

User's Guide for Mixed-Size Sediment Transport Model for Networks of One-Dimensional Open Channels

U. S. Geological Survey

Water-Resources Investigations Report 01-4054



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By James P. Bennett

U. S. Geological Survey

Water-Resources Investigations Report 01-4054

Lakewood, CO
2001



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User's Guide for Mixed-Size Sediment Transport Model for Networks of One-Dimensional Open Channels

by James P. Bennett

Abstract

This user's guide describes a mathematical model for predicting the transport of mixed sizes of sediment by flow in networks of one-dimensional open channels. The simulation package is useful for general sediment routing problems, prediction of erosion and deposition following dam removal, and scour in channels at road embankment crossings or other artificial structures. The model treats input hydrographs as step-wise steady-state, and the flow computation algorithm automatically switches between sub- and supercritical flow as dictated by channel geometry and discharge. A variety of boundary conditions including weirs and rating curves may be applied both external and internal to the flow network. The model may be used to compute flow around islands and through multiple openings in embankments, but the network must be "simple" in the sense that the flow directions in all channels can be specified before simulation commences. The location and shape of channel banks are user specified, and all bed-elevation changes take place between these banks and above a user-specified bedrock elevation. Computation of sediment-transport emphasizes the sand-size range (0.0625-2.0 millimeter) but the user may select any desired range of particle diameters including silt and finer (<0.0625 millimeter). As part of data input, the user may set the original bed-sediment composition of any number of layers of known thickness. The model computes the time evolution of total transport and the size composition of bed- and suspended-load sand through any cross section of interest. It also tracks bed-surface elevation and size composition. The model is written in the FORTRAN programming language for implementation on personal computers using the WINDOWS operating system and, along with certain graphical output display capability, is accessed from a graphical user interface (GUI). The GUI provides a framework for selecting input files and parameters of a number of components of the sediment-transport process. There are no restrictions in the use of the model as to numbers of channels, channel junctions, cross sections per channel, or points defining the cross sections. Following completion of the simulation computations, the GUI accommodates display of longitudinal plots of either bed elevation and size composition, or of transport rate and size composition of the various components, for individual channels and selected times during the simulation period. For

individual cross sections, the GUI also allows display of time series of transport rate and size composition of the various components and of bed elevation and size composition.

INTRODUCTION

A general model for predicting the transport of mixed sizes of sediment by flow in simple networks of open channels is described herein. Within the limitations discussed below, the simulation package is intended to be useful for general sediment-routing problems, prediction of erosion and deposition following dam removal, and scour in channels at road embankment crossings or other artificial structures. Channels appropriate for simulation are characterized as one-dimensional, that is as having reasonably negligible lateral variability in the processes of flow, sediment transport, and any resulting bed-elevation adjustment. Computation of sediment-transport emphasizes the sand-size range (0.0625-2.0 mm), but the user may select any desired range of particle diameters including silt and finer (<0.0625 mm). The objective of this report is to outline the theoretical basis, assumptions, and limitations of the flow and transport algorithms; to describe how the concepts are incorporated into the algorithms and the resulting limitations and consequences to the application of the model; to outline model implementation procedures; and to describe input data requirements and conventions and output capabilities. The model is written in the FORTRAN programming language for implementation on personal computers using the WINDOWS operating system and, along with certain graphical output display capability, is accessed from a graphical user interface (GUI). With the exception of sediment particle sizes (in mm), and time (in days), the model employs only SI units.

Because the time scale of the pertinent channel-bed sorting and elevation adjustment process is long compared to those typically treated with unsteady flow algorithms, the model treats input hydrographs as step-wise steady-state. A default sediment-transport computation time step may be specified by the user, but the actual time step is often determined by a minimum bed-elevation change, which also is user specified. The model may be used to compute flow around islands and through multiple openings in embankments, but the network must be "simple" in the sense that the flow directions in all channels can be specified before

simulation commences. The location and shape of channel banks are user specified, and all bed-elevation changes take place between these banks and above a user-specified bedrock elevation.

The GUI provides a framework for selecting input files and parameters of a number of components of the sediment-transport process. It also allows the user to specify up to 20 sediment sizes to be used in all aspects of the simulation. As part of data input, the user may set the original bed-sediment composition of any number of layers of known thickness. The model computes the time evolution of total transport and the size composition of bed- and suspended-load sand through any cross section of interest. It also tracks bed surface elevation and size composition.

Apart from the limitation of 20 on the number of sediment particle sizes, there are no restrictions in the use of the model as to numbers of channels, channel junctions, cross sections per channel, or points defining the cross sections. Following completion of the simulation computations, the GUI accommodates display of longitudinal plots of either bed elevation and size composition, or of transport rate and size composition of the various components, for individual channels and selected times during the simulation period. For individual cross sections, the GUI also allows display of time series of transport rate and size composition of the various components and of bed elevation and size composition. This report also discusses a series of files that are written during data input and simulation that aid the user in locating problems and tailoring plots and analyses. One of the files provides a "hot start" capability that enables commencement of a new simulation from the termination point of an earlier one.

THEORETICAL DEVELOPMENT

Flow Simulation

The flow computation algorithm of the model accepts time-varying hydrographs, but the computation procedure for individual channels solves the steady-state problem for the instantaneous discharge at the beginning of the time step in question and uses the resulting hydraulic variables to compute transport-related characteristics for the entire time increment. This is appropriate because the time scale of the transport-related processes is much longer than that of the unsteady flow processes, and it is convenient because solution of the steady-state flow equation is much less cumbersome and more stable than that necessary for the transient state. The latter is especially important because the flows must sometimes be computed numerous times each simulation step due to the iterative procedure required for certain

networks. For the steady-state case, the Navier-Stokes equations for free-surface flow in a channel reduce to

$$\frac{d}{dx} \left(\frac{v^2}{2g} + z \right) + S_f = 0. \quad (1)$$

where, as shown in figure 1, v = mean flow velocity, z = water-surface elevation, and g = gravitational constant. For steady-uniform flow, the surface slope S and the friction slope S_f are equivalent and can be obtained from solving the Manning formulation

$$v = \frac{1}{n} D^{2/3} S^{1/2} \quad (2)$$

for S . In (2), the hydraulic depth, $D = A/T$, where A = channel cross section area and T = channel width at the water surface. For a wide channel, D and the flow depth, h , shown on figure 1 are equivalent.

Typically, the flow in streams and canals is subcritical. In general, solution for the water-surface elevation profile in such a channel requires specification of the boundary conditions, respectively, Q , discharge, upstream and z at the downstream-most cross-section. The solution procedure then marches downstream-to-upstream, or repetitively from section 2 to section 1 in figure 1. As described by Chaudhry (1993) this can be accomplished using Newton iteration to solve for z_1 with this discrete version of (1)

$$f(z_1) = z_1 + \frac{Q^2}{2g} (A_1^{-2} - A_2^{-2}) - \Delta x \bar{S}_f - z_2 = 0 \quad (3)$$

where $Q = vA$ is the flow rate in the channel, and subscripts 1 and 2 refer respectively to the upstream and downstream sections. Before attempting to use the upstream marching solution procedure, it must be determined that subcritical flow actually can exist at section 1. This is done first by computing the critical-flow water-surface elevation at section 1 for the imposed discharge, which is only a function of section geometry and roughness. Next, the critical elevation and the corresponding A are entered in (3) along with the known values at section 2. If a negative value is obtained for f , subcritical flow exists at 1 and the solution may proceed. If not, a hydraulic jump exists between the two sections. The jump is ignored in the model, but a search is conducted in the upstream direction until another subcritical flow section is reached. Following this, supercritical flow is routed downstream to the previously determined subcritical section.

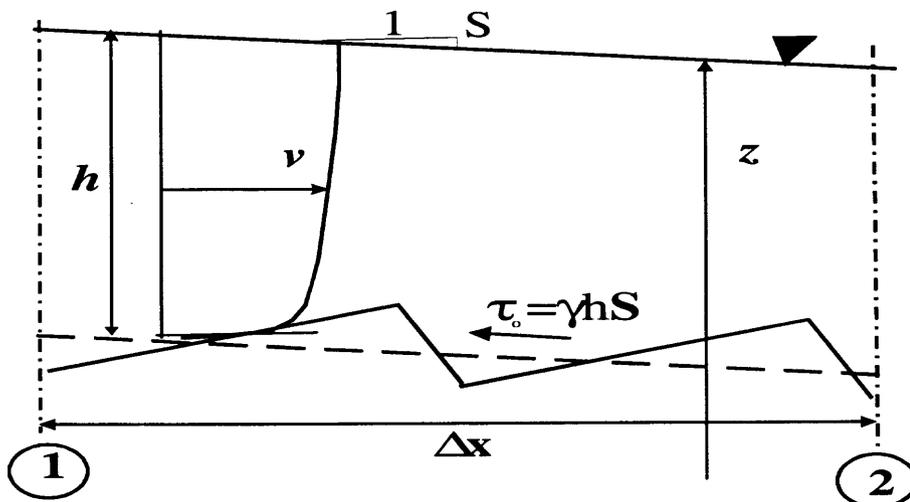


Figure 1.--Definitions of flow-related variables. The vertical lines labeled with circles are the computation sections for the steady-state Navier-Stokes equation.

In (3) the friction slope is obtained from the definition of hydraulic depth D above and using geometric averaging as

$$\bar{S}_f = Q^2 n_1 n_2^3 \sqrt{\frac{(T_1 T_2)^2}{(A_1 A_2)^8}} \quad (4)$$

The Manning n resistance coefficients of (2) and (4) are cross section averages obtained by numerical integration at the same time as the A is computed as described below. For the bank and bedrock portions of each cross-section, user-specified values are employed. The user also specifies a resistance coefficient for the alluvial section of the channel bed but has the option of using values computed specifically for the modeled situation using the techniques and procedures described by Bennett (1995).

The upstream boundary condition is always a specified discharge value for individual channels within a network. The discharge may come from an externally imposed time series, or from conservation of mass at a channel junction internal to the network. External-flow boundary-condition specification includes water temperature. There are five possible downstream boundary conditions. These include specified water-surface elevation time series, hydraulic depth versus discharge rating curve, normal flow depth for a downstream channel with specified slope, water-surface elevation at a specified internal channel junction, and sharp crested weir elevation and crest width. The rating curve and weir boundary conditions may be specified at internal channel junctions, as well as at locations where water leaves the simulation network. For weirs at junctions, a check is made for submergence and the discharge relationship adjusted accordingly. This is not done in the case of an internally applied rating curve. In

the case that a channel discharges to a junction that has water-surface elevation lower than the critical elevation for that channel, the critical elevation is used as the downstream boundary condition for the channel.

Channel Networks

The simulation network may consist of several channels interconnected at one or more internal junctions, which allows the user to conveniently deal with tributary or delta networks, with flow around islands, or flow through multiple openings in embankments. Each channel is made up of a sequence of two or more cross sections, and the use of the term "segment" herein generally refers to that part of an individual channel that lies between two of the adjacent sections. The channel junctions are assumed to have no plan area, so no storage of water or sediment within them is permitted. Mass is conserved in that all flow entering a junction leaves it and, with the exemptions mentioned above, all channels entering or leaving have the same water-surface elevation. The network is termed simple in that the user must be able to specify the direction of flow in each of the channels. Each time step, the flow-simulation algorithm iterates through the entire network until neither the downstream water-surface elevation nor the input discharge varies significantly for any channel. During each iteration, at each junction, water-surface elevation is determined by adjusting it until the sum of discharges leaving the junction differs from that entering by less than a factor of 1 in 1000 (For each interior channel, discharge is the variable to be solved for and the boundary conditions at its ends are water-surface elevations at the respective junctions.). Once the flow rates in all channels have been determined, sediment is distributed to channels

leaving junctions in proportion to the flow rates in those channels.

Sediment-Transport Simulation

All sediment-transport calculations are made on an individual size class basis. The user may select (with a limit of 20) the number and individual magnitudes of the particle size-class boundaries. Because particles finer than the smallest and coarser than the largest selected boundaries are treated as being those sizes, the simulation actually considers one more size range than selected. The transport characteristics of the size ranges are determined for the geometric mean of the size boundaries and, as appropriate, the water temperature of the channel flow. Bedload and suspended transport are assumed to occur in separate layers as described in greater detail by Bennett (1995).

Assuming transport in equilibrium with bed-sediment of known size distribution f_i ($\sum f_i = 1$), for the i 'th size fraction, the model follows Wiberg (1987) in incorporating a Meyer-Peter-type formulation

$$\phi_i = f_i \phi_o (\tau_*' - \tau_{*cr}')^{1.5} \quad (5)$$

for predicting bedload transport rate. In (5), the nondimensional bedload transport

$$\phi_i = \frac{b_i}{[(s-1)gd_i^3]^{0.5}}, \quad (6)$$

where b_i = the unit volumetric bed load transport rate and d_i = the particle size for size fraction i , and s = ratio of specific gravity of particles to that of water. Also in (5), the nondimensional bottom shear stress

$$\tau_*' = \frac{\tau_o'}{\gamma(s-1)d_i}, \quad (7)$$

where γ = unit weight of water, and τ_o' = channel bottom shear stress (figure 1) corrected for the form drag of any bedforms that are present. Finally, following McLean (1992), the critical Shields stress τ_{*cr}' is based on d_{50} , the median bed-sediment size (50 percent of the bed particles are finer). That is, τ_{*cr}' results from (7) with d_i replaced by d_{50} and τ_o' by τ_{cr}' , the shear stress for incipient motion for particles of the median bed-sediment size. In the Meyer-Peter and Müller (1948) version of (5), $\phi_o = 8$; this is the default value taken for this user-adjustable parameter in the model. If the size distribution of the channel bed falls into the sand range, the procedures of Bennett (1995) are incorporated to determine a form drag correction for bottom shear stress,

whether or not the user opts to use the alluvial channel resistance formulation.

