USERS MANUAL FOR AN OPEN-CHANNEL STREAMFLOW MODEL BASED ON THE DIFFUSION ANALOGY

By Harvey E. Jobson

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LIST OF SYMBOLS

A	area of flow
AO	average cross-sectional area at zero flow
AQ	average discharge at a grid point
A1	hydraulic geometry coefficient for area
A2	hydraulic geometry exponent for area
BLTM	Branched Lagrangian Transport Model
C	wave speed
DF	wave dispersion coefficient
DAFLOW	Diffusion Analogy Flow Model
DL	diffusive length scale
DQQ	dispersion factor
DT	time-step size
D_x	longitudinal diffusion coefficient for mass
g	acceleration of gravity
i	grid number
j	time-step number
K	wave number
L	reach length
n	Manning's resistance coefficient
NOBR	maximum number of branches allowed in dimension statement
NOCO	maximum number of constituents allowed in dimension statement
NOIJ	maximum number of junctions allowed in dimension statement
NOPR	maximum number of parcels per branch allowed in dimension statement
NOSC	maximum number of grids per branch allowed in dimension statement
NOSH	maximum number of shocks per branch allowed in dimension statement
Q	volumetric rate of flow
QS	normal discharge defined as the steady-state discharge that corresponds to a cross-sectional area of A
S_f	friction slope
S_o	bed slope
Shock	a step change in discharge
t	time
U	average cross-sectional velocity
V	volume of water in a subreach
W	channel width
Wave	a length of steady flow bounded by shocks
W1	hydraulic geometry coefficient for width
W2	hydraulic geometry exponent for width
X	longitudinal distance along the channel
Y	depth of flow

CONVERSION FACTORS

The Diffusion Analogy Flow Model is capable of receiving input in either inch-pound or metric units, therefore both unit systems are used in this report. The following conversion factors may be used to convert the units of measurement of this report.

Multiply inch-pound unit	by	To obtain metric unit
inch (in.)	0.02540	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.0929	square meter (m^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature conversion: °F = 1.8°C + 32
°C = (°F - 32)/1.8

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ABSTRACT

A digital model for routing streamflow using the diffusion analogy in conjunction with a Lagrangian solution scheme is documented. The model is designed to provide predictions of discharge and flow velocity using a minimum of field data and calibration. One-dimensional flow theory, algorithms used in the model, and two example applications of the model are presented. The model can be used for routine flow routing, but it also produces an output file that can be used as input to a transport model for a system of one-dimensional upland channels. Appendixes discuss interactive programs for constructing input files, determining input coefficients, plotting results, and interfacing of the model with a Branched Lagrangian Transport model.

INTRODUCTION

Predictions of the fate and movement of dissolved constituents in rivers are needed in order to understand the nature and scope of many water-quality problems. The ability to make such predictions depends on the ability to predict the time-dependent rate of flow in the river system. The model documented herein has been designed to simulate flow in upland stream systems where flow reversals do not occur and backwater conditions are not severe. If these two conditions are satisfied, the diffusion analogy form of the flow equations can be applied with acceptable accuracy even with minimal field data. The diffusion analogy forms the basis of the very successful flow model called CONROUT (Doyle and others, 1983). The model described here provides the hydraulic information necessary to drive transport models.

One-dimensional transport models based on the Lagrangian reference frame have been found to be very accurate and stable (McBride and Rutherford, 1984; Thomson and others, 1984; O'Neill, 1981; Jobson, 1980, 1987). Because of the accuracy, stability, and simplicity of using the Lagrangian reference frame in solving the diffusion equation, it is used to solve the diffusive form of the flow equations. The model is called the diffusion analogy flow model (DAFLOW) and should be useful in providing a simple model simulation for any situation where the diffusion analogy form of the flow equations is acceptable. The purpose of this report is to provide the DAFLOW user the information needed to correctly apply the model.

The flow model documented here is designed to be used in conjunction with a transport model to form a transport modeling system as shown schematically on figure 1. The top part of the figure represents the flow model (DAFLOW) and the bottom part of the figure represents the transport model (Branched Lagrangian Transport Model [BLTM]) documented by Jobson and Schoellhamer (1987). Of course, the flow model can be used alone for flood routing applications.

This users manual briefly describes the diffusion analogy method, its limitations, the model solution procedure, and the input/output requirements. Application of the model is then illustrated by use of two simple examples.

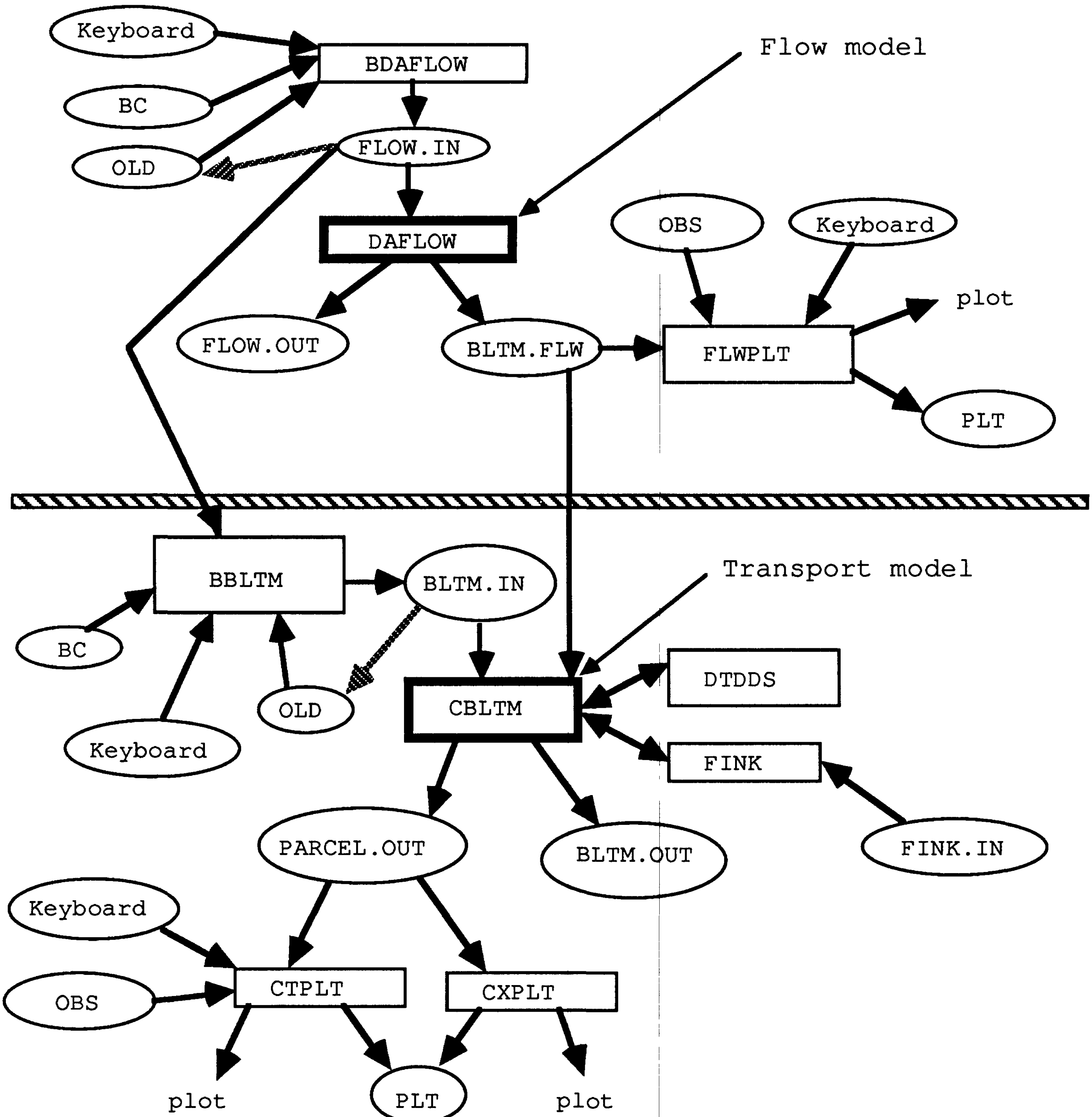

Figure 1.--Organization of flow and transport modeling system. Boxes represent programs, ovals represent files, and heavy arrows indicate the direction of information flow.

THE DIFFUSION ANALOGY

The differential equations derived by Saint-Venant (1871) for one-dimensional, unsteady flow are the theoretical basis for the diffusion analogy method. Assuming no lateral inflow, the Saint-Venant equations for channel flow are a continuity equation:

$$\frac{\partial Q}{\partial X} + \frac{\partial A}{\partial t} = 0, \tag{1}$$

and a momentum equation:

$$\frac{1}{g}\frac{\partial U}{\partial t} + \frac{U\partial U}{g\partial X} + \frac{\partial Y}{\partial X} + S_f - S_o = 0, \tag{2}$$

in which Q = volumetric rate of flow, A = area of flow, X = longitudinal distance along the channel, t = time, Y = depth of flow, U = average cross-sectional velocity, g = acceleration of gravity, S_f = friction slope, and S_o = bed slope.

These complex equations have no analytical solutions, except for cases where the channel geometry is uniform and the nonlinear properties of the equations are neglected or linearized. Numerical solution techniques are available but tend to be very complex and unstable.

While all flow routing models use the continuity equation as shown in equation 1, the momentum equation may be used in the form of equation 2 or in an abbreviated form depending on which terms are retained. The individual terms in the momentum equation from left to right are, dimensionless measures of , respectively, the local and convective acceleration $\frac{1}{g}\frac{\partial U}{\partial t} + \frac{U\partial U}{g\partial X}$, the pressure $\frac{\partial Y}{\partial X}$, friction ($S_f$), and gravity ($S_o$) forces. Models that retain all five terms are called complete dynamic models. If the acceleration terms are neglected, the resulting equation is referred to as the diffusion wave equation; and if additionally the pressure term is dropped, it is referred to as the kinematic wave equation. The diffusion analogy method used here solves the diffusion wave form of the equations with some additional simplifying assumptions.

Much geomorphic information suggests that, in an average sense, the cross-sectional area (A) of natural channels can be approximated by an equation of the form

$$A = A1QS^{A2} + A0, \tag{3}$$

in which A1 and A2 are constants called the hydraulic geometry coefficient and hydraulic geometry exponent, respectively, for area, QS equals the normal discharge, and A0 is the average cross-sectional area at zero flow. The normal discharge is defined as the steady-state discharge that corresponds to a cross-sectional area of A. Equation 3 is the equivalent of an area-discharge rating curve. The value of A0 accounts for water stored in the pools of a channel reach that would not completely drain if the inflow were stopped. The value of A2 theoretically can range from 0 to 1 but its value is usually found to be about 0.66 ± 0.1 (Leopold and Maddock, 1953; Leopold and Miller, 1956; Boning, 1974; Boyle and Spar, 1985; and Graf, 1986). Likewise, the width, W, can be approximated by an equation of the form

$$W = W1\ QS^{W2}, \tag{4}$$

in which W1 and W2 are the hydraulic geometry coefficient and exponent, respectively, for width. Table 1 contains a summary of some observed hydraulic geometry exponents.

For unsteady conditions the DAFLOW model assumes that discharge (Q) can be approximated by

$$Q = QS - DF\ \frac{\partial A}{\partial X}, \tag{5}$$

in which DF is the change in discharge caused by a unit change in the area gradient called a wave dispersion coefficient. Equation 5 is an approximate form of the momentum equation in which QS is the flow that would occur for steady-state conditions and the second term accounts for the pressure term that results from unsteady conditions. For a channel of constant width $\frac{\partial A}{\partial X} = W\ \frac{\partial Y}{\partial X}$, so it is seen that the second term of equation 5 is closely related to the pressure term in equation 2.

Consider the monoclinal rising wave illustrated in figure 2 moving down a rectangular channel of width W at a constant wave speed C. For a wave traveling downstream without changing shape, it is easily seen that

$$C(A_2 - A_1)DT = (QS_2 - QS_1)DT$$

or that

$$C = \frac{QS_2 - QS_1}{A_2 - A_1} \approx \frac{\partial QS}{\partial A}. \tag{6}$$

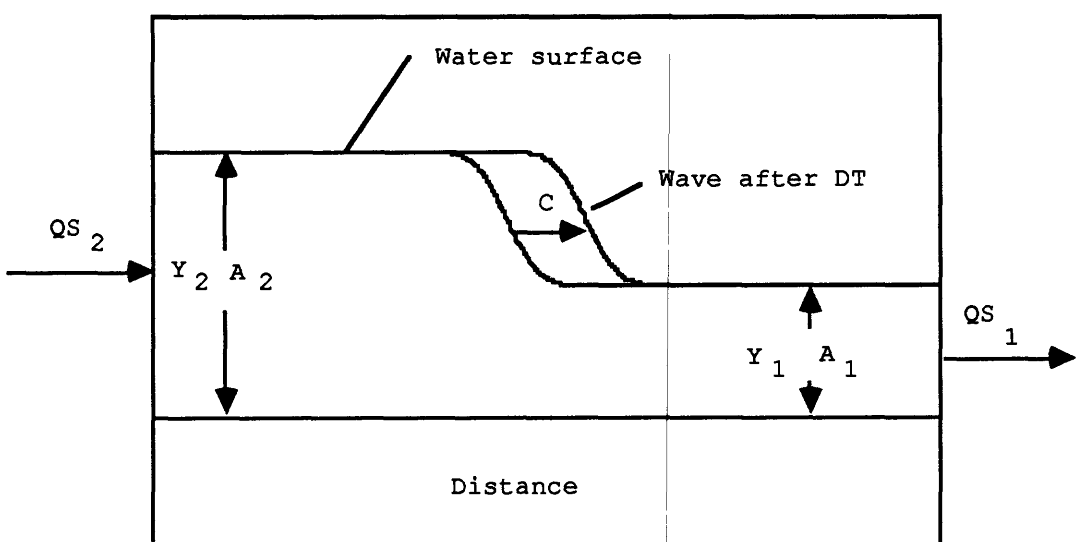

Figure 2.--Monoclinal rising wave moving down a rectangular channel.

Table 1.--Hydraulic geometry exponents as compiled from the indicated locations

Location	Reference	Conditions	A2 Minimum	A2 Mean	A2 Maximum	W2 Minimum	W2 Mean	W2 Maximum
Midwest rivers	Leopold and Maddock, 1953	All		0.66			0.26	
Ten streams in Illinois	Graf, 1986	All		0.65				
New Mexico	Leopold and Miller, 1956	All		0.66				
New Mexico	Leopold and Miller, 1956	Ephemeral		0.68		0.08	0.26	0.44
Theoretical	Daugherty and Ingersoll, 1954	Wide		0.60				
Throughout United States	Boning, 1974	Pool and riffle reaches		0.60				
Throughout United States	Boning, 1974	Channel controlled reaches		0.74				
Throughout United States	Boning, 1974	Lock and dam reaches		0.50				
Colorado-Utah	Boyle and Spahs, 1985	$281<Q<1841$	0.24	0.66	0.70			
United States	Stall and Yang, 1970	Humid regions	0.47	0.61	0.82	0.11	0.21	0.35
United States	Leopold and others, 1954	Semiarid		0.65			0.29	
United States	Judd and Peterson, 1969	Mountain streams		0.59			0.11	

Substituting equation 5 into equation 1 yields

$$\frac{\partial A}{\partial t} + \frac{\partial QS}{\partial A}\frac{\partial A}{\partial x} - DF\frac{\partial^2 A}{\partial x^2} = 0,$$

which by use of equation 6 reduces to the diffusion form of the flow equation

$$\frac{\partial A}{\partial t} + C\frac{\partial A}{\partial x} - DF\frac{\partial^2 A}{\partial x^2} = 0. \qquad (7)$$

Equation 7 indicates that the mass of water per unit length of channel obeys the one-dimensional, convective-diffusion equation. This equation is much easier to solve numerically than the full, dynamic-wave equations and, as will be shown, the assumptions embedded in its derivation (equation 5) often cause little sacrifice in accuracy.

Because the flow hydrograph is approximated by a series of steady-state discharges (QS) called waves, it is convenient to transform equation 7 into an expression for normal discharge by use of equation 3 yielding

$$A1A2QS^{(A2-1)}\left(\frac{\partial QS}{\partial t} + C\frac{\partial QS}{\partial x}\right) - A1A2DF\left\{(A2-1)QS^{(A2-2)}\left(\frac{\partial QS}{\partial x}\right)^2 + QS^{(A2-1)}\frac{\partial^2 QS}{\partial x^2}\right\} = 0,$$

which reduces to

$$\frac{\partial QS}{\partial t} + C\frac{\partial QS}{\partial x} - DF\frac{\partial^2 QS}{\partial x^2} = 0, \qquad (8)$$

by eliminating the first term inside the braces as it is the square of a differential term that will be much smaller than the other terms.

THE SOLUTION PROCEDURE

The space-time variation in discharge is solved by use of equation 8 using a three-step, finite-difference approach for each time interval, DT: (1) equation 8 is first solved to determine the distribution of QS (Area) along the channel at the end of the time interval; (2) the volume of water stored in each subreach of the river is determined using equation 3 and the distribution of QS from step 1; and (3) the discharge out of each subreach is computed using the continuity equation

$$AQ_{i+1} = AQ_i + \frac{V_{j-1} - V_j}{DT}, \qquad (9)$$

in which AQ_i is the average discharge at grid i during the time interval j, of length DT and V_j is the volume of water in the subreach between grid i and i+1 at the end of time interval j. Equation 9 is solved for each subreach sequentially starting at the upstream end where the inflow AQ_1 is known from the boundary conditions. These last two steps are straightforward and will not be explained further. However, the solution of equation 8 in step 1 will be described in some detail below.

Equation 8 is solved using a mode splitting technique, where the dispersion process is simulated first and then the dispersed waves are convected using a Lagrangian reference frame. Furthermore, the flow distribution along the channel is represented by a series of steady discharges (waves) separated by step changes in discharge (shocks).

Figure 3a illustrates the definition of waves and shocks. In this simple example a single shock is assumed to occur at the middle of the reach. The system contains two waves. If a true shock existed as illustrated in figure 3a, it would disperse during a time of DT so that it would appear as shown by the smooth curve in figure 3b. It is assumed for purposes of illustration that the wave speed is zero or that the coordinate system is moving with the wave so that translation does not occur. Notice, the X coordinate is scaled by the diffusive length scale,

$$DL = \sqrt{2(DF)DT}, \tag{10}$$

in which DL is a measure of the distance a diffusion wave will advance in time DT with a diffusion coefficient of DF (Carslaw and Jaeger, 1959). The model approximates the exact dispersion process by replacing the single shock with two shocks placed a dispersive distance, DL, on either side of the original shock. The model selects the value of QS for the new wave such that the volume of water contained in this wave is the same as existed in this space before the mass was redistributed. It can be easily shown that the first and second moments of the exact and approximate curves on figure 3 are identical.

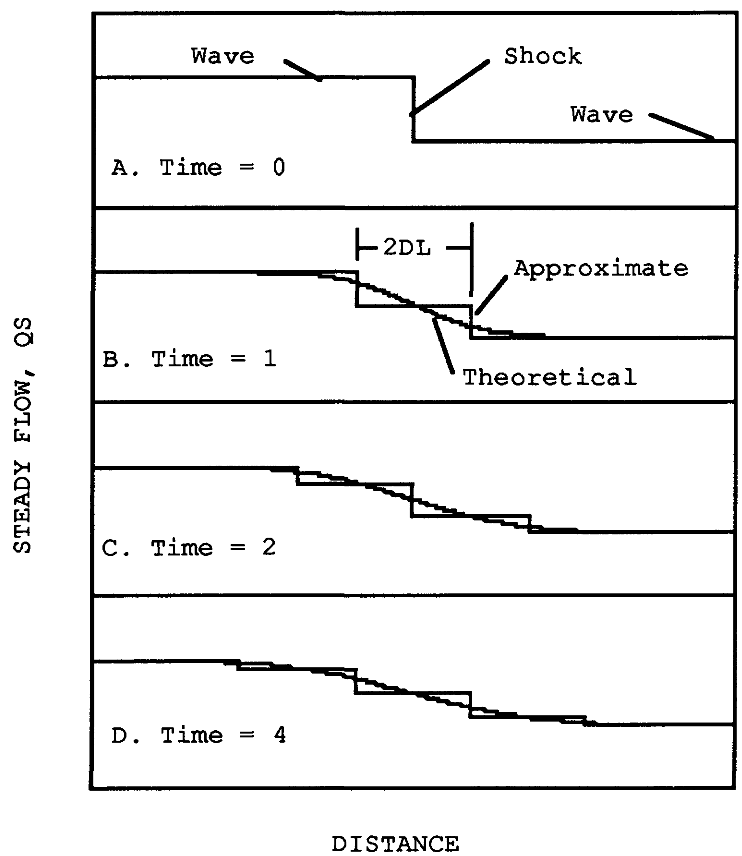

Figure 3.--Procedure for solving the dispersion step with a single shock.

