SIMULATED FLOW AND SOLUTE TRANSPORT, AND MITIGATION OF A HYPOTHETICAL SOLUBLE-CONTAMINANT SPILL FOR THE NEW RIVER IN THE NEW RIVER GORGE NATIONAL RIVER, WEST VIRGINIA

By Jeffrey B. Wiley

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Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square foot (ft^2)	0.09294	square meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
acre-foot (acre-ft)	1,233	cubic meter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound (lb)	453.6	gram

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum 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.

Chemical concentration: In this report, chemical concentration is given in micrograms per liter (µg/L). Micrograms per liter is a unit expressing the concentration of chemical constituents in solution as weight (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter.

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ABSTRACT

This report presents the results of a study to investigate factors affecting mitigation and transport of a hypothetical spill of a soluble contaminant into the New River in the New River Gorge National River, West Virginia. The study reach, 53 miles of the lower New River between Hinton and Fayette, is characterized as a pool-and-riffle stream that becomes narrower, steeper, and deeper in the downstream direction. Three subreaches--Hinton to Meadow Creek, Meadow Creek to Sewell, and Sewell to Fayette--represent similar slopes and geometries of the study reach.

An unsteady-flow model, DAFLOW (Diffusion Analogy FLOW), and a solute-transport model, BLTM (Branch Lagrangian Transport Model), were applied to the study reach. Difficulty in calibration required development of separate models for discharges greater than or equal to 8,000 ft^3/s (high-discharge model) and less than or equal to 8,000 ft^3/s (low-discharge model). The DAFLOW models were calibrated by use of relations between river discharges and traveltimes of the change in discharge at the leading edge of waves. The DAFLOW models were verified by predicting discharges at the streamflow-gaging station at Thurmond using discharges from the Hinton station. The BLTM models were calibrated by use of relations between traveltime of peak concentration and discharge, and peak concentration and traveltime of peak concentration. The BLTM models were verified by predicting peak concentrations and traveltimes of peak concentrations for two unsteady-flow and one steady-flow dye measurements.

This study indicated that the effects of an accidental spill could be mitigated by regulating discharge from Bluestone Dam. Increases in discharge caused decreases in peak concentration and traveltime of peak concentration. Decreases in discharge caused increases in peak concentration and traveltime of peak concentration. Knowledge of the chemical characteristics of the spill, location and time of the spill, and discharge of the river can aid in determining a mitigation response.

INTRODUCTION

The New River flows northward from its headwaters in North Carolina, through western Virginia, and into south-central West Virginia, where it joins the Gauley River to form the Kanawha River (fig. 1). The New River Gorge National River was established by Public Law 95-625 on November 10, 1978, and falls within jurisdiction of the U.S. Department of Interior, National Park Service (NPS) (fig. 2). The NPS is responsible for (1) conserving the natural, scenic, and historical objects, and (2) preserving a 53-mi segment of the lower New River (approximately from Hinton to Fayette) in West Virginia as a free-flowing stream for the enjoyment and benefit of present and future generations. The main attraction of the National River is a combination of scenic wilderness, fishing, and excellent white-water rafting. The recreational quality of the New River depends, in part, on the regulated flow from Bluestone Dam and unregulated flow from the Greenbrier River.

The U.S. Geological Survey (USGS), in cooperation with the NPS, studied the transport and factors affecting mitigation of a hypothetical spill of a soluble contaminant into the New River downstream from Hinton. The potential for such a spill exists because a major east-west railroad traverses the River gorge. In addition, several major highway bridges cross the river.

Purpose and Scope

This report presents a relation between traveltimes of waves and traveltimes of peak concentrations, and effects of changes in discharge on the peak concentration and traveltime of the peak concentration of a soluble cloud in the New River Gorge National River. Effects of changes in discharge are determined by application of flow and solute-transport models. These factors affecting the solute cloud are used to determine a mitigation response to a hypothetical spill of a soluble contaminant in the river reach between Hinton and Fayette within the boundaries of the National River.

Description of Study Reach

The study reach extends for 53 mi from Hinton to Fayette in the New River Gorge National River, West Virginia. The study reach becomes narrower, steeper, and deeper in the downstream direction. Flow in the New River is partially regulated by Bluestone Dam.

The streamflow-gaging station at Hinton is the most upstream location in the study reach. The contributing drainage area is 6,256 mi^2 (Mathes and others, 1982), of which 4,601 mi^2 is regulated by Bluestone Dam (figs. 1 and 2). Approximately 1.5 mi upstream from the Hinton streamflow-gaging station and about 1.0 mi downstream from Bluestone Dam is the confluence with the Greenbrier River. The Greenbrier River is an unregulated stream with a drainage area of 1,641 mi^2. The most downstream point of the study reach is 53 mi from the Hinton streamflow-gaging station; the contributing drainage area at this point is approximately 6,872 mi^2. The additional drainage area within the study reach is about 600 mi^2. Approximately 360 mi^2 of this additional drainage area is accounted for by six small basins (five that range from 28 to 63 mi^2 and one that is 135 mi^2). The remaining inflows are primarily small tributaries that drain less than 5 mi^2.

Channel cross sections for a discharge of 2,000 ft^3/s (a "low flow" discharge) can be described as trapezoids. The long base is three times the length of the short base, and the distance between the bases represents the stream depth. The 53-mile study reach can be divided into three subreaches of similar slope, geometry, and roughness (fig. 3): Hinton to Meadow Creek (13 mi), Meadow Creek to Sewell (32 mi), and Sewell to Fayette (8 mi) (Wiley, 1989).

The stream width is about 850 ft between Hinton and Meadow Creek, and the flood plain is primarily on one bank and is about 1,500 ft wide (discharges considered in this study do not

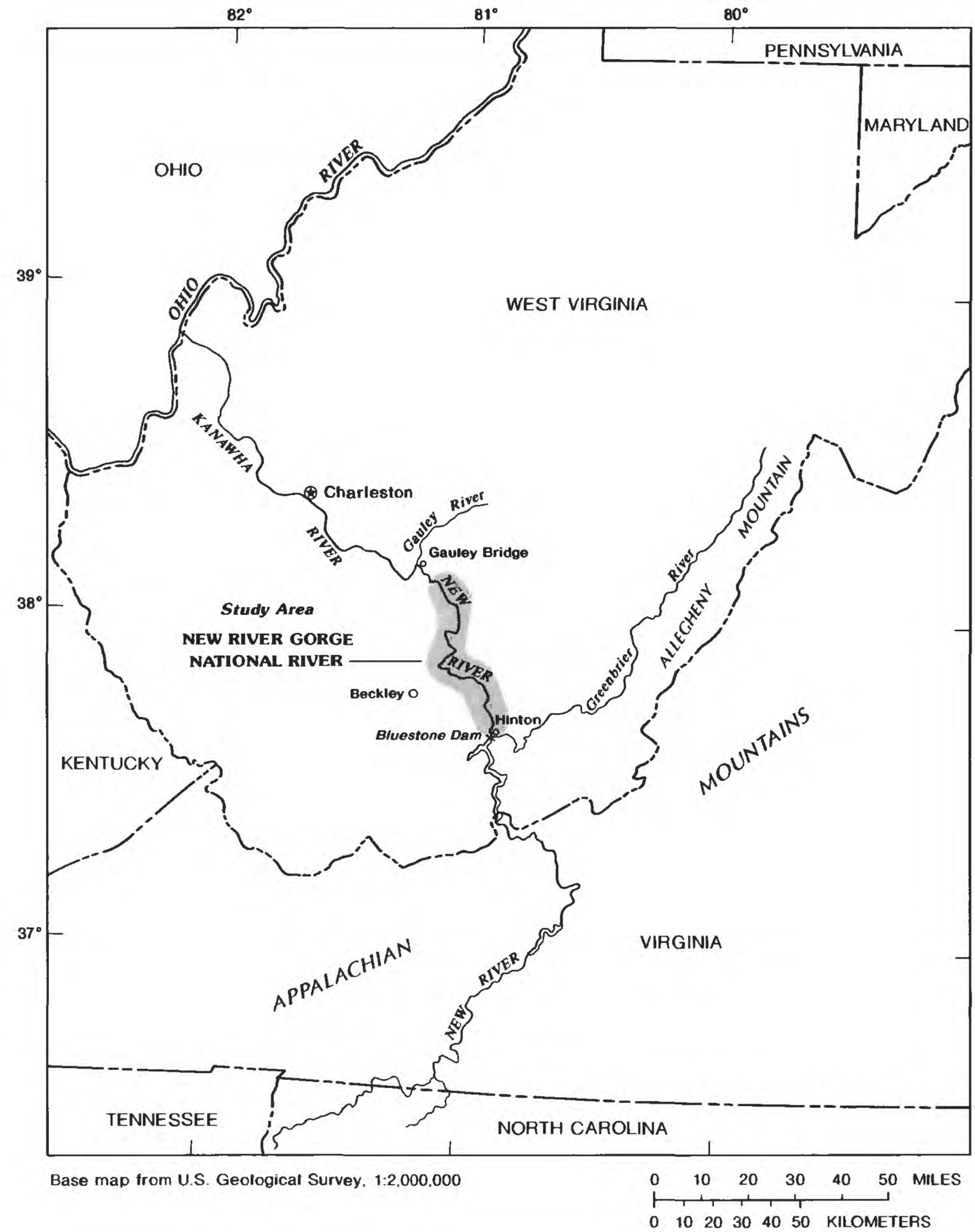

Figure 1.--Location of the New River. (Modified from Appel and Moles, 1987, p. 3.)

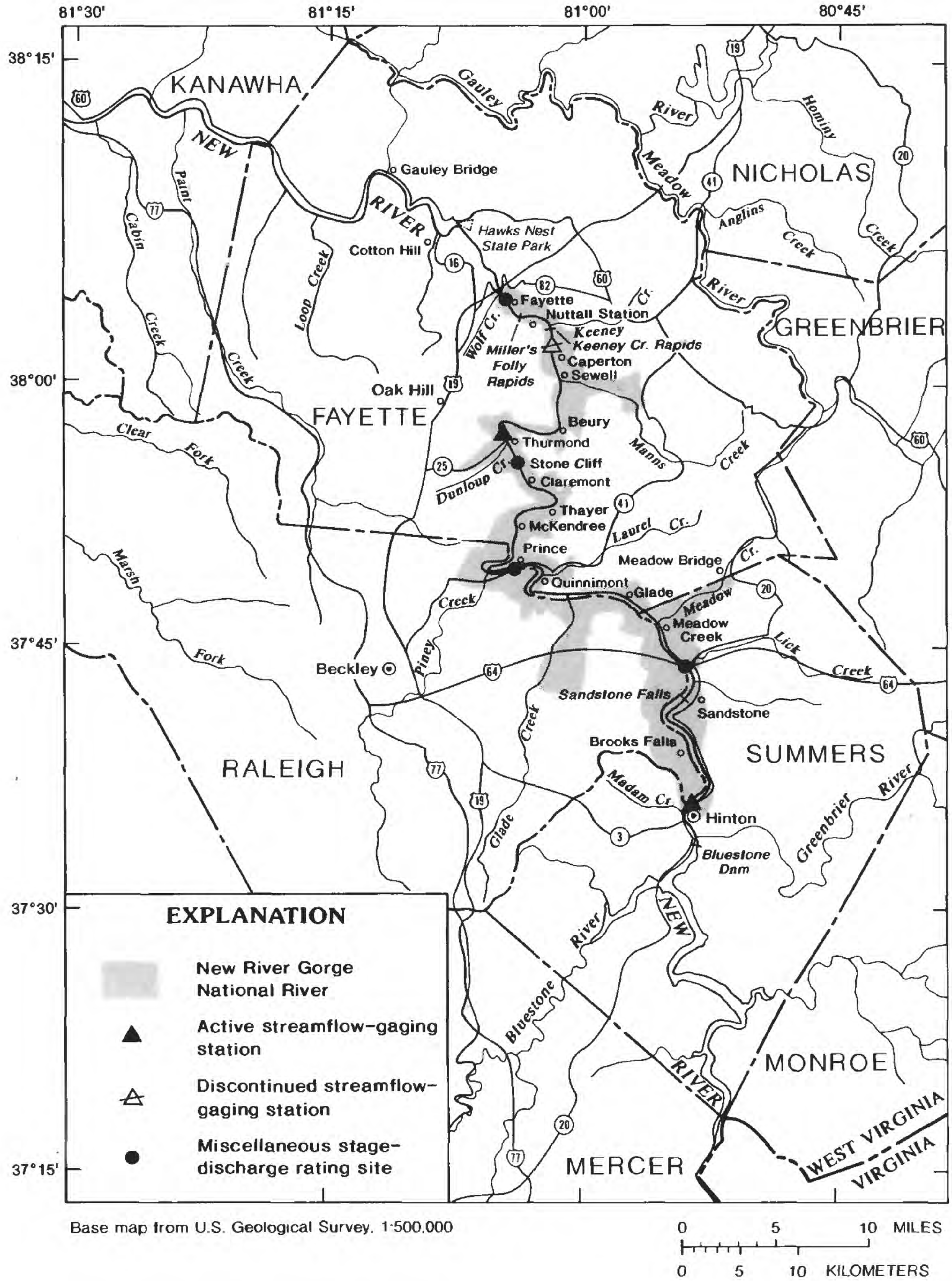

Figure 2.--Study area and New River Gorge National River.

leave the main channel in this subreach). Average depth of the river for a discharge of 2,000 ft^3/s is about 5 ft, and the bed slope is about 1.5 ft per 1,000 ft. This slope includes two large falls--Brooks (an 8- to 10-ft drop) and Sandstone (about a 25-ft drop) (fig 3). The deepest pools for a discharge of 2,000 ft^3/s in this subreach are downstream from these falls and are 15 to 20 ft deep.

Between Meadow Creek and Sewell, the most apparent change in channel geometry, as compared to the Hinton-to-Meadow Creek subreach, is the lack of a wide flood plain. The average stream width in this subreach is about 550 ft, the average depth for a discharge of 2,000 ft^3/s is 8 ft, and the bed slope remains unchanged from that of the Hinton-to-Meadow Creek subreach. Pool depths for a discharge of 2,000 ft^3/s are 20 to 25 ft near the towns of Glade, Thurmond, and Beury (fig. 3).

Between Sewell and Fayette, the most apparent changes in the river, as compared to the other subreaches, are the narrowing of the stream channel and the increasing size of the boulder. For a typical river cross section in this subreach, the stream width is about 350 ft, and the stream bottom is irregular (rough). There is no flood plain because the streambanks are the valley walls. The bed slope is about 4 ft per 1,000 ft. The average depth in this subreach for a discharge of 2,000 ft^3/s is about 12 ft, and the deepest pools are 35 to 40 ft deep. These pools are located about 0.5 mi upstream from Caperton and near Nuttall Station.

A few small islands are scattered throughout the study reach. In all cases, there is a principal channel along one side of the island and a smaller channel along the other side. Three islands, approximately 0.8 mi, 0.4 mi, and 0.2 mi long, are in the Hinton-to-Meadow Creek subreach, and one island, approximately 0.2 mi long, is in the Meadow Creek-to-Sewell subreach. There are no islands in the Sewell-to-Fayette subreach.