Assuming steady, uniform flow and equilibrium transport in the longitudinal direction, the vertical conservation of mass equation for suspended sediment for the i 'th size fraction can be solved analytically to yield

$$C_{zi} = C_{ai} \left(\frac{h-a}{a} \frac{z}{h-z} \right)^{v_{si}/\kappa u_*} \quad (8)$$

where C_{zi} = the concentration at elevation z above the bed and v_{si} = the fall velocity of the sediment. In (8) the

shear velocity $u_* = \sqrt{\tau_o'/\rho}$, wherein τ_o' = total bottom shear stress (figure 1) and ρ = density of water. Also in (8), a = a height above the bed at which the reference concentration C_{ai} is specified; following McLean (1992), the elevation adopted is $a = \delta$, the saltation or bedload layer thickness. Equation (8) is known as the Rouse equation and $v_s/\kappa u_*$ as the Rouse number. Even in the simplest situation, computation of the suspended load by integration of the velocity-concentration product over the flow depth must be accomplished numerically. The model uses numerical integration schemes described by Nakato (1984). For computing reference-level concentration, the model uses a formulation from Smith and McLean (1977),

$$C_{ai} = f_i \frac{C_b \gamma_o S_*'}{1 + \gamma_o S_*'} \quad (9)$$

In (9) C_b = solids volume ratio of the bed and is on the order of 0.65, and $S_*' = \frac{\tau_o'}{\tau_{cr}'} - 1$, called transport

strength or normalized excess shear stress. Parameter γ_o is dimensionless with default value=0.004 and is user adjustable during simulation. Zyserman and Fredsoe (1994) concluded that when bedforms are present the suspended load can best be determined when C_a is evaluated using form-drag corrected or grain shear stress and the Rouse number is computed using total shear stress.

The development in the previous two paragraphs is based on the assumption of a uniform reach of constant bed-sediment composition of length sufficient to achieve equilibrium between the bed make-up and the transport above it. Such situations do not always exist, for example, a sand-transporting flow in a cobble-bedded reach or sand- and silt-depositing flow entering a reservoir or an over-bank expansion. In the model, such situations are accounted for, on a size-by-size basis by computing f_i and C_{ai} for the input size distribution to an increment of channel segment, as well as from its bed size

distribution. Considering channel hydraulics, the largest feasible transport rate is selected. In situations where there may be deposition from an entering flow, fall velocity, water depth, and average flow velocity are considered in computing the applicable downstream value of C_{ai} . Equations (5)-(9) embody the only transport relationships incorporated in the sediment model, and they will reasonably well represent transport processes from coarse gravel into the silt-size range ($d < 0.0625\text{mm}$), but users should keep in mind that they will not at all adequately simulate erosion of deposits of cohesive materials.

Bottom Size Composition and Elevation Accounting

An active layer concept is used to track bed-surface size composition changes. Its use is based on the physically reasonable assumption that only the near-surface fraction of the bed can be sorted through by the flow during a realistic simulation time step. As long as there is sediment on the bed in an increment (the reach Δx in length between any two of the user specified cross sections) of a channel segment, the active layer is present; its thickness is set at some fraction of flow depth. The default fraction is 0.15 and the parameter is user adjustable. For sand-bed channels, a reasonable value is 0.3, which is a commonly observed ratio of bedform height to flow depth. Active layer composition is used to set the size fractions f_i discussed above at the start of a transport time step and, during the step, only sizes present in the active layer may be eroded from it. To satisfy mass conservation, sediment is added to the active layer, for each Δx increment, during each time step in the amount that the upstream supply rate exceeds the downstream export rate. Similarly, up to the amount present there, sediment is taken from the active layer to supply the required excess of export over import rate for that size. If not enough sediment of a particular size is available in the active layer to satisfy the excess capacity, the export rate for that size is adjusted downward accordingly. The final computation for each time step involves re-adjustment of active-layer composition, which is based on the new hydraulic conditions and the additions and subtractions to sediment volume during the step. If layer volume remains constant and net deposition has occurred, the excess sediment from the active layer is added to a second layer called the inactive layer. If the active layer is deficient in volume, an appropriate amount is taken from the next underlying layer, if available. For steady-state hydraulic conditions, if net erosion has occurred over a particular channel increment, the second layer may not be present. There is provision for the user to specify as many layers of different sediment size composition as desirable to begin a simulation scenario. During simulation, once

sediment has been removed from one of the original layers, its surface elevation is adjusted downward to conserve mass and no material may ever be added to it.

The active layer concept also permits simulation of the process of armoring, the development of a coarse protective layer that does not allow erosion, on the surface of otherwise transportable underlying deposits. If a size fraction present in appreciable proportion (arbitrarily set at 5 percent) in the active layer of a channel increment can not be transported by the then prevailing hydraulic conditions, new rules are established for adjusting the active layer composition. The volume of the active layer is set so that it contains just enough of the limiting size and coarser particles to form a one-diameter layer on the surface of the channel bed if all finer sediment were eroded from the layer. The amount of material in the active layer is then fixed and can subsequently not be added to from underlying layers until hydraulic conditions again suffice to transport the sediment size that established the original armor-layer restriction. If this happens, the rules of the previous paragraph again pertain.

Channel-bed elevation accounting is accomplished by keeping strict track of sediment solids volume on a size-by-size basis in each of the layers between each pair of cross sections. Because the section shapes and distance between them is known, the elevation can be determined by numerical integration until the encompassed volume equals the amount known to be in storage in the channel increment. Consistent with in (9), the solids volume ratio (C_b) is assumed to be 0.65 (the porosity of the bed = 0.35) and the parameter is not adjustable.

INPUT DATA REQUIREMENTS AND STRUCTURE

The input network structure, channel geometry, and boundary condition data for a first-time utilization of the model resides in two flat or text files that must be prepared by the user prior to starting the model. The first or network description file describes the network interconnections and channel geometry, the second or boundary condition file sets the type and time span of simulation and describes all necessary internal and external boundary conditions. This section discusses the modeling philosophy and algorithm construction of the modules that implement the theory presented in the preceding section, as well as a number of the ancillary support algorithms so that the data requirements and sequencing for these flat files can be better understood.

In general, the network consists of a numbered sequence of channels; for reference by the model algorithms, the order of a particular channel in the sequence is determined by its location in the network description file. Channel sequencing is not entirely

arbitrary, because no channel description should appear until all those that contribute flow to it have already been listed. The individual channels consist of two or more cross sections and again, for reference by the model algorithms, the order of a particular cross section in the sequence is determined by its location in the network description file. This is best understood by reference to figure 2 that is a duplicate of one of the screens produced during model execution. Flow is from left to right around the island in the figure, and the cross sections are numbered in channel order. Thus the right bank channel around the island is channel 2 and the one toward the left bank is channel 3. The network description is completed by enumerating the channel junctions and noting the channel sequence numbers and flow directions of each channel contributing flow to or exporting flow from each junction. In figure 2, junction I is at the upstream end of the island, and junction II is at the downstream end. The channel description in the network description file includes identification of upstream and downstream boundary condition types so the appropriate boundary condition information must appear in the same sequence as the channels in the boundary condition flat file.

The general (space delimited) FORTRAN format is used for data entry so the values could be entered as a single record, but the author prefers to organize them into

groups with related physical characteristics in separate records. See the annotated file listings in Appendix I as examples and for further explanation of the topics discussed below. During data processing and execution, the model creates a number of other flat files for aid in debugging and interpreting the results of the simulation, and these files will be discussed in the section on model application.

Network Description File

The first section of the network description file describes the channels (Appendix I). The first record of the section lists the number of channel segments to be entered. The sediment-transport algorithm routes sediment in the sequence order in which channel descriptions are supplied, so some care must be exercised in ensuring that no channel description occurs before any other that can be considered to supply sediment to it. In general this means that all tributaries to a junction should be entered before proceeding to list any channel leaving it or "downstream" of channels leaving that junction. Similarly, both channels flowing around an island should be listed before any downstream of the island, even if one

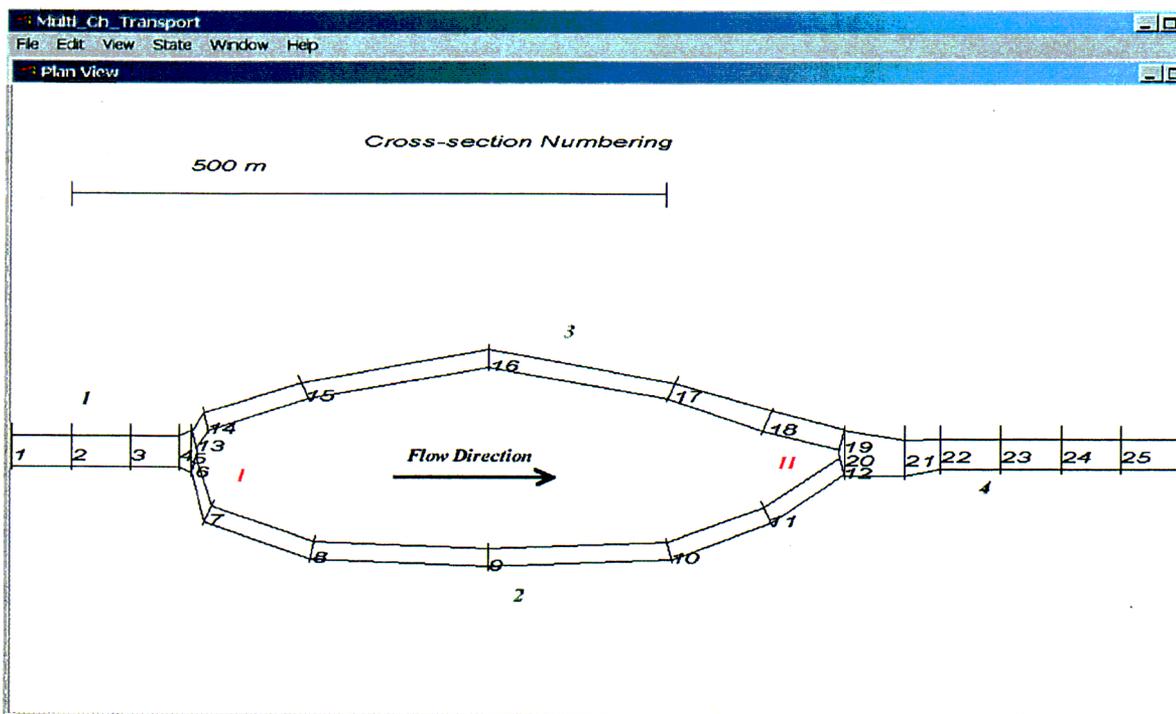


Figure 2. Plan view of cross-section locations for a 4-channel network simulation. Channel numbers are in green, and junctions are noted with red Roman numerals.

Table 1. Allowable channel upstream and downstream boundary conditions and accompanying input data integer codes.

Code	Description	Allowed At Junction?	Boundary Condition File Entry Needed?
Upstream end of channel			
1	Discharge time series	No	Yes
2	Flow from junction	Yes	No
Downstream end of channel			
1	Water surface elevation time series	No	Yes
2	Discharge vs hydraulic depth rating curve	Yes	Yes
3	Normal depth in downstream channel	No	Yes
4	Water surface elevation from junction	Yes	No
5	Sharp-crested weir	Yes	Yes

of these channels is minor and may sometimes not be flowing. The first record in a set describing an individual channel contains codes for the upstream and downstream boundary condition types and then lists the number of individual cross sections comprising that channel. The allowable boundary condition types and accompanying integer codes are listed in table 1. All codes except for the ones for flow from junction and water-surface elevation from junction require an entry in the boundary condition file. The meaning and required formats of those entries are discussed in the appropriate section below. Each channel consists of a set of cross sections. Because the model provides a plan-view plot of the simulation area as in figure 2 and because a mechanism must be provided for determining the distance between cross sections, each description contains coordinates to locate its base line in the x-y plan view. Any right-handed orthogonal coordinate system may be used such as universal transverse mercator, easting-northing, or some arbitrary system established by the user. In the latter case, the inherent plots and output files are most easily interpreted if the x-axis runs generally in the downstream direction. The first record of an individual cross section description contains the x and y coordinates of the base line along which the section is measured. The first pair of x-y coordinates is assumed to locate the right-hand end or right-bank reference in the conventional hydrologic "looking downstream" sense. The second pair of coordinates is required to establish the bearing of the cross section line and is not required to coincide with any of the points used to establish section shape. All

horizontal reference distances used for defining cross section shape and discussed below are assumed to be measured along this base line, that is, in a right-to-left-bank sense. The cross section shape is defined by a series of lines, the end points of which are listed in two or three strings. The reasons for this type of protocol will be discussed after the required information descriptive of the entire cross section has been listed. The second pair of x-y coordinates of the base line is followed by an elevation adjustment factor that is applied to every elevation entered for that particular cross section description. This value may, of course, be zero, but must not be omitted; it is sometimes required to adjust the cross sections to a common datum. This value is followed by a bedrock-elevation (lower scour limit) and a Manning's n for the bedrock surface. Next is a default Manning's n value applicable to the full width of any alluvial surface present at the section. This value is only used in simulation if the alluvial-channel-resistance computation mode of the model is disabled, but must be present in any case. The last four entries of the general cross section description are integers listing the numbers of ground points that comprise each of the three sections of the cross section shape and finally, the number of layers of bed sediment of differing size composition that are present.

The shape of the cross section may be described in either two or three segments. If two, the first sequence describes the entire segment exclusive of the alluvial bed, and the number of entries in the third segment must be enumerated as 0. If three segments are used, they are assumed to comprise the right-bank, alluvial portion, and

left-bank in that order. For the right- and left-bank segments, the ground points are each described by three values, a distance from the right-bank zero reference point discussed above, a ground elevation, and a Manning's n value. Because the alluvial surface resistance coefficient is prescribed for the entire cross-section, only two values, the distance and elevation are required for each point in the second, alluvial, or channel bed, segment. Within a segment, all points must be ranked in increasing order of distance from the right-bank reference point. The elevation values entered for the second segment are ultimately used only to compute an initial average (horizontal) elevation for the alluvial surface. The cross section 3 portion of the network description file in Appendix I shows an example of a two-segment description consisting of four points; the remainder of the cross sections in the file have three-segment descriptions.