The process of replacing each shock by two shocks of smaller magnitude is simply repeated for each time step. Figures 3c and 3d show the exact and approximate solutions after two and three time steps, respectively. It is clear that the numerical approximation closely follows the true curve after a very few time steps. A river reach can potentially contain as many as L/2DL shocks, in which L is the reach length.

Once the dispersion step is completed, the speed of each shock in the system is computed from equation 6 and they are moved to their new location at the end of the time step. Care is taken to adjust the speed of the shock if it overtakes a slower moving shock. Figure 4 illustrates the computational procedure. Figure 4a shows a typical longitudinal distribution of QS at the beginning of a time step. Note that the flood wave is symmetric. Figure 4b shows the flow distribution as modified by the dispersion step and the arrows indicate the displacement each shock will receive during the time step.

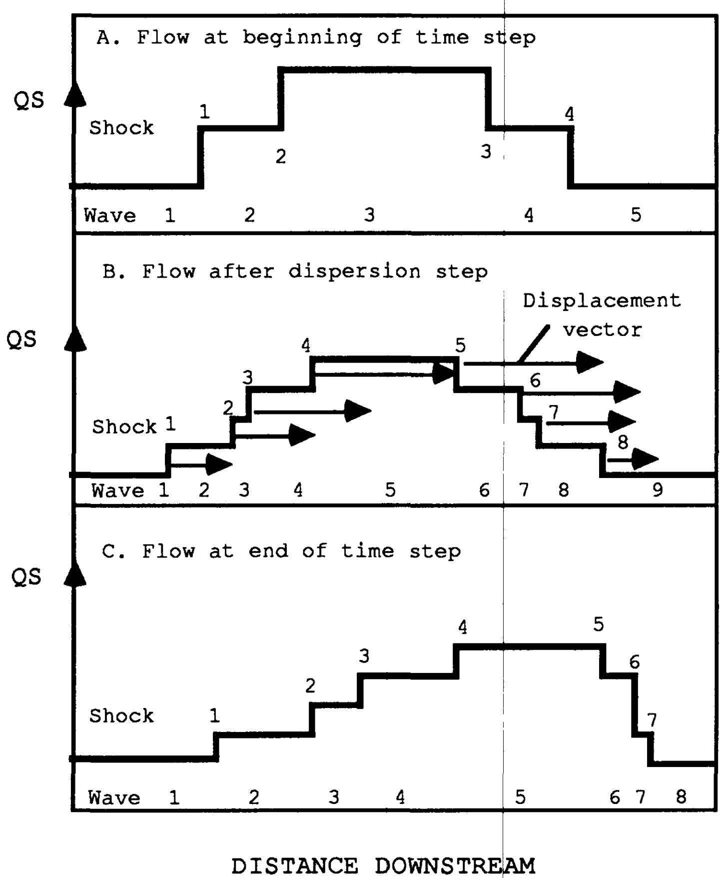

Figure 4.--Movement of shocks during one time step.

Notice that the wave speed has been assumed to increase with QS for this example and that the distribution of QS is still symmetric after the dispersion step.

Figure 4c shows the distribution in QS after the advection step, at the end of the time step. The distribution is no longer symmetric. The rising stage has become steeper and the falling stage has become flatter. In fact, the old shock 7 has been overrun and disappeared. The following is the procedure used by the model to eliminate shocks when they have been overrun. At the instant shock 6 passed shock 7, the program increased the size of shock 6 to the combined value of 6 and 7, eliminated shock 7, and recomputed the wave speed of shock 6 based on its new size, before completing the move.

The model adds a shock at the upstream boundary each time the inflow discharge changes (only between time steps). Tributaries are assumed to enter at each internal grid point and create a shock equal to their discharge at the grid point. If the tributary flow is constant in time, the shock at the tributary is stationary. If the tributary inflow changes between time steps, a moving shock equal to the change in tributary flow is produced.

The upstream boundary condition is the flow rate into the channel. A uniform channel of infinite length and characteristics equal to those in the most downstream subreach is assumed to exist below the downstream end of each branch so a downstream boundary condition is not required.

THE DIFFUSION ANALOGY FLOW MODEL

Figure 5 illustrates the example network used for the first example in this report. Here it will be used to demonstrate how to schematize a river system for DAFLOW and BLTM. The system contains six branches connected by two interior junctions and four exterior junctions.

A branch is considered to be a one-dimensional river segment. Each branch must start and end at a junction; however, any number of branches may begin or end at a junction. Branches can be numbered in any order as long as the numbering system starts with 1 and no numbers are skipped. On figure 5 the system contains six branches. Branches 1, 2, 3, and 4 join at interior junction 1 with branches 1 and 2 delivering flow to the junction and branches 3 and 4 receiving flow from the junction. Branches 3 and 4 in turn deliver flow to interior junction 2 and branches 5 and 6 receive flow from junction 2. Tributaries can enter the system at any interior grid point.

The junctions must be numbered sequentially without skipping or repeating numbers. Interior junctions must be numbered first followed by exterior junctions. The same numbering system can be used for both hydraulic and subsequent transport modeling.

For the first time step, DAFLOW requires as input the flow at all upstream boundaries and tributaries unless they are zero. A tributary is assumed to add or remove flow to the river just upstream of a grid point. Tributaries are not allowed at either the first or last grid point of a branch. After the first time step, values of inflow only need to be provided if they change.

Each branch must contain a grid point at each end of the branch and can contain additional grid points. The grid points for each branch must be numbered sequentially starting at 1 and the numbering must start at the upstream end of the branch. The grid points do not have to be equally spaced and there is no restriction on the distance between grid points. The hydraulic geometry values and the wave dispersion coefficient apply to a subreach between two adjacent grid points and the index number is equal to the upstream grid point number. For example, the coefficient $A1_{(3)}$ is the hydraulic geometry coefficient that applies to the subreach between grids 3 and 4.

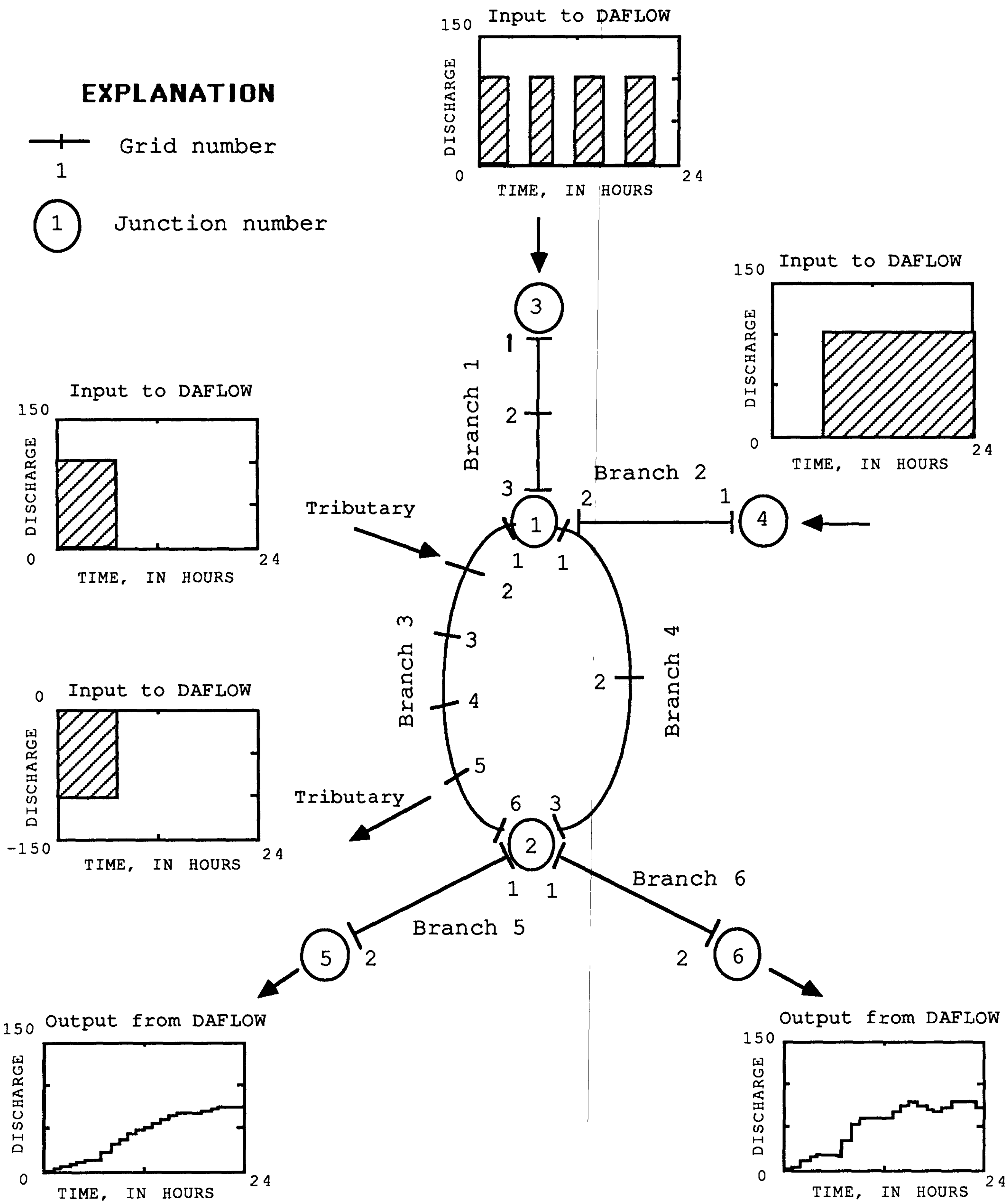

Figure 5.--Network for the first example application of the DAFLOW model.

The maximum allowable number of branches, junctions, grids per branch, and shocks per branch are controlled only by dimension statements, the size of the machine, and considerations of time involved in the computations. The dimension statements should not specify arrays that are much larger than the problem requires in order to conserve storage space and time. The dimensions of the arrays are determined by a PARAMETER statement that occurs in each subroutine. The variables NOBR, NOIJ, NOSC, and NOSH determine the array sizes for the number of branches, junctions, grids per branch, and shocks per branch, respectively. These PARAMETER statements should be modified to fit the problem to be solved because the code contains many arrays with the multiple dimensions based on these numbers.

CAPABILITIES, RESTRICTIONS, AND IMPLEMENTATION

The DAFLOW model can simulate the flow in a network of interconnected one-dimensional channels with unsteady, unidirectional flow. The restrictions of the model include channels characterized by one-dimensional, unstratified flow, fixed-channel geometry, and no backwater. The discharge at all upstream boundary points (upstream ends of external branches and tributary inflows) must be specified as a function of time. When more than one branch originates at a junction, the percentage of flow to enter each branch also must be specified.

The DAFLOW model uses a simplification of the dynamic wave equations and therefore it should be used with caution. The model is most accurate in steep channels where there is a unique relation between stage and discharge, that is where the frictional resistance term in the momentum equation is large. These are the conditions for which numerical solutions to the full dynamic wave equations tend to be most nonlinear and unstable.

The following is a discussion of factors that should be considered in setting up a problem for DAFLOW and BLTM.

The first step is to draw a schematic of the system on a piece of paper somewhat like figure 5. In general, the number of branches is fairly well established by the geometry of the system. On the other hand there is a certain amount of room for judgment. The user must always balance the need for greater detail with the need to keep the problem as simple as possible. For each added branch, the size of the problem is increased significantly. The addition of one branch to the system requires an increase in storage capacity equal to 12*NOSC + 2*NOSH + 6, in which NOSC and NOSH are the maximum number of sections and shocks per branch respectively allowed in the dimension statement. Although this number is not severe, the addition in storage capacity for the transport model may be much larger. For example, the increase in BLTM is about 10+(14+2NOCO)NOSC+(4+6NOCO)NOPR, in which NOCO is the number of constituents modeled and NOPR is the number of parcels allowed in a branch.

In addition, the model allows no dispersion (backwater) through junctions so the peak-flow attenuation is somewhat limited if numerous junctions occur. Tributaries allow flow exchange with the system without affecting backwater or peak-flow attenuation. They also add little complexity to the system so should be used wherever possible in place of a branch. If, however, the flow in a tributary is known only at some large distance from the main river or if a significant lag time and (or) flow attenuation is expected to occur between the point of known flow and the junction of the main river, it is probably desirable to treat the tributary as a branch rather than just a point addition to the system.

Once a diagram of the system is drawn in as simplified a form as possible, it is only a matter of creating an interior junction at the confluence of any two or more branches, numbering the junctions (interior first) and the branches.

The next step is to determine the number of grid points for each branch. Again the need for simplicity and detail must be balanced. The dimensions of the system will be controlled by the number of grids in the branch containing the largest number of grids. Adding one more grid to the dimension statement adds about 12*NOBR + 19 storage units to the system in which NOBR is the maximum number of branches in the dimension statement. Adding one grid to the dimension statement in the BLTM transport model increases the required storage by 15+(9+NOCO)NOBR+3NOCO units and NOPR is dependent on NOSC.

The main concern, however, is to define the flow in enough detail for the desired purposes. For example, a grid is needed at every tributary input. In addition, the hydraulic geometry values and wave dispersion coefficient, are assumed constant in each subreach, between grids, so a grid is needed at any point where there is a significant change in the channel characteristics. If one were only interested in the flow at the downstream end of the branch, these would be the only factors that would need to be considered.

On the other hand, if the flow model is being used to drive a transport model, additional factors need to be considered. The flow model stores the time variation of flow only at the grid points. The cross-sectional area and top width are computed from the volume of water between grid points. If the grid points are too far apart, these numbers are averaged over a long reach. The transport model is very accurate provided it has detailed information on the space-time variation of discharge and cross-sectional area. The addition of grid points provides additional detail on the spatial variation. The transport model essentially determines the position of water parcels by linear interpolation based on the distance between grid points and the total time required for a parcel to traverse the distance. The grid points need to be close enough together so that this is an acceptable assumption. One way to consider the required detail would be to consider the length of a typical hydrograph pulse. If the branch is short enough so that a hydrograph's rising and falling limb both occur in the branch at the same time, the branch should contain at least 5 or 6 grids so that the flood wave would span four or five subreaches.

The flood wave is approximated by a series of waves separated by shocks as illustrated on figures 2 and 3. The number of shocks can become very large. For unsteady flow, the model will place shocks at a distance of 2DL apart and it will add a shock at every tributary for each time step. In order to determine a reasonable size for the variable NOSH (the maximum number of shocks), one should divide the branch length by two times the minimum expected value of DL (equation 10), add the number of tributaries, and add several as a factor of safety. The number computed above may be too large if the waves traverse the branch in a few time steps. The number of shocks is doubled each time step a shock remains in the branch but is limited to the above number. So if the waves traverse the branch quickly, the number of shocks is limited. If the number of shocks exceeds NOSH, the model stops and prints a message stating that there are too many shocks in the branch.

A final consideration is the selection of the time-step size. Here the tradeoff is between time resolution of the results and run time. The computer run time is almost directly proportional to the number of time steps involved in the simulation period.

A smaller time-step size also increases the storage requirements in two ways. First, the shorter the time step the larger the output file BLTM.FLW. Second, the value of the wave diffusive length scale, DL, is proportional to the square root of the time-step size and this value must be considered in determining the value of the variable NOSH.

In general, the time-step size should be selected so that an inflow hydrograph rise will be represented by at least two or three points. The model assumes the boundary conditions to remain constant for the duration of a time step. In other words, the model represents the boundary flow conditions by a series of histograms of width DT. The time step should be small enough so that these histograms provide a reasonable approximation of the inflow hydrograph.

In summary, the procedure should be to:

1. Select the minimum number of branches and junctions to define the network in a reasonable fashion.

2. Place grid points in the branches at each tributary and at points where there is a significant change in channel characteristics. Compare the lengths of the subreaches with the length of a hydrograph rise. Add more grids if needed.

3. Select the largest time-step size that is convenient and will reasonably represent the inflow hydrograph.

4. Compute the value of DL and the distance traveled by a typical wave during a time step for each branch (the program CEL described in Appendix B can be used to estimate the values of DF and wave speed).

5. Compare the distances between grid points to the values computed in step 4 and if the grids seem too far apart, insert additional grid points. If the values of DL and the distance traveled in one time step seem excessive, reduce the time-step size. For example, if shocks traverse the entire system in one or two time steps, you do not need a flow model, just assume steady flow during a time step.

6. Determine the maximum number of shocks needed in each branch (NOSH) by considering the value of DL in relation to the branch length and adding a shock for each grid point. Be a little generous here.

7. Set the values of NOBR, NOIJ, NOSC, and NOSH in the PARAMETER statements of the program and subroutines to the minimum acceptable values. If machine size is of no concern, you may want to set the numbers a little larger than needed to allow for expansion.

All the FORTRAN programs and input files mentioned in this report are available from the U.S. Geological Survey, Office of Surface Water, 415 National Center, Reston, Virginia 22092, and can be run on a personal computer. The following is a summary of the input and output files used or generated by the DAFLOW, and two example applications.

Input Files

All model input is contained in a file called FLOW.IN. This file defines the physical system to be modeled, specifies model options used for the simulation, and contains the boundary conditions as functions of time. The information contained in FLOW.IN can be broken down into three data sets: (1) general information, (2) branch information, and (3) boundary conditions. The first data set consists of nine records that define parameters to control the simulation, such as the title, number of time steps, time-step size, time reference, printout frequency, system of units, and tolerance factor. It also specifies network schematization parameters such as the number of branches and interior junctions. The title is specified as any combination of letters, symbols, or numbers of up to 80 characters in length. The number of time steps in the simulation is calculated as the duration of the simulation divided by the time-step size; both must be specified in hours. The time reference for the simulation is midnight of the first day. This is specified to the model as the number of time steps from midnight to the start of the simulation. For example, if the simulation is to begin at 0600 hours and the time-step size is 0.5 hours, the value specified is 6 divided by 0.5, which equals 12 time steps. The printout frequency is specified in terms of time steps between printouts. For example, if tabular flow information is desired every 3 hours and the time-step size is 0.5 hours, the value specified is 3 divided by 0.5, which equals 6. The model is independent of the system of units, except that the distance to grid points (specified in data set 2) must be input in miles.

DAFLOW uses an iterative solution scheme, such that its solutions must converge to a given tolerance. DAFLOW assumes that discharges, differences in discharges, and water volumes divided by the time-step size less than a tolerance to be insignificant, in other words, zero. The model calculates the tolerance from a given "peak" discharge divided by 100,000. This "peak" discharge should approximate the maximum discharge expected during the simulation. It therefore follows that the accuracy of the model results can be no better than this tolerance value.

Data set 2 consists of three types of records: (1) branch record, (2) header record, and (3) cross-section records. The branch record specifies the number of cross sections (grids) in the branch, the fraction of flow entering the branch, and the upstream and downstream junction numbers of the branch. When more than one branch originates at a junction, the water that enters the junction is split between these outgoing branches. This is specified to the model as the percentage (fraction) of the flow to enter the branch. For example, if two branches receive equal amounts of flow from the junction, this value should be specified as 0.5 for each branch. If only one branch receives flow from a junction, this value is specified as 1.0. The header record is simply textual information used as column headings to make editing of the input file easier. The cross-section records define the location of the grid (cross section), initial flow, output flag, hydraulic geometry and dispersion coefficients, and the cross-section area at zero flow for each subreach in the branch. The number of cross-section records input must equal the number specified on the branch record. Cross-section records are input in sequence starting with the grid at the upstream end of the branch. The grid location is specified as the distance to the cross section from a reference point at or above the upstream end of the branch. This distance must be expressed in miles. The initial discharge and all coefficients apply to subreaches extending from the grid for which it is specified to the next grid downstream. For example, the value of A1 input for grid 1 applies to the subreach extending from grid 1 to grid 2. Because there is one less subreach than grid points, these values need not be specified for the last grid in a branch. Note that the model assumes tributaries enter the river system just slightly upstream of the grid so the initial discharge for subreach I should include the effect of the tributary flow at grid I. The output flag (IOUT) specifies whether or not the flow information for the cross section is to be output to the file BLTM.OUT at the time-step interval specified in the general information.

