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Archived Versions of GSTARS

Background

The GSTARS is a series of Generalized Stream Tube computer models for Alluvial River Simulation developed by the U.S. Bureau of Reclamation for steady and quasi-steady flows. The first version of GSTARS was developed by Molinas and Yang (1985) for mainframe computers to simulate the flow conditions in a semi-two-dimensional manner and the change of channel geometry in a semi-three-dimensional manner based on the stream tube concept. GSTARS 2.0 (Yang et. al.1988) significantly revised and expanded the capabilities of GSTARS for PC applications. With a new graphical interface, GSTARS 2.1(Yang and Simões, 2000) replaced GSTARS 2.0 for cohesive and non-cohesive sediment transport in rivers. GSTARS 3 (Yang and Simões, 2002) further expanded the capabilities of GSTARS 2.1 for cohesive and non-cohesive sediment transport in rivers and reservoirs.

The Bureau of Reclamation no longer supports GSTARS 2.1 and GSTARS 3.0, the Hydroscience and Training Center of Colorado State University has been asked by the Bureau of Reclamation, since 2005, to make GSTARS 2.1 and GSTARS 3.0 available for downloading.

Disclaimer

For further information regarding archived versions of GSTARS, please contact:

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User's Manual for

GSTARS 2.1

(Generalized Stream Tube model for Alluvial River Simulation version 2.1)

by
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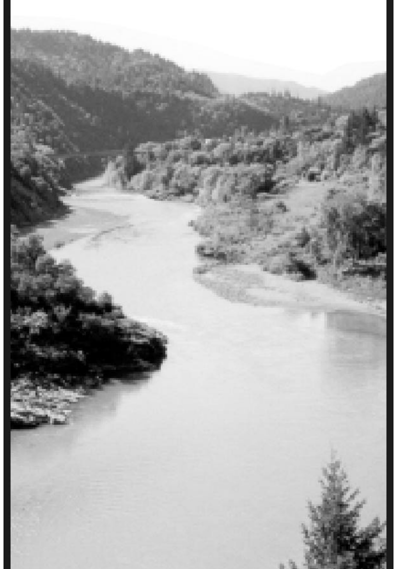
December 2000



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

United States Department of the Interior

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is to protect and provide access to our
Nation's natural and cultural heritage and
honor our trust responsibilities to tribes.

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The mission of the Bureau of Reclamation
is to manage, develop, and protect water
and related resources in an environmentally and
economically sound manner in the interest
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Denver, Colorado

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CHAPTER

1

INTRODUCTION

GSTARS 2.1 (Generalized Stream Tube model for Alluvial River Simulation version 2.1) is the most recent version of a numerical model for simulating the flow of water and sediment transport in alluvial rivers. It is an enhanced version of the GSTARS 2.0 model (Yang et al., 1998). This manual describes the overall theoretical background of the model and its most important implementation details in a computer program. It also guides the interested user in all the steps necessary for data preparation and input. Examples of the application of GSTARS 2.1 are also given.

1.1 Purpose and Capabilities

The GSTARS series of programs were developed due to the need for a generalized water and sediment-routing computer model that could be used to solve complex river engineering problems for which limited data and resources were available. In order to be successful, such a model should have a number of capabilities, namely:

- It should be able to compute hydraulic parameters for open channels with fixed as well as with movable boundaries;
- It should have the capability of computing water surface profiles in the subcritical, supercritical, and mixed flow regimes, i.e., in combinations of subcritical and supercritical flows without interruption;
- It should be able to simulate and predict the hydraulic and sediment variations both in the longitudinal and in the transverse directions;

- It should be able to simulate and predict the change of alluvial channel profile and cross-sectional geometry, regardless of whether the channel width is variable or fixed; and
- It should incorporate site specific conditions such as channel side stability and erosion limits.

GSTARS version 2.1 is based on GSTARS version 2.0 (Yang et al., 1998) and consists of four major parts. The first part is the use of both the energy and the momentum equations for the backwater computations. This feature allows the program to compute the water surface profiles through combinations of subcritical and supercritical flows. In these computations, GSTARS 2.1 can handle irregular cross sections regardless of whether single channel or multiple channels separated by small islands or sand bars.

The second part is the use of the stream tube concept, which is used in the sediment routing computations. Hydraulic parameters and sediment routing are computed for each stream tube, thereby providing a transversal variation in the cross section in a semi-two-dimensional manner. Although no sediment or flow can be transported across the boundary of a stream tube, the position and width of a stream tube can change after each time step of computation. The scour or deposition computed in each stream tube give the variation of channel geometry in the vertical (or lateral) direction. The water surface profiles are computed first. The channel is then divided into a selected number of stream tubes with the following characteristics: (1) the total discharge carried by the channel is distributed equally among the stream tubes; (2) stream tubes are bounded by channel boundaries and by imaginary vertical walls; (3) the discharge along a stream tube is constant; and (4) there is no exchange of water or sediments through stream tube boundaries.

Bed sorting and armoring in each stream tube follows the method proposed by Bennett and Nordin (1977), and the rate of sediment transport can be computed using any of the following methods:

- DuBoys' 1879 method.
- Meyer-Peter and Müller's 1948 method.
- Laursen's 1958 method.
- Toffaleti's 1969 method.
- Engelund and Hansen's 1972 method.
- Ackers and White's 1973 method.
- Revised Ackers and White's 1990 method.
- Yang's 1973 sand and 1984 gravel transport methods.
- Yang's 1979 sand and 1984 gravel transport methods.
- Parker's 1990 method.

- Yang's 1996 modified formula.
- Krone's 1962 and Ariathurai and Krone's 1976 methods for cohesive sediment transport.

The third part is the use of the theory of minimum energy dissipation rate (Yang, 1971, 1976; Yang and Song, 1979, 1986) in its simplified version of minimum total stream power to compute channel width and depth adjustments. The use of this theory allows the channel width to be treated as an unknown variable. Treating the channel width as an unknown variable is one of the most important capabilities of GSTARS 2.1. Whether a channel width or depth is adjusted at a given cross section and at a given time step depends on which condition results in less total stream power.

The fourth part is the inclusion of a channel bank side stability criteria based on the angle of repose of bank materials and sediment continuity.

Some of the potential applications and/or features of GSTARS 2.1 are:

- GSTARS 2.1 can be used for water surface profile computations with or without sediment transport.
- GSTARS 2.1 can compute water surface profiles through subcritical and supercritical flow conditions, including hydraulic jumps, without interruption.
- GSTARS 2.1 can compute the longitudinal and transversal variations of flow and sediment conditions in a semi-two-dimensional manner based on the stream tube concept. If only one stream tube is selected, the model becomes one-dimensional. If multiple stream tubes are selected, both the lateral and vertical bed elevation changes can be simulated.
- The bed sorting and armoring algorithm is based on sediment size fractions and can provide a realistic simulation of the bed armoring process.
- GSTARS 2.1 can simulate channel geometry changes in width and depth simultaneously based on minimum total stream power.
- The channel side stability option allows simulation of channel geometry change based on the angle of repose of bank materials and sediment continuity.

1.1.1 What is New in GSTARS 2.1

GSTARS 2.1 is based on GSTARS 2.0 with the following modifications and improvements:

- It now accepts tributary inflows of water and sediment.
- Most code was re-written from the old Fortran IV and Fortran77 syntax to the new Fortran 90/95 syntax.
- More sediment transport equations.

- A new Java-based graphical user interface that streamlines data entry and analysis and makes the model more user friendly.
- Additional input options to increase data input versatility.
- Overall improvement in the implementation of many algorithms to enhance accuracy and stability.
- Correction of a few known code bugs.
- New user's manual.

Data files prepared for GSTARS 2.0 are fully compatible with GSTARS 2.1. The Bureau of Reclamation will discontinue support of GSTARS 2.0 after the date of publication of this manual.

1.2 Limits of Application

GSTARS 2.1 is a general numerical model developed for a personal computer to simulate and predict river morphological changes caused by natural and engineering events. Although GSTARS 2.1 is intended to be used as a general engineering tool for solving fluvial hydraulic problems, it does have the following limitations from a theoretical point of view:

1. GSTARS 2.1 is a quasi-steady flow model. Water discharge hydrographs are approximated by bursts of constant discharges. Consequently, GSTARS 2.1 should not be applied to rapid, varied, unsteady flow conditions.
2. GSTARS 2.1 is a semi-two-dimensional model for flow simulation and a semi-three-dimensional model for simulation of channel geometry change. It should not be applied to situations where a truly two-dimensional or truly three-dimensional model is needed for detailed simulation of local conditions. However, GSTARS 2.1 should be adequate for solving many river engineering problems.
3. GSTARS 2.1 is based on the stream tube concept. The phenomena of secondary current, diffusion, and superelevation are ignored.
4. Many of the methods and concepts used in GSTARS 2.1 are simplified approximations of real phenomena. Those approximations and their limits of validity are, therefore, embedded in the model.

1.3 Overview of the Manual

This manual is organized into six chapters (including this one) and three appendices. Chapter 2 describes the backwater model, and chapter 3 describes the basis of the sediment routing model, including the use of the stream tube concept. Chapter 4 presents the concepts and the methodology used in the channel width adjustment model. The main data requirements for GSTARS 2.1 are discussed in chapter 5. Chapter 6 describes how to use the GSTARS 2.1 Graphical User Interface to prepare input data files, run the model, and view the results of a run. The appendices provide additional information: appendix A gives a detailed description of the input records used by GSTARS 2.1; appendix B provides several examples to show some of the model's features and to help the user get started; and appendix C contains a reprint of the paper by Molinas and Yang (1985) that describes with more detail the backwater algorithm used in GSTARS 2.1.

1.4 Acquiring GSTARS 2.1

The latest information about the GSTARS 2.1 program is placed on the Web. The GSTARS 2.1 Web page can be found by accessing http://www.usbr.gov/srhg/ and following the links therein. Alternatively, requests may be sent directly to the Bureau of Reclamation's Sedimentation and River Hydraulics Group (U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, P.O. Box 25007 (D-8540), Denver, CO 80225).

GSTARS 2.1 is in a stage of continuous evolution and unannounced changes may be made at any time. The user is encouraged to check regularly the GSTARS 2.1 Web page. Updates to the code and documentation will be posted there as they become available.

1.5 Disclaimer

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CHAPTER

2

THE BACKWATER MODEL

The hydraulic computations in GSTARS 2.1 are based on a model of gradually varied flow. Mixed flow regimes and hydraulic jumps can be calculated by selectively using the energy and the momentum equations. This section presents the basic governing equations for flow computations.

The basic concepts and backwater computational procedures can be found in most open channel hydraulics text books. For quasi-steady flows, discharge hydrographs are approximated by bursts of constant discharge, as shown in figure 2.1. During each constant discharge burst, steady state equations are used for the backwater computations. GSTARS 2.1 solves the energy equation based on the standard-step method. However, when a hydraulic jump occurs, the momentum equation is used instead. Details of these computations were presented by Molinas and Yang (1985) and are given in appendix C.

2.1 Energy Equation

Using the notation of figure 2.2, the energy equation can be written as

$$z + Y + \alpha \frac{V^2}{2g} = H \tag{1}$$

where z = bed elevation; Y = water depth; V = flow velocity; α = velocity distribution coefficient; H = elevation of the energy line above the datum; and g = gravitational acceleration. Eq. (1) is used for most water profile computations. This equation is valid when the channel's bottom slope is small, i.e., when $S_0 < 5\%$, in which case $\sin\theta \approx \tan\theta \approx \theta$. Hydrostatic pressure distribution is also assumed.

Figure 2.1 Representation of a hydrograph by a series of steps with constant discharge (Q_i) and finite duration (Δt_i).

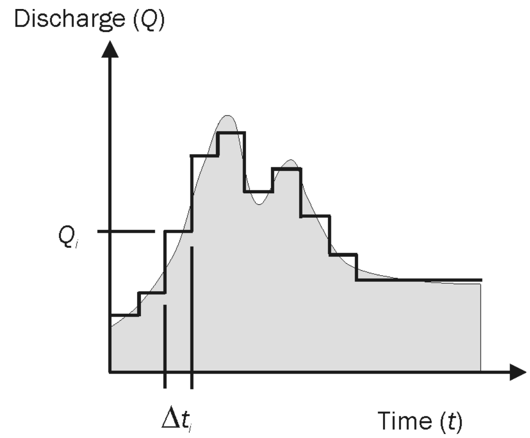
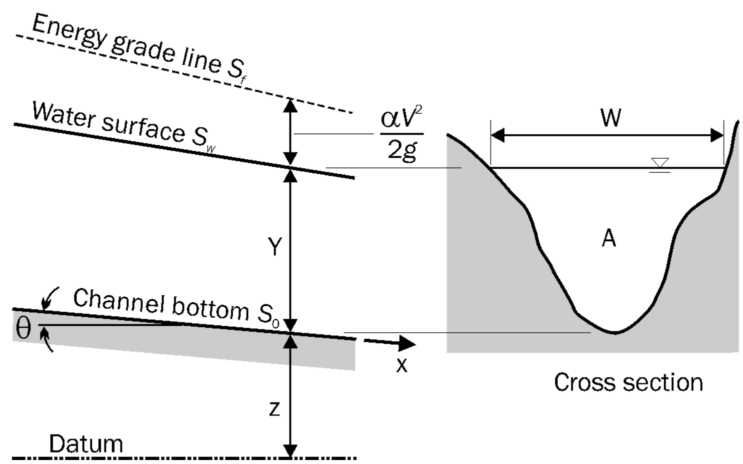


Figure 2.2 Definition of variables.



Eq. (1) is solved using a trial-and-error procedure based on the standard step method (Henderson, 1966). The initial surface elevation is guessed, and that guess is iteratively improved by using

$$Z = \tilde{Z} - \frac{H - \tilde{H}}{1 - \tilde{F}_r^2(1 \mp 0.5C_L) \mp \dfrac{3\tilde{h}_f}{2\tilde{R}}} \tag{2}$$

where Z = water surface elevation; F_r = Froude number; R = hydraulic radius; h_f = friction loss; C_L = energy loss coefficient; and the tilde is used to denote that the respective quantities are computed from the guessed value for the first iteration, and from the previously computed values for the remaining iterations. The iterative procedure ends when $|H - \tilde{H}|$ is very small. Note that $\tilde{H}$ is computed using eq. (1), and H is computed by adding or subtracting the head losses from an adjacent section with known hydraulic parameters. Computations proceed in the upstream direction for subcritical flows and in the downstream direction for supercritical flows. The Froude number is computed from

$$F_r^2 = \frac{\alpha V^2}{gW\cos\theta} \tag{3}$$

where W = cross section width.

2.2 Flow Transitions

The energy equation is applied if there is no change of flow regime throughout the study reach. If there are changes in flow regime, GSTARS 2.1 employs the algorithm described in Molinas and Yang (1985) to compute the water profiles through the regime changes without interruption. The interested reader should refer to that paper for a more detailed description of the algorithm (the paper is included in appendix C of this manual). There are 6 possible changes in the flow regime: from subcritical to critical or supercritical; from supercritical to critical or subcritical; and from critical to supercritical or subcritical. In this section we will address changes between supercritical (or critical) to subcritical, i.e., when an hydraulic jump occurs. In an hydraulic jump there is high curvature of the streamlines, the pressure is not hydrostatic, and the flow is referred to as rapidly varied flow.

Before starting the backwater computations, it is necessary to determine the flow regime, i.e., whether the flow conditions are supercritical, subcritical, or critical. For that purpose, the normal and critical depths are computed along the study reach. This computation is carried out in the upstream direction for subcritical flow and in the downstream direction for supercritical flow. The normal depth is set equal to a very large value when horizontal or adverse slopes are encountered. For the reaches where an hydraulic jump is detected, the momentum equation is used:

$$\frac{Q\gamma}{g}(\beta_2 V_2 - \beta_1 V_1) = p_1 - p_2 + W_g \sin\theta - F_f \tag{4}$$

where γ = unit weight of water; β = momentum coefficient; p = pressure acting on a given cross section; W_g = weight of water enclosed between sections 1 and 2; θ = angle of inclination of channel; and F_f = total external friction force acting along the channel boundary. If the value of θ is small $(\sin\theta \cong 0)$ and if $\beta_1 = \beta_2 = 1$, equation (4) becomes

$$\frac{Q^2}{A_1 g} + A_1\overline{y_1} = \frac{Q^2}{A_2 g} + A_2\overline{y_2} \tag{5}$$

where $\bar{y}$ = depth measured from water surface to the centroid of the cross section containing flow. Eq. (5) is solved by an iterative trial-and-error procedure.

2.2.1 Normal, Critical, and Sequent Depth Computations

Detailed procedures for normal, critical, and sequent depth computations can be found in open channel hydraulics books (e.g., Chow, 1959; Henderson, 1966) and are given here for completeness. The normal depth is computed by satisfying the equation

$$g(D) = Q - K(D)\sqrt{S_0} = 0 \tag{6}$$

where $K(D)$ = conveyance, which is a function of the depth D; and S_0 = bottom slope. For adverse and horizontal slopes, the normal depth is set to a very high value.

Critical depth occurs where the Froude number has a value of 1 for a given discharge. In GSTARS 2.1, the critical depth is calculated by satisfying equation

$$f(D) = 1 - \alpha(D)\frac{Q^2 TW(D)}{gA^3(D)} = 0 \tag{7}$$

where $W(D)$ = channel's top width at a depth D; and $A(D)$ = channel cross-sectional area at depth D.

Sequent depths for a given discharge are the depths with equal specific forces. The specific force of a natural channel can be expressed by

$$SF(D) = \frac{Q^2}{A_t g} + A_m \bar{y} \tag{8}$$

where $SF(D)$ = specific force corresponding to a water depth D; A_t = total flow area; and A_m = flow area in which motion exists. In GSTARS 2.1, the sequent depth is computed where hydraulic jumps occur. An iterative trial-and error procedure is used to find the sequent water surface elevation. The process starts with two guesses: the critical water surface elevation with the theoretical minimum specific force, and the maximum bottom elevation for the cross section. The subcritical sequent water surface elevation is located within these two values. The bisection method is used to solve equation

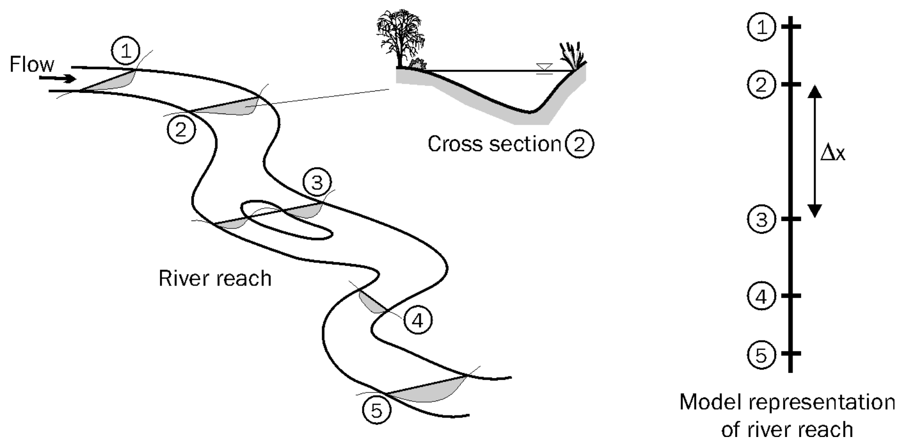
$$SF(D_a) - SF(D_b) = 0 \tag{9}$$

where D_a = computed supercritical water surface elevation, and D_b = desired subcritical sequent water surface elevation.

2.3 Model Representation

In GSTARS 2.1, as in most one-dimensional numerical models, the representation of the region of the watercourse to be modeled is made by discrete cross sections located at specific points throughout the river channel (see figure 2.3). The region between each cross section is called a reach.

Figure 2.3 Conceptual representation of a river reach by discrete cross sections in GSTARS 2.1.



GSTARS 2.1 uses information associated with each cross section to compute the water surface profiles (and the bed changes in movable bed rivers, as described in the next chapter). The water surface elevation is computed at each cross section location, but not between cross sections. Therefore, choosing the appropriate cross section location is very important. Some guidance is given in the next sections on how to optimize a data collection program for computer modeling with GSTARS 2.1.

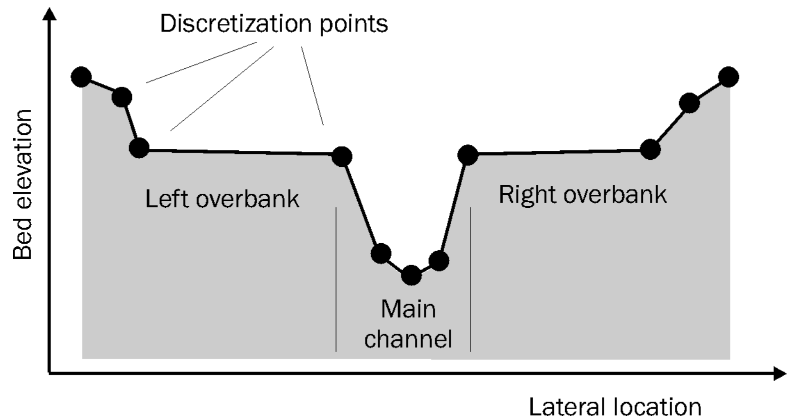
2.3.1 Description of Cross Sections

When setting up a GSTARS 2.1 simulation, the first step is usually the definition and input of the desired channel reach geometry. This is accomplished by selecting cross sections along the channel reach. Each cross section is identified by a number that represents its location expressed as a distance from a downstream reference station. This allows the computer to have a clear representation of the upstream/downstream relationship among the cross sections, as well as to compute reach lengths (Δx in figure 2.3).

Channel geometry is discretized by a set of points, such as those obtained in a surveying field trip, each having an assigned vertical bottom elevation and lateral cross-section location (distance from a reference point situated at the left bank, looking downstream). Linear interpolation is used between these points, as in figure 2.4. This information is used to compute the hydraulic parameters necessary for the backwater computations, such as flow area, wetted perimeter, hydraulic radius, top width, centroid of the cross section, etc.

As mentioned previously, each cross section is discretized by a set of points defined by the bed elevation and cross-section location. The cross sections should be perpendicular to the direction of the flow streamlines and extend all the way from margin to margin of the river, that is, they should extend completely across the channel between high ground of both banks. Although two points are enough to define a region of the cross section with constant side slope, the algorithms implemented in GSTARS 2.1 will work better if more points are given. This will become clearer later, when the usage of stream tubes in GSTARS 2.1 is presented.

Figure 2.4 Representation of a cross section by a discrete set of points.



The number and positions of the cross sections are arbitrary. However, it is recommended that they be chosen to best represent the geometry of the study channel reach. Accurate data of channel cross sections is essential to ensure the that the model works properly. Each cross section represents a portion of the channel upstream and downstream from its actual location. Therefore, the location of each cross section should be chosen to best reflect that approximation. More cross sections are required where there are significant changes in channel geometry and/or hydraulic characteristics. A larger number of cross sections will approximate the channel reach geometry with more accuracy than a smaller number will. Ideally, the user should use as many cross sections as practicable. In the case where too few measured cross sections are available, they may have to be interpolated, especially at abrupt transitions.

Cross section proximity is important where hydraulic jumps occur. Rapidly varied flow usually takes place over much shorter distances than gradually varied flow. Therefore, in order to capture accurately the location of the hydraulic jump, more closely spaced cross sections should be placed in the region where the hydraulic jump is expected to occur. Figure 2.5 schematically shows how to locate cross sections near hydraulic jumps and regions of abrupt slope change.

There are several published articles about the optimal choice of cross section location for numerical models. Here, the cross section selection rules of Samuels (1990) are presented:

1 Select all sites of key interest.

2 Select cross sections adjacent to major structures and control points.

3 Select cross sections representative of the river geometry.

4 As a first estimate, select cross section $20W$ apart.

5 Select sections a maximum of $0.2Y/S_w$ apart.

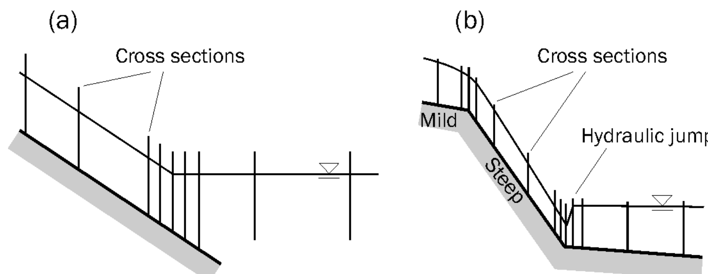
6 For unsteady flow modeling, select sections a maximum of $L/30$ apart, where L is the length scale of the physically important wave (flood or tide).

7 Select sections a minimum of $10^{INT(\log Z) - \varepsilon} / (\delta S - S_w)$ apart, where ε is the machine precision, $INT()$ is the function that represents the integer part of its argument, and δS is the relative error in the slope.

8 The ratio of the areas between two adjacent cross sections should lie between 2/3 and 3/2.

9 Cross-sectional spacing may have to be reduced for shallow flows when the averaging rule is used for the friction slope (more about this in the next section).

Figure 2.5 Examples of reduction of Δx at points where the gradients are high: (a) backwater pool, and (b) change in bottom slope and flow regime transition.



2.3.2 Flow Resistance

One of the fundamental assumptions in GSTARS 2.1 is that a uniform flow formula can be used to compute the friction losses. This formula is used to compute the total conveyance, K. The total conveyance K is used to determine the friction slope, S_f, for a specified discharge:

$$S_f = \left(\frac{Q}{K}\right)^2 \tag{10}$$

In GSTARS 2.1, any of the following formulas can be used to compute K:

Manning's formula:

$$Q = KS_f^{1/2} = \left(\frac{1.49}{n}AR^{2/3}\right)S_f^{1/2} \tag{11}$$

Chézy's formula:

$$Q = KS_f^{1/2} = (CAR^{1/2})S_f^{1/2} \tag{12}$$

or Darcy–Weisbach's formula:

$$Q = KS_f^{1/2} = \left[\left(\frac{8gR}{f}\right)^{1/2} A\right] S_f^{1/2} \tag{13}$$

where n, C, f = roughness coefficients in Manning, Chézy, and Darcy–Weisbach's formulas, respectively; g = acceleration due to gravity; A = cross-sectional area; and R = hydraulic radius.

For each cross section, the desired roughness coefficients are assigned to different regions of the cross section. Using the example in figure 2.4, the left overbank could have one value, the main channel another value, and the right overbank yet another value. The conveyance of each section is computed separately and the total conveyance is taken to be the sum of the individual conveyances. This method is geared towards natural river cross-sectional geometries with large width-to-depth ratios, and it may introduce errors in the water surface elevations in narrow, rectangle-like cross sections.

GSTARS 2.1 assumes a fixed roughness coefficient for each cross section. However, it is well known that cross section roughness depends, for example, on the water depth. For example, in gravel streams the roughness is high for low flows (reflecting the effects of low submergence) and decreases with increased depth. On the other hand, in many natural rivers roughness increases with depth, especially at overbank flow (reflecting the effects of vegetation). Variable roughness coefficients will be implemented in future versions of GSTARS 2.1 already in development.

Estimating roughness is not a trivial task and requires considerable judgement. There are published flow resistance formulae that are more or less successful when applied to specific situations, but their lack of generality precludes its use in a numerical model for broad applications. See, for example, Klaassen et al. (1986) for more details. Some help exists in the form of tables, such as the ones that can be found in Chow (1959) and Henderson (1966). Barnes (1967) provides a photographic guide. The method by Cowan (1956) is summarized here. The basis of this method is on selecting a basic Manning's n value from a short set and to apply modifiers according to the different characteristics of the channel. The method can be applied in steps, with the help of table 2.1:

1 Select a basic n_0.

2 Add a modifier n_1 for roughness or degree of irregularity.

3 Add a modifier n_2 for variations in size and shape of the cross section.

4 Add a modifier n_3 for obstructions (debris, stumps, exposed roots, logs,...).

5 Add a modifier n_4 for vegetation.

6 Add a modifier n_5 for meandering.

The final value of the Manning's n is given by

$$n = n_0 + n_1 + n_2 + n_3 + n_4 + n_5 \tag{14}$$

Table 2.1 Modifiers for basic Manning's n in the method by Cowan (1956) with modifications from Arcement and Schneider (1987).

Basic Manning's roughness values (n_0)			
Concrete	0.011–0.018	Gravel	0.028–0.035
Rock cut	0.025	Coarse gravel	0.026
Firm soil	0.020–0.032	Cobble	0.030–0.050
Coarse sand	0.026–0.035	Boulder	0.040–0.070
Fine Gravel	0.024		
Modifier for degree of irregularity (n_1)			
Smooth	0.000	Moderate	0.006–0.010
Minor	0.001–0.005	Severe	0.011–0.020
Modifier for cross sectional changes in size and shape (n_2)			
Gradual	0.000	Frequent	0.010–0.015
Occasional	0.005		
Modifier for effect of obstructions (n_3)			
Negligible	0.000–0.004	Appreciable	0.020–0.030
Minor	0.005–0.019	Severe	0.060
Modifier for vegetation (n_4)			
Small	0.001–0.010	Very large	0.050–0.100
Medium	0.011–0.025	Extreme	0.100–0.200
Large	0.025–0.050		
Modifier for channel meander (n_5)			
L_m / L_s		n_5	
1.0–1.2 (minor)		0.0	
1.2–1.5 (appreciable)		$0.15(n_0 + n_1 + n_2 + n_3 + n_4)$	
> 1.5 (severe)		$0.30(n_0 + n_1 + n_2 + n_3 + n_4)$	
L_m = meander length		L_s = length of straight reach	

The friction loss, h_f, through each reach is the product of friction slope and the reach length, Δx. The friction slope at the cross section can be determined from one of the following four choices:

from the average friction slope of the adjacent reaches:

$$h_f = \frac{1}{2}(S_{f1} + S_{f2})\Delta x \tag{15}$$

from the geometric mean:

$$h_f = \Delta x \sqrt{S_{f1} S_{f2}} \tag{16}$$

from the average conveyance:

$$h_f = \left(\frac{2Q}{K_1 + K_2}\right)^2 L \Delta x \tag{17}$$

or from the harmonic mean:

$$h_f = \left(\frac{2S_{f1}S_{f2}}{S_{f1} + S_{f2}}\right)\Delta x \tag{18}$$

Although other choices exist for calculating the friction slope, they are not recommended — see, for example, Reed and Wolfkill (1976).

The distance between discretized cross sections (the reach length) is important for proper convergence and accuracy of the methods used in the model. In practice, the reach length used will vary from case to case. A small, nonuniform channel may require much shorter reach lengths than a large, uniform channel with mild slopes. A reach length may be measured along the center line in an artificial channel, along the thalweg in a natural channel, or along the flow path in overbank areas. Note that, for a given reach of a channel, these lengths may vary. However, reach lengths may be optimized by using an appropriate friction slope equation. Table 2.2 shows the methods recommended by Reed and Wolfkill (1976) and those used by the HEC-2 computer model. Laurenson (1986) showed that eq. (15) provides the lowest maximum error, but that it doesn't insure the lowest possible error.

Table 2.2 Recommended friction slope methods (adopted from French, 1985). See figure 2.6 for profile types.

Profile type	Friction slope method recommended by Reed and Wolfkill (1976)	Friction slope method used by HEC-2
M1	Eq. (17)	Eq. (17)
M2	Eq. (16)	Eq. (16)
M3	Eq. (18)	Eq. (15)
S1	Eq. (16)	Eq. (17)
S2	Eq. (17)	Eq. (17)
S3	Eq. (15)	Eq. (15)

The local loss caused by channel expansion and contraction, h_E, is computed from

$$h_E = C_E\left|\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right| \tag{19}$$

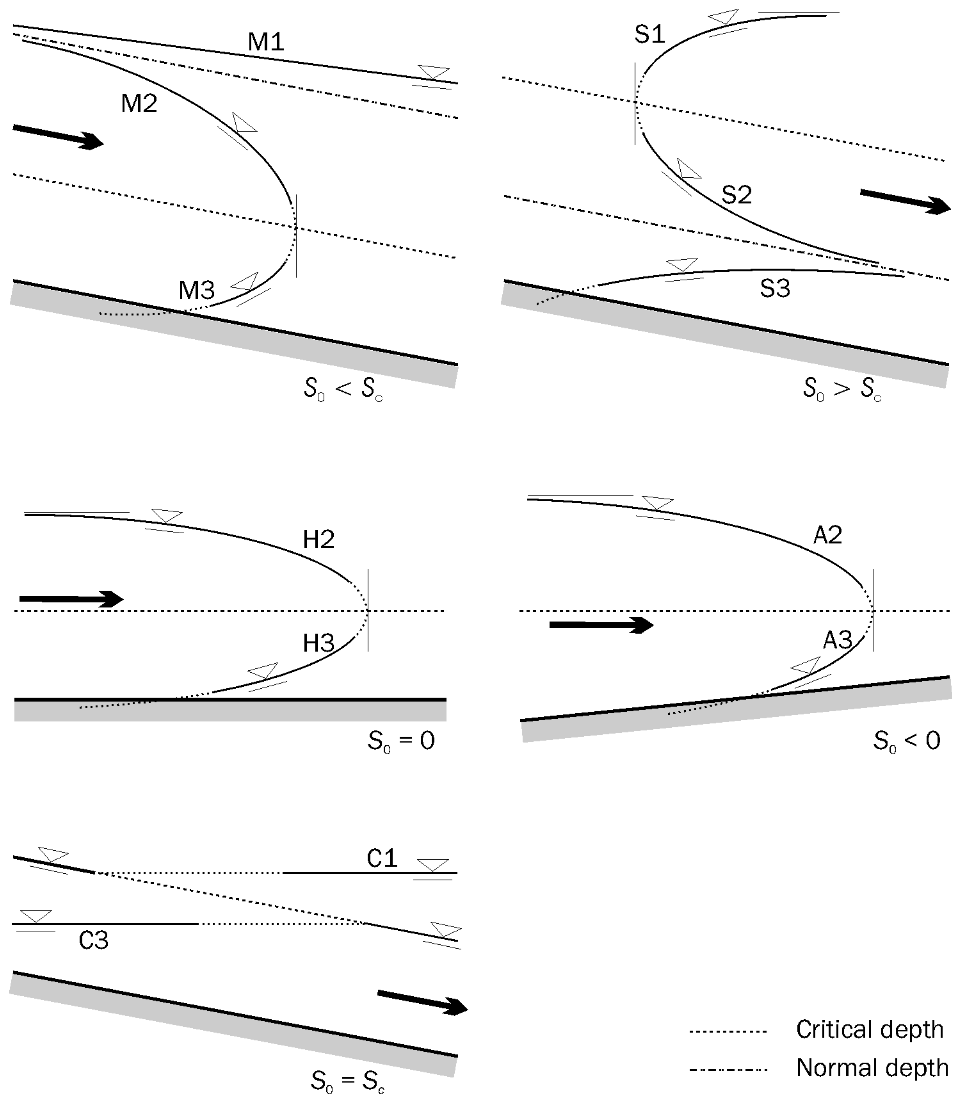
where C_E = energy loss coefficient. In GSTARS 2.1, C_E is internally set to 0.1 for contractions and to 0.3 for expansions.

Other local losses, such as losses due to channel bends or man-made constructions, are computed from

$$h_B = C_B\frac{V_2^2}{2g} \tag{20}$$

where C_B is an energy loss coefficient supplied by the user. For most natural rivers, C_B values are assumed to be zero. The total energy loss between two adjacent cross sections is the sum of friction loss and the local losses.

Figure 2.6 Water surface profile types in gradually varied flow.



CHAPTER

3

SEDIMENT ROUTING AND CHANNEL GEOMETRY ADJUSTMENT

Sediment transport occurs when the flow exceeds a certain threshold and becomes capable of moving the particles that constitute the bed. When the channel's bed becomes mobile, erosion or deposition may occur. These bed changes depend on many parameters, including hydraulic conditions (such as flow velocity and depth), bed composition (such as size of the particles that constitute the bed), and supply rates (amount and type of sediments entering the channel). In this chapter, the sediment transport and bed evolution model employed by GSTARS 2.1 is presented with some detail.

From the user point of view, the backwater and the sediment transport computations can be viewed as two modules belonging to the same numerical model. The backwater module can be used without the need to use the sediment transport module. For fixed bed channels (such as the flow of clear water over lined channels or spillways), the sediment transport computations can be turned off, reducing the data requirements of the model (the description of the bed composition) and allowing faster set-up and shorter run times. The user wishing to employ GSTARS 2.1 to fixed bed channels can safely skip chapters 3 and 4 of this manual.

3.1 Governing Equations

3.1.1 Theoretical Background

It is convenient to distinguish two main types of transportation of sediments: in *suspension* in the water column, and as *bed load*. The particles in motion that remain close to the channel's bed are said to belong to the bed load. These particles move by rolling over the bed and by saltating over relatively short lengths, and constitute a layer of relatively small thickness. In contrast, the particles transported in suspension may span the entire water column above the bed load layer. They are transported by the turbulent forces of the fluid, i.e., the turbulent eddies, and are generally of smaller dimensions than the particles in the bed load. These two layers have different composition and move at different speeds.

The distinction between the two layers is problematic, and it is not easy to locate a clear interface at a certain elevation above the bed. The difficulties are compounded by the fact that there is a continuous exchange of particles between the bed load layer and the suspended load. Furthermore, the separation of the two layers requires distinct governing equations for each layer, each with its own sets of variables and coefficients, some of which are very difficult to determine.

An alternate approach lumps the suspended load and the bed load together in what is called the *bed-material load*. This eliminates the need to describe the interface between the bed load and the suspended load and the sediment fluxes crossing it, which is difficult and, with the present state-of-the-art, imprecise. It also is computationally more efficient, since that a fewer number of equations needs to be solved. Consequently, the bed-material load approach requires less data, some of which is very difficult to obtain (such as the diffusion coefficients necessary to compute the transport of suspended load). The trade-off is in the loss of accuracy, since this approach does not distinguish the two essentially different modes of transport. In GSTARS 2.1 the bed-material load approach was chosen to describe the transport of sediments.

3.1.2 Sediment Continuity Equation

The basis for sediment routing computations in GSTARS 2.1 is the conservation of mass of sediments. In one-dimensional unsteady flow, the sediment continuity equation can be written as

$$\frac{\partial Q_s}{\partial x} + \eta \frac{\partial A_d}{\partial t} + \frac{\partial A_s}{\partial t} - q_s = 0 \tag{21}$$

where η = volume of sediment in a unit bed layer volume (one minus porosity); A_d = volume of bed sediment per unit length; A_s = volume of sediment in suspension at the cross section per unit length; Q_s = volumetric sediment discharge; and q_s = lateral sediment inflow. A number of assumptions are made to simplify this equation.

Firstly, it is assumed that the change in suspended sediment concentration in a cross section is much smaller than the change of the river bed, i.e.:

$$\frac{\partial A_s}{\partial t} \ll \eta \frac{\partial A_d}{\partial t} \tag{22}$$

Secondly, during a time step, the parameters in the sediment transport function for a cross section are assumed to remain constant:

$$\frac{\partial Q_s}{\partial t} = 0 \text{ or } \frac{\partial Q_s}{\partial x} = \frac{dQ_s}{dx} \tag{23}$$

With these assumptions, eq. (21) becomes

$$\eta \frac{\partial A_d}{\partial t} + \frac{dQ_s}{dx} = q_s \tag{24}$$

which is the governing equation used in GSTARS 2.1 for routing sediments in rivers and streams.

3.2 Streamlines and Stream Tubes

GSTARS 2.1 routes sediments using stream tubes. The basic concept and theory regarding streamlines, stream tubes, and stream functions can be found in most basic text books of fluid mechanics. In this section, only some of the basic concepts are given, as they are applied in the model.

By definition, a streamline is a conceptual line to which the velocity vector of the fluid is tangent at each and every point, at each instant in time. Stream tubes are conceptual tubes whose walls are defined by streamlines. The discharge of water is constant along a stream tube because no fluid can cross the stream tube boundaries. Therefore, the variation of the velocity along a stream tube is inversely proportional to the stream tube area. Figure 3.1 illustrates the basic concept of stream tubes used in GSTARS 2.1.

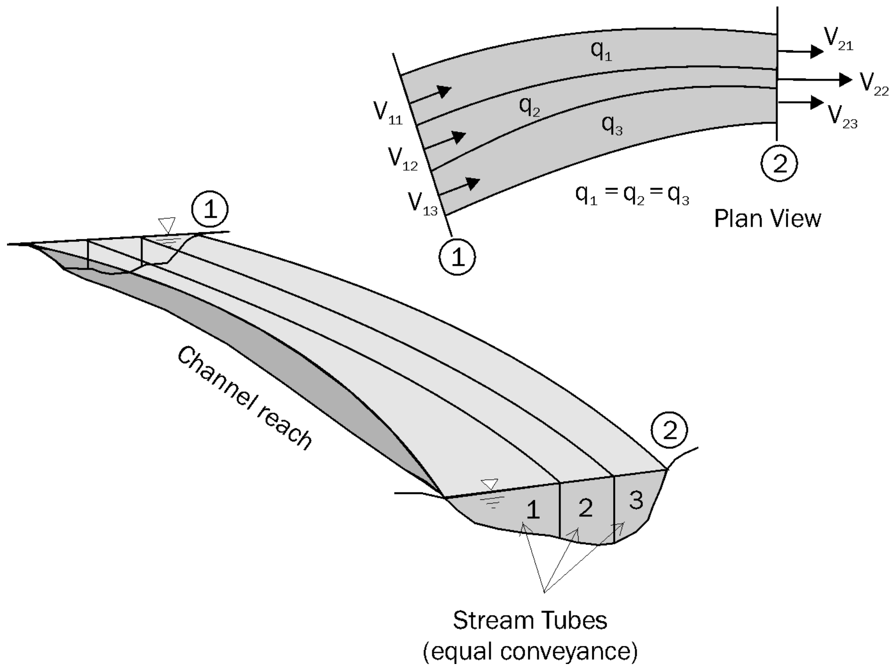
For steady and incompressible fluids, the total head, H_t, along a stream tube of an ideal fluid is constant:

$$\frac{p}{\gamma} + \frac{V^2}{2g} + h = H_t = \text{Constant} \tag{25}$$

where p = pressure acting on the cross section; γ = unit weight of water; V = velocity; g = acceleration due to gravity; and h = hydraulic head. In GSTARS 2.1, however, H_t is reduced along the direction of the flow due to friction and other local losses, as described earlier in section 2.3.2.

In GSTARS 2.1, the backwater profiles are computed first. Then, the cross sections are divided into several sections of equal conveyance. These regions of equal conveyance are treated as stream tubes, and the (computed) locations of their boundaries are the defining streamlines, across which no water can pass. The thus defined stream tubes are used as if they were conventional one-dimensional channels with known hydraulic properties. Sediment routing is carried out within each stream tube independently.

Figure 3.1 Schematic representation illustrating the use of stream tubes by GSTARS 2.1.



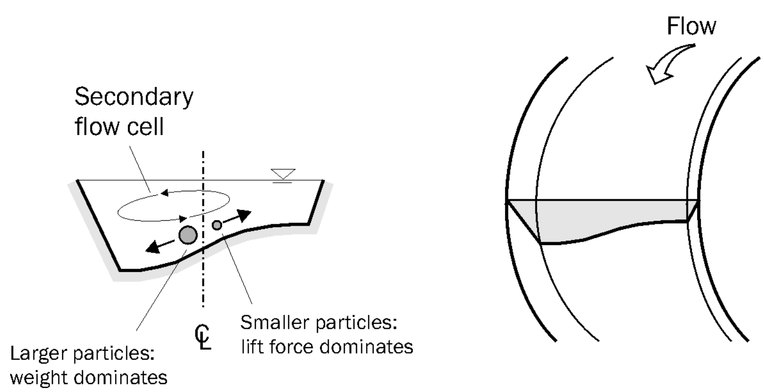
Stream tube locations are computed for each time step, therefore they are allowed to vary with time. Sediment routing is carried out independently for each stream tube and for each time step. Bed material composition is computed for each tube at the beginning of the time step, and bed sorting and armoring computations are also carried out separately for each stream tube. In GSTARS 2.1, lateral variations of bed material composition are accounted for, and this variation is included in the computations of the bed material composition and sorting for each stream tube. Therefore, although no material is allowed to cross stream tube boundaries during a time step, lateral movement of sediment is accomplished by the lateral variation of the stream tube boundaries from time step to time step.

This approach allows the computation of cross-sectional variations in the hydraulic and sediment parameters in a quasi-two-dimensional manner. For example, aggradation and degradation can occur simultaneously at a given cross section. Conventional one-dimensional models are unable to deal with this situation, but GSTARS 2.1 can model it, since erosion or deposition are computed separately within each stream tube, depending on the hydraulics, bed composition, transport capacity, and sediment supply conditions for each stream tube.

There are some limitations to the approach used. Firstly, the backwater curves result from an essentially one-dimensional model, where the water surface elevation is assumed to be horizontal across each cross section. Therefore extrapolation to two-dimensional distributions using the described method has some limitations. Consequently, the maximum recommended number of stream tubes employed is 5 (this is the maximum number of stream tubes allowed by the GSTARS 2.1 program). GSTARS 2.1 is not a truly two-dimensional program, therefore it cannot simulate areas with recirculating flows or eddies. Other limitations include the inability of simulate secondary flows, reverse flows, water surface variations in the transverse direction, hydrograph attenuation, and others that result from the use of the simplified governing equations described in this and the previous chapters.

Another limitation results from the fact that the movement of a sediment particle will have a direction which, in general, is neither the direction of the flow nor the direction of the bed shear stress. For example, in a bend of a channel with a sloping bed such as the one in figure 3.2, the larger particles will tend to roll down the slope (gravitational forces dominate) while the smaller particles may move up the slope (lift forces due to secondary currents dominate) — see, for example, Ikeda et al., (1987). A non-zero transverse flux results in exchange of sediments across stream tube boundaries. Note that this exchange does not violate the theoretical assumptions behind the use of stream tubes because the trajectories of the sediment particles are not the same as the trajectories of the fluid elements (streamlines). Therefore, although there is no net exchange of water between stream tubes, sediment can cross stream tube boundaries, and the use of stream tubes may still be theoretically justified. This phenomenon will be subject to treatment in the next release of the GSTARS program (GSTARS 3.0).

Figure 3.2 Bed sorting in bends due to transverse bed slope and secondary currents.



3.3 Discretization of the Governing Equations

In this section we describe the basic steps to solve eq. (24) numerically. Note that eq. (24) is a partial differential equation, but that the computer can only solve algebraic equations. The term *discretization* means the transformation of the partial differential equation into a set of algebraic equations that can be solved numerically by a computer. The numerical solution of differential equations is a very large field of applied mathematics. The reader interested in its particular application to fluid mechanics should refer to one of many text books dedicated to the subject, such as the ones by Hirsch (1988) or Anderson et al. (1997), for example.

The approach used in GSTARS 2.1 uses a finite difference uncoupled approach. This means that finite differences are used to discretize the governing differential equation. By *uncoupled* solution it is meant that first the backwater profiles are computed; the sediment routing and bed changes are computed afterwords, keeping all the hydraulic parameters frozen during the calculations.

In order to accomplish the discretization process, the change in the volume of bed sediment due to deposition or scour, ΔA_d, is written as

$$\Delta A_d = (aP_{i-1} + bP_i + cP_{i+1})\Delta Z_i \tag{26}$$

where P = wetted perimeter; ΔZ = change in bed elevation (positive for aggradation, negative for scour); i = cross section index; and a, b, and c are constants that must satisfy

$$a + b + c = 1 \tag{27}$$

There are many possible choices for the values of a, b, and c. For example, $a = c = 0$ and $b = 1$ is a frequently used combination that is equivalent to assuming that the wetted perimeter at station i represents the perimeter for the entire reach. If $b = c = 0.5$ and $a = 0$, emphasis is given to the downstream end of the reach.

In practice, it is observed that giving emphasis to the downstream end of the reach may improve the stability of the calculations. Such a scheme may be represented by using the following expressions:

$$a = 0\text{; } b = 1 - \theta\text{; and } c = \theta \tag{28}$$

where θ is a weighting parameter ($\theta > 0.5$). In GSTARS 2.1, the standard values are $a = c = 0.25$ and $b = 0.5$, but the user can change those to any combination that satisfies eq. (27). Using expression (26), the partial derivative terms are approximated as follows:

$$\frac{\partial A_d}{\partial t} \approx \frac{(aP_{i-1} + bP_i + cP_{i+1})\Delta Z_i}{\Delta t} \tag{29}$$

$$\frac{dQ_s}{dx} \approx \frac{Q_{s,i} - Q_{s,i-1}}{1/2(\Delta x_i + \Delta x_{i-1})} \tag{30}$$

Then, the sediment continuity equation, eq. (24), can be used to compute the change in bed elevation, ΔZ_i, which is done for each individual sediment size fraction within each stream tube. Inserting expressions (29) and (30) into eq. (24) we obtain

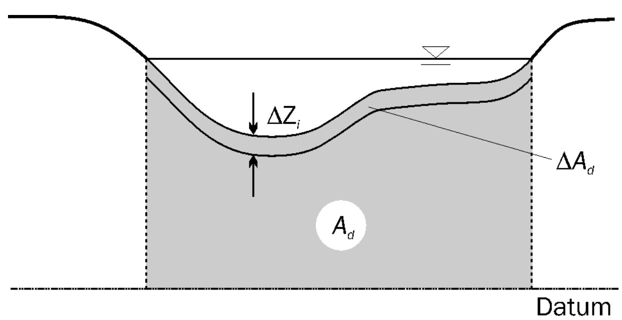
$$\Delta Z_{i,k} = \frac{2\Delta t(Q_{s,i-1,k} - Q_{s,i,k})}{\eta_i(aP_{i-1} + bP_i + cP_{i+1})(\Delta x_i + \Delta x_{i-1})} \tag{31}$$

where k = size fraction index; η_i = volume of sediment in a unit bed layer at cross section i; and $Q_{s,i,k}$ = computed volumetric sediment discharge for size class k at cross section i. The total bed elevation change for a stream tube at cross section i, ΔZ_i, is computed from

$$\Delta Z_i = \sum_{k=1}^{N} \Delta Z_{i,k} \tag{32}$$

where N = total number of size fractions present in cross section i. The new channel cross section at station i, to be used at the next time iteration, is determined by adding the bed elevation change to the old bed elevation. Figure 3.3 provides a schematic definition of some of the variables.

Figure 3.3 Definition of variables for a cross section.



3.3.1 Numerical Stability

The formulation described above is subject to numerical stability constraints. A numerical scheme is said to be stable if, for a certain condition, the solution values constructed with that scheme remain finite for the set of all solutions that take an initial state (at $t = 0$) to its final state (at $t = T$). The condition for which the solution is stable is called the Courant-Friedrichs-Lewy, or CFL, condition. The CFL stability condition is usually expressed via the Courant number

$$C_r = \frac{\text{celerity of propagation in the analytical solution}}{\text{celerity of propagation in the numerical solution}} \tag{33}$$

so that the CFL condition becomes $C_r \le 1$ for stability. Although implicit schemes are generally unconditionally stable (i.e., are not restricted by Courant number values), explicit schemes have stability limits that translate into limits to the maximum size of the time step. GSTARS 2.1 uses an explicit method to solve the sediment routing equation. In this case, the CFL stability criterion is given by

$$\Delta t \le \frac{\Delta x}{c_s} \tag{34}$$

where c_s is the kinematic wave speed of the bed changes.

In practice, instability is observed by the presence of spurious oscillations in an otherwise smooth solution, that is, in the hydraulic parameters and/or bed elevations. These oscillations are purely of numerical nature, having no physical meaning, and they creep into the solution as the time step is increased. Their amplitude increases with simulation time (i.e., with the number of time steps) and eventually causes the computations to stop prematurely due to numerical errors. This phenomenon can be avoided by reducing the time step until the CFL condition is met. In general, the time step has to be smaller when the computational cross sections are placed closer together, and vice versa. Numerical experimentation is required to determine a suitable length for Δt.

3.3.2 Additional Comments

The solution procedure used by GSTARS 2.1 decouples the governing equation for the flow from the governing equation for the sediment routing. For each time step, the backwater computations are solved first. The hydraulic properties are then assumed constant for the remainder of the time step. Sediment routing is carried out in this hydraulically “frozen” state, using a sediment transport formula for uniform flow (eq. (23) expresses this simplification). The change in bed levels are computed from the sediment continuity equation and are updated before the algorithm proceeds to the next time step. The time marching proceeds sequentially in this manner, until the desired time is reached.

This is the most common type of solution approach in numerical modeling. It requires that the variations in the sedimentological parameters, such as bed level and composition, be small when compared to the variation in the hydraulic properties. In general, this can be accomplished by having a computational time step Δt that is small enough. One way to work this out in practice is to have a small enough Δt such that

$$\Delta Z_i \ll h_i \tag{35}$$

for all the computational cross sections and for all time steps. In eq. (35), h_i is the hydraulic depth of cross section *i*.