SIMULATED FLOW AND SOLUTE TRANSPORT

Two USGS computer models were used in this study: an unsteady-flow model and a solute-transport model. The DAFLOW (Diffusion Analogy FLOW) Fortran program is a one-dimensional, open-channel-flow model (unsteady-flow model) based on diffusion analogy (Jobson, 1989). The BLTM (Branch Lagrangian Transport Model) Fortran program is a one-dimensional, water-quality model (solute-transport model) based on the conservation of mass (Jobson and Schoellhamer, 1987).

The unsteady-flow model, DAFLOW, solves the diffusion-analogy equation for unsteady discharge by means of a Lagrangian solution scheme. Input-data requirements include a power-function coefficient and exponent for the relation between area and discharge; an upstream discharge-boundary condition; a wave-dispersion coefficient; a time-step size; and a network configuration of branches, grids, and reference distances representative of the study reach. The model can simulate discharge for interconnected channels and unidirectional flow. Model outputs are discharge, area, top width, and tributary inflows at user-selected grids and time-step increments. The model also includes a plot procedure and an output file containing a flow field for input into the solute-transport model, BLTM.

The solute-transport model, BLTM, solves the convective-dispersion equation using a Lagrangian reference frame. Input-data requirements include a time-step size; a network configuration of branches, grids, and reference distances representative of the study reach; a flow field containing discharge, area, top width, and tributary inflow for each grid at each time step; the upstream boundary conditions for as many as 10 constituents; and the kinetics for as many as 10 constituents. The model will simulate interconnected channels and unidirectional flow. The model computes user-selectable kinetics for several constituent combinations and can include user-defined kinetics

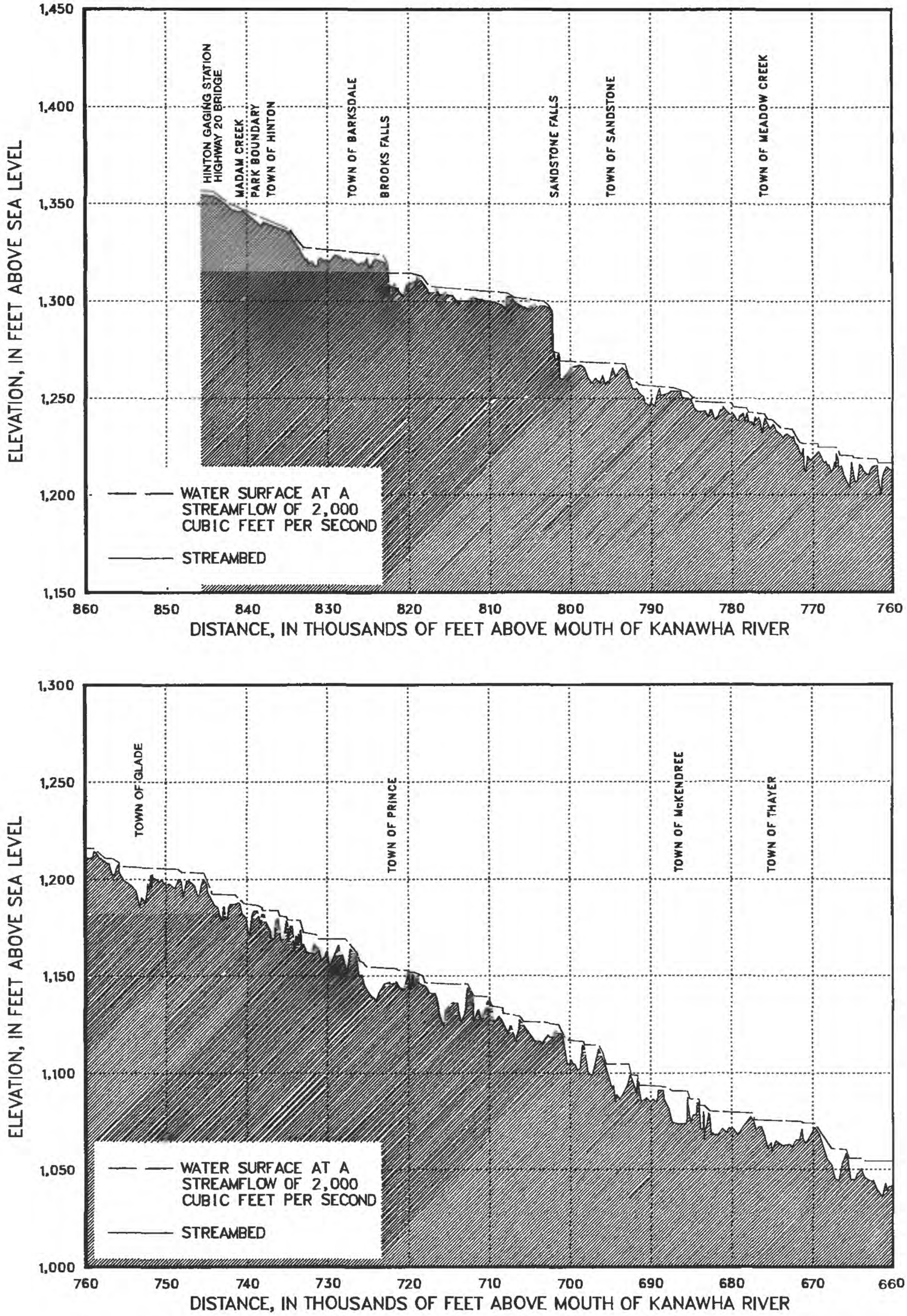

Figure 3.--Water-surface and streambed profiles in the New River Gorge National River.

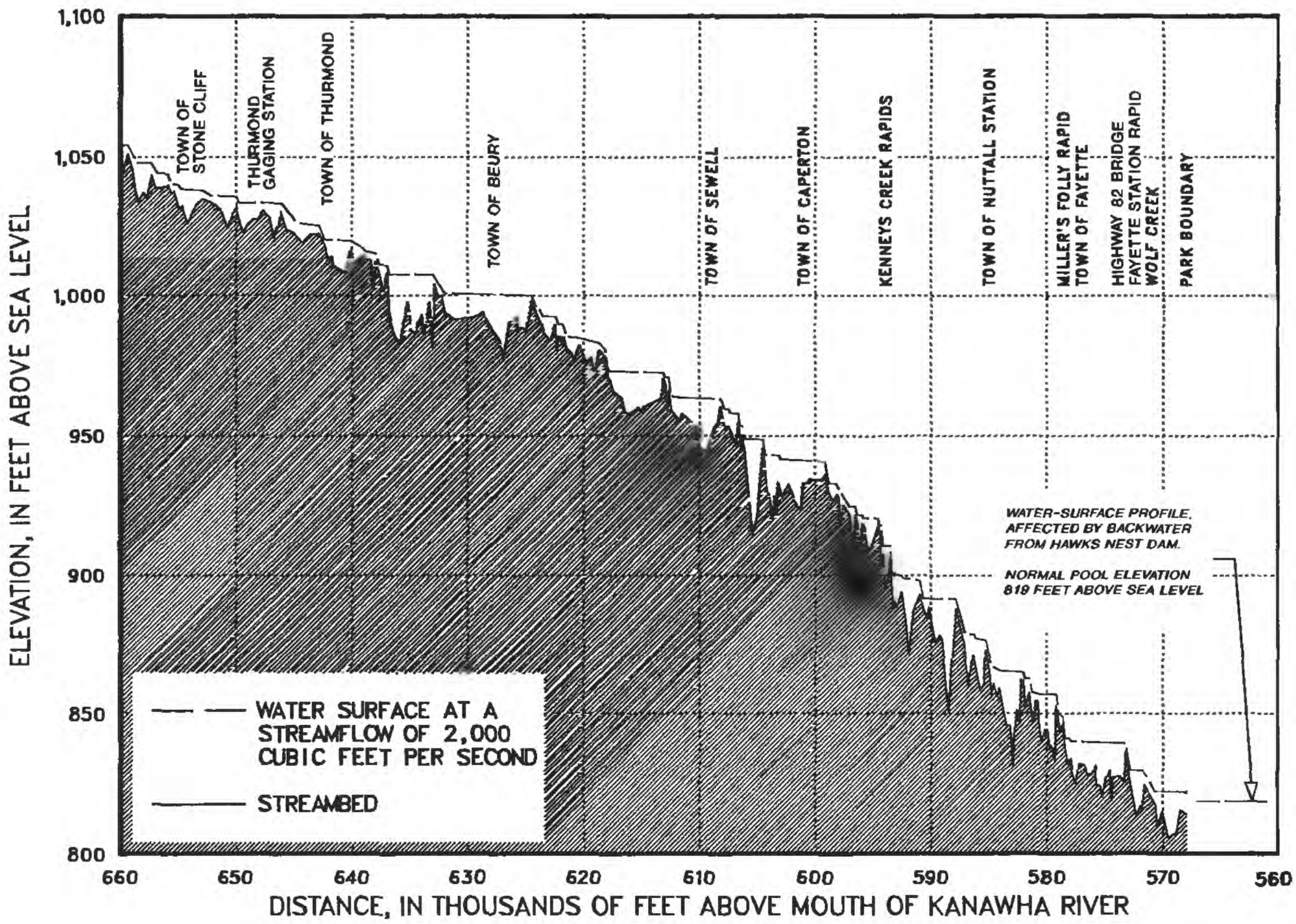

Figure 3.--Water-surface and streambed profiles in the New River Gorge National River--Continued

for as many as 10 constituents. Model output consists of concentrations of each constituent at user-selected time-step increments and grid locations. Plotting procedures are available for visual inspection of model output.

Unsteady-Flow Model

For this study, the unsteady-flow model, DAFLOW, was used to determine unsteady-flow characteristics of the study reach and to provide a flow field for the solute-transport model, BLTM. A single branch with 11 grids was used to represent the study reach for flow modeling. Estimation equations and tables were used to determine the initial model parameters. The model parameters were then adjusted until simulated traveltimes of waves matched measured traveltimes. The reader is referred to the DAFLOW user's manual for additional descriptions of parameters and their meanings (Jobson, 1989).

Calibration

The unsteady-flow model was calibrated by adjusting model parameters until the simulated traveltimes of waves matched the measured traveltimes of waves (fig. 4). These traveltimes, which represent the arrival time of the leading edge of a wave, are referenced to the discharge before the wave is produced. Figure 4 was developed in a previous study by Appel (1983). In Appel's study, waves were produced by regulated releases from Bluestone Dam, and traveltimes of the leading edge of the wave were measured at locations downstream. In addition, traveltimes of selected waves recorded at continuous-record streamflow-gaging stations at Hinton and Thurmond were used to develop figure 4.

The study reach was represented in the unsteady-flow model as a single branch with 11 grids. The location and significance of each

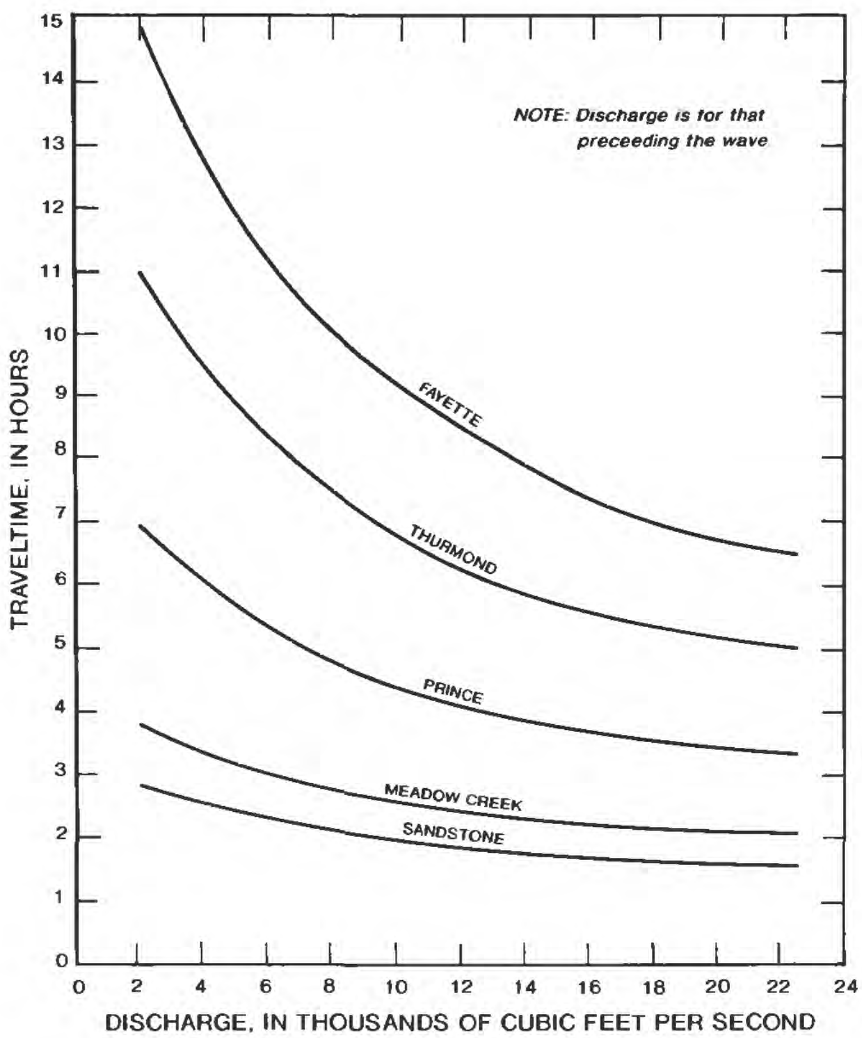

Figure 4.--Traveltimes of flood waves from Hinton to selected communities in the New River Gorge (Modified from Appel, 1983, p. 10.)

grid is summarized in table 1.

Initial values for model parameters were determined by use of tabulated values and equations from the DAFLOW user's manual (Jobson, 1989). Calibration parameters A2 (hydraulic geometry exponent for area) and W2 (hydraulic exponent for width) were estimated from tabulated values as 0.66 and 0.26, respectively (Jobson, 1989, p. 5). Calibration parameters A0 (average cross-sectional area at zero discharge), A1 (hydraulic geometry coefficient for area), DF (wave dispersion coefficient), and W1 (hydraulic geometry coefficient for width) were estimated by use of equations 3, 4, 11, and 13 in the user's manual (Jobson, 1989). A discussion of estimating procedures can be found on pages 24-25 of the user's manual (Jobson, 1989). Additional required information of average river slopes, river widths, and representative discharge for river widths is presented in the Description of Study Reach section of this report. The traveltimes of waves and representative discharges necessary for making initial parameter estimates are found in figure 4 of this report.

Initial flow conditions (time step zero) were set to the calibration discharge (a value from the x-axis of fig. 4). Discharge was increased to a value 10 to 20 percent greater than the initial discharge and held steady at the adjusted discharge to establish a wave. The final discharge does not affect model calibration because the traveltime of the leading edge of a wave depends on the initial discharge before the change occurs, not on the magnitude of the change. The final discharge was rounded to the nearest 100 ft^3/s or 1,000 ft^3/s to simplify changes to the model during calibration. The model was run at a time step of 0.1 hour, and the model output at the appropriate grid point (grid points corresponding to curves in fig. 4) was analyzed to determine the arrival time of the wave.