Possible scenarios for how different sets of entries would be interpreted by the cross section computation algorithms are shown in figure 3. In the figure, the heavy line indicates the "no-erosion" surface for the cross section. The bedrock elevation of the figure comes from the initial cross section description record. Figure 3A indicates that the cross section sides for three-segment sections are extended vertically downward to the stated elevation if they end above it. Figure 3B shows that entered ground point elevations are used to delimit the no-erosion surface instead of the given bedrock elevation if all of them fall above it; no erosion is allowed below any entered ground-point elevation. Figure 3C indicates that if one or more ground points fall below the stated bedrock elevation, the limiting erosion surface is interpolated horizontally where the delimiting lines cross the bedrock elevation, as denoted by the X's in the figure. In all cases, any number of layers of sediment of differing composition may occupy the space between the alluvial surface and the no-erosion surface.

The cross-section area computation algorithm accepts water-surface elevation and alluvial-surface elevation and, for the line connecting each adjacent pair of ground points, from right- to left-bank, computes the area between water-surface and line segment, or alluvial surface if the no-erosion surface is buried. In the process, the cross-section average flow resistance coefficient and distance of the centroid of area from the right-bank reference point are determined. The most current values of these parameters are used immediately in the flow computation algorithm. During simulation, in case the water surface (or alluvial surface for that matter) reaches an elevation higher than the first given point on the right bank or last one on the left bank, the cross section boundary is assumed to be extended vertically upward from these points.

Figure 3 shows that the active width of the alluvial surface of the section (the width of the surface over which bed-sediment is assumed to move) is set by

the elevation of the alluvial surface and the shape of the no-erosion boundary. The volume of sediment contained in a longitudinal channel increment is indexed to the downstream cross section of the increment, section 2 of figure 1. In general, the alluvial surface is assumed to be parallel to the water surface and the downstream and upstream alluvial-surface elevations are computed by summing the volumes in small vertical slices between sections until the total solids volume known to be in the increment is reached. This procedure may result in slightly different alluvial surface elevations being computed at cross sections depending on whether the approach is from upstream or downstream. For the alluvial surface elevation at cross sections internal to the channels during flow computation, then, the average of the two values so obtained is used.

Following description of the cross-section geometry, the characteristics of at least one layer of sediment are required. Although the number and size limits of the fractions used in simulation are set in the GUI, there is flexibility in how the size distributions are entered for the layers and sediment boundary conditions. The first entry (which must be an integer) of the first record of the layer description determines the size distribution code to be entered as in table 2 below. The alluvial-surface elevation of the upper layer of sediment is determined by the averaging process described above for cross section description segment 2. If there is more than one layer, they are numbered from the upper layer down and, for each subsequent layer, the first record of the layer description must include a layer surface elevation following the size distribution code. It is important that the initial surface elevation of each succeeding layer be lower than the previous one or serious errors in sediment-volume conservation calculations can result.

Table 2. Codes and protocols for entering sediment size distributions (I = user-selected number of simulation sediment sizes).

Code	Input
$I < 1$	d_{50} σ_g
1	d_{50} (auto $\sigma_g = 1.2$)
$I > 1$	f_i $i = 1 \dots I$ d_i $i = 1 \dots I$

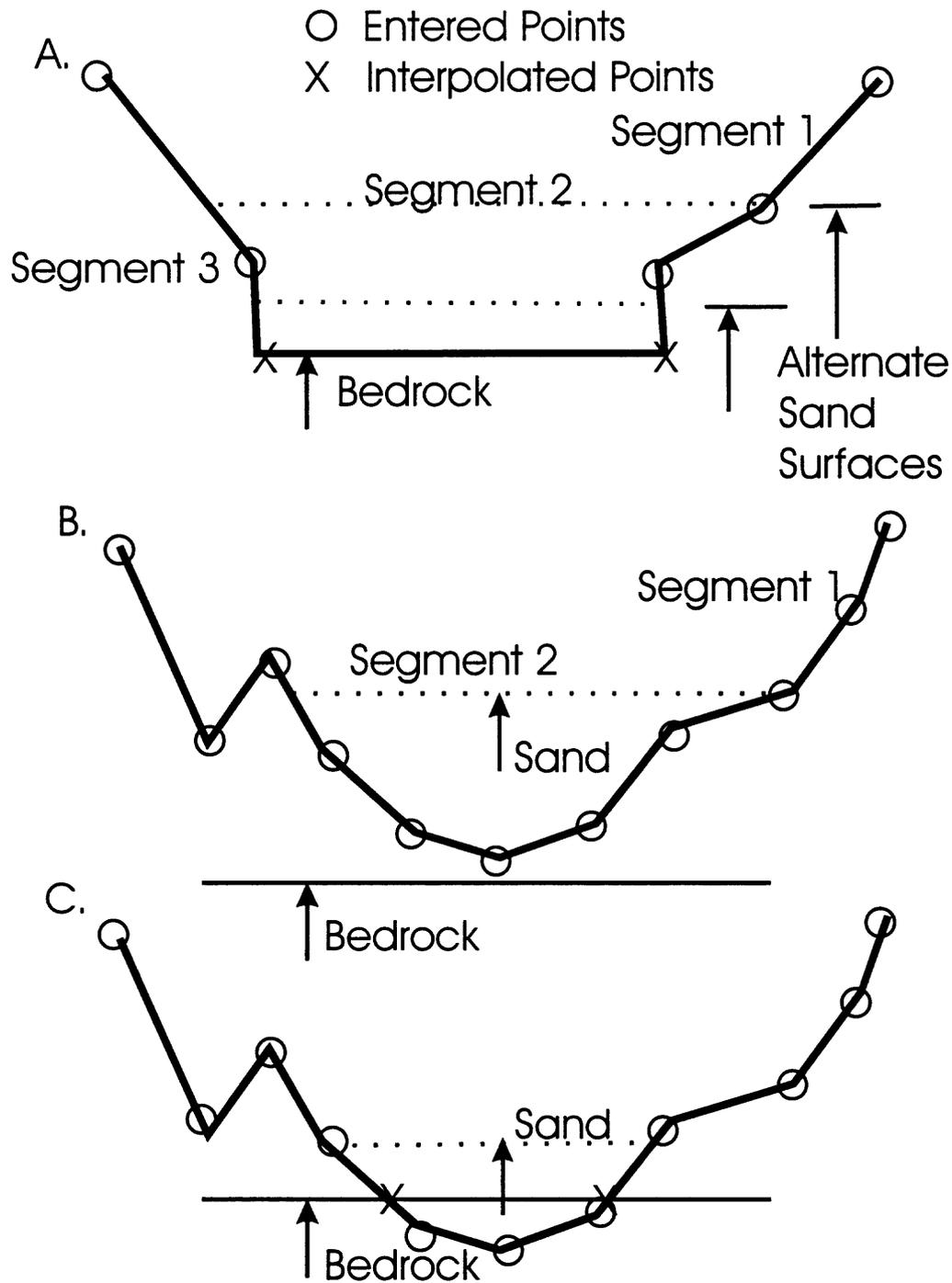


Figure 3. Illustration of cross-section area computation subroutine protocols for interpreting ground point, bedrock, and alluvial surface elevations. A) Cross-section entered in three segments, bedrock elevation lower than the end points of first and third segments (Alluvial surface is always the second segment.) B) Cross section entered in two segments, bedrock below all points on first segment. C) Cross section entered in two segments, bedrock above 3 points of first segment. Section truncated at bedrock elevation and extended along lines between X's. Length of dotted line representing sand surface demonstrates that alluvial-bed active width is determined by sand elevation and location of no-erosion surface.

In table 2, the i subscript refers to fraction or percentage finer by volume. That is, f_i is the volume percentage of the sediment layer that has sizes finer than the particle size d_i , and d_{50} is the particle size such that 50 percent of the volume of the layer consists of finer particles. The d_i 's must be supplied because they are not restricted to any standard format (ie ϕ or half- ϕ intervals) or to the size distribution chosen for a particular instance of model simulation. However, the d_i values must be specified in millimeters and must be monotonic increasing. Similarly, the f_i 's must be supplied in fraction-finer, format so that $0. \leq f_i \leq 1.0$ and the f_i must be monotonic, although it is permissible for two or more successive values to be equal. It is also permissible for the first f_i to be greater than 0 and/or for the last f_i to be less than 1. If one or more of the specified sizes falls below (or above) the range being used by the model, all such material would be classified as the smallest (or largest) current model size. Parameter σ_g known as the geometric standard deviation of the size distribution, gives an alternative mechanism for providing information concerning the distribution of particle sizes. It is defined as

$$\sigma_g = \sqrt{\frac{d_{84}}{d_{16}}} \quad (10)$$

which arises from the common assumption that the distribution is log-normal (the logarithms of the particle diameters are normally distributed). If code 1 is selected, the sediment-size algorithm automatically assigns a value $\sigma_g = 1.2$, the equivalent of $d_{16} = d_{50}/1.2$ and $d_{84} = 1.2d_{50}$. In summary, particle size distributions may be described in any of three ways. The first requires specification of two values, the second only one value, and the third two sets of length l , with the f_i all being supplied first.

After all channel descriptions are provided, the final section of the network description file describes the channel junctions. The efficiency of the iterative network flow-solution algorithm is greatest if this is done as nearly as possible in upstream to downstream order. For the four-channel, two-junction, network of figure 2, see the last three records of the Network Description File section of Appendix I. All entries in this section are integers, and the first is the number of junctions. If the simulation exercise is for a single channel, use 0. For each junction, then, the first entry lists the number of channels associated with the junction. For that junction, this is followed by the sequence number of each involved channel. Direction of flow information, into or away from the junction, must be user specified, and this is accomplished by preceding the sequence number of each

entering channel by a minus sign. The final junction description terminates the network description file.

Boundary Condition File

The boundary condition file contains information to set the initial conditions for the model run, to determine the temporal extent of the simulation, and to specify appropriate boundary conditions for each time step during execution. In general, upstream flow and sediment supply conditions are applied, as appropriate for a particular channel, before downstream hydraulic conditions. Time series values are denoted by time in days and the values pertinent to a particular time step during simulation are determined by linear interpolation between the two bracketing entries in the series.

For an example, see the Boundary Condition File section of Appendix I. As will be explained in more detail below, the model has the capability to provide the initial conditions necessary to commence a simulation from a file that was stored at the completion of a previous simulation using the same network description file (hot start), or to prepare them directly from the network description file (cold start). If the former is to be the case, the first two characters of the first record of the boundary condition file must be the alpha HS, otherwise, any two non-blank alpha values may be used. The next two entries must specify the start and end time of the simulation period in days. Following this, the information supplied for the individual channels must be supplied in the same sequence as they appear in the network description file, and its content depends on the boundary condition codes specified there.

Channels denoted with upstream boundary code 2 come from junctions and receive no external boundary information, those with upstream boundary code 1 must receive discharge, then sediment time series. The first integer in each description must be number of entries in the series, and there must be at least one (but not necessarily the same number in) each of the discharge and sediment series. Each entry in the discharge series must consist of a time, a flow rate in cubic meters per second (m^3/s), and a water temperature in $^{\circ}C$, in that order. The temperature data are necessary to determine fall velocity and critical shear stress values for the particles of the simulation size classes. Temperatures are determined to be the same for all channels downstream of a particular junction and of value equal to the sum of the products of the incoming temperatures and discharges divided by the sum of discharges (discharge-weighted average).

Each discharge series is immediately followed by a sediment series. The first two notations are the number of entries in the sediment series, followed by the slope of the channel upstream of the boundary point. Each entry in the sediment series then consists of two values that are the time of occurrence and the total

volume transport rate in m^3/s of sediment solids for the particular entry. The next piece of information for the entry is an integer code from table 2 describing the number of size-description members for the first entry of the sedigraph. The number and form of the final set of values in the entry must be appropriate to the size distribution code selected, and the required formats are as presented above. If the total-volume transport rate is specified as from measurements or a separate rating curve, the distribution is converted to the format used for simulation computations and interpolation to the simulation time between boundary condition file entries is performed on a volume transport-rate weighted basis. Thus, the instantaneous size distribution may not resemble that of either of the interpolation end points.

In the sediment series, the slope of the channel upstream of the entry section is required because the sediment boundary condition has two possible modes of operation. Which one is used depends on the sign preceding the total volume transport rate. If the sign is negative, the algorithm computes the incoming total transport rate by size class as appropriate to the then-applicable flow rate and under the following assumptions: (1) The channel upstream of the modeled channel is at the slope specified, with cross-section properties and active-width the same as the boundary section. (2) Equilibrium transport exists in that fictional channel and it can be determined using the values of the parameters selected in the GUI for (5)-(9) above. (3) The surface of bed-sediment is of the size composition determined by linear interpolation between the two endpoints bracketing the time of computation. The option to use this type of boundary condition mode is provided because sometimes it is desirable to simulate channel behavior in situations where the upstream sediment-transport rate has not been measured and cannot be predicted. In such situations, it is often unrealistic to assume that a clear-water or zero transport rate sediment supply exists. It is not permitted to interpolate between the two types of input mode, so if the total volume transport rate field has a negative value at either end of the interpolation period, the first method just discussed is used. In this case, however, the bed sediment composition used throughout the time step is the one for the entry with the negative value in the transport-rate field. In general, it is not recommended to mix the two types of input in the same time series. If this must be done, one should keep this computational procedure in mind while preparing the boundary condition file and minimize the length of the time step between the two types of input.

The downstream boundary condition for a particular channel must appear in the boundary condition file immediately following the discharge and sediment upstream-boundary condition information (if any exists). Because sediment transport amounts and timing are determined by hydraulic conditions in the channel, this

boundary condition may only contain specifications relevant to flow hydraulics. The downstream boundary condition code 1 (table 1) for a water-surface elevation time series requires specification of the number of entries in the series (at least one), followed by that number of pairs of time, in days, and water-surface elevation in meters. The water-surface elevation must be true or absolute values, because there is no provision for adjustment as there is with the elevations associated with the cross-section descriptions. This is true for any other water-surface elevation-related boundary condition mentioned.