There are other limitations to the uncoupled approach. First, it should not be used in the region $0.8 < F_r < 1.2$, where F_r is the Froude number (see de Vries (1969) for details about the derivation of this constraint). Second, it does not handle rapidly varying boundary conditions. The first limitation means that the approach is not valid in flow regime transitions. However, in nature regime transitions on movable beds do no occur often, are very localized, and are mostly temporary, therefore this limitation does not pose a serious obstacle to the use of uncoupled models such as GSTARS 2.1.

The second limitation mentioned was treated by Lyn (1987). He shows that uncoupled models are limited to the situations were the input hydrograph obeys the following approximate relationship:

$$\frac{T}{(L/V)} \geq 100 \tag{36}$$

where T = duration of the hydrograph; L = length of the reach being modeled; and V = a characteristic velocity in the channel. V can be computed from

$$V = \sqrt{gh} \tag{37}$$

where g = acceleration due to gravity and h = hydraulic depth. Note, however, that GSTARS 2.1 is limited to stepped hydrographs, and should not be used for situations where the unsteady effects are important. In the quasi-steady range of applications targeted by GSTARS 2.1, it is unlikely that the limitations associated with uncoupling hydraulics and sediment transport are significant.

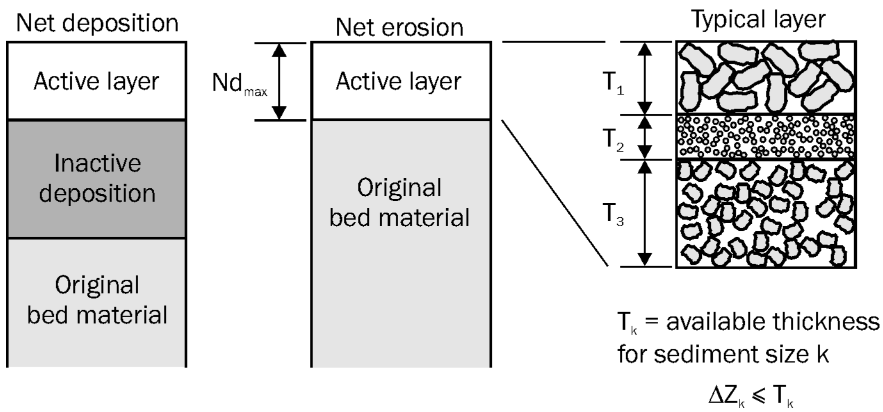
3.4 Bed Sorting and Armoring

GSTARS 2.1 computes sediment transport by size fraction. As a result, particles of different sizes are transported at different rates. Depending on the hydraulic parameters, the incoming sediment distribution, and the bed composition, some particle sizes may be eroded, while others may be deposited or may be immovable. GSTARS 2.1 computes the carrying capacity for each size fraction present in the bed, but the amount of material actually moved is computed by the sediment routing equation — eq. (24). Consequently, several different processes may take place. For example, all the finer particles may be eroded, leaving a layer of coarser particles for which there is no carrying capacity. No more erosion may occur for those hydraulic conditions, and the bed is said to be armored. This armor layer prevents the scour of the underlying materials and the sediment available for transport becomes limited to the amount of sediment entering the reach. However, future hydraulic events, such as an increase of flow velocity, may increase the flow carrying capacity, causing the armor layer to break and restart the erosion processes in the reach.

Many different processes may occur simultaneously within the same channel reach. These depend not only on the composition of the supplied sediment, i.e., the sediment entering the reach, but also on bed composition within that reach. The bed composition may vary within the reach both in space and time. In order to model these type of events, GSTARS 2.1 uses the bed composition accounting procedure proposed by Bennett and Nordin (1977).

In Bennett and Nordin's method, bed accounting is accomplished by the use of two or three conceptual layers (three layers for deposition and two layers for scour). The process is schematically illustrated in figure 3.4. The top layer, which contains the bed material available for transport, is called the *active layer*. Beneath the active layer is the *inactive layer*, which is the layer used for storage. Below these two layers there is the undisturbed bed, with the initial bed material composition.

Figure 3.4 Bed composition accounting procedures. ΔZ_k represents the amount of material in size class k eroded during a time step, and T_k is the amount of material of size k present in the active layer, i.e., available for erosion.



The active layer is the most important concept in this procedure. It contains all the sediment that is available for transport at each time step. The thickness of the active layer is defined by the user as proportional to the geometric mean of the largest size class containing at least 1 percent of the bed material at that location. Active layer thickness is, therefore, closely related to the time step duration. Erosion of a particular size class of bed material is limited by the amount of sediments of that size class present in the active layer. If the flow carrying capacity for a particular size class is greater than what is available for transport in the active layer, the term availability limited is used (Bennett and Nordin, 1977). On the other hand, if more material is available than that necessary to fulfill the carrying capacity computed by a particular sediment transport equation, the term capacity limited is used.

The inactive layer is used when net deposition occurs. The deposition thickness of each size fraction is added to the inactive layer, which in turn is added to the thickness of the active layer. The size composition and thickness of the inactive layer is computed first, after which a new active layer is recomputed and the channel bed elevation updated.

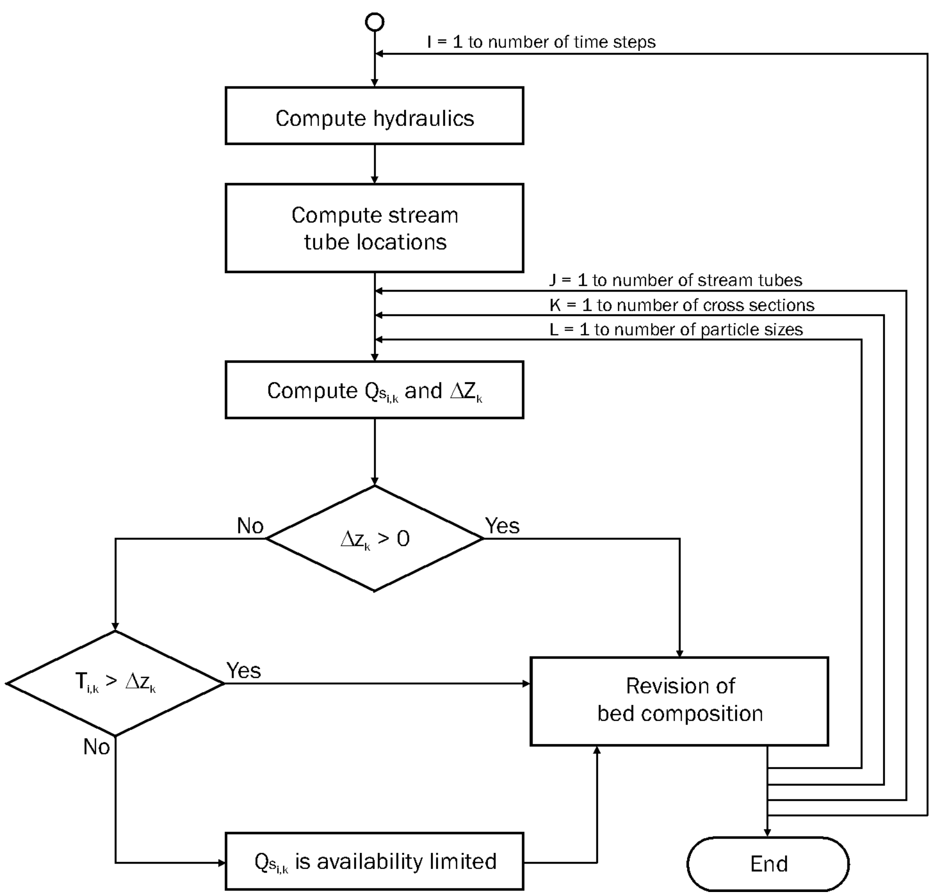
The overall process is illustrated in figure 3.5. The procedures described above are carried out separately along each stream tube. Since the locations of stream tube boundaries change with changing flow conditions and channel geometry, those processes had to be adapted for use in GSTARS 2.1. Bed material is accounted for at the end of each time step for each stream tube. Bed material composition is stored at each point used to describe the geometry for all the cross sections. The values of the active and inactive layer thickness are also stored at those points. At the beginning of the next time step, after the new locations of the stream tube boundaries are determined, these values are used to compute the new layer thicknesses and bed composition for each stream tube. The relations used are

$$P_{i,k} = \frac{1}{X_i} \sum_{m=1}^{NPTS} P_{i,k,m} \cdot \Delta X_i \tag{38}$$

$$TAL_{i,k} = \frac{1}{X_i} \sum_{m=1}^{NPTS} TAL_{i,k,m} \cdot \Delta X_i \tag{39}$$

and

Figure 3.5 Simplified diagram for the bed sorting and armoring processes. Adopted from Bennett and Nordin (1977), with modifications.



$$TIL_{i,k} = \frac{1}{X_i} \sum_{m=1}^{N} TIL_{i,k,m} \cdot \Delta X_i \tag{40}$$

where $P_{i,k}$ = percentage of sediment in size k at station i; $TAL_{i,k}$ = active layer thickness of size fraction k at station i; $TIL_{i,k}$ = active layer thickness of size fraction k at station i; $TAL_{i,k,m}$ and $TIL_{i,k,m}$ = active and inactive layer thickness corresponding to point m for size fraction k at station i, respectively; X_i = wetted perimeter of the stream tube at station i; ΔX_i = averaged distance between adjacent points across the channel; and N = number of points across the channel falling within the stream tube.

3.4.1 Remarks

For a given time step, erosion of the bed or banks will take place when the sediment transport capacity at a given cross section exceeds the load incoming from the upstream cross section. When erosion takes place, sediment transport may be constrained by availability. The materials available for entrainment are those exposed at the bed surface. The concept of the active layer is fundamental. The active layer is the surface layer from which materials can be entrained by the flow. In other words, for each simulation time step, the only material available for erosion is the sediment contained in the active layer. Therefore, the active layer thickness, $\delta = Nd_{max}$, should always be at least as thick as the expected maximum depth of scour (ΔZ). The recommended way to achieve this is by defining the active layer thickness first and then appropriately choosing the time step for sediment transport calculations (Δt_s). A trial-and-error process can be used to ensure that $\Delta Z \le \delta$.

Alternatively, an estimate of Δt_s can be obtained from a simplified form of eq. (31):

$$\frac{Q_{s,i-1} - Q_{si}}{\eta \Delta x_i P_i} = \frac{\Delta Z}{\Delta t_s} \tag{41}$$

where ΔZ is prescribed to satisfy the above criterion (i.e., $\Delta Z \le \delta$). In this case, the estimate should be obtained using the peak inflow discharge.

3.5 Sediment Transport Functions

The literature contains many sediment transport functions. Usually, each transport function was developed for a certain range of sediment size and flow conditions. Computed results based on different transport functions can differ significantly from each other and from measurements. No universal function exists which can be applied with accuracy to all sediment and flow conditions. With the exception of Yang's formulas, most transport functions are intended for subcritical flows. GSTARS 2.1 has 12 transport functions for cohesionless material, presented in table 3.1. More detailed descriptions of these functions were published by Yang (1996), which also includes a number of different comparisons and evaluations.

Table 3.1 Sediment transport functions implemented in GSTARS 2.1 and its type (B = bed load; BM = bed-material load).

Equation	Type
DuBoys (1879)	B
Meyer-Peter and Müller (1948)	B
Laursen (1958)	BM
Toffaleti (1969)	BM
Engelund and Hansen (1972)	BM
Ackers and White (1973)	BM
Ackers and White (1990)	BM
Yang (1973) + Yang (1984)	BM
Yang (1979) + Yang (1984)	BM
Parker (1990)	B
Yang et al. (1996)	BM

Most sediment transport formulas were developed for computing the total bed-material load without breaking it into load by size fraction. In GSTARS 2.1, these formulas have been modified to account for transport by size. The total carrying capacity for a particular river section, C_t, is computed by using the following relationship:

$$C_t = \sum_{i=1}^{N} [rp_i + (1-r)p_i^*]C_i \tag{42}$$

where p_i = percentage of material of size fraction i available in the bed; p_i^* = percentage of material of size fraction i incoming into the reach; C_i = capacity for each size fraction; r = a factor ($0 \le r \le 1$); and N = number of size fractions. C_i is computed by the formulas presented in the following sections for each size fraction as if the entire bed was composed of that size fraction alone.

The factor r is a weighting factor that allows the inclusion of incoming sediment into the carrying capacity of the flow. Most models use a value of $r = 1$. However, in this case, any material entering a reach that is not already present in the bed (i.e., with $p_i = 0$) will deposit instantaneously due to sudden loss in capacity. In other words, if material with a certain size fraction enters a reach ($p_i^* \neq 0$) with $p_i = 0$, then $r = 0$ implies $C_t = 0$. This is an unrealistic situation. Nevertheless, the values of the parameter r should remain in the vicinity of 1. For example, for mountain rivers a value of $r = 0.7$ was found to work well.

The hydraulic parameters used to compute the sediment carrying capacities in each reach are computed as weighted averages from the hydraulic parameters from nearby stations. For each station i, the representative values of the area (A_{Ri}), depth (D_{Ri}), velocity (V_{Ri}), and friction slope (S_{Ri}) are computed as follows:

$$A_{Ri} = aA_{i-1} + bA_i + cA_{i+1} \tag{43}$$

$$D_{Ri} = aD_{i-1} + bD_i + cD_{i+1} \tag{44}$$

$$V_{Ri} = aV_{i-1} + bV_i + cV_{i+1} \tag{45}$$

$$S_{Ri} = aS_{i-1} + bS_i + cS_{i+1} \tag{46}$$

The weighting parameters a, b, and c can be chosen in any combination that satisfies eq. (27). By default, GSTARS 2.1 assumes the values of $a = c = 0$ and $b = 1$, but these values can be changed by the user. For example, in rivers whose properties change more rapidly from section to section, a scheme incorporating information from the upstream and downstream reaches may be more appropriate. The values of $a = c = 0.25$ and $b = 0.5$ may be adopted in those circumstances. By changing *a*, *b*, and *c* appropriately, the user can use the parameters that favor stability or that favor sensitivity. Usually, more sensitive schemes are the less stable, and vice-versa.

For the station located farthest downstream (station $i = NSTA$), the values for the parameters at station $i + 1$ are not defined; therefore only parameters *a* and *b* are necessary. For that station, GSTARS 2.1 defines $a = 0$ and $b = 1$. These values can be changed by the user. For the example given above, a possible combination of values might be $a = b = 0.5$.

For the first upstream station (station $i = 1$), station $i - 1$ is not defined, therefore parameter *a* is not used. GSTARS 2.1 defaults to $b = 1$ and $c = 0$, but these values can be changed by the user.

Note that the coefficients *a*, *b*, and *c* may be numerically different and are independent from those used in eq. (26), although they have a similar function.

3.5.1 DuBoys' Method (1879)

The pioneering work of DuBoys (1879) is based on the premise that the sediment moves in layers that slide over each other. Although the concept was ultimately proven wrong, it was found that his equation could still be used to describe the data. DuBoys reached an expression that is based on the excess of shear stress:

$$q_b = K\tau(\tau - \tau_c) \tag{47}$$

where q_b = bed load discharge by volume per unit channel width; τ = bed shear stress; and τ_c = critical tractive force along the bed. τ_c can be computed from Shields diagram. Straub (1935) found the following relationship for *K*:

$$K = \frac{0.173}{d^{3/4}} \tag{48}$$

where *d* = particle size.

3.5.2 Meyer-Peter and Müller's formula (1948)

The Meyer-Peter and Müller's formula (1948) is a bed load formula for gravel or coarse materials:

$$\gamma RS\left(\frac{K_s}{K_r}\right)^{3/2} = 0.047(\gamma_s - \gamma)d + 0.25\rho^{1/3}q_b^{2/3} \tag{49}$$

where γ and γ_s = specific weights of water and sediment (metric tons/m^3), respectively; R = hydraulic radius (m); S = energy slope; d = mean particle diameter (m); ρ = specific mass of water (metric ton-s/m^4); q_b = bedload rate in underwater weight per unit time and width ([metric tons/s]/m); and $(K_s/K_r)S$ = a kind of slope, which is adjusted such that only a portion of the total energy loss, namely, that caused by the grain resistance, S_r, is responsible for the bed-load motion.

Eq. (49) can also be expressed in dimensionless form as

$$q_b^{2/3}\left(\frac{\gamma}{g}\right)^{1/3}\frac{0.25}{(\gamma_s - \gamma)d} = \frac{(K_s/K_r)^{3/2}\gamma RS}{(\gamma_s - \gamma)d} - 0.047 \tag{50}$$

where

$$\left(\frac{K_s}{K_r}\right)^{3/2} = \frac{S_r}{S} \tag{51}$$

and

$$K_r = \frac{26}{d_{90}^{1/6}} \tag{52}$$

where d_{90} = the size of sediment for which 90 percent of the material is finer.

3.5.3 Laursen's Formula (1958)

Laursen's formula (1958) was expressed in dimensionally homogeneous forms by an American Society of Civil Engineers Task Committee (1971) as

$$C_t = 0.01\gamma\sum_i p_i\left(\frac{d_i}{D}\right)^{7/6}\left(\frac{\tau'}{\tau_{ci}} - 1\right)f\left(\frac{U*}{\omega_i}\right) \tag{53}$$

where C_t = sediment concentration by weight per unit volume; $U* = \sqrt{gDS}$; p_i = percentage of materials available in size fraction i; ω_i = fall velocity of particles of mean size d_i in water; D = average water depth; and τ_{ci} = critical tractive force for sediment size d_i as given by the Shields diagram. Laursen's bed shear stress, τ', caused by grain resistance resulting from the use of the Manning equation is

$$\tau' = \frac{\rho V^2}{58}\left(\frac{d_{50}}{D}\right)^{1/3} \tag{54}$$

In eq. (53), the parameter $\tau'/\tau_{ci} - 1$ is important in determining bed load, and the parameter $U*/\omega_i$ relates to suspended load. The functional relation $f(U*/\omega_i)$ is given by Laursen (1958) in a graphical form.

3.5.4 Toffaleti's Method (1969)

Toffaleti's method (1969) is based on the concept of Einstein (1950) and Einstein and Chen (1953) with the following simplifications: (1) channel width with sediment discharge is equal to that of a rectangular channel of width *B* and depth *R*, with *R* being the hydraulic radius of the actual channel; (2) the total depth of flow is divided into four zones. The bed material, Q_{ti}, for sediment of size d_i is

$$Q_{ti} = B(q_{bi} + q_{sui} + q_{smi} + q_{sli}) \tag{55}$$

where B = channel width; and q_{bi}, q_{sui}, q_{smi}, q_{sli} = sediment load per unit width in the bed zone, upper zone, middle zone, and lower zone, respectively. Semi-empirical and graphical methods were used by Toffaleti for the computation of sediment load in each zone.

3.5.5 Engelund and Hansen's Method (1972)

Engelund and Hansen (1972) proposed the following transport function:

$$f'\phi = 0.1\theta^{5/2} \tag{56}$$

$$f' = \frac{2gSD}{V^2} \tag{57}$$

$$\phi = \frac{q_t}{\gamma_s}\left[\left(\frac{\gamma_s - \gamma}{\gamma}\right)gd^3\right]^{-1/2} \tag{58}$$

$$\theta = \frac{\tau}{(\gamma_s - \gamma)d} \tag{59}$$

where g = gravitational acceleration; S = energy slope; V = average flow velocity; q_t = total sediment discharge by weight per unit width; γ_s and γ = specific weights of sediment and water, respectively; d = median particle diameter; D = mean water depth; and τ = shear stress along the bed.

3.5.6 Ackers and White's Method (1973) and (1990)

Ackers and White (1973) applied dimensional analysis to express the mobility and transport rate of sediment in terms of some dimensionless parameters. Their mobility number for sediment is

$$F_{gr} = U*^n\left[gd\left(\frac{\gamma_s}{\gamma} - 1\right)\right]^{-1/2}\left[\frac{V}{\sqrt{32}\log(\alpha D/d)}\right]^{1-n} \tag{60}$$

where $U*$ = shear velocity; n = transition exponent, depending on sediment size; $\alpha = 10$, in turbulent flow; d = sediment particle size; and D = water depth. They also expressed the sediment size by a dimensionless grain diameter:

$$d_{gr} = d\left[\frac{g}{\nu^2}\left(\frac{\gamma_s}{\gamma} - 1\right)\right]^{1/3} \tag{61}$$

where ν = kinematic viscosity of water. A dimensionless sediment transport function can then be expressed as

$$G_{gr} = f(F_{gr}, d_{gr}) \tag{62}$$

with

$$G_{gr} = \frac{XD}{(d\gamma_s)/\gamma}\left(\frac{U^*}{V}\right)^n \tag{63}$$

where X = rate of sediment transport in terms of mass flow per unit mass flow rate, i.e., concentration by weight of fluid flux. The generalized dimensionless sediment transport function can also be expressed as

$$G_{gr} = C\left(\frac{F_{gr}}{A} - 1\right)^m \tag{64}$$

The values of A, C, m, and n were determined by Ackers and White (1973) based on best-fit curves of laboratory data with sediment size greater than 0.04 mm and Froude number less than 0.8.

The original Ackers and White formula is known to overpredict transport rates for fine sediments (smaller than 0.2 mm) and for relatively coarse sediments. To correct that tendency, a revised form of the coefficients was published in 1990 (HR Wallingford, 1990). Both versions of the coefficients are implemented in GSTARS 2.1. The comparison between the original and the revised coefficients is given in table 3.2.

Table 3.2 Coefficients for the 1973 and 1990 versions of the Ackers and White formula.

	1973	1990
$1 < d_{gr} \le 60$	$A = 0.23 d_{gr}^{-1/2} + 0.14$	$A = 0.23 d_{gr}^{-1/2} + 0.14$
	$\log C = -3.53 + 2.86 \log d_{gr} - (\log d_{gr})^2$	$\log C = -3.46 + 2.79 \log d_{gr} - 0.98(\log d_{gr})^2$
	$m = 9.66 d_{gr}^{-1} + 1.34$	$m = 6.83 d_{gr}^{-1} + 1.67$
	$n = 1.00 - 0.56 \log d_{gr}$	$n = 1.00 - 0.56 \log d_{gr}$
$d_{gr} > 60$	$A = 0.17$	$A = 0.17$
	$C = 0.025$	$C = 0.025$
	$m = 1.50$	$m = 1.78$
	$n = 0$	$n = 0$

3.5.7 Yang's Sand (1973) and Gravel (1984) Transport Formulas

Yang's 1973 dimensionless unit stream power formula for sand transport is

$$\log C_{ts} = 5.435 - 0.286\log\frac{\omega d}{\nu} - 0.457\log\frac{U^*}{\omega} + \left(1.799 - 0.409\log\frac{\omega d}{\nu} - 0.314\log\frac{U^*}{\omega}\right)\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \tag{65}$$

where C_{ts} = total sand concentration in parts per million by weight; ω = sediment fall velocity; d = sediment particle diameter; ν = kinematic viscosity of water; U^* = shear velocity; VS = unit stream power; V = average flow velocity; S = water surface or energy slope; and V_{cr} = critical average flow velocity at incipient motion. The coefficients in eq. (65) were determined from 463 sets of laboratory flume data. Eq. (65) should be applied to sand transport with particle diameter less than 2 mm.

The critical dimensionless unit stream power, $V_{cr}S/\omega$, is the product of dimensionless critical velocity V_{cr}/ω and energy slope S, where

$$\frac{V_{cr}}{\omega} = \begin{cases} \dfrac{2.5}{\log(U^*d/\nu) - 0.06} + 0.66 & \text{if } 1.2 < \dfrac{U^*d}{\nu} < 70 \\ 2.05 & \text{if } 70 \le \dfrac{U^*d}{\nu} \end{cases} \tag{66}$$

Yang's 1984 dimensionless unit stream power formula for gravel transport with particle diameter equal to or greater than 2 mm is

$$\log C_{tg} = 6.681 - 0.633\log\frac{\omega d}{\nu} - 4.816\log\frac{U^*}{\omega} + \left(2.784 - 0.305\log\frac{\omega d}{\nu} - 0.282\log\frac{U^*}{\omega}\right)\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \tag{67}$$

where C_{tg} = total gravel concentration in parts per million by weight. The coefficients in eq. (67) were determined from 167 sets of laboratory flume data.

The incipient motion criteria given in eq. (66) should be used for eqs. (65) and (67). Because of the range of data used for the determination of the coefficients in eq. (67), the equation should be applied to gravel with median particle size between 2 and 10 mm. However, published literature suggests that eq. (67) may be applicable to materials coarser than 10 mm. GSTARS 2.1 uses eq. (67) for sizes up to 100 mm. Eqs. (65) and (67) were originally derived for uniform materials. When they are applied to nonuniform materials, the total sediment concentration should be computed by using eq. (42).

For natural rivers, the bed-material size may vary from sand to gravel. In this case, the use of both eqs. (65) and (67) should be considered. GSTARS 2.1 uses the appropriate equation for a given particle size.

3.5.8 Yang's Sand (1979) and Gravel (1984) Transport Formulas

Yang (1979) proposed a sand transport formula for flow conditions well exceeding those required for incipient motion. In this case, the dimensionless critical unit stream power required at incipient motion can be neglected. Yang's 1979 sand transport formula for sediment concentration greater than 100 parts per million by weight is

$$\begin{aligned}\log C_{ts} &= 5.165 - 0.153\log\frac{\omega d}{\nu} - 0.297\log\frac{U^*}{\omega} \\ &\quad + \left(1.780 - 0.360\log\frac{\omega d}{\nu} - 0.480\log\frac{U^*}{\omega}\right)\log\frac{VS}{\omega}\end{aligned} \tag{68}$$

The coefficients in eq. (68) were determined from 452 sets of laboratory flume data. Eqs. (65) and (68) give about the same degree of accuracy when the bed-material concentration is greater than about 100 parts per million by weight. Users can either use a combination of eqs. (65) and (67) or (68) and (67) for the computation of bed material concentration in a river, depending on sediment size in that river. If bed materials are not uniform, equation (42) is also applied in GSTARS 2.1.

3.5.9 Parker's Method (1990)

Parker (1990) developed an empirical gravel transport function based on the equal mobility concept and field data. Parker's dimensionless bed-load transport function, W_i^*, and dimensionless shear stress parameter, ϕ_i, are defined as

$$W_i^* = \left(\frac{\gamma_s}{\gamma} - 1\right)\frac{q_{bi}}{p_i DS\sqrt{gDS}} \tag{69}$$

$$\phi_i = \frac{DS}{d_i \tau_{ri}^*}\left(\frac{\gamma_s}{\gamma} - 1\right)^{-1} \tag{70}$$

The value of τ_{ri}^* based on d_{50} is 0.875, i.e.,

$$\tau_{ri}^* = 0.875\frac{d_{50}}{d_i} \tag{71}$$

where q_{bi} = bed-load per unit channel width in size fraction d_i; D = water depth; S = slope; and p_i = fraction by weight in size d_i.

Because of equal mobility of all sizes, only one grain size, namely, the subpavement size, d_{50}, is used to characterize bed-load discharge as a function of the dimensionless shear stress, i.e.,

$$W^* = \begin{cases} 0.0025\phi^{14.2} & \text{if} \quad \phi_{50} < 1.0 \\ 0.0025\exp\left\{14.2(\phi_{50}-1) - 9.28(\phi_{50}-1)^2\right\} & \text{if} \quad 1.0 \le \phi_{50} \le 1.59 \\ 13.685\left(1 - \dfrac{0.853}{\phi_{50}}\right)^{4.5} & \text{if} \quad \phi_{50} > 1.59 \end{cases} \tag{72}$$

In eq. (72), ϕ_{50} is based on the subpavement size, d_{50}. This equation was empirically fitted using field data with sediment size ranging from 18 to 28 mm.

3.5.10 Yang's Modified Formula for Sand Transport with High Concentration of Wash Load (1996)

Up to this point, all transport functions were developed for equilibrium sediment transport where the effects of wash load can be neglected. The existence of high concentration of wash load can significantly affect the flow viscosity, sediment fall velocity, and the relative density or relative specific weight of sediment. For a given set of hydraulic conditions, non-equilibrium sediment transport of varying rates may occur because of a varying rate of high concentration of wash load. Yang et al. (1996) rewrote Yang's 1979 formula in the following form for sediment-laden flow with high concentration of wash load:

$$\begin{aligned} \log C_{ts} &= 5.165 - 0.153\log\frac{\omega_m d}{\nu_m} - 0.297\log\frac{U^*}{\omega_m} \\ &+ \left(1.780 - 0.360\log\frac{\omega_m d}{\nu_m} - 0.480\log\frac{U^*}{\omega_m}\right)\log\left(\frac{\gamma_m}{\gamma_s - \gamma_m}\frac{VS}{\omega_m}\right) \end{aligned} \tag{73}$$

where ω_m = particle fall velocity in a sediment-laden flow; ν_m = kinematic viscosity of sediment laden flow; and γ_s, γ_m = specific weights of sediment and sediment-laden flow, respectively.

It should be noted that the coefficients in eq. (73) are identical to those in eq. (68). However, the values of fall velocity, kinematic viscosity, and relative specific weight are modified for sediment transport in sediment-laden flows with high concentrations of fine suspended materials. The modifications made by Yang et al. (1996) were based on sediments from the Yellow River in China, which is noted for its high concentration of wash load and bed-material load. Similar to the applications of eqs. (65), (67), and (68), eq. (73) is used in conjunction with equation (42) for non-uniform bed materials.

3.6 Cohesive Sediment Transport

At present, the equations for computing the transport potential of cohesive sediments† implemented in GSTARS 2.1 are considered state-of-the-art (Partheniades, 1986; Mehta et al., 1989). However, in spite of the progress of recent years in modeling cohesive sediment transport, reliable predictive techniques are still not available. In practice, modeling of fines still relies on extensive calibration and sensitivity analysis, techniques that are useful and can yield excellent results. Our knowledge of the basic physical processes that govern erosion, deposition, and consolidation of cohesive sediments is still incomplete. The present models suffer from this limitation, but are further aggravated from frequent discrepancies observed between laboratory experiments and prototype behavior.

Table 3.3 Sediment grade size scale for particle sizes smaller than the finest sand (62.5 μm) according to the American Geophysical Union (Lane, 1947).

Classification	d_{mean} (μm)
Coarse silt	62 - 31
Medium silt	31 - 16
Fine silt	16 - 8
Very fine silt	8 - 4
Coarse clay	4 - 2
Medium clay	2 - 1
Fine clay	1 - 0.5
Very fine clay	0.5 - 0.25
Colloids	< 0.25

The main difficulty in describing the behavior of muds stems from the fact that cohesive sediments are not characterized by their particle properties alone. All the governing parameters for non-cohesive sediments (those with diameter larger than 62.5 μm) can be known from the particle properties, such as density, diameter, and shape. These parameters are enough to define the fall velocity and the erosion and deposition processes of the sediment. However, the properties of muds do not depend on the sediment mixture alone. The medium where the sediment is contained, that is, its surrounding aqueous mixture, plays a more fundamental role in defining sedimentation characteristics. Parameters such as temperature of the water, its pH, salinity and other mineral composition, organic content, and biological processes, are necessary to characterize the mud and its intrinsic properties. Unfortunately, these highly variable and site dependent parameters are too complex and poorly understood to be used directly by a model. This fact also elucidates why studies of cohesive sediments are empirical, site specific, and seldom of a fundamental

† In this manual, cohesive sediments are sediments whose particles pass through a 62.5 μm sieve, a definition that follows the nomenclature of the American Geophysical Union (Lane, 1947). We also use the terms mud and fines to refer to this type of sediment. See table 3.3 for more detailed description of the subclasses.

nature. Table 3.4 shows some of the parameters that can be used to characterize cohesive sediments.

Table 3.4 List of some the parameters used by the European Community's MAST-1 G6M project to characterize cohesive sediment processes. Note that some of these parameters are interdependent.

Physico-chemical properties of the overflowing fluid	**Physico-chemical properties of the sediments**
Chlorinity	Chlorinity
Temperature	Temperature
Oxygen content	Oxygen content
Redox potential	Redox potential
pH	Gas content
Ions (Na-, K-, Mg-, Ca-, Fe-, and Al-)	Ions (Na-, K-, Mg-, Ca-, Fe-, and Al-)
Sodium adsorption ratio	Organic content
Suspended sediment concentration	Cation exchange capacity (CEC)
Characteristics of bed structure	Bulk density (profile)
Consolidation:	Specific surface area
(a) consolidation curve & density profile	Mineralogical composition
(b) permeability	Grain size distribution
(c) pore pressure & effective stress	Sand content
Rheological parameters:	**Water-bed exchange process**
(a) upper & lower yield stress	Settling velocity (laboratory & field):
(b) Bingham viscosity	(a) as function of sediment concentration and floc density
(c) equilibrium slope of deposits	
Atterberg limits	(b) as function of salinity
	Critical shear stress for deposition
	Critical shear stress for erosion
	Erosion rate

In GSTARS 2.1, the transport of silt and clay is computed separately from the remaining size fractions. GSTARS 2.1 recognizes the presence of clay if any of the particle size fractions given in the input has a geometric mean grain size, d_{mean}, smaller than 0.004 mm (see table 3.3). Similarly, the presence of silt is recognized if a size faction has a d_{mean} between 0.004 and 0.0625 mm. There can be any number of particle groups in the clay or silt sizes, up to a maximum of 10 combined groups (i.e., including cohesive and non-cohesive sediment size groups). While the transport of fractions with $d_{mean} \geq 0.0625$ mm is computed by the traditional transport equations presented in section 3.5, for smaller fractions the methods described in this section are used.

3.6.1 Deposition

The occurrence of erosion or deposition is controlled by the value of the bed shear stress, τ_b. Deposition of clay and silt takes place when τ_b is smaller than the critical bed shear stress for deposition, τ_{cd}. τ_{cd} is the critical value of the bed shear stress above which no deposition occurs. In this case, the deposition is governed by integrating

$$\frac{dC}{dt} = -\frac{P\omega_s C}{h} \tag{74}$$

where C = depth-averaged concentration of sediments, h = the water depth, and ω_s = the settling velocity of the sediment. P is a parameter representing the probability for deposition, and is computed from

$$P = \begin{cases} 1 - \dfrac{\tau_b}{\tau_{cd}} & \text{when} \quad \tau_b < \tau_{cd} \\ 0 & \text{when} \quad \tau_b \geq \tau_{cd} \end{cases} \tag{75}$$

When ω_s does not depend on the concentration of suspended sediments (unhindered settling), eq. (74) can be integrated analytically to yield

$$\frac{C}{C_0} = \exp\left\{-\frac{\omega_s \Delta t}{h}\left(1 - \frac{\tau_b}{\tau_{cd}}\right)\right\} \tag{76}$$

where C_0 and C are the concentration at the beginning and end of time step Δt. The time of residence, Δt, is obtained from $\Delta x/V$, where Δx is the reach length and V is the velocity of the flow. Eq. (76) is the equation implemented in GSTARS 2.1. The concentration obtained is converted into volume and deposited on the bed.

Note that the adoption of eq. (76) requires unhindered settling conditions of the sediment particles. Unhindered settling is a condition under which the particles retain their individuality, and only occurs at relatively low concentrations, say $C < C_1$. At higher concentrations, particles flocculate together, forming larger aggregates that behave differently from the individual particles. Values of C_1 are in the range of 100 to 700 mg/l. Application of GSTARS 2.1 should, therefore, be done carefully and with ample support from field data.

The concept of critical shear stress for deposition is not without its problems. For example, Krone (1962) found a concentration-dependent τ_{cd} for the San Francisco Bay sediments. The values of τ_{cd} were found to vary between 0.06 N/m^2 for $C < 300$ mg/l, and 0.078 N/m^2 for the higher values of C, ranging from 300 to 10,000 mg/l. Furthermore, when the sediment distribution in the bed has a large range of particle sizes, τ_{cd} may not have a unique value. The particular behavior of τ_{cd} for the case at hand should always be considered and supported by field data.

3.6.2 Erosion

Erosion of silt and clay takes place when τ_b is greater than the critical bed shear stress for particle scour, τ_{cs}. GSTARS 2.1 recognizes two modes of erosion of cohesive beds: particle erosion and mass erosion. The first mode, also referred to as surface erosion, corresponds to the state where the erosion proceeds particle by particle, or aggregate by aggregate. The second mode corresponds to a state where the bed is destroyed by the eroding currents and entire blocks of mud are swept away. This type of phenomenological schematization of the erosion process of cohesive beds is shared by many (e.g., Ohtsubo and Muraoka, 1986). A third mode of erosion is sometimes mentioned, which corresponds to the re-entrainment of a stationary suspension (Mehta et al., 1989).

The current methods compute the rate of erosion, $E^{\dagger}$, as a linear function of the excess of the bed shear stress with respect to a critical shear stress for erosion:

$$E = M_i\left(\frac{\tau_b - \tau_{ci}}{\tau_{ci}}\right) \tag{77}$$

where i = 1,2 for particle or mass erosion, respectively, M_i is an experimental parameter, and τ_{ci} are the critical shear stresses for erosion. M_i and τ_{ci} vary with type of sediment, salinity and mineral contents of the water, its pH and temperature, but do not correlate well with the parameters usually used to characterize non-cohesive sediments (particle diameter, specific gravity, Atterberg limits, etc. — see table 3.4). Therefore, to compute the erosion rate of mud beds we need to know how M_1, M_2, τ_{c1}, and τ_{c2} vary within the domain of interest. This variation may be in space and/or time.

Unfortunately, the literature does not provide methods of estimating M_i, therefore eq. (77) was implemented in two stages. Particle erosion takes place when $\tau_b > \tau_{cs}$. Mass erosion takes place when τ_b increases past the critical bed shear stress, τ_{cm}, for mass erosion. The following equations are used for the particle and mass erosion rates, respectively (Partheniades 1965; Ariathurai and Krone 1976):

$\tau_{cs} < \tau_b \le \tau_{cm}$:

$$E_1 = \frac{1}{A}\frac{dm}{dt} = M_1\left(\frac{\tau_b}{\tau_{cs}} - 1\right) \tag{78}$$

$\tau_b > \tau_{cm}$:

$$E_2 = \frac{1}{A}\frac{dm}{dt} = M_2\left(\frac{T_e}{\Delta t}\right) \tag{79}$$

where m = mass; t = time; Δt = time step; M_1, M_2 = material constants that depend on mineral composition, salinity, organic material, etc., with units of mass per unit area and time; A = bottom area; and E_1 = particle erosion rate per unit of area; E_2 = mass erosion rate per unit of area; and T_e = characteristic time of erosion.

The presence of clay in the active layer may increase the cohesive forces between particles. As a result, the shear stress necessary to move the cohesive materials may be greater than that necessary to move the individual particles, which in turn limits the rates of bed erosion. To model this effect, GSTARS 2.1 uses an input parameter that indicates a threshold value for the percentage of clay in the compo-

† Units of mass of eroded sediment per unit of bed area and per unit of time.

sition of the bed, above which the erosion rates of silts, sands, and gravel are limited to the erosion rate of clay. For example, if that parameter is set to 0.3 (i.e., 30 percent), whenever the composition of the bed contains 30 percent or more clay, the erosion of silts, sands, and gravels will be limited to the erosion rate of clay. On the other hand, if the composition of the bed contains less than 30 percent of clay, the erosion rates of the other materials are not constrained by the erosion rate of clay. This methodology prevents erosion of those materials before the erosion of clay begins to take place, which would otherwise occur when the bed shear stress is large enough to erode those particles, but smaller than τ_{cs}.

The equations used for erosion of cohesive sediments do not constrain the concentration of clay and silt being transported. To prevent unlimited growth of the transport of these materials, a maximum mud flow concentration of 800,000 parts per million by weight is allowed (U.S. Army Corps of Engineers, 1993). When the total concentration of silt and clay exceeds this value, each of the grain size fractions is reduced proportionally to meet the 800,000 parts per million limit of fines.

3.7 Non-equilibrium Sediment Transport

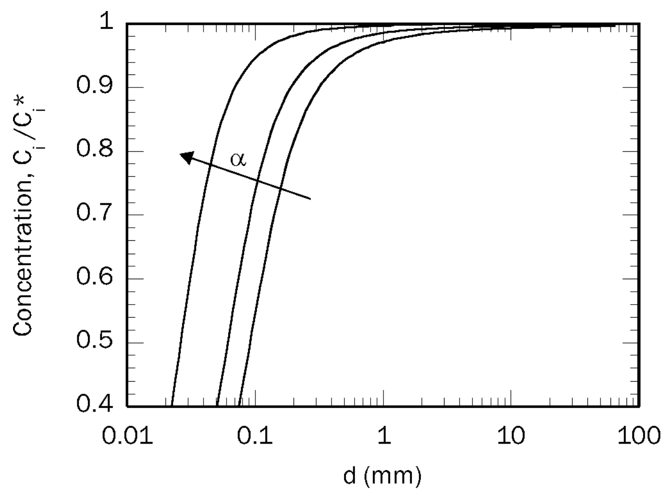
In rivers and streams, it is usually acceptable to assume that the bed-material load discharge is equal to the sediment transport capacity of the flow; i.e., the bed-material load is transported in an equilibrium mode. In other words, the exchange of sediment between the bed and the fractions in transport is instantaneous. However, there are circumstances in which the spatial-delay and/or time-delay effects are important. For example, reservoir sedimentation processes and the siltation of estuaries are essentially non-equilibrium processes. In the laboratory, it has been observed that it may take a significant distance for a clear water inflow to reach its saturation sediment concentration. To model these effects, GSTARS 2.1 uses the method developed by Han (1980). In this method, which is based in the analytical solution of the convection-diffusion equation, the non-equilibrium sediment transport rate is computed from

$$\begin{aligned} C_i = {} & C_i^* + (C_{i-1} - C_{i-1}^*)\exp\left\{-\frac{\alpha\omega_s\Delta x}{q}\right\} + \\ & (C_{i-1}^* - C_i^*)\left(\frac{q}{\alpha\omega_s\Delta x}\right)\left[1 - \exp\left\{-\frac{\alpha\omega_s\Delta x}{q}\right\}\right] \end{aligned} \tag{80}$$

where C = sediment concentration; C^* = sediment carrying capacity; q = discharge of flow per unit width; Δx = reach length; ω_s = sediment fall velocity; i = cross-section index (increasing from upstream to downstream); and α = a dimensionless parameter. Eq. (80) is employed for each of the particle size fractions in the cohesionless range, i.e., with diameter greater than 62.5 μm. The parameter α is a recovery factor. Han and He (1990) recommend a value of 0.25 for deposition and 1.0 for entrainment.

Although eq. (80) was derived for suspended load, its application to bed-material load is reasonable. The asymptotic behavior of eq. (80) for the larger particles (higher values of ω_s) is correct in the sense that $C_i \rightarrow C_i^*$ as ω_s becomes larger. Therefore, for the larger particles that are transported near the bed as bed load, the non-equilibrium correction due to eq. (80) becomes negligible and $C_i \cong C_i^*$. Figure 3.6 shows the ratio C_i / C_i^* as a function of particle size, for the case of erosion (the correction is similar for the case of aggradation). The non-equilibrium capacity becomes almost identical for gravel and larger particle sizes.

Figure 3.6 Ratio between non-equilibrium concentration and carrying capacity as a function of sediment particle size.



The influence of the recovery parameter α is illustrated in figure 3.7. The depositional case represents a situation in which there is a sudden loss of carrying capacity ($C_i^* = 0$) from an upstream equilibrium condition ($C_{i-1} = C_{i-1}^*$). The plot shows the actual normalized concentration for two sizes of the sediment particles. It is clear that the non-equilibrium effect is stronger on the finer particles, and that it diminishes as α increases. The erosional case represents a sudden gain of carrying capacity, such as what happens when clear water enters a channel with erodible bed. In this case, $C_{i-1} = C_{i-1}^* = 0$ and $C_i^* > 0$. The same trend is observed as before, i.e., the non-equilibrium effects tend to diminish with increasing particle sizes and recovery factor.

Another important factor in non-equilibrium calculations is distance between computational cross sections, Δx. Figure 3.8 shows how the non-equilibrium effects vary with distance for the same situations and particle sizes in figure 3.7. In practice, the values of α can vary widely. For example, a value of $\alpha = 0.001$ has been used for depositional rivers with high concentrations of fine material in suspension, such as the Rio Grande in the U.S., and the Yellow River in China. Values of α greater than 1.0 have been used in some occasions, on erosional rivers.

Figure 3.7 Effect of the recovery parameter α on the computation of non-equilibrium sediment concentrations for two sediment particle sizes. (a) deposition and (b) erosion.

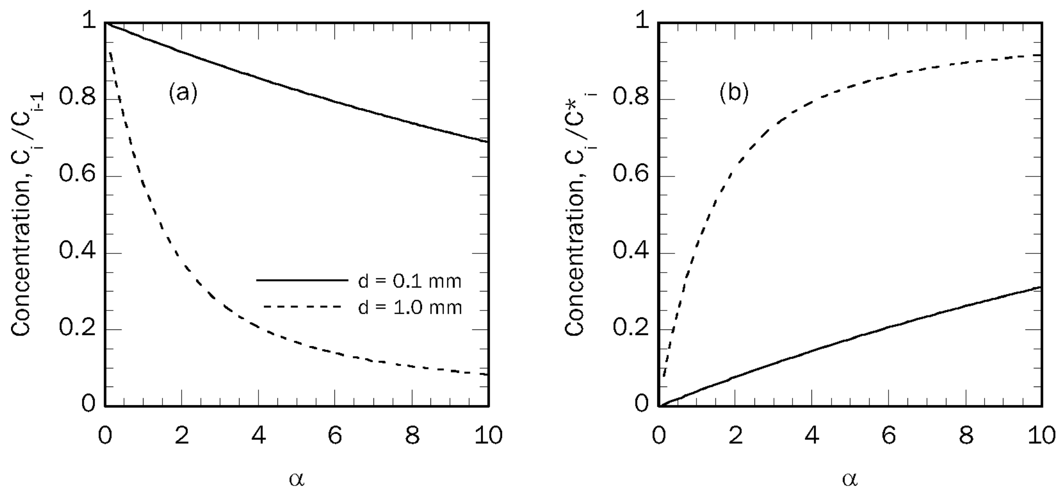
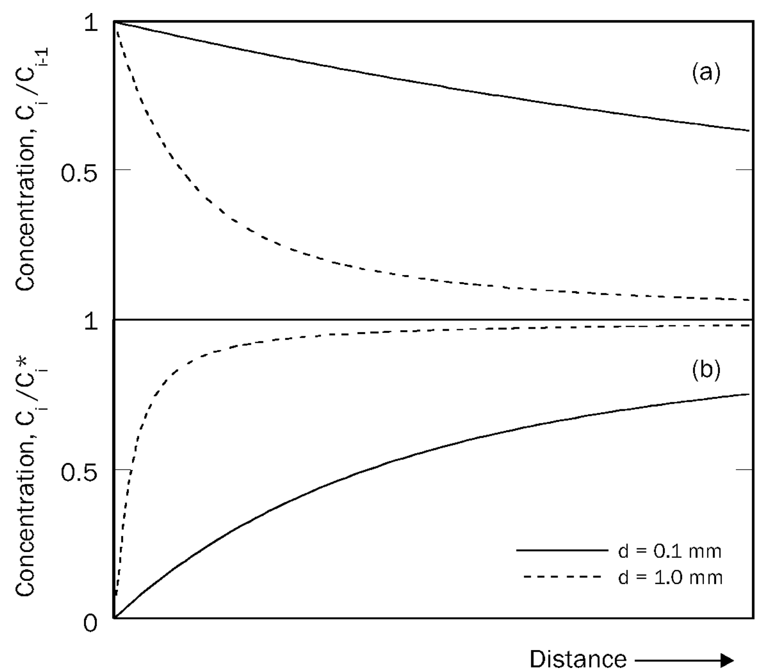


Figure 3.8 Variation of non-equilibrium effects as a function of distance between cross sections for aggradation (a) and for erosion (b).



3.8 Particle Fall Velocity Calculations

Computation of particle fall velocity is necessary for sediment transport capacity calculations. Sediment fall velocities for the sediment particles are computed in different ways, depending on the sediment transport equation used and on particle size. When Toffaleti's equation is used, Rubey's formula (Rubey, 1933) is employed:

$$\omega_s = F\sqrt{dg(G-1)} \tag{81}$$

where

$$F = \left[\frac{2}{3} + \frac{36\nu^2}{gd^3(G-1)}\right]^{1/2} - \left[\frac{36\nu^2}{gd^3(G-1)}\right]^{1/2} \tag{82}$$

for particles with diameter, *d*, between 0.0625 mm and 1 mm, and where F = 0.79 for particles greater than 1 mm. In the above equations, ω_s = fall velocity of sediments; g = acceleration due to gravity; G = specific gravity of sediments; and ν = kinematic viscosity of water. In GSTARS 2.1, the specific gravity of sediments is 2.65 (quartz) and the viscosity of water is computed from the water temperature, T, using the following expression:

$$\nu = \frac{1.792 \times 10^{-6}}{1.0 + 0.0337T + 0.000221T^2} \tag{83}$$

with T in degrees Centigrade and ν in m^2/s.

When any of the other sediment transport formulas are used, the values recommended by the U.S. Interagency Committee on Water Resources Subcommittee on Sedimentation (1957) are used (figure 3.9). GSTARS 2.1 uses a value for the Corey shape factor of SF = 0.7, where

$$SF = \frac{c}{\sqrt{ab}} \tag{84}$$

where *a*, *b*, and *c* = the length of the longest, the intermediate, and the shortest mutually perpendicular axes of the particle, respectively. For particles with diameter greater than 10 mm, which are above the range given in figure 3.9, the following formula is used:

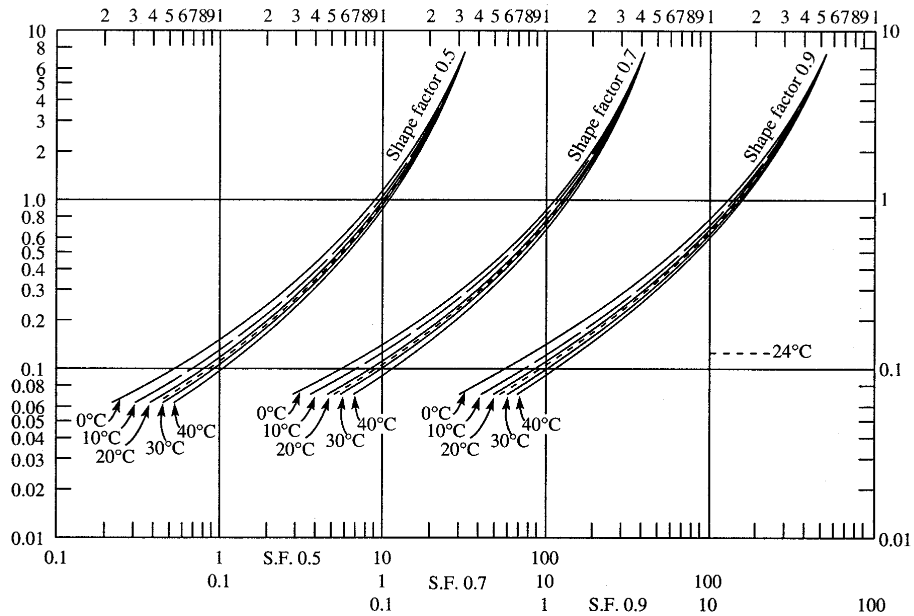
$$\omega_s = 1.1\sqrt{(G-1)gd} \tag{85}$$

For particles in the silt and clay size ranges, that is, with diameters between 1 and 62.5 μm, the sediment fall velocity is computed from

$$\omega_s = \frac{(G-1)gd^2}{18\nu} \tag{86}$$

Eq. (86) is valid only for the case of unhindered settling.

Figure 3.9 Relation between particle sieve diameter and its fall velocity according to the U.S. Interagency Committee on Water Resources Subcommittee on Sedimentation (1957).



CHAPTER

4

COMPUTATION OF WIDTH CHANGES

GSTARS 2.1 is able to compute not only channel bed elevation changes, but also channel width changes. This chapter briefly describes the theoretical basis for those calculations and their implementation in the numerical model. Note that this subject is very complex and that its detailed presentation is not in the scope of this manual. The interested reader is strongly encouraged to use the references in the chapter for a more rigorous and complete presentation of the theory.

4.1 Theoretical Basis

Most one-dimensional models treat channel width as a constant value that does not change with changing flow and sediment conditions. These models use the water depth, D, the flow velocity, V, and channel slope, S, as independent variables. The three independent equations that must be satisfied are the conservation of water,

$$Q = BDV \tag{87}$$

where Q = water discharge and B = channel width; a flow resistance equation (Chézy's equation is used for convenience),

$$V = C\left[\frac{BD}{P}S\right]^{1/2} \tag{88}$$

where C = roughness coefficient and P = wetted perimeter; and a sediment transport equation,

$$Q_s = f(D, B, V, S, d, \ldots) \tag{89}$$

where Q_s = sediment transport capacity and d = sediment particle size. However, a fourth independent relationship must be used if the channel width is to be considered as another independent variable. In GSTARS 2.1, the *theory of total stream power minimization* is used as a starting point to obtain the additional independent equation.