Several methods of model calibration involving adjustment of parameters A1 (hydraulic-geometry exponent for area), A2 (hydraulic-geometry exponent for area), and DF (wave dispersion coefficient) were attempted to fit the simulated traveltimes to the measured traveltimes (fig. 4) for 2,200, 8,000, and 22,800 ft^3/s (H.E. Jobson, U.S. Geological Survey, written commun., 1990). Traveltimes at two of the three discharges were calibrated by adjusting A1 and A2; calibration of the traveltime for the third discharge was attempted by adjusting DF. All combinations of the above method among the three discharges failed to calibrate traveltimes from Sandstone to Prince. This method was tried again, but traveltime was measured at a

Table 1.--*Location and description of grids for the unsteady-flow model of the New River Gorge National River*

Grid no.	Reference distance, in miles	Description of grid
1	0.0	Location of Hinton streamflow-gaging station. Beginning of Hinton-to-Meadow Creek subreach.
2	9.47	Location of traveltime-of-wave site (Sandstone).
3	10.43	Location of dye-measurement site and miscellaneous rating curve (Sandstone).
4	13.07	Location of traveltime-of-wave and dye-measurement site (Meadow Creek). End of Hinton-to-Meadow Creek subreach and beginning of Meadow Creek-to-Sewell subreach.
5	23.86	Location of traveltime-of-wave and dye-measurement site, and miscellaneous rating curve (Prince).
6	36.14	Location of dye-measurement site and miscellaneous rating curve (Stone Cliff).
7	37.58	Location of Thurmond streamflow-gaging station and traveltime-of-wave site.
8	44.87	End of Meadow Creek-to-Sewell subreach and beginning of Sewell-to-Fayette subreach.
9	46.44	Location of Caperton streamflow-gaging station (discontinued).
10	51.36	Location of traveltime-of-wave and dye-measurement site, and miscellaneous rating curve (Fayette).
11	52.50	End of Sewell-to-Fayette subreach.

point above the leading edge of the wave (to increase the sensitivity of the parameter DF). This attempt also failed. The best result of these procedures was the prediction of the traveltime of waves at the third discharge to within 18 minutes of the measured traveltime at Prince. The difference between the predicted traveltime and the measured traveltime at Thurmond was greater than 1 hour. An error of greater than 1 hour was considered unacceptable in this study, and calibration at Fayette was not attempted.

Because one set of model parameters could not reproduce traveltimes for all steady discharges, two sets of model parameters were developed--a low-discharge model for discharges less than or equal to 8,000 ft^3/s, and a high-discharge model for discharges greater than or equal to 8,000 ft^3/s. Attempts to calibrate the low-discharge and high-discharge models by the procedures described above were unsuccessful.

The models were eventually calibrated by (1) calculating DF by use of equation 11 in the unsteady-flow user's manual (Jobson, 1989, p. 24), (2) adjusting A1 and A2 to fit exactly the traveltimes of waves at 8,000 ft^3/s, and (3) balancing the error between traveltimes at 2,200 and 4,000 ft^3/s for the low-discharge model and at 12,000 and 22,800 ft^3/s for the high-discharge model.

Parameters of the calibrated models are listed in appendixes A and B. Parameters A0, DF, W1, and W2 listed in these appendixes are estimated from tables and equations previously discussed in this section. Values of W1 and W2 do not affect calibration of the unsteady-flow model, and the effect of A0 (which will be discussed later) is minimal. A comparison between predicted and measured traveltimes used to calibrate the unsteady-flow models is given in table 2.

Verification

Discharge records at the Hinton and Thurmond streamflow-gaging stations for the period December 26, 1987, 1100 hours, to January 10, 1988, 2400 hours, were compared to the results from model simulations for verification. Discharge during this period ranged from 2,360 to 17,900 ft^3/s at Hinton and from 3,700 to 20,100 ft^3/s at Thurmond.

Table 2.--*Differences between predicted and observed traveltimes of waves used to calibrate the unsteady-flow models*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Positive values indicate the model predicts longer traveltimes of waves than the measured traveltimes. Negative values indicate the model predicts shorter traveltimes of waves than the measured traveltimes]

	Difference between predicted and observed traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
Location	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	0	0	0	0	+1	-1
Meadow Creek	+1	-1	0	0	+1	-1
Prince	+3	-2	0	0	+1	-1
Thurmond	+3	-3	0	0	+2	-2
Fayette	+3	-3	0	0	+1	-1

Discharge records at the Hinton streamflow-gaging station were input into the unsteady-flow models to predict the observed discharges at the Thurmond streamflow-gaging station. The time step used for this verification was increased from 0.1 to 0.5 hour because the longer length of time (approximately 15 days) would produce extensive output and require thousands of model iterations. Increasing the time step by this magnitude did not significantly affect the model predictions of the traveltimes of waves at Thurmond. (See sensitivity tests for time step, tables 11 and 12.) The high-discharge model included data from Hinton from December 26, 1987, 0830 hours, to January 2, 1988, 0830 hours. The flow field from the output of the high-discharge unsteady-flow model was saved. Output for the last time step of the high-discharge model was used as the initial conditions for the low-discharge model. The low-discharge model was run for the remainder of the verification period. The flow field from the output of the low-discharge unsteady-flow model was appended to the flow field of the high-discharge model to create a continuous flow field for the entire period. Editing of the file was necessary to delete a time step where the high-discharge model ends and the low-discharge model begins.

Significant tributary inflows needed to be accounted for in the verification period. This was apparent because the recorded peak discharge at Hinton was 17,900 ft^3/s and the recorded peak discharge at Thurmond was 20,100 ft^3/s for this period. A plot of observed discharges as a function of time for both streamflow-gaging stations was used to estimate an inflow hydrograph. The estimated inflow was introduced into the model at the Thurmond streamflow-gaging-station grid. Because all inflow was not at this location, some accuracy was lost. Applying parts of inflow at different grids upstream based on the location of stream inflows could increase model accuracy; however, this was not done because there were several tributaries (see section Description of Study Reach) and because determination of the magnitude and traveltime of waves to produce the resultant tributary inflow hydrograph at Thurmond would have been a major task.

The predicted, observed, and estimated inflow hydrographs at Thurmond are shown in figure 5. The loss of accuracy near the end of the verification period (when discharges are less than approximately 3,000 ft^3/s) is partly related to the procedure used to apply inflow, as described above. The inflow is large enough to

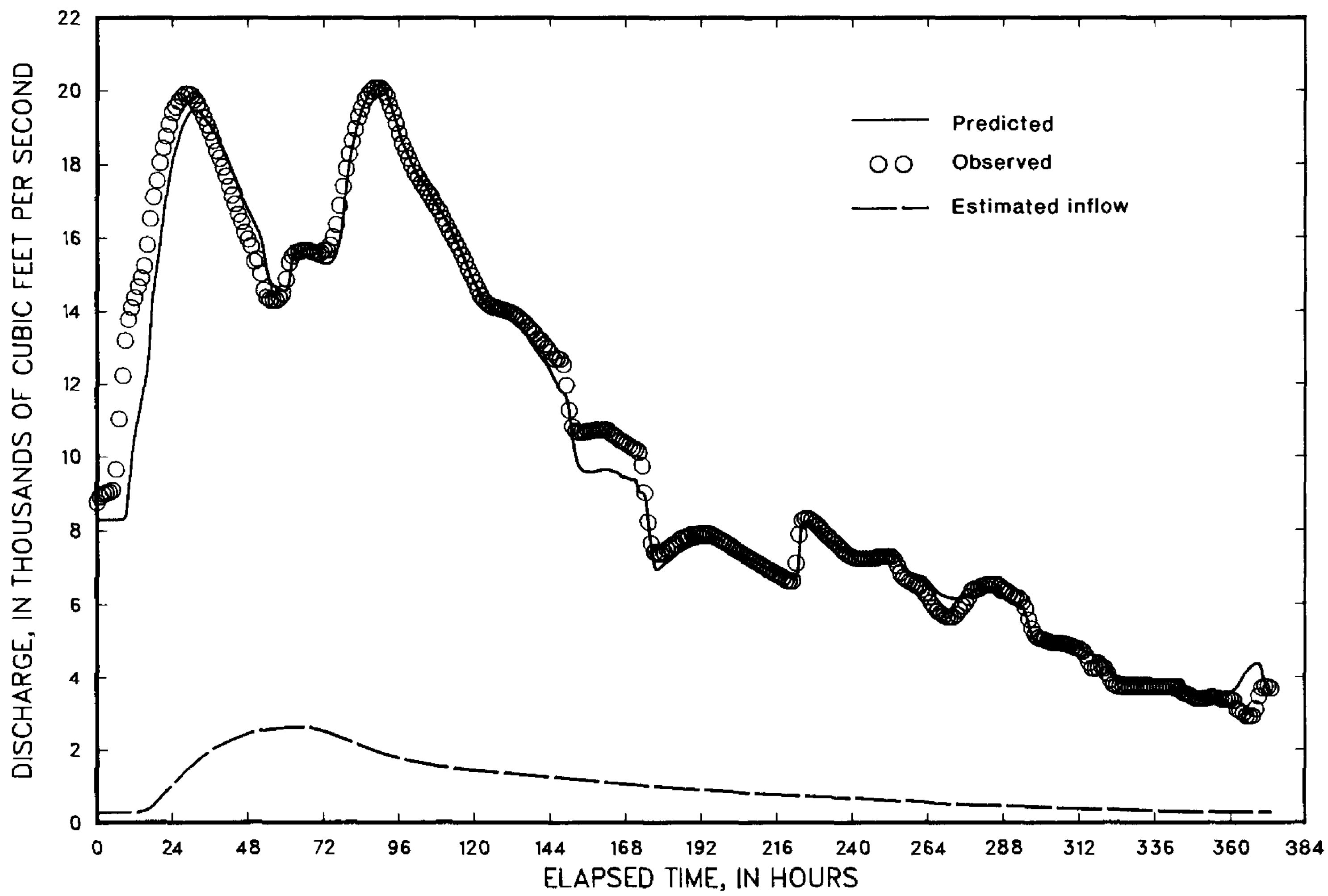

Figure 5.--Predicted, observed, and estimated inflow discharges at Thurmond, December 26, 1987, through January 2, 1988.

alter the prediction of traveltime of the wave because the inflow is applied at the Thurmond grid instead of at grids upstream.

Sensitivity

The parameters A0, A1, A2, and DF were increased and decreased by 20 percent (tables 3-10) and time steps were increased by 100 percent and decreased by 50 percent (tables 11 and 12) to study sensitivity of the unsteady-flow model. During calibration, it was found that adjustment of A0 affected the traveltime of waves. The sensitivity to A0 was caused by placement of the first shock at the upstream end of the model reach (H.E. Jobson, U.S. Geological Survey, oral commun., 1990). The shock-placement step involves equation 3 in the user's manual (Jobson, 1989, p. 3). This equation was also used in the wave-dispersion step (after the first shock is placed); however, A0 "falls out" of this solution procedure and makes the model nonsensitive in the wave-dispersion step. The model was sensitive to adjustments of A0 in the shock-placement step but not in the wave-dispersion step.

The sensitivity of the model to increasing and decreasing A0 by 20 percent is shown in tables 3 and 4. The effects are relatively small as compared to the effects of adjustments of the other parameters. In fact, increases and decreases in A0 do not result in definite increases or decreases in the traveltime of waves.

As A1 increases, the traveltime of waves increases, and as A1 decreases, the traveltime of waves decreases (tables 5 and 6). The magnitudes of differences in the traveltimes of waves are approximately the same for increases and decreases in A1. The differences in traveltime accumulate in the downstream direction. The models are more sensitive to adjustment of A1 at lower discharges than at higher discharges.

Table 3.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the average cross-sectional area of zero flow (A0) is increased by 20 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Positive values indicate the model predicts longer traveltimes of waves than the calibrated traveltimes. Negative values indicate the model predicts shorter traveltimes of waves than the calibrated traveltimes]

Location	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	0	-1	-1	0	0	0
Meadow Creek	0	0	0	+1	+1	0
Prince	0	0	0	0	0	0
Thurmond	-1	-1	+1	-1	0	0
Fayette	0	-2	0	0	0	-1

Table 4.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the average cross-sectional area of zero flow (A0) is decreased by 20 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Positive values indicate the model predicts longer traveltimes of waves than the calibrated traveltimes. Negative values indicate the model predicts shorter traveltimes of waves than the calibrated traveltimes]

Location	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	0	-1	0	0	0	0
Meadow Creek	0	0	0	0	+1	0
Prince	0	0	+1	0	0	0
Thurmond	0	0	0	-1	0	0
Fayette	+1	-1	0	0	0	-1

Table 5.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the hydraulic geometry coefficient for area (A1) is increased by 20 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Positive values indicate the model predicts longer traveltimes of waves than the calibrated traveltimes]

	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
Location	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	+5	+3	+3	+3	+3	+2
Meadow Creek	+7	+6	+4	+5	+5	+3
Prince	+12	+10	+9	+7	+7	+5
Thurmond	+19	+17	+14	+12	+12	+9
Fayette	+28	+22	+21	+17	+16	+11

Table 6.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the hydraulic geometry coefficient for area (A1) is decreased by 20 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Negative values indicate the model predicts shorter traveltimes of waves than the calibrated traveltimes]

	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
Location	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	-5	-4	-4	-3	-3	-2
Meadow Creek	-7	-6	-5	-4	-4	-4
Prince	-13	-11	-1	-8	-7	-6
Thurmond	-21	-17	-20	-14	-11	-10
Fayette	-29	-26	-29	-19	-16	-14

As A2 increases, the traveltime of waves increases, and as A2 decreases, the traveltime of waves decreases (tables 7 and 8). Unlike A1, however, the magnitude of the differences in the traveltimes of waves are greater for increases in A2 than for decreases in A2. The model is more sensitive to increases in A2 than to decreases in A2 because A2 is an exponent of the relation between area and discharge (Jobson, 1989, page 3). The models are more sensitive to adjustments in A2 at high discharges than at low discharges. The differences between predicted and calibrated traveltimes of waves accumulate in the downstream direction. Table 7 is incomplete because the models were not run the necessary number of time steps to predict traveltimes of waves caused by increasing A2 by 20 percent. The models were not run any additional time steps because patterns were apparent from executing the existing number of time steps.

Generally, as DF increases, the traveltime of waves decreases, and as DF decreases, the traveltime of waves increases (tables 9 and 10) ; however, this relation does not hold true for all cases. Output from the low-discharge unsteady-flow model shows an opposite trend in the downstream subreaches at Thurmond and Fayette when DF is decreased (table 10) and also at Fayette when DF is increased (table 9). Why this opposite trend is present is not understood, but the change in the relation of DF to traveltime may be one reason that the unsteady-flow model could not be calibrated throughout the range of discharge.

No general trend in the traveltime of waves was established by increasing and decreasing time steps (tables 11 and 12). The low-discharge unsteady-flow model appears to show a sensitivity similar to that caused by adjustments in DF at Thurmond and Fayette. At 2,200 and 8,000 ft^3/s, the traveltime of waves decreases with an increase in time step, and the traveltime of waves increases with the decrease in time step. This trend at 2,200 and 8,000 ft^3/s is not understood.

In general, the unsteady-flow models are least sensitive to adjustments in A0 and time step, more sensitive to adjustments in A1, and most sensitive to adjustments in A2. The sensitivity at 2,200 and 8,000 ft^3/s to changes in DF and time step cannot be explained.

