50.0	93.0	67.0	89.0	72.0	80.0
0.0	80.0	18.0	97.0	40.0	105.0	50.0	105.0	72.0	97.0	90.0	80.0
0.0	113.0	15.0	118.0	40.0	121.0	50.0	121.0	75.0	118.0	90.0	113.0
0.0	150.0	15.0	150.0	40.0	150.0	50.0	150.0	75.0	150.0	90.0	150.0

X-Y MIDPOINT

7.3	17.3	27.3	15.2	45.0	14.5	62.7	15.2	82.7	17.3
7.8	48.8	27.6	39.7	45.0	37.0	62.3	39.7	82.2	48.8
13.7	63.7	30.5	53.6	45.0	51.0	59.4	53.6	76.3	63.7
23.5	67.7	33.4	63.9	45.0	63.5	56.6	63.9	66.5	67.7
25.4	75.0	35.0	75.0	45.0	75.0	55.0	75.0	64.6	75.0
23.5	82.3	33.4	86.1	45.0	86.5	56.6	86.1	66.5	82.3
13.7	86.3	30.6	96.3	45.0	99.0	59.4	96.3	76.3	86.3
7.8	101.2	27.6	110.3	45.0	113.0	62.3	110.3	82.2	101.2
7.3	132.7	27.3	134.7	45.0	135.5	62.7	134.7	82.7	132.7

VERTICAL DISTANCE

37.0	32.0	29.0	29.0	32.0	37.0
33.0	21.2	16.0	16.0	21.2	33.0
18.0	9.4	12.0	12.0	9.4	18.0
2.8	11.4	13.0	13.0	11.4	2.8
6.0	10.0	10.0	10.0	10.0	6.0
2.8	11.4	13.0	13.0	11.4	2.8
18.0	9.4	12.0	12.0	9.4	18.0
33.0	21.2	16.0	16.0	21.2	33.0
37.0	32.0	29.0	29.0	32.0	37.0

HORIZONTAL DISTANCE

15.0	25.0	10.0	25.0	15.0
15.8	25.2	10.0	25.2	15.8
24.8	23.4	10.0	23.4	24.8
10.3	17.5	10.0	17.5	10.3
10.2	10.0	10.0	10.0	10.2
10.2	10.0	10.0	10.0	10.2
10.3	17.5	10.0	17.5	10.3
24.8	23.4	10.0	23.4	24.8
15.8	25.2	10.0	25.2	15.8
15.0	25.0	10.0	25.0	15.0

VERTICAL ANGLE

180.0	180.0	180.0	180.0	180.0	180.0
180.0	188.1	180.0	180.0	171.9	180.0
270.0	212.0	180.0	180.0	148.0	90.0
225.0	217.9	180.0	180.0	142.1	135.0
180.0	180.0	180.0	180.0	180.0	180.0
135.0	142.1	180.0	180.0	217.9	225.0
90.0	148.0	180.0	180.0	212.0	270.0
180.0	171.9	180.0	180.0	188.1	180.0
180.0	180.0	180.0	180.0	180.0	180.0

HORIZONTAL ANGLES

90.1	90.1	90.1	90.1	90.1
108.4	96.8	90.1	83.2	71.6
133.4	110.0	90.1	70.0	46.6
150.9	103.2	90.1	76.8	29.1
101.3	90.1	90.1	90.1	78.7
78.7	90.1	90.1	90.1	101.3
29.1	76.8	90.1	103.2	150.9
46.6	70.0	90.1	110.0	133.4
71.6	83.2	90.1	96.8	108.4
90.1	90.1	90.1	90.1	90.1

VERTICAL ANGLE BETWEEN MIDPOINTS

180.8	180.8	180.0	179.2	179.2
201.5	191.8	180.0	168.2	158.4
247.9	195.3	180.0	164.7	112.1
194.8	188.4	180.0	171.6	165.2
165.3	171.6	180.0	188.4	194.7
112.1	164.7	180.0	195.3	247.9
158.4	168.2	180.0	191.8	201.6
179.2	179.2	180.0	180.8	180.9

HORIZONTAL ANGLE BETWEEN MIDPOINTS

95.8	92.5	87.5	84.2
114.6	98.9	81.1	65.4
120.7	100.4	79.6	59.3
110.8	92.1	87.9	69.3
90.1	90.1	90.1	90.1
69.3	87.9	92.1	110.7
59.3	79.6	100.4	120.7
65.4	81.1	98.9	114.6
84.2	87.5	92.5	95.8