The basic theory behind the determination of width and depth adjustments is based on the minimum energy dissipation rate theory developed by Song and Yang (1979a; 1979b; 1982a; 1982b) and Yang and Song (1979; 1986) and this general theory's special case, the minimum stream power theory, used by Chang and Hill (1976; 1977; 1982) and Chang (1979; 1980a; 1980b; 1982a; 1982b; 1983). The minimum energy dissipation rate theory (Yang and Song, 1986) states that when a closed and dissipative system reaches its state of dynamic equilibrium, its energy dissipation rate must be at its minimum value:

$$\Phi = \Phi_W + \Phi_S = \text{a minimum} \tag{90}$$

where Φ, Φ_W, and Φ_S are the total rate of energy dissipation, the rate of energy dissipation due to water movement, and the rate of energy dissipation due to sediment movement, respectively. The minimum value must be consistent with the constraints applied to the system. If the system is not at its dynamic equilibrium condition, its energy dissipation rate is not at its minimum value, but the system will adjust itself in a manner that will reduce its energy dissipation rate to a minimum value and regain equilibrium. Because of changing flow and sediment conditions, a natural river is seldom in its true equilibrium condition. However, a natural river will adjust its channel geometry, slope, pattern, roughness, etc., to minimize its energy dissipation rate subject to the water discharge and sediment load supplied from upstream.

For an alluvial channel or river where the energy dissipation rate for transporting water is much higher than that required to transport sediment, i.e., $\Phi_W \gg \Phi_S$, the theory of minimum energy dissipation rate can be replaced by a simplified theory of minimum stream power (Yang, 1992). For this case, a river will minimize its stream power, γQS, per unit channel length subject to hydrologic, hydraulic, sediment, geometric, geologic, and man-made constraints. In the previous equation, γ is the specific weight of water.

4.2 Computational Procedures

In order to apply the minimization procedure to channel reaches with gradually varied flows, γQS is integrated along the channel:

$$\Phi_T = \int \gamma QS\,dx \tag{91}$$

where Φ_T is defined as the total stream power. This expression is discretized following Chang (1982a):

$$\Phi_T = \sum_{i=1}^{N} \frac{1}{2}\gamma(Q_i S_i + Q_{i+1} S_{i+1})\Delta x_i \tag{92}$$

where N = number of stations along the reach; Δx_i = reach length, or distance between stations i and $i+1$; and Q_i, S_i = discharge and slope at station i, respectively. Choosing the direction for channel adjustments is made by minimizing the integral represented by eq. (92) for total stream power at different stations. This process is repeated for each time step: if alteration of the channel widths results in lower total stream power than raising or lowering of the channel's bed, then channel adjustments progress in the lateral direction; otherwise, the adjustments are made in the vertical direction.

Figure 4.1 is used to illustrate the process described above. When erosion takes place, channel adjustments can proceed either by deepening or by widening the cross section. Both channel widening and deepening can reduce the total stream power for the reach, but GSTARS 2.1 selects the adjustment that results in the minimum total stream power for the reach. If deposition is predicted by the sediment routing computations, then either the bed is raised or the cross section is narrowed, but the choice must also result in a minimum of the total stream power for the reach. However, in each case the amount of scour and/or deposition is limited by the predicted sediment load, and geological or man-made restrictions are also accommodated by the computational algorithms.

Quantitatively, the amount of channel adjustment during each time step is determined by the sediment continuity equation, i.e., eq. (31) for each stream tube. Channel widening or narrowing can take place only at the stream tubes adjacent to the banks. In this case, the hydraulic radius, R, replaces the wetted perimeter, P, in eq. (31). For stream tubes that are not adjacent to the banks, i.e., interior tubes, bed adjustments can be made only in the vertical direction. The process is briefly schematized in figure 4.2.

In summary, GSTARS 2.1 channel geometry adjustments can occur in the vertical or lateral directions, or in a combination of both. Whether the adjustment will proceed in the vertical or lateral direction at a given time step of computation depends on which direction results in less total stream power in accordance with the theory of minimum total stream power. The requirement of reducing the total stream power during the channel development process constitutes the basis for determining width or depth adjustments in GSTARS 2.1.

Figure 4.1 Total stream power variation as a function of changes in channel width and bed elevation, with constant discharge and downstream stage.

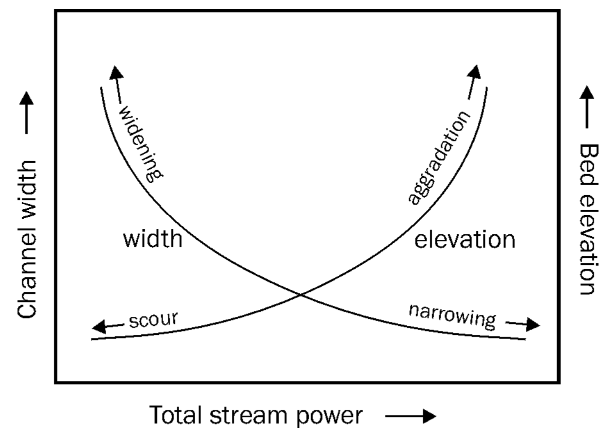
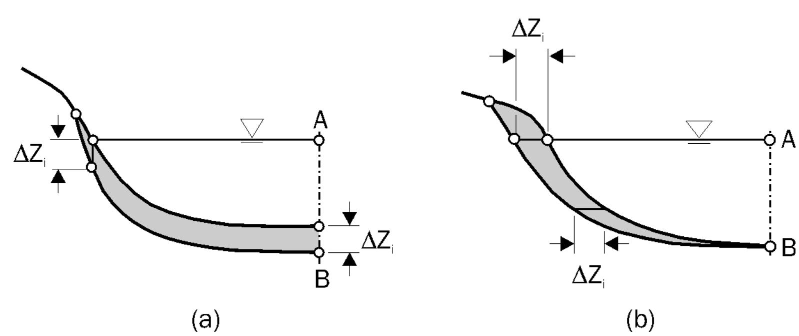


Figure 4.2 Schematic representation of channel changes on exterior stream tubes: (a) bed elevation change due to scour or deposition; (b) width change due to scour or deposition. Line AB denotes the stream tube boundary.



4.3 Channel Side Slope Adjustments

GSTARS 2.1 channel geometry adjustment can take place in both lateral and vertical directions. For an interior stream tube, scour or deposition can take place only on the bed, and the computation of depth change shown in eq. (39) is straightforward. For an exterior stream tube, however, the change can take place on the bed or at the bank.

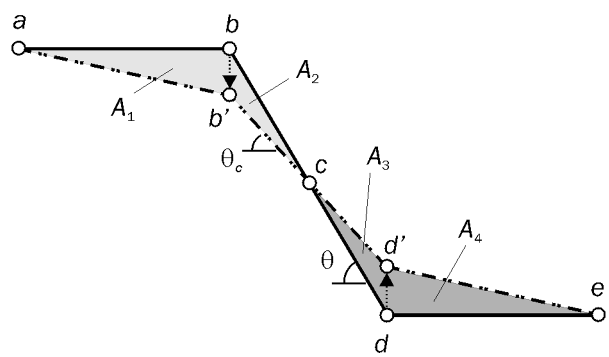
As erosion progresses, the steepness of the bank slope tends to increase. The maximum allowable bank slope depends on the stability of bank materials. When erosion undermines the lower portion of the bank and the slope increases past a critical value, the bank may collapse to a stable slope. The bank slope should not be allowed to increase beyond a certain critical value. The critical angle may vary from case to case, depending on the type of soil and the existence of natural or artificial protection.

GSTARS 2.1 offers the user the option of checking the angle of repose for violation of a known critical slope. If this option is chosen, the user must then supply the critical angle. The user is also allowed the option of specifying one critical angle above the water surface, and a different critical angle for submerged points. GSTARS 2.1 scans each cross section at the end of each time step to determine if any vertical or horizontal adjustments have caused the banks to become too steep. If any violations occur, the two points adjacent to the segment are adjusted vertically until the slope equals the user-provided critical slope. For the situation shown in figure 4.3, the bank is adjusted from *abde* to *ab'd'e*, so that the calculated angle, θ, is reduced to become equal to the critical angle, θ_c. The adjustments are governed by conservation of mass:

$$A_1 + A_2 = A_3 + A_4 \tag{93}$$

where A_1 = area of triangle *abb'a*; A_2 = area of triangle *bcb'b*; A_3 = area of triangle *cd'dc*; and A_4= area of triangle *d'edd'*.

Figure 4.3 Example of angle of repose adjustment.



CHAPTER

5

DATA REQUIREMENTS

Application of the GSTARS 2.1 computer model requires the use of appropriate data. From a conceptual point of view, GSTARS 2.1 provides the governing equations and their solution, and the user's data provides geometric and hydrologic boundary information. Together, data *and* computer program are what is called a *model*, in the sense that they represent an approximation to a concrete and very specific physical reality. The degree of approximation depends both on the physical and numerical representation implemented in the computer program, and on the accuracy and completeness of the data.

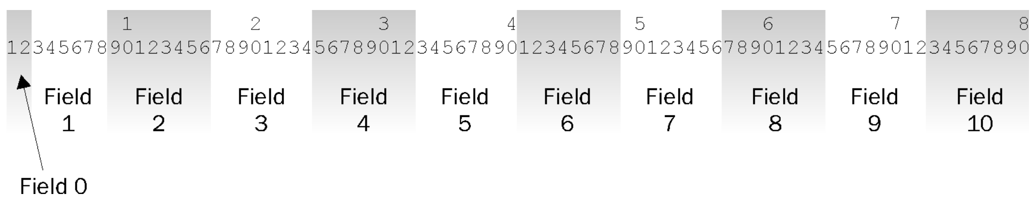
The data requirements of GSTARS 2.1 are described in this chapter. The data has to be processed into ASCII data files that the computer program can understand. There are two ways to do this: by using a plain ASCII text editor to type in the data in a specific format (as it was done for GSTARS 2.0), or by using a graphical user interface (GUI) that works interactively with the user. The GUI streamlines the input process, making it easier and safer than using the old text editor approach. However, both methods achieve the same objectives, i.e., they prepare ASCII input files that GSTARS 2.1 can use.

The GUI is presented with detail in the next chapter. In this chapter we describe the data necessary to run GSTARS 2.1. It is shown how to set-up that data in an ASCII file that can be used to run GSTARS 2.1 from a DOS command line window. The reader should go over this chapter carefully before using the GSTARS 2.1 computer program.

5.1 Input Data Format

In GSTARS 2.1, the data is organized in the same way as it was in GSTARS 2.0. Data is tabulated in ASCII files. The file is organized in sequential records. A record is a line of up to 80 characters in length that is divided into fields of fixed width (see figure 5.1). Fields are numbered from left to right, starting in the left-most character. Field 0 is 2 characters long and is used to specify the record name (all record names are 2 characters long). Fields 1 to 10 are used to input data to GSTARS 2.1. Field 1 is 6 characters long; fields 2 to 10 are 8 characters long.

Figure 5.1 Organization of a data record into different fields.



Each record name is unique and is used to input specific data to the program. A comprehensive list of all the records used by GSTARS 2.1 is given in appendix A. Not all records are used (for example, some are mutually exclusive) but they have to be in an appropriate sequence. That sequence is presented in appendix A. The example input files included in the distribution of GSTARS 2.1 should also be studied for that effect. The data requirements presented in this chapter follow the order that should be used when preparing data input for GSTARS 2.1.

5.2 Hydraulic Data

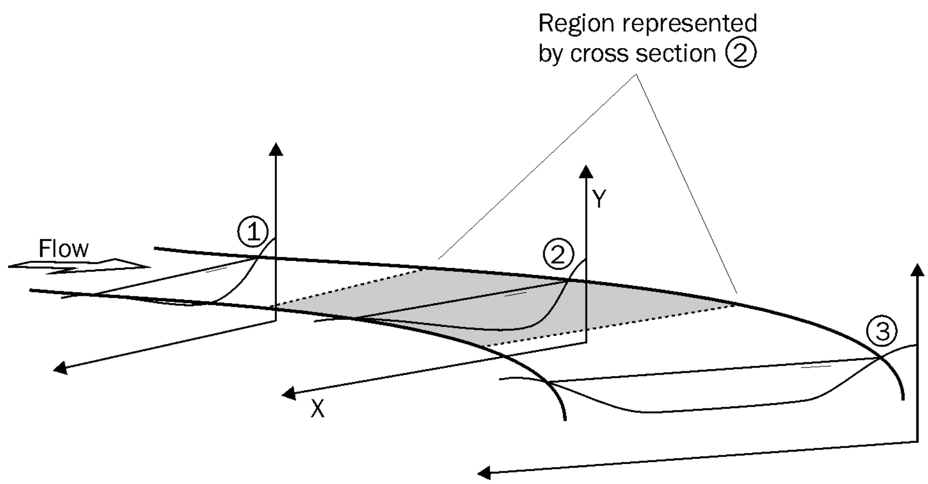
As described in the preceding chapters, GSTARS 2.1 decouples the hydraulics from the sediment routing computations. As a result, the program can be considered as composed by two modules: the first module performs the backwater computations, the second module performs the sediment routing. This modularity is reflected in the way the input data file is designed. The GSTARS 2.1 input file can be divided in four parts: the hydraulics data, the sediment data, the printout control, and the stream power minimization data. The hydraulic and printout parts are always required. The other two parts are optional. The stream power minimization data can only be present if the sediment data is included.

In this section, the hydraulics data requirements are presented. Channel geometry data requirements are presented first, which include cross section geometry, channel roughness, and loss coefficients. Hydrologic data, i.e., water discharges and stages, are presented next.

5.2.1 Channel Geometry, Roughness, and Loss Coefficient Data

The first step to model a river system using GSTARS 2.1 involves the approximation of the channel's bed and banks in a semi-two-dimensional manner. The river reach to be modeled must be described by a finite number of discretized cross sections. Cross section geometry is described by X-Y coordinate pairs, i.e., by coordinate pairs with lateral location and bed elevation. Bed elevations (Y) must be taken using a common datum for the entire reach and must always be positive. Lateral locations (X) must be given using a reference point for each cross section, and the coordinate pairs must be entered in order of increasing X coordinate, i.e., starting from the left-hand side of the cross section and marching towards the right-hand side (looking downstream), as pictured in figure 5.2.

Figure 5.2 Schematic representation of the discretization of a reach by three cross sections.

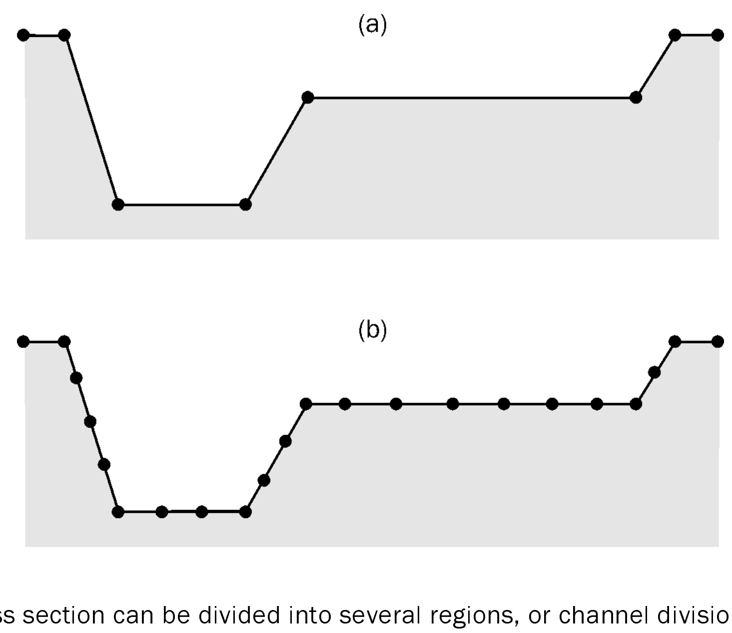


Each cross section, or station, is identified by a value that represents a distance from a reference point located downstream. The distance between stations, which must be a horizontal distance measured along a streamline, is computed by GSTARS 2.1 as the difference between cross section identification numbers. Stations are entered sequentially, starting from the upstream-most cross section and proceeding downstream.

The number and positions of the cross sections are arbitrary. However, it is recommended that they be chosen to best represent the geometry of the study channel reach. Accurate data of channel cross section is essential to ensure the that the model works properly. In GSTARS 2.1, each cross section represents a portion of the channel upstream and downstream from its actual location, as shown in figure 5.2. Therefore, the location of each cross section should be chosen to best reflect that approximation. More cross sections are required where there are significant changes in channel geometry and/or hydraulic characteristics. A larger number of cross sections will approximate the channel reach geometry with more accuracy than a smaller number will. Ideally, the user should use as many cross sections as practicable. In the case where too few measured cross sections are available, they may have to be interpolated, especially at abrupt transitions. Some guidelines to choose the cross section locations were given in section 2.3.1.

As mentioned previously, each cross section is discretized by a set of points defined by the bed elevation and cross-section location. The cross sections should be perpendicular to the direction of the flow and extend all the way from margin to margin of the river, that is, they should extend completely across the channel between high ground of both banks. Although two points are enough to define a region of the cross section with constant side slope, the algorithms implemented in GSTARS 2.1 will work better if more points are given. This is illustrated in figure 5.3, in which a section discretized by a minimal set of points is shown together with a "better" discretization of the same cross-sectional geometry. The higher density of points in discretization (b) allows for the points to be closer to stream tube boundaries. In the course of calculations of the positions of stream tube boundaries, a high density of points will ensure that the boundaries remain near discretization points. This allows GSTARS 2.1 to handle the morphological changes better when variations of deposition and/or scour along the wetted perimeter are expected. However, it is much less important for the case of a single stream tube. Users should experiment with adding points to the discretized cross sections until the results become independent of the discretization. Note that too many points also add a significant computational overhead and may stretch the run times considerably.

Figure 5.3 Example of a cross section. (a) minimum shape-preserving discretization for the cross section; (b) same cross section discretized with additional points.



Each cross section can be divided into several regions, or channel divisions, of constant roughness. For example, a compound channel with two flood plains might have three divisions, corresponding to the left flood plain, the main channel, and the right flood plain. Each one of these channel divisions would have its own value of the roughness coefficient. In GSTARS 2.1, up to nine channel divisions may be defined, therefore up to nine different roughness coefficient values may be entered for each cross section. Manning, Chézy, or Darcy-Weisbach equations can be selected, with corresponding roughness coefficients are entered from left to right across the section. The total conveyance for each cross section, K_T, is computed as the sum of the conveyance for each subsection of constant roughness. For example, using the Manning's roughness n we have

$$K_T = \sum_{j=1}^{N} \frac{1.49 A_j R_j^{2/3}}{n_j} = \sum_{j=1}^{N} K_j \tag{94}$$

where the subscript j refers to each individual subsection of the wetted perimeter with a given Manning's n_j, and N is the number of those segments (to a maximum of 9).

The organization of a cross section in data records is shown in figure 5.4. Each cross section is defined by a set of four records: ST, ND, XS (more than one XS record may be used), and RH. Records ST, ND, XS, and RH should be provided in that order for each measured cross section along the study reach. A detailed description of each of these records is given in appendix A.

Figure 5.4 Organization of cross section data in records.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

ST133100      39       0       0       0       0     0.0
ND     3   199.0   319.0  1209.0
XS4468.0   111.0  4465.5   128.0  4463.7   164.0  4462.8   183.0  4464.1   199.0
XS4464.0   205.0  4454.8   220.0  4452.1   227.0  4450.4   240.0  4451.0   260.0
XS4450.8   276.0  4450.2   285.0  4461.8   302.0  4463.0   310.0  4463.5   319.0
XS4463.7   374.0  4463.5   451.0  4463.4   516.0  4463.4   587.0  4463.4   654.0
XS4463.2   710.0  4461.9   752.0  4461.6   808.0  4461.7   860.0  4461.7   901.0
XS4460.5   929.0  4462.2   970.0  4463.0  1013.0  4461.5  1031.0  4461.2  1072.0
XS4460.0  1116.0  4462.1  1138.0  4461.5  1147.0  4458.7  1170.0  4462.0  1184.0
XS4461.5  1189.0  4463.9  1197.0  4467.8  1206.0  4467.9  1209.0
RH 0.080   0.024   0.080
```

Record ST contains specific information about the corresponding cross section. It contains the location and number of points needed to define each cross section. The ST record is also used to specify whether the cross section is a control section and may contain factors which are used to adjust both the elevation and offset of each section, where necessary. The last field on the ST record contains the local energy loss coefficient. The local energy loss coefficients account for the hydraulic impacts of bends, natural and man-made structures, etc., at or upstream from the cross section. The default value for the local energy loss is zero. Internally, GSTARS 2.1 sets an additional coefficient of loss to 0.1 for contractions and to 0.3 for expansions.

Record ND is used to define the number of channel divisions at a given cross section and their corresponding lateral locations. Record XS is used to enter the channel geometry of a given station using X-Y (or Y-X) coordinate pairs. The RH record defines the roughness coefficient of each channel division identified on the preceding ND record of the cross section.

GSTARS 2.1 can use the Manning, Darcy-Weisbach, or Chézy equations for energy slope and conveyance computations. The desired equation must be selected using one RE record, which must be present after the channel geometry data. If the RE record is not included in the data set, the program will default to Manning's equation. The RE record is also used to specify the equation employed to compute the local friction slope.

5.2.2 Discharge and Stage Data

The hydraulic data necessary for a numerical simulation are water stages and corresponding surface elevation at certain points (boundary conditions). In GSTARS 2.1, the inflow discharge hydrograph entering the study reach, i.e., at the station farthest upstream, must be given for the period of the analysis. As with any steady state model, the hydrograph must be approximated by bursts of constant discharge and finite duration. The water stage hydrograph must be given for the station farthest downstream.

In GSTARS 2.1, discharge hydrographs are given in tables with the discretized values in multiples of a fixed time increment, i.e., of the time step. Corresponding water surface elevations are given either in tabular format or as stage-discharge rating curves. The type of input for the water discharges is chosen by defining the value of *IOPTQ* in record QQ, and the type of input for the corresponding stages is chosen by defining the value of *IOPTSTQ* in record SS. The possible options are summarized in table 5.1. The data is then entered using records IT, QQ, SS, DD, SQ, TL, TQ, RC, and NC. Depending on the option chosen, some of these records may be omitted. Detailed descriptions of these records are given in appendix A.

Table 5.1 Records required for each combination of QQ and SS record selections. The numbers in parentheses correspond to the sections where each case is described.

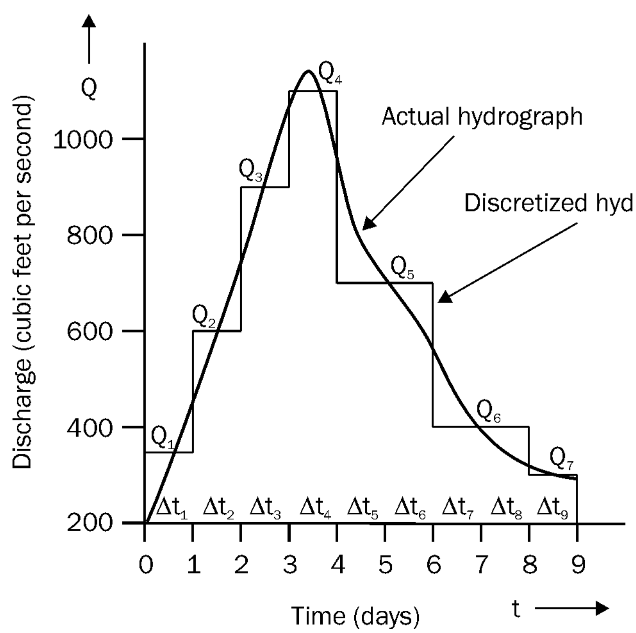
REQUIRED RECORDS	**QQ**	
SS	TABLE OF DISCHARGES	DISCRETIZED DISCHARGES
RATING CURVE	NC, RC, TQ (Sec. 5.2.2.2)	NC, RC, DD (Sec. 5.2.2.1)
STAGE DISCHARGE TABLE	TL, SQ (Sec. 5.2.2.3)	

5.2.2.1 Discharge Hydrograph with a Stage-Discharge Rating Curve

In this case, the water discharges for the reach are given in the form of a hydrograph, and the corresponding water stages are given as a rating curve, i.e., as a function of the discharge. This option is selected by using the RATING CURVE option in record SS and the DISCRETIZED DISCHARGES option in record QQ. The discretized hydrograph is entered using DD records, and the water stage is defined by a rating curve using records NC and RC.

The discretization of the hydrograph is a process that transforms a continuous curve into discrete numerical values with a certain discharge and time duration. The continuous curve is then replaced by a stair-stepping curve with constant discharge bursts with a duration that, in GSTARS 2.1, must be a whole multiple of the time step, Δt. The process is briefly illustrated in figure 5.5. First, a time interval must be chosen for the time step, Δt. It must be small enough so that all the important features of the hydrograph may be preserved without significant distortion. Using Δt, the hydrograph is broken into intervals of constant discharge. The duration of each of these intervals is expressed as whole multiples of Δt.

Figure 5.5 Discretization of input discharge hydrograph. Note that $\Delta t_1 = \Delta t_2 = \ldots = \Delta t_9 = \Delta t = 1$ day in this example.



As an example of this procedure, a hypothetical hydrograph is given as a continuous, smooth line in figure 5.5. A time step Δt = 1 day is chosen to discretize the hydrograph. The hydrograph is then replaced by the stair-stepping curve representing the following discharge bursts: one time step of Q_1, one time step of Q_2, one time step of Q_3, one time step of Q_4, two time steps of Q_5, two time steps of Q_6, and one time step of Q_7 discharges. A total of 7 discharges are used, but 9 time steps must be carried out by the simulation. These values will be entered in DD records, as shown below. Note that a smaller time step could have been used. This would have resulted in a more accurate representation of the hydrograph, but more time steps would have to be computed by the program, resulting in longer computational times.

Usually, the discretization process involves a compromise between accuracy and computational burden, depending also on the availability of data and on the user's experience. Nevertheless, the discretized hydrograph is required to preserve total water and sediment volumes. Furthermore, it is also necessary to preserve the shape and peak discharge of the event. A compromise must be reached to obtain the optimum duration of the bursts (time step Δt) without requiring an unnecessarily large number of time steps. It is recommended that the duration of the time step should be at least long enough to allow the flow to travel across the largest interval between any two adjacent cross sections. However, in most cases, simulations suffer from using time steps that are too large, i.e., the solutions may be unstable and/ or inaccurate.

In this option, the water stage at selected locations must be given as a rating curve, i.e., as a functional expression of the discharge. In GSTARS 2.1, the relationship between stage and discharge is assumed to be in the form

$$\text{Stage (ft)} = C_1 \times Q^{C_2} + C_3 \tag{95}$$

where Q is given in ft^3/s. The values of the constants C_1, C_2, and C_3 are coefficients supplied by the user on the RC record. For example, in the case above a stage-discharge rating curve could be defined at station 23 of the reach. If this relationship is defined as

$$\text{Stage} = 0.41 Q^{0.25} + 1000 \tag{96}$$

then the input data records would be as follows:

```
          1         2         3         4
123456789012345678901234567890123456789012345

IT    9.       1.       1.
QQ       DISCRETIZED DISCHARGES
SS       RATING CURVE
DD     1     350.
DD     1     600.
DD     1     900.
DD     1    1100.
DD     2     700.
DD     2     400.
DD     1     300.
NC     1
RC    23     0.41    0.25    1000.
```

Note that the sum of all the time steps defined in the first column of the DD records (*NDAYS* in field 1 of DD records) must be equal to the total number of time steps for the run (*ITIMAX* in field 1 of the IT record), which, in this case, is 9 time steps for 9 days.

5.2.2.2 Table of Discharges with a Rating Curve at The Control Section

This type of input is a particular form of the input described above. It may be useful when discharges are known from periodic records, at fixed time intervals, in the form of a table. This option is selected by using the RATING CURVE option in record SS and the TABLE OF DISCHARGES option in record QQ. The table is entered using TQ records, and the water stage is defined by a rating curve using records NC and RC.

As an example, consider the following table of daily discharges which could have been obtained from a gaging station at the upstream end of the study reach:

Days	Discharge (ft^3/s)
0	200
1	450
2	700
3	1,020
4	1,000
5	700
6	525
7	400
8	325

With the same stage-discharge rating curve in the example of the previous section, the input data records would be:

```
        1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123

IT    9.       1.       1.
QQ      TABLE OF DISCHARGES
SS      RATING CURVE
TQ  200.     450.     700.    1020.    1000.     700.     525.     400.     325.
NC     1
RC    23     0.41    0.25     1000.
```

Additional TQ records may be supplied for longer simulations.

5.2.2.3 Stage-Discharge Table at a Control Section

In this case, the information for the control station is given in a table with discharges and corresponding water stages. This option is selected by using the STAGE

DISCHARGE TABLE option in record SS and the TABLE OF DISCHARGES option in record QQ. The table is entered using TL and SQ records.

As an example, consider the information given in the table below, which could have been obtained from a gaging station at the control section located at section 35:

Days	Discharge (ft^3/s)	Stage
0	200	1002.6
1	450	1003.1
2	700	1003.3
3	1,020	1003.6
4	1,000	1003.6
5	700	1003.3
6	525	1003.2
7	400	1003.0
8	325	1002.9

For daily time steps, the input data records for this example would be:

```
         1         2         3         4
123456789012345678901234567890123456789012345

IT     9.        1.        1.
QQ        TABLE OF DISCHARGES
SS        STAGE DISCHARGE TABLE
TL     35
SQ   200.   1002.6
SQ   450.   1003.1
SQ   700.   1003.3
SQ  1020.   1003.6
SQ  1000.   1003.6
SQ   700.   1003.3
SQ   525.   1003.2
SQ   400.   1003.0
SQ   325.   1002.9
```

5.3 Sediment Data

The information presented in the last section is enough to have GSTARS 2.1 performing backwater computations in a channel with fixed bed. If, however, sediment routing is required, sediment data must be given to the model. Sediment data includes bed material size distributions for the reach of study and the sediment inflow hydrograph entering the reach, including its particle size distribution. The input data requirements (and corresponding records) for sediment routing computations are presented in this section.

The sediment transport computations are activated by inclusion of the SE record in the input data file. The SE record is used to select the equation for computing sediment transport capacities. In GSTARS 2.1, sediment transport capacities can be determined by any of the following methods (see also table 3.1):

- DuBuois (1879)
- Meyer-Peter and Müller (1948)
- Laursen (1958)
- Toffaleti (1969)
- Engelund and Hansen (1972)
- Ackers and White (1973) or (1990)
- Yang (1973) + Yang (1984)
- Yang (1979) + Yang (1984)
- Parker (1990)
- Yang et al. (1996)
- Krone (1962) and Ariathurai and Krone (1976)

Desired sediment transport equations can be selected by the variable *ISED* in the SE record. These methods were chosen because of their accuracy and associated short computational times. Many of the sediment transport equations available for routing computations are applicable only to sand sizes (0.0625 to 2.0 mm). The Yang gravel equation is recommended for sediments up to 10 mm gravel, although successful applications to coarser materials can be found in the literature. The Meyer-Peter and Müller or Parker methods are often used by engineers for materials coarser than 10 mm. The methods by Krone (1962) and Ariathurai and Krone (1976) are used to compute cohesive sediment (clay and silt) transport. When clay and/or silt size fractions are present, GSTARS 2.1 automatically activates the cohesive sediment transport methods for those fractions, while still using one of the above methods for size fractions larger than 62.5 μm.

The selection of the appropriate sediment transport function remains an unsolved problem. Differences in the assumptions used to derive the equations, study of published data, and practical reasoning and experience are factors that can help in this process. There are tremendous uncertainties involved in estimating sediment discharge under different flow and sediment conditions and under different hydrologic, geologic, and climatic constraints. It is very difficult to recommend a particular equation or method to be used under all circumstances. The following guidelines are based on those given by Yang (1996) and were adapted for inclusion in the present manual:

1. Use as much field and measured data as possible, within the time, budget, and manpower limits of each particular study.
2. Examine as many formulas as possible, based on assumptions used in their derivation and range of data used to determine its coefficients, and select those consistent with the data and measurements obtained in step 1.
3. If more than one formula survived step 2, compute sediment transport rates with these formulas and select those that best agree with any field measurements taken in step 1.
4. In the absence of measured sediment loads for comparison, the following guidelines could be considered:

- Use Meyer-Peter and Müller's formula when the bed material is coarser than 5 mm.
- Use Toffaleti's formula for large sand-bed rivers.
- Use Yang's (1973) formula for sand transport in laboratory flumes and natural rivers; use Yang's (1979) formula for sand transport when the critical unit stream power at incipient motion can be neglected.
- Use Parker's (1990) or Yang's (1984) gravel formulas for bed load or gravel transport;
- Use Yang's (1996) modified formula for high-concentration flows when the wash load or concentration of fine material is high.
- Use Ackers and White's or Engelund and Hansen's formulas for subcritical flow condition in the lower flow regime.
- Use Laursen's formula for laboratory flumes and shallow rivers with fine sand or coarse silt.

5.3.1 Sediment Inflow Data

The inflow sediment hydrograph must be given for the section farthest upstream from the study reach. In GSTARS 2.1, this can be given in the form of either discretized sediment discharges on QS records or a sediment rating curve using record QR. In the first case, the sediment rating curve has to be discretized following a procedure similar to that described in section 5.2.2.1 for the discharge hydrograph. The data is entered using QS records, which follow the same format as the DD records described above.

Alternatively, a sediment rating curve, if known, may be given using a QR record. This record allows the user to specify a sediment discharge that is a function of the water discharge in the form

$$Q_s = aQ^b \tag{97}$$

where Q_s = incoming sediment discharge (in ton/day); Q = water discharge (ft^3/s); and a and b are coefficients to be supplied in the QR record (a, $b > 0$). For example, if it is known that the incoming sediment discharge is a function of the water discharge such that

$$Q_s = 0.4Q^{1.2} \tag{98}$$

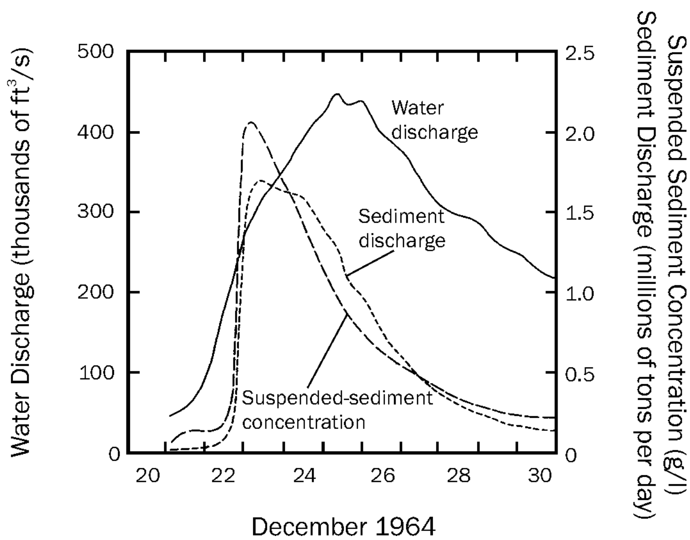
the input QR record would take the following format:

```
         1         2         3         4
12345678901234567890123456789012345678901234 5
-------------------------------------------------

QR    0.4       1.2
```

Caution should be exercised when using a relationship similar to eq. (97). In most practical cases, eq. (97) represents only an approximation, and often a very poor one. Figure 5.6 shows an example of water and sediment discharge curves measured at the same location and at the same time. In this example, the peak of the water discharge rating curve lags the peak of the sediment discharge rating curve by over two days. During that time, the trends of the two hydrographs are opposite (increasing water discharge and decreasing sediment load). Sometimes, it is the sediment rating curve that lags the water discharge rating curve. This well known phenomenon is explained in many textbooks on the subject. However, GSTARS 2.1 provides the facility to use eq. (97) for those cases in which its use may be warranted.

Figure 5.6 Suspended sediment concentration, sediment discharge, and water discharge, Willamette River at Portland, Oregon, December 21-30, 1964. (After Waananen et al., 1971.)



By default, the size gradation distribution of the incoming sediment is set equal to the gradation given for the cross section farthest upstream (the input of sediment gradation curves is discussed in section 5.3.3). However, the user may specify different gradation distributions using IQ and IS records. The gradations must be known as a function of the water discharge, and their input must be given in tabular format. For example, consider the following hypothetical size gradation curves, each one defined for a given discharge:

Size fraction no.	Q = 1,000 ft^3/s	Q = 5,000 ft^3/s	Q = 12,000 ft^3/s
1 (fine sand)	50%	60%	60%
2 (medium sand)	50	30	25
3 (coarse sand)	0	10	15

Using IQ and IS records, that information would be specified in the following way:

```
          1         2         3         4
123456789012345678901234567890123456789012345

IQ     3    1000     5000    12000
IS fsand    0.50     0.60     0.60
IS msand    0.50     0.30     0.25
IS csand    0.00     0.10     0.15
```

GSTARS 2.1 interpolates the gradations for water discharges falling in between the specified discharges, but does not extrapolate for water discharges outside that range (e.g., if the discharge is 13,000 ft^3/s, the distribution specified for Q = 12,000 ft^3/s is used).

GSTARS 2.1 solves the sediment continuity equation, eq. (24), to route sediments through a channel reach. Eq. (24) is discretized following the methods presented in section 3.3, and computations proceed from upstream to downstream. The incoming sediment discharge is specified at the first cross section of the reach (the section located at the upstream end of the reach), therefore a special treatment is necessary there. The reach length for that section is taken to be half the distance between station 1 and station 2, that is, $\Delta x_{i-1} = 0$ in eq. (31). The incoming sediment is used to represent $Q_{s,i\text{-}1}$, and the solution is the obtained in the usual way. Note that the bed composition of station 1 will, in general, change with time, therefore the distribution of the incoming sediment should be specified by the use of IQ/IS sets of records. If the distribution of the incoming sediment is not specified, it is assumed that the distribution of the incoming sediment is identical to that of the bed at station 1.

Note that the last cross section also requires special treatment. For that boundary, GSTARS 2.1 extrapolates all the hydraulic and sediment transport quantities necessary to compute the appropriate rates of scour and deposition. The extrapolation uses upstream information only. Ideally, the first and last cross sections should be located at places where the channel changes are mild or nonexistent. These terminal sections should not be the sections of primary interest to the particular study.

5.3.2 Temperature Data

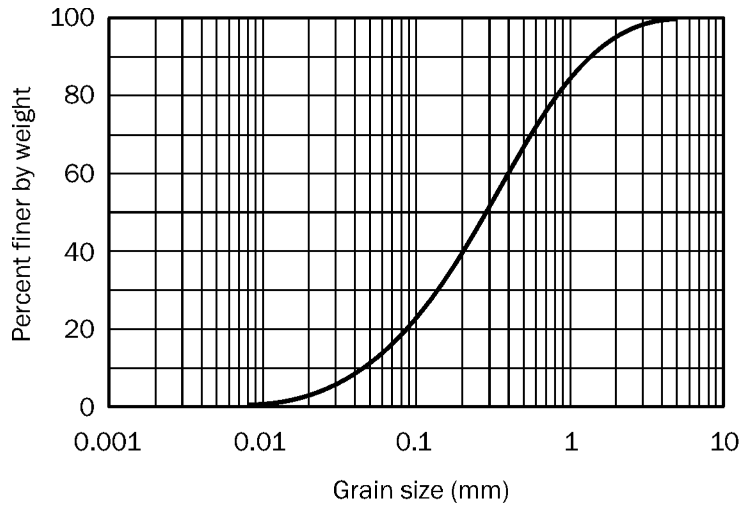
Water temperature data, necessary for kinematic viscosity computations, is given in tabulated form using TM records. The water temperature of the reach must be given for each time step of the run.

5.3.3 Sediment Gradation Data

Sediment mixtures are characterized by gradation curves. A common way of depicting bed gradation distributions is by a graph that shows, for each grain size, the percentage of bed sediments with a smaller size, such as picture in figure 5.7. In

GSTARS 2.1, that information must be given for the bed composition of all the cross sections, and for the grain size distribution of the incoming sediment discharges.

Figure 5.7 Hypothetical size gradation curve.



First, the size classes must be defined by using SF and SG records. The SF record defines the number of size fractions (a maximum of 10 size fractions may be defined), and the SG record identifies the different sediment size groups. Each size class is defined by entering the lower and upper bound of that class in a SG record. For example, for the hypothetical size gradation curve shown in figure 5.7, the following set of SF/SG records could be used:

```
         1         2         3         4
123456789012345678901234567890123456789012345

SF      5
SG 0.008    0.04
SG  0.04     0.2
SG   0.2     0.6
SG   0.6     2.0
SG   2.0     5.0
```

Note that the divisions defined in the SG records (specified in mm) are quite arbitrary. Note also that the SF and SG records can be used to specify different values for the dry specific weight, γ_m:

$$\gamma_m = \gamma G(1 - p_0) \tag{99}$$

where γ = specific weight of water at 4 °C; G = specific gravity (G = 2.65 in GSTARS 2.1); and p_0 = porosity of the sediment. GSTARS 2.1 uses the default value of $\gamma_m = 99.2$ lb/ft^3, for a porosity of 40 percent, but that can be changed in records SF and/or SG. For example, to change the default value of γ_m to 90.0 lb/ft^3, the following records might be used:

```
         1         2         3         4
123456789012345678901234567890123456789012345

SF     5     90.0
SG 0.008     0.04
SG  0.04      0.2
SG   0.2      0.6
SG   0.6      2.0
SG   2.0      5.0
```

The SG records can also be used to selectively change γ_m for specific size fractions. For example, the following set of records would change γ_m for the specified size classes to 41.0, 50.0, and 74.0 lb/ft^3, leaving the remaining size classes to use the values defined in record SF:

```
         1         2         3         4
123456789012345678901234567890123456789012345

SF     5     90.0
SG 0.008     0.04      41.0
SG  0.04      0.2      50.0
SG   0.2      0.6      74.0
SG   0.6      2.0
SG   2.0      5.0
```

When different dry specific weights are used for different size fractions, GSTARS 2.1 uses eq. (99) to compute the porosity of the bed sediments. First, a composite dry specific weight for the bed, γ_m^*, is computed following Colby (1963):

$$\gamma_m^* = \frac{1}{\sum_{i=1}^{N} \frac{p_i}{\gamma_{mi}}} \tag{100}$$

where p_i = the percentage of sediments of size fraction i present in the bed ($0 \le p_i \le 1$); γ_{mi} = dry specific weight of sediments of size fraction i; and N = total number of size fractions. The porosity of the bed is then found using γ_m^* and eq. (99).

Gradation information is specified by converting the bed gradation curves into histograms containing the percentage of sediments in each interval. The process is schematized in figure 5.8. The data can be specified using either SD records, or sets of NB and BG records. These records are used to enter the bed material size fractions that fall within each of the size groups defined by SG records. Using the hypothetical gradation curve of figure 5.7, the SD records would take the form

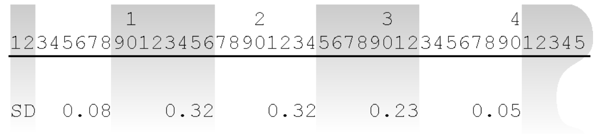
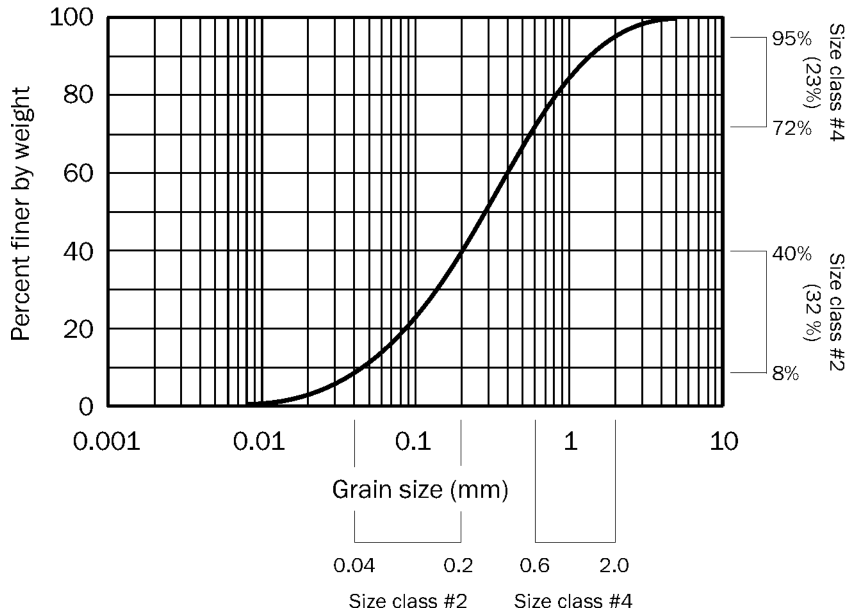


Figure 5.8 Schematic representation on how to extract data from gradation curves for GSTARS 2.1 input. Shown are the second and fourth size classes from a split into five size classes (see text). The gradation curve is the same of figure 5.7.



One SD record must be specified for each cross section. Alternatively, sets of NB and BG records can be used to specify size distributions at particular locations. These locations do not need to coincide with the defined cross-section locations. GSTARS 2.1 will interpolate bed gradations for the defined cross sections using the information from the NB and BG records. In this case, a minimum of one NB/BG set of records must be used. By using this option, one set of NB and BG records could be used to define a whole reach (see the record descriptions in appendix A for more details).

5.3.3.1 Remarks

The questions that remain are:

1 how to define the intervals for each size class; and

2 how many size classes are needed for each particular study.

Sediment particle size classes should be defined reflecting the well known fact that finer particles are more important in the sediment transport process than coarser particles. Therefore, it is reasonable to expect that more classes are necessary in the finer range, and fewer classes can be used in the coarser range of the distribution. This is, in effect, what is reflected in the scale used by the American Geophysical Union and presented in table 5.2.

Table 5.2 Sediment grading scale (Lane, 1947).

Size range in class (mm)		Class nomenclature
4,096–2,048	(2^{12}–2^{11})	Very large boulders
2,048–1,024	(2^{11}–2^{10})	Large boulders
1,024–512	(2^{10}–2^{9})	Medium boulders
512–256	(2^{9}–2^{8})	Small boulders
256–128	(2^{8}–2^{7})	Large cobbles
128–64	(2^{7}–2^{6})	Small cobbles
64–32	(2^{6}–2^{5})	Very coarse gravel
32–16	(2^{5}–2^{4})	Coarse gravel
16–8	(2^{4}–2^{3})	Medium gravel
8–4	(2^{3}–2^{2})	Fine gravel
4–2	(2^{2}–2^{1})	Very fine gravel
2–1	(2^{1}–2^{0})	Very coarse sand
1–0.5	(2^{0}–2^{-1})	Coarse sand
0.5–0.25	(2^{-1}–2^{-2})	Medium sand
0.25–0.125	(2^{-2}–2^{-3})	Fine sand
0.125–0.062	(2^{-3}–2^{-4})	Very fine sand
0.062–0.031	(2^{-4}–2^{-5})	Coarse silt
0.031–0.016	(2^{-5}–2^{-6})	Medium silt
0.016–0.008	(2^{-6}–2^{-7})	Fine silt
0.008–0.004	(2^{-7}–2^{-8})	Very fine silt
0.004–0.002	(2^{-8}–2^{-9})	Coarse clay
0.002–0.001	(2^{-9}–2^{-10})	Medium clay
0.001–0.0005	(2^{-10}–2^{-11})	Fine clay
0.0005–0.00025	(2^{-11}–2^{-12})	Very fine clay
< 0.00025	(< 2^{-12})	Colloids

Although the nomenclature and size class definitions in table 5.2 is quite arbitrary, its theoretical background is based on physical principles and approximations that are convenient follow. Therefore, a similar process can be devised for defining size classes for use in GSTARS 2.1. Of course that the classes defined in table 5.2 can be used in GSTARS 2.1, but it will become clear that there are advantages in not always doing it.

The recommended procedure consists in dividing the range of particle sizes such that they have the same magnitude in the logarithmic space. The process of creating the size classes can be summarized in the following steps:

1. determine the upper and lower bounds of the particle size ranges to be worked with. If d_{max} and d_{min} are the greatest and the smallest particle diameters encompassing the particle range, find the values of a and b such that

$$d_{min} = 2^a \text{ and } d_{max} = 2^b$$

2. let N be the desired number of size classes for a particular application ($N \leq 10$). Select the lower and upper bound diameters for each interval i in the following way:

$$d_{min,\,i} = 2^{a + (i-1)\frac{b-a}{N}}, \; i = 1, \ldots, N \tag{101}$$

and

$$d_{max,\,i} = 2^{a + i\frac{b-a}{N}}, \; i = 1, \ldots, N \tag{102}$$

As an example, consider the grain size distribution presented in figure 5.7. The range of particle sizes is

$$d_{min} = 0.008 \cong 2^{-6.8} \Rightarrow a = -6.8$$

and

$$d_{max} = 5.0 \cong 2^{2.3} \Rightarrow b = 2.3$$

For five size classes ($N = 5$) one gets:

i	$d_{min,i}$ (mm)	$d_{max,i}$ (mm)	$d_{mean,i}$ (mm)
1	0.008	0.031	0.016
2	0.031	0.112	0.059
3	0.112	0.395	0.210
4	0.395	1.39	0.742
5	1.39	5.0	2.64

where

$$d_{mean,\,i} = \sqrt{d_{min,\,i} \times d_{max,\,i}} \tag{103}$$

is the mean grain size of size class i.

The remaining issue is then to determine what value of N to choose. For that purpose we carried an analysis using two sediment grading curves and two sediment transport equations, trying to answer the following question: what is the lowest value of N that characterizes adequately the predicted sediment in transport? In other words, there must be a value of $N = N_0$ beyond which there is no gain in further refinement of the size classes, and we wish to find what that value is.

The criterion to find the optimal N_0 is based on the characteristics of the mixture of the sediment particles in transport. For the purposes in this manual, it is enough to characterize the gradation of the transported sediments by the d_{50} and the geometric standard deviation of the mixture (σ_g), and by the amount of sediment in transport. The geometric standard deviation of the mixture is defined as

$$\sigma_g = \sqrt{\frac{d_{84.1}}{d_{15.9}}} \tag{104}$$

The amount of the sediment in transport is the quantity of sediment predicted by one of the sediment transport equations presented in section 3.5.

The first analysis was carried out using the Yang (1973) unit stream power equation of section 3.5.7. A bed gradation was synthesized using a log-normal distribution:

$$f(d) = \frac{1}{\sigma_z d \sqrt{2\pi}} \exp\left\{-\frac{(\ln d - \mu_z)^2}{\sigma_z^2}\right\} \tag{105}$$

where μ_z and σ_z are the mean value and the standard deviation of $z = \ln d$ (d is the grain diameter), cut at the 1% probabilities at the extremes. In this analysis, the gradation used had $\mu_z = -1.04$ and $\sigma_z = 0.7$, falling in the sand range (62.5 μm to 2.0 mm). Sediment transport capacities were computed for various values of the unit stream power and using increasing number of particle size fractions. The ranges of each size fraction were determined using the procedure described above in this section.

The results are shown in figure 5.9. They show the different quantities normalized by the value obtained with $N = 1$, i.e., by using a single class encompassing the entire gamut of particle sizes. It can be seen that the predicted quantities stabilize at values of $N = 4$ or $N = 5$. Further refinement into more size classes is not followed by a corresponding change in the predicted quantities.

This simple study was repeated using a similarly synthesized bed distribution in the range of sand and gravel (1 to 64 mm), with $\mu_z = 2.08$ and $\sigma_z = 0.7$. The Meyer-Peter and Müller (1948) equation was used. The results, shown in figure 5.10, confirm the above findings, i.e., that 4 or 5 size classes are enough to fully characterize the mixture of the sediments in transport.

Ultimately, it is up to the user to determine how many size classes (and how to define them) are needed for the particular study at hand, but the above guidelines should provide a good starting point for most applications.

Figure 5.9 Normalized sediment concentration, mean diameter, and standard deviation of the transported sediment mixture using Yang (1973) sand transport equation. The arrows show the direction of increasing values of the unit stream power, *VS*.

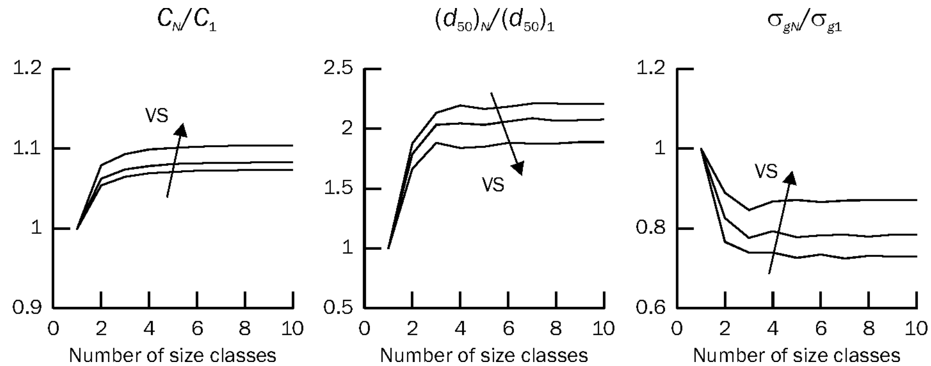
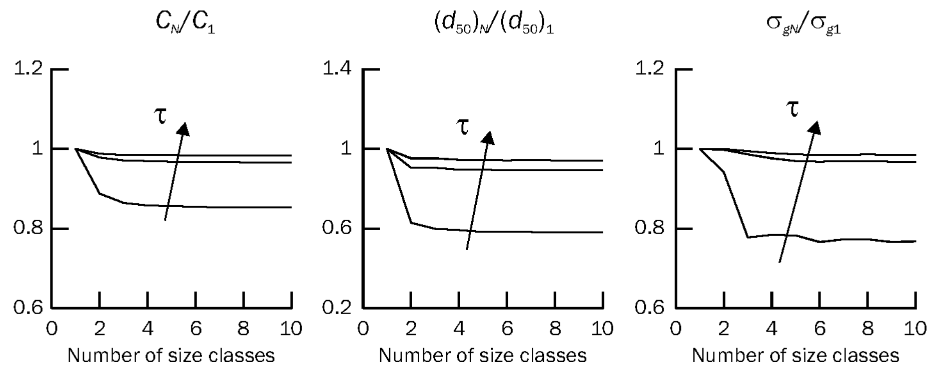


Figure 5.10 Normalized sediment concentration, mean diameter, and standard deviation of the transported sediment mixture using Meyer-Peter and Müller (1948) transport equation. The arrow shows the direction of increasing values of the bed shear stress, τ.

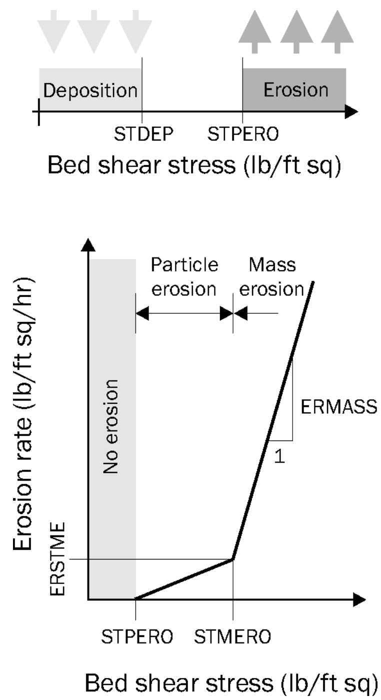


5.3.4 Cohesive Sediment Transport Parameters

The parameters necessary to model cohesive sediment transport are schematically represented in figure 5.11. Because these parameters are highly case dependent, and because they vary within orders of magnitude, GSTARS 2.1 does not assume default values for these quantities. When modeling cohesive sediment transport, the user should rely on field data as much as possible.

In figure 5.11, STDEP = shear threshold for deposition of clay and silt; STPERO = shear threshold for particle erosion of clay and silt; STMERO = shear threshold for mass erosion of clay and silt; ERMASS = slope of the erosion rate curve for mass erosion; and ERSTME = Erosion rate of clay and silt when the bed shear stress is equal to STMERO. Finally, a last parameter is needed, ERLIM, which is the threshold value for the percentage of clay in the bed composition above which the erosion rates of gravels, sands, and silts are limited to the erosion rate of clay, as described in section 3.6.2. Values of ERLIM have been found to have a large range of variation $(7\% \leq \text{ERLIM} \leq 80\%)$.

Figure 5.11 Schematic representation of the parameters necessary to model the transport of cohesive sediments.



5.4 Output Control

GSTARS 2.1 output is accomplished through column-formatted ASCII files that can be accessed via a plain ASCII text editor or imported into spreadsheets, such as Microsoft's Excel. There are two types of output: hydraulic/sediment parameters and geometry data. The hydraulic/sediment parameters are organized in files containing flow velocities, Froude numbers, energy grade line, particle size distributions, etc., for the computational cross sections in the reach. The geometry data is comprised by tables of thalweg elevation and water surface elevation versus longitudinal distance, and by cross-sectional geometries.

Hydraulic/sediment parameter output is controlled in record PR, including the interval at which the output is desired. There are five possible choices in the control of output using parameter *IPRLVL* of record PR:

IPRLVL	Type of output
-1	No output is required.
0	Level 0 output: print water surface profile and sediment routing tables.
1	Level 1 output: in addition to level 0 output, normal and critical depth tables are generated.
2	Level 2 output: in addition to level 1 output, stream tube geometry and conveyances are generated.
3	Level 3 output: in addition to level 2 output, sediment transport capacities are written to the .SED file.

The output of the several quantities is stored in files with extensions .OUT, .SED, and .DBG. The files are well labeled and are straightforward to understand

Geometry data output is controlled using records PX for the cross sections, and PW for water surface profiles. Output is carried out during the model run at time step intervals specified in these records. Output is stored in files of extension .XPL for the cross-sectional information, and in files of extension .WPL for the water surface profiles.

When records PX and/or PW are used, the first output to the respective external data files is a straight dump of the data *before* the first time step is carried out. In the .WPL output file, the first table is built with the water surface elevation set to zero, simply because the water routing computations have not yet been performed. This approach was chosen because it facilitates automatic importing into spreadsheets, and because it is useful for checking the accuracy and consistency of the data used in the input to the model.

5.5 Stream Power Minimization Procedure Data

The total stream power minimization data constitutes the last part of the data described in this chapter. Their inclusion in the input data file is optional. They are necessary only if total stream power minimization computations are requested from GSTARS 2.1.

Minimization computations are activated by the inclusion MR records in the input data file following the printout control records described in the previous section. MR records are used to specify the range of allowable width and depth variation at different cross sections along a study reach (see the detailed description of this record in appendix A). One MR record is necessary for each section in the study reach. MR records must be given in order, starting from the farthest upstream station and proceeding downstream. If the minimization computations are activated, total stream power computations are performed at the end of the each time step.

In the definition of the range of width and depth variations in the MR records, knowledge of man-made restrictions to deposition and/or scour and geological boring data is required. For example, consider the following hypothetical situation: a 100 ft wide channel (lateral locations between 0 and 100 ft) with bed elevation at 1000 ft is discretized by 5 sections. A nonerodible bedrock layer at elevation 920 ft is known to exist under the first three sections. There is a lateral constraint (rock formation) at the right-hand side (looking downstream) of station 3, located at 112 ft; another lateral constraint is located at the left side of station 5 (man-made gaging station) at location 0 ft. No other constraints are known at that reach. The MR records for this hypothetical situation would be:

```
         1         2         3         4
123456789012345678901234567890123456789012345

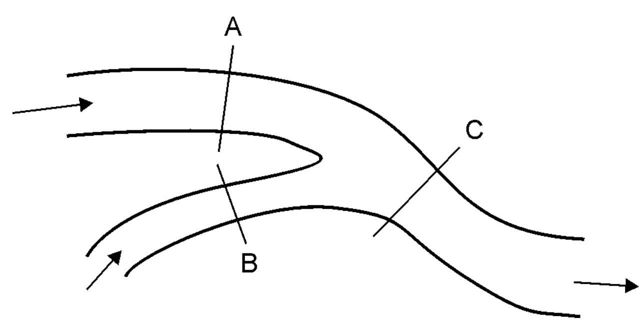
MR-9999.   9999.    920.   9999.
MR-9999.   9999.    920.   9999.
MR-9999.    112.    920.   9999.
MR-9999.   9999.  -9999.   9999.
MR    0.   9999.  -9999.   9999.
```

5.6 Tributary Inflow Data

Although GSTARS 2.1 is limited to single stem rivers, it is possible to include the contributions of water and sediment by tributaries into the modeled reach. At channel junctions (see figure 5.12) continuity requires that

$$Q_C = Q_A + Q_B \tag{106}$$

Figure 5.12 Channel junction.



Let cross section B be located at the tributary, and cross sections A and C represent the computational cross sections used to model the tributary effects. Conservation of energy is used, i.e.,

$$\left(z + Y + \alpha\frac{V^2}{2g}\right)_A = \left(z + Y + \alpha\frac{V^2}{2g}\right)_C + h_f \qquad (107)$$

The energy losses, h_f, are computed from friction alone, i.e., losses due to bends, contraction/expansion losses, and user defined values are ignored. (See section 2.1 and following for details.)

The information necessary to model the effects of a tributary flow are the tributary's water discharge, the inflow sediment and its composition (needed only if sediment transport computations are active), and how sediment mixing takes place among the stream tubes. This information is set-up in separate files. There must be one file for each tributary. The file names for each tributary are passed to GSTARS 2.1 using LI records. For each tributary, use one LI record located after the RH record corresponding to the cross section located immediately downstream from the tributary. For example, using the configuration in figure 5.12, there would be a record LI placed after the RH record corresponding to cross section C.

Tributary inflow information is set-up using DD, MX, QS, IQ, and IS records. A typical file with lateral inflow data could look like this:

```
         1         2         3         4
12345678901234567890123456789012345678901234 5
---------------------------------------------

* Example of lateral input
* data file.

* Tributary discharge:
DD    50      0.0
DD    50     50.0

* Sediment mixing:
MX  0.10     0.30     0.50

* Sediment discharge:
QS    50      0.0
QS    50     10.0

* Sediment composition:
IQ     2     0.10   100.0
IS           0.50     0.40
IS           0.40     0.40
IS           0.10     0.20
```

All data is tabulated in the same format as described in section 5.1. Water discharge is specified using records DD. Do not use any other records for this purpose (the lateral input file does not have the same input facilities as the main data file discussed in the previous sections). The example above will only work for a 100 time step run (two DD records with 50 time steps each), but the principle can be easily extended to any number of time steps.

If sediment transport is requested, the DD records must be followed by an appropriate sequence of MX, QS, IQ, and IS records, in this order. The MX record is used to specify the proportions of sediment entering each stream tube. In the example above, 10% will go into the left stream tube, 30% to the middle, and 50% to the right stream tube, assuming that three stream tubes are used in the run. Incoming sediment loads are specified using QS records and sediment size distribution is defined using records IQ and IS. These records have been defined in the previous sections. No other records are allowed in the lateral input data file, except comment records (CM, *, and blank lines).

5.7 Using GSTARS 2.1 in Command Line Mode

After preparing the input data file using a plain ASCII text editor (using blank spaces, not tabs), GSTARS 2.1 can be used from the command line interface (DOS window — see your system's user's manual for more information regarding your particular computer) like any conventional DOS program. At the prompt simply type

C:\> GSTARS2.1.EXE FILENAME.DAT

As usual, make sure that the executables exist in the system PATH variable. If GSTARS 2.1 is launched without an input file name, the program prompts the user to enter it. For consistency, the input data file should have an extension .DAT (or .dat), but the program will work with any other extension. In order to properly view the GSTARS 2.1 screen output during runtime, the following line must be included in the CONFIG.SYS file:

DEVICE=C:\WINDOWS\COMMAND\ANSI.SYS

The above command is used in systems running under the Microsoft's Windows 95/98 operating system. Users of Windows NT/2000 may have to do something different (please consult your system administrator).

Depending on the output requested using the PR, PW, and PX records, several different output files may be generated by GSTARS 2.1 each time the program is executed. The complete set of output files will have the same base file name, which is that part to the left of the period. Each output file containing specific information will have a unique file extension, as outlined below. Make sure that existing files do not contain any of the following file extensions, because they will be overwritten by the GSTARS 2.1 program.

For a given input file named **sample.dat**, the following files may be generated.

sample.out: the .OUT file is the main output file containing the results from the model run. This file contains information about the input data set, as well as hydraulic and sediment transport information. The output level in this file is determined by record PR.

sample.xpl: The .XPL file contains the cross section data points, which can be imported to any generic spreadsheet program. This file is generated only if requested by the PX record.

sample.wpl: The .WPL file contains the water surface profile data points. A water surface profile plot is created for each requested time step. Similarly to the .XPL file, information in this file may be viewed/plotted using a generic spreadsheet program. This file is generated only if requested by the PW record.

sample.dbg: The .DBG file contains information about the model run which can be helpful in finding errors or anomalies in the model run. This information includes all comment records included in the input data set as well as additional information about the hydraulics and sediment calculations performed by the model. The output level in this file is also determined by record PR.

sample.sed: The .SED file contains sediment carrying capacities for each stream tube at each section for the requested time steps. Bed sorting information for the time step is also included in this file. It is generated if level 3 output is selected on the PR record.

As mentioned above, thalweg and stage output is done to the .WPL file in a tabular format appropriate for use with any general purpose spreadsheet program. Its only purpose is to facilitate plotting of the channel's longitudinal bed and stage profiles. The same information is also supplied in the .OUT file. The first lines of the file contain the date and time stamp of the run, as well as the title of the study, entered using TT records in the input data file (in the .DAT file). The remainder of the file contains the output of the program for the time steps specified in record PW (in the .DAT file).

For each time step of output, a three-column table is printed containing *NSTA* + 1 rows (*NSTA* is the number of stations used in the study). The first row contains (from left to right) the number of stations used in the study, the discharge for that time step, and the time step number. The remaining rows contain (from left to right) the station coordinate, thalweg, and stage for the time step. Note that the first set in the file corresponds to time step zero, i.e., to the conditions defined before the run starts. Therefore, the discharge and stages are not defined (they are printed to the file as zero values).

Cross-sectional geometry is output to file .XPL, also in a tabular format appropriate for use in a spreadsheet program. The data in this file shows cross section evolution in time. Output is made at given time steps, as specified in record PX (in the input .DAT file). Similarly to the .WPL file, the first lines of the file contain the date/time stamp of the run and the title of the study. Cross sectional geometry for the entire reach is dumped to the file at each desired time step. For each time step of the output, the data is structured in the following manner:

- the first line contains the number of stations used in the study (*NSTA*);

- data is grouped by station, starting at the station farthest upstream and ending at the station farthest downstream;
- for each station, the first row of data contains three entries: location of station (as defined in record ST, in the input .DAT file), the number of coordinate pairs used for that station (*NPTS*); and the time step. The remaining rows contain *NPTS* pairs of coordinates, with bed elevation in the first column and lateral coordinate in the second column.

The first set in the file corresponds to time step zero, i.e., to the initial conditions.

Due to the nature of the algorithms used in GSTARS 2.1, the number of coordinate points used to describe each cross section may vary with time. The lateral location of coordinate points may also change, especially if minimization computations are performed. Care must be exercised by the user when preparing the data for plotting using a generic spreadsheet program.

CHAPTER

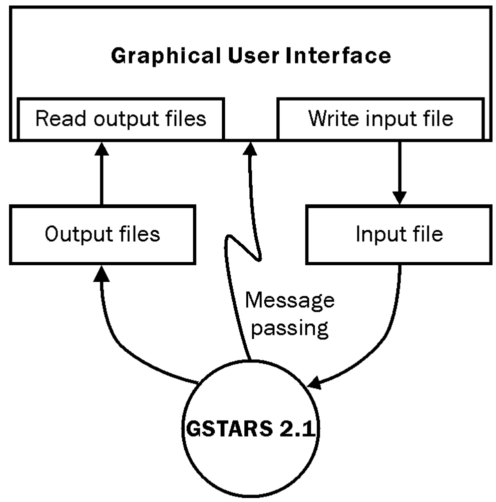
6

THE GRAPHICAL USER INTERFACE

It was briefly described in section 5.7 how to use GSTARS 2.1 from the standard command line interface. In that approach, GSTARS 2.1 communicates with the user using static files: the input files are prepared, the program is executed using the information contained in those files and, upon completion and normal termination, a number of output files are produced. A new run of the program involves the preparation of a new input file and the creation of more output files by the program. In this section an alternative way to use the program is presented: the GSTARS 2.1 Graphical User Interface (GUI for short). This alternate input/output system maintains the basic structure of the program, but encapsulates it within a new interface layer. This layer provides the graphical and interactive environment to prepare the input file required for model execution, and processes the output information for graphical display of results.

During execution of the numerical code, some informational messages are printed in the standard output device, such as the status of the run (percentage of computations completed) and any runtime error messages that may occur. Those messages are also passed directly to the GUI and displayed in real time. This is accomplished by a basic message-passing mechanism that captures all the intermediary ASCII output produced by the numerical engine (a one-way communication path). The overall scheme used in the development of the GSTARS 2.1 GUI is pictured in figure 6.1.

Figure 6.1 Basic architecture followed in the development of the graphical user interface for GSTARS 2.1.



6.1 Application Pull-Down Menus

File

- **New** – Create an empty input window. Data can be added using the functions and tools in the new input frame, including reading a GSTARS 2.1 model input file
- **Open** – Load a project file created previously with the interface. To load a model input file, use File>New, then use the new input frame's File>Import Input File.
- **Exit** – Close all windows and quit the application. Each modified input window that has been modified since the last save has one last chance to save its changes unless Cancel is selected in the message boxes that follow.

Window

- **Organize** – Stacks all input files on top of each other inside the application area. Any tool windows are stacked to the right.

Help

- **Contents** – Pops up a help window. Currently not out of prototype stage.
- **About** – Brings up a dialog showing the version number and software name.

6.2 Project Pull-Down Menus

File

- **Save** – Update project file with the latest changes. If no project file has been selected, then a file selection box will pop up to allow the user to pick a file name for the project.
- **Save As** – Write the project to a new file chosen from a file selection box.
- **Import Input File** – Re-initialize the input view with the contents of a GSTARS 2.1 model input file. If the modeled reach has not been laid out yet, then a default reach will be created. Note that any new input file created will not have the same contents as the original, but the formatted data will be the same.
- **Load Output File** – Pop up a dialog for viewing .XPL and .WPL output data. Any GSTARS 2.1 output files can be loaded and displayed.

Edit

- **Background.**
  - **Add Background Image** – A jpeg or gif image can be displayed in the background of the input frame.
  - **Remove Background Image** – Remove any image that has been loaded into the background. Note that this will reposition the modeled reach to fill the entire viewing area.
- **River.**
  - **Add River Segments** – Creates or appends new river segments. The first segment is placed at the first mouse click; successive river segments are shown by a line drawn from the last river segment to the mouse cursor. When finished, click the right mouse button; this will automatically change the mouse mode to Add Cross-sections and pop up the River Units dialog (see Edit River Parameters). Segment addition can be also be ended by selecting a new mode from the river pull-down menu, although this will not bring up the river preferences dialog.
  - **Insert River Segments** – Drops a new cross-section point in the modeled reach segment. The location of the new point is shown as a circle on the segment; left-click when the point is in the desired location. Right-click when finished; this will put the project into Edit River Segments mode.
  - **Remove River Segments** – Remove cross-section points by clicking on each point. This creates a new segment formed by the two closest cross-section points. If the end of the modeled reach is selected, the segment is deleted. Right-click when finished
  - **Edit River Segments** – Move reach cross-section points by left-clicking on the cross-section point and dragging it to the desired location. Right-click when finished.
  - **Reverse River Direction** – Switches the upstream and downstream points of the model reach. The cross-section locations are not changed.
  - **Edit River Parameters** – Sets the measurement units, length, and starting location for the river.
- **Cross-sections.**

- **Add Cross-sections** – Move the mouse close to where the cross section is to be placed and left-click to make the addition. The cross section will appear as a blue rectangle on the modeled reach. Right-click when finished; this will automatically change the mouse mode to Edit Cross-sections.
- **Remove Cross-sections** – Left-click on the cross section that is to be removed. This will delete all information associated with the cross-section, such as discharge and sediment data.
- **Edit Cross-sections** – Left-click on the cross-section to pop up the cross-section editor.

- **Annotate View.**
  - **Add Text** – Each left-mouse click on the river-view will drop an empty rectangle that can contain text. Double click on the rectangle to edit the text and font.
- **Preferences** – A dialog for changing the foreground and background colors of the project is displayed.

Project.

- **Title** – Brings up a dialog for editing the title of the project.
- **Project Data** – Brings up a dialog for editing non-cross-section project parameters, such as time-step information.
- **Discharge Data** – Brings up a dialog for editing discharge data for the project.
- **Sediment Data** – Brings up a dialog for editing sediment data for the project.
- **Execute** – Generates a GSTARS input file specified by the user and runs the model. When the model run is complete, the View Output dialog is displayed.

6.3 Toolbar Buttons

Geometry: displays a graph of the cross-sectional geometry of the cross-section that the mouse last moved over.

Sediment: displays a graph of the sediment distribution of the cross-section that the mouse last moved over.

Boundaries: displays a graph of the boundary conditions of the cross-section that the mouse last moved over.

Output: displays a graph of the cross-section output for the cross-section that the mouse last moved over.

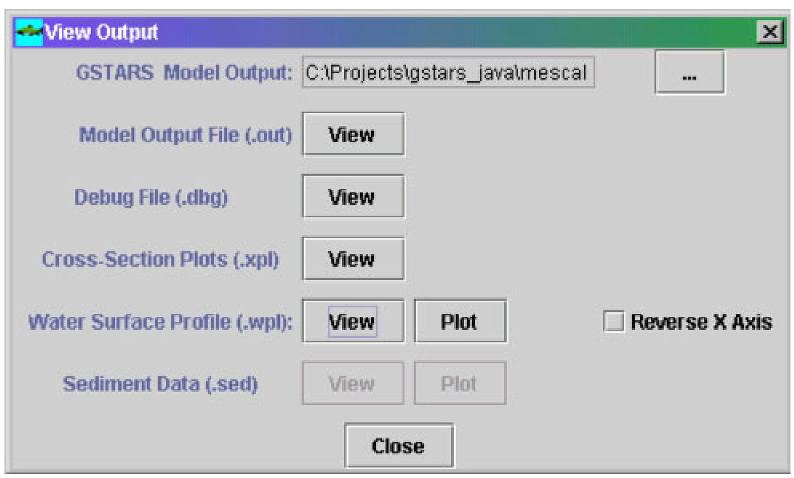
XSec: displays the cross-section view control dialog that can change the current cross-section rather than using the mouse to select the cross-section in the view. If an output file has been loaded, then the time step for the output graph can be set as well.

6.4 Input Dialogs

The tables in all the dialogs function as a limited spreadsheet. By pressing and holding the left mouse, a region can be selected. Clicking on the right mouse button will display a menu of choices that either operate on the selected region (copy, paste, delete) or on the current cell (insert). The insert function will insert as many data values starting at the current cell and moving to the right and down as were last copied either from a table or other spreadsheet such as Microsoft's Excel.

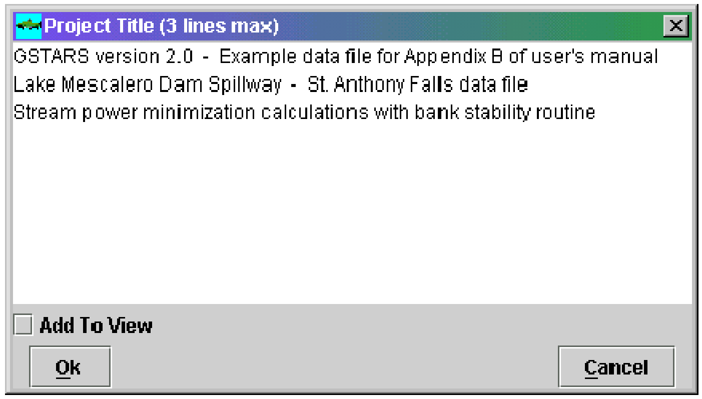
6.4.1 View Output Dialog

Brought up using File>Load Output File. To display each type of output file, select the appropriate View button. The water surface profile output can be plotted by selecting the Plot button. Cross-section plots can be displayed in the application frame by selecting the Output toolbar button.



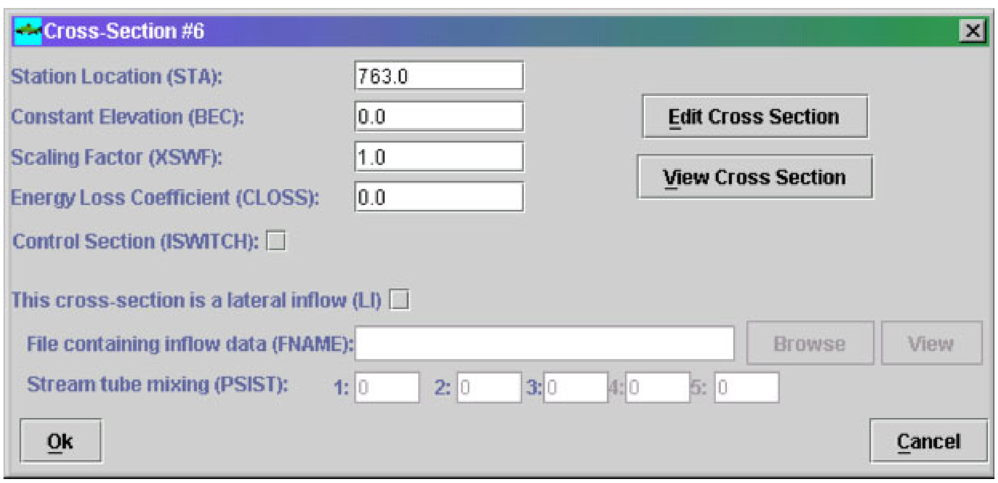
6.4.2 Project Title

Set the GSTARS 2.1 title (record TT).



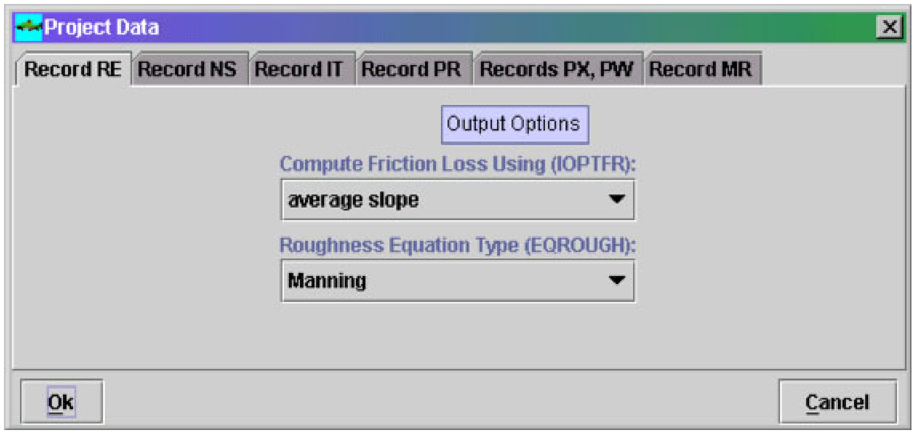
6.4.3 Cross-section Data

By clicking on the cross-section, the cross-section dialog box will be displayed. The edit cross-section button will bring up the geometry spreadsheet and roughness coefficient table. The view cross-section button will bring up a graph with the same information.



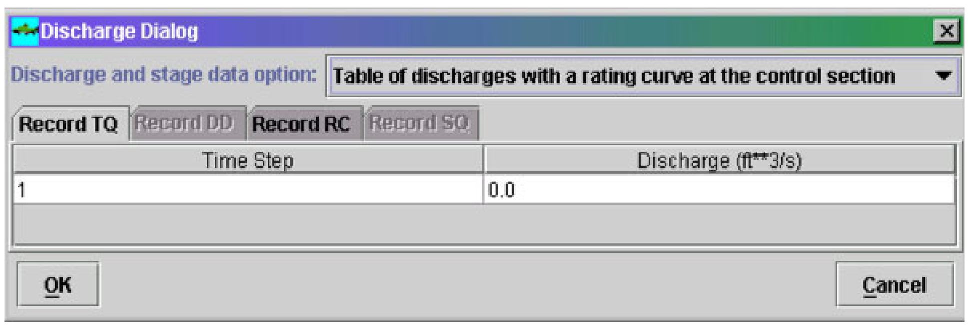
6.4.4 Project Data

The data used by records RE, NS, IT, PR, PX, PW, and MR can be assigned in this dialog.



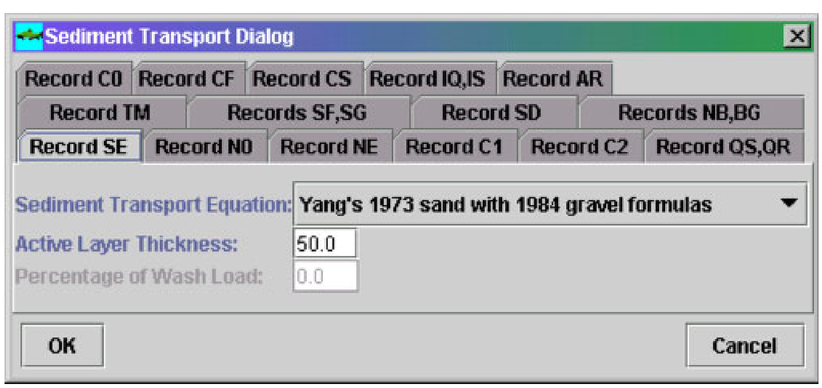
6.4.5 Discharge Data

The data used by records SS, QQ, TQ, DD, RC, and SQ are given in this dialog. Note that records SS and QQ are set based on the “discharge and stage data” selection; this will also sensitize the required tabs in the dialog.



6.4.6 Sediment Transport Data

The data used by records SE, NO, NE, C1, C2, QS, QR, TM, SF, SG, SD, NB, BG, CO, CF, CS, IQ, IS, AR are given in this dialog. Note that the spreadsheet for tab SG affects the layout for tabs SD and BG.



6.5 Final Remarks About the Implementation of the GUI

The GSTARS 2.1 graphical interface is a separate component to the model that functions as pre- and post-processor. Sun's Java (see www.javasoft.com) was the programming language chosen. The primary advantage of using Java is that it has been designed to run on multiple operating systems, including Microsoft Windows (95/98/NT) and Linux. Currently, the interface runs only as an application and not as an applet[†], but after further development there is the possibility of running the interface as an applet in a web browser, which could simplify the distribution of the interface software in future versions of GSTARS 2.1. Java also has a set of functions for connecting to local or networked databases, which could be another important consideration in future development.

The interface was broken into two modules: the graphical user interface dialogs and the controller. The graphical user interface dialogs, which form the physical part of the GUI, were designed using IBM's Visual Age for Java integrated development environment (see www.ibm.com/software/ad/vajava). Using a graphical design board, buttons and other user interface elements are laid out, allowing for rapid prototyping and development. When the user is happy with the appearance of a component, the compiler can output it as a Java class, complete with hooks to each of the component's text fields and buttons.

The controller, which is the code that gives functionality to the GUI dialogs, was written using JPython. JPython is a scripting language written in Java (see www.jpython.com). Where Java is a statically-typed language similar to C++, JPython is an object oriented, dynamically-typed language, and contains native high-level data structures such as lists and dictionaries. This allows for faster development and reduces the number of lines of code, making maintenance easier. Of course, such a system is not without its drawbacks, which include the additional overhead involved with translating JPython code to the equivalent Java. The distribution of the interface is also more complex because of the JPython libraries that need to be installed. The controller functions by subclassing (extending) the dialog components that were written in Java. These JPython classes provide the implementation of each of the buttons, menus, and other interface elements.

A third-party Java class, PtPlot 3.1, was used to perform the graphing functions of the interface (see Ptolemy.eecs.Berkeley.edu/java/ptplot3.1/Ptolemy/plot/doc). While powerful in its own right, a major consideration was that the source code was available. This allows the programmer to easily make modifications without having to worry about copyright issues or waiting for the needed feature to come along in a future development.

[†] An applet is a program designed to be executed from within another application. Unlike an application, applets cannot be executed directly from the operating system, but a well-designed applet can be invoked from many different applications.

References

Ackers, P., and White, W.R. (1973). "Sediment transport: new approach and analysis," *J. of the Hydr. Div. ASCE*, **99**(HY11).

Anderson, D.A., Tannehill, J.C., and Pletcher, R.H. (1997). *Computational fluid mechanics and heat transfer*. 2nd ed. Taylor and Francis.

Arcement, G.J., and Schneider, V.R. (1987). *Roughness coefficients for densely vegetated flood plains*. U.S. Geological Survey Water–Resources Investigation Report 83–4247.

Ariathurai, R., and Krone, R.B. (1976). "Finite element model for cohesive sediment transport," *J. of the Hydr. Div. ASCE*, **102**(HY3).

ASCE Task Committee on Preparation of Sedimentation Manual, (1971). "Sediment transportation mechanics: H. Sediment discharge formulas," *J. of the Hydr. Div. ASCE*, **97**(HY4).

Barnes, H.H. (1967). *Roughness characteristics of natural channels*. U.S. Geological Survey Water–Supply Paper 1849.

Bennett, J.P., and Nordin, C.F. (1977). "Simulation of sediment transport and armouring," *Hydrological Sciences Bulletin*, **XXII**.

Chang, H.H. (1979). "Minimum stream power and river channel patterns," *J. of Hydrology*, **41**.

Chang, H.H. (1980a). "Stable alluvial canal design," *J. of the Hydr. Div. ASCE*, **106**,(HY5).

Chang, H.H. (1980b). "Geometry of gravel streams," *J. of the Hydr. Div. ASCE*, **106**(HY9).

Chang, H.H. (1982a). "Mathematical model for erodible channels," *J. of the Hydr. Div. ASCE*, **108**(HY5).

Chang, H.H. (1982b). "Fluvial hydraulics of deltas and alluvial fans," *J. of the Hydr. Div. ASCE*, **108**(HY11).

Chang, H.H. (1983). "Energy expenditure in curved open channels," *J. of the Hydr. Div. ASCE*, **109**(HY7).

Chang, H.H., and Hill, J.C. (1976). "Computer modeling of erodible flood channels and deltas," *J. of the Hydr. Div. ASCE*, **102**(HY10).

Chang, H.H., and Hill, J.C. (1977). "Minimum stream power for rivers and deltas," *J. of the Hydr. Div. ASCE*, 103(HY12).

Chang, H.H., and Hill, J.C. (1982). "Modelling river-channel changes using energy approach," Proc. of the ASCE Hydraulics Division Conference on Applying Research to Hydraulic Practice, Peter E. Smith (ed.).

Chow, V.T. (1959). *Open-channel hydraulics*. McGraw-Hill, New York, NY.

Colby, B.R., (1963). Discussion of "Sediment transport mechanics: introduction and properties of sediment," *J. of the Hydr. Div. ASCE*, **89**(HY1).

Cowen, W.L. (1956). "Estimating hydraulic roughness coefficients," *Agricultural Engineering* **37**, July, pp. 473–475.

DuBoys, M.P. (1879). "Le Rhône et les rivières à lit affouillable," *Annals de Ponts et Chaussée*, **18**(5), pp. 141-195. (In French.)

Einstein, H.A. (1950). *The bed-load function for sediment transportation in open channel flows*. U.S. Department of Agriculture, Soil Conservation Service, Technical Bulletin No. 1026.

Einstein, H.A., and Chien, N. (1953). *Transport of sediment mixtures with large range of grain size*. University of California Institute of Engineering Research, Missouri River Division Sediment Series, No. 2.

Engelund, F., and Hansen, E. (1972). *A monograph on sediment transport in alluvial streams*. Teknish Forlag, Technical Press, Copenhagen, Denmark.

French, R.H. (1985). *Open-channel hydraulics*. McGraw-Hill Book Company, New York, NY.

Han, Q. (1980). "A study on the non-equilibrium transportation of suspended load," Proc. of the Int. Symp. on River Sedimentation, Beijing, China, pp. 793–802. (In Chinese.)

Han, Q., and He, M. (1990). "A mathematical model for reservoir sedimentation and fluvial processes," *Int. J. of Sediment Res.*, **5**(2), IRTCES, pp. 43–84.

Henderson, F.M. (1966). *Open channel flow*. MacMillan Book Company, New York, NY.

Hirsch, C. (1988). *Numerical computation of internal and external flows*. 2 vols. John Wiley & Sons, Inc.

HR Wallingford (1990). *Sediment transport, the Ackers and White theory revised*. Report SR237, HR Wallingford, England.

Ikeda, S., Yamasaka, M., and Chiyoda, M. (1987). "Bed topography and sorting in bends," *J. of Hydr. Engng.*, ASCE, **113**(2), pp. 190–206.

Klaassen, G., Ogink, H., and van Rijn, L. (1986). "DHL–Research on bedforms, resistance to flow and sediment transport," 3rd Int. Symp. on River Sedimentation, Jackson, MS, pp. 58–82.

Krone, R. B. (1962). *Flume studies of the transport of sediment in estuarial processes*. Hydraulic Engineering Laboratory and Sanitary Engineering Research Laboratory, University of California, Berkeley, CA.

Lane, E. W. (1947). "Report of the subcommittee on sediment terminology," *Trans., Amer. Geophys. Union,* **28**(6), Washington, D.C.

Laurenson, E.M. (1986). “Friction slope averaging in backwater calculations,” *J. Hydr. Engng.*, ASCE, **112**(2), pp. 1151–1163.

Laursen, E.M.(1958). "The total sediment load of streams," *J. of the Hydr. Div. ASCE*, **84**(HY1).

Mehta, A. J., Hayter, E. J.,Parker, W. R., Krone, R. B., and Teeter, A. M. (1989). “Cohesive sediment transport. I: Processes description,” *J. Hydr. Engng.*, ASCE, **115**(8), pp. 1076–1093.

Meyer-Peter, E., and Müller, R. (1948). "Formula for bed-load transport," Proc. of the Int. Assoc. for Hydraulic Research, 2nd Meeting, Stockholm.

Molinas, A., and Yang, C.T. (1985). "Generalized water surface profile computations," *J. of the Hydr. Div. ASCE*, **111**(HY3).

Ohtsubo, K., and Muraoka, K. (1986). “Resuspension of cohesive sediments by currents,” 3rd Int. Symp. on River Sedimentation, Jackson, MS, pp. 1680–1689.

Parker, G. (1990). "Surface based bedload transport relationship for gravel rivers," *J. of Hydr. Res.*, **28**(4), pp. 417–436.

Partheniades, E. (1965). "Erosion and deposition of cohesive soils." *J. of the Hydr. Div. ASCE*, **91**(HY1).

Partheniades, E. (1986). “The present state of knowledge and needs for future research on cohesive sediment dynamics,” 3rd Int. Symp. on River Sedimentation, Jackson, MS, pp. 3–25.

Reed, J.R., and Wolfkill, A.J. (1976). "Evaluation of friction slope models," Rivers'76 Symposium on Inland Waterways for Navigation, Flood Control, and Water Diversions, Colorado State University, Ft. Collins.

Rubey, W. (1933). "Setting velocities of gravel, sand, and silt particles," *Am. J. of Science*, **25**.

Samuels, P.G. (1990). “Cross-section location in 1-D models,” *Int. Conf. on River Hydraulics*, ed. by W. White, John Wiley & Sons, pp. 339–350.

Song, C.C.S., and Yang, C.T. (1979a). "Velocity profiles and minimum stream power," *J. of the Hydr. Div. ASCE*, **105**(HY8).

Song, C.C.S., and Yang, C.T. (1979b). "Minimum stream power: theory," *J. of the Hydr. Div. ASCE*, **105**(HY8).

Song, C.C.S., and Yang, C.T. (1982a). "Application of variation principle to river flow," Applying Research to Hydraulic Practice, ASCE, Peter E. Smith (ed.).

Song, C.C.S., and Yang, C.T. (1982b). "Minimum energy and energy dissipation rate," *J. of the Hydr. Div. ASCE*, **108**(HY5).

Straub, L.G. (1935). Missouri River report. In-House Document 238, 73rd Congress, 2nd Session, U.S. Government Printing Office, Washington, D.C.

Toffaleti, F.B. (1968). "Definitive computations of sand discharge in rivers," *J. of the Hydr. Div. ASCE*, **95**(HY1).

U.S. Army Corps of Engineers (1993). *The Hydraulic Engineering Center, HEC-6 Scour and Deposition in Rivers and Reservoirs, User's Manual.* Mar. 1977 (revised 1993).

U.S. Interagency Committee on Water Resources, Subcommittee on Sedimentation (1957). *Some fundamentals of particle size analysis*. Report no. 12.

Vries, M. de (1969). *Solving river problems by hydraulic and mathematical models*. Delft Hydraulics Laboratory Publication 76-II.

Waananen, A.O., Harris, D.D., and Williams, R.C. (1971). *Floods of December 1964 and January 1965 in the far Western United States: Part 1, Description*.U.S. Geological Survey Water-Supply Paper 1866-A.

Yang, C.T. (1971). "Potential energy and stream morphology," *Water Resources Research, AGU*, **7**(2).

Yang, C.T. (1973). "Incipient motion and sediment transport," *J. of the Hydr. Div. ASCE*, **99**(HY10).

Yang, C.T. (1976). "Minimum unit stream power and fluvial hydraulics," *J. of the Hydr. Div. ASCE*, **102**(HY7).

Yang, C.T. (1979). "Unit stream power equations for total load," *J. of Hydrology*, **40**.

Yang, C.T. (1984). "Unit stream power equation for gravel," *J. of the Hydr. Div. ASCE*, **110**(HY12).

Yang, C.T. (1992). "Force, energy, entropy, and energy dissipation rate," *Entropy and Energy Dissipation in Water Resources*, V.P. Sing and M. Fiorentino (eds.), Kluwer Academic Publisher, Netherlands.

Yang, C.T. (1996). *Sediment transport: theory and practice*. McGraw-Hill Companies, Inc., New York, NY.

Yang, C.T., and Song, C.C.S. (1979). "Theory of minimum rate of energy dissipation," *J. of the Hydr. Div. ASCE*, **105**(HY7).

Yang, C.T., and Song, C.C.S. (1986). "Theory of minimum energy and energy dissipation rate," Encyclopedia of Fluid Mechanics, Vol. 1, Chapter 11, Gulf Publishing Company, N.P. Cheremisinoff (ed.).

Yang, C.T., Molinas, A., and Wu, B. (1996). "Sediment transport in the Yellow River," *J. of Hydr. Engng., ASCE*, **122**(5).

Yang, C.T., Treviño, M.A., and Simões, F.J.M. (1998). *User's manual for GSTARS 2.0 (Generalized Stream Tube model for Alluvial River Simulation version 2.0)*. U.S. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

APPENDIX A

List of input data records used by GSTARS 2.1.

Alphabetic list of the input data records used in GSTARS 2.1

The detailed descriptions of the records are given in the following pages. The records are presented in the same order in which they should appear in the GSTARS 2.1 input file.

Record CM

COMMENT

Optional

Comment lines are lines containing informative text usually employed to document the input data files. The input data file can have any number of comment lines anywhere in the file. Any line beginning with the uppercase characters CM will be ignored. Any input record that has an asterisk ('*') or a blank character as the first character will also be ignored. Comment lines using CM or an asterisk are echoed to the .DBG output file, but the lines with a blank character in the first column will not.

Field	Variable	Value	Description
0	*ID*	CM	Record identification.
		*	Record identification.
		Blank	Record identification.
1–10			Any ASCII string.

TT

Record TT

TITLE OF STUDY

Required

The TT record is used to define a title, i.e., a short text that may be used to identify the study or the datafile. Three TT records have to be used (they must be present, but they may be left blank). The text typed in fields 1 to 10, including blank spaces, will be echoed to the output files generated by GSTARS 2.1

Field	Variable	Value	Description
0	*ID*	TT	Record identification.
1–10	*TITLE*		ASCII text to be echoed in the GSTARS 2.1 output files.

Record MT

METRIC UNITS OPTION

Optional

Although the foot (ft) and the pound (lb) are the primary units of length and mass used throughout this manual, GSTARS 2.1 can also use the International System (SI) of units. This is accomplished by including record MT in the input file. Record MT is used to set-up GSTARS 2.1 to use the SI units in its input and output files. If this record is used, follow the table below to specify the appropriate units for all of the fields in each record:

If manual reads:	Use SI unit:
feet (ft)	meter (m)
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)
ton per day (ton/day)	tonne per day, i.e., metric ton per day(tonne/day)
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)
pound per square foot (lb/ft^2) (stress)	Pascal (Pa)
pound per square foot per hour (lb/ft^2/hr)	Pascal per hour (Pa/hr)

Table of conversion factors used in GSTARS 2.1

1 ft = 0.3048 m	1 m = 3.281 ft
1 ft^2 = 0.0929 m^2	1 m^2 = 10.76 ft^2
1 ft^3 = 0.02832 m^3	1 m^3 = 35.31 ft^3
1 ft^3/s = 0.02832 m^3/s	1 m^3/s = 35.31 ft^3/s
1 lb = 0.4536 kg	1 kg = 2.205 lb
1 ton = 2,000 lb = 907.2 kg = 0.9072 tonne	1 tonne = 1,000 kg = 2,205 lb = 1.102 ton
1 lb/ft^3 = 16.02 kg/m^3	1 kg/m^3 = 0.06243 lb/ft^3
1 lb/ft^2 = 4.788 Pa (stress)	1 Pa = 0.2089 lb/ft^2 (stress)

The units of the following parameters remain unchanged: in record TM, the water temperature units remain as defined; in record SG, the values of *DRL* and *DRU* are always given in mm, but the dry specific weight must be specified in kg/m^3; in record CS, the unit of ERMASS becomes s^2/m/h.

Field	Variable	Value	Description
0	*ID*	MT	Record identification.

NS

Record NS

NUMBER OF STATIONS

Required

The NS record defines the number of cross sections, or stations, to be used by the program. The maximum number of cross sections allowed in GSTARS 2.1 is 100. However, this number may be changed in future versions without notice. The user should check this value against the value printed at the top of the .DBG output file.

Field	Variable	Value	Description
0	*ID*	NS	Record identification.
1	*NSTA*	+	Number of cross sections defined in the study.

Record YX

ALTERNATE COORDINATE ORDER

Optional

The YX record allows the option of using cross-section coordinate input data pairs with the bed elevation (y value) followed by the lateral location (x value) on the XS record. The default is lateral location followed by bed elevation (see record XS).

Field	Variable	Value	Description
0	*ID*	YX	Record identification.

ST

Record ST

STATION (CROSS SECTION) PROPERTIES

Required

The ST record is used to define a number of cross section properties: its location, number of coordinate points used to define its geometry, type of section (whether it is a control or not), constant modifications to coordinate data, and local energy loss coefficient. The stations are entered in order, in the downstream direction, starting at the farthest upstream cross section. Each station is identified by a set of several records: ST, ND, XS, and RH.

Field	Variable	Value	Description
0	*ID*	ST	Record identification.
1	*STA*	+	Location of the station, i.e., its coordinate measured from a reference station located downstream (ft).
2	*NPOINTS*	+	Total number of points, i.e., coordinate pairs, used in records XS to define the geometry of the cross section.
3	*ISWITCH*	0 or blank	The current station is not a control section; therefore, no boundary condition is imposed there.
		1	The current station is a control section; therefore, the water surface elevation is a known function of the discharge (boundary condition) at this station.
4	*ITYP*	0 or blank	If *ISWITCH* is equal to 0.
		1	If *ISWITCH* = 1. This information is redundant, but it is kept here to allow for future developments of GSTARS 2.1 without compromising backward datafile compatibility.
5	*BEC*	0 or blank	No action is taken by GSTARS 2.1.
		+/-	The constant elevation, BEC, will be added to the given bed elevations across the channel at the present station.
6	*XSWF*	0 or blank	No action is taken by GSTARS 2.1.
		+	The scaling factor *XSWF* is applied to the lateral location of the data points that define the cross section at this station.
7	*CLOSS*	+	Local energy loss coefficient to account for bends or natural and man-made structures upstream or at this cross section.

Record ND

NUMBER OF SUBCHANNELS

Required

The ND record is used to define areas of same roughness in the cross section. Its most common use is to define main channel and flood plain locations. The roughness coefficient values corresponding to each channel division are given on the RH record. The subchannels are confined within the lateral locations specified in this record. The first subchannel is defined by the first coordinate pair entered in the XS record and by the first lateral location defined in the ND record. A maximum of 9 channel divisions can be defined. Note that if $XSWF \neq 0$ in record ST, the values of DL will also be multiplied by that factor.

Field	Variable	Value	Description
0	*ID*	ND	Record identification.
1	*NDIVI*	+	Number of channel divisions at the present station.
2–10	*DL*	+/-	Locations of the channel division boundaries. These locations are defined as a distance from a reference point in the cross section. They must be given in order, starting at the point farthest left in the cross section (looking downstream).

Example: if the cross section consists of only one channel, i.e., if the roughness coefficient is the same along the cross section, then *NDIVI* = 1 and DL must be equal to or greater than the last *CROSLOC* value on the XS record(s) defining the cross section. This would be the case if a river consists of main channel only, with no flood plains.

If a river has, say, a main channel, a left, and a right flood plain, then *NDIVI* = 3 which would be followed by 3 locations for the channel division boundaries. The value corresponding to the end point of the left flood plain (looking downstream) would be entered first. The left flood plain would be bounded by this point and by the first *CROSLOC* value of the station's XS record. The point corresponding to the end of the main channel/start of the right flood plain would be entered as the next *DL* value. The main channel would be defined as the perimeter bounded by the first two *DL* values. Finally, a number equal to, or greater than, the last *CROSLOC* value on the XS record would be entered as the last *DL* value to define the right flood plain.

XS

Record XS

CROSS SECTION GEOMETRY

Required

The XS record is used to define the cross section geometry at the given station. The cross section is described by a set of coordinate pairs. Each coordinate pair contains a lateral location and a bed elevation. The set of data points for each cross section must be given starting from the left side of the channel, looking downstream, and progress towards the right-hand side. The maximum number of coordinate points per cross section allowed in GSTARS 2.1 is 196. However, this number may be changed in future releases without notice. The user should check this value against the value printed at the top of the .DBG output file.

Field	Variable	Value	Description
0	*ID*	XS	Record identification.
1,3,5,7,9†	*CROSLOC*	+/-	Lateral coordinate, measured from a reference point, of the data points that define the cross-sectional geometry at the current station (ft).
2,4,6,8,10†	*BOTTOM*	+	Vertical coordinate (bottom elevation) of the data points that define the cross-sectional geometry at the current station (ft).

† Note: Input of cross section coordinate data does not require that the pair values fill all available fields. However, fields must be skipped in pairs, i.e., if field 5 (*CROSLOC*) is skipped, then field 6 (the corresponding *BOTTOM*) must also be skipped. The number of XS records per station is not a consideration, but the number of coordinate pairs entered in each station must equal the corresponding *NPOINTS* value in record ST. In addition, if a YX record is included in the input file, the cross section geometry must be input using bottom elevation, lateral location pairs instead of the lateral location and bottom elevation pairs as shown above.

Record RH

ROUGHNESS COEFFICIENTS

Required

Record RH is used to specify the roughness coefficient for each of the channel divisions defined in record ND for each station. The friction factors, or resistance coefficients, used must correspond to the particular roughness equation selected (see RE record description). By default, GSTARS 2.1 uses Manning equation.

Field	Variable	Value	Description
0	*ID*	RH	Record identification.
1–9	*RN*	+	Friction factor for each of the channel divisions defined in record ND. Values must be entered using the same order as in record ND, i.e., from the left to the right side of the cross section (looking downstream).

LI

Record LI

LATERAL INFLOW OF SEDIMENT AND/OR WATER

Optional

This record is used to indicate that a particular section has a lateral inflow of sediment and/or water. The information regarding the lateral inflows is stored in a separate external file whose name is given to GSTARS 2.1 using record LI. There should be one external data file for each lateral inflow. One record LI should appear at each cross section with lateral inflow.

Field	Variable	Value	Description
0	*ID*	LI	Record identification.
1–5	*FNAME*	string	An alphanumeric text string of up to 40 characters, including extension, with the name of the file containing the data corresponding to the lateral inflow for the section.

Record MX

SEDIMENT MIXING ACROSS STREAM TUBES AT LATERAL INFLOW POINTS

Optional (Required if lateral inflows are specified using LI record(s))

Record MX is used to specify the distribution of sediment across stream tubes at lateral inflow points. The data is entered in tabular format, specifying the percentage of the total incoming sediment (from the lateral inflow only; the sediment coming from the upstream computational reach will not be affected by the data in this record) falling into stream tube. If no sediment transport computations are performed, this record will be ignored.

Field	Variable	Value	Description
0	*ID*	MX	Record identification.
1–5	*PSIST*	+	The percentage of sediment staying in the corresponding stream tube. A maximum number of *NSTUBE* values must be entered, and the sum of all *PSIST* values should be 1.

Example: A river reach is being simulated using three stream tubes. If the incoming sediment is coming from the left bank and no mixing is allowed (i.e., no mixing across stream tubes), the following record could be used:

```
         1         2         3         4
123456789012345678901234567890123456789012345
MX    1.0      0.0      0.0
```

If the incoming sediment is entering from the right bank and if 20% of it is allowed to move into the middle stream tube, the following record may be used:

```
         1         2         3         4
123456789012345678901234567890123456789012345
MX    0.0     0.20     0.80
```

If five stream tubes are used and the lateral inflow gets fully mixed:

```
         1         2         3         4
123456789012345678901234567890123456789012345
MX   0.20     0.20     0.20     0.20     0.20
```

RE

Record RE

ROUGHNESS EQUATION AND FRICTION LOSS CALCULATION

Optional

The RE record is used to select the calculation method for friction loss calculations and the roughness equation. These parameters are used in the backwater computations. The Manning, Darcy-Weisbach, and Chézy equations are available. If present, record RE must be placed after the last cross-sectional set of records, i.e., after the [ST, ND, XS, RH] set for the last cross section. If no RE record is found, the program will default to the Manning equation.

Field	Variable	Value	Description
0	*ID*	RE	Record identification.
1	*IOPTFR*	1	Compute friction loss using the average slope of the adjacent reaches (default).
		2	Friction loss is computed using the geometric mean slope of the adjacent reaches.
		3	Friction loss is computed using average conveyances.
		4	Friction loss is computed using the harmonic mean slope of the adjacent reaches.
2	*EQROUGH*	MANNING	Use Manning equation; use Manning's roughness coefficients in record RH (default).
		DARCY	Use Darcy-Weisbach equation; use Darcy's friction factors in record RH.
		CHEZY	Use Chézy equation; use Chézy's resistance coefficients in record RH.

Record NT

NT

NUMBER OF STREAM TUBES

Required

The number of stream tubes used in sediment-routing computations is defaulted to three. The NT record defines an alternate number of stream tubes to be used in computations. The number of calculations performed in GSTARS 2.1 is proportional to the number of stream tubes used, therefore more stream tubes also means longer computation times. In general, three stream tubes provide enough detail across a channel, but up to five stream tubes can be used in GSTARS 2.1. (This value may change without notice in future releases of the program; see header of .DBG output file for updated information.)

Field	Variable	Value	Description
0	*ID*	NT	Record identification.
1	*NSTUBE*	1–5	Number of stream tubes to be used in the computations.

IT

Record IT

NUMBER OF ITERATIONS

Required

This record is used to define the desired number of time steps for the run. There are two time stepping procedures in GSTARS 2.1: the water-routing and the sediment-routing procedures. Time steps can be defined for each of these procedures. The number of water routing time steps is defined by *ITIMAX*, and its duration is defined by *DTIME* (all time steps have the same duration in time). The number of sediment-routing time steps is defined by *NITRQS*, and their duration is *DTIME/NITRQS*. The number of sediment-routing time steps is a multiple of *ITIMAX*; i.e., several sediment routing time steps can be performed during each water-routing time step. During each of the sediment time steps, the hydraulic parameters are kept constant.

Field	Variable	Value	Description
0	*ID*	IT	Record identification.
1	*ITIMAX*	+	The number of time steps to be performed, pertaining to the water-routing calculations.
2	*NITRQS*	+	The number of sediment-routing time steps to be carried out during each hydraulic time step.
3	*DTIME*	+	Duration of time step for the backwater computations.
4	*TSUNITS*	0, DAY	Time step unit is a day. This is the default value.
		HOUR	Time step unit is the hour.
		MIN	Time step unit is the minute.
		SEC	Time step unit is the second.

Record QQ

TYPE OF DISCHARGE INPUT

Required

This record is used to specify the type of input format chosen for the water discharge information. There are two options: the discharge values can be given as a table (discharge per time step) or as discretized discharges in time blocks of different durations.

Field	Variable	Value	Description
0	*ID*	QQ	Record identification.
1	–	–	Leave blank.
2	*IOPTQ*	TABLE OF DISCHARGES†	Enter the discharges in tabular form. Discharges must be given for each time step. This is the default.
		DISCRETIZED DISCHARGES‡	Enter the discharges as time blocks with specified duration.

† TA or 0 in field 2 is also acceptable to select the table of discharges option.

‡ DI or DD in field 2 is also acceptable to select the discretized discharges option.

SS

Record SS

TYPE OF STAGE INPUT

Required

Record SS is used to define the type of stage input format at the control section(s). There are two options: a rating curve defining a stage-discharge relationship or a table with a list of stage-discharge values.

Field	Variable	Value	Description
0	*ID*	SS	Record identification.
1	–	–	Leave blank.
2–3	*IOPTQ*	RATING CURVE	Use a rating curve, as described in the RC record.
		STAGE DISCHARGE TABLE	Use a list of stage values with corresponding discharges (see description of SQ record).

Record TQ

TQ

TABLE OF DISCHARGES

Optional

This record is used when the TABLE OF DISCHARGES option (QQ record) is used in conjunction with the RATING CURVE option (SS record). The TQ record is used to enter a table with the water discharge for each time step. One value of the water discharge must be entered for each time step; i.e., *ITIMAX* values of the water discharge must be given (see IT record). When the TQ record is used, a stage-discharge relationship must be defined using the RC record.

Field	Variable	Value	Description
0	*ID*	TQ	Record identification.
1–10	*QQ*	+	Value of the water discharge for each time step. The number of water discharge values must be equal to the value of *ITIMAX* entered in the IT record (ft^3/s).

DD

Record DD

DISCRETIZED DISCHARGES

Optional

This record is used when the option DISCRETIZED DISCHARGES is used in record QQ. The values of the discharges are entered in time blocks with duration multiple of the time step. The values are entered in a two-column table with the duration of the discharge in field 1 and its value in field 2. The sum of all the values in field 1 must correspond to the total duration of the run; i.e., it must equal the number of time steps for the run (value *ITIMAX* in record IT).

Field	Variable	Value	Description
0	*ID*	DD	Record identification.
1	*NDAY*	+	Number of time steps corresponding to the duration of the discharge defined in field 2.
2	*QI*	+	Value of the water discharge. Note that, for the duration of *NDAY**DTIME*, the system is considered in steady state with the constant discharge given in *QI* (ft^3/s).

Record NC

Number of Rating Curves

Optional

The NC record is used to input the number of rating curves used for the reach being modeled. This record must be entered immediately before the RC records with the rating curve information.

Field	Variable	Value	Description
0	*ID*	NC	Record identification.
1	*NCURVES*	+	Number of rating curves defined in the reach.

RC

Record RC

RATING CURVE

Optional

Each RC record contains all the information pertinent to a particular rating curve. Each rating curve is a stage-discharge relationship defined in the form

$$Stage\ (\text{ft}) = C1\ \ (discharge\ [\text{ft}^3/\text{s}])^{C2} + C3$$

The RC record, which is used when the options RATING CURVE is selected in the SS record, contains the number of the station where the rating curve applies, as well as the values of the coefficients *C*1, *C*2, and *C*3. The total number of rating curves used is defined in the NC record.

Field	Variable	Value	Description
0	*ID*	RC	Record identification.
1	*ISTA*	+	Number of the station where the rating curve applies. Note that the cross section numbering starts at the station farthest upstream and proceeds downstream.
2	*C*1	+/-	Value of the coefficient *C*1.
3	*C*2	+/-	Value of the coefficient *C*2.
4	*C*3	+/-	Value of the coefficient *C*3.

Record TL

CROSS SECTION IDENTIFICATION RECORD FOR THE STAGE-DISCHARGE TABLE

Optional

Record TL is used when SQ records are used to define pairs of stage-discharge values. It is used to identify the station number for which the SQ records apply. The cross sections are numbered starting from the section farthest upstream (station 1) and proceeding downstream. The last station (farthest downstream) is numbered *NSTA* (see record NS).

Field	Variable	Value	Description
0	*ID*	TL	Record identification.
1	*ITABLE*	+	Number of the station for which the values given in record SQ apply.

SQ

Record SQ

STAGE-DISCHARGE TABLE

Optional

The SQ record is used when option TABLE OF DISCHARGES in record QQ is used in conjunction with option STAGE DISCHARGE TABLE in record SS. In this case, SQ records are used to build a table defining water discharges and corresponding stages for each time step. The stage-discharge pairs are entered in each row of the table in the proper time sequence. The same pair can be used for multiple consecutive time steps, but the summation of all *TSCOUNT* values must equal the variable *ITIMAX* defined in the IT record. Record TL is used to define the station number for which the table is valid.

Field	Variable	Value	Description
0	*ID*	SQ	Record identification.
1	*QQ*	+	Value of water discharge (ft^3/s).
2	*STAGE*	+	Value of corresponding water elevation (ft).
3	*TSCOUNT*	0, 1	Use discharge and stage values for a single time step (default).
		+	Use discharge and stage values for multiple time steps.

Record SE

SEDIMENT TRANSPORT EQUATION

Required for Sediment Transport

The SE record selects the sediment transport equation used to compute sediment carrying capacities for size fractions greater than 0.0625 mm. This record also allows the control of the active layer thickness.

Field	Variable	Value	Description
0	*ID*	SE	Record identification.
1	*ISED*	+	Variable to choose the sediment transport equation used to compute sediment carrying capacity. The options are:
		1	Meyer-Peter and Müller's method.
		2	Laursen's method.
		3	Toffaleti's method.
		4	Engelund and Hansen's method.
		5	Ackers and White's 1973 method.
		6	Yang's 1973 sand with 1984 gravel formulas.
		7	Yang's 1979 sand with 1984 gravel formulas.
		8	Parker's method.
		9	Yang's 1996 modified formula. (Requires additional wash load parameter input. See SP record.)
		10	Ackers and White's method with the revised (1990) coefficients.
		11	DuBoys' method.
2	*NALT*	0	Use the default active layer thickness of 14**D(LSF)*, where *D(LSF)* is the geometric mean sediment size of the largest size fraction available (with at least 1%) at a specific cross section for a particular time step.
		+	A user-specified positive multiplication factor for defining the thickness of active layer given as *TAL = NALT * D(LSF)*.

SP

Record SP

High Concentration Transport Parameters

Optional (Required with Yang's 1996 modified formula)

The SP record allows the user to input the additional parameter values needed by Yang's 1996 modified formula. This record must be included in the input file if the *ISED* value on the SE input record is set to select Yang's 1996 modified formula. The SP record immediately follows the SE input record.

Field	Variable	Value	Description
0	*ID*	SP	Record identification.
1	*PWASHLD*	+	Percentage of wash load $(0 \leq PWASHLD \leq 1)$.

Record NE

NON-EQUILIBRIUM SEDIMENT TRANSPORT

Optional

The NE record is used to input the parameters necessary for non-equilibrium sediment transport calculations. The non-equilibrium calculations are activated if this record is present in the input file.

Field	Variable	Value	Description
0	*ID*	NE	Record identification.
1	*ALPHAD*	0, +	Recovery factor for deposition (default is 0.25).
2	*ALPHAS*	0, +	Recovery factor for scour (default is 1.0).

NO

Record NO

VARIABLE NON-EQUILIBRIUM SEDIMENT TRANSPORT PARAMETERS

Optional

The NO record is used to input the parameters necessary for non-equilibrium sediment transport calculations when the non-equilibrium recovery factors vary along a certain reach. The non-equilibrium calculations are activated if this record is present in the input file. Any number of NO records can be used, to a maximum of NMXSTA records (NMXSTA is the variable that defines the maximum number of cross sections allowed in each release of GSTARS 2.1). The records must be given from downstream to upstream, i.e., the records must be specified in the order of increasing *NESTA*. NO records can be used instead of NE records, but not simultaneously.

Each record defines the recovery factors for deposition and scour at a particular location. The given location does not need to coincide with an actual station defined by a ST record. Stations located in between NO record locations will have interpolated values of the recovery factors. Stations located outside NO record ranges will not be extrapolated, i.e., stations located downstream from the first NO record will have the recovery factors defined by the first NO record; the stations located upstream from the last NO record will have the same distribution as the last NO record.

Field	Variable	Value	Description
0	*ID*	NO	Record identification.
2	*NESTA*	+	The location where the recovery factors are defined (ft).
1	*ALPHAD*	0, +	Recovery factor for deposition at the current location (no default value).
2	*ALPHAS*	0, +	Recovery factor for scour at the current location (no default value).

Record C1

Coefficients for the Discretization of Exner's Equation

Optional

This record is used to define the coefficients used to approximate the change in the volume of bed sediments due to deposition or scour, ΔA_d, which is used in the numerical solution of Exner's equation, that is, of the sediment routing equation. ΔA_d is discretized using

$$(\Delta A_d)_i = (aP_{i-1} + bP_i + cP_{i+1})\Delta Z_i$$

where P = wetted perimeter; i = cross section index (i-1 is upstream, i+1 is downstream); ΔZ = change in bed elevation; and a, b, and c are coefficients that must satisfy $a + b + c = 1$. The values of a, b, and c are entered using this record. If the record is absent from the input data file, GSTARS 2.1 uses the values $a = c = 0.25$ and $b = 0.5$. If the record is present, then all the coefficients must be specified. For the first cross section ($i = 1$) the value of P_{i-1} is not defined, therefore $a = 0$. The user must specify separately the values for b and c for this particular station, with the requirement that $b + c = 1$.

Note that GSTARS 2.1 adds a dummy section to the downstream end of the channel in order to complete the sediment routing computations. The dummy section added has the same properties as the last cross section ($i = NSTA$). Therefore, in this case the area change will be approximated by

$$(\Delta A_d)_{NSTA} = (aP_{NSTA-1} + bP_{NSTA} + cP_{NSTA})\ \Delta Z_{NSTA}$$

Field	Variable	Value	Description
0	*ID*	C1	Record identification.
1	*C1WP*	+	Value of the coefficient a in the equations above (default is 0.25).
2	*C2WP*	+	Value of the coefficient b in the equations above (default is 0.5).
3	*C3WP*	+	Value of the coefficient c in the equations above (default is 0.25).
4	*C1WPU*	+	Value of the coefficient b for the cross section $i = 1$ (default is 0.75).
5	*C2WPU*	+	Value of the coefficient c for the cross section $i = 1$ (default is 0.25).

C2

Record C2

COEFFICIENTS FOR COMPUTING SEDIMENT TRANSPORT CAPACITY

Optional

The hydraulic parameters used for the computation of sediment transport capacities are values of the cross-sectional area, depth, velocity, and friction slope. These representative values are computed from a weighted average in the following manner:

$\Theta R_i = a\Theta_{i-1} + b\Theta_i + c\Theta_{i+1}$ for interior sections ($i < NSTA$)

$\Theta R_i = a^*\Theta_{NSTA-1} + b^*\Theta_{NSTA}$ for the downstream most section ($i = NSTA$)

$\Theta R_i = b^{**}\Theta_1 + c^{**}\Theta_2$ for the upstream most section ($i = 1$)

where Θ represents the hydraulic property of interest (cross-sectional area, depth, velocity, or friction slope); i = cross section index (i-1 is upstream, i+1 is downstream); a, b, and c are coefficients that must satisfy $a + b + c = 1$; a^* and b^* are coefficients that must satisfy $a^* + b^* = 1$; and b^{**} and c^{**} are coefficients that must satisfy $b^{**} + c^{**} = 1$. The values of a, b, c, a^*, b^*, b^{**}, and c^{**} are entered using this record. If the record is absent from the input data file, GSTARS 2.1 uses the values $a = c = 0$, $b = 1$, $a^* = 0$, and $b^* = 1$. If the record is present, then all the coefficients must be specified.

Field	Variable	Value	Description
0	*ID*	C2	Record identification.
1	*C1Q*	+	Value of the coefficient a in the equation above (default is 0).
2	*C2Q*	+	Value of the coefficient b in the equation above (default is 1).
3	*C3Q*	+	Value of the coefficient c in the equation above (default is 0).
4	*C1QD*	+	Value of the coefficient a^* in the equation above (default is 0).
5	*C2QD*	+	Value of the coefficient b^* in the equation above (default is 1).
6	*C1QU*	+	Value of the coefficient b^{**} in the equation above (default is 1).
7	*C2QU*	+	Value of the coefficient c^{**} in the equation above (default is 0).

Record QS

QS

SEDIMENT DISCHARGE

Required for Sediment Transport (May be eliminated if QR record is used)

Sediment transport modeling requires specifying the sediment entering the reach being studied. In GSTARS 2.1, the sediment discharge hydrograph must be approximated by a series of bursts having a constant value and a certain duration. The resulting discretized hydrograph is entered in tabular format in QS records. The table has two columns: one for the duration of the constant discharge burst (as a multiple of the time step *DTIME* defined in record IT), another for the value of the sediment discharge. The values are entered sequentially.

Note that record QR can be used instead of record QS, but these two records are mutually exclusive.

Field	Variable	Value	Description
0	*ID*	QS	Record identification.
1	*NDAY*	+	Number of time steps for the specified sediment discharge. Note that the sum of all *NDAY* values must equal the value of *ITIMAX* specified in record IT.
2	*QSI*	+	Sediment discharge entering the study reach for the specified period of time (tons/day, US units of 2,000 lb/day).

QR Record QR

SEDIMENT DISCHARGE RATING CURVE

Optional

The QR record defines the sediment discharge entering the study reach at the cross section farthest upstream as a function of the water discharge. The assumed relationship between the water discharge and the sediment discharge is of the form:

$$\textit{Sediment discharge}\ [\text{ton/day}] = AQRC \cdot (\textit{Water discharge}\ [\text{ft}^3/\text{s}])^{BQRC}$$

Only one QR record is permitted. The QR record can be used instead of record QS, but not at the same time; i.e., the records QR and QS are mutually exclusive.

Field	Variable	Value	Description
0	*ID*	QR	Record identification.
1	*AQRC*	+	Value of the coefficient *AQRC*.
2	*BQRC*	+	Value of the exponent *BQRC*.

Record TM

WATER TEMPERATURE

Required for Sediment Transport

Record TM is used to enter the water temperature of the study reach for each time step. The temperatures are entered in a two-field record, with the values of the temperature in field 2 and the number of time steps for which the temperature is valid in field 1. Field 3 may be used to specify the temperature units used (Centigrade or Fahrenheit). The summation of *NDAY* from all the TM records must equal the value of *ITIMAX* defined in the IT record.

Field	Variable	Value	Description
0	*ID*	TM	Record identification.
1	*NDAY*	+	Number of time steps for which the given water temperature (*TEMP*) applies to the study reach.
2	*TEMP*	+	Water temperature of the study reach.
3	*TEMPU*	0, F	Temperature is given in degrees Fahrenheit (default).
		C	Temperature is given in degrees Centigrade.

SF

Record SF

NUMBER OF SEDIMENT SIZE FRACTIONS

Required for Sediment Transport

This record is used to specify the dry specific weight of sediments and the number of sediment size fractions used in the study. In the present release of GSTARS 2.1, this value is limited to 10, but it may change in future releases. The user should consult the header of the .DBG output file to check this value.

Field	Variable	Value	Description
0	*ID*	SF	Record identification.
1	*NF*	+	Number of size fractions defined for the current study $(1 \leq NF \leq 10)$.
2	*BDINPUT*	0†	Use a dry specific weight default value of 99.26 lb/ft^3.
		+†	Specify a dry specific weight value (lb/ft^3).

† Porosity is calculated from the specified dry specific weight and specific gravity values.

Record SG

SEDIMENT SIZE GROUPS

Required for Sediment Transport

The sediment size groups for the study are defined using SG records. The dry specific weight for individual size groups can also be defined in these records. The number of SG records must equal the value of NF defined in record SF (one SG record is required for each size fraction), and the records must be ordered with increasing sediment sizes.

The lower bound for sand sizes is 0.0625 mm. If a lower mean particle size is given, the cohesive sediment transport methods will automatically be activated, and a CS record is required. For each size group, GSTARS 2.1 computes the geometric mean grain size as $D_{mean} = \sqrt{DRU \times DRL}$.

Field	Variable	Value	Description
0	*ID*	SG	Record identification.
1	*DRL*	+	Lower bound of the particle size for this group (mm).
2	*DRU*	+	Upper bound of the particle size for this group (mm).
3	*BDINPK*	0	Use the default dry specific weight (99.26 lb/ft^3) or the dry specific weight specified in record SF.
		+	Dry specific weight for this size fraction (lb/ft^3). This value will override the value of *BDINPUT* given in record SF.

SD

Record SD

SEDIMENT SIZE DISTRIBUTION

Required for Sediment Transport

SD records are used to specify the bed material composition for each station in the study reach. At each station, the bed composition is defined as the bed material size fractions falling within each one of the size fractions defined in SG records. One SD record must be entered for each section of the study reach, starting at the upstream-most station and proceeding downstream. Note that a combination of NB and BG records may be used instead of SD records.

Field	Variable	Value	Description
0	*ID*	SD	Record identification.
1–10	*P*		Percentage of bed material falling within each of the size groups defined in SG records. The values of *P* must be entered in order, from the smallest to the largest size fractions defined for the study. A total of *NF* values must be entered in each record (*NF* is defined in record SF). The sum of all *P* values must be equal to 1. $(0 \le P \le 1)$

Record NB

SEDIMENT SIZE DISTRIBUTION LOCATION

Optional

Record NB is used in conjunction with record BG to specify the bed material size fractions for a specific location. Each NB record requires one BG record, and a maximum of *NSTA* (record NS) sets of NB/BG records is allowed. The NB/BG records may be used instead of SD records. See description of BG record for more details.

The NB record specifies the location where the bed gradation is known. This location does not have to coincide with an actual computational cross section, as defined in records [ST,ND,XS,RE]. However, the location must be given as a distance from the downstream reference location used for variable *STA* (record ST). The [NB,BG] pairs of records must be ordered, starting with the location having the lowest *BGSTA* value and ending with the location having the highest *BGSTA* value.

Field	Variable	Value	Description
0	*ID*	NB	Record identification.
1	*BGSTA*	+	The location where the bed gradation is given (ft).

BG

Record BG

SEDIMENT SIZE DISTRIBUTION FOR SPECIFIC LOCATION

Optional (Required if record NB is present)

Record BG is used to input the bed material size fractions falling within each size group defined by SG records. The location where the BG data is defined is given in the associated NB record. GSTARS 2.1 uses [NB,BG] records to determine the bed material size fractions at each computational cross section by interpolation. The records must be given from downstream to upstream; i.e., the records must be specified in the order of increasing *BGSTA*.

The bed material size fractions of the computational cross sections located between two *BGSTA* locations are determined from a linear interpolation of the corresponding values specified in BG records. However, GSTARS 2.1 does not extrapolate values: the stations located downstream from the first [NB,BG] set will have the same distribution as the first BG record; the stations located upstream from the last [NB,BG] set will have the same distribution as the last BG record.

Field	Variable	Value	Description
0	*ID*	BG	Record identification.
1–10	*P*		Percentage of bed material falling within each one of the size groups defined in SG records. The values of *P* must be entered in order, from the smallest to the largest size fractions defined for the study. A total of *NF* values must be entered in each record (*NF* is defined in record SF). The sum of all *P* values must be equal to 1. $(0 \le P \le 1)$

Record CS

CS

Transport Parameters for Cohesive Sediments

Optional (Required if sediment size fractions in the silt/clay range are included in the SG record)

The CS record is used for cohesive sediment (clay and silt) transport modeling. If a sediment size group (defined in the SG record) has a geometric mean grain size lower than 0.0625 mm, the cohesive sediment transport methods will be selected for those size groups. The equation specified in record SE will be used for the remaining size groups.

If silt and/or clay group sizes are not present, this record must not be given. Otherwise, the record should be inserted immediately after the last SD (or BG) record. No default values are available for any of the variables in this record.

Field	Variable	Value	Description
0	*ID*	CS	Record identification.
1	*STDEP*	+	Shear threshold for deposition of clay and silt (lb/ft^2).
2	*STPERO*	+	Shear threshold for particle erosion of clay and silt (lb/ft^2).
3	*STMERO*	+	Shear threshold for mass erosion of clay and silt (lb/ft^2).
4	*ERMASS*	+	Slope of the erosion rate curve for mass erosion (1/hr).
5	*ERSTME*	+	Erosion rate of clay and silt when the bed shear stress is equal to *STMERO* (lb/ft^2/hr).
6	*ERLIM*	+	Threshold value for the percentage of clay in the bed composition above which the erosion rates of gravels, sands, and silts are limited to the erosion rate of clay $(0 < ERLIM \leq 1)$.

CO

Record CO

VARIABLE PARAMETERS FOR COHESIVE SEDIMENT TRANSPORT

Optional (Required if sediment size fractions in the silt/clay range are included in the SG record)

The CO record is used for cohesive sediment transport modeling. If a sediment size group (defined in the SG record) has a geometric mean grain size lower than 62.5 μm, the clay/silt transport methods will be selected for those size groups. The equation specified in record SE will be used for the remaining size groups. This record can be used instead of record CS, but not simultaneously.

Each record defines the cohesive transport parameters at a particular location. The given location does not need to coincide with an actual station defined by a ST record. Stations located in between CO record locations will have interpolated values of the parameters. Stations located outside CO record ranges will not be extrapolated, i.e., stations located downstream from the first CO record will have the parameters defined by the first CO record; the stations located upstream from the last CO record will have the same parameters as the last CO record.

Any number of CO records can be used, to a maximum of *NMXSTA* records (*NMXSTA* is the variable that defines the maximum number of cross sections allowed in a particular release of GSTARS 2.1). The records must be given from downstream to upstream, i.e., the records must be specified in the order of increasing *NESTA*.

Field	Variable	Value	Description
0	*ID*	CO	Record identification.
1	*NESTA*	+	The location where the parameters are defined (ft).
2	*STDEP*	+	Shear threshold for deposition of clay and silt (lb/ft^2).
3	*STPERO*	+	Shear threshold for particle erosion of clay and silt (lb/ft^2).
4	*STMERO*	+	Shear threshold for mass erosion of clay and silt (lb/ft^2).
5	*ERMASS*	+	Slope of the erosion rate curve for mass erosion (1/hr).
6	*ERSTME*	+	Erosion rate of clay and silt when the bed shear stress is equal to *STMERO* (lb/ft^2/hr).
7	*ERLIM*	+	Threshold value for the percentage of clay in the bed composition above which the erosion rates of gravels, sands, and silts are limited to the erosion rate of clay $(0 < ERLIM \leq 1)$.

Record CF

SEDIMENT SIZE DISTRIBUTION FOR TRANSPORT CAPACITY CALCULATIONS

Optional

The CF record defines the C_{factor} coefficient for bed load computations:

$$FBB_k = C_{factor} FB_k + (1 - C_{factor}) FS_k$$

where FB_k = percentage of bed material belonging to size fraction k; FS_k = percentage of incoming sediment belonging to size fraction k; and FBB_k = percentage used to compute the transport capacity of size fraction k.

This parameter may be useful to model situations in which the distribution of the sediment incoming to a reach may be different from the distribution of the sediment present in the bed. This record should be placed after record CS or CO (or after the place where record CS would be, if present).

Field	Variable	Value	Description
0	*ID*	CF	Record identification.
1	*CFACTOR*	+	Value of C_{factor}. Must have a value between 0 and 1. If C_{factor} = 1 (default), only material present in the bed will have non-zero carrying capacity.

IQ

Record IQ

INPUT SEDIMENT DISTRIBUTION

Optional

This record is used to vary the size distribution of the input sediment discharge. It is used in conjunction with IS records to construct a table of size distribution as a function of water discharge entering the channel. Record IQ is used to define the water discharges for which sediment size distributions are defined. For values of the discharge between the values defined in record IQ, the sediment size distribution is interpolated from the corresponding size distributions defined in the corresponding fields of IS record(s). See description of IS record.

Field	Variable	Value	Description
0	*ID*	IQ	Record identification.
1	*NDISCH*	1–9	Number of columns in the table, i.e., number of entries for which water discharge is defined. A maximum of nine water discharge entries is allowed.
2–10	*QIC*	+	Water discharge values which will define interpolation segments of the incoming sediment size distribution. A maximum of nine values is permitted. Each value entered must be larger than its predecessor (ft^3/s).

Record IS

IS

INPUT SEDIMENT DISTRIBUTION BY SIZE FRACTION

Optional (Required if record IQ is present)

This record is used in conjunction with record IQ to construct a table of input sediment size distribution as a function of water discharge:

	QIC_1	QIC_2	...	QIC_{NDISCH}
Size fraction 1	$PISED_{1,1}$	$PISED_{2,1}$	...	$PISED_{NDISCH,1}$
Size fraction 2	$PISED_{1,2}$	$PISED_{2,2}$	...	$PISED_{NDISCH,2}$
...	...	...	...	...
Size fraction *NF*	$PISED_{1,NF}$	$PISED_{2,NF}$	...	$PISED_{NDISCH,NF}$

The values QIC_i are the water discharges for which the size distributions of the incoming sediment are known. Using IS records, the percentage of material, $PISED_{i,j}$, for each size fraction defined in the SF and SG records is entered in columns corresponding to each value of QIC_i defined on the IQ record. The size distributions are given in each column in order from the finest to the coarsest size fractions. The number of IS records must equal the number of SG records (i.e., must be equal to *NF*, which is the number of size fractions defined in record SF). The size distributions are interpolated for discharges between the specified *QIC* values. For values of the discharge outside the table, no extrapolation is done; i.e., if $Q < QIC_1$ the size distribution for QIC_1 is used; if $Q > QIC_{NDISCH}$ the size distribution for QIC_{NDISCH} is used.

Field	Variable	Value	Description
0	*ID*	IS	Record identification.
1	*COMNT*	string	A comment, i.e., an alphanumeric ASCII string of up to six characters.
2–10	*PISED*	+	The percentage of the incoming sediment corresponding to the given size fraction and discharge $(0 \le PISED \le 1)$.

Example: If three size fractions are specified, for example silt, sand, and gravel (*NF* = 3), and the corresponding distributions are known for three discharges, 100, 1,000, and 10,000 ft^3/s (*NDISCH* = 3), then the following records could be used:

IS

```
             1         2         3         4
123456789012345678901234567890123456789012345

IQ     3     100.    1000.  10000.
IS silt      0.50     0.60    0.90
IS sand      0.40     0.25    0.07
IS gravl     0.10     0.15    0.03
```

Record AR

AR

ANGLE OF REPOSE

Optional

The input record AR allows users the option to input bank slope criteria both above and below the calculated water surface. Each time step, the bank slopes will be flattened to the specified angle of repose limits. Mass is conserved in this adjustment.

Field	Variable	Value	Description
0	*ID*	AR	Record identification.
1	*ANGLE1*	90†	Default angle of repose at and above the water surface.
		+	The value of the angle, specified in degrees from horizontal, limits the bank slope at and above the water surface.
2	*ANGLE2*	90†	Default angle of repose below the water surface.
		+	The value of the angle, specified in degrees from horizontal, limits the bank slope below the water surface.

† Note: a negative angle of repose specified for either *ANGLE1* or *ANGLE2* will deactivate the computations and the program will behave as if a 90 degree angle was entered. However, the overall computational time of the run will be reduced.

PR

Record PR

PRINTOUT CONTROL

Required

GSTARS 2.1 output is given in ASCII files with different extensions. Usually, the output of relevant quantities is required at the end of the computer run. The PR record is used to define the level of output generated and its interval, i.e., the amount of information required and the number of time steps elapsing between successive writings to the output files during the run.

Field	Variable	Value	Description
0	*ID*	PR	Record identification.
1	*IPRLVL*	-1	No output is required.
		0	Level 0 output: print only water surface profile and sediment routing tables (default).
		1	Level 1 output: in addition to level 0 output, normal and critical depth tables are generated.
		2	Level 2 output: in addition to level 1 output, stream tube geometry and conveyances are generated.
		3	Level 3 output: in addition to level 2 output, sediment transport capacities are written to the .SED file.
2	*INTPR*	+	Number of time steps between output. If *INTPR* = 1, output takes place at each time step. If *INTPR* > *ITMAX* (record IT), no output is generated.

Record PX

CHANNEL CROSS SECTION PLOTTING

Optional

This record is used to generate cross section data for plotting at certain time intervals during the run. Cross section geometry is written in an external ASCII file with extension .XPL containing the title of the study followed by tables of coordinate pairs. Each table contains bottom elevation and lateral location of the points describing each cross section of the reach. The data is used by the GSTARS 2.1 GUI, but it can be easily imported into almost any spreadsheet program for graphing purposes. Cross-sectional geometry is printed at specified time step intervals. The first set of cross sections represent the initial conditions at the reach; i.e., they are the cross sections before the run has started (at time step 0).

Field	Variable	Value	Description
0	*ID*	PX	Record identification.
1	*INTPL1*	0	No cross section plots are generated.
		> 0	Cross section plots are generated for all of the stations in the study reach, at time intervals with duration equal to *INTPL1* time steps. If *INTPL1* = 1, output is generated at every time step. If *INTPL1* > *ITIMAX*, no output is generated (except for time step 0).

PW

Record PW

WATER SURFACE PROFILE PLOTTING

Optional

The PW record is used to generate longitudinal profiles with the thalweg and the water surface of the study reach at certain time intervals during the run. The data are written in an external ASCII file with extension .WPL containing the title of the study followed by tables with three entries: station location, bottom elevation, and free surface elevation. Each table contains information for a particular time step of the run, and the information is generated at a specified interval. The first table represents the reach at time step 0, i.e., before the run has started. The data is used by the GSTARS 2.1 GUI, but it can be easily imported into almost any spreadsheet program for graphing purposes.

Field	Variable	Value	Description
0	*ID*	PW	Record identification.
1	*INTPL2*	0	No profiles are generated.
		> 0	Longitudinal profiles of thalweg and water surface elevation are generated at time intervals with duration equal to *INTPL2* time steps. If *INTPL2* = 1, output is generated at every time step. If *INTPL2* > *ITIMAX*, no output is generated (except for time step 0).

Record MR

RANGE OF BED ELEVATION AND WIDTH VARIATION

Required for Stream Power Minimization Calculations

When the MR record is used, GSTARS 2.1 automatically activates the total stream power minimization routines. Record MR is also used to define bed elevation and width limits for each station in the reach. These limits correspond to restrictions, geological or man-made, to deposition and/or scour. The MR records must be omitted if minimization is not requested. For each time iteration, the total stream power minimization computations are used in the program's logic to decide whether to make scour or deposition adjustments in the lateral or vertical directions. One MR record has to be specified for each station. MR records must be entered in sequential order, starting at the station farthest upstream and proceeding downstream.

Field	Variable	Value	Description
0	*ID*	MR	Record identification.
1	*XLFTI*	+/-	Lateral location beyond which no cross section widening is allowed. This location corresponds to the left-hand side restriction, looking downstream, and is valid for a particular station (ft).
		-9999.	No left-hand side boundary.
2	*XRGHTI*	+/-	Lateral location beyond which no cross section widening is allowed. This location corresponds to the right-hand side restriction, looking downstream, and is valid for a particular station (ft).
		9999.	No right-hand side boundary.
3	*CBLI*	+	Limit for scour in the vertical direction. No scour is allowed beyond this bottom elevation (ft).
		0	No restrictions for scour in the vertical direction.
4	*CBHI*	+	Limit for deposition in the vertical direction. No deposition is allowed above this bottom elevation (ft).
		9999.	No restrictions for deposition in the vertical direction.

END

Record END

END OF INPUT DATA

Required

The END record is required at the end of each input data file to terminate the data input operations.

Field	Variable	Value	Description
0	*ID*	END	Record identification.

APPENDIX B

Example applications of GSTARS 2.1.

Table of contents for Appendix B

NOTE: The sets of examples presented in this appendix are conceptual problems. They are presented here to show the user how to set-up input data files for GSTARS 2.1. Although some of the examples are part of actual field studies carried out using GSTARS 2.1 or earlier versions, they should not be used for any other purpose without appropriate verification and validation of the input data and of the computed results.

GSTARS 2.1 is in a stage of constant evolution and is subject to change without notice. Because of that, and because of the time lag between the writing of this manual and its actual typesetting and publication, there may be some differences between the release version of GSTARS 2.1 and the version that was used to run the examples. As a result, there may be slight differences between the printed output presented in this appendix and the actual output generated by GSTARS 2.1.

EXAMPLE 1

WATER SURFACE CALCULATIONS

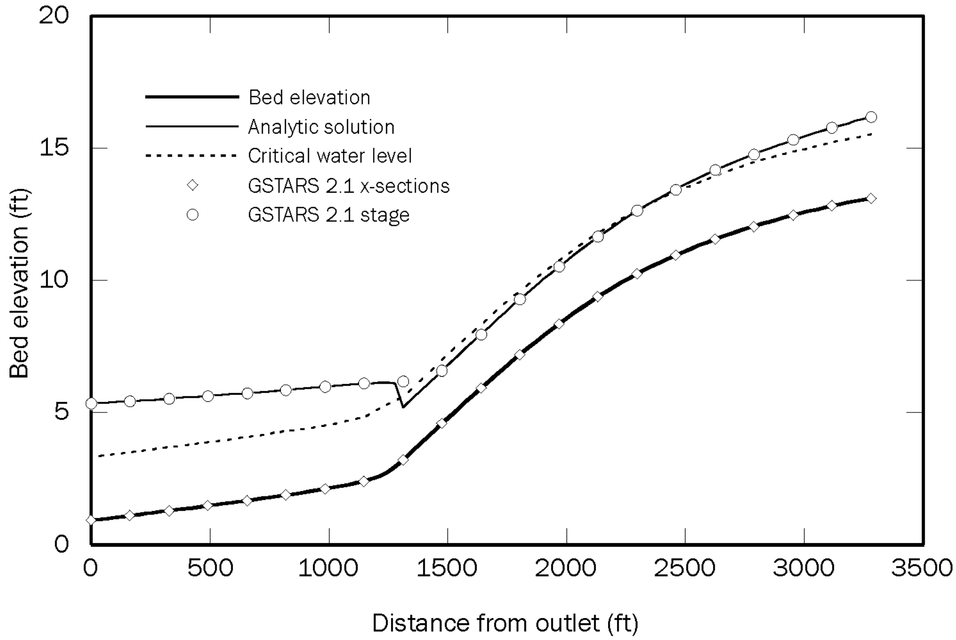
This example shows a GSTARS 2.1 data file set-up for water surface profile calculations without sediment transport. For that purpose we use test problem 4 in MacDonald et al. (1997). This example was chosen because it contains mixed flow regimes: the flow is subcritical at the channel's inlet, turns supercritical one third down the channel, and becomes subcritical again at the downstream end, involving two regime transitions (including one hydraulic jump).

The channel is 3281 ft (1000 m) in length and has a Manning's roughness coefficient of 0.02. It has a trapezoidal cross section with side slopes of 1:1 and a bottom width of 32.8 ft (10 m). A discharge of 706.2 ft^3/s (20 m^3/s) is specified at the inlet. The bed slope varies along the channel's length, as seen in figure 1.1. In figure 1.1 the critical water depth level is also plotted to help determine the regions of sub- and supercritical flow.

The data file (given in the next section) was prepared using a table of discharges and a rating curve to specify the known water stage at the channel's outlet. The results of the GSTARS 2.1, shown in figure 1.1, present a very good agreement with the analytical solution. In particular, GSTARS 2.1 was able to accurately compute the flow regime transitions. Note that the GSTARS 2.1 cross sections used for this example run (i.e., their locations) are shown by the position of the diamond markers in figure 1.1. More accuracy in locating the hydraulic jump could be achieved by using more cross sections near the region of interest. For this run only 21 equally spaced cross sections were used, located 164 ft (50 m) apart.

Note that in this case no sediment transport takes place, therefore no stream tube hydraulics is necessary (the program is set to use one stream tube). Print options are set to 2 in record PR and 0 in record PX (no cross section plots are requested).

Figure 1.1 Plot of test case #4 of MacDonald et al. (1997) showing channel geometry, analytical solution, and GSTARS 2.1 computation.



1.1 Input data file

The files shown in this and the next sections are part of the main GSTARS 2.1 distribution package. They can be found under directory Example1.

```
TT    Example problem for GSTARS 2.1: mixed flow regime, hydraulics only.
TT        Set-up based on Test Problem 4 of MacDonald et al. (1997).
TT                   File set-up by F. Simoes, Dec. 2000.

********************************************************************************
***  NOTE: this is a datafile to be used as an example of input data as it   ***
***  might be used in a GSTARS version 2.1 simulation.  It represents a      ***
***  ficticious case and it sould be viewed as such.  It should not be used  ***
***  for any other purpose without appropriate verification and validation.  ***
***                                                                          ***
***  ------------------------------------------------------------            ***
***  Problem Description: problem #4 of MacDonald et al. (1997).             ***
***  Data Filename: Ex1.data                                                 ***
***  Shape: trapezoidal channel, top width = 32.81 + 2y (ft).                ***
***  Side Slopes: 1:1                                                        ***
***  Channel Length: 3280.8 ft (1000 m).                                     ***
***  Channel Slope (s): 0.001                                                ***
***  Number of Stations: 21 equally spaced at 164 ft (50 m).                 ***
***  Testing: mixed flow regimes with hydraulic jump.                        ***
***  ------------------------------------------------------------            ***
********************************************************************************

NS    21
```

```
*** Station  1
ST3280.8       9       1       1
ND     1 32.8084
XS 0.000 45.9318 16.4042 29.5276 32.8084 13.1234 41.0105 13.1234 49.2126 13.1234
XS57.415 13.1234 65.6168 13.1234
XS82.021 29.5276 98.4252 45.9318
RH 0.020
*** Station  2
ST3116.8       9
ND     1 32.8084
XS 0.000 45.6336 16.4042 29.2294 32.8084 12.8252 41.0105 12.8252 49.2126 12.8252
XS57.415 12.8252 65.6168 12.8252
XS82.021 29.2294 98.4252 45.6336
RH 0.020
*** Station  3
ST2952.8       9
ND     1 32.8084
XS 0.000 45.2824 16.4042 28.8782 32.8084 12.4740 41.0105 12.4740 49.2126 12.4740
XS57.415 12.4740 65.6168 12.4740
XS82.021 28.8782 98.4252 45.2824
RH 0.020
*** Station  4
ST2788.7       9
ND     1 32.8084
XS 0.000 44.8662 16.4042 28.4620 32.8084 12.0578 41.0105 12.0578 49.2126 12.0578
XS57.415 12.0578 65.6168 12.0578
XS82.021 28.4620 98.4252 44.8662
RH 0.020
*** Station  5
ST2624.7       9
ND     1 32.8084
XS 0.000 44.3703 16.4042 27.9661 32.8084 11.5619 41.0105 11.5619 49.2126 11.5619
XS57.415 11.5619 65.6168 11.5619
XS82.021 27.9661 98.4252 44.3703
RH 0.020
*** Station  6
ST2460.6       9
ND     1 32.8084
XS 0.000 43.7764 16.4042 27.3722 32.8084 10.9680 41.0105 10.9680 49.2126 10.9680
XS57.415 10.9680 65.6168 10.9680
XS82.021 27.3722 98.4252 43.7764
RH 0.020
*** Station  7
ST2296.6       9
ND     1 32.8084
XS 0.000 43.0617 16.4042 26.6575 32.8084 10.2533 41.0105 10.2533 49.2126 10.2533
XS57.415 10.2533 65.6168 10.2533
XS82.021 26.6575 98.4252 43.0617
RH 0.020
*** Station  8
ST2132.5       9
ND     1 32.8084
XS 0.000 42.1991 16.4042 25.7949 32.8084  9.3907 41.0105  9.3907 49.2126  9.3907
XS57.415  9.3907 65.6168  9.3907
XS82.021 25.7949 98.4252 42.1991
RH 0.020
*** Station  9
ST1968.5       9
ND     1 32.8084
XS 0.000 41.1757 16.4042 24.7715 32.8084  8.3673 41.0105  8.3673 49.2126  8.3673
```

```
XS57.415  8.3673 65.6168  8.3673
XS82.021 24.7715 98.4252 41.1757
RH 0.020
*** Station 10
ST1804.5       9
ND     1 32.8084
XS 0.000 40.0100 16.4042 23.6058 32.8084  7.2016 41.0105  7.2016 49.2126  7.2016
XS57.415  7.2016 65.6168  7.2016
XS82.021 23.6058 98.4252 40.0100
RH 0.020
*** Station 11
ST1640.4       9
ND     1 32.8084
XS 0.000 38.7386 16.4042 22.3344 32.8084  5.9302 41.0105  5.9302 49.2126  5.9302
XS57.415  5.9302 65.6168  5.9302
XS82.021 22.3344 98.4252 38.7386
RH 0.020
*** Station 12
ST1476.4       9
ND     1 32.8084
XS 0.000 37.3976 16.4042 20.9934 32.8084  4.5892 41.0105  4.5892 49.2126  4.5892
XS57.415  4.5892 65.6168  4.5892
XS82.021 20.9934 98.4252 37.3976
RH 0.020
*** Station 13
ST1312.3       9
ND     1 32.8084
XS 0.000 36.0144 16.4042 19.6102 32.8084  3.2060 41.0105  3.2060 49.2126  3.2060
XS57.415  3.2060 65.6168  3.2060
XS82.021 19.6102 98.4252 36.0144
RH 0.020
*** Station 14
ST1148.3       9
ND     1 32.8084
XS 0.000 35.2253 16.4042 18.8211 32.8084  2.4169 41.0105  2.4169 49.2126  2.4169
XS57.415  2.4169 65.6168  2.4169
XS82.021 18.8211 98.4252 35.2253
RH 0.020
*** Station 15
ST 984.3       9
ND     1 32.8084
XS 0.000 34.9243 16.4042 18.5201 32.8084  2.1159 41.0105  2.1159 49.2126  2.1159
XS57.415  2.1159 65.6168  2.1159
XS82.021 18.5201 98.4252 34.9243
RH 0.020
*** Station 16
ST 820.2       9
ND     1 32.8084
XS 0.000 34.6943 16.4042 18.2901 32.8084  1.8859 41.0105  1.8859 49.2126  1.8859
XS57.415  1.8859 65.6168  1.8859
XS82.021 18.2901 98.4252 34.6943
RH 0.020
*** Station 17
ST 656.2       9
ND     1 32.8084
XS 0.000 34.4871 16.4042 18.0829 32.8084  1.6787 41.0105  1.6787 49.2126  1.6787
XS57.415  1.6787 65.6168  1.6787
XS82.021 18.0829 98.4252 34.4871
RH 0.020
*** Station 18
ST 492.1       9
```

```
ND     1 32.8084
XS 0.000 34.2908 16.4042 17.8866 32.8084  1.4824 41.0105  1.4824 49.2126  1.4824
XS57.415  1.4824 65.6168  1.4824
XS82.021 17.8866 98.4252 34.2908
RH 0.020
*** Station 19
ST 328.1       9
ND     1 32.8084
XS 0.000 34.1006 16.4042 17.6964 32.8084  1.2922 41.0105  1.2922 49.2126  1.2922
XS57.415  1.2922 65.6168  1.2922
XS82.021 17.6964 98.4252 34.1006
RH 0.020
*** Station 20
ST 164.0       9
ND     1 32.8084
XS 0.000 33.9146 16.4042 17.5104 32.8084  1.1062 41.0105  1.1062 49.2126  1.1062
XS57.415  1.1062 65.6168  1.1062
XS82.021 17.5104 98.4252 33.9146
RH 0.020
*** Station 21
ST   0.0       9       1       1
ND     1 32.8084
XS 0.000 33.7316 16.4042 17.3274 32.8084  0.9232 41.0105  0.9232 49.2126  0.9232
XS57.415  0.9232 65.6168  0.9232
XS82.021 17.3274 98.4252 33.7316
RH 0.020

RE     1MANNING
NT     1
IT     1       1       1 DAY
QQ      TABLE OF DISCHARGES
SS      RATING CURVE
TQ706.29
NC     2
RC     10.022920     1.0     0.0
RC    210.007578     1.0     0.0

PR     2       1
PX     0
PW     1
END
```

1.2 Output data files

1.2.1 Main Output File (.OUT)

```
  GGGGG     SSSSS   TTTTTTTT     A     RRRRRR     SSSSS
 GGGGGGG   SSSSSSS  TTTTTTTT    AAA    RRRRRRR   SSSSSSS
GG     GG SS     SS    TT      AA AA   RR    RR SS     SS
GG        SS           TT     AA   AA  RR    RR SS
GG  GGGGG  SSSSSSS     TT    AA     AA RRRRRRR   SSSSSSS
GG  GGGGG   SSSSSSS    TT    AAAAAAAAA RRRRRR     SSSSSSS
GG     GG        SS    TT    AAAAAAAAA RR RR           SS
GG     GG SS     SS    TT    AA     AA RR  RR   SS     SS
 GGGGGGG   SSSSSSS     TT    AA     AA RR   RR   SSSSSSS
  GGGGG     SSSSS      TT    AA     AA RR    RR   SSSSS
```

```
GSTARS Version 2.1 - Dec 2000                          U.S. Bureau of Reclamation
INPUT FILE:  Ex1.data                                  Technical Service Center
DATE OF RUN: 13 Feb 2001                               Denver, Colorado
TIME OF RUN: 16:35:02


********************************************************************************
*     Example problem for GSTARS 2.1: mixed flow regime, hydraulics only.      *
*         Set-up based on Test Problem 4 of MacDonald et al. (1997).           *
*                    File set-up by F. Simoes, Dec. 2000.                      *
********************************************************************************


* * * * * * *   SUMMARY OF INPUT PARAMETERS   * * * * * * *

Number of cross sections:...........................    21
Number of stream tubes:.............................     1
Number of time steps:...............................     1
Duration of time step (days):.......................  1.0000E+00
Formula selected for conveyance calculations:........  MANNING
Formula selected for friction slope:.................  average
Printout control is  2; print interval:.............     1
Do not generate x-sec plots.
Number of time steps for thalweg plots:.............     1
No minimization requested.