Solute-Transport Model

For this study, the solute-transport model, BLTM (Branch Lagrangian Transport Model), was applied to the study reach to track the transport of a suspended solute by selecting kinetics for a conservative solute (dye). Estimating equations were used to determine initial conditions. Changes in channel characteristics were defined by 3 branches and 13 grids. The parameter A0, an unsteady-flow model parameter, is adjusted to calibrate the traveltime of peak concentration in the solute-transport model (this flow parameter does not significantly affect discharge calculations by the unsteady-flow model). The flow fields used with the solute-transport models were supplied by two (high-discharge and low-discharge) unsteady-flow models. Because the solute-transport model does not allow for multiple flow fields describing the flow characteristics of the same branch, two solute-transport models were developed. The reader is referred to the solute-transport model user's manual for additional definition and description of parameters (Jobson and Schoellhamer, 1987).

Calibration

Two solute-transport models--high-discharge and low-discharge--were calibrated by adjusting model parameters until the simulated peak concentrations and the traveltimes of peak concentrations matched the peak concentrations and the traveltimes of peak concentrations from figures 6 and 7. These figures were developed in a previous study by Appel and Moles (1987).

The study subreaches--Hinton to Meadow Creek, Meadow Creek to Sewell, and Sewell to

Table 7.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the hydraulic geometry exponent for area (A2) is increased by 20 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Positive values indicate the model predicts longer traveltimes of waves than the calibrated traveltimes]

	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
Location	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	+55	+46	+48	+23	+26	+25
Meadow Creek	+79	+72	+74	+32	+33	+29
Prince	([1])	([1])	+122	+63	+66	+55
Thurmond	([1])	([1])	([1])	([1])	+103	+88
Fayette	([1])	([1])	([1])	([1])	([1])	([1])

[1] Value is greater than number of time steps used in the model.

Table 8.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the hydraulic geometry exponent for area (A2) is decreased by 20 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Negative values indicate the model predicts shorter traveltimes of waves than the calibrated traveltimes]

	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
Location	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	-20	-18	-16	-13	-12	-10
Meadow Creek	-28	-24	-22	-16	-15	-13
Prince	-51	-42	-36	-30	-27	-22
Thurmond	-81	-67	-57	-49	-43	-33
Fayette	-110	-93	-76	-67	-57	-44

Table 9.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the wave-dispersion coefficient (DF) is increased by 20 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Positive values indicate the model predicts longer traveltimes of waves than the calibrated traveltimes. Negative values indicate the model predicts shorter traveltimes of waves than the calibrated traveltimes]

Location	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	-1	-1	-1	-2	0	-1
Meadow Creek	-1	-1	-1	-1	0	-1
Prince	-2	-2	-1	-1	-1	-1
Thurmond	-2	-2	-1	-2	-1	-1
Fayette	-1	-2	+1	-3	-2	-2

Table 10.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the wave-dispersion coefficient (DF) is decreased by 20 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Positive values indicate the model predicts longer traveltimes of waves than the calibrated traveltimes. Negative values indicate the model predicts shorter traveltimes of waves than the calibrated traveltimes]

Location	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge					
	Low-discharge model			High-discharge model		
	2,200 ft^3/s	4,000 ft^3/s	8,000 ft^3/s	8,000 ft^3/s	12,000 ft^3/s	22,800 ft^3/s
Sandstone	+1	+1	+1	+1	+1	+1
Meadow Creek	+1	+1	0	+2	+2	+2
Prince	+2	+1	+2	+2	+2	+1
Thurmond	+2	+2	-3	+2	+2	+1
Fayette	+4	+1	-6	+3	+1	0

Table 11.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when the time step is increased by 100 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Negative values indicate the model predicts shorter traveltimes of waves than the calibrated traveltimes]

Location	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge: Low-discharge model, 2,200 ft^3/s	Low-discharge model, 4,000 ft^3/s	Low-discharge model, 8,000 ft^3/s	High-discharge model, 8,000 ft^3/s	High-discharge model, 12,000 ft^3/s	High-discharge model, 22,800 ft^3/s
Sandstone	0	0	0	0	0	0
Meadow Creek	0	0	0	0	0	0
Prince	0	0	-2	0	0	0
Thurmond	0	0	-4	0	-1	0
Fayette	-2	-2	-5	-1	-2	-1

Table 12.--*Differences between predicted traveltimes of waves and those of the calibrated unsteady-flow models when time step is decreased by 50 percent*

[ft^3/s, cubic feet per second. All differences are in 0.1-hour time steps. Positive values indicate the model predicts longer traveltimes of waves than the calibrated traveltimes. Negative values indicate the model predicts shorter traveltimes of waves than the calibrated traveltimes]

Location	Difference between predicted and calibrated traveltimes for a given unsteady-flow model and discharge: Low-discharge model, 2,200 ft^3/s	Low-discharge model, 4,000 ft^3/s	Low-discharge model, 8,000 ft^3/s	High-discharge model, 8,000 ft^3/s	High-discharge model, 12,000 ft^3/s	High-discharge model, 22,800 ft^3/s
Sandstone	+2	-1	-1	+1	+1	0
Meadow Creek	+2	0	0	+1	+1	-1
Prince	0	0	+1	+1	+1	0
Thurmond	+2	+1	+1	0	+3	+1
Fayette	+4	0	+4	0	+1	-1

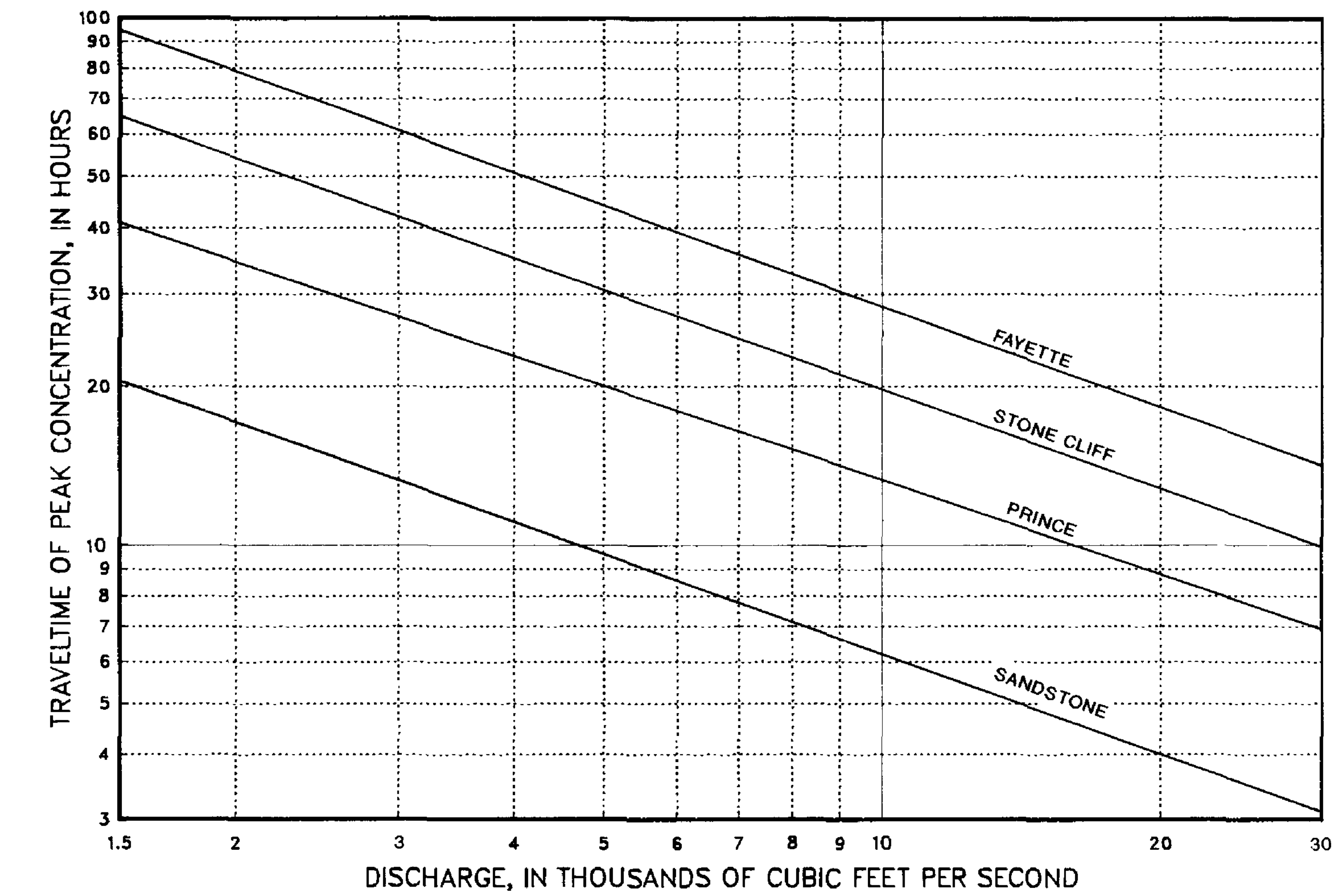

Figure 6.--Relations between discharge and the traveltime of peak concentrations of dye from Hinton to selected communities in the New River Gorge. (Modified from Appel and Moles, 1987, p. 14.)

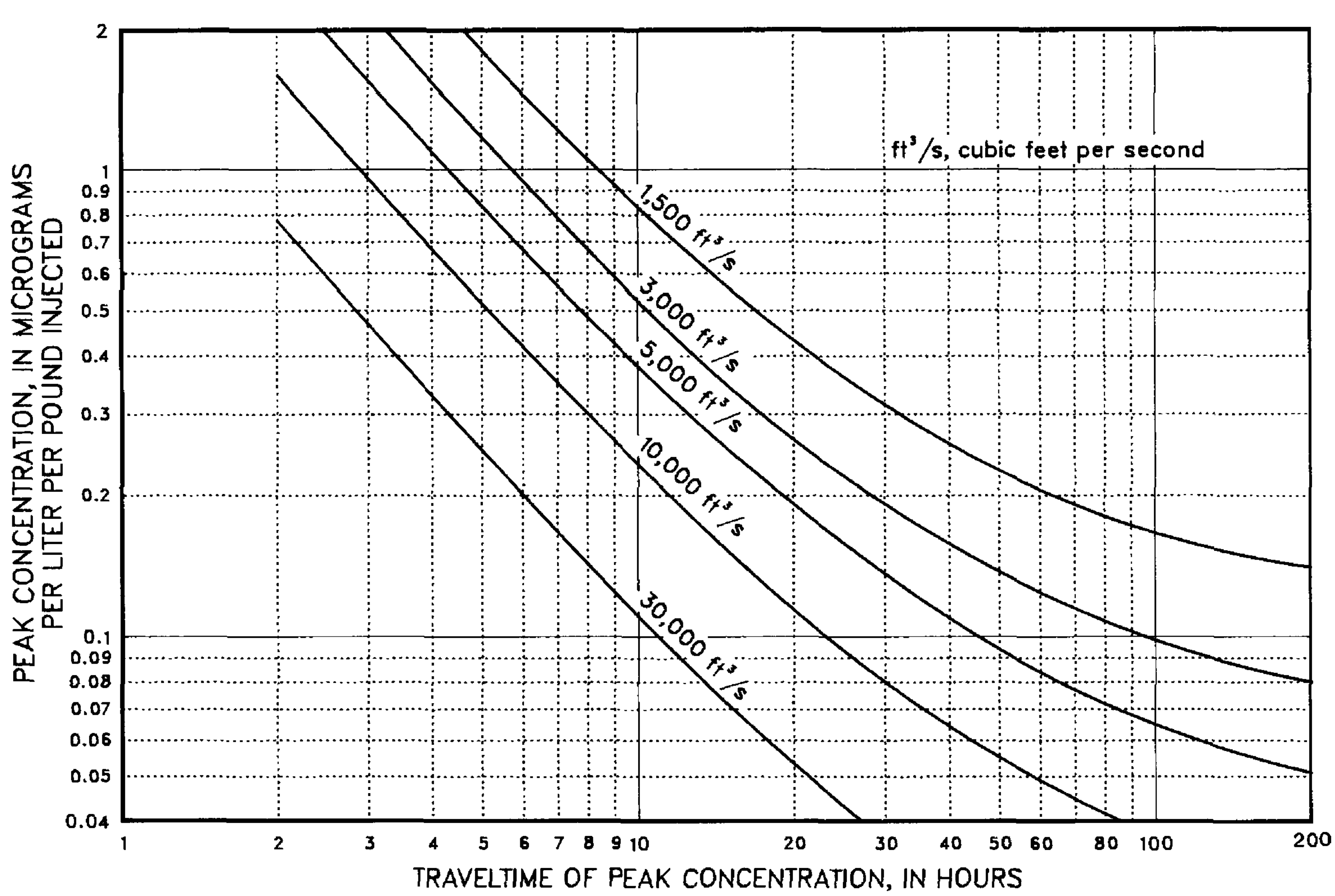

Figure 7.--Peak concentrations resulting from the injection of 1 pound of a conservative soluble material at selected discharges in the New River Gorge. (Modified from Appel and Moles, 1987, p. 19.)

Fayette--were represented by the models as three branches (allowing for separate dispersion factors for each branch). The flow fields from the unsteady-flow models were easily modified from one branch to three; however, the unsteady-flow models were still run as a single branch. Flow-field modifications involved (1) renumbering of branches and grids, and (2) copying flow characteristics at junctions between branches to obtain flow characteristics for each grid of each branch. Thirteen grids (including two grids copied at junctions between branches) and three branches represented the study reach for application of the solute-transport model.

The parameters A0 (average cross-sectional area of zero discharge), W1 (hydraulic geometry coefficient for width), and W2 (hydraulic geometry exponent for width) in the unsteady-flow model effect calculations of the solute-transport model. Initial conditions for these parameters were discussed previously in the Unsteady-Flow Model section of this report. For this application of the solute-transport model, parameters W1 and W2 had no effect on transport because decay subroutines that use these parameters were not necessary for predicting a conservative solute. Parameter A0 had a minimal effect in the unsteady-flow model (tables 3 and 4), but it significantly affected the traveltime of peak concentration in the solute-transport model. The solute-transport model parameter DQQ (dispersion factor) was estimated to be 0.75 from inspection of other model-simulation examples.

A dye-concentration curve must be input into the model at the most upstream grid. The most upstream grid is at Hinton, but no dye measurement was made at this location. The most upstream dye-measurement site was at Sandstone. Because Sandstone is near the downstream end of the Hinton-to-Meadow Creek subreach, the concentration curve measured at Sandstone could be applied at Hinton. This procedure was acceptable because the hydraulics that affected the solute cloud were repeated and should not affect A0 or DQQ calibration parameters. The input concentration curves for each calibration discharge were developed from (1) traveltimes of the leading edge, the peak concentration, and the trailing edge, and (2) peak concentrations of a 20-pound slug injection predicted at Sandstone (figs. 6 and 7, and others developed by Appel and Moles, 1987, p. 13 and p. 15).