For downstream boundary condition code 2 (table 1), the user must supply the constants a and b for a rating curve in the form

$$\log_{10}Q = a + b \log_{10}D \quad (10)$$

where, as previously, D is hydraulic depth. This means that the water-surface elevations computed as model execution proceeds are in relation to the cumulative scour or fill that has been computed at the rated cross-section. This boundary condition may also be applied to a channel ending internal to the network, but, unlike the case for an internal weir, there is no check for submergence. On occasion, such as when the flow depth is very shallow, the solution algorithm used for this boundary condition can cause instability or even termination of program execution, and the user may find it necessary to take corrective action. One way this can be done is to apply the rating external to the model and instead supply a water-surface elevation time series for simulation purposes.

For the normal-depth condition of downstream boundary condition code 3 (table 1), only the slope of the downstream channel need be specified, the required Manning resistance coefficient is taken to be the one applicable to the downstream section at the time the boundary condition is required.

Specification of downstream boundary condition code 4 (table 1) requires that the channel be listed as terminating at a junction in the network description file discussed above, and no downstream boundary condition information may be entered in the boundary condition file.

Finally, downstream boundary condition code 5 (table 1) specifies the existence of a sharp-crested weir and requires the user to provide an absolute crest elevation and crest length, both in meters. This boundary condition may be applied at an internal junction, providing the capability to include a low-head dam or diversion structure in the simulation, and a check- and appropriate correction- for submergence due to downstream flow conditions is applied. The equations governing flow over sharp-crested weirs are discussed in such hydraulics text books as Henderson (1966, p. 178),

and the necessary modifications for submergence are presented by Cunge and others (1980, p. 76).

MODEL APPLICATION REQUIREMENTS AND OPTIONS

Once the network and boundary condition files have been prepared as described in the previous section, model execution is one of three or four phases in model utilization. The first phase involves locating the input files and setting run-time parameters and certain execution modes. The second phase is model execution. The third consists of review and plotting of the resulting output calculations using the model's GUI. The final phase includes extraction of other desired results from files written by the model during the second phase. The purpose of this section is to describe the steps necessary to accomplish each phase and to outline the output file formats (abridged listings of these files are given in Appendix II) to expedite their use by individual users. The model options and execution are invoked from standard Windows-type menus, and it is assumed that the user is familiar with their operation.

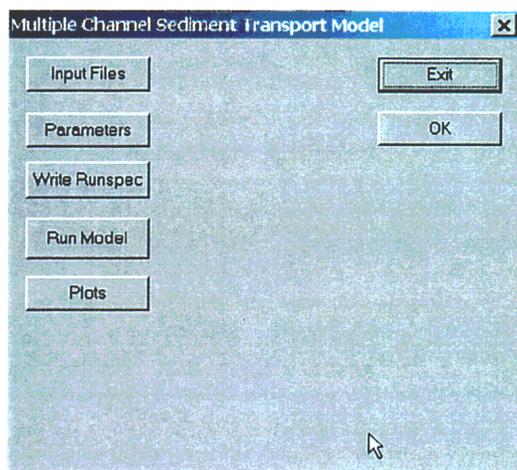


Figure 4. Main menu of model.

Preparation for Model Execution

To commence a modeling session in the Windows environment, the user should double-click on the application file `Multi_Ch_Transport.exe`. The main menu of the application is shown in figure 4 and a typical simulation would proceed using the buttons from top to bottom along the left side of the menu. The *Input Files* button invokes the menu shown in figure 5 and the paths to the network description and boundary condition files may be typed in the edit boxes shown in the figure or located using the standard Windows file browser invoked

using the *Browse* button. In this case, both files must be located and selected, the network description file as Unit 1, and the boundary condition file as Unit 3.

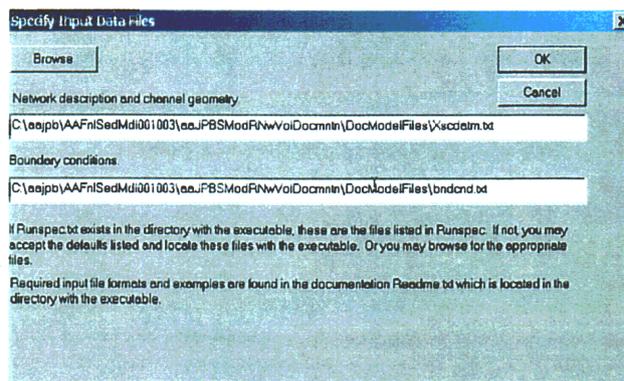


Figure 5. Browser interface for model input files.

It sometimes happens that there are errors in context or formatting during initial preparation of the input files and that such errors will cause model execution to terminate. To aid in locating such problems, the model writes a file in the same directory as the model application file `InputEcho.txt` (Appendix II). In this file, the user usually can locate the point at which data processing ceased due to the formatting error. In using each menu to be discussed here, no changes made in edit boxes or resulting from mouse actions will take effect unless the *OK* button is selected before closing the menu.

The next step in preparation for model execution is selection of, process parameters, sediment size classes, and execution mode. The options available are illustrated in figures 6 and 7. Figure 6 illustrates the *Simulation Parameters* menu with user-adjustable parameters appearing in the edit boxes. For a first-time use of the model, default values of the parameters appear in the edit boxes. Clicking the *Simulation Sediment Sizes* button of the menu shown in figure 6 causes the size-range selection dialog of figure 7 to appear. The defaults appearing in the dialog are 14 range-delimiting sizes commencing with the lower limit of the sand sizes, 0.0625 mm, and increasing in half- ϕ steps (by a factor equal to the square root of two) through the sand-size range (to 2.0 mm) then increasing by full- ϕ steps to 16 mm. As many as 20 range-delimiting particle sizes may be entered (or altered) using the edit boxes. As mentioned previously, any particles falling below the specified lower limit or above the upper limit will be treated as if they are of the respective limiting size selected using this dialog.

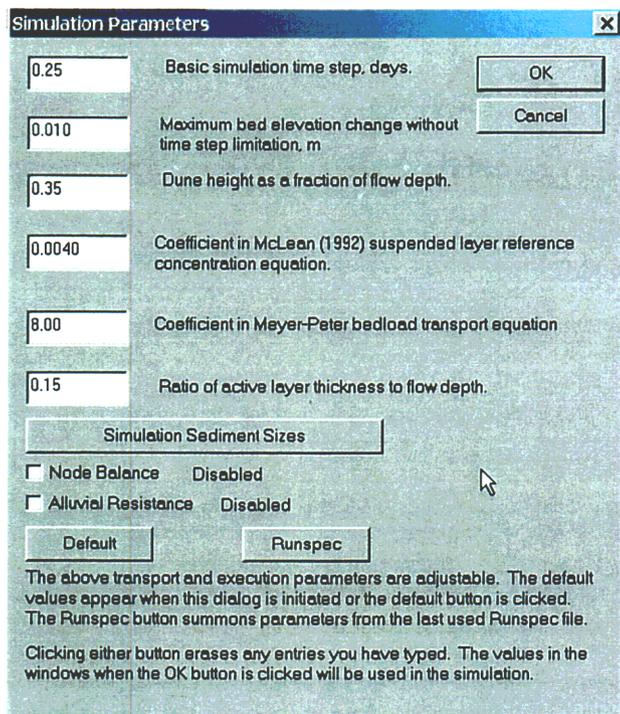


Figure 6. Menu for model execution mode and parameter selection.

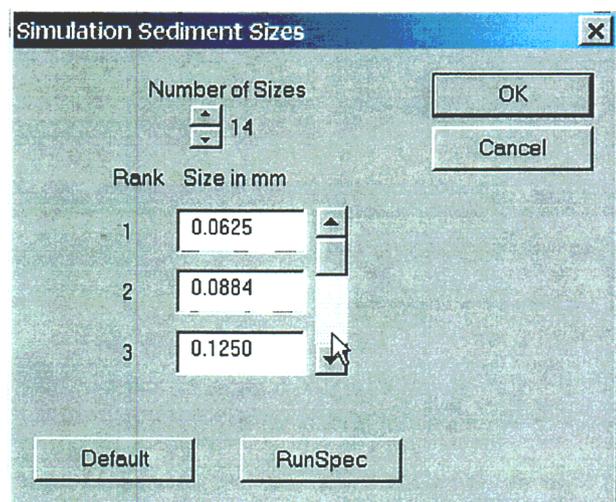


Figure 7. Sediment-size selection menu.

Returning to figure 6, the time step value shown in the upper edit box is the maximum that will be applied during the simulation. The length of time step actually employed is often determined by the parameter shown in the second box, which is a maximum bed elevation change allowed due to longitudinal transport-rate disequilibrium before flow hydraulics must be re-

computed. This limitation is included in the model to help ensure that the flow and transport are always synchronized. It is made user adjustable to enhance stability of the calculations but allow some flexibility in differing types of applications.

The parameter in the third edit box allows the user to select the maximum height (as a fraction of flow depth) of bedforms (dunes) achieved in the algorithm that computes alluvial-channel flow resistance and skin friction for sand-bed channels. The former is important only if the *Alluvial Resistance* check box is enabled, but the latter adjustment is made whenever the bed surface is in the sand-size range and the existence of bedforms is indicated.

The parameters in the next two edit boxes allow adjustment of the proportionality coefficients in the sediment-transport equations. The first is term γ_0 of (9), from McLean (1992), that sets the concentration at the base of the suspended transport layer. The second is ϕ_0 of (5), the Meyer-Peter-type bedload-transport equation from Wiberg (1987). These two coefficients provide the only direct mechanism within the model to calibrate or adjust predicted sediment-transport rates to match observed rates.

The parameter in the last edit box sets the ratio of computational active layer thickness to flow depth and thus determines the amount of sediment available for erosion during a time step. As mentioned previously, for sand-bed channels, a reasonable value is 0.3, which is a commonly observed ratio of bedform height to flow depth. Despite the fact that it can limit the amount of a particular sediment size that can be eroded from the layer, this parameter seems to have little effect on average rate of transport. This is probably due to the fact that, for any physically reasonable ratio, the composition of the layer adjusts towards that which will produce a transport size mixture in equilibrium with the bed composition relatively rapidly. However, due to the fact that certain sizes tend to appear and disappear from thinner layers more frequently, transport rates will tend to appear smoother on time-series plots if larger values of the ratio are used.

The Simulation Parameters menu also contains two check boxes for enabling or disabling particular model computation modes. The first of these is called "node-balance" mode; it provides a mechanism for maintaining at the same level the bed elevations of the first or last channel increments of all channels entering or leaving a junction. If invoked, the mode acts for all junctions of a network. Following the normal sediment-transport routing and bed-composition and -elevation accounting calculations in node-balance mode, an additional step is implemented that results in "transferring" sediment from channel increments higher than the average elevation for the junction to those that are lower until all have the same bed elevation at the

junction. The procedure is necessitated by the channel-bed elevation of one or more channels at a junction becoming radically different than the others and sometimes causing computational instability. This happens because of an imbalance between hydraulic conveyance, sediment-transport capacity, or bed composition of the offending channel compared to others involved with the junction. In general, models with well-posed geometry and balanced bed compositions do not encounter the problem; it is best to conduct simulations without the node-balance mode enabled if possible. For first-time simulations, the default state for this computation mode is "disabled". If one must use the mode, the channel increments entering the junctions should be appreciably shorter than those that make up the remainder of the network.

The second check box of the Simulation Parameters menu enables the alluvial-channel-resistance computation algorithms of Bennett (1995) instead of using the alluvial-bed Manning's *n* values specified in the first record of each cross section description of the network file. In situations such as when sand-channel bedform type can switch back and forth between dunes, transition, and plane, it may be particularly desirable to use this computation mode. The assumptions, considerations, and procedures are too lengthy to be discussed here, but may be found in detail in Bennett (1995). For first-time simulations, the default state for this computation mode is "disabled".

The third button of the main menu (fig. 4) bears the title *Write Runspec* and causes the GUI to write a file, called Runspec.txt (see Appendix II), that lists the path names of the two selected input files, the number and sediment size ranges selected, the values of all of the current parameters and the states of the check boxes. This file, along with all others to be discussed that are written during model execution, appear in the directory with the model application file. For any subsequent implementation of the model, the information in file Runspec.txt (if it exists) is first read from the file and becomes the default for starting the next model run. The reason for this capability is that it avoids the need for repetitive entering of file names and parameters and provides the convenience of conducting replicate model runs with constant parameters but different time spans or input hydrographs. It also allows replicate runs with minor changes in only one or two parameters, and, so long as the *Write Runspec* button is not clicked, no permanent changes are made to the default parameter set. Similarly, selecting the *Runspec* button on the Simulation Parameters menu (fig. 6) causes the information from the Runspec.txt file (if one exists) to be reloaded into any fields that have been changed. In a similar fashion, clicking the *Default* button of that menu (fig. 6) causes the default number and sediment size ranges and parameter set to be loaded into the appropriate fields.

These defaults are as have been introduced here and will appear in the edit and check boxes just discussed.

Once the user is satisfied with the selected sediment sizes, parameters, and operating modes, he should close the Simulation Parameters menu and return to the main menu using the *OK* button. If it is desired to save this configuration for future model implementations, the user should then select the *Write Runspec* button. The next step is to click the *Run Model* button, following which the evidence of progress of the computations is the gradual appearance of a row of X's below the row of I's as is shown in figure 8. Once simulation computations are completed, the user may view the results using the built-in graphics capability of the model and/or analyze them by accessing model output files as discussed below.

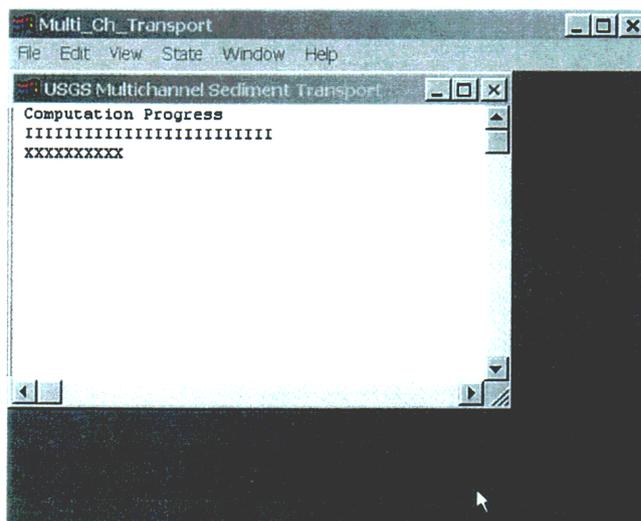


Figure 8. Model executing with approximately 40 percent of time period simulated.