Sect.  Location   ISWITCH  ITYP   Thalweg     Bed slope   Loss  NDIVI NPOINTS
   #     (ft)                       (ft)                  Coef.
-----------------------------------------------------------------------------
   1   3.2808E+03    1       1   1.3123E+01   1.8183E-03  0.00    1       9
   2   3.1168E+03    0       0   1.2825E+01   1.8183E-03  0.00    1       9
   3   2.9528E+03    0       0   1.2474E+01   2.1415E-03  0.00    1       9
   4   2.7887E+03    0       0   1.2058E+01   2.5363E-03  0.00    1       9
   5   2.6247E+03    0       0   1.1562E+01   3.0238E-03  0.00    1       9
   6   2.4606E+03    0       0   1.0968E+01   3.6191E-03  0.00    1       9
   7   2.2966E+03    0       0   1.0253E+01   4.3579E-03  0.00    1       9
   8   2.1325E+03    0       0   9.3907E+00   5.2566E-03  0.00    1       9
   9   1.9685E+03    0       0   8.3673E+00   6.2402E-03  0.00    1       9
  10   1.8045E+03    0       0   7.2016E+00   7.1079E-03  0.00    1       9
  11   1.6404E+03    0       0   5.9302E+00   7.7477E-03  0.00    1       9
  12   1.4764E+03    0       0   4.5892E+00   8.1768E-03  0.00    1       9
  13   1.3123E+03    0       0   3.2060E+00   8.4290E-03  0.00    1       9
  14   1.1483E+03    0       0   2.4169E+00   4.8116E-03  0.00    1       9
  15   9.8430E+02    0       0   2.1159E+00   1.8354E-03  0.00    1       9
  16   8.2020E+02    0       0   1.8859E+00   1.4016E-03  0.00    1       9
  17   6.5620E+02    0       0   1.6787E+00   1.2634E-03  0.00    1       9
  18   4.9210E+02    0       0   1.4824E+00   1.1962E-03  0.00    1       9
  19   3.2810E+02    0       0   1.2922E+00   1.1598E-03  0.00    1       9
  20   1.6400E+02    0       0   1.1062E+00   1.1335E-03  0.00    1       9
  21   0.0000E+00    1       1   9.2320E-01   1.1159E-03  0.00    1       9
-----------------------------------------------------------------------------


********************************************************************************
********************************************************************************
    TIME STEP NO.     1 AFTER  1.0000E+00 DAYS; DISCHARGE IS  7.0629E+02 CFS
********************************************************************************
********************************************************************************
```

```
                    *********************************************
                    *     RESULTS OF BACKWATER COMPUTATIONS     *
                    *       DISCHARGE =  7.0629E+02 C.F.S.      *
                    *********************************************

STA.  STATION   WATER SURFACE   FLOW AREA  FLOW VELCTY  ENERGY GRADE    FROUDE
  #    (ft)     ELEVATION(ft)    (ft^2)      (ft/s)     LINE ELEV(ft)   NUMBER
********************************************************************************
  1  3.2808E+03  1.61929E+01  1.10128E+02  6.41334E+00  1.68666E+01  6.90289E-01
  2  3.1168E+03  1.57846E+01  1.05853E+02  6.67237E+00  1.65126E+01  7.29816E-01
  3  2.9528E+03  1.53207E+01  1.01499E+02  6.95862E+00  1.61110E+01  7.74316E-01
  4  2.7887E+03  1.47861E+01  9.69551E+01  7.28471E+00  1.56506E+01  8.26036E-01
  5  2.6247E+03  1.41923E+01  9.32191E+01  7.57667E+00  1.51260E+01  8.73253E-01
  6  2.4606E+03  1.34369E+01  8.70959E+01  8.10934E+00  1.45036E+01  9.61562E-01
  7  2.2966E+03  1.26594E+01  8.47294E+01  8.33583E+00  1.37854E+01  1.00000E+00
  8  2.1325E+03  1.16726E+01  8.00709E+01  8.82081E+00  1.29308E+01  1.08375E+00
  9  1.9685E+03  1.05198E+01  7.52552E+01  9.38527E+00  1.19412E+01  1.18403E+00
 10  1.8045E+03  9.29388E+00  7.30221E+01  9.67228E+00  1.08020E+01  1.23611E+00
 11  1.6404E+03  7.97271E+00  7.11835E+01  9.92210E+00  9.55837E+00  1.28205E+00
 12  1.4764E+03  6.60384E+00  7.01561E+01  1.00674E+01  8.23552E+00  1.30902E+00
 13  1.3123E+03  6.19693E+00  1.07073E+02  6.59632E+00  6.90871E+00  7.18138E-01
 14  1.1483E+03  6.10528E+00  1.34614E+02  5.24679E+00  6.56052E+00  5.21347E-01
 15  9.8430E+02  5.98240E+00  1.41804E+02  4.98076E+00  6.39377E+00  4.84993E-01
 16  8.2020E+02  5.85872E+00  1.46125E+02  4.83345E+00  6.24674E+00  4.65223E-01
 17  6.5620E+02  5.74196E+00  1.49819E+02  4.71429E+00  6.11157E+00  4.49423E-01
 18  4.9210E+02  5.63287E+00  1.53397E+02  4.60434E+00  5.98590E+00  4.34998E-01
 19  3.2810E+02  5.53178E+00  1.57068E+02  4.49671E+00  5.86895E+00  4.21023E-01
 20  1.6400E+02  5.43830E+00  1.60896E+02  4.38972E+00  5.76006E+00  4.07273E-01
 21  0.0000E+00  5.35227E+00  1.64927E+02  4.28244E+00  5.65892E+00  3.93630E-01


* * * * * *  GSTARS run completed successfully  * * * * * *
```

1.2.2 Debug File (.DBG)

```
GSTARS Version 2.1 - Dec 2000                       U.S. Bureau of Reclamation
INPUT FILE:  Ex1.data                               Technical Service Center
DATE OF RUN: 13 Feb 2001                            Denver, Colorado
RUN STARTED: 16:35:02:94

               ************ Limits for this version ************
               Maximum number of cross sections:.............101
               Maximum number of points per cross section:...197
               Maximum number of particle size fractions:.... 10
               Maximum number of stream tubes:................ 5
               *************************************************


********************************************************************************
***  NOTE: this is a datafile to be used as an example of input data as it   ***
***  might be used in a GSTARS version 2.1 simulation.  It represents a      ***
***  ficticious case and it sould be viewed as such.  It should not be used  ***
***  for any other purpose without appropriate verification and validation.  ***
***                                                                          ***
***  ------------------------------------------------------------            ***
***  Problem Description: problem #4 of MacDonald et al. (1997).             ***
***  Data Filename: Ex1.data                                                 ***
***  Shape: trapezoidal channel, top width = 32.81 + 2y (ft).                ***
***  Side Slopes: 1:1                                                        ***
```

```
***  Channel Length: 3280.8 ft (1000 m).                                     ***
***  Channel Slope (s): 0.001                                                ***
***  Number of Stations: 21 equally spaced at 250 ft (50 m).                 ***
***  Testing: mixed flow regimes with hydraulic jump.                        ***
***  -----------------------------------------------------------             ***
********************************************************************************
********************************************************************************
*     Example problem for GSTARS 2.1: mixed flow regime, hydraulics only.      *
*         Set-up based on Test Problem 4 of MacDonald et al. (1997).           *
*                    File set-up by F. Simoes, Dec. 2000.                      *
********************************************************************************
*** Station  1
  Cross section coordinate order is X-Y
*** Station  2
*** Station  3
*** Station  4
*** Station  5
*** Station  6
*** Station  7
*** Station  8
*** Station  9
*** Station 10
*** Station 11
*** Station 12
*** Station 13
*** Station 14
*** Station 15
*** Station 16
*** Station 17
*** Station 18
*** Station 19
*** Station 20
*** Station 21

 NO SEDIMENT TRANSPORT REQUESTED

********************************************************************************
********************************************************************************
    TIME STEP NO.     1 AFTER  1.0000E+00 DAYS; DISCHARGE IS  7.0629E+02 CFS
********************************************************************************
********************************************************************************

                          CRITICAL        CRITICAL
                         DEPTH (ft)     W.S.ELV.(ft)
                        ****************************
                         2.4061E+00     1.55295E+01
                         2.4061E+00     1.52313E+01
                         2.4061E+00     1.48801E+01
                         2.4061E+00     1.44639E+01
                         2.4061E+00     1.39680E+01
                         2.4061E+00     1.33741E+01
                         2.4061E+00     1.26594E+01
                         2.4061E+00     1.17968E+01
                         2.4061E+00     1.07734E+01
                         2.4061E+00     9.60770E+00
                         2.4061E+00     8.33630E+00
                         2.4061E+00     6.99530E+00
                         2.4061E+00     5.61210E+00
                         2.4061E+00     4.82300E+00
                         2.4061E+00     4.52200E+00
                         2.4061E+00     4.29200E+00
```

```
2.4061E+00     4.08480E+00
2.4061E+00     3.88850E+00
2.4061E+00     3.69830E+00
2.4061E+00     3.51230E+00
2.4061E+00     3.32930E+00
```

```
*************************************
*   NORMAL DEPTH PROPERTIES TABLE   *
*************************************
```

STA. ID	BOTTOM ELEVATION (ft)	BOTTOM SLOPE	FLOW AREA (ft^2)	NORM FLOW VELOCITY (ft/s)	FROUDE NO.	NORMAL DEPTH (ft)	NORMAL W.S.ELV. (ft)
1	1.31234E+01	1.818E-03	1.141E+02	6.190E+00	0.657	3.171E+00	1.62946E+01
2	1.28252E+01	1.818E-03	1.141E+02	6.190E+00	0.657	3.171E+00	1.59964E+01
3	1.24740E+01	2.141E-03	1.082E+02	6.528E+00	0.708	3.020E+00	1.54936E+01
4	1.20578E+01	2.536E-03	1.024E+02	6.897E+00	0.765	2.870E+00	1.49282E+01
5	1.15619E+01	3.024E-03	9.675E+01	7.300E+00	0.829	2.723E+00	1.42849E+01
6	1.09680E+01	3.619E-03	9.131E+01	7.735E+00	0.900	2.580E+00	1.35481E+01
7	1.02533E+01	4.358E-03	8.602E+01	8.211E+00	0.979	2.440E+00	1.26935E+01
8	9.39070E+00	5.257E-03	8.100E+01	8.720E+00	1.066	2.307E+00	1.16974E+01
9	8.36730E+00	6.240E-03	7.668E+01	9.211E+00	1.153	2.191E+00	1.05582E+01
10	7.20160E+00	7.108E-03	7.356E+01	9.601E+00	1.224	2.107E+00	9.30851E+00
11	5.93020E+00	7.748E-03	7.157E+01	9.868E+00	1.273	2.053E+00	7.98326E+00
12	4.58920E+00	8.177E-03	7.036E+01	1.004E+01	1.304	2.020E+00	6.60929E+00
13	3.20600E+00	8.429E-03	6.968E+01	1.014E+01	1.322	2.002E+00	5.20773E+00
14	2.41690E+00	4.812E-03	8.333E+01	8.476E+00	1.024	2.369E+00	4.78568E+00
15	2.11590E+00	1.835E-03	1.137E+02	6.209E+00	0.660	3.162E+00	5.27818E+00
16	1.88590E+00	1.402E-03	1.242E+02	5.686E+00	0.583	3.428E+00	5.31391E+00
17	1.67870E+00	1.263E-03	1.285E+02	5.496E+00	0.556	3.536E+00	5.21472E+00
18	1.48240E+00	1.196E-03	1.308E+02	5.398E+00	0.543	3.594E+00	5.07662E+00
19	1.29220E+00	1.160E-03	1.322E+02	5.343E+00	0.535	3.628E+00	4.91988E+00
20	1.10620E+00	1.133E-03	1.332E+02	5.303E+00	0.529	3.653E+00	4.75884E+00
21	9.23200E-01	1.116E-03	1.339E+02	5.276E+00	0.526	3.670E+00	4.59284E+00

```
          STEP METHOD COMPUTATIONS
POTENTIAL CONTROL AT SECTION    1
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    3.0648E+00 FT
   CONTROL ELEV.=    1.6188E+01 FT

POTENTIAL CONTROL AT SECTION    7
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    2.4061E+00 FT
   CONTROL ELEV.=    1.2659E+01 FT

POTENTIAL CONTROL AT SECTION   21
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    4.4291E+00 FT
   CONTROL ELEV.=    5.3523E+00 FT

NO CONVERGENCE AFTER 26 ITERATIONS AT STATION  12
   COMPUTED HEAD:  7.2281E+00
   GUESSED HEAD:   8.4332E+00
   HYDRAULIC JUMP HEAD LOSS:   0.0000E+00
   DIRECTION & FLOW TYPE UPSTREAM        S1
   MIN H ERROR=      0.541 AT WSEL=      7.006 KTMIN=   0
WSE BEFORE AND AFTER ADJUSTING  0.7868099E+01  0.7006296E+01      S1
```

```
CONTROL AT SECTION    1
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    4.4291E+00 FT
   CONTROL ELEV.=    5.3523E+00 FT

CONTROL AT SECTION    7
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    4.4291E+00 FT
   CONTROL ELEV.=    5.3523E+00 FT

CONTROL AT SECTION   21
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    4.4291E+00 FT
   CONTROL ELEV.=    5.3523E+00 FT
```

CONVEYANCE TABLE FOR INDIVIDUAL STREAM TUBES

STA.	TUBE-1	TUBE-2	TUBE-3	TUBE-4	TUBE-5
1	1.5686E+04				
2	1.4759E+04				
3	1.3832E+04				
4	1.2886E+04				
5	1.2125E+04				
6	1.0909E+04				
7	1.0451E+04				
8	9.5674E+03				
9	8.6817E+03				
10	8.2809E+03				
11	7.9556E+03				
12	7.7757E+03				
13	1.5022E+04				
14	2.1324E+04				
15	2.3077E+04				
16	2.4151E+04				
17	2.5080E+04				
18	2.5990E+04				
19	2.6933E+04				
20	2.7927E+04				
21	2.8986E+04				

STREAM HYDRAULICS FOR TUBE NO. = 1

STA. #	AREA (ft^2)	HYDRAULIC RADIUS (ft)	VELOCITY (ft/s)	FRICTION SLOPE	TUBE START (ft)	TUBE END (ft)
1	1.101E+02	2.654E+00	6.413E+00	2.027E-03	0.000E+00	6.869E+01
2	1.059E+02	2.571E+00	6.672E+00	2.290E-03	0.000E+00	6.858E+01
3	1.015E+02	2.484E+00	6.959E+00	2.607E-03	0.000E+00	6.846E+01
4	9.696E+01	2.392E+00	7.285E+00	3.004E-03	0.000E+00	6.835E+01
5	9.322E+01	2.316E+00	7.577E+00	3.393E-03	0.000E+00	6.825E+01
6	8.710E+01	2.189E+00	8.109E+00	4.192E-03	0.000E+00	6.809E+01
7	8.473E+01	2.139E+00	8.336E+00	4.567E-03	0.000E+00	6.802E+01
8	8.007E+01	2.039E+00	8.821E+00	5.450E-03	0.000E+00	6.790E+01
9	7.526E+01	1.935E+00	9.385E+00	6.618E-03	0.000E+00	6.777E+01
10	7.302E+01	1.886E+00	9.672E+00	7.275E-03	0.000E+00	6.771E+01
11	7.118E+01	1.845E+00	9.922E+00	7.882E-03	0.000E+00	6.766E+01
12	7.016E+01	1.822E+00	1.007E+01	8.251E-03	0.000E+00	6.763E+01
13	1.071E+02	2.595E+00	6.596E+00	2.211E-03	0.000E+00	6.861E+01
14	1.346E+02	3.113E+00	5.247E+00	1.097E-03	0.000E+00	6.931E+01
15	1.418E+02	3.242E+00	4.981E+00	9.367E-04	0.000E+00	6.948E+01
16	1.461E+02	3.318E+00	4.833E+00	8.553E-04	0.000E+00	6.959E+01

```
 17   1.498E+02   3.382E+00   4.714E+00   7.931E-04   0.000E+00   6.968E+01
 18   1.534E+02   3.443E+00   4.604E+00   7.385E-04   0.000E+00   6.977E+01
 19   1.571E+02   3.506E+00   4.497E+00   6.877E-04   0.000E+00   6.986E+01
 20   1.609E+02   3.571E+00   4.390E+00   6.396E-04   0.000E+00   6.995E+01
 21   1.649E+02   3.638E+00   4.282E+00   5.937E-04   0.000E+00   7.005E+01



RUN ENDED: 16:35:02:99
```

1.2.3 Water Surface Elevation File (.WPL)

Note that the water surface file (.WPL file) was designed to be easily imported into spreadsheet-type plotting programs. The data is organized in three columns of fixed width, thus allowing for easy import to any spreadsheet program, such as Microsoft's Excel. Output includes (column by column, from left to right) distance from outlet (location of the cross sections as defined in the input data file), bed elevation, and free surface elevation. One set of data is produced for each time step requested in record PW, starting at time step zero (i.e., before any computations take place). For each time step, a set of three numbers is printed, followed by the data in columnar format. The initial set of numbers contains an integer with the number of cross sections used in the study, the water discharge for that time step, and an integer with the time step number. For the first set printed, the value of the water discharge and time step appear with a zero (to indicate values preceding the simulation). The free surface of the first set of data also appears zeroed out, because the data is printed before the backwater computations are performed.

```
* Run on  2/13/2001 At 16:35: 2:95
    Example problem for GSTARS 2.1: mixed flow regime, hydraulics only.
        Set-up based on Test Problem 4 of MacDonald et al. (1997).
                   File set-up by F. Simoes, Dec. 2000.
          21           0           0
  3.28080E+03  1.31234E+01   0
  3.11680E+03  1.28252E+01   0
  2.95280E+03  1.24740E+01   0
  2.78870E+03  1.20578E+01   0
  2.62470E+03  1.15619E+01   0
  2.46060E+03  1.09680E+01   0
  2.29660E+03  1.02533E+01   0
  2.13250E+03  9.39070E+00   0
  1.96850E+03  8.36730E+00   0
  1.80450E+03  7.20160E+00   0
  1.64040E+03  5.93020E+00   0
  1.47640E+03  4.58920E+00   0
  1.31230E+03  3.20600E+00   0
  1.14830E+03  2.41690E+00   0
  9.84300E+02  2.11590E+00   0
  8.20200E+02  1.88590E+00   0
  6.56200E+02  1.67870E+00   0
  4.92100E+02  1.48240E+00   0
  3.28100E+02  1.29220E+00   0
  1.64000E+02  1.10620E+00   0
  0.00000E+00  9.23200E-01   0
          21   706.290000000000                1
```

```
3.28080E+03  1.31234E+01  1.61929E+01
3.11680E+03  1.28252E+01  1.57846E+01
2.95280E+03  1.24740E+01  1.53207E+01
2.78870E+03  1.20578E+01  1.47861E+01
2.62470E+03  1.15619E+01  1.41923E+01
2.46060E+03  1.09680E+01  1.34369E+01
2.29660E+03  1.02533E+01  1.26594E+01
2.13250E+03  9.39070E+00  1.16726E+01
1.96850E+03  8.36730E+00  1.05198E+01
1.80450E+03  7.20160E+00  9.29388E+00
1.64040E+03  5.93020E+00  7.97271E+00
1.47640E+03  4.58920E+00  6.60384E+00
1.31230E+03  3.20600E+00  6.19693E+00
1.14830E+03  2.41690E+00  6.10528E+00
9.84300E+02  2.11590E+00  5.98240E+00
8.20200E+02  1.88590E+00  5.85872E+00
6.56200E+02  1.67870E+00  5.74196E+00
4.92100E+02  1.48240E+00  5.63287E+00
3.28100E+02  1.29220E+00  5.53178E+00
1.64000E+02  1.10620E+00  5.43830E+00
0.00000E+00  9.23200E-01  5.35227E+00
```

1.3 References

MacDonald, I., Baines, M.J., Nichols, N.K., and Samuels, P.G. (1997). "Analytic benchmark solutions for open-channel flow," *J. Hydr. Engng., ASCE*, **123**(11), 1041–1045.

EXAMPLE 2

MAIN CHANNEL WITH ONE TRIBUTARY INFLOW

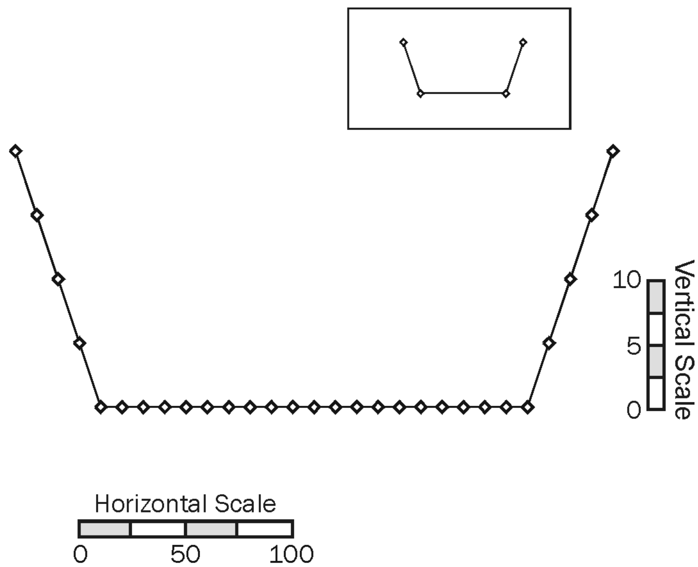
This example illustrates how to set-up sediment transport parameters and how to define tributary inflow data. A 5,000 ft long trapezoidal channel with bottom width of 200 ft and side slopes of 1V:2H is used. The channel slope is 0.0001, and it is set in medium sand with d_{50} = 0.447 mm. The main channel water discharge is 3,000 cfs and the downstream water surface elevation is set to normal depth (7.95 ft). The input sediment load is very close to the equilibrium load (using the revised Ackers and White equation in record SE), which is aproximately 95.11 ton/day. In this example only one size class is used in records SF/SG. The channel was discretized with 21 cross sections placed 250 ft apart.

Three stream tubes are used. To ensure that enough discretization points fall within each stream tube, each cross section uses 29 points, as shown in figure 2.1. The cross section template is defined as a set of (y,x) points (record YX is used) and each elevation above datum is set using variable *BEC* in record ST.

Sediment transport is activated by the presence of record SE, which defines the transport equation used in the study. In example 2, the revised Ackers and White equation is used (*ISED* = 10 in record SE). Water temperature is necessary for sediment transport computations and is set at 50 degrees Fahrenheit in record TM. Since only one size fraction is used to define the bed composition, there is no need to specify the size distribution of the incoming sediment (it is assumed to be the same as the bed size distribution of the first cross section). Bed size distributions are set using SD records.

Tributary inflow data is defined at cross section #9, located 3,000 ft upstream from the downstream-most cross section. The incoming flow is laden with sediment such that it will exceed the channel's carrying capacity. Therefore, deposition is expected to occur at that cross section and, possibly, at nearby cross sections. Distribution across the stream tubes is uniform (see record MX in tributary datafile). Both the main input datafile and tributary datafile are presented in the next sections.

Figure 2.1 Sketch showing the discretization points used in the cross section template to define the channel. The smaller insert shows an equivalent cross section using the minimum possible number of discretization points.



Finally, output control is set at level 3 (*IPRLVL* in record PR) for every 3,000 time steps. Since the run has 3,000 time steps overall, this means that output will take place only at the last time step. The same is defined for channel cross section plots (record PX). Water and bed profile plots (record PW) are printed at every 1,000 time steps, so that figure 2.2 can be plotted.

2.1 Input Data Files

The files shown in this and the next sections are part of the main GSTARS 2.1 distribution package. They can be found under directory Example2.

2.1.1 Main Input Data File

```
TT GSTARS version 2.1  -  Example data file for Appendix B of user's manual.
TT Trapezoidal channel with sediment transport and tributary inflow.
TT Input sediment equals initial carrying capacity: no erosion or deposition.

********************************************************************************
***  NOTE: this is a datafile to be used as an example of input data as it   ***
***  might be used in a GSTARS version 2.1 simulation.  It represents a      ***
***  ficticious case and it sould be viewed as such.  It should not be used  ***
```

```
***  for any other purpose without appropriate verification and validation.  ***
***                                                                         ***
***  ------------------------------------------------------------------    ***
***  Problem Description: how to set up tributary inflows in GSTARS 2.1.   ***
***  Data Filename: trapzoid.data                                          ***
***  Shape: trapezoidal channel, top width = 200 + 4y ft (61 + 4y m).      ***
***  Side Slopes: 1:2                                                      ***
***  Channel Length: 5000 ft (1524 m).                                     ***
***  Channel Slope (s): 0.0001                                             ***
***  Number of Stations: 21 equally spaced at 250 ft (76.2 m).             ***
***  ------------------------------------------------------------------    ***
********************************************************************************

***  Number of cross sections
NS    21

***  YX Record - Cross-Section Coordinate Order is Y-X
YX

ST  5000      29       0       0   0.500       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  =========================================================================
ST  4750      29       0       0   0.475       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  =========================================================================
ST  4500      29       0       0   0.450       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  =========================================================================
ST  4250      29       0       0   0.425       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  =========================================================================
ST  4000      29       0       0   0.400       1
ND     1     280
```

```
XS  1020      0    1015     10    1010     20    1005     30    1000     40
XS  1000     50    1000     60    1000     70    1000     80    1000     90
XS  1000    100    1000    110    1000    120    1000    130    1000    140
XS  1000    150    1000    160    1000    170    1000    180    1000    190
XS  1000    200    1000    210    1000    220    1000    230    1000    240
XS  1005    250    1010    260    1015    270    1020    280
RH  0.03
***  ==========================================================================
ST  3750     29       0       0   0.375      1
ND     1    280
XS  1020      0    1015     10    1010     20    1005     30    1000     40
XS  1000     50    1000     60    1000     70    1000     80    1000     90
XS  1000    100    1000    110    1000    120    1000    130    1000    140
XS  1000    150    1000    160    1000    170    1000    180    1000    190
XS  1000    200    1000    210    1000    220    1000    230    1000    240
XS  1005    250    1010    260    1015    270    1020    280
RH  0.03
***  ==========================================================================
ST  3500     29       0       0   0.350      1
ND     1    280
XS  1020      0    1015     10    1010     20    1005     30    1000     40
XS  1000     50    1000     60    1000     70    1000     80    1000     90
XS  1000    100    1000    110    1000    120    1000    130    1000    140
XS  1000    150    1000    160    1000    170    1000    180    1000    190
XS  1000    200    1000    210    1000    220    1000    230    1000    240
XS  1005    250    1010    260    1015    270    1020    280
RH  0.03
***  ==========================================================================
ST  3250     29       0       0   0.325      1
ND     1    280
XS  1020      0    1015     10    1010     20    1005     30    1000     40
XS  1000     50    1000     60    1000     70    1000     80    1000     90
XS  1000    100    1000    110    1000    120    1000    130    1000    140
XS  1000    150    1000    160    1000    170    1000    180    1000    190
XS  1000    200    1000    210    1000    220    1000    230    1000    240
XS  1005    250    1010    260    1015    270    1020    280
RH  0.03
***  ==========================================================================
ST  3000     29       0       0   0.300      1
ND     1    280
XS  1020      0    1015     10    1010     20    1005     30    1000     40
XS  1000     50    1000     60    1000     70    1000     80    1000     90
XS  1000    100    1000    110    1000    120    1000    130    1000    140
XS  1000    150    1000    160    1000    170    1000    180    1000    190
XS  1000    200    1000    210    1000    220    1000    230    1000    240
XS  1005    250    1010    260    1015    270    1020    280
RH  0.03
LI tributary.data
***  ==========================================================================
ST  2750     29       0       0   0.275      1
ND     1    280
XS  1020      0    1015     10    1010     20    1005     30    1000     40
XS  1000     50    1000     60    1000     70    1000     80    1000     90
XS  1000    100    1000    110    1000    120    1000    130    1000    140
XS  1000    150    1000    160    1000    170    1000    180    1000    190
XS  1000    200    1000    210    1000    220    1000    230    1000    240
XS  1005    250    1010    260    1015    270    1020    280
RH  0.03
***  ==========================================================================
ST  2500     29       0       0   0.250      1
ND     1    280
```

```
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST  2250      29       0       0   0.225       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST  2000      29       0       0   0.200       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST  1750      29       0       0   0.175       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST  1500      29       0       0   0.150       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST  1250      29       0       0   0.125       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST  1000      29       0       0   0.100       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
```

```
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST   750      29       0       0   0.075       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST   500      29       0       0   0.050       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST   250      29       0       0   0.025       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================
ST     0      29       1       1       0       1
ND     1     280
XS  1020       0    1015      10    1010      20    1005      30    1000      40
XS  1000      50    1000      60    1000      70    1000      80    1000      90
XS  1000     100    1000     110    1000     120    1000     130    1000     140
XS  1000     150    1000     160    1000     170    1000     180    1000     190
XS  1000     200    1000     210    1000     220    1000     230    1000     240
XS  1005     250    1010     260    1015     270    1020     280
RH  0.03
***  ==========================================================================

  RE Record (Using Mannings Equation)
RE      MANNING

***  NT Record - Number of Stream Tubes
NT     3

***  IT Record
IT  3000       1    30.0 MIN

***  QQ Record
QQ      TABLE OF DISCHARGES
***  SS Record
SS      STAGE DISCHARGE TABLE
```

```
***  TL Record
TL    21
***  SQ Record
SQ  3000 1007.66    3000

***  --------------------------------------------------------------------------
***  Sediment Transport Records
***  --------------------------------------------------------------------------

*** Sediment transport using the revised Ackers and White equation
SE    10
QS  3000   95.11

TM  3000    50.0

***  SF Record - medium sand (Dmean = 0.447 mm)
SF     1
SG  0.10     2.0

***  SD Records: size fractions falling within each size group. 1 record for
***  each Station. In this example: 1 group size => 1 value per SD record;
***  21 cross sections => 21 SD records; SD for cross section 1 defines size
***  distribution for sediment source.

SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0
SD   1.0

***  --------------------------------------------------------------------------
***  Print-out Control
***  --------------------------------------------------------------------------

PR     3    3000
PX  3000      CHANNEL CROSS SECTION PLOTS
PW  1000      WATER SURFACE PROFILE PLOTS

END
```

2.1.2 Input Data File with Tributary Data

```
********************************************************************************
***  NOTE: this is a datafile to be used as an example of input data as it   ***
***  might be used in a GSTARS version 2.1 simulation.  It represents a      ***
```

```
***  ficticious case and it sould be viewed as such.  It should not be used  ***
***  for any other purpose without appropriate verification and validation.  ***
***                                                                          ***
***  ----------------------------------------------------------------------   ***
***  Problem Description: how to set up tributary inflows in GSTARS 2.1.     ***
***  Data Filename: trapzoid.data                                            ***
***  Shape: trapezoidal channel, top width = 200 + 4y ft (61 + 4y m).        ***
***  Side Slopes: 1:2                                                        ***
***  Channel Length: 5000 ft (1524 m).                                       ***
***  Channel Slope (s): 0.0001                                               ***
***  Number of Stations: 21 equally spaced at 250 ft (76.2 m).               ***
***  ----------------------------------------------------------------------   ***
********************************************************************************
***              THIS FILE CONTAINS ALL THE TRIBUTARY DATA                   ***
********************************************************************************

DD  1000     0.0
DD  2000   200.0

MX 33.33   33.33   33.33

QS  1000     0.0
QS  2000   120.0

IQ     1   200.0
IS          1.00
```

2.2 Output Data Files

In order to save space, the cross section plot file (.XPL) and the bed and water surface profile file (.WPL) will not be included in this manual. However, those files can be found in directory Example2 in the main GSTARS 2.1 distribution package.

2.2.1 Main Output File (.OUT)

```
             GGGGG     SSSSS   TTTTTTTT     A     RRRRRR     SSSSS
            GGGGGGG   SSSSSSS  TTTTTTTT    AAA    RRRRRRR   SSSSSSS
           GG     GG SS     SS    TT      AA AA   RR    RR SS     SS
           GG        SS           TT     AA   AA  RR    RR SS
           GG  GGGGG  SSSSSSS     TT    AA     AA RRRRRRR   SSSSSSS
           GG  GGGGG   SSSSSSS    TT    AAAAAAAAA RRRRRR     SSSSSSS
           GG     GG        SS    TT    AAAAAAAAA RR RR           SS
           GG     GG SS     SS    TT    AA     AA RR  RR   SS     SS
            GGGGGGG   SSSSSSS     TT    AA     AA RR   RR   SSSSSSS
             GGGGG     SSSSS      TT    AA     AA RR    RR   SSSSS


GSTARS Version 2.1 - Dec 2000                         U.S. Bureau of Reclamation
INPUT FILE:  trapzoid.data                            Technical Service Center
DATE OF RUN:  1 Mar 2001                              Denver, Colorado
TIME OF RUN: 15:39:07


********************************************************************************
*  GSTARS version 2.1  -  Example data file for Appendix B of user's manual.   *
```

```
*  Trapezoidal channel with sediment transport and tributary inflow.          *
*  Input sediment equals initial carrying capacity: no erosion or deposition.  *
********************************************************************************


* * * * * * *   SUMMARY OF INPUT PARAMETERS   * * * * * * *

Number of cross sections:...........................    21
Number of stream tubes:.............................     3
Number of time steps:...............................  3000
Number of sediment time steps (NITRQS):.............     1
Duration of time step (days):.......................  2.0833E-02
Formula selected for conveyance calculations:........  MANNING
Formula selected for friction slope:.................  average
Formula for sediment transport: ..............  Revised Ackers and White (1990)
NALT for active layer thickness:....................    14
Transport parameter CFACTOR:........................  1.00
Angle of repose above the water surf. (deg):.........  90.0
Angle of repose below the water surf. (deg):.........  90.0
Printout control is  3; print interval:.............  3000
Number of time steps to generate x-sec plots:........  3000
Number of time steps for thalweg plots:.............  1000
No minimization requested.

Sect.  Location   ISWITCH  ITYP   Thalweg     Bed slope   Loss  NDIVI NPOINTS
   #     (ft)                       (ft)                  Coef.
-----------------------------------------------------------------------------
   1   5.0000E+03    0       0   1.0005E+03   1.0000E-04  0.00    1      29
   2   4.7500E+03    0       0   1.0005E+03   1.0000E-04  0.00    1      29
   3   4.5000E+03    0       0   1.0005E+03   1.0000E-04  0.00    1      29
   4   4.2500E+03    0       0   1.0004E+03   1.0000E-04  0.00    1      29
   5   4.0000E+03    0       0   1.0004E+03   1.0000E-04  0.00    1      29
   6   3.7500E+03    0       0   1.0004E+03   1.0000E-04  0.00    1      29
   7   3.5000E+03    0       0   1.0004E+03   1.0000E-04  0.00    1      29
   8   3.2500E+03    0       0   1.0003E+03   1.0000E-04  0.00    1      29
   9   3.0000E+03    0       0   1.0003E+03   1.0000E-04  0.00    1      29
  10   2.7500E+03    0       0   1.0003E+03   1.0000E-04  0.00    1      29
  11   2.5000E+03    0       0   1.0002E+03   1.0000E-04  0.00    1      29
  12   2.2500E+03    0       0   1.0002E+03   1.0000E-04  0.00    1      29
  13   2.0000E+03    0       0   1.0002E+03   1.0000E-04  0.00    1      29
  14   1.7500E+03    0       0   1.0002E+03   1.0000E-04  0.00    1      29
  15   1.5000E+03    0       0   1.0001E+03   1.0000E-04  0.00    1      29
  16   1.2500E+03    0       0   1.0001E+03   1.0000E-04  0.00    1      29
  17   1.0000E+03    0       0   1.0001E+03   1.0000E-04  0.00    1      29
  18   7.5000E+02    0       0   1.0001E+03   1.0000E-04  0.00    1      29
  19   5.0000E+02    0       0   1.0000E+03   1.0000E-04  0.00    1      29
  20   2.5000E+02    0       0   1.0000E+03   1.0000E-04  0.00    1      29
  21   0.0000E+00    1       1   1.0000E+03   1.0000E-04  0.00    1      29
-----------------------------------------------------------------------------

Coefficients used in Exner equation and in
computing hydraulic properties for sediment capacity
------------------------------------------------------------------------
      C1WP      C2WP      C3WP     C1WPU     C2WPU
     0.250     0.500     0.250     0.750     0.250
      C1Q       C2Q       C3Q       C1QD      C2QD      C1QU      C2QU
     0.000     1.000     0.000     0.000     1.000     1.000     0.000
------------------------------------------------------------------------

Number of particle size classes:  1
                                 Geometric  Dry specific
```

```
Class     DRL         DRU          mean        weight
  #       (mm)        (mm)         (mm)       (lb/ft^3)
--------------------------------------------------------
  1   1.0000E-01   2.0000E+00   4.4721E-01   9.9259E+01
--------------------------------------------------------

Percentage of bed material for each size fraction and for each cross section
Section    Bed material size fraction for each group
   #     1
-----------------------------------------------------------------------------
   1   100.0
   2   100.0
   3   100.0
   4   100.0
   5   100.0
   6   100.0
   7   100.0
   8   100.0
   9   100.0
  10   100.0
  11   100.0
  12   100.0
  13   100.0
  14   100.0
  15   100.0
  16   100.0
  17   100.0
  18   100.0
  19   100.0
  20   100.0
  21   100.0
-----------------------------------------------------------------------------


                  LATERAL INFLOW INFORMATION
Station     Lateral inflow file name
--------------------------------------------------------------------------------
    9       tributary.data



********************************************************************************
********************************************************************************
    TIME STEP NO.  3000 AFTER  6.2500E+01 DAYS; DISCHARGE IS  3.0000E+03 CFS
********************************************************************************
********************************************************************************



********** SIDE DISCHARGE AT STATION   9; Q LATERAL =  2.0000E+02 CFS **********

                    *********************************************
                    *     RESULTS OF BACKWATER COMPUTATIONS     *
                    *       DISCHARGE =  3.0000E+03 C.F.S.      *
                    *********************************************

STA.  STATION   WATER SURFACE   FLOW AREA  FLOW VELCTY  ENERGY GRADE    FROUDE
  #    (ft)     ELEVATION(ft)    (ft^2)      (ft/s)     LINE ELEV(ft)   NUMBER
********************************************************************************
  1  5.0000E+03  1.00821E+03  1.65330E+03  1.81455E+00  1.00827E+03  1.21072E-01
```

2	4.7500E+03	1.00819E+03	1.65589E+03	1.81171E+00	1.00824E+03	1.20670E-01
3	4.5000E+03	1.00817E+03	1.65948E+03	1.80780E+00	1.00822E+03	1.20234E-01
4	4.2500E+03	1.00814E+03	1.66139E+03	1.80572E+00	1.00819E+03	1.20037E-01
5	4.0000E+03	1.00812E+03	1.66216E+03	1.80488E+00	1.00817E+03	1.19954E-01
6	3.7500E+03	1.00809E+03	1.66249E+03	1.80453E+00	1.00814E+03	1.19920E-01
7	3.5000E+03	1.00807E+03	1.66268E+03	1.80432E+00	1.00812E+03	1.19900E-01
8	3.2500E+03	1.00804E+03	1.66284E+03	1.80415E+00	1.00810E+03	1.19884E-01
9	3.0000E+03	1.00800E+03	1.57483E+03	2.03196E+00	1.00807E+03	1.38468E-01
10	2.7500E+03	1.00797E+03	1.59238E+03	2.00957E+00	1.00803E+03	1.36245E-01
11	2.5000E+03	1.00794E+03	1.61736E+03	1.97854E+00	1.00800E+03	1.33165E-01
12	2.2500E+03	1.00791E+03	1.63817E+03	1.95340E+00	1.00797E+03	1.30689E-01
13	2.0000E+03	1.00789E+03	1.64945E+03	1.94005E+00	1.00795E+03	1.29378E-01
14	1.7500E+03	1.00786E+03	1.65371E+03	1.93504E+00	1.00792E+03	1.28887E-01
15	1.5000E+03	1.00783E+03	1.65467E+03	1.93392E+00	1.00789E+03	1.28774E-01
16	1.2500E+03	1.00780E+03	1.65444E+03	1.93419E+00	1.00786E+03	1.28799E-01
17	1.0000E+03	1.00777E+03	1.65385E+03	1.93488E+00	1.00783E+03	1.28864E-01
18	7.5000E+02	1.00774E+03	1.65315E+03	1.93570E+00	1.00780E+03	1.28942E-01
19	5.0000E+02	1.00772E+03	1.65242E+03	1.93655E+00	1.00778E+03	1.29023E-01
20	2.5000E+02	1.00769E+03	1.65168E+03	1.93742E+00	1.00775E+03	1.29105E-01
21	0.0000E+00	1.00766E+03	1.65093E+03	1.93830E+00	1.00772E+03	1.22352E-01

```
**************************************************************
*       SEDIMENT ROUTING RESULTS FOR TIME STEP    3000       *
**************************************************************

      ------------------------------------------------
      INCOMING SEDIMENT DISTRIBUTION PER SIZE FRACTION
      SIZE FRACTION       PERCENT       QSED (TON/DAY)
          1               100.00          9.5110E+01
        TOTAL                             9.5110E+01
      ------------------------------------------------


***************************************************************
*                    STREAM TUBE NO.   1                      *
***************************************************************
 STA  DISTANCE           TOTAL LOAD          CHANGE   DIRECTION
                     (TONS)       (FT**3)      (FT)
***************************************************************
```

STA	DISTANCE	TOTAL LOAD (TONS)	TOTAL LOAD (FT**3)	CHANGE (FT)	DIRECTION
1	5.0000E+03	5.6337E-01	6.8109E+00	0.000	VERTICAL
2	4.7500E+03	6.3208E-01	7.6416E+00	0.000	VERTICAL
3	4.5000E+03	6.0078E-01	7.2632E+00	0.000	VERTICAL
4	4.2500E+03	5.9875E-01	7.2387E+00	0.000	VERTICAL
5	4.0000E+03	5.9600E-01	7.2055E+00	0.000	VERTICAL
6	3.7500E+03	5.9513E-01	7.1949E+00	0.000	VERTICAL
7	3.5000E+03	5.9458E-01	7.1883E+00	0.000	VERTICAL
8	3.2500E+03	5.9413E-01	7.1828E+00	0.000	VERTICAL
9	3.0000E+03	1.3778E+00	1.6657E+01	0.000	VERTICAL
10	2.7500E+03	1.2839E+00	1.5522E+01	0.000	VERTICAL
11	2.5000E+03	1.1475E+00	1.3872E+01	0.000	VERTICAL
12	2.2500E+03	1.0467E+00	1.2654E+01	0.000	VERTICAL
13	2.0000E+03	9.9532E-01	1.2033E+01	0.000	VERTICAL
14	1.7500E+03	9.7650E-01	1.1806E+01	0.000	VERTICAL
15	1.5000E+03	9.7223E-01	1.1754E+01	0.000	VERTICAL
16	1.2500E+03	9.7315E-01	1.1765E+01	0.000	VERTICAL
17	1.0000E+03	9.7566E-01	1.1795E+01	0.000	VERTICAL
18	7.5000E+02	9.7861E-01	1.1831E+01	0.000	VERTICAL
19	5.0000E+02	9.8171E-01	1.1868E+01	0.000	VERTICAL
20	2.5000E+02	9.8487E-01	1.1907E+01	0.000	VERTICAL
21	0.0000E+00	9.8809E-01	1.1946E+01	0.000	VERTICAL

```
**************************************************************
*                      STREAM TUBE NO.   2                   *
**************************************************************
 STA  DISTANCE          TOTAL LOAD           CHANGE   DIRECTION
                   (TONS)       (FT**3)       (FT)
**************************************************************
  1   5.0000E+03   8.2802E-01   1.0010E+01     0.000   VERTICAL
  2   4.7500E+03   6.6014E-01   7.9809E+00     0.000   VERTICAL
  3   4.5000E+03   6.8819E-01   8.3199E+00     0.000   VERTICAL
  4   4.2500E+03   6.7557E-01   8.1674E+00     0.000   VERTICAL
  5   4.0000E+03   6.7420E-01   8.1509E+00     0.000   VERTICAL
  6   3.7500E+03   6.7314E-01   8.1380E+00     0.000   VERTICAL
  7   3.5000E+03   6.7258E-01   8.1313E+00     0.000   VERTICAL
  8   3.2500E+03   6.7211E-01   8.1255E+00     0.000   VERTICAL
  9   3.0000E+03   1.4945E+00   1.8068E+01     0.000   VERTICAL
 10   2.7500E+03   1.3766E+00   1.6642E+01     0.000   VERTICAL
 11   2.5000E+03   1.2486E+00   1.5095E+01     0.000   VERTICAL
 12   2.2500E+03   1.1467E+00   1.3863E+01     0.000   VERTICAL
 13   2.0000E+03   1.0955E+00   1.3245E+01     0.000   VERTICAL
 14   1.7500E+03   1.0768E+00   1.3018E+01     0.000   VERTICAL
 15   1.5000E+03   1.0726E+00   1.2967E+01     0.000   VERTICAL
 16   1.2500E+03   1.0736E+00   1.2980E+01     0.000   VERTICAL
 17   1.0000E+03   1.0763E+00   1.3012E+01     0.000   VERTICAL
 18   7.5000E+02   1.0793E+00   1.3049E+01     0.000   VERTICAL
 19   5.0000E+02   1.0826E+00   1.3088E+01     0.000   VERTICAL
 20   2.5000E+02   1.0859E+00   1.3128E+01     0.000   VERTICAL
 21   0.0000E+00   1.0892E+00   1.3168E+01     0.000   VERTICAL


**************************************************************
*                      STREAM TUBE NO.   3                   *
**************************************************************
 STA  DISTANCE          TOTAL LOAD           CHANGE   DIRECTION
                   (TONS)       (FT**3)       (FT)
**************************************************************
  1   5.0000E+03   5.6337E-01   6.8109E+00     0.000   VERTICAL
  2   4.7500E+03   6.3208E-01   7.6416E+00     0.000   VERTICAL
  3   4.5000E+03   6.0078E-01   7.2632E+00     0.000   VERTICAL
  4   4.2500E+03   5.9875E-01   7.2387E+00     0.000   VERTICAL
  5   4.0000E+03   5.9600E-01   7.2055E+00     0.000   VERTICAL
  6   3.7500E+03   5.9513E-01   7.1949E+00     0.000   VERTICAL
  7   3.5000E+03   5.9458E-01   7.1883E+00     0.000   VERTICAL
  8   3.2500E+03   5.9413E-01   7.1828E+00     0.000   VERTICAL
  9   3.0000E+03   1.3778E+00   1.6657E+01     0.000   VERTICAL
 10   2.7500E+03   1.2839E+00   1.5522E+01     0.000   VERTICAL
 11   2.5000E+03   1.1475E+00   1.3872E+01     0.000   VERTICAL
 12   2.2500E+03   1.0467E+00   1.2654E+01     0.000   VERTICAL
 13   2.0000E+03   9.9532E-01   1.2033E+01     0.000   VERTICAL
 14   1.7500E+03   9.7650E-01   1.1806E+01     0.000   VERTICAL
 15   1.5000E+03   9.7223E-01   1.1754E+01     0.000   VERTICAL
 16   1.2500E+03   9.7315E-01   1.1765E+01     0.000   VERTICAL
 17   1.0000E+03   9.7566E-01   1.1795E+01     0.000   VERTICAL
 18   7.5000E+02   9.7861E-01   1.1831E+01     0.000   VERTICAL
 19   5.0000E+02   9.8171E-01   1.1868E+01     0.000   VERTICAL
 20   2.5000E+02   9.8487E-01   1.1907E+01     0.000   VERTICAL
 21   0.0000E+00   9.8809E-01   1.1946E+01     0.000   VERTICAL


      ************************************************
```

```
            *** ACCUMMULATED DEPOSITION FOR WHOLE STREAM ***
            ************************************************

--------------------------------------------------------------------------------
 STA   ACCU.DEPS.  ACCU DEPS.     ACCU. DEPS. FOR DIFFRNT SIZE GROUPS (FT^3)
 NO.    (TONS)      (FT^3)            1
--------------------------------------------------------------------------------
   1  8.7047E+01  1.7539E+03   1.7539E+03
   2  6.9700E+01  1.4044E+03   1.4044E+03
   3  3.6668E+01  7.3884E+02   7.3884E+02
   4  1.3017E+01  2.6228E+02   2.6228E+02
   5  5.2346E+00  1.0547E+02   1.0547E+02
   6  3.0197E+00  6.0845E+01   6.0845E+01
   7  2.5476E+00  5.1333E+01   5.1333E+01
   8  2.4792E+00  4.9955E+01   4.9955E+01
   9 -3.9262E+03 -7.9111E+04  -7.9111E+04
  10  8.3031E+02  1.6730E+04   1.6730E+04
  11  5.0100E+02  1.0095E+04   1.0095E+04
  12  2.2662E+02  4.5661E+03   4.5661E+03
  13  7.4218E+01  1.4954E+03   1.4954E+03
  14  1.1007E+01  2.2178E+02   2.2178E+02
  15 -1.0378E+01 -2.0910E+02  -2.0910E+02
  16 -1.6704E+01 -3.3657E+02  -3.3657E+02
  17 -1.8512E+01 -3.7301E+02  -3.7301E+02
  18 -1.9147E+01 -3.8580E+02  -3.8580E+02
  19 -1.9515E+01 -3.9320E+02  -3.9320E+02
  20 -1.9831E+01 -3.9958E+02  -3.9958E+02
  21 -2.0143E+01 -4.0587E+02  -4.0587E+02
 SUM -2.1876E+03 -4.4079E+04  -4.4079E+04

--------------------------------------------------------------------------------
         ACCUMULATED SEDIMENT DISTRIBUTION THAT EXITED THE REACH (TONS)
SIZE FR    TOTAL        TUBE #1     TUBE #2     TUBE #3     TUBE #
   1    8.1320E+03    2.6166E+03  2.8988E+03  2.6166E+03
 TOTAL  8.1320E+03    2.6166E+03  2.8988E+03  2.6166E+03
--------------------------------------------------------------------------------


* * * * * *  GSTARS run completed successfully  * * * * * *
```

2.2.2 Debug File (.DBG)

```
GSTARS Version 2.1 - Dec 2000                        U.S. Bureau of Reclamation
INPUT FILE:  trapzoid.data                           Technical Service Center
DATE OF RUN:  1 Mar 2001                             Denver, Colorado
RUN STARTED: 15:39:07:06

               ************ Limits for this version ************
               Maximum number of cross sections:.............101
               Maximum number of points per cross section:...197
               Maximum number of particle size fractions:.... 10
               Maximum number of stream tubes:................ 5
               *************************************************


********************************************************************************
***  NOTE: this is a datafile to be used as an example of input data as it   ***
***  might be used in a GSTARS version 2.1 simulation.  It represents a      ***
***  ficticious case and it sould be viewed as such.  It should not be used  ***
***  for any other purpose without appropriate verification and validation.  ***
```

```
***                                                                         ***
***  -------------------------------------------------------------------    ***
***  Problem Description: how to set up tributary inflows in GSTARS 2.1.    ***
***  Data Filename: trapzoid.data                                           ***
***  Shape: trapezoidal channel, top width = 200 + 4y ft (61 + 4y m).       ***
***  Side Slopes: 1:2                                                       ***
***  Channel Length: 5000 ft (1524 m).                                      ***
***  Channel Slope (s): 0.0001                                              ***
***  Number of Stations: 21 equally spaced at 250 ft (76.2 m).              ***
***  -------------------------------------------------------------------    ***
********************************************************************************
***  Number of cross sections
********************************************************************************
*  GSTARS version 2.1  -  Example data file for Appendix B of user's manual.   *
*  Trapezoidal channel with sediment transport and tributary inflow.           *
*  Input sediment equals initial carrying capacity: no erosion or deposition.  *
********************************************************************************
***  YX Record - Cross-Section Coordinate Order is Y-X
  Cross section coordinate order is Y-X
***  ==========================================================================
***  ==========================================================================
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***  ==========================================================================

WARNING: illegal value in record RE, variable IOPTFR.  IOPTFR set to 1.
***  NT Record - Number of Stream Tubes
***  IT Record
***  QQ Record
***  SS Record
***  TL Record
***  SQ Record
***  -------------------------------------------------------------------------
***  Sediment Transport Records
***  -------------------------------------------------------------------------
*** Sediment transport using the revised Ackers and White equation
***  SF Record - medium sand (Dmean = 0.447 mm)
***  SD Records: size fractions falling within each size group. 1 record for
***  each Station. In this example: 1 group size => 1 value per SD record;
***  21 cross sections => 21 SD records; SD for cross section 1 defines size
***  distribution for sediment source.
***  -------------------------------------------------------------------------
***  Print-out Control
***  -------------------------------------------------------------------------
********************************************************************************
```

```
***  NOTE: this is a datafile to be used as an example of input data as it   ***
***  might be used in a GSTARS version 2.1 simulation.  It represents a      ***
***  ficticious case and it sould be viewed as such.  It should not be used  ***
***  for any other purpose without appropriate verification and validation.  ***
***                                                                          ***
***  -------------------------------------------------------------------     ***
***  Problem Description: how to set up tributary inflows in GSTARS 2.1.     ***
***  Data Filename: trapzoid.data                                            ***
***  Shape: trapezoidal channel, top width = 200 + 4y ft (61 + 4y m).        ***
***  Side Slopes: 1:2                                                        ***
***  Channel Length: 5000 ft (1524 m).                                       ***
***  Channel Slope (s): 0.0001                                               ***
***  Number of Stations: 21 equally spaced at 250 ft (76.2 m).               ***
***  -------------------------------------------------------------------     ***
********************************************************************************
***                 THIS FILE CONTAINS ALL THE TRIBUTARY DATA                ***
********************************************************************************

********************************************************************************
********************************************************************************
    TIME STEP NO.  3000 AFTER  6.2500E+01 DAYS; DISCHARGE IS  3.0000E+03 CFS
********************************************************************************
********************************************************************************



********** SIDE DISCHARGE AT STATION   9; Q LATERAL =  2.0000E+02 CFS **********

                          CRITICAL        CRITICAL
                         DEPTH (ft)     W.S.ELV.(ft)
                        ****************************
                         2.6172E+00     1.00245E+03
                         2.0088E+00     1.00242E+03
                         1.9396E+00     1.00237E+03
                         1.9079E+00     1.00233E+03
                         1.9054E+00     1.00231E+03
                         1.9055E+00     1.00228E+03
                         1.9055E+00     1.00226E+03
                         1.9055E+00     1.00223E+03
                         1.9908E+00     1.00266E+03
                         2.0117E+00     1.00255E+03
                         1.9961E+00     1.00241E+03
                         1.9934E+00     1.00229E+03
                         1.9898E+00     1.00221E+03
                         1.9896E+00     1.00217E+03
                         1.9900E+00     1.00214E+03
                         1.9901E+00     1.00211E+03
                         1.9901E+00     1.00208E+03
                         1.9901E+00     1.00206E+03
                         1.9901E+00     1.00203E+03
                         1.9901E+00     1.00201E+03
                         1.9901E+00     1.00198E+03


                     *************************************
                     *   NORMAL DEPTH PROPERTIES TABLE   *
                     *************************************

  STA.  BOTTOM     BOTTOM       FLOW      NORM FLOW  FROUDE   NORMAL      NORMAL
   ID  ELEVATION   SLOPE        AREA      VELOCITY    N0.     DEPTH      W.S.ELV.
         (ft)                  (ft^2)      (ft/s)              (ft)        (ft)
```

```
*******************************************************************************
  1 9.99836E+02 -2.306E-03  1.000E+05  1.000E-03  0.001  9.999E+02 9.99990E+04
  2 1.00041E+03 -2.306E-03  1.000E+05  1.000E-03  0.001  9.999E+02 9.99990E+04
  3 1.00043E+03 -5.857E-05  1.000E+05  1.000E-03  0.001  9.999E+02 9.99990E+04
  4 1.00043E+03 -5.987E-07  1.000E+05  1.000E-03  0.001  9.999E+02 9.99990E+04
  5 1.00040E+03  1.021E-04  1.638E+03  1.832E+00  0.123  7.611E+00 1.00801E+03
  6 1.00038E+03  1.020E-04  1.638E+03  1.831E+00  0.123  7.611E+00 1.00799E+03
  7 1.00035E+03  1.005E-04  1.646E+03  1.822E+00  0.122  7.648E+00 1.00800E+03
  8 1.00033E+03  1.001E-04  1.649E+03  1.820E+00  0.121  7.657E+00 1.00798E+03
  9 1.00067E+03 -1.366E-03  1.000E+05  1.000E-03  0.001  9.999E+02 9.99990E+04
 10 1.00054E+03  5.043E-04  1.033E+03  3.099E+00  0.255  4.942E+00 1.00548E+03
 11 1.00042E+03  5.031E-04  1.035E+03  3.092E+00  0.254  4.939E+00 1.00535E+03
 12 1.00030E+03  4.663E-04  1.058E+03  3.023E+00  0.246  5.042E+00 1.00534E+03
 13 1.00022E+03  2.986E-04  1.217E+03  2.630E+00  0.200  5.754E+00 1.00598E+03
 14 1.00018E+03  1.826E-04  1.420E+03  2.254E+00  0.160  6.656E+00 1.00683E+03
 15 1.00015E+03  1.313E-04  1.576E+03  2.031E+00  0.138  7.340E+00 1.00749E+03
 16 1.00012E+03  1.097E-04  1.668E+03  1.918E+00  0.127  7.743E+00 1.00786E+03
 17 1.00009E+03  1.028E-04  1.703E+03  1.879E+00  0.124  7.892E+00 1.00799E+03
 18 1.00007E+03  1.010E-04  1.713E+03  1.868E+00  0.123  7.935E+00 1.00800E+03
 19 1.00004E+03  1.006E-04  1.715E+03  1.866E+00  0.122  7.944E+00 1.00799E+03
 20 1.00002E+03  1.005E-04  1.716E+03  1.865E+00  0.122  7.947E+00 1.00796E+03
 21 9.99992E+02  1.005E-04  1.716E+03  1.865E+00  0.122  7.947E+00 1.00794E+03