Boundary conditions must represent the average flow rate during the time step. For example, the first boundary condition should represent the average inflow between time 0 and the time DT. All boundary conditions should be entered for the first time step (DAFLOW assumes all unspecified boundary conditions to be zero). After the first time step, DAFLOW assumes all boundary flows remain constant unless specifically changed. Data set 3 is used to input the boundary conditions that have changed since the last time step (including the first time step). Data set 3 consists of two record types. The first record specifies the number of boundary conditions that have changed for this time step (NBC). This must be followed by NBC number of records that specify the branch number, grid number, and flow rate of the changed boundary condition. A data set 3 must be input for each time step for the duration of the simulation. The first record is always required, while the second record(s) are only required when a boundary condition changes.

Table 2 is a summary description of the input data records as required to build the file FLOW.IN. DAFLOW expects all numeric input to be right justified in the assigned field as defined in this table. Appendix A describes a program that interactively creates the file FLOW.IN in the format as required by the DAFLOW model.

Output Files

The output of the DAFLOW model is written to two files: FLOW.OUT and BLTM.FLW (see fig. 1). FLOW.OUT is designed to provide tabular information summarizing the simulation and BLTM.FLW provides flow field information for the BLTM (Jobson and Schoellhamer, 1987) and postprocessor programs. Appendix C describes a postprocessor program that generates plots of computed and observed values as functions of time from the BLTM.FLW file.

FLOW.OUT echoes the input information from FLOW.IN and presents a summary of the simulation results at the selected cross sections and time frequency. This summary consists of the time, branch number, grid point number, and the average flow rate during the time step at the grid point. A debug option is available during interactive execution; if selected, a very detailed summary of the results is written to FLOW.OUT. The debug option is useful if a problem is encountered with the model and it is desired to investigate further where and (or) why the problem is occurring. In general, the debug option should not be used.

The second output file, BLTM.FLW, contains the flow field information at every grid point for each time step of the simulation. This information includes the flow rate, cross-section area, top width, and tributary flow. The grid and tributary flow represent the average flow during the time step, and the area and top width represent the instantaneous values at the end of the time step but averaged over the subreach. The cross-section area for the subreach is computed as the volume of water in the subreach divided by the length of the subreach. The width is computed from the cross-sectional area by first computing the value of QS from equation 3 and then using this value in equation 4. The information in BLTM.FLW is designed to be used to provide hydraulic information to a transport model like BLTM or to be used with postprocessor programs such as the one described in Appendix C, which plots the computed results and compares them with measured values.

Table 2.--Input format for DAFLOW

Data Set 1 - General information

Record	Field	Variable	Format	Description
	1	TITLE	20A4	Title of simulation
2	1	NBRCH	20X,I10	Number of branches
3	1	NJNCT	20X,I10	Number of interior junctions
4	1	NHR	20X,I10	Number of time steps to be modeled
5	1	JTS	20X,I10	Number of time steps between midnight and the start of the simulation
6	1	JGO	20X,I10	Number of time steps between printouts in FLOW.OUT
7	1	IENG	20X,I10	Input units [0 = metric (length unit is meters except for river miles), 1 = English (length unit is feet except river miles)]
8	1	DT	20X,F10.3	Time-step size in hours
9	1	QP	20X,F10.3	Maximum discharge of interest ("peak discharge"), discharges below QP/100000.0 will be considered to be zero

Data Set 2 - Branch information

(one data set required for each branch)

Record	Field	Variable	Format	Description
1	1	NXSEC(N)	13X,I3	Number of grids (cross sections) in branch N
1	2	PF(N)	16X,F5.2	Fraction of flow at upstream junction to enter branch N
1	3	JNCU(N)	16X,I3	Junction number at upstream end of branch N
1	4	JNCD(N)	8X,I3	Junction number at downstream end of branch N
2	1	---	20A4	Header card for information only
3	1	X(N,I)	3X,G11.4	Distance of grid I of branch N from reference point in miles
3	2	IOUT(N,I)	I2	Output flag (equal 1 if output in BLTM.OUT is desired for this grid, 0 otherwise)
3	3	F(N,I)	G11.4	Initial flow in subreach I (between grid I and I+1)
3	4	A1(N,I)	G10.3	Constant A1 in equation 3 for subreach I
3	5	A2(N,I)	G10.3	Constant A2 in equation 3 for subreach I
3	6	A0(N,I)	G10.3	Constant A0 in equation 3 for subreach I
3	7	DF(N,I)	G10.3	Wave dispersion coefficient for subreach I
3	8	W1(N,I)	F7.1	Constant W1 in equation 4 for subreach I
3	9	W2(N,I)	F6.3	Constant W2 in equation 4 for subreach I

Table 2.--Input format for DAFLOW--continued

Data Set 3 - Boundary condition (one data set for each time step)				
Record	Field	Variable	Format	Description
1	1	NBC	18X,I3	Number of new boundary conditions to be input for this time step
2	1	N	10X,I3	Branch number for new boundary condition
2	2	I	5X,I3	Grid number for new boundary condition
2	3	TRB(I,N)	3X,G14.5	New boundary flow for branch N, grid I

EXAMPLE 1 (NETWORK)

The first example is purely hypothetical and designed to illustrate the capability of the model, not to represent a realistic flow situation. The assumed network of channels contains branching flow (the flow splits at junctions 1 and 2) as shown in figure 5. At time 0 the flow is everywhere zero except between grids 2 and 5 of branch 3. It is assumed that an inflow of 100 m^3/s occurs at branch 3, grid 2, and the entire flow is extracted at grid 5. The inflow at branch 1, grid 1, is assumed to be a square wave, alternating between 0 and 100 m^3/s on 3-hour intervals and the flow at the upstream end of branch 2 is assumed to remain 0 until hour 7 when it suddenly increases to 100 m^3/s. Forty percent of the flow reaching junction 1 is assumed to enter branch 4, and 60 percent of the flow reaching junction 1 is assumed to enter branch 3. Hydraulic geometry and wave dispersion coefficients were assumed arbitrarily.

Figure 6 is a listing of the FLOW.IN file that is used for example 1. As can be seen from figure 6, the title of this example is "Example 1 for 6 Branch Model." The next three records of figure 6 specify that the example contains 6 branches, 2 interior junctions (see fig. 5), and that 24 time steps will be simulated. The remainder of data set 1 (general information) specifies: the model begins at midnight (JTS = 0), the output is given every two time steps (JGO = 2) in the file FLOW.OUT, metric units will be used (IENG = 0), the time-step size is 1 hour (DT = 1.000), and the maximum discharge of interest (peak discharge) is 1000 (QP = 1,000). Trial-and-error solutions in the model, therefore, will be truncated at 1,000/100,000 = 0.01 cubic meter per second.

The branch information for the example specifies that branch 1 contains three cross sections (grids) (NXSEC = 3) (see fig. 5) and routes 100 percent of the flow at junction 3 to junction 1. Junction 3 is known to be an external junction because 3 > 2, the number of internal junctions. Three additional records are needed because the branch has three grid points (cross sections). Grid point 2, for example, is 0.303 mile downstream of the reference point, tabular output is not desired in FLOW.OUT (IOUT = 0), the initial flow between grid points 2 and 3 is 0.0, and the coefficients A1, A2, and A0 in equation 3 are [illegible] 50, 0.750, and 0.000, respectively. The top widths of all subreaches in branch 1 are defined by W1 = 100.0 and W2 = 0.2 in equation 4.

```
Example 1 for 6 Branch Model
No. of Branches              6 *
Internal Junctions           2 *
Time Steps Modeled          24 *
Model Starts                 0 time steps after midnight.
Output Given Every           2 Time Steps in FLOW.OUT.
0=Metric,1=English           0 *
Time Step Size           1.000 Hours.
Peak Discharge           1000. *
Branch  1 has  3 xsects & routes 1.00 of flow at JNCT  3 To JNCT  1
Grd R Mile  IOUT  Disch        A1       A2        AO        DF         W1    W2
  1 0.0000    0 0.0000       4.50    0.750     0.000    0.500E+04  100.0 0.200
  2 0.3030    0 0.0000       4.50    0.750     0.000    0.500E+04  100.0 0.200
  3 0.6060    0
Branch  2 has  2 xsects & routes 1.00 of flow at JNCT  4 To JNCT  1
Grd R Mile  IOUT  Disch        A1       A2        AO        DF         W1    W2
  1 0.0000    0 0.0000       4.25    0.900      250.    0.600E+05  200.0 0.100
  2  1.420    0
Branch  3 has  6 xsects & routes 0.60 of flow at JNCT  1 To JNCT  2
Grd R Mile  IOUT  Disch        A1       A2        AO        DF         W1    W2
  1 0.0000    0 0.0000       65.0    0.500     0.000    0.700E+05   50.0 0.300
  2 0.4730    0  100.0       65.0    0.500     0.000    0.700E+05   50.0 0.100
  3 0.9470    0  100.0       8.20    0.960      99.0    0.100E+05   99.0 0.200
  4  1.420    0  100.0       65.0    0.500     0.000    0.700E+05   50.0 0.300
  5  1.894    1 0.0000       65.0    0.500     0.000    0.700E+05   50.0 0.300
  6  2.367    0
Branch  4 has  3 xsects & routes 0.40 of flow at JNCT  1 To JNCT  2
Grd R Mile  IOUT  Disch        A1       A2        AO        DF         W1    W2
  1 0.0000    0 0.0000       5.50    0.870     0.000    0.800E+04  200.0 0.150
  2 0.8520    0 0.0000       5.50    0.870     0.000    0.800E+04  200.0 0.150
  3  1.705    0
Branch  5 has  2 xsects & routes 0.50 of flow at JNCT  2 To JNCT  5
Grd R Mile  IOUT  Disch        A1       A2        AO        DF         W1    W2
  1 0.0000    0 0.0000       8.20    0.960     0.000    0.900E+04  500.0 0.100
  2  1.042    0
Branch  6 has  2 xsects & routes 0.50 of flow at JNCT  2 To JNCT  6
Grd R Mile  IOUT  Disch        A1       A2        AO        DF         W1    W2
  1 0.0000    0 0.0000       8.60    0.610     0.000    0.900E+04  500.0 0.100
  2  1.042    1
for Time    1 NBC=  3 *
 Branch     1 Grid  1 Q=    100.00     *
 Branch     3 Grid  2 Q=    100.00     *
 Branch     3 Grid  5 Q=   -100.00     *
for Time    2 NBC=  0 *
for Time    3 NBC=  0 *
for Time    4 NBC=  1 *
 Branch     1 Grid  1 Q=   0.00000     *
for Time    5 NBC=  0 *
for Time    6 NBC=  0 *
for Time    7 NBC=  2 *
 Branch     1 Grid  1 Q=    100.00     *
 Branch     2 Grid  1 Q=    100.00     *
```

(continued on next page)

Figure 6.--Input data in file FLOW.IN for example 1.

```
for Time     8 NBC=  2 *
 Branch      3 Grid  2 Q=   0.00000     *
 Branch      3 Grid  5 Q=   0.00000     *
for Time     9 NBC=  0 *
for Time    10 NBC=  1 *
 Branch      1 Grid  1 Q=   0.00000     *
for Time    11 NBC=  0 *
for Time    12 NBC=  0 *
for Time    13 NBC=  1 *
 Branch      1 Grid  1 Q=    100.00     *
for Time    14 NBC=  0 *
for Time    15 NBC=  0 *
for Time    16 NBC=  1 *
 Branch      1 Grid  1 Q=   0.00000     *
for Time    17 NBC=  0 *
for Time    18 NBC=  0 *
for Time    19 NBC=  1 *
 Branch      1 Grid  1 Q=    100.00     *
for Time    20 NBC=  0 *
for Time    21 NBC=  0 *
for Time    22 NBC=  1 *
 Branch      1 Grid  1 Q=   0.00000     *
for Time    23 NBC=  0 *
for Time    24 NBC=  0 *
```

Figure 6.--Input data in file FLOW.IN for example 1--continued.

Notice that this example shows that the hydraulic coefficients A1, A2, A0, W1, and W2 can be varied from subreach to subreach. The selection of these coefficients is discussed in some detail for the second example. Appendix B describes a program that is helpful in selecting the coefficients from various known information.

As can be seen from figure 6, at branch 1, grid 1 the inflow during the first time step is specified as 100 m^3/s. Likewise, at branch 3, grid 2 there is a tributary inflow of 100 m^3/s, and at branch 3, grid 5 there is a with-drawal of 100 m^3/s (-100.00). All other boundary conditions (external junctions and tributaries) default to zero. All boundary conditions remain constant at the values set for the first time step during the second and third time steps because no boundary conditions are changed. At the beginning of the fourth time step, the inflow at branch 1, grid 1 is changed from 100 m^3/s to 0.0 m^3/s; and at the beginning of the seventh time step, two boundary conditions are changed, the inflow at branch 1, grid 1 is changed to 100 m^3/s, and the inflow at branch 2, grid 1 is changed from 0 to 100 m^3/s.

Output from DAFLOW is written to the two files: FLOW.OUT and BLTM.FLW. figure 7 is a listing of the FLOW.OUT file for this example. This is a summary of the input parameters as contained in FLOW.IN and tabular summaries of the results at the specified printout frequency (2 hours) and for the specified cross sections. Figure 8 is a listing of the data written to the BLTM.FLW file for this example after one time step. Time-step 0 represents the initial conditions. For example, figure 8 shows that the initial flow was everywhere zero except between grids 2 and 5 of branch 3. That is, the channels are dry except for the inflow at branch 3, grid 2, which is taken out at branch 3, grid 5. Notice that tributaries are assumed to enter the system

```
                  Example 1 for 6 Branch Model

The  6 Branch Model with  2 Internal Junctions is run   24 Time Steps each 1.00 hours long.
The Model starts at  0.00 hours past midnight.
The grid output is given in BLTM.OUT every 2 time steps.
Input units are Metric (Meters) except river miles
 Cross sectional area = AO+A1(Q**A2)
 AO = Cross sectional area at zero flow.
 Width = W1(Q)**W2

                         * * *  INITIAL CONDITIONS  * * *

 Grid    Mile  Disch       Area      Width  Disp Cof         A1         A2         W1         W2         AO

Branch   1 Extends from JNCT  3 to JNCT  1 and receives 1.00 of flow at JNCT  3

    1    0.00 0.0000     0.0000     0.0000      5000.     4.500     0.7500     100.0     0.2000     0.0000
    2    0.30 0.0000     0.0000     0.0000      5000.     4.500     0.7500     100.0     0.2000     0.0000
    3    0.61 0.0000

Branch   2 Extends from JNCT  4 to JNCT  1 and receives 1.00 of flow at JNCT  4

    1    0.00 0.0000      250.0     0.0000 0.6000E+05  4.250     0.9000     200.0     0.1000      250.0
    2    1.42 0.0000

Branch   3 Extends from JNCT  1 to JNCT  2 and receives 0.60 of flow at JNCT  1

    1    0.00 0.0000     0.0000     0.0000 0.7000E+05  65.00     0.5000     50.00     0.3000     0.0000
    2    0.47  100.0      650.0      79.24 0.7000E+05  65.00     0.5000     50.00     0.1000     0.0000
    3    0.95  100.0      781.0      248.7 0.1000E+05  8.200     0.9600     99.00     0.2000      99.00
    4    1.42  100.0      650.0      199.1 0.7000E+05  65.00     0.5000     50.00     0.3000     0.0000
    5    1.89 0.0000     0.0000     0.0000 0.7000E+05  65.00     0.5000     50.00     0.3000     0.0000
    6    2.37 0.0000
```

(continued on next page)

Figure 7.--Output to file FLOW.OUT for example 1.

```
Branch   4 Extends from JNCT  1 to JNCT  2 and receives 0.40 of flow at JNCT  1

    1    0.00 0.0000    0.0000    0.0000    8000.    5.500    0.8700    200.0    0.1500    0.0000
    2    0.85 0.0000    0.0000    0.0000    8000.    5.500    0.8700    200.0    0.1500    0.0000
    3    1.70 0.0000

Branch   5 Extends from JNCT  2 to JNCT  5 and receives 0.50 of flow at JNCT  2

    1    0.00 0.0000    0.0000    0.0000    9000.    8.200    0.9600    500.0    0.1000    0.0000
    2    1.04 0.0000

Branch   6 Extends from JNCT  2 to JNCT  6 and receives 0.50 of flow at JNCT  2

    1    0.00 0.0000    0.0000    0.0000    9000.    8.600    0.6100    500.0    0.1000    0.0000
    2    1.04 0.0000

                     * * *  OUTPUT  * * *

 Day   1  Hour   1.5 Branch  Grid  Discharge
                        3      5     22.55
                        6      2     3.084
 Day   1  Hour   3.5 Branch  Grid  Discharge
                        3      5     20.23
                        6      2     13.85
 Day   1  Hour   5.5 Branch  Grid  Discharge
                        3      5     8.332
                        6      2     15.14
 Day   1  Hour   7.5 Branch  Grid  Discharge
                        3      5     164.9
                        6      2     33.12
 Day   1  Hour   9.5 Branch  Grid  Discharge
                        3      5     82.78
                        6      2     60.53
 Day   1  Hour  11.5 Branch  Grid  Discharge
                        3      5     70.70
                        6      2     59.06
 Day   1  Hour  13.5 Branch  Grid  Discharge
                        3      5     86.87
                        6      2     65.89
 Day   1  Hour  15.5 Branch  Grid  Discharge
                        3      5     93.16
                        6      2     76.81
 Day   1  Hour  17.5 Branch  Grid  Discharge
                        3      5     77.52
                        6      2     68.75
 Day   1  Hour  19.5 Branch  Grid  Discharge
                        3      5     91.24
                        6      2     71.59
 Day   1  Hour  21.5 Branch  Grid  Discharge
                        3      5     96.23
                        6      2     80.13
 Day   1  Hour  23.5 Branch  Grid  Discharge
                        3      5     79.33
                        6      2     70.57
```

Figure 7.--Output to file FLOW.OUT for example 1--(continued).

TIME	STEP	BRANCH	GRID	DISCHARGE	AREA	TOP WIDTH	TRIBUTARY DISCHARGE
0	1	1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0	1	2	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0	1	3	0.00000E+00			
0	2	1	0.00000E+00	0.25000E+03	0.00000E+00	0.00000E+00
0	2	2	0.00000E+00			
0	3	1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0	3	2	0.10000E+03	0.65000E+03	0.79245E+02	0.10000E+03
0	3	3	0.10000E+03	0.78105E+03	0.24868E+03	0.00000E+00
0	3	4	0.10000E+03	0.65000E+03	0.19905E+03	0.00000E+00
0	3	5	0.00000E+00	0.00000E+00	0.00000E+00	-0.10000E+03
0	3	6	0.00000E+00			
0	4	1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0	4	2	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0	4	3	0.00000E+00			
0	5	1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0	5	2	0.00000E+00			
0	6	1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0	6	2	0.00000E+00			
1	1	1	0.10000E+03	0.14230E+03	0.25119E+03	0.00000E+00
1	1	2	0.80725E+02	0.11799E+03	0.23895E+03	0.00000E+00
1	1	3	0.64742E+02			
1	2	1	0.00000E+00	0.25000E+03	0.30916E+03	0.00000E+00
1	2	2	0.00000E+00			
1	3	1	0.38845E+02	0.94842E+02	0.62723E+02	0.00000E+00
1	3	2	0.11879E+03	0.65364E+03	0.79333E+02	0.10000E+03
1	3	3	0.11802E+03	0.78840E+03	0.24923E+03	0.00000E+00
1	3	4	0.11646E+03	0.65364E+03	0.19972E+03	0.00000E+00
1	3	5	0.15692E+02	0.68909E+02	0.51783E+02	-0.10000E+03
1	3	6	0.11208E+01			
1	4	1	0.25897E+02	0.28158E+02	0.26504E+03	0.00000E+00
1	4	2	0.15172E+02	0.24908E+02	0.25949E+03	0.00000E+00
1	4	3	0.56741E+01			
1	5	1	0.33974E+01	0.58187E+01	0.48245E+03	0.00000E+00
1	5	2	0.68700E+00			
1	6	1	0.33974E+01	0.63559E+01	0.47582E+03	0.00000E+00
1	6	2	0.43676E+00			

Figure 8.--Output to file BLTM.FLW after one time step for example 1.

just upstream of the grid so that flow at grid 5, branch 3 is zero even though it is 100 m^3/s in the subreach between grids 4 and 5. Notice that no area or top width are computed for the last grid in a branch because there is no associated subreach.

EXAMPLE 2 (CHATTAHOOCHEE RIVER)

Faye and Cherry (1980) published stage and discharge records for the highly unsteady flow downstream of Buford Dam on the Chattahoochee River in north-central Georgia (fig. 9). Jobson and Keefer (1979) published results of a dye study for the same reach. Flow and transport will be simulated in the 17.33-mile reach below Buford Dam for the period March 21-24, 1976, and October 20-26, 1975, as the second example.