High-discharge and low-discharge unsteady-flow models, and high-discharge and low-discharge solute-transport models were run at a time step of 0.2 hour. This increase in time step for the unsteady-flow models did not significantly affect the predicted traveltimes of waves (tables 11 and 12). The unsteady-flow models were run for steady discharges of 3,000, 5,000, 10,000, and 22,800 ft^3/s. The solute-transport model was run such that the peak concentration of the input-concentration curve occurred at 6.2 hours.

For the high-discharge solute-transport model (discharges greater than or equal to 8,000 ft^3/s), measured and predicted peak concentrations and traveltimes of peak concentrations were balanced between steady discharges of 10,000 and 22,800 ft^3/s. Between Hinton and Sandstone, for calibration of 22,800 ft^3/s, A0 was reduced to zero, and the predicted traveltime of peak concentration was more than 1 hour later than the measured traveltime. Similarly, the 10,000 ft^3/s calibration predicted a later traveltime of peak concentration, but the difference from the measured traveltime was smaller. The value of A0 would have to be reduced further to decrease the difference between measured and predicted traveltimes of peak concentrations. The model could not be calibrated between Hinton and Sandstone because it was not feasible for the average cross-sectional area of zero discharge (A0) to be less than zero. The value of A0 computed for initial conditions was used between Hinton and Sandstone, and corrections to the traveltime of peak concentration were applied to calibrate the remaining study reach. DQQ was adjusted to calibrate the peak concentrations.

For the low-discharge solute-transport model (discharges less than or equal to 8,000 ft^3/s), the measured and the predicted peak concentrations and traveltimes of peak concentrations were balanced between 3,000 and 5,000 ft^3/s. The value of A0 computed for initial conditions was used between Hinton and Sandstone to avoid problems encountered in calibrating the high-discharge solute-transport model. Corrections to the traveltimes of peak concentrations were evaluated at Sandstone and applied to calibrate the rest of the study reach. DQQ was adjusted to calibrate the peak concentrations.

The difference between measured and predicted peak concentrations and traveltimes of peak concentrations used to calibrate the low-discharge and high-discharge solute-transport models are shown in table 13. For the high-discharge solute-transport model, a partial listing of the input file containing transport parameters (including DQQ) is given in appendix C, and a partial listing of the input file containing flow parameters (including A0, W1, and W2) is given in appendix D. For the low-discharge solute-transport model, a partial listing of the input file containing transport parameters is given in appendix E, and a partial listing of the input file containing flow parameters is given in appendix F.

Verification

Two unsteady-flow dye measurements (Appel, 1987, and Wiley and Appel, 1989) and one steady-flow dye measurement (Appel and Moles, 1987) were used to verify results of the solute-transport model simulations. The flow fields produced by the unsteady-flow models were modified into three branches, as in the calibration of the solute-transport models, except for the location of the first grid point of the first branch. Instead of starting at Hinton, the first grid was placed at Sandstone. Peak concentrations and traveltimes of peak concentrations between Hinton and Sandstone were not

Table 13.--*Differences between predicted and observed peak concentrations, and between predicted and observed traveltimes of peak concentrations used to calibrate the solute-transport models*

[TT, the traveltime of peak concentration. PC, peak concentration. ft^3/s, cubic feet per second. All differences in peak concentration are in percent. All differences in traveltime are in 0.2-hour time step. Positive values indicate the model predicts a higher peak concentration or traveltime of peak concentration than the measured concentration or traveltime. Negative values indicate the model predicts a lower peak concentration or traveltime of peak concentration than the measured concentration or traveltime]

	Difference between predicted and calibrated traveltimes for a given solute-transport model and discharge							
	Low-discharge model				High-discharge model			
	3,000 ft^3/s		5,000 ft^3/s		10,000 ft^3/s		22,800 ft^3/s	
Location	TT	PC	TT	PC	TT	PC	TT	PC
Sandstone	[1]-16	[1]+13	[1]-11	[1]-9	[1]+11	[1]+3	[1]+8	[1]-3
Prince	+4	+6	-2	-14	+1	-10	0	+10
Stone Cliff	+5	+7	-5	-9	-2	-12	-2	+21
Fayette	+5	+14	-5	-6	0	-7	-2	+38

[1] A correction for this difference is applied to calibrate at other locations.

verified. The observed dye-concentration curve at Sandstone was input into the model beginning at the time step equal to the time since the slug injection. The unsteady-flow model was run with appropriate discharges, and output was modified to meet the input requirements of a three-branch solute-transport model that begins at Sandstone.

Decreasing unsteady flow.--The predicted and observed traveltimes and concentrations for decreasing unsteady flow (fig. 8) were verified as follows:

1. The high-discharge unsteady-flow model was run at a steady discharge of 8,100 ft^3/s for 9.0 hours.
2. The discharge was reduced to 8,000 ft^3/s from 9.0 to 9.2 hours.
3. Output from the high-discharge unsteady-flow model was used for initial conditions of the low-discharge unsteady-flow model.
4. The low-discharge model was run for 1.0 hour as discharge was reduced from 8,000 to 4,500 ft^3/s and then was continued at a steady discharge for the remaining time steps.
5. Output from the two unsteady-flow models were combined into one flow field, and the flow field was then modified to be one of three branches with the first grid at Sandstone.
6. The low-discharge solute-transport model was run.

The high-discharge solute-transport model was not used, although some discharges exceeded 8,000 ft^3/s. Predictions from the low-discharge solute-transport model were used because transition from the high-discharge

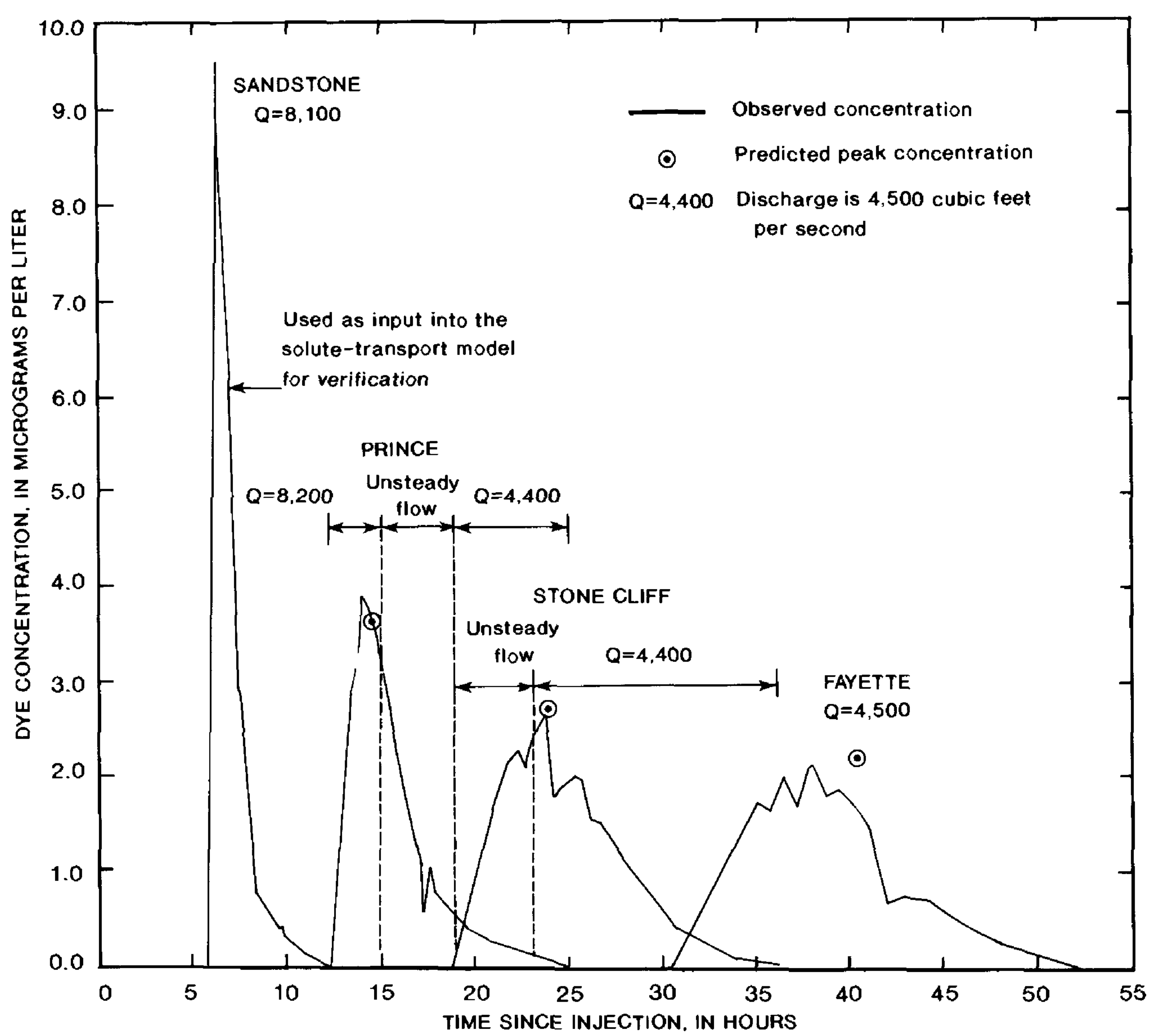

Figure 8.--Predicted and observed peak concentrations and traveltimes of peak concentrations for decreasing unsteady flow. (Modified from Wiley and Appel, 1989, p. 11.)

model to the low-discharge model (that is, stopping and starting the solute-transport model) would cause locations and concentrations of parcels to be lost.

Increasing unsteady flow.--The predicted and observed traveltimes and concentrations for increasing unsteady flow (fig. 9) were verified as follows:

1. The low-discharge unsteady-flow model was run at a steady discharge of 4,500 ft^3/s for 18.0 hours.
2. The discharge was increased to 8,000 ft^3/s from 18.0 to 19.6 hours.
3. Output from the low-discharge unsteady-flow model was used for initial conditions of the high-discharge unsteady-flow model.
4. The high-discharge model was run for 1.4 hours as discharge was increased from 8,000 to 11,200 ft^3/s and then was continued at a steady discharge for the remaining time steps.
5. Output from the two unsteady-flow models were combined into one flow field, and the flow field was modified to be one of three branches with the first grid at Sandstone.
6. The low-discharge solute-transport model was run.

Again, the high-discharge solute-transport model was not used because of the high-discharge/low-discharge transition problems that occur when the solute-transport model is stopped and then started again. The initial low-discharge solute-transport model output predicted the traveltime of peak concentration at Prince approximately 2 hours sooner than the observed traveltime, and the traveltime of waves predicted by the unsteady-flow model reached Prince before the peak concentration predicted by the solute-transport model. A review of the

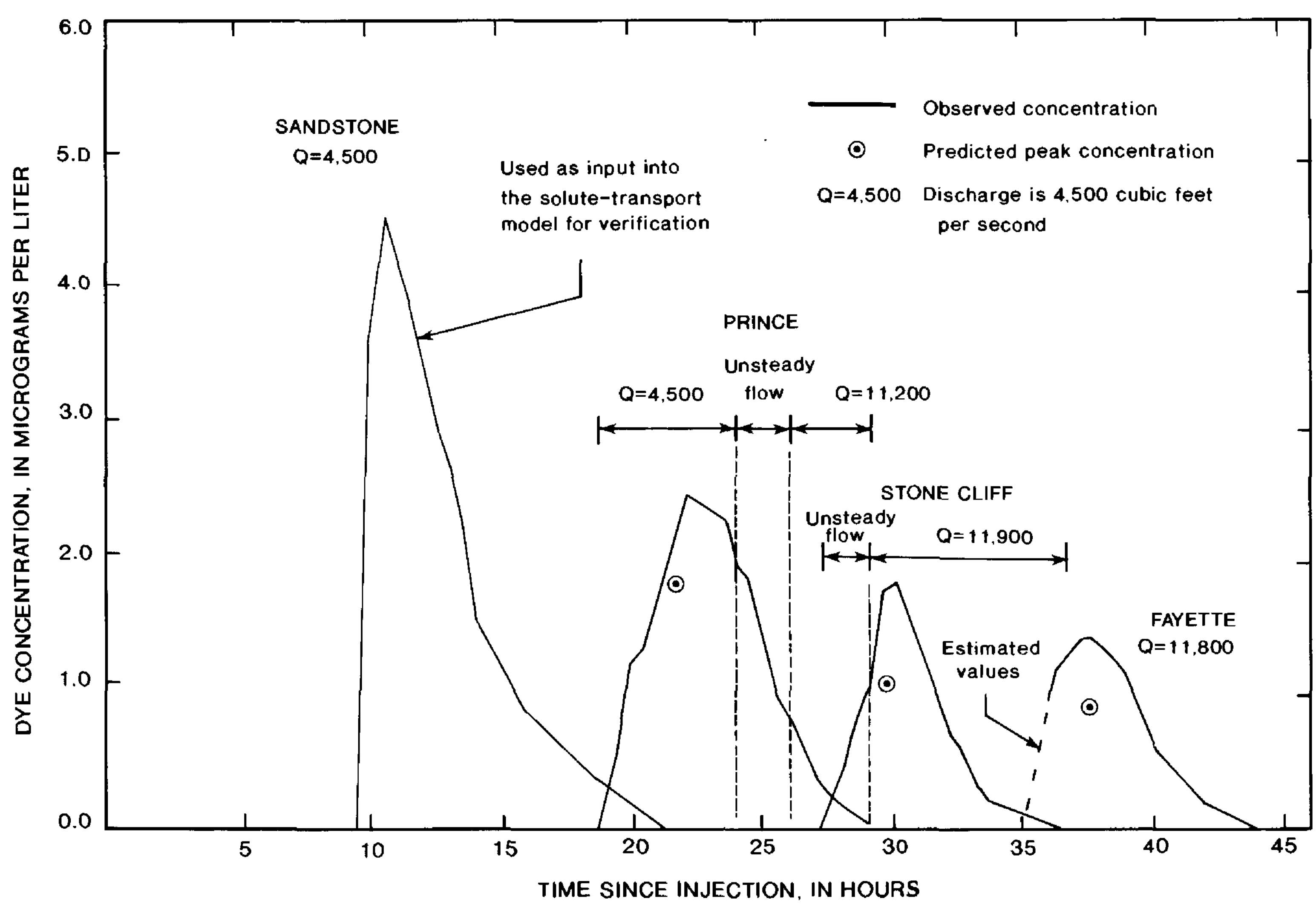

Figure 9.--Predicted and observed peak concentrations and traveltimes of peak concentrations for increasing unsteady flow. (Modified from Appel, 1987, p. 68.)

dye measurement records showed that the initial discharge should have been 4,000 ft^3/s, not 4,500 ft^3/s. Once this correction was made, verification was successful (fig. 9).

Steady flow.--The predicted and observed peak concentrations and traveltimes of peak concentrations for a steady-flow dye measure-ment at 9,200 ft^3/s (fig. 10) were verified as follows:

1. The high-discharge unsteady-flow model was run at a steady discharge of 9,200 ft^3/s for all time steps.
2. Output from the high-discharge model was modified to a flow field of three branches with the first grid at Sandstone.
3. The high-discharge solute-transport model was run.