                STEP METHOD COMPUTATIONS
     POTENTIAL CONTROL AT SECTION   21
        CONTROL TYPE =  NATURAL
        CONTROL DEPTH=    7.6679E+00 FT
        CONTROL ELEV.=    1.0077E+03 FT

     CONTROL AT SECTION   21
        CONTROL TYPE =  NATURAL
        CONTROL DEPTH=    0.0000E+00 FT
        CONTROL ELEV.=    0.0000E+00 FT


             CONVEYANCE TABLE FOR INDIVIDUAL STREAM TUBES
     STA.     TUBE-1      TUBE-2      TUBE-3      TUBE-4      TUBE-5
-------------------------------------------------------------------------------
         1  1.0060E+05  1.0060E+05  1.0060E+05
         2  1.0058E+05  1.0058E+05  1.0058E+05
         3  1.0101E+05  1.0101E+05  1.0101E+05
         4  1.0119E+05  1.0119E+05  1.0119E+05
         5  1.0127E+05  1.0127E+05  1.0127E+05
         6  1.0130E+05  1.0130E+05  1.0130E+05
         7  1.0131E+05  1.0131E+05  1.0131E+05
         8  1.0133E+05  1.0133E+05  1.0133E+05
         9  9.2831E+04  9.2831E+04  9.2831E+04
        10  9.4492E+04  9.4492E+04  9.4492E+04
        11  9.6905E+04  9.6905E+04  9.6905E+04
        12  9.8929E+04  9.8929E+04  9.8929E+04
        13  1.0003E+05  1.0003E+05  1.0003E+05
        14  1.0045E+05  1.0045E+05  1.0045E+05
        15  1.0055E+05  1.0055E+05  1.0055E+05
        16  1.0053E+05  1.0053E+05  1.0053E+05
        17  1.0047E+05  1.0047E+05  1.0047E+05
        18  1.0041E+05  1.0041E+05  1.0041E+05
        19  1.0034E+05  1.0034E+05  1.0034E+05
        20  1.0027E+05  1.0027E+05  1.0027E+05
        21  1.0019E+05  1.0019E+05  1.0019E+05

                   STREAM HYDRAULICS FOR TUBE NO. =  1
```

STA. #	AREA (ft^2)	HYDRAULIC RADIUS (ft)	VELOCITY (ft/s)	FRICTION SLOPE	TUBE START (ft)	TUBE END (ft)
1	5.715E+02	6.618E+00	1.750E+00	9.880E-05	2.491E+01	1.095E+02
2	5.546E+02	6.852E+00	1.803E+00	9.884E-05	2.451E+01	1.036E+02
3	5.605E+02	6.801E+00	1.784E+00	9.800E-05	2.459E+01	1.052E+02
4	5.604E+02	6.819E+00	1.785E+00	9.767E-05	2.457E+01	1.049E+02
5	5.608E+02	6.820E+00	1.783E+00	9.752E-05	2.457E+01	1.050E+02
6	5.609E+02	6.822E+00	1.783E+00	9.746E-05	2.456E+01	1.050E+02
7	5.609E+02	6.822E+00	1.783E+00	9.742E-05	2.456E+01	1.050E+02
8	5.610E+02	6.823E+00	1.783E+00	9.739E-05	2.456E+01	1.050E+02
9	5.312E+02	6.494E+00	2.008E+00	1.320E-04	2.496E+01	1.051E+02
10	5.362E+02	6.573E+00	1.989E+00	1.274E-04	2.487E+01	1.047E+02
11	5.453E+02	6.659E+00	1.956E+00	1.212E-04	2.477E+01	1.049E+02
12	5.524E+02	6.735E+00	1.931E+00	1.163E-04	2.469E+01	1.049E+02
13	5.564E+02	6.776E+00	1.917E+00	1.137E-04	2.465E+01	1.050E+02
14	5.579E+02	6.791E+00	1.912E+00	1.128E-04	2.464E+01	1.050E+02
15	5.582E+02	6.795E+00	1.911E+00	1.125E-04	2.464E+01	1.050E+02
16	5.581E+02	6.794E+00	1.911E+00	1.126E-04	2.464E+01	1.050E+02
17	5.579E+02	6.792E+00	1.912E+00	1.127E-04	2.465E+01	1.050E+02
18	5.577E+02	6.790E+00	1.913E+00	1.129E-04	2.465E+01	1.050E+02
19	5.575E+02	6.787E+00	1.913E+00	1.130E-04	2.466E+01	1.050E+02
20	5.572E+02	6.785E+00	1.914E+00	1.132E-04	2.467E+01	1.050E+02
21	5.569E+02	6.782E+00	1.915E+00	1.133E-04	2.467E+01	1.050E+02

STREAM HYDRAULICS FOR TUBE NO. = 2

STA. #	AREA (ft^2)	HYDRAULIC RADIUS (ft)	VELOCITY (ft/s)	FRICTION SLOPE	TUBE START (ft)	TUBE END (ft)
1	5.104E+02	8.370E+00	1.959E+00	9.880E-05	1.095E+02	1.705E+02
2	5.466E+02	7.510E+00	1.830E+00	9.884E-05	1.036E+02	1.764E+02
3	5.384E+02	7.736E+00	1.857E+00	9.800E-05	1.052E+02	1.748E+02
4	5.406E+02	7.707E+00	1.850E+00	9.767E-05	1.049E+02	1.751E+02
5	5.406E+02	7.716E+00	1.850E+00	9.752E-05	1.050E+02	1.750E+02
6	5.408E+02	7.717E+00	1.849E+00	9.746E-05	1.050E+02	1.750E+02
7	5.408E+02	7.718E+00	1.849E+00	9.742E-05	1.050E+02	1.750E+02
8	5.409E+02	7.718E+00	1.849E+00	9.739E-05	1.050E+02	1.750E+02
9	5.125E+02	7.334E+00	2.081E+00	1.320E-04	1.051E+02	1.749E+02
10	5.200E+02	7.369E+00	2.051E+00	1.274E-04	1.047E+02	1.753E+02
11	5.269E+02	7.505E+00	2.025E+00	1.212E-04	1.049E+02	1.751E+02
12	5.333E+02	7.602E+00	2.000E+00	1.163E-04	1.049E+02	1.751E+02
13	5.367E+02	7.658E+00	1.987E+00	1.137E-04	1.050E+02	1.750E+02
14	5.380E+02	7.679E+00	1.983E+00	1.128E-04	1.050E+02	1.750E+02
15	5.382E+02	7.684E+00	1.982E+00	1.125E-04	1.050E+02	1.750E+02
16	5.382E+02	7.683E+00	1.982E+00	1.126E-04	1.050E+02	1.750E+02
17	5.380E+02	7.680E+00	1.983E+00	1.127E-04	1.050E+02	1.750E+02
18	5.378E+02	7.677E+00	1.984E+00	1.129E-04	1.050E+02	1.750E+02
19	5.375E+02	7.674E+00	1.984E+00	1.130E-04	1.050E+02	1.750E+02
20	5.373E+02	7.671E+00	1.985E+00	1.132E-04	1.050E+02	1.750E+02
21	5.370E+02	7.668E+00	1.986E+00	1.133E-04	1.050E+02	1.750E+02

STREAM HYDRAULICS FOR TUBE NO. = 3

STA. #	AREA (ft^2)	HYDRAULIC RADIUS (ft)	VELOCITY (ft/s)	FRICTION SLOPE	TUBE START (ft)	TUBE END (ft)
1	5.715E+02	6.618E+00	1.750E+00	9.880E-05	1.705E+02	2.600E+02
2	5.546E+02	6.852E+00	1.803E+00	9.884E-05	1.764E+02	2.600E+02
3	5.605E+02	6.801E+00	1.784E+00	9.800E-05	1.748E+02	2.600E+02
4	5.604E+02	6.819E+00	1.785E+00	9.767E-05	1.751E+02	2.600E+02
5	5.608E+02	6.820E+00	1.783E+00	9.752E-05	1.750E+02	2.600E+02
6	5.609E+02	6.822E+00	1.783E+00	9.746E-05	1.750E+02	2.600E+02

```
  7   5.609E+02   6.822E+00   1.783E+00   9.742E-05   1.750E+02   2.600E+02
  8   5.610E+02   6.823E+00   1.783E+00   9.739E-05   1.750E+02   2.600E+02
  9   5.312E+02   6.494E+00   2.008E+00   1.320E-04   1.749E+02   2.600E+02
 10   5.362E+02   6.573E+00   1.989E+00   1.274E-04   1.753E+02   2.600E+02
 11   5.453E+02   6.659E+00   1.956E+00   1.212E-04   1.751E+02   2.600E+02
 12   5.524E+02   6.735E+00   1.931E+00   1.163E-04   1.751E+02   2.600E+02
 13   5.564E+02   6.776E+00   1.917E+00   1.137E-04   1.750E+02   2.600E+02
 14   5.579E+02   6.791E+00   1.912E+00   1.128E-04   1.750E+02   2.600E+02
 15   5.582E+02   6.795E+00   1.911E+00   1.125E-04   1.750E+02   2.600E+02
 16   5.581E+02   6.794E+00   1.911E+00   1.126E-04   1.750E+02   2.600E+02
 17   5.579E+02   6.792E+00   1.912E+00   1.127E-04   1.750E+02   2.600E+02
 18   5.577E+02   6.790E+00   1.913E+00   1.129E-04   1.750E+02   2.600E+02
 19   5.575E+02   6.787E+00   1.913E+00   1.130E-04   1.750E+02   2.600E+02
 20   5.572E+02   6.785E+00   1.914E+00   1.132E-04   1.750E+02   2.600E+02
 21   5.569E+02   6.782E+00   1.915E+00   1.133E-04   1.750E+02   2.600E+02


RUN ENDED: 15:41:15:73
```

2.2.3 Sediment Data (.SED)

The .SED file contains the computed sediment transport capacity and bed size distribution at the beginning of the time step. For each time step requested, that information is presented for each stream tube and for every cross section.

```
*********************************************************************************
*  GSTARS version 2.1  -  Example data file for Appendix B of user's manual.   *
*  Trapezoidal channel with sediment transport and tributary inflow.           *
*  Input sediment equals initial carrying capacity: no erosion or deposition.  *
*********************************************************************************


TIME STEP =   3000; TUBE # =  1; STA. # =    1
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.70416E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.70416E+01

TIME STEP =   3000; TUBE # =  1; STA. # =    2
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.03399E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.03399E+01

TIME STEP =   3000; TUBE # =  1; STA. # =    3
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.88374E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.88374E+01

TIME STEP =   3000; TUBE # =  1; STA. # =    4
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.87400E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.87400E+01

TIME STEP =   3000; TUBE # =  1; STA. # =    5
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.86082E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.86082E+01

TIME STEP =   3000; TUBE # =  1; STA. # =    6
```

```
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.85661E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.85661E+01

TIME STEP =   3000; TUBE # =  1; STA. # =    7
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.85399E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.85399E+01

TIME STEP =   3000; TUBE # =  1; STA. # =    8
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.85183E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.85183E+01

TIME STEP =   3000; TUBE # =  1; STA. # =    9
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      6.61361E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                6.61361E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   10
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      6.16278E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                6.16278E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   11
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.50777E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                5.50777E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   12
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.02419E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                5.02419E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   13
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.77754E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.77754E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   14
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.68721E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.68721E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   15
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.66670E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.66670E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   16
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.67112E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.67112E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   17
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.68316E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.68316E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   18
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
```

```
 1     0.10000     2.00000     0.44721     100.000      4.69735E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.69735E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   19
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.71221E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.71221E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   20
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.72739E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.72739E+01

TIME STEP =   3000; TUBE # =  1; STA. # =   21
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.74281E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.74281E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    1
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.97451E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.97451E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    2
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.16869E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.16869E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    3
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.30329E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.30329E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    4
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.24276E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.24276E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    5
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.23618E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.23618E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    6
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.23107E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.23107E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    7
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.22841E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.22841E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    8
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.22613E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.22613E+01

TIME STEP =   3000; TUBE # =  2; STA. # =    9
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      7.17370E+01
```

```
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              7.17370E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   10
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      6.60764E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              6.60764E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   11
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.99317E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.99317E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   12
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.50421E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.50421E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   13
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.25859E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.25859E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   14
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.16847E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.16847E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   15
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.14845E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.14845E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   16
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.15344E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.15344E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   17
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.16607E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.16607E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   18
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.18086E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.18086E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   19
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.19634E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.19634E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   20
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.21214E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.21214E+01

TIME STEP =   3000; TUBE # =  2; STA. # =   21
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.22820E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):              5.22820E+01
```

```
TIME STEP =   3000; TUBE # =  3; STA. # =    1
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.70416E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.70416E+01

TIME STEP =   3000; TUBE # =  3; STA. # =    2
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      3.03399E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                3.03399E+01

TIME STEP =   3000; TUBE # =  3; STA. # =    3
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.88374E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.88374E+01

TIME STEP =   3000; TUBE # =  3; STA. # =    4
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.87400E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.87400E+01

TIME STEP =   3000; TUBE # =  3; STA. # =    5
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.86082E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.86082E+01

TIME STEP =   3000; TUBE # =  3; STA. # =    6
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.85661E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.85661E+01

TIME STEP =   3000; TUBE # =  3; STA. # =    7
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.85399E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.85399E+01

TIME STEP =   3000; TUBE # =  3; STA. # =    8
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      2.85183E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                2.85183E+01

TIME STEP =   3000; TUBE # =  3; STA. # =    9
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      6.61361E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                6.61361E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   10
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      6.16278E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                6.16278E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   11
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.50777E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                5.50777E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   12
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      5.02419E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                5.02419E+01
```

```
TIME STEP =   3000; TUBE # =  3; STA. # =   13
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.77754E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.77754E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   14
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.68721E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.68721E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   15
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.66670E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.66670E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   16
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.67112E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.67112E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   17
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.68316E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.68316E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   18
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.69735E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.69735E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   19
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.71221E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.71221E+01

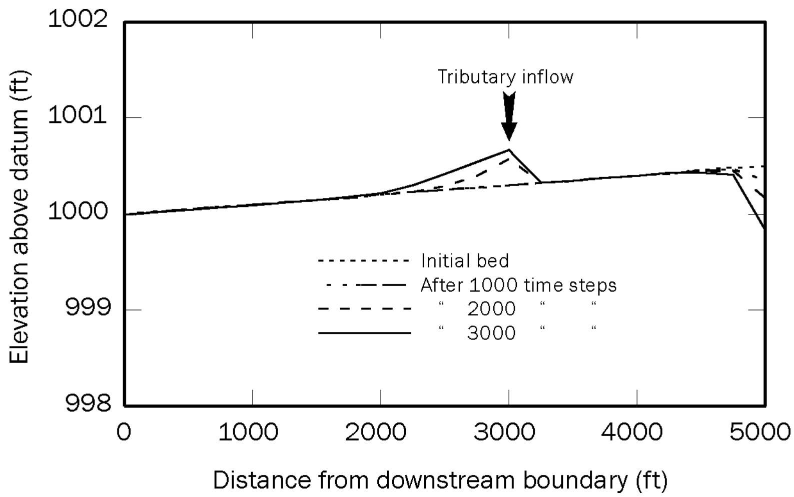
TIME STEP =   3000; TUBE # =  3; STA. # =   20
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.72739E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.72739E+01

TIME STEP =   3000; TUBE # =  3; STA. # =   21
 I     DRL(I)      DRU(I)     D(I)(mm)    FRACTION(%)   SEDIMNT LOAD
 1     0.10000     2.00000     0.44721     100.000      4.74281E+01
TOTAL SEDIMENT LOAD (CAPACITY, TON/DAY):                4.74281E+01
```

2.3 Final Remarks

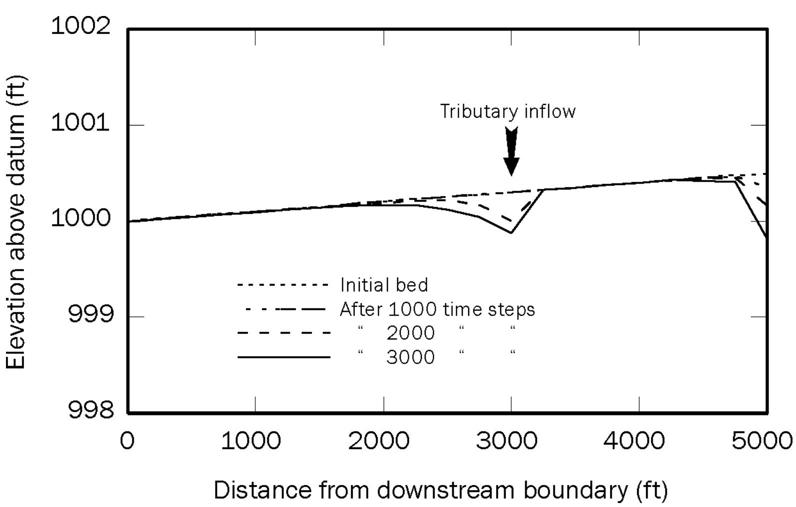
The run was set up such that the initial 1,000 time steps do not have tributary inflow. Under the conditions of equilibrium set for this problem, no bed changes are expected. However, a very small change is observed at the first two cross sections of the reach (see figure 2.2). This happens because the sediment load specified at the inlet of the channel only approximately satisfies the carrying capacity of those sections. This is due to the nature of the approximate calculations and to the fact that different stream tubes will have different capacity, in spite of having equal conveyance. Therefore, those sections supply the sediment necessary to satisfy the equilibrium conditions for the downstream reach. The computational reach was developed such that what happens in the upstream sections does not influence the region of interest, which is the region near the tributary inflow.

Figure 2.2 Bed evolution profiles for example 2.



For the remaining 2,000 time steps of the run, the tributary discharges 200 cfs of sediment laden water into the main channel. Tributary sediment inflow rate is 120 ton/day, far exceeding the sediment transport capacity of the channel. A depositional cusp is formed at the point of tributary inflow. The volume of deposited sediments grows with time, as shown in figure 2.2. Notice that the upstream cross sections continue to degrade in order to maintain the additional supply of sediments necessary to preserve equilibrium transport in the downstream reach.

Figure 2.3 Bed evolution for the same data configuration presented in example 2, except that the tributary discharges clear water into the main channel (Q_S = 0 in all records QS in file tributary.data).



EXAMPLE 3

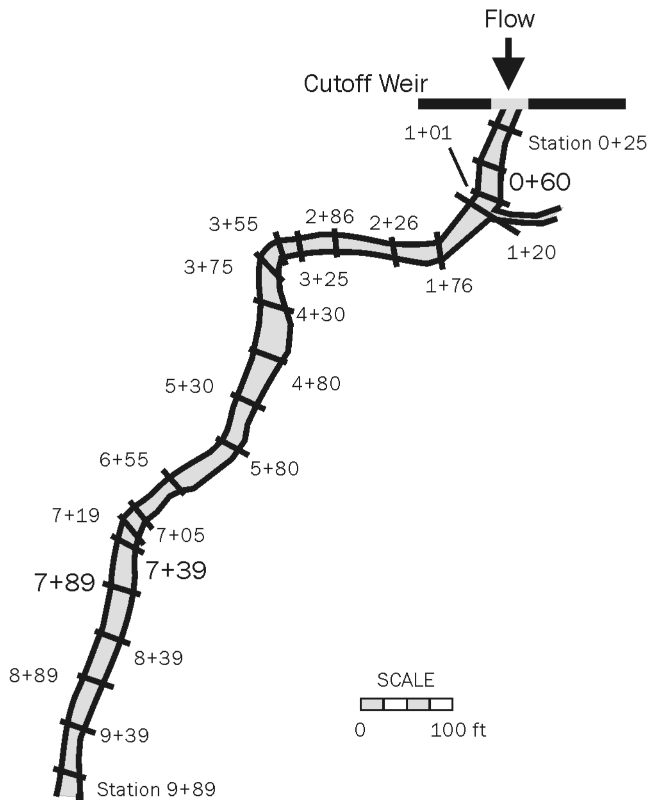
LAKE MESCALERO SPILLWAY CHANNEL

This example shows how to apply the concepts of bank stability and total stream power minimization implemented in GSTARS 2.1. Together, these two concepts allow the computation of channel width variation and river meandering while maintaining the proper angle of repose of the river banks. To illustrate these features we used data from a study conducted on Lake Mescalero Dam and Dike. The study was performed by Song et al. (1995) using an earlier version of GSTARS. Their data was adopted, with modifications, for inclusion as an example in this manual.

The Lake Mescalero Dam and Dike were constructed in 1974 and are located at the confluence of Ciewegita and Carrige Creeks on the Mescalero Apache Indian Reservation about 2.5 miles southwest of Ruidoso, New Mexico. In this example we use data from the channel immediately downstream from the emergency spillway. The spillway is located in a bedrock cut in the sandstone and shale of the left abutment of the dam. The spillway consists of a 290-ft long approach channel, a 103.8-ft wide concrete weir, a 138-ft long concrete-lined discharge chute, a 15-ft long flip bucket, and a concrete erosion cutoff wall located about 250 ft downstream from the flip bucket. The spillway crest rises 5.0 ft above the spillway approach channel floor and the discharge chute floor, to a crest elevation of 6905.0 ft.

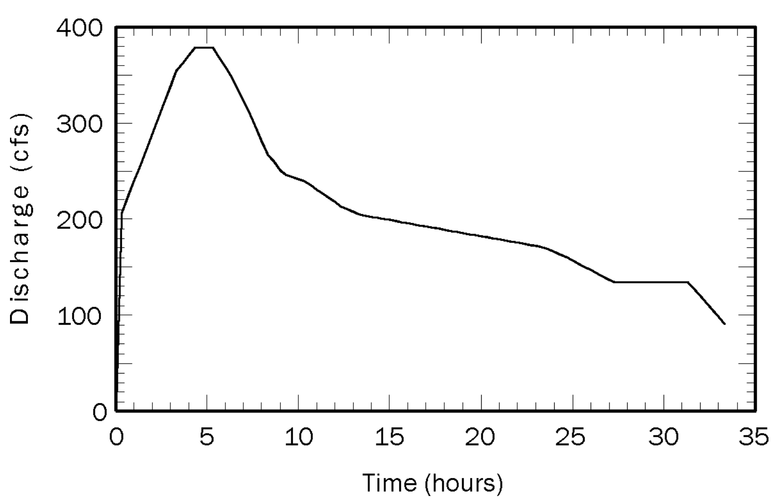
The data of the flood period of 20 December 1984 through 31 December 1984 was used in this example. The water surface elevation of the reservoir was available for that period. Cross-sectional data was taken from a detailed topographic survey of the study area carried out on 12 June 1979. Figure 3.1 shows the layout of the channel below the spillway at that time. Also, cross-sectional channel geometry was available at two locations after the 1984 flood. These sections are used later for comparison purposes.

Figure 3.1 Plan view of the channel below spillway used for this example data file.



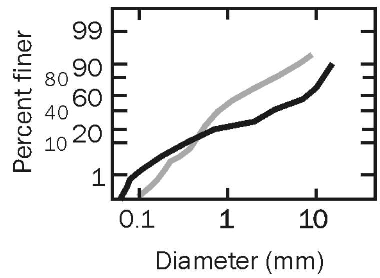
The water surface elevation of the reservoir was available for the period of the flood. The discharge hydrograph was generated using the water levels and a standard weir equation, $Q = CLH^{3/2}$ with $C = 3.65$. The flood hydrograph is shown in figure 3.2.

Figure 3.2 Spillway hydrograph for the December 1984 flood.



The sediment data used was based on bed samples collected from several sites along the channel. Two typical size distributions are plotted in figure 3.3. Based on the mean sediment size, a Manning's roughness coefficient of 0.06 was chosen for stage-discharge computations.

Figure 3.3 Typical sediment particle size distributions collected in the spillway channel.



3.1 Input Data File

The files shown in this and the next sections are part of the main GSTARS 2.1 distribution package. They can be found under directory Example3.

```
TT GSTARS version 2.1  -  Example data file for Appendix B of user's manual
TT Lake Mescalero Dam Spillway  -  St. Anthony Falls data file
TT Stream power minimization calculations with bank stability routine

********************************************************************************
***                                                                          ***
***  NOTE: this is a simplified version of the datafile used to simulate     ***
***  the Lake Mescalero spillway.  It may not represent the actual flow and  ***
***  geological conditions at the site, and is used here only as an example  ***
***  of input data as it might be used in a GSTARS version 2.1 simulation.   ***
***  This file was constructed for didactic purposes only.                   ***
***                                                                          ***
********************************************************************************

NS    23
*** Cross Section Coordinate Order is X-Y
*** section 1
ST  989.      22     0.0     0.0     0.0     1.0     0.0
ND     1   227.0
XS 178.0   503.0   186.0   498.9   188.0   495.0   190.0   494.4   193.0   494.4
XS 195.0   494.3   196.5   494.3   198.0   494.3   199.0   494.3   200.0   494.2
XS 201.0   494.4   202.0   494.5   203.0   494.8   204.0   495.3   205.5   495.5
XS 208.0   496.5   210.0   497.7   215.0   497.9   220.0   498.1   223.0   498.3
XS 225.0   499.0   227.0   502.6
***
RH 0.060
*** ============================================================================
***  section 2
ST 964.0      22     0.0     0.0     0.0     1.0     0.0
ND     1   214.0
```

```
***
XS 180.0   498.5   186.0   497.0   188.0   496.0   190.0   495.3   192.0   494.8
XS 194.0   493.8   195.5   493.4   197.0   493.0   198.5   492.8   200.0   492.7
XS 201.0   494.0   202.0   493.5   203.0   493.0   204.0   492.9   206.0   493.0
XS 207.0   494.0   208.0   493.1   210.0   495.5   212.0   497.0   214.0   498.7
XS 217.0   499.0   226.0   499.0
***
RH 0.060
*** ============================================================================
***   section 3
ST 929.0      20     0.0     0.0     0.0     1.0     0.0
ND     1   205.0

XS 172.0   498.5   178.0   494.1   180.0   491.5   183.0   491.0   185.0   490.5
XS 186.0   490.0   189.0   489.6   192.0   489.2   193.0   489.3   194.0   489.4
XS 195.0   489.5   196.0   489.6   197.0   489.7   198.4   489.8   199.0   490.1
XS 199.5   490.3   200.0   490.4   201.5   490.8   203.0   491.3   219.0   497.6
***
RH 0.060
*** ============================================================================
*** section 4
ST 888.0      22     0.0     0.0     0.0     1.0     0.0
ND     1   221.0

XS 177.0   495.0   179.0   492.9   181.0   487.5   181.7   486.5   182.5   486.4
XS 183.5   486.3   185.0   486.3   186.0   486.2   187.5   486.0   189.0   485.8
XS 190.0   485.6   192.0   485.3   193.0   487.0   194.0   488.0   195.0   491.0
XS 196.0   492.7   198.0   493.5   200.0   494.8   205.0   495.1   210.0   495.4
XS 215.0   495.8   221.0   496.1
***
RH 0.060
*** ============================================================================
*** section 5
ST 813.0      24     0.0     0.0     0.0     1.0     0.2
ND     1   182.0

XS 127.0   494.4   131.0   487.0   131.5   486.0   132.4   485.0   135.0   479.9
XS 136.0   480.3   137.0   480.6   138.0   480.8   139.0   481.0   140.0   481.5
XS 141.0   481.5   142.0   481.5   143.5   481.5   145.0   482.0   147.0   483.0
XS 150.0   484.0   157.0   486.0   161.0   487.7   165.0   489.0   170.0   490.0
XS 173.0   491.0   176.0   492.0   179.0   492.8   182.0   493.4
***
RH 0.060
*** ============================================================================
*** section 6
ST 763.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   185.0

XS 138.0   492.9   140.0   488.0   142.0   483.0   144.0   480.0   145.0   479.0
XS 148.0   479.0   150.0   478.6   151.0   478.6   153.0   478.7   155.0   478.7
XS 157.0   478.7   159.0   478.7   160.0   478.7   162.0   478.7   164.0   478.8
XS 165.0   478.8   167.0   478.9   168.5   478.9   170.0   478.9   172.0   479.2
XS 173.5   479.6   175.0   480.0   180.0   483.0   185.0   488.0
***
RH 0.060
*** ============================================================================
*** section 7
ST 703.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   198.5

XS 155.0   490.5   157.0   485.0   159.0   480.9   163.0   480.0   167.0   479.0
```

```
XS 168.5   478.0   170.0   478.0   171.0   477.8   172.0   477.8   173.0   477.0
XS 174.0   476.9   175.0   476.9   176.0   476.9   177.0   476.8   178.0   476.6
XS 179.0   476.6   180.0   476.3   181.5   478.0   183.0   480.0   186.0   484.5
XS 190.0   488.0   193.0   490.0   197.0   490.0   198.5   491.0
***
RH 0.060
*** ============================================================================
*** section 8
ST 664.0      21     0.0     0.0     0.0     1.0     0.0
ND     1   194.0

XS 158.0   488.3   160.0   483.0   162.0   480.0   165.0   478.0   166.0   477.0
XS 167.0   476.0   168.0   474.3   169.0   475.0   170.0   475.1   171.0   475.1
XS 172.0   475.2   174.0   475.2   176.0   475.3   178.0   475.4   179.0   475.4
XS 180.0   477.0   183.0   480.0   187.0   483.0   190.0   487.0   192.0   489.0
XS 194.0   489.5
***
RH 0.060
*** ============================================================================
***   section 9
ST 634.0      23     0.0     0.0     0.0     1.0     0.0
ND     1   194.0

XS 153.0   488.9   157.0   485.0   160.0   483.5   163.0   483.0   165.0   478.0
XS 166.0   476.0   167.0   475.0   168.0   474.0   169.0   474.0   170.0   474.1
XS 171.0   474.1   172.0   474.2   173.0   474.2   174.0   474.3   175.0   474.3
XS 176.0   474.4   177.0   475.4   178.0   476.0   180.0   477.0   183.0   480.0
XS 187.0   483.0   190.0   487.0   194.0   491.0
***
RH 0.060
*** ============================================================================
***   section 10
ST 614.0      22     0.0     0.0     0.0     1.0     0.2
ND     1   204.0

XS 148.0   489.3   150.0   482.0   152.0   477.7   155.0   477.0   157.0   476.0
XS 160.0   475.0   163.0   474.0   165.0   473.5   167.0   473.1   168.5   473.1
XS 170.0   473.1   173.0   473.0   176.0   473.0   179.0   473.1   182.0   477.1
XS 185.0   478.0   188.0   480.0   191.0   483.0   194.0   487.0   197.0   490.0
XS 200.0   492.3   204.0   492.3
***
RH 0.060
*** ============================================================================
***   section 11
ST 559.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   190.0

XS 135.0   488.0   138.0   480.0   139.0   475.0   141.5   472.5   143.0   472.6
XS 144.5   472.6   146.0   472.7   147.0   472.7   148.0   472.7   149.0   472.8
XS 150.0   472.8   153.0   472.9   155.0   473.0   157.0   473.0   158.0   473.0
XS 159.0   473.1   160.0   473.1   162.0   473.2   164.0   473.2   166.0   473.3
XS 170.0   473.4   175.0   477.0   185.0   479.5   190.0   491.0
***
RH 0.060
*** ============================================================================
***   section 12
ST 509.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   204.0

XS 130.0   485.1   131.5   480.0   133.0   475.6   137.0   474.0   140.0   473.0
XS 143.0   472.0   147.0   471.5   153.0   470.1   157.0   471.0   160.0   471.0
```

```
XS 164.0   471.0   167.0   473.0   170.0   475.0   173.0   478.0   177.0   481.0
XS 180.0   482.0   183.0   483.5   187.0   485.0   190.0   486.3   193.0   486.8
XS 197.0   487.0   200.0   487.3   202.0   487.5   204.0   487.6
***
RH 0.060
*** ============================================================================
***   section 13
ST 459.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   190.0

XS 123.0   483.9   130.0   480.0   135.0   478.0   140.0   476.0   143.0   474.0
XS 147.0   478.0   150.0   472.7   151.0   469.0   152.0   469.0   153.0   468.0
XS 155.0   467.0   157.0   467.0   159.0   466.7   161.0   466.5   163.0   466.2
XS 164.5   467.0   166.0   468.0   170.0   470.0   173.0   473.0   177.0   476.0
XS 180.0   479.0   182.0   483.2   186.0   484.0   190.0   485.5
***
RH 0.060
*** ============================================================================
***  section 14
ST 409.0      22     0.0     0.0     0.0     1.0     0.2
ND     1   205.0

XS 135.0   482.4   137.0   477.0   139.0   470.9   143.0   468.0   144.0   467.0
XS 146.0   466.0   148.0   465.0   150.0   464.0   151.0   463.6   153.0   463.2
XS 155.0   463.3   157.0   463.4   158.5   463.5   160.0   463.6   162.5   464.5
XS 165.0   466.0   170.0   469.0   175.0   472.0   180.0   474.0   185.0   476.0
XS 190.0   478.0   205.0   482.5
***
RH 0.060
*** ============================================================================
***   section 15
ST 334.0      23     0.0     0.0     0.0     1.0     0.0
ND     1   200.0

XS 144.0   479.7   147.0   478.0   150.0   475.0   153.0   473.0   157.0   471.0
XS 160.0   469.4   162.0   467.4   164.0   465.2   166.0   464.2   168.0   463.2
XS 169.5   462.3   171.0   461.5   172.0   461.3   173.0   461.1   174.0   460.7
XS 175.0   460.4   177.0   461.5   178.5   463.5   180.0   465.0   185.0   470.0
XS 190.0   475.0   195.0   478.0   200.0   480.5
***
RH 0.060
*** ============================================================================
***   section 16
ST 284.0      23     0.0     0.0     0.0     1.0     0.0
ND     1   197.0

XS 146.0   478.0   150.0   476.0   153.0   474.0   157.0   472.0   160.0   470.0
XS 164.0   468.5   167.0   465.5   168.5   464.5   170.0   463.5   172.0   461.5
XS 174.0   460.3   175.0   460.3   177.0   460.4   178.0   460.4   179.0   460.4
XS 180.0   460.5   182.0   460.6   184.0   465.0   187.0   470.0   189.0   475.2
XS 191.0   477.2   194.0   479.3   197.0   479.4
***
RH 0.060
*** ============================================================================
***   section 17
ST 270.0      24     0.0     0.0     0.0     1.0     0.2
ND     1   200.0

XS 145.0   477.7   148.0   475.7   150.0   473.7   153.0   472.2   157.0   469.0
XS 160.0   466.0   161.5   465.9   163.0   463.0   165.0   461.0   167.0   459.0
XS 168.5   458.9   170.0   458.6   172.5   458.5   175.0   459.0   177.5   459.3
```

```
XS 180.0   459.5   182.0   460.0   184.0   460.5   185.5   465.0   187.0   470.0
XS 190.0   478.1   193.0   478.3   197.0   478.6   200.0   478.8
***
RH 0.060
*** ============================================================================
***   section 18
ST 250.0      23     0.0     0.0     0.0     1.0     0.0
ND     1   211.0

XS 149.0   477.3   155.0   475.3   160.0   473.0   163.0   470.0   166.0   468.0
XS 167.0   462.0   169.0   460.0   171.0   458.0   172.5   458.0   174.0   458.1
XS 176.0   458.1   178.0   458.1   179.0   458.1   180.0   458.2   181.5   458.2
XS 183.0   458.2   185.5   460.0   187.0   462.0   190.0   466.0   197.0   472.0
XS 200.0   475.0   205.0   474.8   211.0   474.6
***
RH 0.060
*** ============================================================================
***   section 19
ST 200.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   188.0

XS 138.0   476.6   140.0   473.1   142.0   469.6   145.0   469.4   147.0   460.9
XS 149.0   457.4   151.0   457.2   153.0   457.0   155.0   456.8   157.0   456.6
XS 160.0   456.3   162.0   456.5   164.0   456.7   166.0   457.0   168.0   457.3
XS 170.0   457.6   172.0   457.8   174.0   458.0   176.0   458.2   178.0   460.7
XS 180.0   463.2   182.0   465.7   184.0   468.2   188.0   473.2
***
RH 0.060
*** ============================================================================
***   section 20
ST 150.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   190.0

XS 144.0   474.2   145.0   473.2   146.0   470.2   147.0   467.5   148.0   462.5
XS 150.0   461.3   152.0   460.1   154.0   459.0   156.0   457.8   158.0   456.5
XS 160.0   455.5   162.0   455.7   164.0   456.0   166.0   456.2   168.0   456.4
XS 170.0   456.6   172.0   456.7   174.0   456.6   176.0   456.9   178.0   457.0
XS 182.0   460.7   185.0   464.3   187.0   467.3   190.0   471.3
***
RH 0.060
*** ============================================================================
***   section 21
ST 100.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   190.0

XS 150.0   472.5   151.0   466.5   152.0   460.5   153.0   455.1   155.0   455.1
XS 157.0   455.1   159.0   455.0   161.0   455.0   163.0   455.0   165.0   454.9
XS 167.0   454.9   169.0   454.8   171.0   454.8   173.0   454.9   175.0   455.1
XS 177.0   455.2   179.0   455.4   181.0   455.5   183.0   455.6   186.0   455.7
XS 189.0   460.5   191.0   463.0   194.0   466.7   200.0   469.1
***
RH 0.060
*** ============================================================================
***   section 22
ST  50.0      24     0.0     0.0     0.0     1.0     0.0
ND     1   184.0

XS 144.0   470.2   147.0   469.0   150.0   467.5   154.0   466.3   155.0   464.0
XS 156.0   462.3   157.0   459.6   159.0   459.4   161.0   459.2   163.0   459.0
XS 165.0   458.9   168.0   458.7   170.0   458.0   172.0   457.3   174.0   456.6
XS 176.0   456.0   177.0   455.3   178.0   454.7   179.0   454.0   180.0   457.0
```

```
XS 181.0   460.0   182.0   463.0   183.0   466.0   184.0   468.7
***
RH 0.060
*** ==========================================================================
***   section 23
ST   0.0      24     1.0     1.0     0.0     1.0     0.0
ND     1   170.0

XS 129.0   463.8   133.0   463.0   136.0   462.1   139.0   461.2   141.0   460.0
XS 143.0   458.8   145.0   457.6   147.0   456.4   149.0   455.2   151.0   454.0
XS 152.0   452.6   153.0   452.5   154.0   452.4   155.0   452.4   156.0   452.3
XS 157.0   452.3   158.0   452.2   160.0   452.2   162.0   452.1   163.0   452.1
XS 165.0   455.6   167.0   459.0   169.0   462.5   170.0   466.2
***
RH 0.060
*** ==========================================================================
RE      MANNING
   number of stream tubes
NT     3
IT   100       1      20 min
QQ      TABLE OF DISCHARGES
SS      STAGE DISCHARGE TABLE
TL    23

   stage discharge table for section cross section #23
SQ 206.4   454.0
SQ 222.8   454.0
SQ 239.3   454.0
SQ 255.7   454.0
SQ 272.1   454.0
SQ 288.6   454.0
SQ 305.0   454.0
SQ 321.4   454.0
SQ 337.8   454.0
SQ 354.2   454.0
SQ 362.4   454.0
SQ 370.7   454.0
SQ 378.9   454.0
SQ 378.9   454.0
SQ 378.9   454.0
SQ 378.9   454.0
SQ 368.7   454.0
SQ 358.6   454.0
SQ 348.2   454.0
SQ 335.6   454.0

SQ 323.0   454.0
SQ 310.4   454.0
SQ 295.9   454.0
SQ 281.4   454.0
SQ 267.0   454.0
SQ 260.0   454.0
SQ 251.0   454.0
SQ 246.1   454.0
SQ 243.9   454.0
SQ 241.7   454.0
SQ 239.6   454.0
SQ 235.3   454.0
SQ 231.0   454.0
SQ 226.6   454.0
SQ 222.3   454.0
```

```
SQ 218.3   454.0
SQ 213.6   454.0
SQ 210.6   454.0
SQ 207.6   454.0
SQ 204.7   454.0

SQ 203.6   454.0
SQ 202.5   454.0
SQ 201.4   454.0
SQ 200.3   454.0
SQ 199.2   454.0
SQ 198.0   454.0
SQ 196.9   454.0
SQ 195.8   454.0
SQ 194.6   454.0
SQ 193.5   454.0
SQ 192.4   454.0
SQ 191.3   454.0
SQ 190.2   454.0
SQ 189.1   454.0
SQ 187.9   454.0
SQ 186.9   454.0
SQ 185.7   454.0
SQ 184.5   454.0
SQ 183.4   454.0
SQ 182.3   454.0

SQ 181.2   454.0
SQ 180.1   454.0
SQ 179.0   454.0
SQ 177.8   454.0
SQ 176.7   454.0
SQ 175.6   454.0
SQ 174.4   454.0
SQ 173.3   454.0
SQ 172.2   454.0
SQ 171.1   454.0
SQ 168.6   454.0
SQ 166.2   454.0
SQ 163.7   454.0
SQ 160.4   454.0
SQ 157.1   454.0
SQ 153.8   454.0
SQ 150.5   454.0
SQ 147.2   454.0
SQ 143.9   454.0
SQ 140.6   454.0

SQ 137.3   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
```

```
SQ 134.0   454.0
SQ 127.0   454.0
SQ 120.0   454.0
SQ 112.7   454.0
SQ 105.6   454.0
SQ  98.5   454.0
SQ  91.4   454.0

    sediment
SE   6.0    50.0
QS   2.0     0.0
QS   2.0    11.0
QS   2.0    23.0
QS   2.0    17.0
QS   2.0    11.0
QS   2.0     6.0
QS  88.0     0.0

    water temperature
TM 100.0    70.0

    particle size classes
SF   5.0
SG   .06     .80
SG   .80    2.00
SG  2.00    5.00
SG  5.00   10.00
SG 10.00   20.00

    bed gradation
SD   .11     .17     .24     .41     .07
SD   .11     .17     .24     .41     .07
SD   .11     .17     .24     .41     .07
SD   .38     .30     .17     .10     .05
SD   .38     .30     .17     .10     .05
SD   .38     .30     .17     .10     .05
SD   .24     .26     .24     .09     .17
SD   .24     .26     .24     .09     .17
SD   .24     .26     .24     .09     .17
SD   .10     .23     .23     .19     .25
SD   .10     .23     .23     .19     .25
SD   .10     .23     .23     .19     .25
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15
SD   .06     .26     .30     .23     .15

AR    60      90

PR     2     100
PX   100  CROSS SECTION PLOTS
PW   100  WATER SURFACE PROFILE PLOTS

   minimization instructions
```

```
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0

END
```

3.2 Output Data Files

3.2.1 Main Output File (.OUT)

```
             GGGGG     SSSSS   TTTTTTTT     A     RRRRRR     SSSSS
            GGGGGGG   SSSSSSS  TTTTTTTT    AAA    RRRRRRR   SSSSSSS
           GG     GG SS     SS    TT      AA AA   RR    RR SS     SS
           GG        SS           TT     AA   AA  RR    RR SS
           GG  GGGGG  SSSSSSS     TT    AA     AA RRRRRRR   SSSSSSS
           GG  GGGGG   SSSSSSS    TT    AAAAAAAAA RRRRRR     SSSSSSS
           GG     GG        SS    TT    AAAAAAAAA RR RR           SS
           GG     GG SS     SS    TT    AA     AA RR  RR   SS     SS
            GGGGGGG   SSSSSSS     TT    AA     AA RR   RR   SSSSSSS
             GGGGG     SSSSS      TT    AA     AA RR    RR   SSSSS


GSTARS Version 2.1 - Dec 2000                        U.S. Bureau of Reclamation
INPUT FILE:  mescal.dat                              Technical Service Center
DATE OF RUN: 22 Feb 2001                             Denver, Colorado
TIME OF RUN: 14:39:17


********************************************************************************
*  GSTARS version 2.1  -  Example data file for Appendix B of user's manual    *
*  Lake Mescalero Dam Spillway  -  St. Anthony Falls data file                 *
*  Stream power minimization calculations with bank stability routine          *
********************************************************************************


* * * * * * *   SUMMARY OF INPUT PARAMETERS   * * * * * * *
```

```
Number of cross sections:...........................    23
Number of stream tubes:.............................     3
Number of time steps:...............................   100
Number of sediment time steps (NITRQS):.............     1
Duration of time step (days):.......................  1.3889E-02
Formula selected for conveyance calculations:........  MANNING
Formula selected for friction slope:.................  average
Formula for sediment transport: ..............  Yang (1973) with gravel (1984)
NALT for active layer thickness:.....................    50
Transport parameter CFACTOR:.........................  1.00
Angle of repose above the water surf. (deg):.........  60.0
Angle of repose below the water surf. (deg):.........  90.0
Printout control is  2; print interval:..............   100
Number of time steps to generate x-sec plots:........   100
Number of time steps for thalweg plots:..............   100
Minimization is requested.
```

Sect. #	Location (ft)	ISWITCH	ITYP	Thalweg (ft)	Bed slope	Loss Coef.	NDIVI	NPOINTS
1	9.8900E+02	0	0	4.9420E+02	6.0000E-02	0.00	1	22
2	9.6400E+02	0	0	4.9270E+02	6.0000E-02	0.00	1	22
3	9.2900E+02	0	0	4.8920E+02	1.0000E-01	0.00	1	20
4	8.8800E+02	0	0	4.8530E+02	9.5122E-02	0.00	1	22
5	8.1300E+02	0	0	4.7990E+02	7.2000E-02	0.20	1	24
6	7.6300E+02	0	0	4.7860E+02	2.6000E-02	0.00	1	24
7	7.0300E+02	0	0	4.7630E+02	3.8333E-02	0.00	1	24
8	6.6400E+02	0	0	4.7430E+02	5.1282E-02	0.00	1	21
9	6.3400E+02	0	0	4.7400E+02	1.0000E-02	0.00	1	23
10	6.1400E+02	0	0	4.7300E+02	5.0000E-02	0.20	1	22
11	5.5900E+02	0	0	4.7250E+02	9.0909E-03	0.00	1	24
12	5.0900E+02	0	0	4.7010E+02	4.8000E-02	0.00	1	24
13	4.5900E+02	0	0	4.6620E+02	7.8000E-02	0.00	1	24
14	4.0900E+02	0	0	4.6320E+02	6.0000E-02	0.20	1	22
15	3.3400E+02	0	0	4.6040E+02	3.7333E-02	0.00	1	23
16	2.8400E+02	0	0	4.6030E+02	2.0000E-03	0.00	1	23
17	2.7000E+02	0	0	4.5850E+02	1.2857E-01	0.20	1	24
18	2.5000E+02	0	0	4.5800E+02	2.5000E-02	0.00	1	23
19	2.0000E+02	0	0	4.5630E+02	3.4000E-02	0.00	1	24
20	1.5000E+02	0	0	4.5550E+02	1.6000E-02	0.00	1	24
21	1.0000E+02	0	0	4.5480E+02	1.4000E-02	0.00	1	24
22	5.0000E+01	0	0	4.5400E+02	1.6000E-02	0.00	1	24
23	0.0000E+00	1	1	4.5210E+02	3.8000E-02	0.00	1	24

Coefficients used in Exner equation and in
computing hydraulic properties for sediment capacity

C1WP	C2WP	C3WP	C1WPU	C2WPU		
0.250	0.500	0.250	0.750	0.250		
C1Q	C2Q	C3Q	C1QD	C2QD	C1QU	C2QU
0.000	1.000	0.000	0.000	1.000	1.000	0.000

Number of particle size classes: 5

Class #	DRL (mm)	DRU (mm)	Geometric mean (mm)	Dry specific weight (lb/ft^3)
1	6.0000E-02	8.0000E-01	2.1909E-01	9.9259E+01
2	8.0000E-01	2.0000E+00	1.2649E+00	9.9259E+01

3	2.0000E+00	5.0000E+00	3.1623E+00	9.9259E+01
4	5.0000E+00	1.0000E+01	7.0711E+00	9.9259E+01
5	1.0000E+01	2.0000E+01	1.4142E+01	9.9259E+01

Percentage of bed material for each size fraction and for each cross section

Section #	Bed material size fraction for each group 1	2	3	4	5
1	11.0	17.0	24.0	41.0	7.0
2	11.0	17.0	24.0	41.0	7.0
3	11.0	17.0	24.0	41.0	7.0
4	38.0	30.0	17.0	10.0	5.0
5	38.0	30.0	17.0	10.0	5.0
6	38.0	30.0	17.0	10.0	5.0
7	24.0	26.0	24.0	9.0	17.0
8	24.0	26.0	24.0	9.0	17.0
9	24.0	26.0	24.0	9.0	17.0
10	10.0	23.0	23.0	19.0	25.0
11	10.0	23.0	23.0	19.0	25.0
12	10.0	23.0	23.0	19.0	25.0
13	6.0	26.0	30.0	23.0	15.0
14	6.0	26.0	30.0	23.0	15.0
15	6.0	26.0	30.0	23.0	15.0
16	6.0	26.0	30.0	23.0	15.0
17	6.0	26.0	30.0	23.0	15.0
18	6.0	26.0	30.0	23.0	15.0
19	6.0	26.0	30.0	23.0	15.0
20	6.0	26.0	30.0	23.0	15.0
21	6.0	26.0	30.0	23.0	15.0
22	6.0	26.0	30.0	23.0	15.0
23	6.0	26.0	30.0	23.0	15.0

MINIMIZATION PARAMETERS

Station #	Left constraint	Right constraint	Lower constraint	Upper constraint
1	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
2	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
3	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
4	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
5	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
6	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
7	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
8	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
9	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
10	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
11	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
12	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
13	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
14	0.0000E+00	4.0000E+02	4.2000E+02	7.0000E+02
15	0.0000E+00	4.0000E+02	4.0000E+02	7.0000E+02
16	0.0000E+00	4.0000E+02	4.0000E+02	7.0000E+02
17	0.0000E+00	4.0000E+02	4.0000E+02	7.0000E+02
18	0.0000E+00	4.0000E+02	4.0000E+02	7.0000E+02
19	0.0000E+00	4.0000E+02	4.0000E+02	7.0000E+02
20	0.0000E+00	4.0000E+02	4.0000E+02	7.0000E+02
21	0.0000E+00	4.0000E+02	4.0000E+02	7.0000E+02
22	0.0000E+00	4.0000E+02	4.0000E+02	7.0000E+02

```
   23      0.0000E+00    4.0000E+02    4.0000E+02    7.0000E+02
------------------------------------------------------------------


*********************************************************************************
*********************************************************************************
    TIME STEP NO.   100 AFTER  1.3889E+00 DAYS; DISCHARGE IS  9.1400E+01 CFS
*********************************************************************************
*********************************************************************************


                    *********************************************
                    *     RESULTS OF BACKWATER COMPUTATIONS     *
                    *       DISCHARGE =  9.1400E+01 C.F.S.      *
                    *********************************************

STA.  STATION   WATER SURFACE   FLOW AREA  FLOW VELCTY  ENERGY GRADE    FROUDE
  #     (ft)     ELEVATION(ft)    (ft^2)      (ft/s)     LINE ELEV(ft)   NUMBER
*********************************************************************************
  1  9.8900E+02  4.83991E+02  2.63250E+01  3.47199E+00  4.84188E+02  6.14416E-01
  2  9.6400E+02  4.83099E+02  1.79985E+01  5.07821E+00  4.83552E+02  7.98278E-01
  3  9.2900E+02  4.81419E+02  1.46025E+01  6.25919E+00  4.82119E+02  9.91294E-01
  4  8.8800E+02  4.78730E+02  2.32214E+01  3.93602E+00  4.79023E+02  5.32599E-01
  5  8.1300E+02  4.77708E+02  2.48123E+01  3.68366E+00  4.77991E+02  5.95879E-01
  6  7.6300E+02  4.76565E+02  2.44547E+01  3.73752E+00  4.76854E+02  7.20952E-01
  7  7.0300E+02  4.74693E+02  2.18163E+01  4.18952E+00  4.75027E+02  7.52660E-01
  8  6.6400E+02  4.73665E+02  2.27264E+01  4.02175E+00  4.73940E+02  7.03060E-01
  9  6.3400E+02  4.72785E+02  2.15054E+01  4.25009E+00  4.73121E+02  7.80019E-01
 10  6.1400E+02  4.72269E+02  2.34054E+01  3.90507E+00  4.72650E+02  5.84252E-01
 11  5.5900E+02  4.70963E+02  2.08969E+01  4.37386E+00  4.71330E+02  7.83300E-01
 12  5.0900E+02  4.69258E+02  2.22152E+01  4.11430E+00  4.69659E+02  9.41067E-01
 13  4.5900E+02  4.67528E+02  2.03091E+01  4.50044E+00  4.67957E+02  7.63201E-01
 14  4.0900E+02  4.66039E+02  2.13742E+01  4.27618E+00  4.66444E+02  7.17810E-01
 15  3.3400E+02  4.62039E+02  1.52784E+01  5.98232E+00  4.62819E+02  9.78869E-01
 16  2.8400E+02  4.59444E+02  1.79508E+01  5.09169E+00  4.59968E+02  7.02102E-01
 17  2.7000E+02  4.59269E+02  2.99728E+01  3.04943E+00  4.59450E+02  5.14377E-01
 18  2.5000E+02  4.59026E+02  2.86149E+01  3.19414E+00  4.59212E+02  4.29127E-01
 19  2.0000E+02  4.58231E+02  2.47194E+01  3.69750E+00  4.58559E+02  5.63036E-01
 20  1.5000E+02  4.57101E+02  2.26912E+01  4.02799E+00  4.57445E+02  7.64905E-01
 21  1.0000E+02  4.55902E+02  2.49066E+01  3.66971E+00  4.56149E+02  6.53926E-01
 22  5.0000E+01  4.54755E+02  2.63705E+01  3.46600E+00  4.54997E+02  6.49027E-01
 23  0.0000E+00  4.54000E+02  3.16575E+01  2.88715E+00  4.54173E+02  4.17376E-01