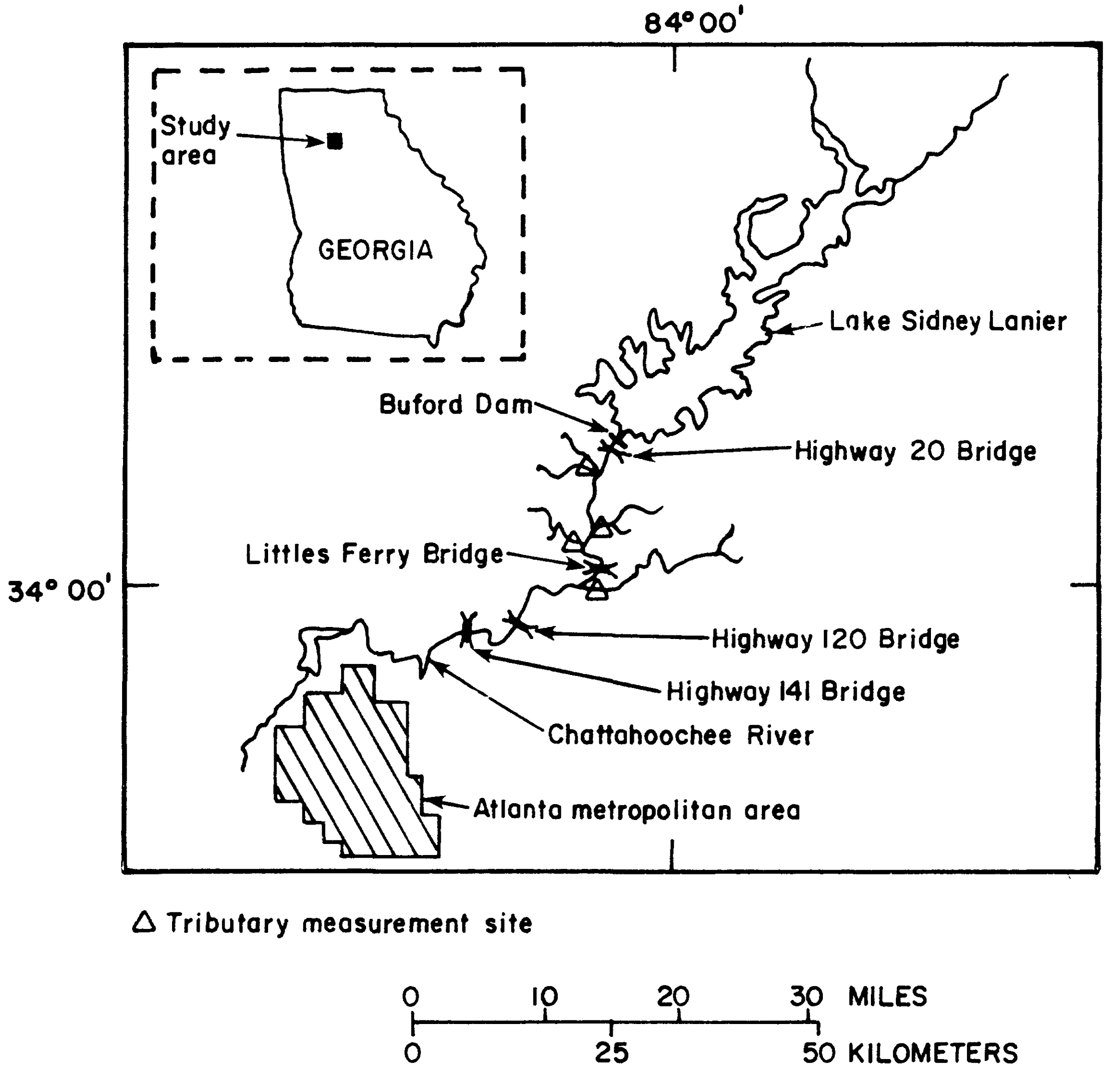

Figure 9.--Data-collection points and tributary measurement sites along the Chattahoochee River.

Many times, hydrologists are asked to make predictions of flow and transport when little field data are available. The DAFLOW model is designed to be consistent with the hydraulic geometry exponents shown in table 1, which allows it to make reasonable predictions with little site specific data. In this example the hydraulic geometry exponents proposed by Leopold and Maddock (1953) (table 1) will be assumed to apply. This leaves only three additional coefficients, A1, W1, and DF, to define the flow in the river. Knowing the value of W2, the value of W1 can be computed using equation 4 from the average top width at a known discharge. A value for DF can be obtained from the channel slope and a representative discharge using the expression (Doyle and others, 1983)

$$DF = \frac{Q}{2S_oW}, \tag{11}$$

in which S_o is the channel slope. Finally, a value for A1 can be obtained either from a representative Manning's roughness coefficient or a known wave speed.

Jobson and Keefer (1979, p. 2) give the bed slope to be 0.00036. The value could also be determined from a topographic map. It will be assumed that a reconnaissance was made of the river on March 21, 1976, and that the discharge was measured at each of the four bridges (fig. 9) at 2:00 p.m. Cross sections presented by Faye and Cherry (1980) show that at 2:00 p.m. on March 21 field crews could have measured the data contained in table 3. Using the average values from table 3, the value of W1 can be determined from equation 4 to be 31.0.

Table 3.--Data for the Chattahoochee River that could have been obtained at 2:00 p.m. on March 21, 1976

Grid	Site	Miles downstream	Top width feet	Flow ft^3/s
1	Buford Dam	0		
2	Richland Creek	1.49		
3	Highway 20	2.30	195	600
4	James Creek	2.62		
5	Level Creek	5.90		
6	Dick Creek	6.72		
7	Littles Ferry Bridge	8.14	165	800
8	Gwinnett County intake	9.91		
9	Suwanee Creek	9.96		
10	Highway 120	12.84	160	1,100
11	Highway 141	17.33	208	1,100
	Average		182	900

Jobson and Keefer (1979, p. 2) state that a typical Manning's n for the reach is 0.042. Expressing the hydraulic radius as the area divided by the top width, Manning's equation can be written as

$$Q = \frac{1.49}{n} A^{5/3} (W)^{-2/3} \sqrt{S_o} , \tag{12}$$

from which the area of 602 ft^2 is estimated for a discharge of 900 ft^3/s. A1 can then be estimated to be 6.76 by use of equation 3. A better estimate of A1 can usually be obtained if the wave speed is known.

Figure 10 presents the observed discharges on the Chattahoochee River during March 21-23, 1976, as presented by Faye and Cherry (1980). The travel time of the second stage peak (fig. 10) can be estimated from stage records contained in Faye and Cherry (1980) to be 5.93 hours. This travel time yields

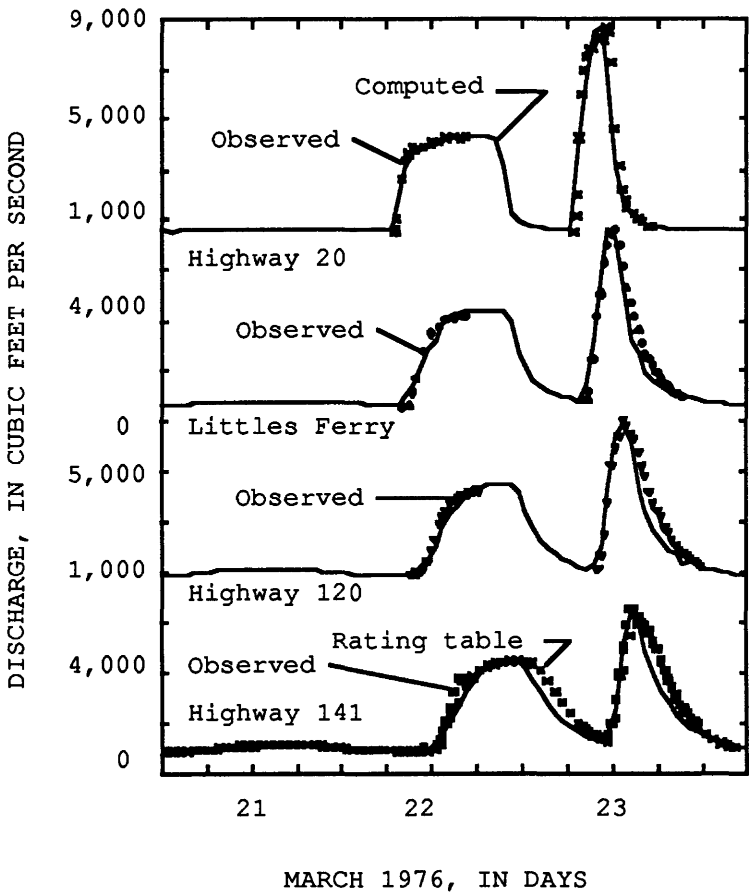

Figure 10.--Comparison of observed and computed flows in the Chattahoochee River.

a wave speed of 4.29 ft/s for the flow pulse that started at about 8,500 ft^3/s at Buford Dam and had a discharge at Highway 141 of about 6,550 ft^3/s. Differentiating equation 3, inverting and substituting it into equation 6, yields an expression for the wave speed, C

$$C = \frac{Q^{1-A2}}{A1\ A2} , \tag{13}$$

assuming a representative discharge for the moving wave to be (8,500 + 6,550)/2 = 7,525 ft^3/s, the value of A1 can be computed from equation 13 as 7.35. Similar computations for the first pulse and the trough between the two peaks yield estimates of A1 of 8.00 and 5.19, respectively. Because the 4,000 ft^3/s wave is very broad, the travel time is difficult to measure accurately. Because of the difference in shape of the rising and falling limbs of the hydrograph, the travel time of the trough is not considered reliable. It is therefore assumed for this example that A1 is 7.35.

Finally, an estimate of a "representative" discharge during the simulation is required to determine the wave dispersion coefficient from equation 11. A value of 3,000 ft^3/s (fig. 10) is chosen because it represents the approximate average of the flow at Littles Ferry (half way down the reach) during the unsteady part of the hydrograph. The width is determined for this discharge using equation 4 and the value of the wave dispersion coefficient DF is found to be 16,800 ft^2/s using equation 11.

The flow at the upstream boundary and at all tributaries also is required as input to DAFLOW. Faye and Cherry (1980) did not publish complete hydrographs of the tributary inflow but did publish spot measurements of the flow in the largest tributary (Suwanee Creek). To account for a rainfall event that occurred on March 21, 1976, a smooth hydrograph was drawn through the observed discharges on Suwanee Creek and all tributaries (except the withdrawal at grid 8, table 3) were assumed to have similar hydrographs. Visual inspection during rapidly changing stage indicated that the tributary valleys allowed for considerable storage. The actual interchange of water between the tributaries and the river was adjusted to account for the change in storage caused by a change in stage of the main channel using the procedure described by Jobson and Keefer (1979).

The reach was simulated using one branch with 11 grid points and 78 1-hour time steps. A grid point was placed at the confluence of each tributary (table 3) and at each bridge crossing. The hydraulic geometry and wave dispersion coefficients were assumed to be the same for all subreaches. Figure 11 is a listing of the first part of the input file (FLOW.IN). The value of cross-sectional area at zero flow, A0, is assumed to be 0 at this point. The maximum discharge of interest, QP, is set at 10,000 ft^3/s, which implies that computations will be carried out to the nearest 0.1 ft^3/s.

Figure 10 shows a comparison of the simulated flows at the four bridges to the observed discharges published by Faye and Cherry (1980). At the Highway 141 bridge the discharge computed from the rating table is also shown. It is important to remember that the results on figure 10 were obtained without calibration of the model. On the other hand, there is no assurance that equally good results could be obtained without calibration for other rivers. The simulation of both the timing and the peak discharges on figure 10 are considered to be excellent. The computed peak flow at Highway 141 in the second pulse is only 0.6 percent larger than the observed peak and 11 percent larger than the peak value obtained from the observed stage and rating table. The root-mean-square (RMS) error between the computed and observed (including rating table values) discharges is 586 ft^3/s based on 249 observations and the mean error is 227 ft^3/s. These results could, of course, be improved by "calibrating" the model, that is adjusting the hydraulic geometry and wave dispersion coefficient values. The mean error also implies that either the inflow or tributary flows have a bias of 227 ft^3/s. Appendix B describes a program that is useful in model calibration as well as for computing the input coefficients for the flow model.

```
  Example 2 Chattahoochee River flow March 21-24, 1976
No. of Branches               1 *
Internal Junctions            0 *
Time Steps Modeled           78 *
Model Starts                  0 TIME STEPS AFTER MIDNIGHT
Output Given Every            1 Time Steps in FLOW.OUT
0=Metric,1=English            1 *
Time Step Size            1.000 Hours
Peak discharge          10000.0 *
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    0   500.0   7.350   0.660   000.0   0.168E+05   31.0   0.26
  2  1.490    0   588.2   7.350   0.660   000.0   0.168E+05   31.0   0.26
  3  2.300    0   588.2   7.350   0.660   000.0   0.168E+05   31.0   0.26
  4  2.620    0   642.8   7.350   0.660   000.0   0.168E+05   31.0   0.26
  5  5.900    0   659.2   7.350   0.660   000.0   0.168E+05   31.0   0.26
  6  6.720    0   681.0   7.350   0.660   000.0   0.168E+05   31.0   0.26
  7  8.140    1   681.0   7.350   0.660   000.0   0.168E+05   31.0   0.26
  8  9.910    0   674.0   7.350   0.660   000.0   0.168E+05   31.0   0.26
  9  9.960    0   892.4   7.350   0.660   000.0   0.168E+05   31.0   0.26
 10  12.84    0   892.4   7.350   0.660   000.0   0.168E+05   31.0   0.26
 11  17.33    1   892.4
 TIME STEP   1 NBC=   7
BRANCH       1 GRID   8 Q=   -7.0000
BRANCH       1 GRID   1 Q=    550.00
BRANCH       1 GRID   2 Q=    41.160
BRANCH       1 GRID   4 Q=    58.761
BRANCH       1 GRID   5 Q=    17.633
BRANCH       1 GRID   6 Q=    23.513
BRANCH       1 GRID   9 Q=    235.20
 TIME STEP   2 NBC=   6
BRANCH       1 GRID   1 Q=    550.00
BRANCH       1 GRID   2 Q=    50.618
BRANCH       1 GRID   4 Q=    72.193
BRANCH       1 GRID   5 Q=    21.769
BRANCH       1 GRID   6 Q=    28.902
BRANCH       1 GRID   9 Q=    289.10
```

Figure 11.--Part of the input file (FLOW.IN) used for example 2, which simulated the flow in the Chattahoochee River in the predictive mode.

By way of comparison, Jobson and Keefer (1979) calibrated a linear-implicit, finite-difference model based on the complete dynamic wave equations to the data shown on figure 10. This "calibrated" model still underpredicted the peak flow at the Highway 141 bridge by 20 percent.

The DAFLOW flow model was developed to provide input to transport models. Another, more critical, test of the accuracy of the flow model is to test its ability to predict the transport velocity of a dissolved substance, such as dye. As discussed by Jobson and Keefer (1979), dye was injected to the river below Buford Dam at a constant rate starting at 11:00 a.m. on March 21, 1976. The dye concentrations of the river were observed at 5-minute intervals for the next 60 hours at both the Littles Ferry and Highway 141 Bridges.

The data stored in BLTM.FLW was used in conjunction with the BLTM transport model documented by Jobson and Schoellhamer (1987) to predict the observed dye concentrations. The BLTM model was originally designed to accept instantaneous values of the discharge, cross-sectional area, and top widths at the grid points while the DAFLOW model outputs the time-step-averaged discharge at the grid points and instantaneous subreach-averaged values of top width and cross-sectional area. Appendix D describes the minor modifications to the BLTM model necessary for it to accept the data in BLTM.FLW. Appendix E describes a program that reads the file FLOW.IN, extracts the pertinent information for the BLTM model and interactively prompts for input of any additional information required to create the input file, BLTM.IN. After executing the program in Appendix E, the only additional information necessary is the initial and boundary values for the dye and the mass dispersion coefficient. The initial concentrations are all zero and the upstream concentration after 11:00 a.m. on March 21, 1976, was determined as 7,549 divided by the flow at grid 1. The mass dispersion coefficient is always difficult to estimate. Fischer (1973) presents experimental data that relate observed dispersion coefficients to the product of the depth times the shear velocity. There is a large amount of scatter in the relationship but the author has found that a dispersion coefficient of about 1,000 times the product of depth and shear velocity often works for natural rivers. This ratio will be assumed here. Depth and shear velocity, of course, depend on the discharge but the representative discharge of 3,000 ft^3/s was used.

Approximating the depth as the ratio of the area to top width, and using equations 3 and 4, it is seen that the representative depth, for 3,000 ft^3/s, is 5.8 feet and the shear velocity is 0.26 ft/s. Therefore, a mass dispersion coefficient of 1,500 ft^2/s was assumed to apply. As a point of reference, Nordin and Sabol (1974) report travel time data on other reaches of the Chattahoochee River that indicate dispersion coefficients ranging from 1,300 ft^2/s to 2,000 ft^2/s. The BLTM model requires the dispersion coefficient to be input as a dispersion factor

$$DQQ = \frac{Dx}{U^2 DT}, \tag{14}$$

in which DQQ is the dispersion factor, Dx is the mass dispersion coefficient, U is the representative stream velocity, and DT is the time-step size. Using 3,000 ft^3/s as the representative discharge, the representative velocity can be computed from equation 3 to be 2.1 ft/s yielding DQQ = 0.09. The BLTM model was run using these input data to produce the results shown on figure 12. Notice that the model predicts the first arrival of the dye to occur about 3 hours before the observed values at both Littles Ferry and Highway 141. This indicates that the actual water volume, in the river, at low flow, is larger than that predicted by the flow model. Large pools in the river are the likely cause of the poor timing on figure 12. The variable AO allows a dead storage volume to be added to the river (actually the cross-sectional area at zero flow). The discharges computed by the DAFLOW model are independent of the value of A0 but it does affect the cross-sectional areas and therefore the transport velocity of a dissolved constituent. The transport model was calibrated by assigning a value of A0 equal to 140 ft^2 in the flow model for the first six subreaches (above Littles Ferry). The value of A0 was left at 0.0 for the rest of the subreaches. With this modification, the discharges (fig. 10) are unchanged but the predicted dye concentrations are much improved as shown on figure 13. The RMS error for the computed concentrations on figure 13 is 1.97 at Littles Ferry and 1.43 at Highway 141.

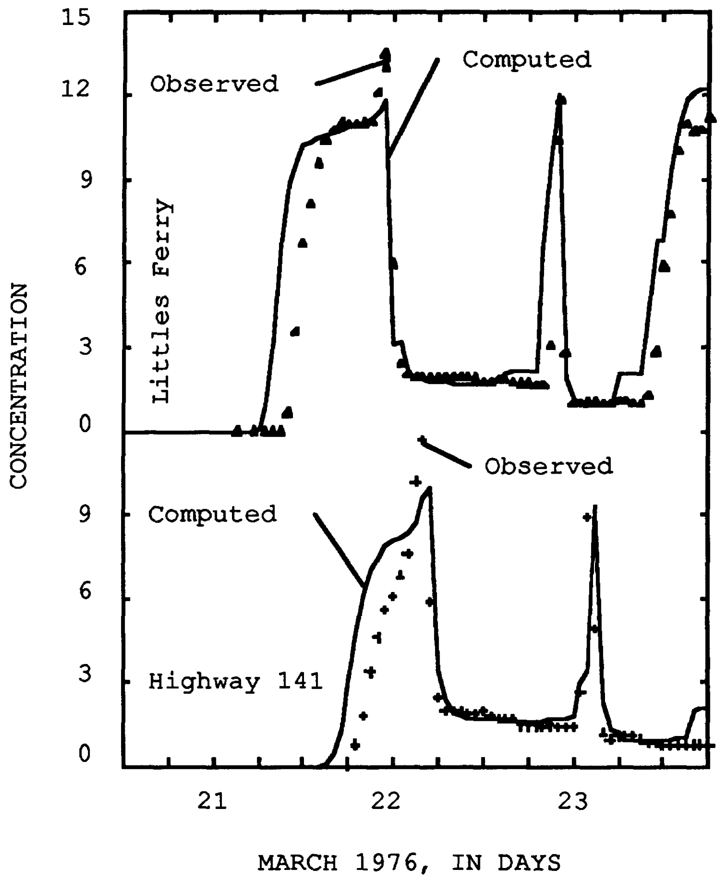

Figure 12.--Comparison of observed dye concentrations in the Chattahoochee River to those predicted without calibration.