ATTACHMENT I

LISTING OF OP.ITER FILE

```
ITERATION =   1   SUMDZ =     0.0    SUMDQ =    597.1  SUMDS=     0.3  TFAJ =1.00
ITERATION =   2   SUMDZ =     0.0    SUMDQ =    486.4  SUMDS=     0.1  TFAJ =1.00
ITERATION =   3   SUMDZ =     0.0    SUMDQ =    180.0  SUMDS=     0.1  TFAJ =1.00
ITERATION =   4   SUMDZ =     0.0    SUMDQ =    164.0  SUMDS=     0.1  TFAJ =1.00
ITERATION =   5   SUMDZ =     0.0    SUMDQ =    144.1  SUMDS=     0.1  TFAJ =1.00
ITERATION =   6   SUMDZ =     0.0    SUMDQ =     60.9  SUMDS=     0.0  TFAJ =1.00
ITERATION =   7   SUMDZ =     0.0    SUMDQ =     53.8  SUMDS=     0.0  TFAJ =1.00
ITERATION =   8   SUMDZ =     0.0    SUMDQ =     46.6  SUMDS=     0.0  TFAJ =1.00
ITERATION =   9   SUMDZ =     0.0    SUMDQ =     23.5  SUMDS=     0.0  TFAJ =1.00
ITERATION =  10   SUMDZ =     0.0    SUMDQ =     19.7  SUMDS=     0.0  TFAJ =1.00
   CHANGE IN STAGE AT UPSTR END = 0.05   AVERAGE STAGE = 15.05  IPHASE =  0
ITERATION =  11   SUMDZ =     0.0    SUMDQ =     16.8  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       1.       15.03     15.00     14.85
       1.       15.03     15.00     14.80
   CHANGE IN STAGE AT UPSTR END = 0.02   AVERAGE STAGE = 15.07  IPHASE =  0
ITERATION =  12   SUMDZ =     0.0    SUMDQ =     10.3  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       2.       15.04     15.01     14.85
       2.       15.04     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.01   AVERAGE STAGE = 15.08  IPHASE =  0
ITERATION =  13   SUMDZ =     0.0    SUMDQ =      8.7  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       3.       15.05     15.01     14.85
       4.       15.05     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.01   AVERAGE STAGE = 15.09  IPHASE =  0
ITERATION =  14   SUMDZ =     0.0    SUMDQ =      6.0  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       4.       15.06     15.01     14.85
       5.       15.06     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  0
ITERATION =  15   SUMDZ =     0.0    SUMDQ =      4.2  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       5.       15.06     15.01     14.85
       6.       15.06     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  0
ITERATION =  16   SUMDZ =     0.0    SUMDQ =      3.3  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       5.       15.06     15.01     14.85
       6.       15.06     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  0
ITERATION =  17   SUMDZ =     0.0    SUMDQ =      2.7  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       5.       15.06     15.01     14.85
       7.       15.06     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  0
ITERATION =  18   SUMDZ =     0.0    SUMDQ =      2.5  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       5.       15.06     15.01     14.85
       7.       15.06     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  0
ITERATION =  19   SUMDZ =     0.0    SUMDQ =      2.5  SUMDS=     0.0  TFAJ =1.00
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
       5.       15.06     15.01     14.85
       7.       15.06     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  0
ITERATION =  20   SUMDZ =     0.0    SUMDQ =      2.4  SUMDS=     0.0  TFAJ =1.01
ITERATION =  21   SUMDZ =     0.0    SUMDQ =      7.5  SUMDS=     0.0  TFAJ =1.00
ITERATION =  22   SUMDZ =     0.0    SUMDQ =      5.8  SUMDS=     0.0  TFAJ =2.06
ITERATION =  23   SUMDZ =     0.0    SUMDQ =      4.0  SUMDS=     0.0  TFAJ =1.84
ITERATION =  24   SUMDZ =     0.0    SUMDQ =      2.8  SUMDS=     0.0  TFAJ =1.56
```

```
ITERATION =  25    SUMDZ =     0.0     SUMDQ =      3.0  SUMDS=     0.0  TFAJ =1.33
ITERATION =  26    SUMDZ =     0.0     SUMDQ =      2.3  SUMDS=     0.0  TFAJ =1.39
ITERATION =  27    SUMDZ =     0.0     SUMDQ =      2.8  SUMDS=     0.0  TFAJ =1.23
ITERATION =  28    SUMDZ =     0.0     SUMDQ =      2.6  SUMDS=     0.0  TFAJ =1.38
ITERATION =  29    SUMDZ =     0.0     SUMDQ =      2.2  SUMDS=     0.0  TFAJ =1.33
ITERATION =  30    SUMDZ =     0.0     SUMDQ =      2.0  SUMDS=     0.0  TFAJ =1.25