Model Graphics Capabilities

The plots generated by the model are produced from a combination of the file RawPlots.txt, which is written during model execution, and the input network description file. To access the plotting capability of the model, the user first selects the main menu *Plots* button (fig. 4). This activates the Inquiry dialog shown in figure 9; the user needs to verify that the network description file shown in the edit box is the one used for the simulation run that produced the plot file to be processed. If the listed network description file is correct, the *Continue* button should be selected. If the listed network description file is incorrect, the *Abort* button should be selected and the model main menu screen will reappear. In this case, the appropriate network description file should be found using the *Input Files* button of the main menu (fig. 4) and the procedures described above. When

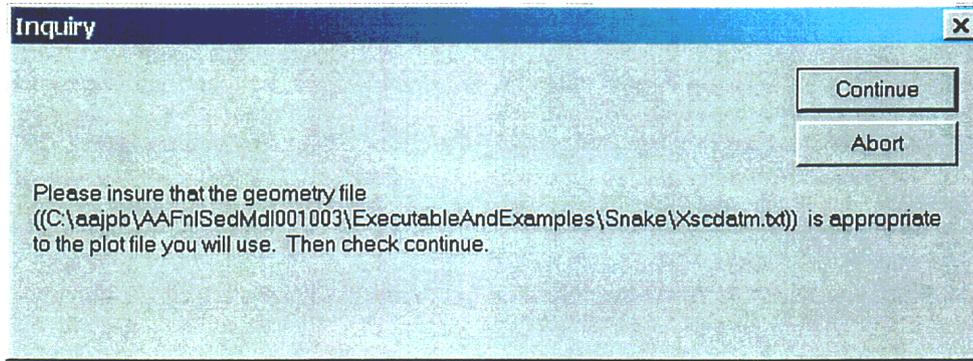


Figure 9. Dialog box requesting the user to confirm that the RunSpec.txt file references a network description file appropriate to the file containing the plot information.

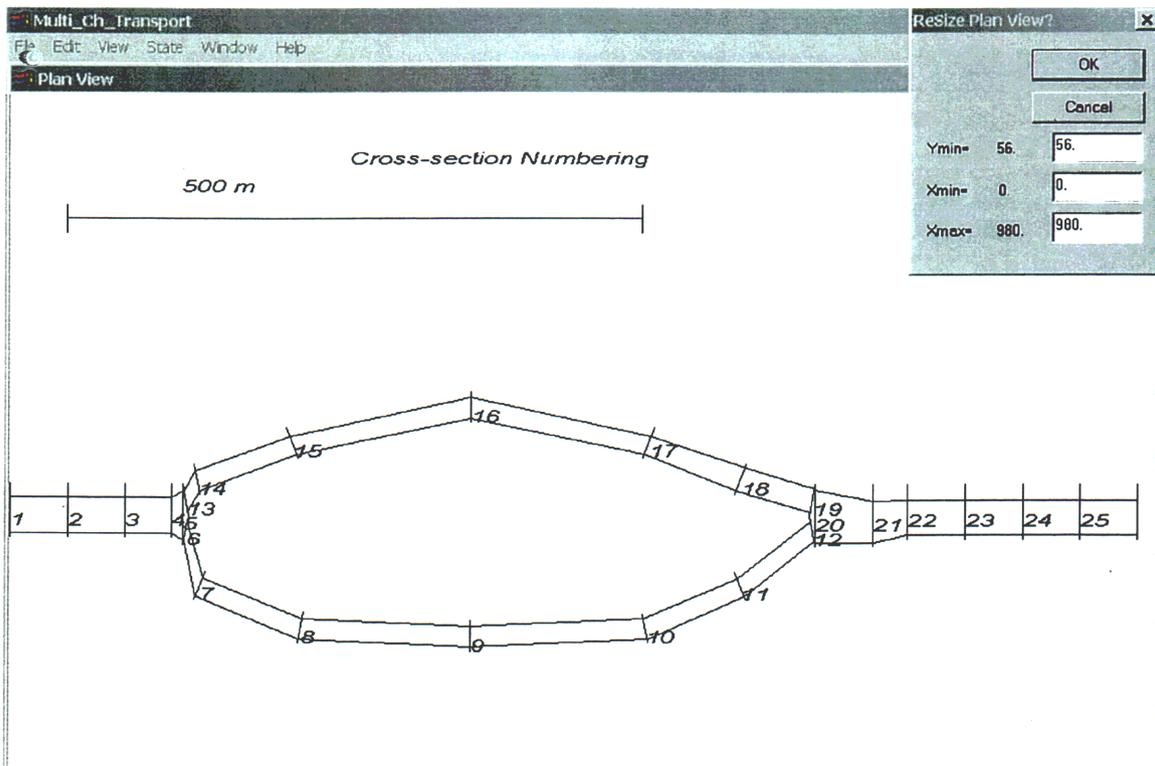


Figure 10. Study-area plot plan showing cross-section numbers, scale, and the dialog box used to re-scale or zoom the drawing.

this has been done, the *Write Runspec* button should be selected before returning to the plotting menus. Given an appropriate network description file, selection of the *Continue* button of the Inquiry dialog (fig. 9) produces study area plot like that shown in figure 10. The scale of the plot is indicated in the upper left and the "Resize Plan View" dialog allows the user to change the scale or "zoom" to various portions of the study area by changing the values in the edit boxes. The absolute limits of study

area dimensions are given in the text to the left of the edit boxes. Selecting the *OK* button of the Resize Plan View dialog replots the plan view using the current or any new user-specified dimensions. These full-screen plots can be printed using the "File" option of the main Windows task bar.

When the user selects the *Cancel* button of the Resize Plan View dialog of figure 10, the Plots menu of figure 11 is produced. The edit box on this menu lists the name of the file to be searched for information to be

plotted. As mentioned above, the default name for this file is RawPlots.txt, and its default location is the directory containing the model application file (Multi_Ch_Transport.exe). If the file containing the plotting information is in some other location, the complete path of the file can be entered in the edit box or it can be selected using the *File Browse* button (fig. 11). The user needs to keep in mind that the default RawPlots.txt file will only contain information from the most recent model execution run. If it is desirable to save plotting information from multiple model runs, the RawPlots.txt file should be renamed or moved from the directory containing the model application file prior to the next model execution run. As shown in figure 11, at-a-cross section time series plots or along-individual-channel (instantaneous) profile plots may be made by selecting the appropriate buttons from the Plots menu.

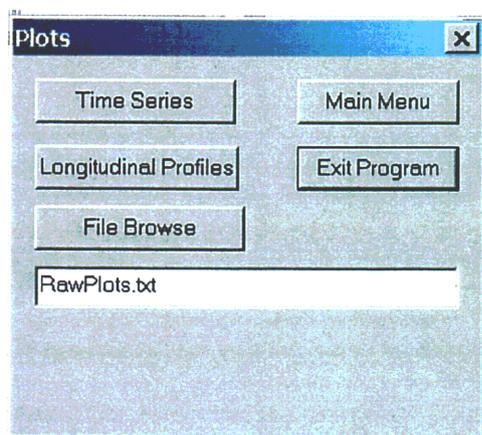


Figure 11. Plot menu showing edit box with path to the file containing data to be plotted and buttons for selecting type of data to be displayed.

The general format for viewing model results is shown in figure 12, with menus along the left of the monitor screen, a plan view of the simulation area showing the location of the function plot in the lower right corner, and the function plot in the upper right corner. The function plots may, under menu control, be expanded to full-screen for printing if desired.

A typical time series of sediment-transport is shown in figure 12 for cross section 16 which is on the left channel flowing around the island. Such plots show total transport input to the system (Total Input), total transport (Stat. Total), sand fraction (Stat. Sand), and suspended sand (Susp. Sand) transport past the section. The axis for the median diameters of the total sand (Sand D50) and suspended sand (Sus. Sand D50) in transport appears on the right side of the figure. As the Time Series Plots menu of figure 12 illustrates, the GUI can also produce at-section plots of discharge (*Station Q*) and bed

elevation. The latter also chronicles the evolution of the active-layer size distribution.

Figure 13 illustrates the capability of the GUI to produce longitudinal profiles at specified times during the simulation period for individual channels within the network. This plot shows profiles of bed- (Bottom) and water-surface (Surface) elevation and active layer median diameter (Bed D50) following day 5.00 of the simulation period. For ready reference, this plot also shows the bed elevation (Orig. Bot.) at the start of the simulation period. As the Longitudinal Profiles menu shows, longitudinal transport rate variations may also be graphed for particular instances during the simulation period.

Output Files

The model prepares several files during data entry and execution for a variety of purposes such as debugging, evaluating conservation of mass, and summarizing results in ways not possible using the graphing capabilities of the GUI. The files are all found in the directory with the model application file. Abridged entries from each file are found in Appendix II under file name headings and in the same order as discussed in this section.

The first file, called InputEcho.txt, is written record-by-record as the network and boundary condition files are read during the input data processing step. The only difference between this file and the original data is that the path to the file being processed is given before the data are listed. This file is intended primarily to aid the user in locating formatting errors in the input data file streams.

The second file, RunSpec.txt, is written only when the *Write Runspec* button of the main menu (fig. 4) is clicked and lists the path names of the network description and boundary condition files, current values of the parameters to be used in simulation and appearing in the edit boxes of the Simulation Parameters menu (fig. 6). This is then followed by two integer values that will be 0 if the check boxes of that menu are disabled or 1 if they are enabled. The last set of entries gives the number and class-boundary particle sizes to be used in the simulation.

The Sumry.txt file gives information concerning parameters and execution modes, simulation beginning and ending sediment volumes and size characteristics. It also provides an overall assessment of mass conservation and by-channel summaries of bed- and water-surface elevation, flow and transport-rate distribution by increments of approximately 5 percent of the total simulation time as it progresses. Similarly, the By_Secn_Sumry.txt file provides information concerning the temporal evolution of at-station hydraulic- and sediment-related variables. Both files are intended to be read "by eye", and the headings and other descriptions

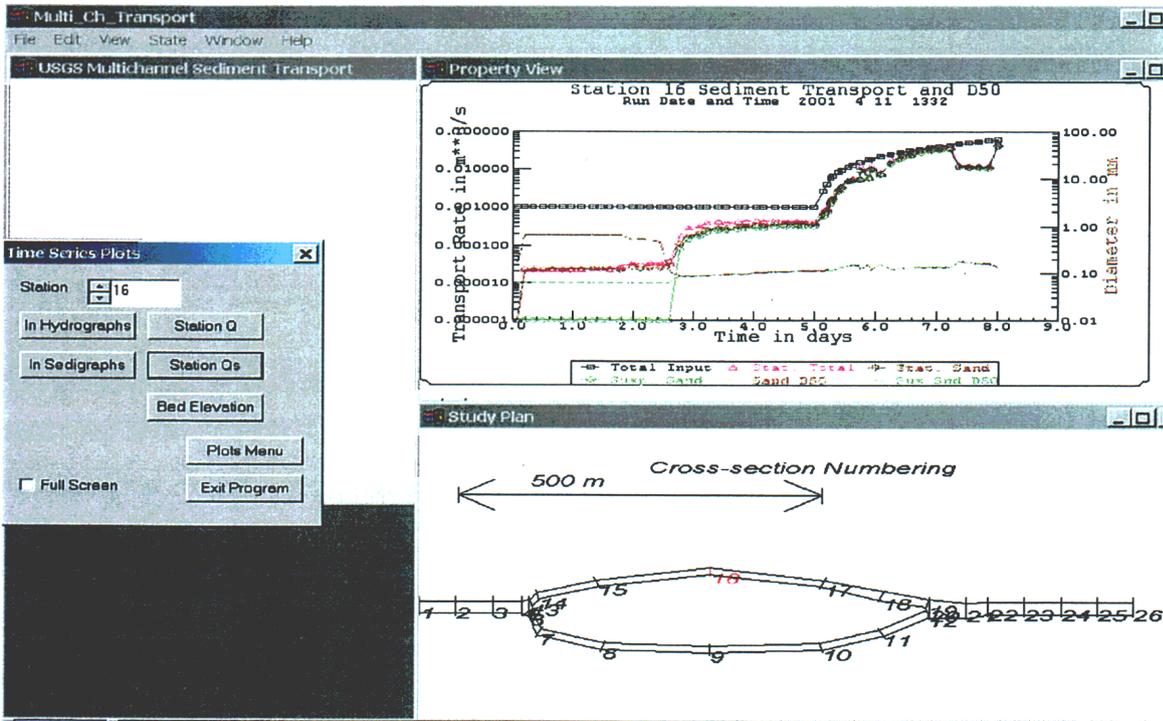


Figure 12. Typical time series plot of transport rate past station 16 on the left channel around an island.