The storage volume in the 8.14-mile reach above Littles Ferry associated with a value of A0 = 140 ft^2 is about 6 x 10^6 ft^3. Jobson and Keefer (1979) published a depth profile for the river at steady low flow that indicates a large pool in the river near the Highway 20 bridge. The volume of this pool (at zero flow) can be estimated from data presented in their table 1 to be about 4.5 x 10^6 ft^3. This depth profile shows no large pools below the Littles Ferry Bridge.

One may question why the predicted peak concentration at 11:00 a.m. at Littles Ferry on figure 13 is so much smaller than that on figure 12. Figure 14 is a plot of the computed concentration profile in the river at 11:00 a.m. and 12:00 noon on March 23. As can be seen from figure 14, the peak concentration is upstream of Littles Ferry at 11:00 a.m. and downstream of Littles Ferry at 12:00 noon. The program that produces the plots shown in figures 12 and 13 determined the instantaneous concentration at Littles Ferry at each hour and connected the points with a straight line. The time step was too large to catch the very sharp peak in dye concentrations as it passed Littles Ferry. As can be seen on figure 12, the timing was such that the sharp peak just happened to occur at Littles Ferry at 11:00 a.m.

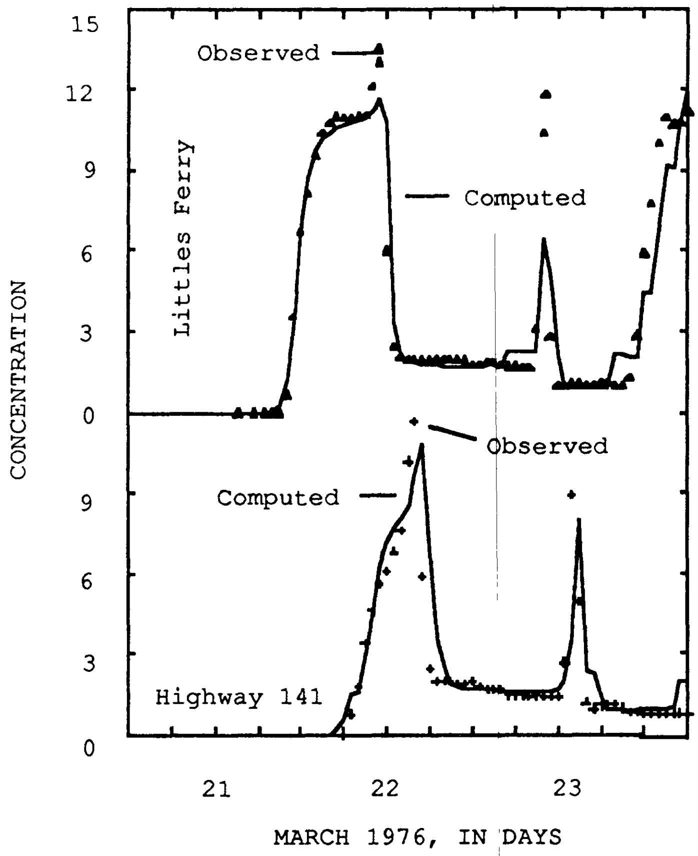

Figure 13.--Comparison of observed dye concentrations in the Chattahoochee River to those predicted with A0 = 140 square feet for subreaches above Littles Ferry.

Although the flow model was not calibrated to predict the results shown on figure 10, it was assumed that the reconnaissance was conducted on March 21, 1976. One may question how stable the model parameters are with time. Stage was also collected during a week in October 1975 on the Chattahoochee (Keefer and Jobson, 1978). The 15-minute stage data below Buford Dam and at Highway 141 were obtained from R. E. Faye (written commun., 1976) and converted to discharges by use of the rating tables at each site. The stages below Buford Dam and at Highway 141 are given in tables 4 and 5, respectively. For time periods where no data are presented in these tables, the stage was constant. Rating tables for the two sites are given in table 6. The slope of the rating curve is constant between the break points shown in the table. The tributary flows were assumed constant for the entire simulation at values of 12, 17.2, 9.5, 10.6, -7.0, and 62.0, respectively, for Richland Creek, James Creek, Level Creek, Dick Creek, Gwinnett County intake, and Suwanee Creek, respectively. All model parameters were unchanged from those used in the previous example. The value of A0 was assumed to be 140 ft^2 for the first six subreaches as before. Figure 15 shows a comparison of the observed and simulated discharges at Highway 141 as well as the inflow hydrograph. The model produces excellent results for both large and small pulses. The RMS error for the data shown on figure 15 is 274 ft^3/s and the mean error is 0.99 ft^3/s based on 167 observations.

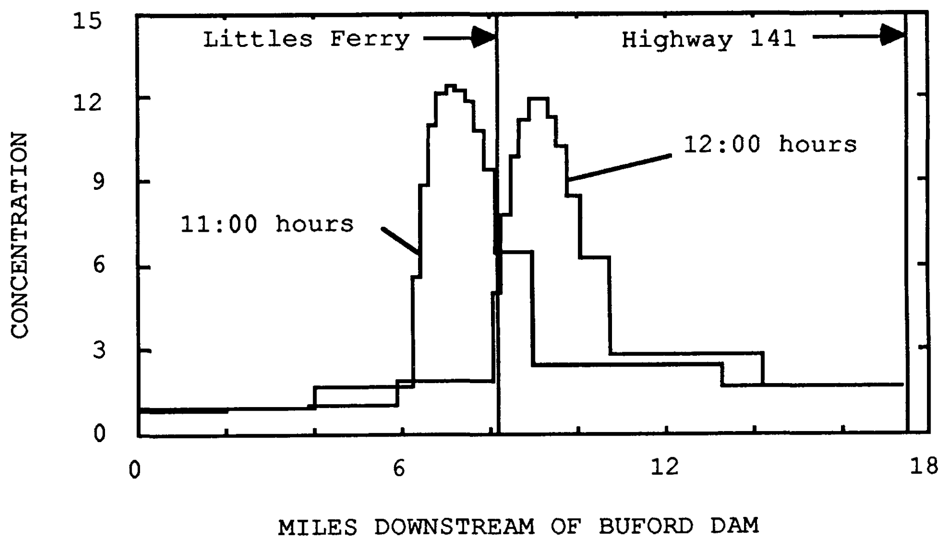

Figure 14.--Computed concentration profiles in the Chattahoochee River at two instants in time on March 23, 1976.

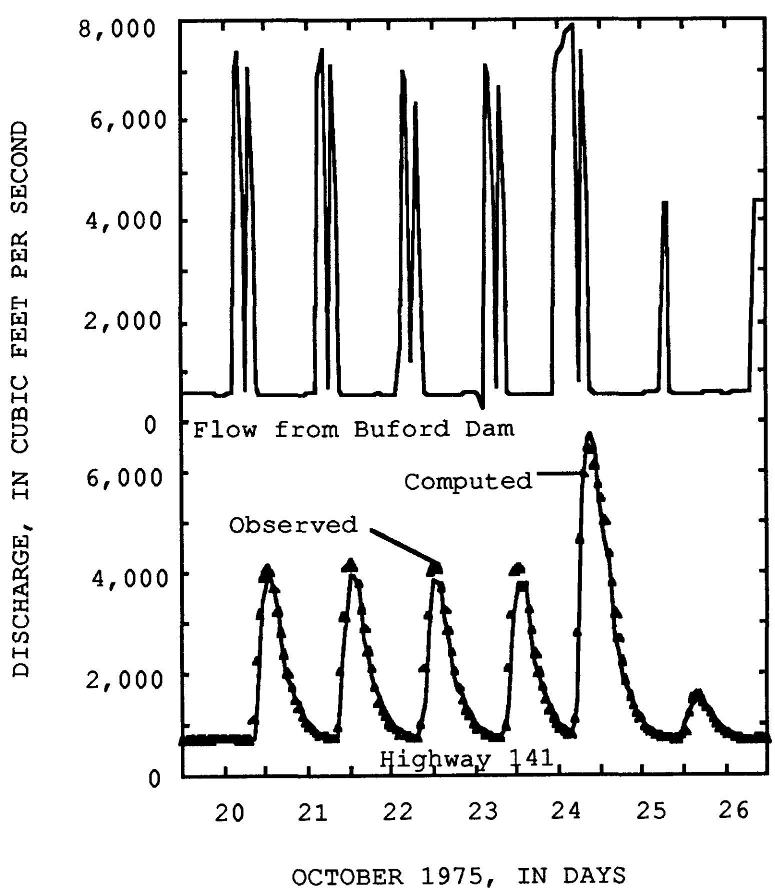

Figure 15.--Comparison of observed and computed flows in the Chattahoochee River.

Table 4.--<u>Stage at Buford Dam starting on October 20, 1975</u>
Zero stage = 10.04 feet

Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)
October 20, 1975		*October 21, 1975*		*October 22, 1975*		*October 23, 1975*	
0.00	15.39	18.00	19.03	18.50	15.85	15.25	19.86
1.00	15.43	19.00	15.53	18.75	15.54	15.50	20.82
4.00	15.43	20.00	21.10	19.00	16.09	15.75	20.99
5.00	15.41	21.00	18.89	19.25	20.20	16.00	21.08
8.00	15.41	22.00	15.47	19.50	20.83	16.25	21.15
9.00	15.41	23.00	15.38	19.75	21.03	16.50	21.23
10.00	15.40	*October 22, 1975*		20.00	20.50	16.75	21.28
11.00	15.37	0.00	15.38	20.25	19.36	17.00	20.96
12.00	15.36	1.00	15.37	20.50	19.06	17.25	19.63
13.00	15.36	2.00	15.37	20.75	18.96	17.50	19.23
14.00	15.40	3.00	15.38	21.00	18.58	17.75	19.07
15.00	15.40	8.00	15.38	21.25	16.58	18.00	18.83
16.00	21.02	9.00	15.39	21.50	15.85	18.25	16.74
17.00	21.30	10.00	15.36	21.75	15.54	18.50	15.95
18.00	18.96	11.50	15.36	22.00	15.43	18.75	15.59
19.00	15.48	11.75	15.38	22.25	15.40	19.00	15.54
20.00	21.06	14.75	15.38	22.50	15.38	19.25	19.59
21.00	18.83	15.00	16.38	23.25	15.38	19.50	20.75
22.00	15.55	15.25	20.24	23.50	15.37	19.75	20.97
23.00	15.38	15.50	20.75	*October 23, 1975*		20.00	20.74
October 21, 1975		15.75	20.99	5.25	15.37	20.25	19.39
7.00	15.38	16.00	21.02	5.50	15.38	20.50	19.05
8.00	15.35	16.25	21.15	9.25	15.38	20.75	18.92
9.00	15.35	16.50	21.25	9.50	15.39	21.00	18.77
10.00	15.38	16.75	21.31	9.75	15.40	21.25	16.68
12.00	15.38	17.00	20.83	13.00	15.40	21.50	15.89
13.00	15.41	17.25	19.51	13.25	15.39	21.75	15.55
14.00	15.40	17.50	19.11	13.50	15.39	22.00	15.43
15.00	15.40	17.75	18.94	13.75	15.38	22.25	15.38
16.00	20.92	18.00	18.47	14.75	15.38	22.75	15.38
17.00	21.34	18.25	16.55	15.00	15.01	23.00	15.37

Table 4.--Stage at Buford Dam starting on October 20, 1975--continued
Zero stage = 10.04 feet

Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)
October 24, 1975		*October 24, 1975*		*October 25, 1975*		*October 26, 1975*	
6.25	15.37	18.50	16.50	19.75	18.85	21.75	18.89
6.50	15.38	18.75	15.93	20.00	18.86	22.00	18.89
11.00	15.38	19.00	15.61	20.25	17.54	22.25	17.87
11.25	18.95	19.25	17.08	20.50	16.13	22.50	16.27
11.50	20.64	19.50	20.89	20.75	15.64	22.75	15.71
11.75	20.94	19.75	21.16	21.00	15.46	23.00	15.51
12.00	21.00	20.00	21.36	21.25	15.40	23.25	15.44
12.25	21.07	20.25	20.30	21.50	15.38	23.50	15.42
12.50	21.16	20.50	19.46	21.75	15.38	23.75	15.41
12.75	21.22	20.75	19.18	22.00	15.37	*October 27, 1975*	
13.00	21.27	21.00	19.06	*October 26, 1975*		4.00	15.41
13.25	21.27	21.25	17.15	9.00	15.37	5.00	15.38
13.50	21.29	21.50	16.13	9.25	15.39	6.00	15.38
13.75	21.34	21.75	15.67	9.50	15.40	7.00	17.12
14.00	21.37	22.00	15.47	11.25	15.40	8.00	21.48
14.25	21.45	22.25	15.40	11.50	15.39	9.00	21.85
14.50	21.51	22.5	15.38	11.75	15.38	10.00	22.19
14.75	21.56	22.75	15.38	14.50	15.38	11.00	21.21
15.00	21.59	23.00	15.37	14.75	15.39	12.00	15.99
15.25	21.61	*October 25, 1975*		15.00	15.39	13.00	15.40
15.50	21.65	13.25	15.37	15.25	15.40	14.00	15.39
15.75	21.66	13.50	15.38	17.00	15.40	15.00	15.39
16.00	21.69	13.75	15.38	17.25	15.41	16.00	15.37
16.25	21.72	14.00	15.39	17.50	15.40	18.00	15.37
16.50	21.75	14.25	15.40	17.75	15.39	19.00	21.24
16.75	21.74	18.00	15.40	20.00	15.39	20.00	16.82
17.00	21.76	18.25	17.31	20.25	16.80	21.00	15.42
17.25	20.46	18.50	18.60	20.50	18.57	22.00	15.37
17.50	19.84	18.75	18.78	20.75	18.79	23.00	15.35
17.75	19.53	19.00	18.81	21.00	18.85	20.00	15.34
18.00	19.34	19.25	18.83	21.75	18.88		
18.25	17.67	19.50	18.84	21.50	18.88		

Table 5.--Stage at Highway 141 starting on October 20, 1975
Zero gage = 78.14 feet

Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)
October 20, 1975		*October 21, 1975*		*October 21, 1975*		*October 21, 1975*	
0.00	80.02	0.00	84.01	8.00	81.69	15.75	80.23
8.75	80.02	0.25	84.12	8.25	81.57	16.00	80.21
9.00	80.03	0.50	84.19	8.50	81.48	16.25	80.20
9.50	80.03	0.75	84.24	8.75	81.40	16.50	80.19
9.75	80.04	1.00	84.28	9.00	81.34	16.75	80.17
16.75	80.04	1.50	84.28	9.25	81.25	17.00	80.15
17.00	80.03	1.75	84.26	9.50	81.20	17.15	80.14
17.75	80.03	2.00	84.22	9.75	81.14	17.50	80.13
18.00	80.02	2.25	84.14	10.00	81.07	17.75	80.12
18.5	80.02	2.50	84.04	10.25	81.00	18.00	80.11
18.75	80.01	2.75	83.97	10.50	80.94	18.25	80.10
19.50	80.01	3.00	83.89	10.75	80.89	18.50	80.09
19.75	80.00	3.25	83.76	11.00	80.84	18.75	80.08
20.00	80.03	3.50	83.64	11.25	80.78	19.00	80.07
20.25	80.06	3.75	83.54	11.50	80.74	19.25	80.05
20.50	80.23	4.00	83.44	11.75	80.69	20.25	80.05
20.75	80.34	4.25	83.29	12.00	80.65	20.50	80.14
21.00	80.69	4.50	83.18	12.25	80.62	20.75	80.24
21.25	81.14	4.75	83.06	12.50	80.59	21.00	80.44
21.50	81.49	5.00	82.97	12.75	80.54	21.25	80.79
21.75	81.94	5.25	82.84	13.00	80.49	21.50	81.24
22.00	82.34	5.50	82.74	13.25	80.47	21.75	81.64
22.25	82.64	5.75	82.64	13.50	80.43	22.00	82.04
22.50	82.86	6.00	82.49	13.75	80.39	22.25	82.44
22.75	83.23	6.25	82.34	14.00	80.36	22.50	82.84
23.00	83.38	6.50	82.24	14.25	80.34	22.75	83.04
23.25	83.55	6.75	82.15	14.50	80.32	23.00	83.29
23.50	83.76	7.00	82.07	14.75	80.30	23.25	83.59
23.75	83.92	7.25	81.94	15.00	80.28	23.50	83.74
		7.50	81.84	15.25	80.26	23.75	83.89
		7.75	81.75	15.50	80.24		

Table 5.--Stage at Highway 141 starting on October 20, 1975--continued
Zero gage = 78.14 feet

Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)
October 22, 1975		*October 22, 1975*		*October 22, 1975*		*October 22, 1975*	
0.00	84.11	6.00	82.57	12.00	80.63	18.00	80.10
0.25	84.25	6.25	82.44	12.25	80.57	18.25	80.09
0.50	84.31	6.50	82.34	12.50	80.53	18.50	80.08
0.75	84.38	6.75	82.24	12.75	80.49	18.75	80.07
1.00	84.40	7.00	82.13	13.00	80.46	19.00	80.06
1.25	84.40	7.25	82.02	13.25	80.44	19.25	80.05
1.50	84.39	7.50	81.89	13.50	80.41	20.00	80.05
1.75	84.36	7.75	81.79	13.75	80.38	20.25	80.06
2.00	84.33	8.00	81.69	14.00	80.35	20.50	80.14
2.25	84.29	8.25	81.58	14.25	80.34	20.75	80.28
2.50	84.20	8.50	81.47	14.50	80.31	21.00	80.54
2.75	84.09	8.75	81.40	14.75	80.28	21.25	80.94
3.00	84.00	9.00	81.32	15.00	80.22	21.50	81.34
3.25	83.92	9.25	81.26	15.25	80.25	21.75	81.74
3.50	83.79	9.50	81.19	15.50	80.23	22.00	82.14
3.75	83.65	9.75	81.12	15.75	80.21	22.25	82.52
4.00	83.51	10.00	81.04	16.00	80.20	22.50	82.84
4.25	83.40	10.25	80.97	16.25	80.19	22.75	83.06
4.50	83.28	10.50	80.92	16.50	80.17	23.00	83.34
4.75	83.16	10.75	80.86	16.75	80.16	23.25	83.54
5.00	83.05	11.00	80.82	17.00	80.15	23.50	83.74
5.25	82.93	11.25	80.76	17.25	80.13	23.75	83.90
5.50	82.79	11.50	80.72	17.50	80.12		
5.75	82.65	11.75	80.67	17.75	80.11		

Table 5.--Stage at Highway 141 starting on October 20, 1975--continued
Zero gage = 78.14 feet

Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)
October 23, 1975		*October 23, 1975*		*October 23, 1975*		*October 23, 1975*	
0.00	84.04	6.00	82.52	12.00	80.62	18.00	80.08
0.25	84.14	6.25	82.39	12.25	80.58	18.25	80.07
0.50	84.24	6.50	82.27	12.50	80.54	18.50	80.06
0.75	84.33	6.75	82.15	12.75	80.49	18.75	80.05
1.00	84.37	7.00	82.08	13.00	80.45	20.25	80.05
1.25	84.37	7.25	81.94	13.25	80.42	20.50	80.14
1.50	84.35	7.50	81.87	13.50	80.39	20.75	80.24
1.75	84.34	7.75	81.77	13.75	80.36	21.00	80.49
2.00	84.29	8.00	81.68	14.00	80.34	21.25	80.84
2.25	84.22	8.25	81.58	14.25	80.31	21.50	81.24
2.50	84.14	8.50	81.49	14.50	80.28	21.75	81.74
2.75	84.04	8.75	81.42	14.75	80.26	22.00	82.09
3.00	83.94	9.00	81.34	15.00	80.24	22.25	82.54
3.25	83.82	9.25	81.27	15.25	80.22	22.50	82.79
3.50	83.30	9.50	81.20	15.50	80.20	22.75	83.04
3.75	83.62	9.75	81.13	15.75	80.19	23.00	83.34
4.00	83.49	10.00	81.06	16.00	80.18	23.25	83.54
4.25	83.37	10.25	80.99	16.25	80.17	23.50	83.69
4.50	83.24	10.50	80.93	16.50	80.15	23.75	83.84
4.75	83.12	10.75	80.86	16.75	80.14		
5.00	82.99	11.00	80.82	17.00	80.13		
5.25	82.86	11.25	80.76	17.25	80.12		
5.50	82.74	11.50	80.72	17.50	80.10		
5.75	82.63	11.75	80.67	17.75	80.09		
October 24, 1975		*October 24, 1975*		*October 24, 1975*		*October 24, 1975*	
0.00	83.99	6.00	82.50	12.00	80.61	18.00	82.89
0.25	84.11	6.25	82.38	12.25	80.57	18.25	83.44
0.50	84.20	6.50	82.27	12.50	80.52	18.50	83.94
0.75	84.27	6.75	82.17	12.75	80.48	18.75	84.44
1.00	84.32	7.00	82.07	13.00	80.45	19.00	84.84
1.50	84.32	7.25	81.96	13.25	80.42	19.25	85.24
1.75	84.31	7.50	81.85	13.50	80.39	19.50	85.54
2.00	84.28	7.75	81.77	13.75	80.36	19.75	85.74
2.25	84.24	8.00	81.69	14.00	80.32	20.00	85.99
2.50	84.14	8.25	81.59	14.25	80.30	20.25	86.19
2.75	84.04	8.50	81.48	14.50	80.27	20.50	86.28
3.00	83.94	8.75	81.39	14.75	80.25	20.75	86.41
3.25	83.84	9.00	81.33	15.00	80.23	21.00	86.44
3.50	83.74	9.25	81.26	15.25	80.22	21.25	86.47
3.75	83.62	9.50	81.18	15.50	80.20	21.50	86.47
4.00	83.49	9.75	81.11	15.75	80.18	21.75	86.45
4.25	83.37	10.00	81.04	16.00	80.17	22.00	86.40
4.50	83.24	10.25	80.97	16.25	80.17	22.25	86.34
4.75	83.12	10.50	80.89	16.50	80.24	22.50	86.29
5.00	82.99	10.75	80.84	16.75	80.34	22.75	86.24
5.25	82.86	11.00	80.80	17.00	80.69	23.00	86.18
5.50	82.75	11.25	80.75	17.25	81.14	23.25	86.12
5.75	82.63	11.50	80.70	17.50	81.64	23.50	86.05
		11.75	80.65	17.75	82.24	23.75	85.99