ITERATION =  31    SUMDZ =     0.0     SUMDQ =      2.0  SUMDS=     0.0  TFAJ =1.20
ITERATION =  32    SUMDZ =     0.0     SUMDQ =      1.9  SUMDS=     0.0  TFAJ =1.18
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        5.      15.06      15.01      14.85
        7.      15.06      15.01      14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  1
ITERATION =  33    SUMDZ =     0.0     SUMDQ =      1.8  SUMDS=     0.0  TFAJ =1.16
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        5.      15.06      15.01      14.85
        7.      15.06      15.01      14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  2
ITERATION =  34    SUMDZ =     0.0     SUMDQ =      1.7  SUMDS=     0.0  TFAJ =1.14
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        5.      15.06      15.01      14.85
        7.      15.06      15.01      14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  3
ITERATION =  35    SUMDZ =     0.0     SUMDQ =      1.6  SUMDS=     0.0  TFAJ =1.12
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        5.      15.06      15.01      14.85
        7.      15.06      15.01      14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  4
ITERATION =  36    SUMDZ =     0.0     SUMDQ =      1.6  SUMDS=     0.0  TFAJ =1.10
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        5.      15.06      15.01      14.85
        7.      15.06      15.01      14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.09  IPHASE =  5
ITERATION =  37    SUMDZ =     0.0     SUMDQ =      1.6  SUMDS=     0.0  TFAJ =1.09
   CHANGE IN STAGE AT UPSTR END = 0.05   AVERAGE STAGE = 15.14  IPHASE =  6
ITERATION =  38    SUMDZ =     0.7     SUMDQ =      1.5  SUMDS=     0.0  TFAJ =1.08
ITERATION =  39    SUMDZ =     0.7     SUMDQ =      3.1  SUMDS=     0.0  TFAJ =1.08
ITERATION =  40    SUMDZ =     0.7     SUMDQ =      2.4  SUMDS=     0.0  TFAJ =1.66
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        6.      15.11      15.00      14.85
        8.      15.11      15.00      14.80
   CHANGE IN STAGE AT UPSTR END = 0.02   AVERAGE STAGE = 15.16  IPHASE =  6
ITERATION =  41    SUMDZ =     0.7     SUMDQ =      1.4  SUMDS=     0.0  TFAJ =1.46
ITERATION =  42    SUMDZ =     0.7     SUMDQ =      2.0  SUMDS=     0.0  TFAJ =1.16
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        7.      15.12      15.01      14.85
        9.      15.13      15.00      14.80
   CHANGE IN STAGE AT UPSTR END = 0.01   AVERAGE STAGE = 15.17  IPHASE =  6
ITERATION =  43    SUMDZ =     0.7     SUMDQ =      1.6  SUMDS=     0.0  TFAJ =1.42
ITERATION =  44    SUMDZ =     0.7     SUMDQ =      2.0  SUMDS=     0.0  TFAJ =1.27
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        7.      15.13      15.01      14.85
        9.      15.14      15.01      14.80
   CHANGE IN STAGE AT UPSTR END = 0.01   AVERAGE STAGE = 15.18  IPHASE =  7
ITERATION =  45    SUMDZ =     0.7     SUMDQ =      1.4  SUMDS=     0.0  TFAJ =1.47
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        8.      15.14      15.01      14.85
       10.      15.14      15.01      14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.18  IPHASE =  8
ITERATION =  46    SUMDZ =     0.7     SUMDQ =      1.5  SUMDS=     0.0  TFAJ =1.26
 DISCHARGE     UPS WS    DSTR WS   HWY ELEV
        8.      15.14      15.01      14.85
       11.      15.14      15.01      14.80
```

```
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.18  IPHASE =  9
ITERATION =  47   SUMDZ =    0.7    SUMDQ =     1.5  SUMDS=    0.0  TFAJ =1.30
 DISCHARGE    UPS WS   DSTR WS  HWY ELEV
       9.      15.14     15.01     14.85
      11.      15.15     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.18  IPHASE = 10
ITERATION =  48   SUMDZ =    0.7    SUMDQ =     1.4  SUMDS=    0.0  TFAJ =1.33
 DISCHARGE    UPS WS   DSTR WS  HWY ELEV
       9.      15.14     15.01     14.85
      11.      15.15     15.01     14.80
   CHANGE IN STAGE AT UPSTR END = 0.00   AVERAGE STAGE = 15.18  IPHASE = 11
```


*U.S. Government Printing Office: 1992 — 654-193/40008