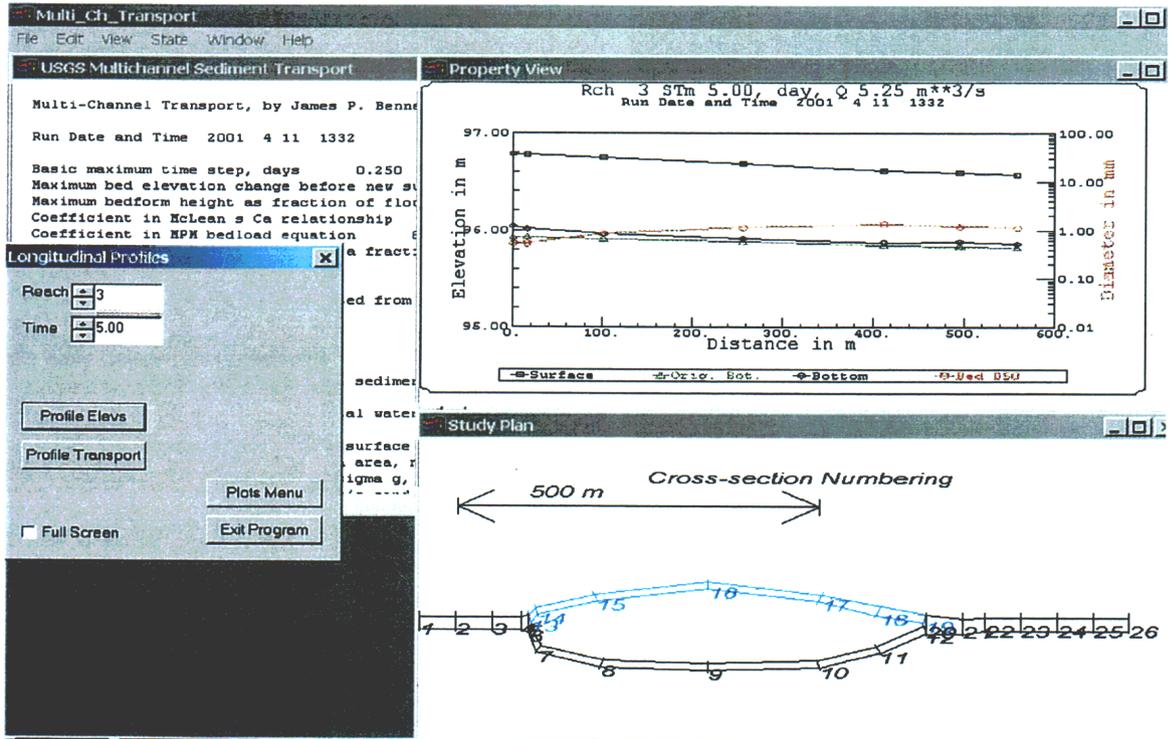


Figure 13. Typical longitudinal plot of bed elevation and size composition at the end of a simulation period for channel reach 3, the left channel flowing around an island.

found for the examples in Appendix II are self-explanatory

The HotStart.txt file is a once-through by cross-section compilation consisting of variables that are updated sequentially by time step, such as active width, Manning coefficient, and armoring index and the then-current by-size-class volumes of sediment in each of the layers. It represents conditions at the last point in time corresponding to when the Sumry.txt and By_Secn_Sumry.txt files were indexed for which the model execution was successful. That is, it is completely rewritten approximately each 0.05 fraction of the way through the prescribed simulation period. Its purpose, when used in combination with the original data of the network and boundary condition files, is to allow long simulations to recommence near the point in time at which they were terminated whether by accident or on purpose at the end of the simulation period. It is intended entirely for use by the model itself.

The RawPlots.txt file is appended to approximately each 0.02 fraction of the way through the prescribed simulation period, or when the sum of input hydrographs vary by more than 10 percent, for the purpose of providing information to subsequently be used to prepare the plots that the GUI provides. The file is organized by time step, then by channel, and finally by cross section to list the temporal evolution of a variety of hydraulic, sediment-transport, and active-layer size-composition characteristics. As is seen from the listing of the file in Appendix II, there is a section at its beginning that describes the variables and units for the entries in that file. Using this description, it is relatively simple to write FORTRAN programs to sort through this information, as do the GUI plotting algorithms, and prepare summary statistics not available from the GUI plots or the other files that have been discussed here.

Using the RawPlots.txt file, the last step of model execution is the preparation of the file SecTSSprSht.txt that is intended to enable users to conduct their own time-series oriented analyses and construct plots not available in the model's graphics library. The SecTSSprSht.txt file is organized to facilitate its use by commercial spread-sheet software. Figure 14 shows an example of a portion of such a spread sheet that reproduces the columns (including headings) in the file. In the spread sheet, the first and second columns list the channel and cross section number. The third column lists the time during the simulation of the remaining variables in the row. The fourth column shows distance to the cross section from the upstream end of the channel and the remaining columns list hydraulic and sediment characteristics as described in the figure caption.

SUMMARY

This document describes a new general model developed by USGS for predicting the transport of mixed sizes of sediment by flow in simple networks of open channels. The simulation package is intended to be useful for general sediment-routing problems, prediction of erosion and deposition following dam removal, and scour in channels at certain road embankment crossings or other artificial structures. Channels appropriate for simulation are characterized as one-dimensional, that is as having reasonably negligible lateral variability in the processes of flow, sediment transport, and any resulting bed-elevation adjustment. Because the time scale of the pertinent channel-bed sorting and elevation adjustment process is long compared to those typically treated with unsteady flow algorithms, the model treats input hydrographs as step-wise steady-state. The flow computation algorithm automatically switches between sub- and supercritical flow as dictated by channel geometry and discharge. A variety of boundary conditions including weirs and rating curves may be applied both external and internal to the flow network. A default sediment-transport computation time step is specified by the user, but the actual time step is often determined by a minimum bed-elevation change which is also user specified. The model may be used to compute flow around islands and through multiple openings in embankments, but the network must be "simple" in the sense that the flow directions in all channels can be specified before simulation commences. The location and shape of channel banks are user specified and all bed-elevation changes take place between these banks and above a user-specified bedrock elevation. Computation of sediment-transport emphasizes the sand-size range (0.0625-2.0 mm), but the user may select any desired range of particle diameters including silt and finer (<0.0625 mm). As part of data input, the user may set the original bed-sediment composition of any number of layers of known thickness. The model computes the time evolution of total transport and the size composition of bed- and suspended-load sand through any cross section of interest. It also tracks bed-surface elevation and size composition. The model is written in the FORTRAN programming language for implementation on personal computers using the WINDOWS operating system and, along with certain graphical output display capability, is accessed from a graphical user interface (GUI). The GUI provides a framework for selecting input files and parameters of a number of components of the sediment-transport process. Apart from a limitation of 20 on the number of sediment particle sizes, there are no restrictions in the use of the model as to numbers of channels, channel junctions, cross sections, or points defining the cross sections. Following completion of the simulation computations, the GUI

accommodates display of longitudinal plots of either bed elevation and size composition, or of transport rate and size composition of the various components for individual channels and selected times during the simulation period. For individual cross sections, the GUI also allows display of time series of transport rate and size composition of the various components and of bed elevation and size composition.

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Figure 14. Example spread sheet from file SecTSSSprSht.txt. Columns contain information as follows: (1) Network channel segment number (fig. 2). (2) Network cross-section number (fig. 2). (3) Time during the simulation period. (4) Downstream distance of cross section from start of channel segment. (5) Cross-section water surface elevation. (6) Cross-section hydraulic radius. (7) Cross-section-average flow velocity. (8) Cross-section standard deviation cross-section bed elevation. (9) Cross-section median diameter cross-section bed sediment. (10) Median diameter cross-section bed sediment. (11) Geometric standard deviation cross-section bed sediment. (12) Index number of smallest immobile sediment size for the simulation distribution in the bed at the cross section. (13) Cross-section total volumetric sediment transport rate. (14) Cross-section sand-fraction volumetric transport rate. (15) Cross-section sand-fraction volumetric transport median diameter. (16) Geometric standard deviation cross-section sand transport. (17) Geometric standard deviation cross-section sand-fraction volumetric transport rate. (18) Cross-section suspended sand transport. (19) Geometric standard deviation cross-section suspended sand transport. (20) Geometric standard deviation cross-section suspended sand transport.

Channel Segment	Cross Section	Time (days)	Ch Dist (m)	WS Elev (m)	Hyd Rad (m)	X-Sec Area (m ² m)	Velocity (m/s)	Discharge (m ³ m/s)	Elevation (m)	d50 (mm)	sig g	Bed		Non Total Tran		Sand		Transport		Susp Sand		Transport	
												d50 (mm)	(11)	(12)	(13)	(14)	Rate (m ³ m/s)	Rate (m ³ m/s)	d50 (mm)	sig g	Rate (m ³ m/s)	Rate (m ³ m/s)	d50 (mm)
1	1	6.8494E-02	0.0000E+00	9.6808E+01	7.6036E-01	1.6684E+01	5.9938E-01	1.0000E+01	9.5986E+01	0.408	1.969	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0707E-04	0.136	1.441				
1	1	1.2475E-01	0.0000E+00	9.6809E+01	7.6488E-01	1.6788E+01	5.9565E-01	1.0000E+01	9.5991E+01	0.418	1.93	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0766E-04	0.136	1.441				
1	1	1.8538E-01	0.0000E+00	9.6810E+01	7.6908E-01	1.6885E+01	5.9223E-01	1.0000E+01	9.5987E+01	0.428	1.897	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0816E-04	0.136	1.441				
1	1	2.5152E-01	0.0000E+00	9.6810E+01	7.7287E-01	1.6975E+01	5.8909E-01	1.0000E+01	9.5984E+01	0.436	1.874	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0825E-04	0.136	1.441				
1	1	3.2292E-01	0.0000E+00	9.6811E+01	7.7653E-01	1.7058E+01	5.8624E-01	1.0000E+01	9.5980E+01	0.444	1.86	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0871E-04	0.136	1.441				
1	1	3.9931E-01	0.0000E+00	9.6812E+01	7.7984E-01	1.7135E+01	5.8361E-01	1.0000E+01	9.5977E+01	0.45	1.853	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0897E-04	0.136	1.441				
1	1	4.8004E-01	0.0000E+00	9.6813E+01	7.8284E-01	1.7205E+01	5.8124E-01	1.0000E+01	9.5975E+01	0.455	1.845	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0901E-04	0.136	1.441				
1	1	5.6474E-01	0.0000E+00	9.6814E+01	7.8565E-01	1.7270E+01	5.7903E-01	1.0000E+01	9.5972E+01	0.459	1.842	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0943E-04	0.136	1.441				
1	1	6.5531E-01	0.0000E+00	9.6815E+01	7.8834E-01	1.7333E+01	5.7694E-01	1.0000E+01	9.5970E+01	0.463	1.842	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0945E-04	0.136	1.441				
1	1	6.6538E-01	0.0000E+00	9.6816E+01	7.8938E-01	1.7358E+01	5.7611E-01	1.0000E+01	9.5970E+01	0.463	1.843	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0987E-04	0.136	1.441				
1	1	6.7665E-01	0.0000E+00	9.6816E+01	7.8989E-01	1.7370E+01	5.7571E-01	1.0000E+01	9.5970E+01	0.463	1.843	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0971E-04	0.136	1.441				
1	1	6.9475E-01	0.0000E+00	9.6816E+01	7.9054E-01	1.7385E+01	5.7521E-01	1.0000E+01	9.5969E+01	0.464	1.844	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0976E-04	0.136	1.441				
1	1	7.1676E-01	0.0000E+00	9.6817E+01	7.9129E-01	1.7403E+01	5.7462E-01	1.0000E+01	9.5969E+01	0.464	1.845	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0982E-04	0.136	1.441				
1	1	7.3316E-01	0.0000E+00	9.6817E+01	7.9194E-01	1.7418E+01	5.7412E-01	1.0000E+01	9.5969E+01	0.465	1.846	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0988E-04	0.136	1.441				
1	1	7.5871E-01	0.0000E+00	9.6817E+01	7.9248E-01	1.7431E+01	5.7371E-01	1.0000E+01	9.5968E+01	0.465	1.848	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0992E-04	0.136	1.441				
1	1	7.7260E-01	0.0000E+00	9.6818E+01	7.9293E-01	1.7441E+01	5.7335E-01	1.0000E+01	9.5968E+01	0.466	1.849	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0997E-04	0.136	1.441				
1	1	7.9448E-01	0.0000E+00	9.6818E+01	7.9334E-01	1.7451E+01	5.7304E-01	1.0000E+01	9.5967E+01	0.466	1.85	0	1.0000E-03	8.5000E-04	0.136	1.441	8.0999E-04	0.136	1.441				
1	1	8.0897E-01	0.0000E+00	9.6818E+01	7.9361E-01	1.7457E+01	5.7284E-01	1.0000E+01	9.5967E+01	0.467	1.851	0	1.0000E-03	8.5000E-04	0.136	1.441	8.1002E-04	0.136	1.441				
1	1	8.3374E-01	0.0000E+00	9.6818E+01	7.9405E-01	1.7467E+01	5.7250E-01	1.0000E+01	9.5967E+01	0.467	1.853	0	1.0000E-03	8.5000E-04	0.136	1.441	8.1005E-04	0.136	1.441				
1	1	8.4936E-01	0.0000E+00	9.6817E+01	7.9369E-01	1.7458E+01	5.7279E-01	1.0000E+01	9.5966E+01	0.467	1.854	0	1.0000E-03	8.5000E-04	0.136	1.441	8.1002E-04	0.136	1.441				

APPENDIX I-ANNOTATED INPUT FILES

Network Description File

The following is the input network description file for the example from the model application section. Input data is in red print; description of data fields is in green italic print.

```
4          Number of channel segments in simulation.
1 4 5      First channel upstream and downstream boundary
           condition type codes(Table 1), number of
           cross sections in channel segment.
0 120 0 150. Coordinates, plan, x-y of two points on base
           line along which cross section runs.
0.         Elevation adjustment applicable to all cross-
           section elevation values supplied with
           this file.
93.5 .030  Bedrock elevation and Manning's n.
.028      Alluvial bed Manning's n.
2 1 2 2   Numbers of ground points in each of three cross-
           section segments. Number of bed layers.
0 100 .035 3.48 93.9 .035
           Triplets of cross-channel distance along base line,
           elevation, and Manning's n for right bank
           of cross section.
10 96     Distance, elevation pairs for alluvial portion
           of cross section.
21.16 93.9 .035 24.64 100 .035
           Triplets of distance along base line,
           elevation, and Manning's n for left bank
           of cross section.
9         Number of entries in sediment size description
           for layer 1.
.0625 .125 .25 .5 1 2 4 8 16
           Sizes of entries in sediment size description
           for layer 1.
0. .11 .3 .55 .7 .84 .9 .98 1.
           Fraction finer of entries in sediment size
           description for layer 1.
9 95.7    Number of entries in sediment size description
           for layer 2, elevation of top of layer 2.
.0625 .125 .25 .5 1 2 4 8 16
           Sizes of entries in sediment size description
           for layer 2.
0. .00 .01 .05 .2 .4 .9 .98 1.
           Fraction finer of entries in sediment size
           description for layer 2.
           End of description for cross section 1 of
           channel 1.
50 120 50 150 -.025 94.5 .030 .028 2 1 2 2
           Beginning of description for cross section 2 of
           channel 1, G (general) format allows all data
           entries to appear in a single record if
           desired.
0 100 .035 3.48 93.9 .035
10 96
```

```

21.16 93.9 .035 24 64 100 .035
-1                               Layer 1 size description as  $d_{50}$  and  $\sigma_g$  .
.4 2
-1 95.7
2.5 2
100 120 100 150 -.05 94.5 .030 .028 4 1 0 1
                               Beginning of description for cross section 3 of
                               channel 1. A two-segment description is shown,
                               the first string describes both banks, the second
                               describes the alluvial surface.
0 100 .035 3.48 93.9 .035 21.16 93.9 .035 24.64 100 .035
10 96
1
2.7
140 120 140 150 -.07 94.5 .030 .028 2 1 2 2
0 100 .035 3.48 93.9 .035
10 96
21.16 93.9 .035 24.64 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .10 .21 .45 .7 .99 1. 1. 1.
9 95.5
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
150 116 150 150 -.075 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
28.8 93.9 .035 32.28 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
                               End of description for cross section 5 of
                               channel 1, end of channel 1 entries.
2 4 7                               Begin entries for 7 cross sections, channel 2.
150 116 155 132. -.075 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
160 85 170 101. -.08 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
250 61 255 78. -.1 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
400 56 400 73. -.125 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035