Table 5.--Stage at Highway 141 starting on October 20, 1975--continued
Zero gage = 78.14 feet

Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)
October 25, 1975		*October 25, 1975*		*October 25, 1975*		*October 25, 1975*	
0.00	85.94	6.00	82.84	12.00	80.71	18.00	80.10
0.25	85.90	6.25	82.67	12.25	80.66	18.25	80.09
0.50	85.84	6.50	82.54	12.50	80.59	18.50	80.08
0.75	85.74	6.75	82.44	12.75	80.54	18.75	80.07
1.00	85.64	7.00	82.34	13.00	80.50	19.00	80.06
1.25	85.54	7.25	82.20	13.25	80.47	19.25	80.06
1.50	85.44	7.50	82.10	13.50	80.44	19.50	80.05
1.75	85.34	7.75	82.01	13.75	80.40	20.00	80.05
2.00	85.22	8.00	81.89	14.00	80.38	20.25	80.04
2.25	85.04	8.25	81.76	14.25	80.35	21.50	80.04
2.50	84.89	8.50	81.67	14.50	80.33	21.75	80.03
2.75	84.74	8.75	81.61	14.75	80.30	22.75	80.03
3.00	84.59	9.00	81.48	15.00	80.28	23.00	80.02
3.25	84.46	9.25	81.40	15.25	80.26	23.50	80.02
3.50	84.34	9.50	81.32	15.50	80.23	23.75	80.03
3.75	84.19	9.75	81.24	15.75	80.22		
4.00	84.02	10.00	81.18	16.00	80.20		
4.25	83.84	10.25	81.12	16.25	80.19		
4.50	83.66	10.50	81.03	16.50	80.18		
4.75	83.54	10.75	80.95	16.75	80.16		
5.00	83.39	11.00	80.90	17.00	80.15		
5.25	83.24	11.25	80.84	17.25	80.14		
5.50	83.14	11.50	80.78	17.50	80.13		
5.75	82.97	11.75	80.74	17.75	80.12		
October 26, 1975		*October 26, 1975*		*October 26, 1975*		*October 26, 1975*	
0.00	80.04	6.00	81.32	12.00	80.30	18.00	80.00
0.25	80.07	6.25	81.28	12.25	80.27	18.25	79.99
0.50	80.14	6.50	81.23	12.50	80.26	18.50	79.99
0.75	80.24	6.75	81.17	12.75	80.24	18.75	79.98
1.00	80.32	7.00	81.11	13.00	80.22	19.75	79.98
1.25	80.45	7.25	81.04	13.25	80.20	20.00	79.97
1.50	80.63	7.50	80.99	13.50	80.18	23.75	79.97
1.75	80.74	7.75	80.94	13.75	80.16		
2.00	80.92	8.00	80.91	14.00	80.14		
2.25	81.09	8.25	80.86	14.25	80.12		
2.50	81.21	8.50	80.79	14.50	80.10		
2.75	81.30	8.75	80.76	14.75	80.09		
3.00	81.37	9.00	80.73	15.00	80.08		
3.25	81.44	9.25	80.70	15.25	80.07		
3.50	81.48	9.50	80.66	15.50	80.06		
3.75	81.51	9.75	80.62	15.75	80.05		
4.25	81.51	10.00	80.55	16.00	80.04		
4.50	81.50	10.25	80.51	16.25	80.04		
4.75	81.49	10.50	80.48	16.50	80.03		
5.00	81.47	10.75	80.44	16.75	80.03		
5.25	81.44	11.00	80.41	17.00	80.02		
5.50	81.40	11.25	80.38	17.25	80.02		
5.75	81.35	11.50	80.35	17.50	80.01		
		11.75	80.33	17.75	80.01		

Table 5.--Stage at Highway 141 starting on October 20, 1975--continued
Zero gage = 78.14 feet

Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)	Time (hours)	Stage (feet)
October 27, 1975		*October 27, 1975*		*October 27, 1975*		*October 27, 1975*	
0.00	79.97	6.00	81.47	12.00	80.55	18.00	84.84
2.00	79.97	6.50	81.47	12.25	80.55	18.25	84.64
2.25	80.02	6.75	81.45	12.50	80.59	18.50	84.44
2.50	80.06	7.00	81.44	12.75	80.72	18.75	84.34
2.75	80.14	7.25	81.41	13.00	80.99	19.00	84.19
3.00	80.26	7.50	81.37	13.25	81.44	19.25	83.99
3.25	80.34	7.75	81.33	13.50	81.94	19.50	83.84
3.50	80.54	8.00	81.29	13.75	82.49	19.75	83.74
3.75	80.64	8.25	81.25	14.00	83.04	20.00	83.51
4.00	80.82	8.50	81.21	14.25	83.74	20.25	83.35
4.25	80.94	8.75	81.16	14.50	84.14	20.50	83.23
4.50	81.14	9.00	81.10	14.75	84.44	20.75	83.12
4.75	81.23	9.25	81.04	15.00	84.84	21.00	82.98
5.00	81.31	9.50	80.99	15.25	85.10	21.25	82.77
5.25	81.36	9.75	80.95	15.50	85.24	21.50	82.70
5.50	81.44	10.00	80.90	15.75	85.34	21.75	82.54
5.75	81.45	10.25	80.85	16.00	85.38	22.00	82.41
		10.50	80.82	16.25	85.39	22.25	82.27
		10.75	80.75	16.50	85.37	22.50	82.14
		11.00	80.72	16.75	85.34	22.75	82.06
		11.25	80.69	17.00	85.27	23.00	81.98
		11.50	80.64	17.25	85.16	23.25	81.84
		11.75	80.60	17.50	85.04	23.50	81.80
				17.75	84.92	23.75	81.73

Table 6.--Rating tables for Chattahoochee River below Buford Dam and at Highway 141

Buford Dam		Highway 141			
Stage (feet)	discharge (ft^3/s)	Stage (feet)	discharge (ft^3/s)	Stage (feet)	discharge (ft^3/s)
14.84	200	78.14	0	81.14	1,350
15.04	300	79.64	577	81.34	1,480
15.14	360	79.74	607	81.54	1,620
15.24	430	79.84	642	82.34	2,260
15.64	750	79.94	683	83.54	3,340
15.84	930	80.04	730	84.94	4,740
16.54	1,630	80.24	830	85.54	5,400
17.04	2,180	80.34	882	86.34	6,360
21.04	4,580	80.44	936	87.04	7,270
24.04	10,880	80.54	992	88.14	8,810
		80.64	1,050	88.54	9,410
				90.14	11,970

SUMMARY

A digital model for routing streamflow using the diffusion analogy form of the flow equations in conjunction with a Lagrangian solution scheme has been presented. Use of the model is demonstrated by use of two examples. The flow model is designed to provide reasonable predictions of discharge and transport velocity using a minimum of field data and calibration. The use of hydraulic geometry coefficients for area and top width is believed to contribute to the model's predictive capability. The flow model presented here is designed to support the BLTM transport model documented by Jobson and Schoellhamer (1987), which simulates the fate and movement of dissolved water-quality constituents through a network of upland streams and rivers. It also should be useful for routine flow routing applications.

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APPENDIX A

Interactive program (BDAFLOW) to generate the input file FLOW.IN for the flow model (DAFLOW)

The DAFLOW model requires an input file called FLOW.IN. This file contains a large amount of information that must be in a specific format. The interactive program BDAFLOW is designed to help construct the input file. The file FLOW.IN is divided into three parts: general information, branch information, and boundary conditions. The data for the first two parts can be entered, through BDAFLOW, either from the terminal or from an existing file called OLD. The file OLD must have the same format as FLOW.IN so the terminal should be used to create the input file. Once created, the information can be stored in OLD and the third part of the file, the boundary conditions, can be modified without having to reenter the first two parts of the file. Once constructed, the file FLOW.IN is designed to be easily edited using any text editor (see figs. 6 and 11).

The information in the third part of the file, the boundary conditions, is more voluminous and more difficult to edit. The program BDAFLOW allows the boundary conditions to be entered from the terminal, from the file OLD, or from a file called BC. If the file OLD is used, any boundary conditions stored there will be transferred to FLOW.IN and the boundary condition at one grid can be added or changed based on input from either the terminal or the file BC. If two or more boundary conditions are to be changed or added, the program BDAFLOW could be run repeatedly with different boundary conditions stored in the file BC for each run and the file FLOW.IN copied to the file OLD after each run.

The file BC is assumed to contain two lines of text information at the top of the file, which could be used to identify the data, and so forth. Following these two lines of text, the file is assumed to contain two columns of data that are 12 columns wide. The first column is ignored but could contain the times at which the boundary conditions apply. The second column is assumed to contain the average discharge at the grid point during each time step. It is assumed to be stored in the format G12.4. The first entry after the text information, line 3, is assumed to contain the average discharge during the first time step of the model. It is assumed that there are at least NHR (number of time steps run by DAFLOW) boundary values in the file BC.

The following is a listing of the source code for BDAFLOW.

```
C     + + + PURPOSE + + +
C
C     This program builds the input file for DAFLOW
C
C***  BEGIN DIMENSIONING DEFINITION
C
C     NOBR      Maximum number of branches allowed in model
C     NOSC      Maximum number of cross sections (grids) allowed in branch
C     NONBC     Maximum number of boundary conditions allowed (NOSC*NOBR)
C
      INTEGER NOBR,NOSC,NONBC
      PARAMETER (NOBR=10, NOSC=12, NONBC=120)
C
C     + + + LOCAL VARIABLES + + +
C
      INTEGER I,IED,IENG,IOUT(NOSC),ITRM,J,JGO,JGOT,JNCD,JNCU,JTS,
     #        JTST,K,N,NB(NONBC),NBC,NBN,NBRCH,NG(NONBC),NGN,NHR,
     #        NJNCT,NXSEC
      REAL    AO(NOSC),A1(NOSC),A2(NOSC),DF(NOSC),DT,PF,PFT,Q(NONBC),
     #        QP,TA1,TA2,TAO,TD,TQ,TW1,TW2,TRIB(NOSC,NOBR),TITLE(20),
     #        W1(NOSC),W2(NOSC),X(NOSC)
      LUBC=17
      LUOUT=16
      OPEN (LUOUT,FILE='FLOW.IN')
      LUIN=15
C
C     + + + INPUT FORMATS
C
 1000 FORMAT(20A4)
 1010 FORMAT(20X,I10)
 1020 FORMAT(20X,F10.3)
 1030 FORMAT(13X,I3,16X,F5.2,16X,I3,8X,I3)
 1040 FORMAT('Grd R Mile  IOUT  Disch        A1        A2        AO
     &   DF         W1    W2')
 1050 FORMAT(I3,G11.4,I2,G11.4,4G10.3,F7.1,F6.3)
 1060 FORMAT(12X,G12.4)
 1070 FORMAT(18X,I3)
 1080 FORMAT(10X,I3,5X,I3,3X,G14.5)
C
C     + + + OUTPUT FORMATS + + +
C
 2000  FORMAT('  Enter title (no more than 80 characters)',/)
 2010 FORMAT('No. of Branches     ',I10,' *')
 2020 FORMAT('Internal Junctions  ',I10,' *')
 2030 FORMAT('Time Steps Modeled  ',I10,' *')
 2040 FORMAT('Model Starts        ',I10,' time steps after midnight.')
 2050 FORMAT('Output Given Every  ',I10,' time steps in FLOW.OUT.')
 2060 FORMAT('0=Metric,1=English  ',I10,' *')
 2070 FORMAT('Time Step Size      ',F10.3,' Hours.')
 2080 FORMAT('Peak Discharge      ',F10.0,' *')
 2090 FORMAT('Branch',I3,' has',I3,' xsects & routes',F5.2,' of flow at
     $JNCT',I3,' To JNCT',I3)
 2100 FORMAT('for Time',I5,' NBC=',I3,' *')
 2110 FORMAT(' Branch   ',I3,' Grid',I3,' Q=',G14.5,' *')
 2120 FORMAT('for Time',I5,' NBC=',I3,' *')
 2130 FORMAT(' Branch   ',I3,' Grid',I3,' Q=',G14.5,' *')
C
C     + + + CODE + + +
```

```
C
      WRITE(*,*)'Enter 0 to create new file, 1 to edit existing file- '
      READ(*,*)IED
      IF(IED.EQ.1) THEN
       OPEN(LUIN,FILE='OLD')
       READ(LUIN,1000)(TITLE(K),K=1,20)
      ELSE
       WRITE(*,2000)
       READ (*,1000)(TITLE(K),K=1,20)
      END IF
      WRITE(LUOUT,1000)(TITLE(K),K=1,20)
      IF(IED.EQ.1) THEN
       READ(LUIN,1010)NBRCH
      ELSE
       WRITE(*,*)'Enter number of branches = '
       READ(*,*)NBRCH
      END IF
      WRITE(LUOUT,2010)NBRCH
      IF(IED.EQ.1)THEN
       READ(LUIN,1010)NJNCT
      ELSE
       WRITE(*,*)'Enter number of internal junctions = '
       READ(*,*)NJNCT
      END IF
      WRITE(LUOUT,2020)NJNCT
      IF(IED.EQ.1)THEN
       READ(LUIN,1010)NHR
      ELSE
       WRITE(*,*)'Enter number of time steps to be modeled = '
       READ(*,*)NHR
      END IF
      WRITE(LUOUT,2030)NHR
      IF(IED.EQ.1)THEN
       READ(LUIN,1010)JTS
      ELSE
       JTS=1
       WRITE(*,*)'Enter number of time steps from midnight to start of m
     #odel. '
      WRITE(*,*)' To select default enter any letter, Default=1, JTS = '
       READ(*,*,ERR=1)JTST
       JTS=JTST
    1 END IF
      WRITE(LUOUT,2040)JTS
      IF(IED.EQ.1)THEN
       READ(LUIN,1010)JGO
      ELSE
       JGO=1
      WRITE(*,*)'Enter number of time steps between outputs in FLOW.OUT
     #file, Default=1, JGO = '
       READ(*,*,ERR=2)JGOT
       JGO=JGOT
    2 END IF
      WRITE(LUOUT,2050)JGO
      IF(IED.EQ.1)THEN
       READ(LUIN,1010)IENG
      ELSE
       WRITE(*,*)'Enter 0 for metric units or 1 for English units-  '
       READ(*,*)IENG
```

```
      END IF
      WRITE(LUOUT,2060)IENG
      IF(IED.EQ.1)THEN
       READ(LUIN,1020)DT
      ELSE
       WRITE(*,*)'Enter time step size in hours = '
       READ(*,*)DT
      END IF
      WRITE(LUOUT,2070)DT
      IF(IED.EQ.1)THEN
       READ(LUIN,1020)QP
      ELSE
       WRITE(*,*)'Enter maximum discharge of interest = '
       READ(*,*)QP
      END IF
      WRITE(LUOUT,2080)QP
      QP=QP/100000.0
      QO=0.0
      TQ=0.0
      TA1=7.0
      TA2=0.66
      TAO=0.0
      TD=5000.0
      TW1=50.0
      TW2=0.26
      DO 15 N=1,NBRCH
       IF(IED.EQ.1)THEN
        READ(LUIN,1030)NXSEC,PF,JNCU,JNCD
       ELSE
        WRITE(*,*)'For branch',N
        WRITE(*,*)'                              Number of cross sections = '
        READ(*,*)NXSEC
        WRITE(*,*)'  Junction number at upstream end of branch = '
        READ(*,*)JNCU
        WRITE(*,*)'Junction number at downstream end of branch = '
        READ(*,*)JNCD
        PF=1.0
        WRITE(*,*)'Part of flow at upstream junction to enter branch'
       WRITE(*,*)'                                    Default=1.0 (100 %), PF = '
        READ(*,*,ERR=3)PFT
        PF=PFT
    3  END IF
       WRITE(LUOUT,2090)N,NXSEC,PF,JNCU,JNCD
       IF(IED.EQ.1) READ(LUIN,1000)(TITLE(K),K=1,20)
       WRITE(LUOUT,1040)
       IF(IED.EQ.0)WRITE(*,*)'For each cross section (grid) enter the fo
     #llowing:'
       DO 11 I=1,NXSEC
        IF(IED.EQ.1)THEN
         READ(LUIN,1050)K,X(I),IOUT(I),Q(I),A1(I),A2(I),AO(I),DF(I),
     $                    W1(I),W2(I)
        ELSE
         WRITE(*,*)'Distance downstream from reference point (miles)'
         WRITE(*,*)'                                    For grid',I,'   X(I) = '
         READ(*,*) X(I)
         IOUT(I)=0
         IF(I.EQ.NXSEC) GO TO 11
        WRITE(*,*)'Initial discharge at grid (Tribs enter just U/S of g
```

```
 #rid).  '
        WRITE(*,*)'Default =',TQ,' Q = '
        READ(*,*,ERR=4)Q(I)
        TQ=Q(I)
 4      Q(I)=TQ
        WRITE(*,*)'Cross sectional area = A1*Q**A2'
        WRITE(*,*)'Enter A1 for subreach, default=',TA1,' A1 = '
        READ(*,*,ERR=5)A1(I)
        TA1=A1(I)
 5      A1(I)=TA1
        WRITE(*,*)'Enter A2 for subreach (0.0<A2<1.0), default=',TA2,'
 #A2 = '
        READ(*,*,ERR=6)A2(I)
        TA2=A2(I)
 6      A2(I)=TA2
       WRITE(*,*)'Enter cross sectional area at zero flow, default =',
 #TAO,' AO = '
        READ(*,*,ERR=7)AO(I)
        TAO=AO(I)
 7      AO(I)=TAO
       WRITE(*,*)'Enter dispersion coefficient for subreach, default =
 #',TD,' DF = '
        READ(*,*,ERR=8)DF(I)
        TD=DF(I)
 8      DF(I)=TD
        WRITE(*,*)'Width=W1*(Q**W2)'
       WRITE(*,*)'Enter W1 for subreach downstream of grid, default ='
 #,TW1,' W1 = '
        READ(*,*,ERR=9)W1(I)
        TW1=W1(I)
 9      W1(I)=TW1
       WRITE(*,*)'Enter W2 for subreach (0.0<W2<0.8), default =',TW2,'
 # W2 = '
        READ(*,*,ERR=10)W2(I)
        TW2=W2(I)
10      W2(I)=TW2
       END IF
11    CONTINUE
      IF(IED.EQ.1)GO TO 13
      WRITE(*,*)'For branch',N
12    WRITE(*,*)'Enter grid of desired output (enter Q to quit) '
      READ(*,*,ERR=13) I
      IOUT(I)=1
      GO TO 12
13    INX=NXSEC-1
      DO 14 I=1,INX
       WRITE(LUOUT,1050)I,X(I),IOUT(I),Q(I),A1(I),A2(I),AO(I),DF(I),
 $                       W1(I),W2(I)
14    CONTINUE
      I=NXSEC
      WRITE(LUOUT,1050)I,X(I),IOUT(I)
15   CONTINUE
     WRITE(*,*)'Enter 0 to input boundary conditions from terminal, 1 f
 #rom file BC- '
     READ(*,*)ITRM
     IF(ITRM.EQ.0)GO TO 16
      OPEN(LUBC,FILE='BC')
      WRITE(*,*)'Enter BRANCH of boundary condition in file BC- '
```

```
    READ(*,*)NBN
    WRITE(*,*)'Enter  GRID  of boundary condition in file BC- '
    READ(*,*)NGN
    READ(LUBC,1000)(TITLE(K),K=1,20)
    READ(LUBC,1000)(TITLE(K),K=1,20)
16 IF(IED.EQ.0)THEN
   DO 19 J=1,NHR
    NBC=1
    IF(ITRM.EQ.1)GO TO 17
    WRITE(*,*)'For time step',J,' enter number of new boundary condit
  #ions-  '
    READ(*,*)NBC
17  WRITE(LUOUT,2100)J,NBC
    IF(NBC.EQ.0)GO TO 19
    DO 18 K=1,NBC
     IF(ITRM.EQ.1)THEN
      READ(LUBC,1060)TRIB(NGN,NBN)
     ELSE
      WRITE(*,*)'Enter BRANCH of new boundary condition- '
      READ(*,*)NBN
      WRITE(*,*)'Enter  GRID  of new boundary condition- '
      READ(*,*)NGN
      WRITE(*,*)'            Enter new boundary FLOW = '
      READ(*,*) TRIB(NGN,NBN)
     END IF
     WRITE(LUOUT,2110)NBN,NGN,TRIB(NGN,NBN)
18  CONTINUE
19 CONTINUE
   ELSE
     IF(ITRM.EQ.1)GO TO 20
      WRITE(*,*)'Enter BRANCH of new boundary condition- '
      READ(*,*)NBN
      WRITE(*,*)'Enter  GRID  of new boundary condition- '
      READ(*,*)NGN
20  DO 23 J=1,NHR
     READ(LUIN,1070)NBC
     K=0
     DO 21 KK=1,NBC
      K=K+1
      READ(LUIN,1080)NB(K),NG(K),Q(K)
      IF(NB(K).EQ.NBN.AND.NG(K).EQ.NGN)K=K-1
21   CONTINUE
     NBC=K+1
     IF(ITRM.EQ.1)THEN
      READ(LUBC,1060)Q(NBC)
     ELSE
      WRITE(*,*)'For time step',J,' Enter new boundary FLOW = '
      READ(*,*)Q(NBC)
     END IF
     NB(NBC)=NBN
     NG(NBC)=NGN
     DIF=ABS(Q(NBC)-QO)
     IF(DIF.LT.QP)NBC=NBC-1
     IF(DIF.GE.QP)QO=Q(NBC)
     WRITE(LUOUT,2120)J,NBC
     IF(NBC.EQ.0)GO TO 23
     DO 22 K=1,NBC
      WRITE(LUOUT,2130)NB(K),NG(K),Q(K)
```

```
22    CONTINUE
23   CONTINUE
      END IF
      ENDFILE(LUOUT)
      CLOSE(LUOUT)
      IF(IED.EQ.1)CLOSE(LUIN)
      IF(ITRM.EQ.1)CLOSE(LUBC)
      STOP
      END
```