The initial output from the high-discharge solute-transport model predicted a peak concentration at Prince of about one-half of what was observed. Reviewing the dye measurement records, it was determined that mixing was incomplete when measurements were made at Sandstone. A composite sample from three observation points across the I-64 bridge at Sandstone had a peak concentration of 6.44 μg/L (a concentration of 8.0 μg/L is reported in fig. 10). Data also indicated that the dye cloud was traveling close to the left bank. An attempt was made to verify the model by use of the composite concentrations from records of the dye measurement, but the predicted concentrations were not significantly increased. The model could not be verified with dye data at Sandstone to predict peak concentrations and the traveltimes of peak concentrations at Prince, Stone Cliff, and Fayette.

Because the model could not be verified with data from Sandstone, verification was attempted by use of observed dye data from Prince. This required that the high-discharge solute-transport model be modified from three to two branches. Two branches are necessary because the solute-transport model requires the input-concentration curve to be at the most upstream grid. The output from the high-discharge unsteady-flow model also was modified to fit the two-branch network.

The initial run of the two-branch high-discharge solute-transport model predicted the traveltime of peak concentration at Fayette to be 2 hours later than what was observed. Reviewing the dye-measurement records, the author noted that considerable inflow was indicated by comparison of discharges between the Hinton and Thurmond streamflow-gaging stations. The average discharge of the dye measurement was 9,200 ft^3/s, but at the Thurmond gage, discharge was 10,800 ft^3/s while the dye cloud was in the lower areas of the study reach. The two-branch high-discharge solute-transport model was rerun with a steady discharge of 10,800 ft^3/s.

The predicted and observed concentrations are shown in figure 10. The predicted concentrations are less than the observed concentrations. These differences could be attributed to the fact that (1) the dye data at Prince indicate that the dye cloud was still concentrated near the left bank, and (2) the calibration of the high-discharge solute-transport model predicts concentrations approximately 10 percent lower than the observed concentrations at a discharge of 10,000 ft^3/s (table 13).

Sensitivity

The parameters A0 and DQQ were increased and decreased by 20 percent (tables 14-17) and time steps were increased and decreased by 50 percent (tables 18 and 19) to study sensitivity of the solute-transport model. Parameters W1 and W2 do not affect model results because they only affect decay computations that were not necessary with conservative constituents (dye); hence, sensitivity to adjustments of W1 and W2 is not reported. (W1 and W2 were adjusted in several runs of the model to ensure that they made no difference in model output.)

As A0 increases, peak concentrations decrease and the traveltimes of peak concentrations increase (table 14). As A0 decreases, peak concentrations increase and the traveltimes of

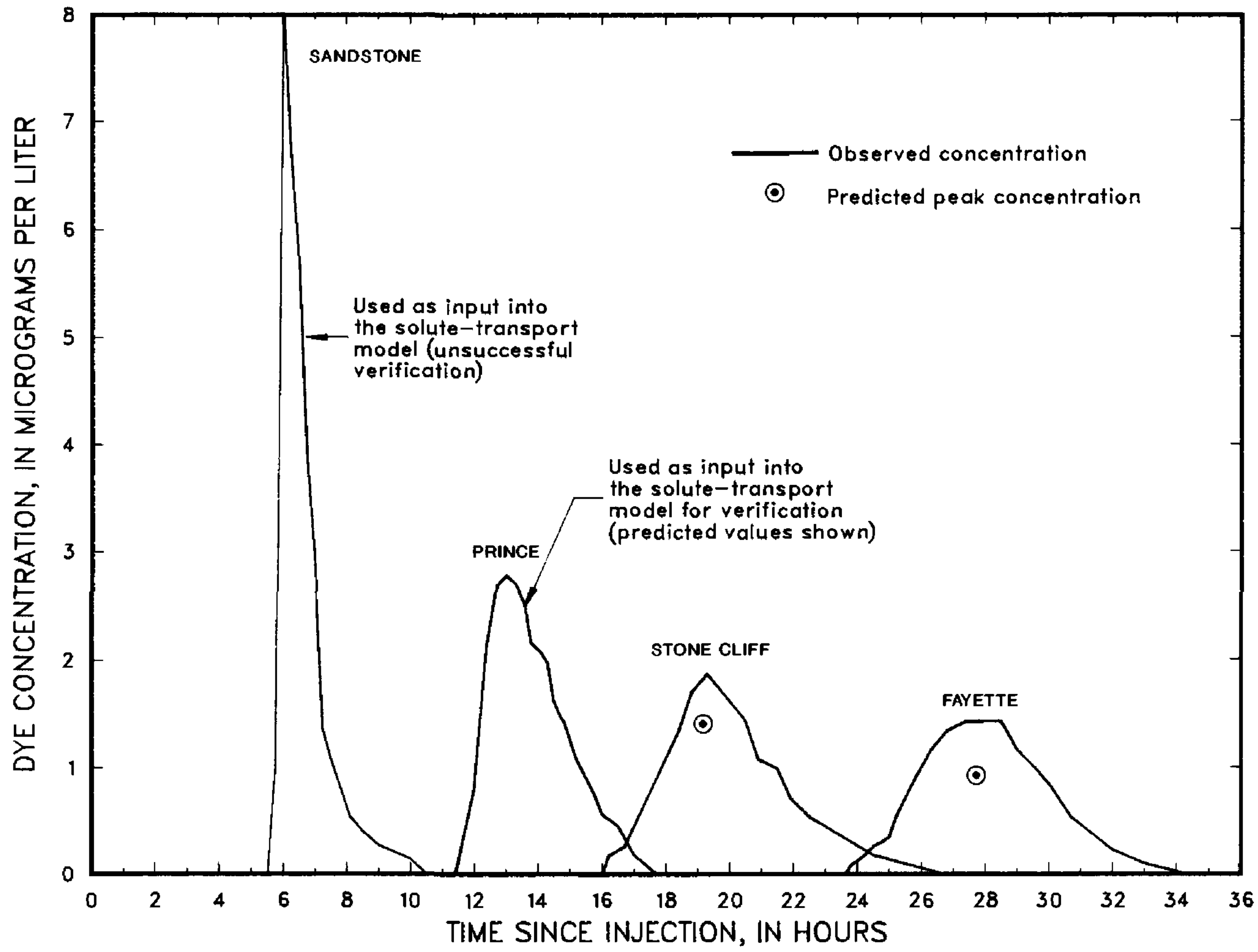

Figure 10.--Predicted and observed peak concentrations and traveltimes of peak concentrations for the May 1986 steady-flow study. (Modified from Appel and Moles, 1987, p. 4.)

Table 14.--*Differences between predicted peak concentrations and those of the calibrated solute-transport models, and between predicted traveltimes of peak concentrations and those of the calibrated solute-transport models when the average cross-sectional area of zero flow (A0) is increased by 20 percent*

[TT, the traveltime of peak concentration. PC, peak concentration. ft^3/s, cubic feet per second. All differences in peak concentration are in percent. All differences in traveltime are in 0.2-hour time step. Positive values indicate the model predicts a higher peak concentration or traveltime of peak concentration than the measured concentration or traveltime. Negative values indicate the model predicts a lower peak concentration or traveltime of peak concentration than the measured concentration or traveltime]

	Difference in peak concentration and traveltime for a given solute-transport model and discharge							
	Low-discharge model				High-discharge model			
	3,000 ft^3/s		5,000 ft^3/s		10,000 ft^3/s		22,800 ft^3/s	
Location	TT	PC	TT	PC	TT	PC	TT	PC
Sandstone	+2	-2	+1	-1	+1	-2	0	0
Prince	+5	-6	+8	-6	0	-4	0	0
Stone Cliff	+7	-7	+8	-7	+4	-5	+1	-2
Fayette	+29	-7	+19	-7	+6	-5	+2	-3

peak concentrations decrease (table 15). The magnitude of the differences is approximately the same for peak concentration and the traveltime of peak concentration when A0 is increased and decreased. The models are more sensitive to adjustments of A0 at low discharges than at high discharges. In addition, there is an accumulative effect in the downstream direction.

As DQQ increases, peak concentrations decrease, and as DQQ decreases, peak concentrations increase (tables 16 and 17). Adjusting DQQ does not significantly affect the traveltime of peak concentration as compared to the effect on peak concentration. On the basis of sensitivity-test results, there is a tendency for the traveltime of peak concentration to decrease when DQQ is increased and for the traveltime of peak concentration to increase when DQQ is decreased.

Increasing and decreasing time steps indicated more sensitivity at high discharges than at low discharges when predicting peak concentrations (tables 18 and 19). No trend was established for adjusting time step to predict the traveltimes of peak concentrations.

Peak concentration is about equally sensitive to adjustments of A0 and DQQ. Increasing and decreasing time steps showed little variability in peak concentration calculations. The prediction of the traveltime of peak concentration is least sensitive to adjustments of DQQ, more sensitive to adjustments of time step, and most sensitive to adjustments of A0.

Table 15.--*Differences between predicted peak concentrations and those of the calibrated solute-transport models, and between predicted traveltimes of peak concentrations and those of the calibrated solute-transport models when the average cross-sectional area of zero flow (A0) is decreased by 20 percent*

[TT, the traveltime of peak concentration. PC, peak concentration. ft^3/s, cubic feet per second. All differences in peak concentration are in percent. All differences in traveltime are in 0.2-hour time step. Positive values indicate the model predicts a higher peak concentration or traveltime of peak concentration than the measured concentration or traveltime. Negative values indicate the model predicts a lower peak concentration or traveltime of peak concentration than the measured concentration or traveltime]

	Difference in peak concentration and traveltime for a given solute-transport model and discharge							
	Low-discharge model				High-discharge model			
	3,000 ft^3/s		5,000 ft^3/s		10,000 ft^3/s		22,800 ft^3/s	
Location	TT	PC	TT	PC	TT	PC	TT	PC
Sandstone	-3	+3	-3	+2	0	+1	0	0
Prince	-13	+7	-5	+6	-3	+5	-2	+2
Stone Cliff	-22	+7	-10	+8	-2	+4	-4	+4
Fayette	-31	+9	-18	+8	-7	+4	-3	+4

Table 16.--*Differences between predicted peak concentrations and those of the calibrated solute-transport models, and between predicted traveltimes of peak concentrations and those of the calibrated solute-transport models when the dispersion factor (DQQ) is increased by 20 percent*

[TT, the traveltime of peak concentration. PC, peak concentration. ft^3/s, cubic feet per second. All differences in peak concentration are in percent. All differences in traveltime are in 0.2-hour time step. Negative values indicate the model predicts a lower peak concentration or traveltime of peak concentration than the measured concentration or traveltime]

	Difference in peak concentration and traveltime for a given solute-transport model and discharge							
	Low-discharge model				High-discharge model			
	3,000 ft^3/s		5,000 ft^3/s		10,000 ft^3/s		22,800 ft^3/s	
Location	TT	PC	TT	PC	TT	PC	TT	PC
Sandstone	0	-3	-1	-5	0	-6	0	-6
Prince	0	-5	0	-6	0	-7	-1	-7
Stone Cliff	-6	-5	0	-7	0	-7	0	-8
Fayette	0	-6	0	-7	-1	-7	-1	-7

Table 17.--*Differences between predicted peak concentrations and those of the calibrated solute-transport models, and between predicted traveltimes of peak concentrations and those of the calibrated solute-transport models when the dispersion factor (DQQ) is decreased by 20 percent*

[TT, the traveltime of peak concentration. PC, peak concentration. ft^3/s, cubic feet per second. All differences in peak concentration are in percent. All differences in traveltime are in 0.2-hour time step. Positive values indicate the model predicts a higher peak concentration or traveltime of peak concentration than the measured concentration of traveltime]

	Difference in peak concentration and traveltime for a given solute-transport model and discharge							
	Low-discharge model				High-discharge model			
	3,000 ft^3/s		5,000 ft^3/s		10,000 ft^3/s		22,800 ft^3/s	
Location	TT	PC	TT	PC	TT	PC	TT	PC
Sandstone	0	+4	0	+6	0	+11	+1	+8
Prince	0	+6	0	+8	0	+9	0	+10
Stone Cliff	0	+7	0	+9	+2	+10	0	+11
Fayette	+2	+7	+2	+9	+1	+10	0	+10

Table 18.--*Differences between predicted peak concentrations and those of the calibrated solute-transport models, and between predicted traveltimes of peak concentrations and those of the calibrated solute-transport models when the time step is increased by 50 percent*

[TT, the traveltime of peak concentration. PC, peak concentration. ft^3/s, cubic feet per second. All differences in peak concentration are in percent. All differences in traveltime are in 0.2-hour time step. Positive values indicate the model predicts a higher peak concentration or traveltime of peak concentration than the measured concentration or traveltime. Negative values indicate the model predicts a lower peak concentration or traveltime of peak concentration than the measured concentration or traveltime]

Location	Difference in peak concentration and traveltime for a given solute-transport model and discharge							
	Low-discharge model				High-discharge model			
	3,000 ft^3/s		5,000 ft^3/s		10,000 ft^3/s		22,800 ft^3/s	
	TT	PC	TT	PC	TT	PC	TT	PC
Sandstone	0	-6	-1	-10	-1	-10	-1	-11
Prince	-5	0	0	+3	0	+2	-2	-13
Stone Cliff	-3	+1	0	+6	0	-4	-1	-10
Fayette	+1	+1	+1	0	0	-7	0	-7

Table 19.--*Differences between predicted peak concentrations and those of the calibrated solute-transport models, and between predicted traveltimes of peak concentrations and those of the calibrated solute-transport models when the time step is decreased by 50 percent*

[TT, the traveltime of peak concentration. PC, peak concentration. ft^3/s, cubic feet per second. All differences in peak concentration are in percent. All differences in traveltime are in 0.2-hour time step. Positive values indicate the model predicts a higher peak concentration or traveltime of peak concentration than the measured concentration or traveltime. Negative values indicate the model predicts a lower peak concentration or traveltime of peak concentration than the measured concentration or traveltime]

Location	Difference in peak concentration and traveltime for a given solute-transport model and discharge							
	Low-discharge model				High-discharge model			
	3,000 ft^3/s		5,000 ft^3/s		10,000 ft^3/s		22,800 ft^3/s	
	TT	PC	TT	PC	TT	PC	TT	PC
Sandstone	-4	+2	-1	+3	-2	-6	+1	+10
Prince	+1	0	+1	0	+4	+2	-2	+4
Stone Cliff	+1	0	+1	0	+8	+4	-2	+7
Fayette	+1	+1	+2	0	+7	+3	-1	+9

Effects of Changes in Discharge on the Traveltime of Peak Concentration and the Peak Concentration of a Solute Cloud

Changes in discharge (an increase or decrease) in the New River Gorge National River can be regulated by Bluestone Dam or can occur naturally from changing streamflows on the Greenbrier River. The effects of changes in discharge on a solute cloud were examined by (1) evaluating traveltimes of waves with traveltimes of peak concentrations to determine elapsed times for changes in discharge to overtake peak concentrations at different river locations, (2) evaluating changes in discharge with traveltimes of peak concentrations to determine relative changes in traveltimes at different river locations (through application of flow and solute-transport models), and (3) evaluating changes in discharge with peak concentrations to determine relative changes in peak concentrations at different river locations (through application of flow and solute-transport models). Knowledge of the effects of changes in discharge on a solute cloud in the New River Gorge National River can assist river managers in mitigating an accidental spill.