```

```

10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
555 61 550 77. -.15 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
640 85 630 101. -.17 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
700 116 695 132. -.175 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
2 4 7 Begin entries for 7 cross sections, channel 3.
155 132.1 150 150. -.075 94 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
165 144 160 161. -.08 94 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
250 165 240 182. -.1 94 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
400 185 400 202. -.125 94 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
550 165 560 182. -.15 94 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035

```

```

10 96
12.66 93.9 .035 16.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
630 144 640 161. -.17 94 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
16.66 93.9 .035 20.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
695 132.1 700 150. -.175 94 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
14.66 93.9 .035 18.14 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
2 1 7 Begin entries for 7 cross sections, channel 4.
700 115 700 150 -.175 94.0 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
30.8 93.9 .035 34.28 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
750 115 750 150 -.18 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
24.16 93.9 .035 28.64 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
780 119 780 150 -.2 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
21.16 93.9 .035 24.64 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
830 119 830 150 -.225 95.95 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
21.16 93.9 .035 24.64 100 .035
9
.0625 .125 .25 .5 1 2 4 8 16
0. .00 .01 .05 .2 .4 .9 .98 1.
880 119 880 150 -.25 95.95 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96
21.16 93.9 .035 24.64 100 .035
-1
.1 1.1
930 119 930 150 -.275 94.5 .030 .028 2 1 2 1
0 100 .035 3.48 93.9 .035
10 96

```

21.16 93.9 .035 24.64 100 .035
 9
 .0625 .125 .25 .5 1 2 4 8 16
 0. .00 .01 .05 .2 .4 .9 .98 1.
 980 119 980 150 -.3 95.9 .030 .028 2 1 2 1
 0 100 .035 3.48 93.9 .035
 10 96

21.16 93.9 .035 24.64 100 .035
 9

.0625 .125 .25 .5 1 2 4 8 16
 0. .00 .01 .05 .2 .4 .9 .98 1.

End of channel descriptions.
 2 *Begin entries for describing 2 junctions.*
 3 -1 2 3 *Three channels at first junction, channel 1
 enters and channels 2 and 3 leave.*
 3 -2 -3 4 *Three channels at second junction, channels 2
 and 3 enter and channel 4 leaves.*
End of network description file.

Boundary Condition File

The following is the input boundary condition description file for the example from the model application section. Input data is in red print; description of data fields is in green italic print.

CS *Run start condition, must be HS for hot start.*
 0. 4.9 *Start and end times for simulation, days.*
 6 *Number of hydrograph entries, channel 1.*
 0 10 15. *Time, discharge, temperature for hydrograph
 entry.*
 5 10 15.
 10 100 15.
 11 100 15.
 20 20 15.
 50 10 15.
 1 .0002 *Number of sedigraph entries, upstream slope,
 channel 1.*
 501. -.001 9 *Time, sediment transport rate (if <0, model
 computes transport rate), number of size-
 description members for first entry of
 sedigraph, channel 1.*
 .0625 .125 .25 .5 1 2 4 8 16
Size descriptions, first entry sedigraph.
 .15 .48 .98 1. 1. 1. 1. 1. 1.
Fractions finer, first entry sedigraph.
 6 *Number entries, stage boundary condition,
 channel 4.*
 0 96.4 *Time, water surface elevation, first entry,
 channel 4 boundary condition.*
 5 96.4
 10 98.45
 11 98.45
 20 96.7
 50 96.4
End of boundary condition file.

APPENDIX II-ABRIDGED OUTPUT FILES

This section contains fragments of all output files generated by the sediment model. A description of the organization and purpose of each file is found in the section on Output Files in the body of this report. Headings are the file names. The files are all found in the directory with the model application file.

InputEcho.txt

Reach Geometry
E:\aajpbSModRNwVol1000216\MCBGBF\Xscdatm.txt

4				
1	4	5		
0.0000000E+00	120.0000	0.0000000E+00	150.0000	0.0000000E+00

Missing records.

6.2500000E-02	0.1250000	0.2500000	0.5000000	1.000000
2.000000	4.000000	8.000000	16.00000	
0.0000000E+00	0.0000000E+00	9.999998E-03	5.0000001E-02	0.2000000
0.4000000	0.9000000	0.9800000	1.000000	
2				
3	-1	2	3	
3	-2	-3	4	

Boundary condition file
E:\aajpbSModRNwVol1000216\MCBGBF\bndhyd.txt

cS

0.0000000E+00	4.900000	
6		
0.0000000E+00	10.00000	15.00000
5.000000	10.00000	15.00000
10.00000	100.0000	15.00000
11.00000	100.0000	15.00000
20.00000	20.00000	15.00000
50.00000	10.00000	15.00000
2	1.9999999E-04	

RunSpec.txt

E:\aajpbSModRNwVol1000216\MCBGBF\Xscdatm.txt
E:\aajpbSModRNwVol1000216\MCBGBF\bndhyd.txt

0.250E+00	0.100E-01	0.350E+00	0.400E-02	0.800E+01	0.150E+00
0	0				
14					
0.625E-01	0.884E-01	0.125E+00	0.177E+00	0.250E+00	0.354E+00
0.500E+00	0.707E+00	0.100E+01	0.141E+01	0.200E+01	0.400E+01
0.800E+01	0.160E+02				

Sumry.txt

Multi-Channel Transport, by James P. Bennett, US Geological Survey, 2000

Run Date and Time 2000 4 21 815

Basic maximum time step, days 0.250
 Maximum bed elevation change before new sub-timestep, m, 0.010
 Maximum bedform height as fraction of flow depth 0.350
 Coefficient in McLean s Ca relationship 0.0040
 Coefficient in MPM bedload equation 8.000
 Default active layer thickness as a fraction of depth 0.150

Node elevation balancing Disabled
 Alluvial channel resistance computed from User supplied coefficients

There are 15 Simulation sediment sizes. Sizes in mm.
 0.062 0.074 0.105 0.149 0.210 0.297 0.421 0.595
 0.841 1.187 1.679 2.828 5.657 11.314 16.000

File sumry.txt

xsec	layer	d50(mm),	sig,	elev,	and solids volume (m**3) for channel	
1	1	0.437	3.597	96.000	0.0	1
	2	2.242	2.008	95.700	0.0	
2	1	0.400	2.000	95.975	278.1	
	2	2.500	2.000	95.675	1045.8	
3	1	2.700	1.200	95.950	1005.8	
4	1	0.572	2.521	95.930	277.1	
	2	2.242	2.008	95.430	527.6	
5	1	2.242	2.008	95.925	241.1	

xsec	layer	d50(mm),	sig,	elev,	and solids volume (m**3) for channel	
6	1	2.242	2.008	95.925	0.0	2
7	1	2.242	2.008	95.920	268.1	
8	1	2.242	2.008	95.900	997.7	
9	1	2.242	2.008	95.875	1631.4	
10	1	2.242	2.008	95.850	1681.1	
11	1	2.242	2.008	95.830	948.3	
12	1	2.242	2.008	95.825	773.8	

xsec	layer	d50(mm),	sig,	elev,	and solids volume (m**3) for channel	
13	1	2.242	2.008	95.925	0.0	3
14	1	2.242	2.008	95.920	186.3	
15	1	2.242	2.008	95.900	1220.5	
16	1	2.242	2.008	95.875	2169.1	
17	1	2.242	2.008	95.850	2169.1	
18	1	2.242	2.008	95.830	1382.6	
19	1	2.242	2.008	95.825	1151.3	

xsec	layer	d50(mm),	sig,	elev,	and solids volume (m**3) for channel	
20	1	2.242	2.008	95.825	0.0	4
21	1	2.242	2.008	95.820	1558.6	
22	1	2.242	2.008	95.800	654.1	
23	1	2.242	2.008	95.775	529.2	
24	1	0.096	1.069	95.750	31.6	

25	1	2.242	2.008	95.725	529.2
26	1	2.242	2.008	95.700	546.0

Time= 0.09 Days

Input To Channels

Ch	Sec	Flow	W S Ele	Load Rate	Snd Fr	d50	Sig	Sus Fr	Cum Load
1*	1	10.00	96.808	6.073E-04	0.850	0.136	1.44	0.949	4.671E+00
2	6	4.84	96.758	5.060E-06	0.302	0.074	1.05	1.000	3.891E-02
3	13	5.16	96.758	4.425E-05	0.302	0.074	1.05	1.000	3.403E-01
4	20	10.00	96.570	0.000E+00	0.000	0.000	1.00	0.000	0.000E+00

Output From Channels

Ch	Sec	Temp	W S Ele	Load Rate	Snd Fr	d50	Sig	Sus Fr	Cum Load
1	5	15.00	96.758	4.931E-05	0.302	0.074	1.05	1.000	3.792E-01
2	12	15.00	96.570	0.000E+00	0.000	0.000	1.00	0.000	0.000E+00
3	19	15.00	96.570	0.000E+00	0.000	0.000	1.00	0.000	0.000E+00
4*	26	15.00	96.400	0.000E+00	0.000	0.000	1.00	0.000	0.000E+00

* Network input or output channel

Channel Elevation and Size Composition

Ch	Bed Ele	Upstream		Downstream		Cumulative	
		d50	Sig	Bed Ele	d50	Sig	Deposition
1	95.978	0.412	1.96	95.926	2.238	2.02	4.291E+00
2	95.920	2.242	2.01	95.815	2.242	2.01	3.891E-02
3	95.922	2.237	2.02	95.819	2.242	2.01	3.403E-01
4	95.817	2.242	2.01	95.697	2.242	2.01	0.000E+00

Network Input-Output Summary

	Total Load	Frac.	Sand d50	Sig-g	Net Deposition	Volume Error	PerCent Error
--	------------	-------	----------	-------	----------------	--------------	---------------

Time Step Rates

In	6.073E-04	0.850	0.136	1.44			
Out	0.000E+00	0.000	0.000	1.00	6.073E-04		

Simulation Period Totals

In	4.671E+00	0.850	0.136	1.44			
Out	0.000E+00	0.000	0.000	1.00	4.686E+00	-1.494E-02	-0.32

Missing Records

Time= 4.91 Days

Input To Channels

Ch	Sec	Flow	W S Ele	Load Rate	Snd Fr	d50	Sig	Sus Fr	Cum Load
1*	1	10.00	96.832	9.687E-04	0.850	0.136	1.44	0.958	3.560E+02

2	6	4.81	96.774	1.026E-04	0.856	0.142	1.56	0.843	1.849E+02
3	13	5.19	96.774	9.006E-04	0.856	0.142	1.56	0.843	1.525E+02
4	20	10.00	96.563	8.676E-05	0.384	0.562	1.71	0.000	1.389E+01

Output From Channels

Ch	Sec	Temp	W S Ele	Load Rate	Snd Fr	d50	Sig	Sus Fr	Cum Load
1	5	15.00	96.774	1.003E-03	0.856	0.142	1.56	0.843	3.374E+02
2	12	15.00	96.563	7.380E-05	0.276	0.656	1.74	0.000	1.103E+01
3	19	15.00	96.563	1.296E-05	1.000	0.487	1.45	0.000	2.866E+00
4*	26	15.00	96.400	1.792E-04	0.869	0.593	3.00	0.000	6.488E+01

* Network input or output channel

Channel Elevation and Size Composition

Ch	Bed Ele	Upstream		Downstream			Cumulative Deposition
		d50	Sig	Bed Ele	d50	Sig	
1	95.988	0.444	2.36	96.118	0.652	2.60	1.859E+01
2	96.002	0.428	3.54	95.822	2.074	3.73	1.739E+02
3	96.001	0.530	3.72	95.821	2.179	2.19	1.496E+02
4	95.800	2.234	2.02	95.694	2.261	2.14	-5.099E+01

Network Input-Output Summary

	Total Load	Frac.	Sand d50	Sig-g	Net Deposition	Volume Error	PerCent Error
In	9.687E-04	0.850	0.136	1.44			
Out	1.792E-04	0.869	0.593	3.00	7.895E-04		

Time Step Rates

In	9.687E-04	0.850	0.136	1.44			
Out	1.792E-04	0.869	0.593	3.00	7.895E-04		

Simulation Period Totals

In	3.560E+02	0.850	0.136	1.44			
Out	6.488E+01	0.990	0.595	3.16	2.911E+02	-1.227E-02	0.00

Layer Composition and elevation at end of simulation

xsec	layer	d50(mm),	sig,	elev,	and solids volume (m**3) for channel	1
	1			95.929		
2	Surf	0.444	2.359	95.988	43.3	
	1	0.400	2.000	95.850	187.0	
	2	2.500	2.000	95.580	1045.8	
3	Surf	0.676	3.549	95.971	23.4	
	InActv	2.095	4.079	96.013	127.9	
	1	2.700	1.200	95.830	920.2	
4	Surf	0.687	2.532	95.996	28.9	
	InActv	0.571	2.548	95.824	8.6	
	1	0.572	2.521	95.808	208.1	
	2	2.242	2.008	95.431	527.6	
5	Surf	0.652	2.603	96.118	18.2	
	InActv	0.889	3.494	96.008	34.6	
	1	2.242	2.008	95.801	220.4	