APPENDIX B

Interactive program (CEL) for use in selecting or adjusting hydraulic geometry and wave dispersion values

The accuracy of the flow model is critically dependent on the proper selection of the hydraulic geometry coefficients (A1, A2, W1, W2) and the wave dispersion coefficient (DF). These values can be computed from estimates of flow resistance and channel width, from the wave speed of flood hydrographs, or a combination of these approaches. The accuracy of the model is mainly dependent on the proper specification of the wave speed and rate of attenuation of the peak flow. These two values are rather complex functions of the hydraulic geometry and wave dispersion values, however, so the program CEL is designed to aid in the selection or adjustment of these values.

The program has five options. The first option is to compute the wave dispersion coefficient and hydraulic geometry coefficients from estimates of flow resistance and channel width. These data could be obtained during one reconnaissance trip along the river as assumed for example 2. It is assumed that the slope, width, and Manning's n are known at a specified flow rate and that A2 and W2 are known. The values of A2 and W2 can be selected from table 1. If this option is selected, the program will request the slope of the river bed in the subreach, the system of units to be used, and the discharge for which the flow resistance and top width are known. It then asks for the average top width and the average Manning's resistance coefficient for the subreach at the given flow rate. Finally, the values of A2 and W2 and a representative discharge are requested. The representative discharge is the value used in equation 11 to compute the wave dispersion coefficient and so it should be the approximate average discharge to be expected during the simulation period.

Option 1 determines the values of A1, W1, DF, and DL by use of equations 3, 4, 10, 11, and 12, and prints the values to the screen.

If the wave speed cannot be obtained from a stage hydrograph and the values of A2 and W2 from table 1 are not acceptable, these values can be estimated from a knowledge of the flow resistance and channel width at two discharges. These data could be obtained from two reconnaissance trips to the river, at different discharges, preferably much different. The second option is used for this condition. The data required are the top width and Manning's n for two known discharges and the bed slope. The wave dispersion coefficient is computed for a representative discharge as in option 1. As in option 1, the coefficients are computed by use of equations 3, 4, 10, 11, and 12.

Probably the most accurate way to estimate the hydraulic geometry values is by use of stage hydrographs from which wave travel times for peaks of different sizes can be measured. Option 3 computes A1 and A2 from observed travel times of the peaks of two waves having different flow by use of equation 13. The two wave speeds should be obtained at discharges as much different as possible. The flow rate for each wave speed should be the approximate average of the peak flow as the peak passed each end of the subreach. For example, if the peak flow was 5,000 ft^3/s as it passed the upstream grid and had attenuated to 4,000 ft^3/s as it passed the downstream grid, the average discharge for the peak would be 4,500 ft^3/s. This option requires at least one estimate of the top width but will accept two widths if it is known at two flow rates. If only one width is provided, the value of W2 must be provided. The option also estimates and prints the approximate Manning's n value representative of each peak flow. If these values are not reasonable, a recheck of the data would be in order. Finally, a representative discharge is used to compute the wave dispersion coefficient as in option 1. This value should be an approximation of the average flow during the simulation.

The last two options are useful for calibrating the model. Wave speed is one of the main processes to be adjusted, but as can be seen from equation 13, it is a highly nonlinear function of A1 and A2. Options 4 and 5 allow the adjustment of A2 while holding the wave speed constant at a specified discharge or adjustment of the wave speed while holding A2 constant.

A complete listing of the source code for the program CEL follows.

```
C      This program computes Coefficients for area and width
C           A=A1*(Q**A2)
C           W=W1*(Q**W2)
      INTEGER IENG,IC,IW
      REAL A1,A2,AA,AH,AL,AN,ANL1,ANH,ANL,C,CH,CL,D,DL,DT,FN,Q,QH,QL,QM,RM,S,
     #     TA2,TW2,TH,TL,W1,W2,WL,WH
      WRITE(*,*)'What do you want to do?'
      WRITE(*,*)'1.  Compute coefficients from Mannings n.'
      WRITE(*,*)'2.  Compute coefficients from lag times of hydrograph.'
      WRITE(*,*)'3.  Adjust wave speed holding A2 constant.'
      WRITE(*,*)'4.  Adjust A2 holding wave speed constant.'
      WRITE(*,*)'Enter number of option    '
      READ(*,*)IW
      IF(IW.EQ.3)GO TO 30
      IF(IW.EQ.4)GO TO 40
      WRITE(*,*)'Enter bed slope=  '
      READ(*,*)S
      WRITE(*,*)'Enter 0 for English units, 1 for metric    '
      READ(*,*)IENG
      FN=1.49
      IF(IENG.EQ.1)FN=1.0
C
C     Compute width coefficients
C
      WRITE(*,*)'Enter discharge (not zero) where width is known = '
      READ(*,*)QL
      WRITE(*,*)'Enter width = '
      READ(*,*)WL
      WRITE(*,*)'Enter 0 to input W2 directly, 1 otherwise  '
      READ(*,*)IC
      IF(IC.EQ.0)THEN
       W2=0.26
       WRITE(*,*)'To select default enter any letter.  '
       WRITE(*,*)'Enter W2, default=0.26, Value = '
       READ(*,*,ERR=1)TW2
        W2=TW2
    1  CONTINUE
      ELSE
       WRITE(*,*)'Enter second discharge where width is known = '
       READ(*,*)QH
       WRITE(*,*)'Enter width at second discharge = '
       READ(*,*)WH
       W2=ALOG(WH/WL)/ALOG(QH/QL)
      END IF
      W1=WL/(QL**W2)
C
C     Compute A1 and A2
C
      IF(IW.EQ.2)GO TO 20
       WRITE(*,*)'Enter discharge where Mannings n is known = '
       READ(*,*)QL
       WRITE(*,*)'Enter Mannings n =  '
       READ(*,*)AN
       WL=W1*(QL**W2)
       AA=AN*QL*(WL**0.6667)/(FN*SQRT(S))
       AL=AA**0.6
       WRITE(*,*)'Enter 0 to input A2 directly, 1 otherwise  '
       READ(*,*)IC
```

```
      IF(IC.EQ.0)THEN
       A2=0.66
       WRITE(*,*)'      Enter A2 ,default=0.66, Value= '
       READ(*,*,ERR=2)TA2
        A2=TA2
 2     A1=AL/(QL**A2)
      ELSE
       WRITE(*,*)'Enter second discharge where Mannings n is known =  '
       READ(*,*)QH
       WRITE(*,*)'Enter second Mannings n = '
       READ(*,*)AN
       WH=W1*(QH**W2)
       AA=AN*QH*(WH**0.6667)/(FN*SQRT(S))
       AH=AA**0.6
       A2=(ALOG(AH)-ALOG(AL))/(ALOG(QH)-ALOG(QL))
       A1=AH/(QH**A2)
      END IF
      WRITE(*,*)'Enter representative discharge during simulation = '
      READ(*,*)Q
      WRITE(*,*)'A=',A1,' Q**',A2
      WRITE(*,*)'W=',W1,' Q**',W2
      D=(Q**(1.0-W2))/(2.0*S*W1)
      WRITE(*,*)' Wave dispersion coefficient =',D
      WRITE(*,*)' Enter time step size (hours)='
      READ(*,*)DT
      DL=SQRT(2.0*D*DT*3600.)
      WRITE(*,*)'DL=',DL
      GO TO 50
20 CONTINUE
     WRITE(*,*)'Enter discharge where wave speed is known =   '
     READ(*,*)QL
     WRITE(*,*)'Enter travel time of wave in hours = '
     READ(*,*)TL
     WRITE(*,*)'Enter reach length in miles = '
     READ(*,*)RM
     RM=RM*5280.0
     IF(IENG.EQ.1)RM=RM*0.3048
     CL=RM/(TL*3600.0)
     WRITE(*,*)'Celerity at first flow = ',CL
     WRITE(*,*)'Enter 0 to input A2 directly, 1 otherwise   '
     READ(*,*)IC
     IF(IC.EQ.0)THEN
      A2=0.66
      WRITE(*,*)'Enter A2, default=0.66, Value = '
      READ(*,*,ERR=21)TA2
      A2=TA2
21    CONTINUE
     ELSE
      WRITE(*,*)'Enter discharge at second peak = '
      READ(*,*)QH
      WRITE(*,*)'Enter travel time of wave in hours = '
      READ(*,*)TH
      CH=RM/(TH*3600.0)
      WRITE(*,*)'Celerity at second flow =  ',CH
      A2=1.0-(ALOG(CH/CL)/ALOG(QH/QL))
     END IF
     A1=(QL**(1.0-A2))/(A2*CL)
     WRITE(*,*)'Enter representative discharge during simulation = '
```

```
      READ(*,*)Q
      WRITE(*,*)'A= ',A1,'  Q** ',A2
      WRITE(*,*)'W= ',W1,' Q**',W2
      D=(Q**(1.0-W2))/(2.0*S*W1)
      WRITE(*,*)' Wave Dispersion coefficient =',D
      WRITE(*,*)' Enter time step size (hours)='
      READ(*,*)DT
      DL=SQRT(2.0*D*DT*3600.)
      WRITE(*,*)'DL=',DL
      ANL1=FN*(A1**1.6667)*(W1**(-0.6667))*SQRT(S)
      ANL=ANL1*(QL**(1.66667*A2-1.0-0.66667*W2))
      WRITE(*,*)'At a flow of',QL,' the approx. Mannings n is',ANL
      IF(IC.EQ.0)GO TO 50
       ANH=ANL1*(QH**(1.66667*A2-1.0-0.66667*W2))
       WRITE(*,*)'At a flow of',QH,' the approx. Mannings n is',ANH
       GO TO 50
 30   CONTINUE
      WRITE(*,*)'Enter value of A2 = '
      READ(*,*)A2
      WRITE(*,*)'Enter discharge where wave speed is known = '
      READ(*,*)Q
      WRITE(*,*)'Enter known wave speed = '
      READ(*,*)C
      A1=(Q**(1.0-A2))/(C*A2)
      WRITE(*,*)'A=',A1,' Q**',A2
      GO TO 50
 40   CONTINUE
       WRITE(*,*)'Enter old A1 = '
       READ(*,*)A1
       WRITE(*,*)'Enter old A2 = '
       READ(*,*)A2
       WRITE(*,*)'Enter discharge where wave speed is to be constant = '
       READ(*,*)QM
       C=(QM**(1.0-A2))/(A2*A1)
       WRITE(*,*)'Enter new A2 = '
       READ(*,*)A2
       A1=(QM**(1.0-A2))/(A2*C)
       WRITE(*,*)'A1=',A1
 41    WRITE(*,*)'Enter  Q where celerity is to be computed = '
        WRITE(*,*)'Enter Q to quit- '
        READ(*,*,ERR=50)Q
        C=(Q**(1.0-A2))/(A2*A1)
        WRITE(*,*)'C=',C
       GO TO 41
50    CONTINUE
      STOP
      END
```

APPENDIX C

Program (FLWPLT) used to plot values stored in BLTM.FLW as a function of time as well as plot observed values and compute the RMS errors

The file BLTM.FLW contains the computed discharge at every grid point in the system averaged over each time step of the simulation used to create it. This file also contains the tributary inflow averaged over the time step as well as the subreach averaged value of top width and cross-sectional area at the end of the time step for every subreach in the system. It is often desirable to plot one of these hydraulic variables as a function of time for a specified grid point or subreach and perhaps compare the computed values with observed data. The program FLWPLT is designed to help accomplish this.

The program FLWPLT issues prompts to determine the location (as specified by branch and grid or subreach), the type of data to be plotted, the system of units to be used, and the time-step size used during the simulation. It then retrieves the appropriate values from BLTM.FLW and prints a table of times and hydraulic values to a file called PLT.

The program next issues a prompt to determine if observed values are to be plotted. If the user selects to plot observed values, the program reads the values from a file called OBS. The first two records of the OBS file are not used by the program FLWPLT but are assumed to contain identification information. The remaining records of the file OBS contain pairs of time and hydraulic data ordered chronologically starting with the smallest time. The format of the input data should be 2G12.4. The times should be measured in hours starting at the beginning of the model time. For example, if the simulation starts at 0600 hours on March 23, the time of an observed value is the number of hours since 0600 hours on March 23.

Once the observed values are read, they are also rewritten to the file PLT. FLWPLT then determines the computed hydraulic variable at the time of each observed value by linear interpolation between the nearest computed values. The error is determined as the computed value minus the observed value. The errors and squares of errors are summed. The mean error and the root mean square error are written to the file PLT along with the number of observed points upon which the means are based.

At this point the program could be terminated if the DISSPLA[1/] software is not available. The file PLT can be imported to various other software packages and plotted.

If DISSPLA is available, FLWPLT displays the maximum and minimum values from the simulation and prompts for the maximum, minimum, and tick mark increments to be used in scaling each plot axis. The program then generates a plot of the computed values as a continuous curve and the observed values, if present, as a series of points. The following is a listing of the Fortran code of the program FLWPLT.

[1/]Reference to trade names, commercial products, manufacturers, or distributors in this manual is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey nor recommendation for use.

```
C     This program builds a file which can be imported to plot flow data
C     It can also plot by use of DISSPLA
C     FLOW(M)  flow field for M where:
C              M=1  for discharge in cu m/s
C              M=2  for area in sq meters
C              M=3  for top width in meters
C              M=4  for tributary inflow in cu m/s
C     X(NP)  x plotting position for point NP
C     Y(NP)  y plotting position for point NP
C     MP flow number to be plotted
C     NP  number of points to be plotted
C     DT  time step size in hours
C     NG  grid number where flow is desired
C
      INTEGER I,IC,IENG,IO,IOUT,K,J,LUIN,LUOBS,LUOUT,M,MP,N,NB,NG,NP
      REAL    BLK(20),DT,DX,DY,ER,FLOW(4),Q,QMAX,QMIN,SR,SRR,
     #        XC,X(2000),XMAX,XO(500),Y(2000),YC,YMAX,YMIN,YO(500)
      LUIN=35
      LUOUT=36
      LUOBS=37
      OPEN(LUIN,FILE='BLTM.FLW')
      OPEN(LUOUT,FILE='PLT')
C
C               + + + FORMATS + + +
C
 1500 FORMAT(I5,I5,I5,4E18.5)
 1600 FORMAT('Flow in branch',I3,' grid',I3,' DT=',F7.3)
 1601 FORMAT('Area in branch',I3,' subreach',I3,' DT=',F7.3)
 1602 FORMAT('Top width in branch',I3,' subreach',I3,' DT=',F7.3)
 1603 FORMAT('Tributary inflow to branch',I3,' grid',I3,' DT=',F7.3)
 1604 FORMAT(2G12.4)
 1700 FORMAT(20A4)
 1701 FORMAT(2G12.4)
C
C     ****** read plot data ******
C
      WRITE(*,*)'enter branch number where plot is desired  '
      READ(*,*)NB
      WRITE(*,*)'enter grid number where plot is desired  '
      READ(*,*)NG
      WRITE(*,*)'enter time step size, in hours  '
      READ(*,*) DT
      WRITE(*,*)'enter 1 to plot discharge at grid'
      WRITE(*,*)'enter 2 to plot cross sectional area in subreach'
      WRITE(*,*)'enter 3 to plot top width in subreach'
      WRITE(*,*)'enter 4 to plot tributary inflow at grid   '
      READ(*,*)MP
      WRITE(*,*)'enter 1 for English units, 2 for metric.  '
      READ(*,*)IENG
      IF(MP.EQ.1)WRITE(LUOUT,1600)NB,NG,DT
      IF(MP.EQ.2)WRITE(LUOUT,1601)NB,NG,DT
      IF(MP.EQ.3)WRITE(LUOUT,1602)NB,NG,DT
      IF(MP.EQ.4)WRITE(LUOUT,1603)NB,NG,DT
      WRITE(LUOUT,*)'   TIME    COMPUTED'
      NP=0
      X(1)=0.0
      IC=0
    1 CONTINUE
```

```
      READ(LUIN,1500,END=2)J,N,I,(FLOW(M),M=1,4)
      IF(N.NE.NB)GO TO 1
      IF(I.NE.NG)GO TO 1
      IF(IC.EQ.0)QMAX=FLOW(MP)
      IF(IC.EQ.0)QMIN=FLOW(MP)
      IC=1
      NP=NP+1
      IF(NP.GT.1)X(NP)=DT*(FLOAT(NP)-1.5)
      Y(NP)=FLOW(MP)
      IF(QMAX.LT.Y(NP))QMAX=Y(NP)
      IF(QMIN.GT.Y(NP))QMIN=Y(NP)
      WRITE(LUOUT,1604)X(NP),Y(NP)
      GO TO 1
    2 CONTINUE
C
C     BUILD OBSERVED FLOW FILE
C
      WRITE(*,*)'ENTER 1 TO PLOT OBSERVED Q, 0 OTHERWISE   '
      READ(*,*)IC
      IF(IC.NE.1)GO TO 10
      OPEN(LUOBS,FILE='OBS')
      IO=0
      READ(LUOBS,1700)(BLK(K),K=1,20)
      WRITE(LUOUT,1700)(BLK(K),K=1,20)
      READ(LUOBS,1700)(BLK(K),K=1,20)
      WRITE(LUOUT,1700)(BLK(K),K=1,20)
      WRITE(LUOUT,*)'   TIME     OBSERVED'
   12 READ(LUOBS,1701,END=11)XC,Q
      IO=IO+1
      XO(IO)=XC
      YO(IO)=Q
      WRITE(LUOUT,1604)XO(IO),YO(IO)
      GO TO 12
   11 CONTINUE
C
C     COMPUTE RMS
C
      SR=0.0
      SRR=0.0
      DO 13 I=1,IO
       N=0
   14  N=N+1
       IF(X(N).LT.XO(I)) GO TO 14
       YC=Y(N-1)+(Y(N)-Y(N-1))*(XO(I)-X(N-1))/(X(N)-X(N-1))
       ER=YC-YO(I)
       SR=SR+ER
       SRR=SRR+ER*ER
   13 CONTINUE
      SR=SR/(FLOAT(IO))
      SRR=SQRT(SRR/(FLOAT(IO)))
      WRITE(LUOUT,*)'MEAN ERROR=',SR,' RMS=',SRR,' BASED ON',IO,' POINTS
     #'
   10 CONTINUE
C
C     *****  plot results  *****
C
      WRITE(*,*)'ENTER 1 FOR HP OUTPUT OR 0 FOR SCREEN OUTPUT   '
      READ(*,*)IOUT
```

```
      IF(IOUT.EQ.1) CALL HP 7475 (1)
      IF(IOUT.EQ.0)CALL PTEKAL
      WRITE(*,*)'the maximum computed flow is',QMAX
      WRITE(*,*)'enter YMAX  '
      READ(*,*) YMAX
      WRITE(*,*)'the minimum computed flow is',QMIN
      WRITE(*,*)'enter YMIN  '
      READ(*,*)YMIN
      YC=ABS(YMIN)
      IF(YC.LT.0.00001)YMIN=0.0000001
      WRITE(*,*)'enter DY  '
      READ(*,*) DY
      WRITE(*,*)'the maximum time is',X(NP)
      WRITE(*,*)'enter XMAX in hours  '
      READ(*,*)XMAX
      WRITE(*,*)'enter DX in hours  '
      READ(*,*) DX
      CALL RESET('ALL')
      CALL PAGE(11.0,8.5)
      CALL AREA2D(10.0,7.0)
      CALL XNAME('Time, in hours$',100)
      IF(IENG.EQ.1)GO TO 21
      IF(MP.EQ.1)CALL YNAME('Discharge, in cu m/s$',100)
      IF(MP.EQ.2)CALL YNAME('Area, in sq meters$',100)
      IF(MP.EQ.3)CALL YNAME('Top width, in meters$',100)
      IF(MP.EQ.4)CALL YNAME('Tributary discharge, in cu m/s$',100)
      GO TO 20
   21 CONTINUE
      IF(MP.EQ.1)CALL YNAME('Discharge, in cu ft/s$',100)
      IF(MP.EQ.2)CALL YNAME('Area, in sq feet$',100)
      IF(MP.EQ.3)CALL YNAME('Top Width, in feet$',100)
      IF(MP.EQ.4)CALL YNAME('Tributary discharge, in cu ft/s$',100)
   20 CONTINUE
      CALL GRAF(0.0,DX,XMAX,YMIN,DY,YMAX)
      CALL CURVE(X,Y,NP,0)
      IF(IC.EQ.1)CALL CURVE(XO,YO,IO,-1)
      CALL MESSAG('GRID $',100,7.0,6.0)
      CALL INTNO(NG,'ABUT','ABUT')
      CALL ENDPL(0)
      CALL DONEPL
      CLOSE(LUIN)
      ENDFILE(LUOUT)
      CLOSE(LUOUT)
      IF(IC.EQ.1)CLOSE(LUOBS)
      STOP
      END
```