Response Time

"Response time" is defined in this report as the time elapsed before a change in discharge at Hinton is required in order to reach the peak concentration of a soluble-contaminant spill at a specific location downstream from Hinton. Response times (fig. 11) were determined from subtracting the traveltimes of waves (from fig. 4) from the traveltimes of peak concentrations (from fig. 6) at the same discharges. Figure 11 indicates that, as discharge increases, response time decreases. Examples of the use of figure 11 follow:

1. Assume that the discharge of the river is 4,000 ft^3/s and that a spill occurs at

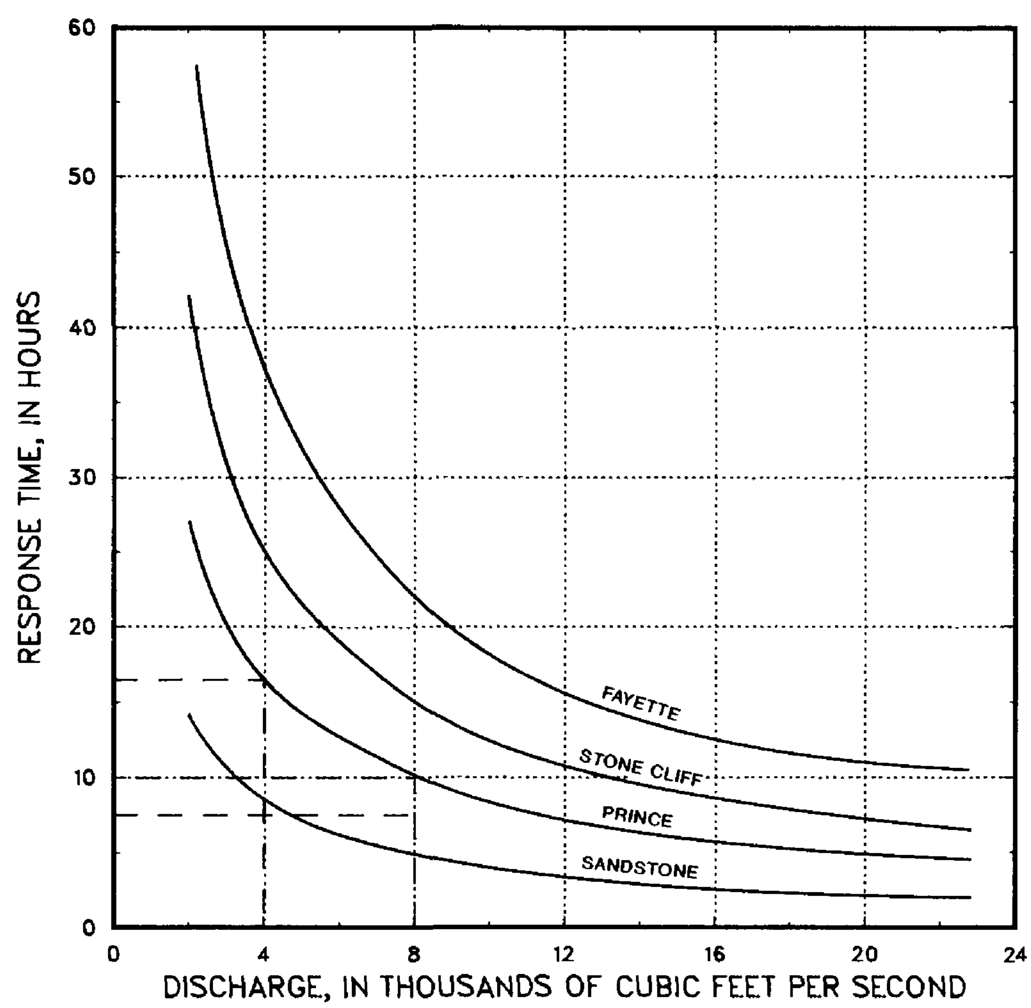

Figure 11.--Relations between discharge and response time for selected communities in the New River Gorge. (Response time is time required for a wave of increased or decreased discharge to overtake the peak concentration of a solute cloud.

Hinton. For a change in discharge at Hinton to affect peak concentration before reaching Prince, the change in discharge must take place no more than 16.5 hours after the spill.

2. Assume that the discharge of the river is 8,000 ft^3/s and that a spill occurs midway between Sandstone and Prince. For a change in discharge at Hinton to affect the peak concentration before reaching Prince, the change in discharge must take place no more than 2.5 hours after the spill (10 hours - 7.5 hours).

Traveltime of Peak Concentration

The high-discharge and low discharge unsteady-flow models were run at a steady discharge of 8,000 ft^3/s. The high-discharge and low-discharge solute-transport models were run, and a concentration curve was input at Hinton with a peak concentration of 8.0 µg/L. The shape of the concentration curve was developed in the same manner as discussed in the Solute-Transport Model section of this report. A correction to the traveltime of peak concentration was applied to the output of both models to account for the inability to calibrate models between Hinton and Sandstone. Predicted traveltimes of peak concentrations for the steady discharge of 8,000 ft^3/s were determined. The unsteady-flow models and solute-transport models were then run with a change in discharge introduced to affect the peak concentration just after passing Sandstone. The discharge was increased and decreased by 50 percent.

The traveltimes of peak concentrations predicted by the high-discharge and low-discharge models at steady, increased, and decreased discharges for the river at and downstream from Sandstone are shown in figure 12. At the steady discharge of 8,000 ft^3/s, both models predict approximately the same peak concentration. This prediction includes a correction for the inability to calibrate the models from Hinton to Sandstone. The corrections required for the traveltimes of peak concentrations were the addition of 2.4 hours to those predicted by the low-discharge solute-transport models and the subtraction of 1.4 hours from those predicted by the high-discharge solute-transport models. As figure 12 shows, an increase in discharge decreases the traveltimes of peak concentrations, and a decrease in discharge increases the traveltimes of peak concentrations.

Peak Concentration

The models were run exactly as described above for steady, increased, and decreased discharges. The corrections for the inability to calibrate from Hinton to Sandstone for peak concentration were the addition of 0.01 µg/L to concentrations predicted by the low-discharge solute-transport models and the addition of 0.40 µg/L to concentrations predicted by the high-discharge solute-transport models.

At a steady discharge of 8,000 ft^3/s, the high-discharge and low-discharge solute-transport models predict approximately the same peak concentrations at and downstream from Sandstone (fig. 13). In addition, the peak concentration decreases as discharge increases, and the peak concentration increases as discharge decreases.

MITIGATION OF A HYPOTHETICAL SOLUBLE-CONTAMINANT SPILL

The effects of an accidental soluble-contaminant spill in the New River Gorge National River could be mitigated by regulating discharge from Bluestone Dam. If such a spill should occur, it would be important to determine (almost) immediately the chemical characteristics of the substance, the time of the spill, and the volume of the spill. Additional knowledge about the spill would take additional time to ascertain. Because response time decreases as discharge increases (fig. 11), the time available to ascertain information about the spill decreases as discharge increases. Therefore, methods for making decisions for mitigation should rely on minimal information about the spill. Also, available time needed for measuring exact peak concentration and for execution of computer models is unlikely.

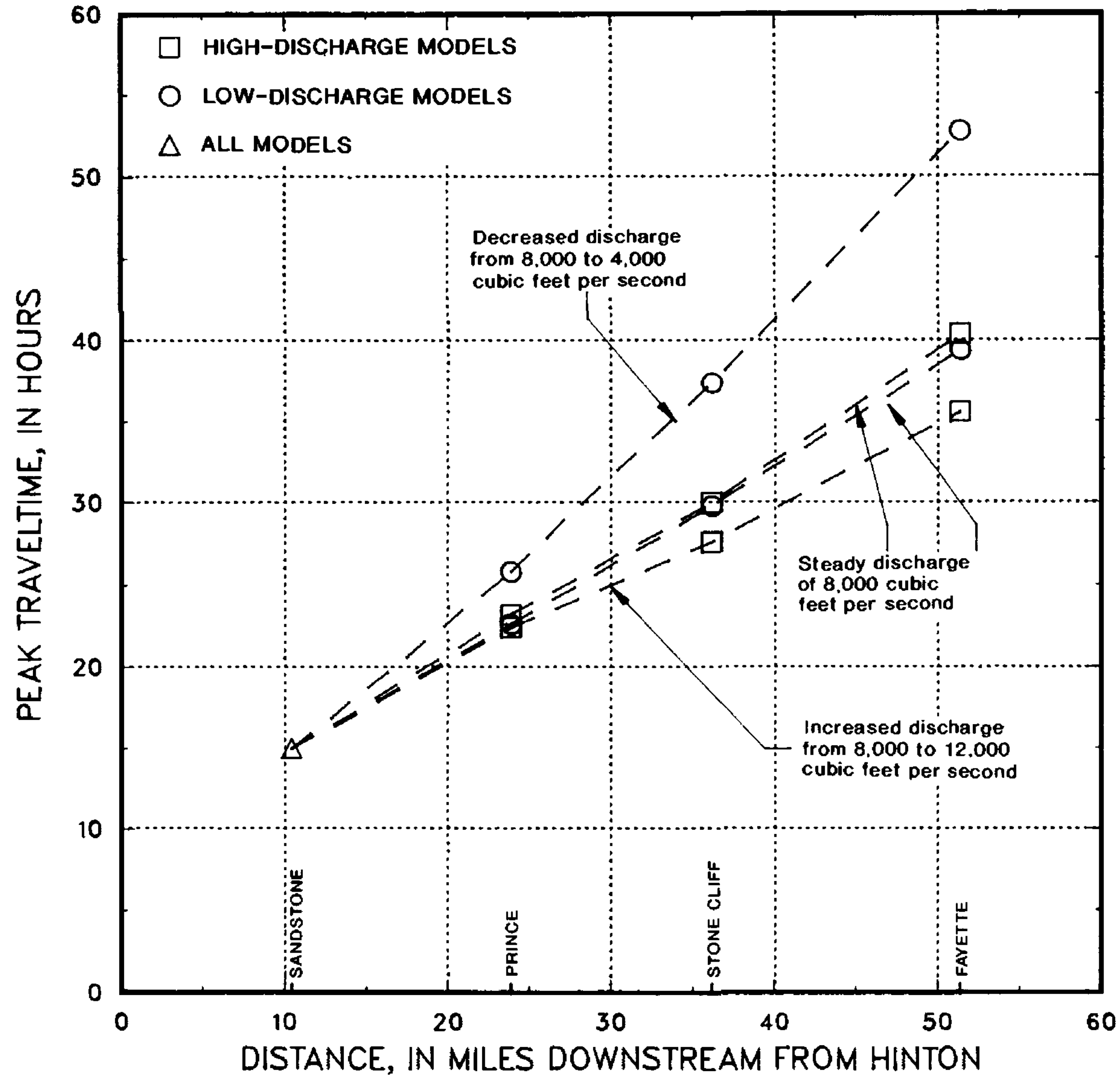

Figure 12.--Changes in traveltimes of peak concentrations downstream from Sandstone due to increased and decreased discharges. (Peak concentration and wave of increased or decreased discharge arrive at Sandstone simultaneously.

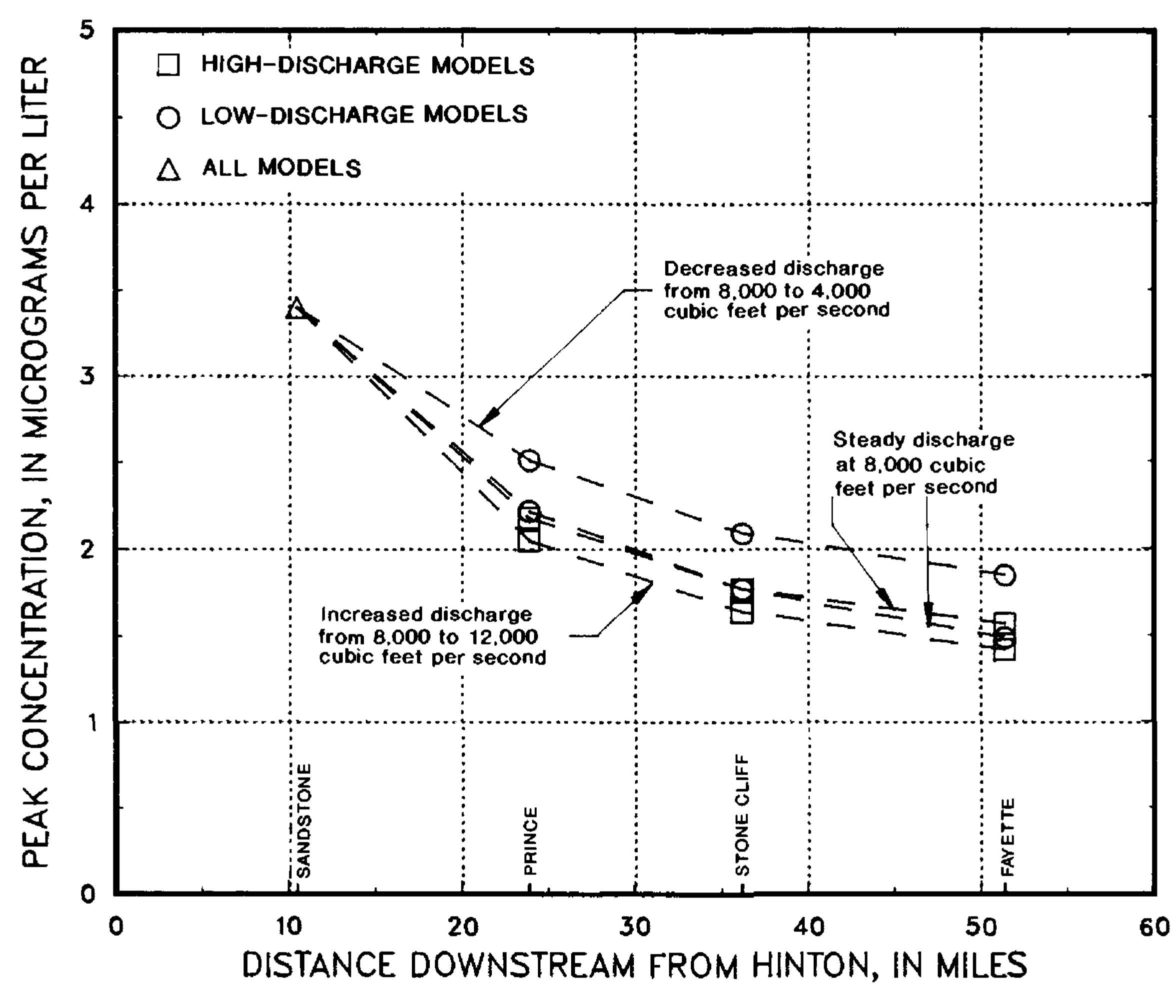

Figure 13.--Changes in peak concentration downstream from Sandstone due to increased and decreased discharges. (Peak concentration and wave of increased or decreased discharge arrive at Sandstone simultaneously.

Identification of the solute and its chemical characteristics is necessary to treat a contaminant spill quickly and successfully. Knowledge of what substances are commonly transported in the river area and how they are transported can be used to identify potential spill materials and to shorten the fact-gathering phase of a response. Certain questions about potential contaminants can be answered in advance. For example, if a particular solute will adversely affect the environment, at what concentration or length of exposure will the minimal effects be incurred? Is the solute more harmful to plants than to animals? Will the solute react with other substances in the water and produce byproducts that are harmful? Will the solute adhere to sediments?