Missing Records

Elapsed computation time= 17. seconds

Multi-Channel Transport, by James P. Bennett, US Geological Survey, 2000

Run Date and Time 2000 4 21 815

Basic maximum time step, days 0.250
 Maximum bed elevation change before new sub-timestep, m, 0.010
 Maximum bedform height as fraction of flow depth 0.350
 Coefficient in McLean s Ca relationship 0.0040
 Coefficient in MPM bedload equation 8.000
 Default active layer thickness as a fraction of depth 0.150

By_Secn_Sumry.txt

Multi-Channel Transport, by James P. Bennett, US Geological Survey, 1998

Run Date and Time 2000 3 27 1411

Basic maximum time step, days 0.250
 Maximum bed elevation change before new sub-timestep, m, 0.010
 Maximum bedform height as fraction of flow depth 0.350
 Coefficient in McLean s Ca relationship 0.0040
 Coefficient in MPM bedload equation 8.000
 Default active layer thickness as a fraction of depth 0.150

Node elevation balancing Disabled
 Alluvial channel resistance computed from User supplied coefficients

There are 15 Simulation sediment sizes. Sizes in mm.
 0.062 0.074 0.105 0.149 0.210 0.297 0.421 0.595
 0.841 1.187 1.679 2.828 5.657 11.314 16.000

File by_secn_sumry.txt

Day	0.09 Input Discharge				10.000 m**3/s								
Sta	WS Elev	Hyd R	Area	Vel	Bed Elev	Bed d50	Arm Sig	Arm Ind	Total Tran Rate	Sand Load Frc	Sand Load d50	Sand Load Sig	Sus Frc
1	96.808	0.762	16.7	0.598	95.994				6.0732E-04	0.85	0.136	1.44	0.95
2	96.788	0.758	16.6	0.601	95.978	0.412	1.96	0	1.0120E-03	0.91	0.146	1.47	0.99
3	96.768	0.760	16.7	0.599	95.956	2.546	1.23	0	9.7939E-05	0.43	0.074	1.05	1.00
4	96.752	0.768	16.9	0.592	95.931	0.568	2.55	0	5.7497E-05	0.32	0.074	1.05	1.00
5	96.758	0.791	23.5	0.426	95.926	2.238	2.02	0	4.9308E-05	0.30	0.074	1.05	1.00
6	96.758	0.742	10.0	0.483	95.927				5.0600E-06	0.30	0.074	1.05	1.00
7	96.749	0.740	10.0	0.485	95.920	2.242	2.01	0	3.4227E-06	0.24	0.074	1.05	1.00
8	96.723	0.733	9.9	0.490	95.903	2.242	2.01	0	7.0708E-08	0.24	0.000	1.00	0.00
9	96.678	0.718	9.6	0.502	95.876	2.242	2.01	0	0.0000E+00	0.24	0.000	1.00	0.00
10	96.627	0.702	9.4	0.515	95.846	2.242	2.01	0	0.0000E+00	0.24	0.000	1.00	0.00
11	96.596	0.688	9.2	0.527	95.833	2.242	2.01	0	0.0000E+00	0.24	0.000	1.00	0.00
12	96.570	0.681	9.1	0.534	95.815	2.242	2.01	0	0.0000E+00	0.24	0.000	1.00	0.00
13	96.758	0.744	10.0	0.514	95.925				4.4248E-05	0.30	0.074	1.05	1.00
14	96.753	0.742	10.0	0.516	95.922	2.237	2.02	0	3.7505E-05	0.28	0.074	1.05	1.00
15	96.725	0.733	9.9	0.523	95.906	2.238	2.02	0	5.0658E-06	0.00	0.595	1.05	0.00
16	96.671	0.713	9.6	0.541	95.877	2.242	2.01	0	2.2855E-42	1.00	0.595	1.05	0.00
17	96.609	0.690	9.2	0.561	95.843	2.242	2.01	0	0.0000E+00	1.00	0.000	1.00	0.00
18	96.590	0.701	12.1	0.425	95.832	2.242	2.01	0	0.0000E+00	1.00	0.000	1.00	0.00
19	96.570	0.687	10.5	0.491	95.819	2.242	2.01	0	0.0000E+00	1.00	0.000	1.00	0.00

20	96.570	0.708	22.3	0.449	95.832					0.0000E+00	1.00	0.000	1.00	0.00
21	96.548	0.694	17.5	0.573	95.817	2.242	2.01	0		0.0000E+00	1.00	0.000	1.00	0.00
22	96.526	0.682	14.8	0.674	95.802	2.242	2.01	0		0.0000E+00	1.00	0.000	1.00	0.00
23	96.496	0.679	14.8	0.677	95.775	2.242	2.01	0		0.0000E+00	1.00	0.000	1.00	0.00
24	96.465	0.674	14.6	0.683	95.750	0.096	1.07	0		0.0000E+00	1.00	0.000	1.00	0.00
25	96.433	0.668	14.5	0.690	95.725	2.242	2.01	0		0.0000E+00	1.00	0.000	1.00	0.00
26	96.400	0.664	14.4	0.694	95.697	2.242	2.01	0		0.0000E+00	1.00	0.000	1.00	0.00

Missing records.

Day	4.91 Input Discharge				10.000 m**3/s				Arm		Total		Sand Load		Sus	
Sta	WS Elev	Hyd R	Area	Vel	Elev	Bed d50	Sig	Ind	Tran Rate	Frc	d50	Sig	Frc			
1	96.832	0.839	18.5	0.540	95.929				9.6872E-04	0.85	0.136	1.44	0.96			
2	96.812	0.771	16.9	0.590	95.988	0.444	2.36	11	1.0096E-03	0.86	0.139	1.50	0.89			
3	96.793	0.769	16.9	0.592	95.971	0.676	3.55	11	9.6009E-04	0.85	0.139	1.49	0.90			
4	96.773	0.730	16.0	0.625	95.996	0.687	2.53	11	1.0483E-03	0.86	0.144	1.54	0.85			
5	96.774	0.631	18.6	0.538	96.118	0.652	2.60	11	1.0032E-03	0.86	0.142	1.56	0.84			
6	96.774	0.676	9.1	0.531	96.026				1.0257E-04	0.86	0.142	1.56	0.84			
7	96.762	0.686	9.2	0.523	96.002	0.428	3.54	11	3.3606E-04	0.96	0.161	1.31	0.84			
8	96.731	0.698	9.4	0.514	95.955	0.799	4.34	11	4.6961E-04	0.85	0.127	1.33	0.94			
9	96.680	0.692	9.3	0.519	95.911	1.017	4.79	11	4.2675E-04	0.79	0.109	1.30	0.88			
10	96.624	0.675	9.0	0.535	95.876	1.253	5.84	11	3.5737E-04	0.63	0.088	1.19	0.86			
11	96.590	0.668	8.9	0.542	95.851	1.373	6.65	11	3.6043E-04	0.51	0.084	1.16	0.85			
12	96.563	0.669	8.9	0.542	95.822	2.074	3.73	11	7.3801E-05	0.28	0.656	1.74	0.00			
13	96.774	0.678	9.1	0.570	96.024				9.0064E-04	0.86	0.142	1.56	0.84			
14	96.769	0.692	9.3	0.558	96.001	0.530	3.72	11	6.2797E-04	0.79	0.124	1.38	1.00			
15	96.735	0.700	9.4	0.551	95.957	0.968	4.30	11	4.1856E-04	0.82	0.136	1.41	0.84			
16	96.674	0.693	9.3	0.560	95.904	1.256	4.91	11	4.0224E-04	0.73	0.099	1.28	0.92			
17	96.605	0.668	8.9	0.584	95.867	1.467	5.82	11	4.1011E-04	0.65	0.090	1.23	0.80			
18	96.584	0.677	11.7	0.443	95.854	1.372	6.36	11	2.8233E-05	0.48	0.637	1.35	0.00			
19	96.563	0.679	10.4	0.500	95.821	2.179	2.19	11	1.2962E-05	1.00	0.487	1.45	0.00			

HotStart.txt

HS	Run Date and Time	2000	3	27	1411											
	4.909435															
	1	0	0	12.26582	0.0000000E+00											
	0.0000000E+00															
	2.1673435E-38	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00										

Missing records.

0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00													
0.0000000E+00	0.0000000E+00															
	2	11	11	12.26582	186.9886											
	1045.799															
0.0000000E+00	7.1520284E-10	1.0215140E-09	0.1250470	0.2071168												
0.1025628	9.9199556E-02	0.1458644	0.1379228	0.1094827												
5.0887547E-02	2.1916319E-02	0.0000000E+00	0.0000000E+00													
4.1024938E-07	1.4489736E-04	0.0000000E+00	0.0000000E+00													
0.0000000E+00	0.0000000E+00															
3.9241158E-07	1.3857895E-04	3.0997178E-08	0.0000000E+00													
2.783188	0.0000000E+00															
5.1174175E-07	1.8019360E-04	4.4272824E-08	0.0000000E+00													
5.974738	0.0000000E+00															
1.7529650E-05	3.3405254E-04	5.419588	0.0000000E+00													
13.67928	0.0000000E+00															
2.8353801E-05	9.9320285E-05	8.976527	0.0000000E+00													

24.13434	0.0000000E+00			
1.3402569E-05	1.2740917E-05	4.445115	0.0000000E+00	
33.84871	0.0000000E+00			
1.1937687E-05	4.9602627E-06	4 299348	0 0000000E+00	
36.65763	10.90252			
1.4061588E-05	0.0000000E+00	6.321823	0 0000000E+00	
31.41236	24.97412			
7.5193539E-06	0.0000000E+00	5.977628	0 0000000E+00	
21.05393	61.68749			
7.1357840E-07	0.0000000E+00	4.745023	0 0000000E+00	
10.96883	116.4413			
0.0000000E+00	0.0000000E+00	2 205487	0.0000000E+00	
4.526254	176.9946			
0.0000000E+00	0.0000000E+00	0.9498620	0.0000000E+00	
1.949373	394.3311			
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	
0.0000000E+00	211.4858			
0.0000000E+00	0.0000000E+00	0.0000000E+00	0 0000000E+00	
0.0000000E+00	48.98173			
0.0000000E+00	0.0000000E+00	0.0000000E+00	0 0000000E+00	
0.0000000E+00	0.0000000E+00			
3	11	11	11.82758	920.1951
4.3666684E-03	6.9815232E-03	1.5513272E-02	9.5778763E-02	0.1384830
7.2137713E-02	7.9440214E-02	0.1005192	7.4035831E-02	1.6487397E-02

Missing records.

RawPlots.txt

Multi-Channel Transport, by James P. Bennett, US Geological Survey, 1998

Run Date and Time 2000 3 27 1411

Basic maximum time step, days 0.250
 Maximum bed elevation change before new sub-timestep, m, 0.010
 Maximum bedform height as fraction of flow depth 0.350
 Coefficient in McLean s Ca relationship 0.0040
 Coefficient in MPM bedload equation 8.000
 Default active layer thickness as a fraction of depth 0.150

Node elevation balancing Disabled
 Alluvial channel resistance computed from User supplied coefficients

File Organization:

For each output time:

Number of channels, time in days,

m*m*m/s total water in, cms total sediment in, total sediment out

For each channel segment:

Number of x-sections, m*m*m/s total water in

For each x-section:

m distance down channel, m water surface elev,

m hydraulic radius, m*m x-section area, m/s velocity,

m bed elevation, mm bed d50, bed sigma g,

m*m*m/s total sediment load, m*m*m/s sand load, mm sand load d50,

sand load sigma g, m*m*m/s suspended sand load,
 mm suspended sand d50, suspended sand sigma g,
 non-transportable size index

2000	3	27	-420	14	11
4	8.9010306E-02	10.00000			6.0732226E-04 0.0000000E+00
5	10.00000				
0.0000000E+00	96.80836	0.7617092		16.71490	0.5982685
95.99435	32.00000	1.000000		6.0732226E-04	5.1622390E-04
0.1358705	1.440805	4.9002975E-04		0.1358705	1.440805
0					
50.00000	96.78799	0.7579651		16.63297	0.6012157
95.97828	0.4122865	1.960244		1.0119845E-03	9.2088612E-04
0.1463557	1.473554	9.1093348E-04		0.1465081	1.473724
0					
100.0000	96.76807	0.7604013		16.69328	0.5990434
95.95559	2.545838	1.229978		9.7939002E-05	4.2041356E-05
7.4330345E-02	1.045452	4.2041356E-05		7.4330345E-02	1.045452
0					
140.0000	96.75243	0.7683740		16.88025	0.5924082
95.93083	0.5682343	2.549529		5.7496625E-05	1.8641324E-05
7.4330345E-02	1.045452	1.8641324E-05		7.4330345E-02	1.045452
0					
150.0016	96.75827	0.7913810		23.45103	0.4264205
95.92645	2.238236	2.016685		4.9308255E-05	1.4872621E-05
7.4330345E-02	1.045452	1.4872621E-05		7.4330345E-02	1.045452
0					
7	4.836471				
0.0000000E+00	96.75826	0.7423000		10.01512	0.4829169
95.92732	32.00000	1.000000		5.0599810E-06	1.5262186E-06
7.4330345E-02	1.045452	1.5262186E-06		7.4330345E-02	1.045452
0					
33.99871	96.74873	0.7401808		9.980444	0.4845947
95.92041	2.241764	2.009398		3.4226862E-06	8.1402618E-07
7.4330345E-02	1.045452	8.1402618E-07		7.4330345E-02	1.045452
0					
124.9804	96.72256	0.7328621		9.868818	0.4900760
95.90338	2.242091	2.008733		7.0708438E-08	0.0000000E+00
0.0000000E+00	1.000000	0.0000000E+00		0.0000000E+00	1.000000
0					

Missing records.