APPENDIX D

Modifications necessary to the BLTM transport model so that it properly interprets the data in BLTM.FLW generated by DAFLOW

The major reason for developing the diffusion analogy flow model (DAFLOW) was to provide a simple yet accurate model that could provide input to the Branched Lagrangian Transport Model (BLTM) for upland streams. The BLTM documented by Jobson and Schoellhamer (1987) was developed to accept input of instantaneous values of discharge, cross-sectional area, and top widths at grid points (cross sections) as produced by an Eulerian flow model, such as the Branched-network flow model documented by Schaffranek and others (1981). The DAFLOW model, however, produces values of discharge that have been averaged over the time step and subreach averaged values of cross-sectional area and top width. Three modifications to the BLTM Fortran source code are necessary to enable it to properly interpret the data in BLTM.FLW file generated by DAFLOW.

First, the computation of the initial volumes of the water parcels must be computed by a slightly different formula by changing the eighth line of the following sequence

```
        DO 210 I=1,INX
          DX(N,I)=(X(N,I+1)-X(N,I))*XFACT
          DO 205 KK=1,IPPR(N)
            K=(I-1)*IPPR(N)+KK
            NIPX(N,K)=I
            IF (KK .EQ. 1) NIPX(N,K)=I-1
            PX(K)=FLOAT(I)+FLOAT(KK-1)/FLOAT(IPPR(N))
            GPV(N,K)=(FLOW(N,2,I)+FLOW(N,2,I+1))*0.5*DX(N,I)
     #              /FLOAT(IPPR(N))
            GPH(N,K)=-K
            DO 200 L=1,NEQ
```

from

```
            GPV(N,K)=(FLOW(N,2,I)+FLOW(N,2,I+1))*0.5*DX(N,I)
```

to

```
            GPV(N,K)=FLOW(N,2,I)*0.5*DX(N,I).
```

Second, only one time step needs to be read to establish the initial conditions so sixth line of the following sequence

```
C       route branches
C
        DO 490 N=1,NBRCH
C         ROUTE BRANCHES
          I1=NXSEC(N)
          IF (ITDDS.EQ.0.AND.J.GT.1) THEN
C           read flow from file
            READ(110,1100) ((FLOW(N,M,I),M=1,4),I=1,I1)
```

must be changed from

```
          IF (ITDDS.EQ.0.AND.J.GT.1) THEN
```

to

```
          IF (ITDDS.EQ.0) THEN
```

Finally, the subreach averaged values of cross-sectional area and top width do not have to be computed by averaging the values at each end of the subreach, so the sequence

```
C     compute hydraulics statements
C
      INX=NXSEC-1
      IPX(NS+1)=NXSEC
      DO 10 I=1,INX
```

```
       A(I)=(A(I)+A(I+1))*0.5
       W(I)=(W(I)+W(I+1))*0.5
 10   CONTINUE
C
C     disperse constituents statements
must be changed to
C     compute hydraulics statements
C
      INX=NXSEC-1
      IPX(NS+1)=NXSEC
C
C     disperse constituents statements
```

With these modifications the BLTM model is called the CBLTM model.

APPENDIX E

Interactive program (BBLTM) to generate the input file (BLTM.IN) for transport program CBLTM

The program BBLTM is designed to help construct the input file BLTM.IN, which is used as input to the transport model CBLTM. The file BLTM.IN can be divided into three parts: general information, branch information, and boundary conditions. The data for the first two parts can be entered, through BBLTM, either from the terminal or from an existing file called OLD. The file OLD must have the same format as BLTM.IN so the terminal is to be used to create the input file. Once created, the information can be stored in OLD and the third part of the file, the boundary conditions, can be modified without having to reenter the first two parts of the file. If a new file is being created, the program reads the input file for the flow model (FLOW.IN) and extracts whatever information is available in that file and then prompts for all remaining information that is necessary to build the input file BLTM.IN for the CBLTM model. The first two parts of the input file can only be entered by use of BBLTM, no editing capability is available.

The information in the third part of BLTM.IN is more voluminous and more difficult to edit. The program BBLTM allows the boundary conditions to be entered from the terminal, from file OLD, or from a file called BC. If the file OLD is used, any boundary conditions stored there will be transferred to BLTM.IN and the boundary condition at one grid can be added or changed based on input from either the terminal or the file BC. If two or more boundary conditions are to be changed or added, the program BBLTM could be run repeatedly with different boundary conditions stored in the file BC for each run and the file FLOW.IN copied to the file OLD after each run.

The file BC is assumed to contain two lines of text information at the top of the file, which could be used to identify the data and so forth. Following these two lines of text, the file is assumed to contain up to eleven columns of data that are seven fields wide. The first column is ignored but could contain the times at which the boundary conditions apply. The other columns are assumed to contain the average concentrations at the grid point during each time step. The second column should contain the concentration for constituent 1, the third for constituent 2, and so forth. The format of the data is assumed to be 10F7.2. The first entry after the text information, line 3, is assumed to contain the average concentration during the first time step of the model. It is assumed that there are at least NHR (number of time steps run by CBLTM) boundary values in the file BC.

The following is a listing of the source code for BBLTM.

```
C     This program builds the input file (BLTM.IN) for CBLTM.FOR
C     It reads the terminal, FLOW.IN or OLD for  information.
C     It reads boundary values from either the terminal, OLD, or BC.
C
C***  BEGIN DIMENSIONING DEFINITION
C
C     IED       Code 0 to create a new file 1 to read an 'OLD', BLTM.IN
C     NOBC      Maximum number of boundary conditions (NOBR*NOSC)
C     NOBR      Maximum number of branches allowed in model
C     NOSC      Maximum number of cross sections (grids) allowed in branch
C     NOCO      Maximum number of constituents allowed
C
      INTEGER NOBC,NOSC,NOCO
      PARAMETER (NOBC=120, NOSC=12, NOCO=10)
C
C     + + + LOCAL VARIABLES + + +
C
      CHARACTER*4 LABEL(NOCO)
      INTEGER I,IED,IENG,INX,IOUT(NOSC),IPPR,ITDDS,J,JGO,JNCD,JNCU,JPO,JTS,
     #        K,L,LL,LR,N,NBC,NBRCH,NEQ,NHR,NJNCT,NN(NOBC),NI(NOBC),
     #        NXSEC
      REAL DQQ,DQV,DT,GPT(NOCO,NOSC),HR,QP,RQ,TGPT(NOCO),TITLE(20),
     #     X(NOSC)
      LUIN=15
      LUOUT=16
      LUBC=17
      OPEN (LUOUT,FILE='BLTM.IN')
C
C     + + + OUTPUT FORMATS + + +
C
 1600 FORMAT (20A4)
 1610 FORMAT ('HEADER 1  ',10I7)
 1611 FORMAT (10X,10I7)
 1620 FORMAT ('HEADER 2  ',10F7.2)
 1621 FORMAT (10X,10F7.2)
 1630 FORMAT ('LABEL     ',I7,3X,A4,I7)
 1631 FORMAT (10X,I7,3X,A4,I7)
 1640 FORMAT('BRANCH',I4,I7,F7.2,4I7)
 1641 FORMAT (10X,I7,F7.2,4I7)
 1650 FORMAT(' GRID',I5,F7.3,I7,8F7.2)
 1651 FORMAT (10X,F7.3,I7,8F7.3)
 1660 FORMAT(10X,2F7.2)
 1670 FORMAT('TIME',I6,I7)
 1680 FORMAT(' B',I3,' G',I3,10F7.2)
C
C     + + + INPUT FORMATS + + +
C
 1510 FORMAT(20X,I10)
 1530 FORMAT(20X,F10.3)
 1540 FORMAT (13X,I3,16X,F5.2,16X,I3,8X,I3)
 1550 FORMAT (3X,G11.4,I2,G11.4,4G10.3,F7.1,F6.3)
 1560 FORMAT (10X,I3,5X,I3,3X,G14.5)
 1570 FORMAT(2X,I3,2X,I3,10F7.2)
C
 1700    FORMAT(7X,10F7.2)
C
      WRITE(*,*)'Enter 0 to create new file, 1 to edit existing file- '
      READ(*,*)IED
```

```
      IF(IED.EQ.0)THEN
      OPEN (LUIN,FILE='FLOW.IN')
      READ (LUIN,1600)(TITLE(K),K=1,20)
      WRITE(*,1600)(TITLE(K),K=1,20)
      WRITE(*,*)'Enter new title (do not exceed 80) characters'
      WRITE(*,*)' '
      READ(*,1600)(TITLE(K),K=1,20)
      WRITE(LUOUT,1600)(TITLE(K),K=1,20)
      READ(LUIN,1510)NBRCH
      READ(LUIN,1510)NJNCT
      READ(LUIN,1510)NHR
      READ(LUIN,1510)JTS
      READ(LUIN,1510)JGO
      JPO=1
      WRITE(*,*)'Enter number of time steps between outputs in PARCEL.OU
     $T-  '
      WRITE(*,*)'To select default enter any letter, Default=1, JPO=  '
      READ(*,*,ERR=20)LL
      JPO=LL
   20 READ(LUIN,1510)IENG
      WRITE(*,*)'Enter number of constituents to be modeled-  '
      READ(*,*)NEQ
      ITDDS=0
      WRITE(LUOUT,1610)NBRCH,NJNCT,NHR,NEQ,JTS,JGO,JPO,ITDDS,IENG
      READ(LUIN,1530)DT
      READ(LUIN,1530)QP
      DQV=0.0
      WRITE(*,*)'Enter minimum dispersive velocity, Default=0.0, DQV=  '
      READ(*,*,ERR=21)DQV
   21 WRITE(LUOUT,1620)DT,DQV
      DO 1 L=1,NEQ
      TGPT(L)=0.0
      WRITE(*,*)'Enter label for constituent',L,' (4 char max)-  '
      READ(*,1600)LABEL(L)
      LR=L
      WRITE(*,*)'Enter constituent no. to be tracked by PDC, Default=',L
     # ,' LR= '
      READ(*,*,ERR=22)LL
      LR=LL
   22 WRITE(LUOUT,1630)L,LABEL(L),LR
    1 CONTINUE
      DQQ=0.2
      IPPR=1
      DO 2 N=1,NBRCH
       READ(LUIN,1540)NXSEC,RQ,JNCU,JNCD
       READ(LUIN,1600)TITLE(1)
       WRITE(*,*)'Enter the following for branch',N
       WRITE(*,*)'Dispersion factor = dis coef/(U*U*DT), Default=',DQQ,'
     # DQQ = '
       READ(*,*,ERR=23)RQ
       DQQ=RQ
   23  WRITE(*,*)' Initial number of parcels in each subreach, Default='
     #,IPPR,' IPPR = '
       READ(*,*,ERR=24)JGO
       IPPR=JGO
   24  WRITE(LUOUT,1640)N,NXSEC,DQQ,JNCU,JNCD,IPPR
       WRITE(*,*)'For each cross section (grid) enter the following:'
       DO 3 I=1,NXSEC
```

```
        READ(LUIN,1550)X(I)
        IOUT(I)=0
        IF(I.EQ.NXSEC) GO TO 3
        WRITE(*,*)' Initial concentration for subreach',I
        DO 4 L=1,NEQ
         WRITE(*,*)(LABEL(L)),' Default=',TGPT(L),',  Value = '
         READ(*,*,ERR=25)RQ
         TGPT(L)=RQ
   25    GPT(L,I)=TGPT(L)
    4   CONTINUE
    3 CONTINUE
      WRITE(*,*)'For branch',N
    5 WRITE(*,*)'Enter GRID of desired output (enter q to quit) '
      READ(*,*,ERR=6) I
       IOUT(I)=1
       GO TO 5
    6 INX=NXSEC-1
      DO 7 I=1,INX
        LL=8
        IF(NEQ.LT.8)LL=NEQ
        WRITE(LUOUT,1650)I,X(I),IOUT(I),(GPT(L,I),L=1,LL)
        IF(NEQ.GT.8)WRITE(LUOUT,1660)(GPT(L,I),L=9,NEQ)
    7  CONTINUE
       I=NXSEC
       WRITE(LUOUT,1650)I,X(I),IOUT(I)
    2 CONTINUE
      ELSE
C
C     ******  read data from BLTM.IN *********
C
      OPEN(LUIN,FILE='OLD')
      READ(LUIN,1600)(TITLE(K),K=1,20)
      WRITE(LUOUT,1600)(TITLE(K),K=1,20)
      READ(LUIN,1611) NBRCH,NJNCT,NHR,NEQ,JTS,JGO,JPO,ITDDS,IENG
      WRITE(LUOUT,1610) NBRCH,NJNCT,NHR,NEQ,JTS,JGO,JPO,ITDDS,IENG
      READ(LUIN,1621) DT,DQV
      WRITE(LUOUT,1620)DT,DQV
      DO 100 L=1,NEQ
       READ(LUIN,1631)M,LABEL(L),LR
       WRITE(LUOUT,1630)M,LABEL(L),LR
  100 CONTINUE
      DO 110 N=1,NBRCH
       READ(LUIN,1641) NXSEC,DQQ,JNCU,JNCD,IPPR
       WRITE(LUOUT,1640)N,NXSEC,DQQ,JNCU,JNCD,IPPR
       I1=NXSEC-1
       DO 120 I=1,I1
        I2=8
        IF (NEQ.LT.8) I2=NEQ
        READ(LUIN,1651) X(I),IOUT(I),(GPT(L,I),L=1,I2)
        WRITE(LUOUT,1650)I,X(I),IOUT(I),(GPT(L,I),L=1,I2)
         IF(NEQ.GT.8) READ(LUIN,1621) (GPT(L,I),L=9,NEQ)
         IF(NEQ.GT.8)WRITE(LUOUT,1660)(GPT(L,I),L=9,NEQ)
 120    CONTINUE
        I=NXSEC
        READ(LUIN,1651) X(I),IOUT(I)
        WRITE(LUOUT,1650)I,X(I),IOUT(I)
 110  CONTINUE
      END IF
```

```
C
C      Build boundary conditions
C
      WRITE(*,*)'Enter 0 to input boundary conditions from terminal, 1 f
     #rom file BC- '
      READ(*,*)ITRM
      IF(ITRM.EQ.0)GO TO 200
       OPEN(LUBC,FILE='BC')
       WRITE(*,*)'Enter BRANCH of boundary condition in file BC- '
       READ(*,*)NBN
       WRITE(*,*)'Enter  GRID  of boundary condition in file BC- '
       READ(*,*)NGN
       READ(LUBC,1600)(TITLE(K),K=1,20)
       READ(LUBC,1600)(TITLE(K),K=1,20)
  200 IF(IED.EQ.0)THEN
       DO 300 J=1,NHR
        NBC=1
        IF(ITRM.EQ.1)GO TO 310
         WRITE(*,*)'For time step',J,' enter number of new boundary cond
     #itions-  '
         READ(*,*)NBC
  310  CONTINUE
       WRITE(LUOUT,1670)J,NBC
       IF(NBC.EQ.0)GO TO 300
        DO 320 K=1,NBC
         IF(ITRM.EQ.1)THEN
          READ(LUBC,1700)(TGPT(L),L=1,NEQ)
         ELSE
          WRITE(*,*)'Enter BRANCH of new boundary condition- '
          READ(*,*)NBN
          WRITE(*,*)'Enter  GRID  of new boundary condition- '
          READ(*,*)NGN
          DO 330 L=1,NEQ
           WRITE(*,*)LABEL(L),' Default=',TGPT(L),' Value= '
           READ(*,*,ERR=320)RQ
           TGPT(L)=RQ
  330     CONTINUE
         END IF
  320   CONTINUE
        WRITE(LUOUT,1680)NBN,NGN,(TGPT(L),L=1,NEQ)
  300  CONTINUE
      ELSE
       IF(ITRM.EQ.1)GO TO 400
        WRITE(*,*)'Enter BRANCH of new boundary condition- '
        READ(*,*)NBN
        WRITE(*,*)'Enter  GRID  of new boundary condition- '
        READ(*,*)NGN
  400  DO 410 J=1,NHR
        READ(LUIN,1611)NBC
        K=0
        IF(NBC.EQ.0)GO TO 460
        DO 420 KK=1,NBC
         K=K+1
         READ(LUIN,1570)NN(K),NI(K),(GPT(L,K),L=1,NEQ)
         IF(NN(K).EQ.NBN.AND.NI(K).EQ.NGN)K=K-1
  420   CONTINUE
  460   NBC=K+1
        WRITE(LUOUT,1670)J,NBC
```

```
      I1=NBC-1
      IF(I1.LT.1)GO TO 450
      DO 440 K=1,I1
       WRITE(LUOUT,1680)NN(K),NI(K),(GPT(L,K),L=1,NEQ)
440   CONTINUE
450   IF(ITRM.EQ.1)THEN
       READ(LUBC,1700)(TGPT(L),L=1,NEQ)
      ELSE
       WRITE(*,*)'For time step',J,' Enter new boundary values '
       DO 430 L=1,NEQ
        WRITE(*,*)LABEL(L),' Default=',TGPT(L),' Value= '
        READ(*,*,ERR=430)RQ
        TGPT(L)=RQ
430    CONTINUE
      END IF
      WRITE(LUOUT,1680)NBN,NGN,(TGPT(L),L=1,NEQ)
410  CONTINUE
    END IF
    ENDFILE(LUOUT)
    CLOSE(LUOUT)
    IF(IED.EQ.1)CLOSE(LUIN)
    IF(ITRM.EQ.1)CLOSE(LUBC)
    STOP
    END
```