The characteristics of a contaminant cloud can be considerably different depending on where the spill occurs and the rate at which it enters the stream. Examples of such location and rate factors include whether the spill occurred as a slug in the main channel of streamflow or only near one bank, or whether the spill was a constant inflow for a short period of time. Knowledge of where the spill occurred is essential if an estimate of the peak concentration needs to be made.

Mitigation may be accomplished by either increasing or decreasing discharge. Increased discharges can result in negative side effects. For example, if discharges are increased, sediments will be picked up by increasing velocities and sediments near the riverbanks may also be picked up because of increasing stages. In addition, plants living near the edge of the water that would not be exposed to a solute if discharge remained steady or decreased could be exposed if discharge is increased.

In consideration of the preceding discussion, a possible scenario follows:

> Assume that a spill occurred at Sandstone 6 hours ago. During the next hour, the discharge of the river is determined to be 8,000 ft^3/s. The contaminant is determined to be harmful to aquatic animals at a concentration of 1,000 µg/L after several days of exposure; however, the contaminant will damage plant life at concentrations lower than 1,000 µg/L after a shorter exposure time. If a spill occurred at Hinton, required response times would be 5 hours at Sandstone, 10 hours at Prince, and 15 hours at Stone Cliff according to figure 11. Because a total of 7 hours has passed since the spill occurred (6 hours since the spill and 1 hour of assessment), no change in discharge can be expected to reach the peak concentration at Prince (10 - 5 = 5 hours required response time). A change in discharge can reach the peak concentration at or before reaching Stone Cliff if it is done within the next 3 hours (15 - 5 = 10 hours required response time, and 10 - 7 = 3 hours). A decision to reduce discharge will increase the peak concentration and the traveltime of peak concentration but will expose fewer plants living on the banks to the contaminant. This decision may have to be made without knowledge of the volume of the spill, the peak concentration, or the possible extent of plant life on the riverbed or floating in the river that could be damaged by the increase in peak concentration and exposure time.

SUMMARY

Two U.S. Geological Survey computer models, an unsteady-flow model and a solute-transport model, were applied in the New River Gorge National River, West Virginia, to determine factors involved in mitigating a hypothetical spill of a soluble contaminant.

The study reach is 53 mi of the lower New River between Hinton and Fayette. The study becomes narrower, steeper, and deeper in the downstream direction. Three subreaches--Hinton to Meadow Creek, Meadow Creek to Sewell, and Sewell to Fayette--can represent similar slopes and geometries of the study reach.

The unsteady-flow models, DAFLOW (Diffusion Analogy FLOW), were calibrated by use of relations developed from measurements between the traveltime of waves and discharge. Difficulty in calibration required development of separate models for discharges greater than or equal to 8,000 ft^3/s (high-discharge model) and less than or equal to 8,000 ft^3/s (low-discharge model). The models were verified by predicting discharges at the Thurmond streamflow-gaging station by means of inputing discharges from the Hinton station. The models were most sensitive to adjustments of the parameter A1 (hydraulic geometry coefficient for area).

The solute-transport models, BLTM (Branch Lagrangian Transport Model), were calibrated by use of the relations between the traveltime of peak concentration and discharge, and peak concentration and the traveltime of peak concentration. The models were verified by predicting peak concentrations and the traveltimes of peak concentrations for two unsteady-flow and one steady-flow dye measurements. The models were most sensitive to adjustments of A0 (average cross-sectional area at zero discharge) when predicting the traveltime of the peak concentration and were about as equally sensitive to adjustments of A0 and DQQ (dispersion factor) when predicting peak concentrations.

Increases in discharge decreased the peak concentration and the traveltime of peak concentration. Decreases in discharge increased the peak concentration and the traveltime of peak concentration.

An accidental spill of a soluble contaminant could be mitigated by regulating discharge from Bluestone Dam. Knowledge of the chemical characteristics of the spill, location and time of the spill, and the discharge of the river could assist river managers in determining whether an increase or a decrease in discharge would promote a mitigation effect. Changes in river velocities and stages resulting from changes in the discharge could expose animals, plants, and sediments to the contaminant. Factors affecting a solute cloud (relation between traveltime of waves and traveltimes of peak concentrations, and effects of changes in discharge on the peak concentration and traveltime of peak concentration) were used to determine a mitigation response to a hypothetical spill.

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APPENDIXES

APPENDIX A .--*Example of the input file containing flow parameters for the low-discharge unsteady-flow model*

```
New River / low-flow DAFLOW FLOW.IN
No. of Branches              1 *
Internal Junctions           0 *
Time Steps Modeled         180 *
Model Starts                 0 time steps after midnight.
Output Given Every           1 Time Steps in FLOW.OUT.
0=Metric,1=English           1 *
Time Step Size           0.100 Hours.
Peak Discharge          90000. *
Branch  1 has 11 xsects & routes 1.00 of flow at JNCT  1 To JNCT  2
Grd R Mile  IOUT  Disch        A1        A2        AO        DF          W1    W2
  1 0.0000   1    2200.      2.44     0.760      440.     1568.       118.0 0.260
  2  9.470   1    2200.      1.08     0.810      440.     1568.       118.0 0.260
  3  10.43   0    2200.      1.08     0.810      440.     1568.       118.0 0.260
  4  13.07   1    2200.     6.431     0.630      440.     2423.        76.2 0.260
  5  23.86   1    2200.     3.448     0.690      440.     2423.        76.2 0.260
  6  36.14   0    2200.     3.448     0.690      440.     2423.        76.2 0.260
  7  37.58   1    2200.     3.448     0.690      440.     2423.        76.2 0.260
  8  44.87   0    2200.     2.010     0.730     2150.     1428.        48.5 0.260
  9  46.44   0    2200.     2.010     0.730     2150.     1428.        48.5 0.260
 10  51.36   1    2200.     2.010     0.730     2150.     1428.        48.5 0.260
 11  52.50   0
for Time     1 NBC=  1 *
 Branch      1 Grid  1 Q=     2400.0    *
for Time     2 NBC=  0 *
for Time     3 NBC=  0 *
for Time     4 NBC=  0 *
for Time     5 NBC=  0 *
.
.
.
.
.
.
for Time   175 NBC=  0 *
for Time   176 NBC=  0 *
for Time   177 NBC=  0 *
for Time   178 NBC=  0 *
for Time   179 NBC=  0 *
for Time   180 NBC=  0 *
```

APPENDIX B.--*Example of the input file containing flow parameters for the high-discharge unsteady-flow model*

```
New River / high-flow DAFLOW FLOW.IN
No. of Branches               1 *
Internal Junctions            0 *
Time Steps Modeled          180 *
Model Starts                  0 time steps after midnight.
Output Given Every            1 Time Steps in FLOW.OUT.
0=Metric,1=English            1 *
Time Step Size            0.100 Hours.
Peak Discharge           90000. *
Branch  1 has 11 xsects & routes 1.00 of flow at JNCT  1 To JNCT  2
Grd R Mile  IOUT  Disch         A1        A2         AO        DF          W1    W2
  1 0.0000    1  22800.    35.74     0.530       440.      3552.       118.0 0.260
  2  9.470    1  22800.    134.2     0.370       440.      3552.       118.0 0.260
  3  10.43    0  22800.    134.2     0.370       440.      3552.       118.0 0.260
  4  13.07    1  22800.    22.00     0.514       440.      5490.        76.2 0.260
  5  23.86    1  22800.    26.63     0.500       440.      5490.        76.2 0.260
  6  36.14    0  22800.    26.63     0.500       440.      5490.        76.2 0.260
  7  37.58    1  22800.    26.63     0.500       440.      5490.        76.2 0.260
  8  44.87    0  22800.    22.00     0.497      2150.      3235.        48.5 0.260
  9  46.44    0  22800.    22.00     0.497      2150.      3235.        48.5 0.260
 10  51.36    1  22800.    22.00     0.497      2150.      3235.        48.5 0.260
 11  52.50    0
for Time    1 NBC=  1 *
 Branch     1 Grid  1 Q=    25000.0    *
for Time    2 NBC=  0 *
for Time    3 NBC=  0 *
for Time    4 NBC=  0 *
for Time    5 NBC=  0 *
.
.
.
.
.
for Time  175 NBC=  0 *
for Time  176 NBC=  0 *
for Time  177 NBC=  0 *
for Time  178 NBC=  0 *
for Time  179 NBC=  0 *
for Time  180 NBC=  0 *
```

APPENDIX C.--*Example of the input file containing transport parameters for the high discharge solute-transport model*

```
New River / high-flow BLTM.IN
HEADER 1        3      2    350       1       0       1       1       0       1
HEADER 2     0.20   0.00
LABEL           1   DYE       1
BRANCH   1      4   0.75      3       1      50
 GRID    1  0.000      0   0.00
 GRID    2  9.470      0   0.00
 GRID    3 10.430      1   0.00
 GRID    4 13.070      0
BRANCH   2      5   1.30      1       2      40
 GRID    1 13.070      0   0.00
 GRID    2 23.860      1   0.00
 GRID    3 36.140      1   0.00
 GRID    4 37.580      0   0.00
 GRID    5 44.870      0
BRANCH   3      4   1.50      2       4      40
 GRID    1 44.870      0   0.00
 GRID    2 46.440      0   0.00
 GRID    3 51.360      1   0.00
 GRID    4 52.500      1
TIME     1      1
 B  1 G  1   0.00
.
.
.
TIME      29      1
 B  1 G  1   0.00
TIME      30      1
 B  1 G  1   6.20
TIME      31      1
 B  1 G  1   9.40
TIME      32      1
 B  1 G  1   8.33
TIME      33      1
 B  1 G  1   7.27
.
.
.
TIME      43      1
 B  1 G  1   0.34
TIME      44      1
 B  1 G  1   0.00
.
.
.
TIME     350      1
 B  1 G  1   0.00
```

APPENDIX D.--*Example of the input file containing flow parameters for the high-discharge solute-transport model*

```
New River / high-flow BLTM FLOW.IN
No. of Branches               1 *
Internal Junctions            0 *
Time Steps Modeled          350 *
Model Starts                  0 time steps after midnight.
Output Given Every            1 Time Steps in FLOW.OUT.
0=Metric,1=English            1 *
Time Step Size            0.200 Hours.
Peak Discharge           90000. *
Branch  1 has 11 xsects & routes 1.00 of flow at JNCT  1 To JNCT  2
Grd R Mile   IOUT  Disch        A1        A2        AO        DF          W1    W2
  1 0.0000     1  22800.    35.74     0.530      440.     3552.       118.0 0.260
  2  9.470     1  22800.    134.2     0.370      440.     3552.       118.0 0.260
  3  10.43     0  22800.    134.2     0.370      440.     3552.       118.0 0.260
  4  13.07     1  22800.    22.00     0.514      800.     5490.        76.2 0.260
  5  23.86     1  22800.    26.63     0.500      800.     5490.        76.2 0.260
  6  36.14     0  22800.    26.63     0.500      800.     5490.        76.2 0.260
  7  37.58     1  22800.    26.63     0.500      800.     5490.        76.2 0.260
  8  44.87     0  22800.    22.00     0.497     2750.     3235.        48.5 0.260
  9  46.44     0  22800.    22.00     0.497     2750.     3235.        48.5 0.260
 10  51.36     1  22800.    22.00     0.497     2750.     3235.        48.5 0.260
 11  52.50     0
for Time     1 NBC=  1 *
 Branch      1 Grid  1 Q=    22800.0     *
for Time     2 NBC=  0 *
for Time     3 NBC=  0 *
for Time     4 NBC=  0 *
for Time     5 NBC=  0 *
.
.
.
.
.
for Time   345 NBC=  0 *
for Time   346 NBC=  0 *
for Time   347 NBC=  0 *
for Time   348 NBC=  0 *
for Time   349 NBC=  0 *
for Time   350 NBC=  0 *
```

APPENDIX E.--*Example of the input file containing transport parameters for the low-discharge solute-transport model*

```
New River / low-flow BLTM BLTM.IN
HEADER 1          3      2    350       1       0       1       1       0       1
HEADER 2       0.20   0.00
LABEL             1   DYE       1
BRANCH    1       4   1.30      3       1      50
 GRID     1   0.000      0   0.00
 GRID     2   9.470      0   0.00
 GRID     3  10.430      1   0.00
 GRID     4  13.070      0
BRANCH    2       5   0.55      1       2      40
 GRID     1  13.070      0   0.00
 GRID     2  23.860      1   0.00
 GRID     3  36.140      1   0.00
 GRID     4  37.580      0   0.00
 GRID     5  44.870      0
BRANCH    3       4   1.50      2       4      40
 GRID     1  44.870      0   0.00
 GRID     2  46.440      0   0.00
 GRID     3  51.360      1   0.00
 GRID     4  52.500      1
TIME      1       1
 B   1 G  1    0.00
 .
 .
 .
TIME     27       1
 B   1 G  1    0.00
TIME     28       1
 B   1 G  1    0.60
TIME     29       1
 B   1 G  1    1.30
TIME     30       1
 B   1 G  1    5.20
TIME     31       1
 B   1 G  1    7.80
TIME     32       1
 B   1 G  1    7.51
 .
 .
 .
TIME     70       1
 B   1 G  1    0.00
 .
 .
 .
TIME    350       1
 B   1 G  1    0.00
```

APPENDIX F.-- *Example of the input file containing flow parameters for the low-discharge solute-transport model*

```
New River / low-flow BLTM FLOW.IN
No. of Branches                1 *
Internal Junctions             0 *
Time Steps Modeled           350 *
Model Starts                   0 time steps after midnight.
Output Given Every             1 Time Steps in FLOW.OUT.
0=Metric,1=English             1 *
Time Step Size             0.200 Hours.
Peak Discharge            90000. *
Branch  1 has 11 xsects & routes 1.00 of flow at JNCT  1 To JNCT  2
Grd R Mile  IOUT  Disch        A1        A2        AO        DF          W1    W2
  1 0.0000     1   5000.     2.44     0.760      440.     1568.       118.0 0.260
  2  9.470     1   5000.     1.08     0.810      440.     1568.       118.0 0.260
  3  10.43     0   5000.     1.08     0.810      440.     1568.       118.0 0.260
  4  13.07     1   5000.    6.431     0.630     1500.     2423.        76.2 0.260
  5  23.86     1   5000.    3.448     0.690     1500.     2423.        76.2 0.260
  6  36.14     0   5000.    3.448     0.690     1500.     2423.        76.2 0.260
  7  37.58     1   5000.    3.448     0.690     1500.     2423.        76.2 0.260
  8  44.87     0   5000.    2.010     0.730     2200.     1428.        48.5 0.260
  9  46.44     0   5000.    2.010     0.730     2200.     1428.        48.5 0.260
 10  51.36     1   5000.    2.010     0.730     2200.     1428.        48.5 0.260
 11  52.50     0
for Time    1 NBC=  1 *
 Branch     1 Grid  1 Q=      5000.0     *
for Time    2 NBC=  0 *
for Time    3 NBC=  0 *
for Time    4 NBC=  0 *
for Time    5 NBC=  0 *
.
.
.
.
.
for Time  345 NBC=  0 *
for Time  346 NBC=  0 *
for Time  347 NBC=  0 *
for Time  348 NBC=  0 *
for Time  349 NBC=  0 *
for Time  350 NBC=  0 *
```