          **************************************************************
          *       SEDIMENT ROUTING RESULTS FOR TIME STEP     100       *
          **************************************************************

                ------------------------------------------------
                INCOMING SEDIMENT DISTRIBUTION PER SIZE FRACTION
                SIZE FRACTION       PERCENT       QSED (TON/DAY)
                     1               11.00          0.0000E+00
                     2               17.00          0.0000E+00
                     3               24.00          0.0000E+00
                     4               41.00          0.0000E+00
                     5                7.00          0.0000E+00
                   TOTAL                            0.0000E+00
                ------------------------------------------------
```

```
**************************************************************
*                      STREAM TUBE NO.   1                   *
**************************************************************
 STA  DISTANCE          TOTAL LOAD          CHANGE   DIRECTION
                    (TONS)       (FT**3)      (FT)
**************************************************************
   1  9.8900E+02   2.8896E-01   3.4935E+00    -0.071   VERTICAL
   2  9.6400E+02   6.4633E-01   7.8139E+00    -0.044   VERTICAL
   3  9.2900E+02   1.2604E+00   1.5238E+01    -0.064   VERTICAL
   4  8.8800E+02   4.0613E-01   4.9100E+00     0.046   VERTICAL
   5  8.1300E+02   3.9479E-01   4.7729E+00     0.000   VERTICAL
   6  7.6300E+02   4.8935E-01   5.9160E+00    -0.003   VERTICAL
   7  7.0300E+02   8.7588E-01   1.0589E+01    -0.015   LATERAL
   8  6.6400E+02   8.2900E-01   1.0022E+01     0.003   VERTICAL
   9  6.3400E+02   7.5274E-01   9.1004E+00     0.063   LATERAL
  10  6.1400E+02   3.3428E-01   4.0414E+00     0.027   LATERAL
  11  5.5900E+02   1.1136E+00   1.3463E+01    -0.038   LATERAL
  12  5.0900E+02   5.6032E-01   6.7741E+00     0.030   VERTICAL
  13  4.5900E+02   1.0996E+00   1.3294E+01    -0.030   LATERAL
  14  4.0900E+02   6.5000E-01   7.8583E+00     0.020   VERTICAL
  15  3.3400E+02   1.8734E+00   2.2649E+01    -0.061   LATERAL
  16  2.8400E+02   7.8734E-01   9.5187E+00     0.107   VERTICAL
  17  2.7000E+02   1.8199E+00   2.2001E+01    -0.182   LATERAL
  18  2.5000E+02   1.4320E+00   1.7313E+01     0.031   LATERAL
  19  2.0000E+02   1.1765E+00   1.4224E+01     0.014   VERTICAL
  20  1.5000E+02   1.3165E+00   1.5916E+01    -0.008   LATERAL
  21  1.0000E+02   1.3273E+00   1.6047E+01    -0.001   LATERAL
  22  5.0000E+01   1.0104E+00   1.2216E+01     0.014   VERTICAL
  23  0.0000E+00   7.8151E-01   9.4482E+00     0.009   VERTICAL


**************************************************************
*                      STREAM TUBE NO.   2                   *
**************************************************************
 STA  DISTANCE          TOTAL LOAD          CHANGE   DIRECTION
                    (TONS)       (FT**3)      (FT)
**************************************************************
   1  9.8900E+02   2.0605E-01   2.4911E+00    -0.050   VERTICAL
   2  9.6400E+02   4.3175E-01   5.2197E+00    -0.037   VERTICAL
   3  9.2900E+02   7.3613E-01   8.8995E+00    -0.063   VERTICAL
   4  8.8800E+02   4.3984E-01   5.3175E+00     0.045   VERTICAL
   5  8.1300E+02   5.5925E-01   6.7611E+00    -0.015   VERTICAL
   6  7.6300E+02   5.2721E-01   6.3738E+00     0.003   VERTICAL
   7  7.0300E+02   1.1090E+00   1.3408E+01    -0.060   VERTICAL
   8  6.6400E+02   1.0319E+00   1.2475E+01     0.012   VERTICAL
   9  6.3400E+02   1.6191E+00   1.9574E+01    -0.159   VERTICAL
  10  6.1400E+02   1.1186E+00   1.3524E+01     0.130   VERTICAL
  11  5.5900E+02   3.3958E+00   4.1054E+01    -0.428   VERTICAL
  12  5.0900E+02   1.7390E+00   2.1024E+01     0.316   VERTICAL
  13  4.5900E+02   8.7842E-01   1.0620E+01     0.170   VERTICAL
  14  4.0900E+02   2.7982E-01   3.3829E+00     0.090   VERTICAL
  15  3.3400E+02   2.0498E+00   2.4781E+01    -0.237   VERTICAL
  16  2.8400E+02   8.6785E-01   1.0492E+01     0.177   VERTICAL
  17  2.7000E+02   2.3094E+00   2.7919E+01    -0.284   VERTICAL
  18  2.5000E+02   2.3348E+00   2.8227E+01    -0.003   VERTICAL
  19  2.0000E+02   2.4996E+00   3.0220E+01    -0.031   VERTICAL
  20  1.5000E+02   4.9163E+00   5.9436E+01    -0.371   VERTICAL
  21  1.0000E+02   1.5362E+00   1.8572E+01     0.356   VERTICAL
  22  5.0000E+01   1.8055E+00   2.1828E+01    -0.028   VERTICAL
  23  0.0000E+00   9.7189E-01   1.1750E+01     0.097   VERTICAL
```

****
*   STREAM TUBE NO.   3   *
****

STA	DISTANCE	TOTAL LOAD (TONS)	TOTAL LOAD (FT**3)	CHANGE (FT)	DIRECTION
1	9.8900E+02	1.3862E-01	1.6758E+00	-0.023	VERTICAL
2	9.6400E+02	5.9629E-01	7.2089E+00	-0.044	VERTICAL
3	9.2900E+02	1.0909E+00	1.3189E+01	-0.049	VERTICAL
4	8.8800E+02	5.9718E-01	7.2196E+00	0.029	VERTICAL
5	8.1300E+02	1.0302E+00	1.2455E+01	-0.018	VERTICAL
6	7.6300E+02	1.1991E+00	1.4497E+01	-0.006	VERTICAL
7	7.0300E+02	2.2279E+00	2.6934E+01	-0.042	LATERAL
8	6.6400E+02	1.1586E+00	1.4007E+01	0.069	VERTICAL
9	6.3400E+02	3.6632E+00	4.4287E+01	-0.232	LATERAL
10	6.1400E+02	1.7318E+00	2.0937E+01	0.113	LATERAL
11	5.5900E+02	4.2878E+00	5.1838E+01	-0.084	LATERAL
12	5.0900E+02	2.1396E+00	2.5867E+01	0.062	VERTICAL
13	4.5900E+02	5.7115E+00	6.9050E+01	-0.115	LATERAL
14	4.0900E+02	1.6950E+00	2.0491E+01	0.128	VERTICAL
15	3.3400E+02	7.5894E+00	9.1753E+01	-0.202	LATERAL
16	2.8400E+02	3.9760E+00	4.8069E+01	0.220	VERTICAL
17	2.7000E+02	6.8969E+00	8.3381E+01	-0.310	LATERAL
18	2.5000E+02	3.4898E+00	4.2191E+01	0.199	LATERAL
19	2.0000E+02	4.9693E+00	6.0077E+01	-0.055	VERTICAL
20	1.5000E+02	2.4158E+00	2.9206E+01	1.369	LATERAL
21	1.0000E+02	2.1936E+00	2.6520E+01	0.135	LATERAL
22	5.0000E+01	1.8885E+00	2.2831E+01	0.008	VERTICAL
23	0.0000E+00	1.3919E+00	1.6827E+01	0.017	VERTICAL

****
*** ACCUMMULATED DEPOSITION FOR WHOLE STREAM ***
****

STA NO.	ACCU.DEPS. (TONS)	ACCU DEPS. (FT^3)	ACCU. DEPS. FOR DIFFRNT SIZE GROUPS (FT^3) 1	2	3	4
1	-2.2278E+02	-4.4889E+03	-1.0002E+03	-1.3779E+03	-7.1631E+02	-1.2244E+03
2	-4.3040E+02	-8.6722E+03	-1.3771E+03	-2.1563E+03	-1.5874E+03	-3.0287E+03
3	-3.8264E+02	-7.7100E+03	-1.9462E+03	-2.8060E+03	-7.6094E+02	-1.8286E+03
4	-7.7742E+02	-1.5665E+04	-1.1322E+04	-8.1477E+03	7.0881E+02	2.9875E+03
5	-2.9308E+02	-5.9054E+03	-4.3435E+03	-3.0677E+03	3.9863E+02	9.7488E+02
6	-9.7260E+01	-1.9597E+03	-2.2002E+03	-2.0134E+03	7.3027E+02	1.0607E+03
7	-2.4862E+02	-5.0095E+03	-2.5253E+03	-1.7183E+03	-3.4374E+02	2.1156E+02
8	-2.2656E+02	-4.5650E+03	-1.3692E+03	-2.0004E+03	-5.3734E+02	-1.0158E+02
9	4.8457E+01	9.7637E+02	-6.9576E+02	-4.2008E+02	1.0115E+03	4.3177E+02
10	8.9641E+01	1.8062E+03	1.4086E+03	2.5644E+02	2.1990E+02	-1.3193E+02
11	-1.3496E+02	-2.7193E+03	-9.3168E+01	-1.7663E+03	-2.7639E+02	-3.5225E+02
12	-1.5663E+02	-3.1559E+03	8.0269E+02	-2.2105E+03	-5.4285E+02	-5.2040E+02
13	2.0919E+01	4.2151E+02	6.8857E+02	-1.0533E+03	1.8542E+02	1.0245E+02
14	8.6816E+01	1.7493E+03	8.1186E+02	-4.9795E+01	2.2207E+02	2.5097E+02
15	-2.5730E+02	-5.1844E+03	6.4857E+01	-2.3752E+03	-1.1659E+03	-1.0341E+03
16	6.0570E+01	1.2204E+03	1.4032E+03	-1.0689E+03	4.2762E+02	2.8747E+02
17	2.6135E+02	5.2660E+03	3.5585E+00	1.6528E+03	1.3890E+03	1.3132E+03
18	1.4397E+02	2.9009E+03	2.0574E+03	2.7583E+02	2.1779E+02	2.3536E+02
19	-2.3989E+01	-4.8337E+02	1.0269E+02	1.5474E+03	-8.9807E+02	-7.7550E+02
20	6.2394E+01	1.2572E+03	1.0111E+03	-2.6362E+02	2.1122E+02	1.6267E+02
21	8.8550E+01	1.7842E+03	8.9174E+02	-1.5829E+01	3.3792E+02	3.3721E+02

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 22 -3.3258E+02 -6.7012E+03  -8.9852E+02 -2.5971E+03 -1.3356E+03 -1.1331E+03
 23  5.8691E+01  1.1826E+03   1.6110E+02  5.6680E+02  3.1675E+02  1.3181E+02
SUM -2.6628E+03 -5.3655E+04  -1.8363E+04 -3.0809E+04 -1.7876E+03 -1.6430E+03
--------------------------------------------------------------------------------
   ACCUMULATED DEPOSITION FOR DIFFERENT SIZE GROUPS (CONT.)
 STA          5
--------------------------------------------------------------------------------
   1 -1.6998E+02
   2 -5.2270E+02
   3 -3.6816E+02
   4  1.0841E+02
   5  1.3224E+02
   6  4.6294E+02
   7 -6.3374E+02
   8 -5.5657E+02
   9  6.4890E+02
  10  5.3176E+01
  11 -2.3127E+02
  12 -6.8483E+02
  13  4.9836E+02
  14  5.1417E+02
  15 -6.7410E+02
  16  1.7105E+02
  17  9.0738E+02
  18  1.1459E+02
  19 -4.5995E+02
  20  1.3579E+02
  21  2.3318E+02
  22 -7.3691E+02
  23  6.1220E+00
 SUM -1.0519E+03
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------
         ACCUMULATED SEDIMENT DISTRIBUTION THAT EXITED THE REACH (TONS)
SIZE FR    TOTAL        TUBE #1     TUBE #2     TUBE #3     TUBE #
   1    9.1156E+02    3.5538E+02  2.0721E+02  3.4898E+02
   2    1.5294E+03    5.2201E+02  5.2564E+02  4.8170E+02
   3    8.9171E+01    3.1952E+01  1.8110E+01  3.9109E+01
   4    8.2314E+01    2.8640E+01  1.8444E+01  3.5230E+01
   5    5.2336E+01    1.7386E+01  1.3072E+01  2.1878E+01
 TOTAL  2.6647E+03    9.5537E+02  7.8247E+02  9.2690E+02
--------------------------------------------------------------------------------


* * * * * *  GSTARS run completed successfully  * * * * * *
```

3.2.2 Debug File (.DBG)

```
GSTARS Version 2.1 - Dec 2000                        U.S. Bureau of Reclamation
INPUT FILE:  mescal.dat                              Technical Service Center
DATE OF RUN: 22 Feb 2001                             Denver, Colorado
RUN STARTED: 14:39:17:29

               ************ Limits for this version ************
               Maximum number of cross sections:.............101
               Maximum number of points per cross section:...197
               Maximum number of particle size fractions:.... 10
               Maximum number of stream tubes:................ 5
               *************************************************
```

```
*******************************************************************************
***                                                                         ***
***  NOTE: this is a simplified version of the datafile used to simulate    ***
***  the Lake Mescalero spillway.  It may not represent the actual flow and ***
***  geological conditions at the site, and is used here only as an example ***
***  of input data as it might be used in a GSTARS version 2.1 simulation.  ***
***  This file was constructed for didactic purposes only.                  ***
***                                                                         ***
*******************************************************************************
*******************************************************************************
*  GSTARS version 2.1  -  Example data file for Appendix B of user's manual    *
*  Lake Mescalero Dam Spillway  -  St. Anthony Falls data file                 *
*  Stream power minimization calculations with bank stability routine         *
*******************************************************************************
*** Cross Section Coordinate Order is X-Y
*** section 1
  Cross section coordinate order is X-Y
***
*** ===========================================================================
***  section 2
***
***
*** ===========================================================================
***   section 3
***
*** ===========================================================================
*** section 4
***
*** ===========================================================================
*** section 5
***
*** ===========================================================================
*** section 6
***
*** ===========================================================================
*** section 7
***
*** ===========================================================================
*** section 8
***
*** ===========================================================================
***   section 9
***
*** ===========================================================================
***   section 10
***
*** ===========================================================================
***   section 11
***
*** ===========================================================================
***   section 12
***
*** ===========================================================================
***   section 13
***
*** ===========================================================================
***  section 14
***
```

```
*** ============================================================================
***   section 15
***
*** ============================================================================
***   section 16
***
*** ============================================================================
***   section 17
***
*** ============================================================================
***   section 18
***
*** ============================================================================
***   section 19
***
*** ============================================================================
***   section 20
***
*** ============================================================================
***   section 21
***
*** ============================================================================
***   section 22
***
*** ============================================================================
***   section 23
***
*** ============================================================================

WARNING: illegal value in record RE, variable IOPTFR.  IOPTFR set to 1.

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

Warning- Control depth < zero; reset to critical depth

********************************************************************************
********************************************************************************
```

TIME STEP NO. 100 AFTER 1.3889E+00 DAYS; DISCHARGE IS 9.1400E+01 CFS

CRITICAL DEPTH (ft)	CRITICAL W.S.ELV.(ft)
1.2930E+00	4.83693E+02
1.7247E+00	4.82871E+02
2.4868E+00	4.81410E+02
2.1306E+00	4.77804E+02
3.0529E+00	4.77215E+02
4.9128E+00	4.76333E+02
2.9396E+00	4.74446E+02
2.6525E+00	4.73346E+02
2.9882E+00	4.72548E+02
4.2296E+00	4.70439E+02
2.4531E+00	4.70522E+02
3.2623E+00	4.69219E+02
3.4110E+00	4.66605E+02
5.4582E+00	4.65384E+02
5.6400E+00	4.62011E+02
4.0595E+00	4.58368E+02
5.2572E+00	4.58771E+02
2.3295E+00	4.57712E+02
5.0677E+00	4.57138E+02
3.3275E+00	4.56688E+02
2.4951E+00	4.55578E+02
3.5529E+00	4.54045E+02
4.3117E+00	4.52361E+02

* NORMAL DEPTH PROPERTIES TABLE *

STA. ID	BOTTOM ELEVATION (ft)	BOTTOM SLOPE	FLOW AREA (ft^2)	NORM FLOW VELOCITY (ft/s)	FROUDE NO.	NORMAL DEPTH (ft)	NORMAL W.S.ELV. (ft)
1	4.82400E+02	5.013E-02	1.947E+01	4.694E+00	0.961	1.317E+00	4.83717E+02
2	4.81146E+02	5.013E-02	1.314E+01	6.958E+00	1.216	1.551E+00	4.82697E+02
3	4.78923E+02	6.352E-02	1.143E+01	7.996E+00	1.372	2.175E+00	4.81098E+02
4	4.75674E+02	7.926E-02	1.420E+01	6.437E+00	0.974	2.163E+00	4.77837E+02
5	4.74162E+02	2.016E-02	1.981E+01	4.615E+00	0.830	3.216E+00	4.77378E+02
6	4.71420E+02	5.485E-02	1.464E+01	6.244E+00	1.170	4.619E+00	4.76039E+02
7	4.71506E+02	-1.433E-03	1.000E+05	1.000E-03	0.001	9.999E+02	9.99990E+04
8	4.70693E+02	2.083E-02	2.673E+01	3.419E+00	0.571	3.160E+00	4.73854E+02
9	4.69560E+02	3.777E-02	1.739E+01	5.255E+00	0.988	2.999E+00	4.72559E+02
10	4.66209E+02	1.675E-01	7.378E+00	1.239E+01	1.664	3.221E+00	4.69430E+02
11	4.68069E+02	-3.381E-02	1.000E+05	1.000E-03	0.001	9.999E+02	9.99990E+04
12	4.65956E+02	4.225E-02	2.122E+01	4.306E+00	1.002	3.261E+00	4.69218E+02
13	4.63194E+02	5.524E-02	1.229E+01	7.438E+00	1.027	3.371E+00	4.66565E+02
14	4.59926E+02	6.537E-02	1.132E+01	8.076E+00	1.124	4.971E+00	4.64896E+02
15	4.56371E+02	4.739E-02	1.646E+01	5.553E+00	0.893	5.790E+00	4.62161E+02
16	4.54308E+02	4.126E-02	2.442E+01	3.743E+00	0.546	5.762E+00	4.60070E+02
17	4.53514E+02	5.674E-02	1.815E+01	5.035E+00	1.069	5.204E+00	4.58718E+02
18	4.55382E+02	-9.342E-02	1.000E+05	1.000E-03	0.001	9.999E+02	9.99990E+04
19	4.52070E+02	6.624E-02	1.470E+01	6.219E+00	0.968	5.131E+00	4.57201E+02
20	4.53360E+02	-2.580E-02	1.000E+05	1.000E-03	0.001	9.999E+02	9.99990E+04
21	4.53083E+02	5.553E-03	4.042E+01	2.261E+00	0.337	3.484E+00	4.56567E+02

```
22 4.50492E+02  5.180E-02  1.366E+01  6.691E+00  1.158  3.415E+00 4.53907E+02
23 4.48050E+02  4.885E-02  1.347E+01  6.787E+00  0.973  4.352E+00 4.52401E+02

             STEP METHOD COMPUTATIONS
   POTENTIAL CONTROL AT SECTION    1
      CONTROL TYPE =  NATURAL
      CONTROL DEPTH=    1.2930E+00 FT
      CONTROL ELEV.=    4.8369E+02 FT

   POTENTIAL CONTROL AT SECTION    5
      CONTROL TYPE =  NATURAL
      CONTROL DEPTH=    3.0529E+00 FT
      CONTROL ELEV.=    4.7722E+02 FT

   NO CONVERGENCE AFTER 26 ITERATIONS AT STATION   3
      COMPUTED HEAD:  4.8034E+02
      GUESSED HEAD:   4.8226E+02
      HYDRAULIC JUMP HEAD LOSS:   0.0000E+00
      DIRECTION & FLOW TYPE UPSTREAM        M1M2
      MIN H ERROR=      1.135 AT WSEL=    481.421 KTMIN=   0
   WSE BEFORE AND AFTER ADJUSTING  0.4818613E+03  0.4814211E+03      M1M2

   POTENTIAL CONTROL AT SECTION    9
      CONTROL TYPE =  NATURAL
      CONTROL DEPTH=    2.9882E+00 FT
      CONTROL ELEV.=    4.7255E+02 FT

   NO CONVERGENCE AFTER 26 ITERATIONS AT STATION   3
      COMPUTED HEAD:  4.8028E+02
      GUESSED HEAD:   4.8213E+02
      HYDRAULIC JUMP HEAD LOSS:   0.0000E+00
      DIRECTION & FLOW TYPE UPSTREAM        M1M2
      MIN H ERROR=      1.676 AT WSEL=    481.420 KTMIN=  14
   WSE BEFORE AND AFTER ADJUSTING  0.4814814E+03  0.4814197E+03      M1M2

   POTENTIAL CONTROL AT SECTION   11
      CONTROL TYPE =  NATURAL
      CONTROL DEPTH=    2.4531E+00 FT
      CONTROL ELEV.=    4.7052E+02 FT

   NO CONVERGENCE AFTER 26 ITERATIONS AT STATION   3
      COMPUTED HEAD:  4.8028E+02
      GUESSED HEAD:   4.8213E+02
      HYDRAULIC JUMP HEAD LOSS:   0.0000E+00
      DIRECTION & FLOW TYPE UPSTREAM        M1M2
      MIN H ERROR=      1.675 AT WSEL=    481.419 KTMIN=  14
   WSE BEFORE AND AFTER ADJUSTING  0.4814796E+03  0.4814186E+03      M1M2

   POTENTIAL CONTROL AT SECTION   16
      CONTROL TYPE =  NATURAL
      CONTROL DEPTH=    4.0595E+00 FT
      CONTROL ELEV.=    4.5837E+02 FT

   NO CONVERGENCE AFTER 26 ITERATIONS AT STATION   3
      COMPUTED HEAD:  4.8028E+02
      GUESSED HEAD:   4.8213E+02
      HYDRAULIC JUMP HEAD LOSS:   0.0000E+00
      DIRECTION & FLOW TYPE UPSTREAM        M1M2
      MIN H ERROR=      1.676 AT WSEL=    481.419 KTMIN=  14
   WSE BEFORE AND AFTER ADJUSTING  0.4814802E+03  0.4814190E+03      M1M2
```

```
POTENTIAL CONTROL AT SECTION   21
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    2.4951E+00 FT
   CONTROL ELEV.=    4.5558E+02 FT

NO CONVERGENCE AFTER 26 ITERATIONS AT STATION   3
   COMPUTED HEAD:  4.8028E+02
   GUESSED HEAD:   4.8213E+02
   HYDRAULIC JUMP HEAD LOSS:   0.0000E+00
   DIRECTION & FLOW TYPE UPSTREAM        M1M2
   MIN H ERROR=      1.676 AT WSEL=    481.419 KTMIN=  14
WSE BEFORE AND AFTER ADJUSTING  0.4814800E+03  0.4814189E+03      M1M2

POTENTIAL CONTROL AT SECTION   23
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    5.9502E+00 FT
   CONTROL ELEV.=    4.5400E+02 FT

NO CONVERGENCE AFTER 26 ITERATIONS AT STATION  20
   COMPUTED HEAD:  4.5743E+02
   GUESSED HEAD:   4.5744E+02
   HYDRAULIC JUMP HEAD LOSS:   0.0000E+00
   DIRECTION & FLOW TYPE UPSTREAM        M1M2
   MIN H ERROR=      0.014 AT WSEL=    457.101 KTMIN=   4
WSE BEFORE AND AFTER ADJUSTING  0.4570956E+03  0.4571011E+03      M1M2

NO CONVERGENCE AFTER 26 ITERATIONS AT STATION   3
   COMPUTED HEAD:  4.8028E+02
   GUESSED HEAD:   4.8213E+02
   HYDRAULIC JUMP HEAD LOSS:   0.0000E+00
   DIRECTION & FLOW TYPE UPSTREAM        M1M2
   MIN H ERROR=      1.676 AT WSEL=    481.419 KTMIN=  14
WSE BEFORE AND AFTER ADJUSTING  0.4814800E+03  0.4814189E+03      M1M2

CONTROL AT SECTION   23
   CONTROL TYPE =  NATURAL
   CONTROL DEPTH=    5.9502E+00 FT
   CONTROL ELEV.=    4.5400E+02 FT


        CONVEYANCE TABLE FOR INDIVIDUAL STREAM TUBES
STA.     TUBE-1      TUBE-2      TUBE-3      TUBE-4      TUBE-5
--------------------------------------------------------------------------------
   1  2.1922E+02  2.1922E+02  2.1922E+02
   2  1.7735E+02  1.7735E+02  1.7735E+02
   3  1.3501E+02  1.3501E+02  1.3501E+02
   4  2.7336E+02  2.7336E+02  2.7336E+02
   5  2.4795E+02  2.4795E+02  2.4795E+02
   6  1.7485E+02  1.7485E+02  1.7485E+02
   7  1.7472E+02  1.7472E+02  1.7472E+02
   8  1.9147E+02  1.9147E+02  1.9147E+02
   9  1.7795E+02  1.7795E+02  1.7795E+02
  10  2.2864E+02  2.2864E+02  2.2864E+02
  11  1.7528E+02  1.7528E+02  1.7528E+02
  12  1.5926E+02  1.5926E+02  1.5926E+02
  13  1.7162E+02  1.7162E+02  1.7162E+02
  14  1.7891E+02  1.7891E+02  1.7891E+02
  15  1.1800E+02  1.1800E+02  1.1800E+02
  16  1.4472E+02  1.4472E+02  1.4472E+02
  17  2.4871E+02  2.4871E+02  2.4871E+02
  18  3.2632E+02  3.2632E+02  3.2632E+02
```

19	2.3466E+02	2.3466E+02	2.3466E+02
20	1.8301E+02	1.8301E+02	1.8301E+02
21	1.9848E+02	1.9848E+02	1.9848E+02
22	2.0315E+02	2.0315E+02	2.0315E+02
23	3.1041E+02	3.1041E+02	3.1041E+02

STREAM HYDRAULICS FOR TUBE NO. = 1

STA. #	AREA (ft^2)	HYDRAULIC RADIUS (ft)	VELOCITY (ft/s)	FRICTION SLOPE	TUBE START (ft)	TUBE END (ft)
1	7.950E+00	1.124E+00	3.832E+00	1.931E-02	1.887E+02	1.952E+02
2	6.062E+00	1.231E+00	5.026E+00	2.951E-02	1.937E+02	1.978E+02
3	5.014E+00	1.072E+00	6.076E+00	5.093E-02	1.901E+02	1.934E+02
4	8.663E+00	1.397E+00	3.517E+00	1.242E-02	1.950E+02	2.003E+02
5	9.393E+00	1.100E+00	3.243E+00	1.510E-02	1.398E+02	1.462E+02
6	9.420E+00	6.025E-01	3.234E+00	3.036E-02	1.495E+02	1.600E+02
7	7.429E+00	8.497E-01	4.101E+00	3.041E-02	1.666E+02	1.741E+02
8	7.648E+00	8.480E-01	3.984E+00	2.532E-02	1.754E+02	1.840E+02
9	8.310E+00	8.406E-01	3.666E+00	2.931E-02	1.703E+02	1.799E+02
10	1.048E+01	1.379E+00	2.906E+00	1.776E-02	1.682E+02	1.725E+02
11	7.812E+00	9.621E-01	3.900E+00	3.021E-02	1.422E+02	1.493E+02
12	8.292E+00	1.038E+00	3.674E+00	3.660E-02	1.437E+02	1.504E+02
13	7.740E+00	1.270E+00	3.936E+00	3.151E-02	1.526E+02	1.558E+02
14	8.208E+00	9.031E-01	3.712E+00	2.900E-02	1.427E+02	1.520E+02
15	5.466E+00	1.079E+00	5.574E+00	6.666E-02	1.664E+02	1.703E+02
16	6.549E+00	9.657E-01	4.652E+00	4.432E-02	1.707E+02	1.731E+02
17	8.600E+00	1.228E+00	3.542E+00	1.501E-02	1.646E+02	1.693E+02
18	9.975E+00	1.619E+00	3.054E+00	8.717E-03	1.725E+02	1.768E+02
19	9.517E+00	1.047E+00	3.201E+00	1.686E-02	1.573E+02	1.629E+02
20	7.079E+00	1.307E+00	4.304E+00	2.771E-02	1.597E+02	1.642E+02
21	7.803E+00	1.097E+00	3.905E+00	2.356E-02	1.593E+02	1.654E+02
22	8.756E+00	1.002E+00	3.480E+00	2.249E-02	1.613E+02	1.666E+02
23	1.197E+01	1.083E+00	2.546E+00	9.633E-03	1.499E+02	1.560E+02

STREAM HYDRAULICS FOR TUBE NO. = 2

STA. #	AREA (ft^2)	HYDRAULIC RADIUS (ft)	VELOCITY (ft/s)	FRICTION SLOPE	TUBE START (ft)	TUBE END (ft)
1	8.567E+00	1.087E+00	3.556E+00	1.931E-02	1.952E+02	2.031E+02
2	5.384E+00	1.757E+00	5.659E+00	2.951E-02	1.978E+02	2.009E+02
3	4.225E+00	1.674E+00	7.210E+00	5.093E-02	1.934E+02	1.958E+02
4	6.457E+00	2.957E+00	4.719E+00	1.242E-02	2.003E+02	2.025E+02
5	6.077E+00	2.580E+00	5.013E+00	1.510E-02	1.462E+02	1.484E+02
6	6.306E+00	1.709E+00	4.831E+00	3.036E-02	1.600E+02	1.620E+02
7	6.150E+00	1.514E+00	4.954E+00	3.041E-02	1.741E+02	1.775E+02
8	6.339E+00	1.567E+00	4.806E+00	2.532E-02	1.840E+02	1.874E+02
9	5.826E+00	1.716E+00	5.229E+00	2.931E-02	1.799E+02	1.825E+02
10	5.292E+00	4.789E+00	5.757E+00	1.776E-02	1.725E+02	1.734E+02
11	5.900E+00	2.237E+00	5.164E+00	3.021E-02	1.493E+02	1.518E+02
12	4.771E+00	2.674E+00	6.386E+00	3.660E-02	1.504E+02	1.521E+02
13	5.543E+00	2.457E+00	5.497E+00	3.151E-02	1.558E+02	1.576E+02
14	5.150E+00	2.796E+00	5.915E+00	2.900E-02	1.520E+02	1.530E+02
15	4.486E+00	1.684E+00	6.792E+00	6.666E-02	1.703E+02	1.716E+02
16	4.782E+00	1.949E+00	6.371E+00	4.432E-02	1.731E+02	1.744E+02
17	9.683E+00	1.051E+00	3.147E+00	1.501E-02	1.693E+02	1.735E+02
18	8.389E+00	2.636E+00	3.632E+00	8.717E-03	1.768E+02	1.796E+02
19	5.639E+00	3.505E+00	5.403E+00	1.686E-02	1.629E+02	1.641E+02
20	5.309E+00	2.589E+00	5.739E+00	2.771E-02	1.642E+02	1.659E+02
21	7.071E+00	1.477E+00	4.309E+00	2.356E-02	1.654E+02	1.700E+02
22	7.123E+00	1.937E+00	4.277E+00	2.249E-02	1.666E+02	1.696E+02
23	8.410E+00	2.477E+00	3.623E+00	9.633E-03	1.560E+02	1.583E+02

STREAM HYDRAULICS FOR TUBE NO. = 3

STA. #	AREA (ft^2)	HYDRAULIC RADIUS (ft)	VELOCITY (ft/s)	FRICTION SLOPE	TUBE START (ft)	TUBE END (ft)
1	9.808E+00	8.892E-01	3.106E+00	1.931E-02	2.031E+02	2.172E+02
2	6.552E+00	1.127E+00	4.650E+00	2.951E-02	2.009E+02	2.136E+02
3	5.363E+00	1.048E+00	5.681E+00	5.093E-02	1.958E+02	2.024E+02
4	8.101E+00	1.542E+00	3.761E+00	1.242E-02	2.025E+02	2.085E+02
5	9.342E+00	1.207E+00	3.261E+00	1.510E-02	1.484E+02	1.624E+02
6	8.729E+00	7.923E-01	3.490E+00	3.036E-02	1.620E+02	1.748E+02
7	8.237E+00	8.215E-01	3.699E+00	3.041E-02	1.775E+02	1.863E+02
8	8.740E+00	9.731E-01	3.486E+00	2.532E-02	1.874E+02	1.962E+02
9	7.369E+00	9.044E-01	4.134E+00	2.931E-02	1.825E+02	1.906E+02
10	7.630E+00	8.051E-01	3.993E+00	1.776E-02	1.734E+02	1.849E+02
11	7.185E+00	7.447E-01	4.240E+00	3.021E-02	1.518E+02	1.656E+02
12	9.152E+00	5.175E-01	3.329E+00	3.660E-02	1.521E+02	1.710E+02
13	7.027E+00	6.239E-01	4.336E+00	3.151E-02	1.576E+02	1.695E+02
14	8.016E+00	8.011E-01	3.801E+00	2.900E-02	1.530E+02	1.631E+02
15	5.326E+00	5.819E-01	5.720E+00	6.666E-02	1.716E+02	1.845E+02
16	6.620E+00	7.068E-01	4.602E+00	4.432E-02	1.744E+02	1.844E+02
17	1.169E+01	8.640E-01	2.606E+00	1.501E-02	1.735E+02	1.877E+02
18	1.025E+01	1.238E+00	2.972E+00	8.717E-03	1.796E+02	1.897E+02
19	9.564E+00	1.023E+00	3.186E+00	1.686E-02	1.641E+02	1.694E+02
20	1.030E+01	6.426E-01	2.957E+00	2.771E-02	1.659E+02	1.844E+02
21	1.003E+01	6.985E-01	3.037E+00	2.356E-02	1.700E+02	1.816E+02
22	1.049E+01	6.232E-01	2.904E+00	2.249E-02	1.696E+02	1.842E+02
23	1.128E+01	1.127E+00	2.701E+00	9.633E-03	1.583E+02	1.690E+02

STREAM POWER CALCULATIONS FOR MINIMIZATION

Station	Direction of change	Stream power
1	Vertical	-
2	Vertical	-
3	Vertical	-
4	Vertical	+
5	Lateral	-
6	Vertical	-
7	Vertical	-
8	Lateral	+
9	Vertical	-
10	Lateral	+
11	Lateral	-
12	Lateral	+
13	Vertical	-
14	Lateral	+
15	Vertical	-
16	Lateral	+
17	Vertical	-
18	Vertical	+
19	Vertical	-
20	Vertical	-
21	Lateral	+
22	Lateral	+
23	Lateral	+

```
RUN ENDED: 14:44:07:19
```

The remaining output files are too long to be included in this section. They can be found under directory Example3 in the GSTARS 2.1 distribution.

3.3 Final Remarks

In the GSTARS 2.1 distribution we include both the input file of section 3.1 (file name mescal.dat under directory Example3) and a similar file for a run without using the stream power minimization routines (file name mescal_nm.dat under directory Example3). The file are identical with the exception of records MR. The results produced using both data files are shown in figures 3.4 and 3.5. The survey data is also plotted in those graphs.

Section 0+60 is located 60 ft downstream from the spillway (section #3 in the GSTARS 2.1 file, at 929 ft) and section 7+30 is located 739 ft downstream from the spillway (section #18 in the GSTARS 2.1 file, at 250 ft). Significant differences are observed when stream power calculations are activated, especially for section 0+60. Both the shape of the cross sections and their thalwegs were more accurately predicted when the stream power minimization computations were activated by the use of the MR records.

Figure 3.4 Comparison of results produced by GSTARS 2.1 and survey data. for runs with and without width changes due to stream power minimization. Section 0+60.

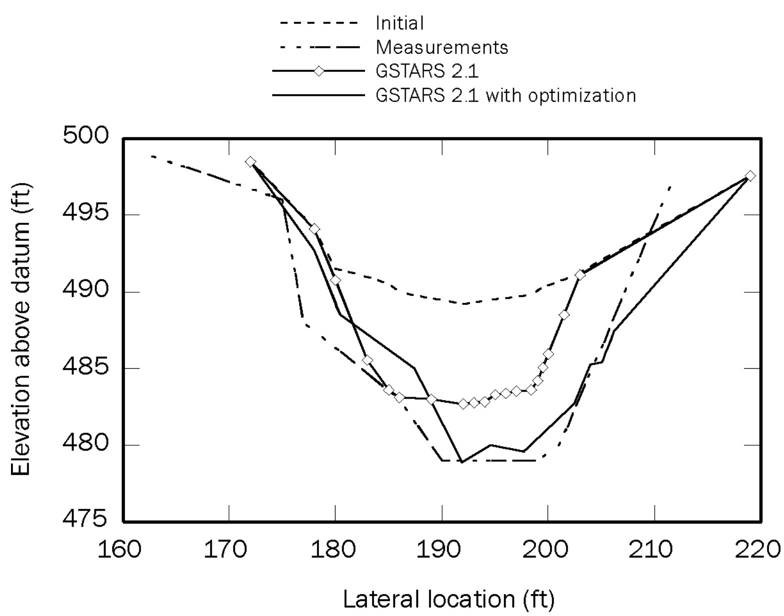


Figure 3.5 Comparison of results produced by GSTARS 2.1 and survey data. for runs with and without width changes due to stream power minimization. Section 7+39. Se figure 3.4 for legend.

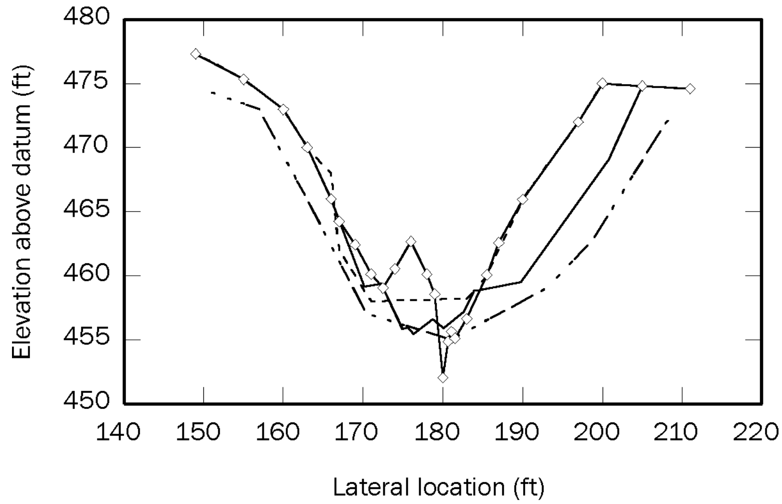
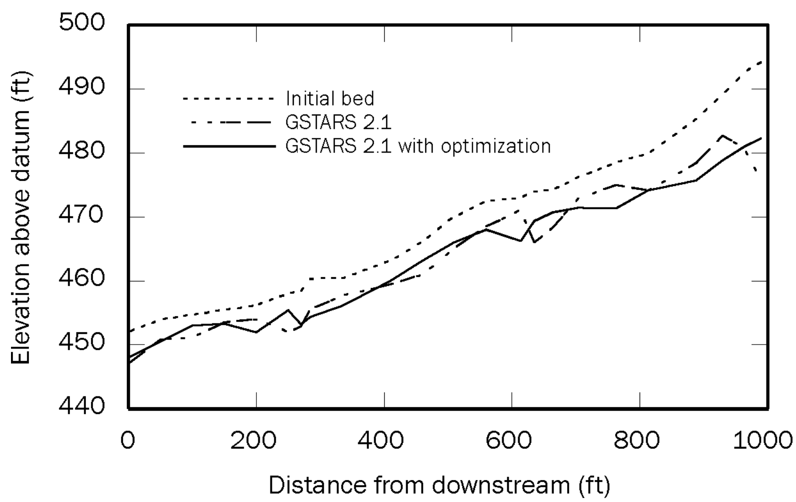


Figure 3.6 Plot of the thalweg for both GSTARS 2.1 runs, i.e., for runs with and without stream power minimization computations.



Note that the results obtained with GSTARS 2.1 and shown in this section differ from the results obtained earlier by Song et a. (1995). There are several reasons for these differences:

1 The version of GSTARS used by Song et al. (1995) was an early version, preceding GSTARS 2.0, dated back to 1986. Their data file was adopted for the present example for didactic purposes only, therefore there was no attempt to recalibrate the data using GSTARS 2.1.

2 Song et al. (1995) used an algorithm to compute exchange of sediment across stream tubes which is not present in GSTARS 2.1. A similar algorithm will be implemented in GSTARS 3.0.

3 Song et al. (1995) used a method to compute the scour due to a water fall. This method uses an approach specifically developed to computer the scour by a free falling water jet. The free falling jet occurs at the end of the spillway, which is formed by a concrete wall followed by an unpaved natural channel. As the unlined channel gets eroded, the difference in level between the lined (unerodible) spillway and the natural channel becomes too large and results in a free falling jet. Such a method is not implemented in GSTARS 2.1.

3.4 References

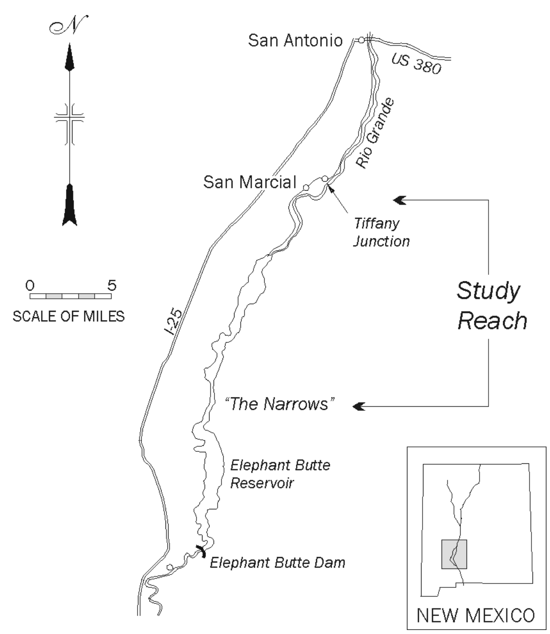
Song. C.C.S., Zheng, Y., and Yang, C.T. (1995). "Modeling of river morphologic changes," *Int. J. Sed. Res.* **10**(2), pp. 1–20.

EXAMPLE 4

RIO GRANDE FLOODWAY

Example 4 is included here to illustrate the use of the cohesive sediment transport features of GSTARS 2.1, as well as the use of non-equilibrium sediment transport. For this purpose some actual survey data collected in the Rio Grande floodway are used. The data corresponds to a stretch of the Rio Grande between San Marcial, New Mexico, at the upper end of Elephant Butte Reservoir, as shown in figure 4.1. This example consists of a reservoir sedimentation problem, with very fine sediments entering a reservoir and depositing in the upper reach of the modeled region (delta formation).

Figure 4.1 Location of the reach modeled in this example problem.



For this example, a total of 33 cross sections are used to represent a reach approximately 28 miles in length. The values of the Manning's roughness coefficients used are 0.024 for the main channel and 0.080 for the flood plains (RH records; see the input data file given in the next section). The hydrology data consist of daily flows and monthly water temperatures at the upstream end of the reach, and of daily reservoir elevations at the downstream end (figures 4.2 and 4.3). The input of these data is made by the use of the STAGE DISCHARGE TABLE (records QQ and SS) using SQ and TM records. The simulation is carried out for an 8-year period with time steps of 1 day (see record IT).

Figure 4.2 Hydrologic data for the Rio Grande example problem.

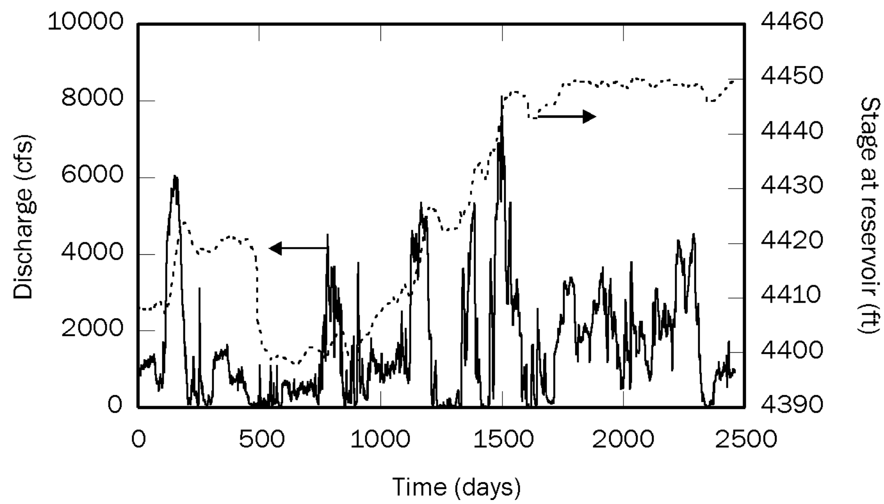
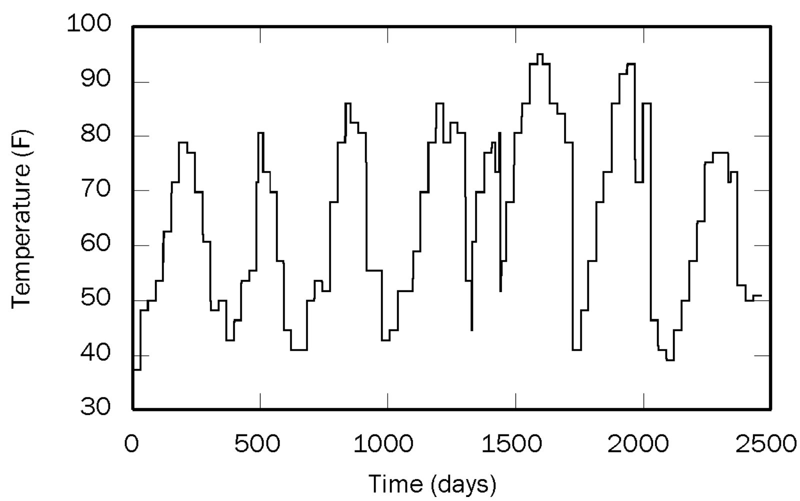


Figure 4.3 Monthly water temperatures used in the present example problem.

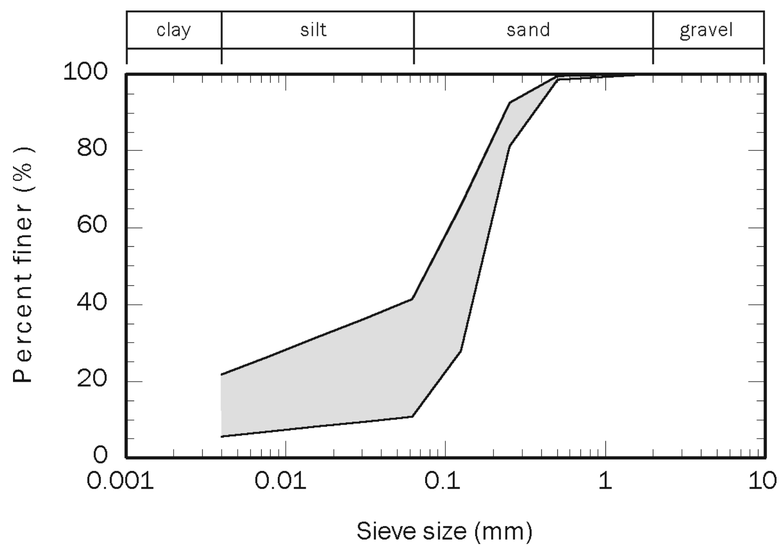


The incoming sediment discharge is specified as a function of the water discharge, and is given by the relation:

$$Q_s = 0.890Q^{1.411}$$

where Q_s = sediment discharge (ton/day) and Q = water discharge (ft^3/s). This rating curve is given in record QR. The bed material and incoming sediment distributions have a relatively high percentage of very fine particles, in the silt and clay range. The incoming sediment distribution is given as a function of the water discharge and specified by the use of IQ and IS records. The bed material distribution over the simulated reach is known at specific locations (rangelines) and interpolated between those locations. This is accomplished by the use of NB/BG records. Note that if NB/BG records are used, the locations where the bed distribution is specified do not need to coincide with the cross sections specified by ST/ND/XS/RH records. In this example there are 33 cross sections, but only 8 sets of NB/BG records. The range of bed material size distributions is shown in figure 4.4.

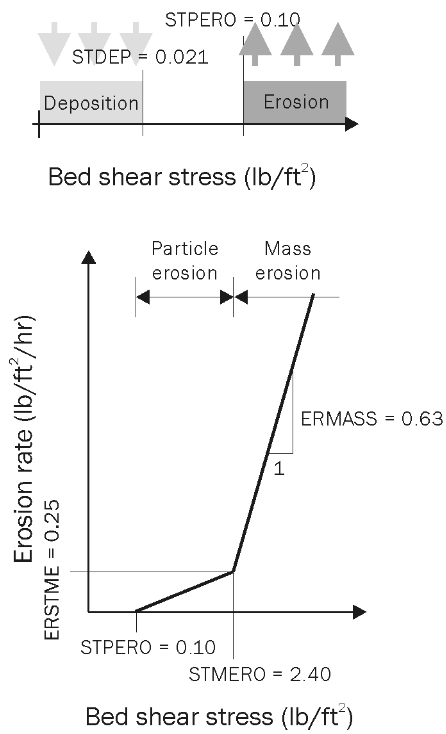
Figure 4.4 Range of bed material size distributions used in this study.



The non-equilibrium parameters are specified using NO records. Since we are modeling a reach with mixed characteristics (river-like upstream and reservoir-like downstream), different values for the recovery factors were defined. The reach is in depositional mode, therefore only the recovery factor for deposition is important In this case. The values were determined by numerical calibration, and vary between 0.25 and 0.001..

The cohesive sediment transport parameters are specified in record CS. These parameters, which characterize the particles with a diameter smaller than 62 µm, should be determined in situ or by laboratory tests. They are highly dependent on the local conditions and may vary widely from case to case, always requiring field verification. In the present example, the characteristics of the cohesive sediments are the following: the threshold value for the shear stress above which there is no deposition of silts or clays is 0.021 lb/ft^2; the threshold value for the shear stress above which there is particle erosion of cohesive sediments is 0.10 lb/ft^2; the threshold value for the shear stress above which there is mass erosion is 2.40 lb/ft^2 ; the slope of the mass erosion rate line is 0.63, in units of hour^{-1}; the erosion rate of cohesive sediment when the bed shear stress equals 2.40 lb/ft^2 is 0.250 lb/ft^2/hr ; finally, the last entry indicates the threshold for the percentage of clay, in the bed, above which the erosion rates of the other particle sizes become limited to the erosion rate of clay. All these values are schematically represented in figure 4.5.

Figure 4.5 Schematic representation of the parameters used to model the transport of cohesive sediments in record CS of example 4.



4.1 Input Data File

Due to the length of this data file, the full extent of records SQ and TM is not included. The complete data file is bundled in the GSTARS 2.1 distribution files in directory Example4. All the files shown in this and the next sections are included in the main GSTARS 2.1 distribution package.

```
TT GSTARS version 2.1  -  Example data file for Appendix B of user's manual
TT Middle Rio Grande, 1980 survey data, rangelines 9 to 59
TT Simulation of nonequilibrium and cohesive sediment transport

*********************************************************************************
***                                                                           ***
***  NOTE: this is a simplified version of the datafile used to simulate     ***
***  the Rio Grande floodway between San Marcial and the upper reach of the  ***
```

```
***  Elephant Butte Reservoir (to The Narrows).  It may not contain an       ***
***  accurate representation of the actual flow and geological conditions    ***
***  at the site.  This data file should be viewed only as an example of     ***
***  input data as it might be used in a GSTARS version 2.1 simulation.      ***
***  This file was constructed for didactic purposes only.                   ***
***                                                                          ***
********************************************************************************

***
NS    33
YX
*** Station #2
ST148011      50       0       0       0       0     0.0
ND     3   124.0   494.0  1882.0
XS4495.4     0.0  4488.3    21.0  4483.3    37.0  4481.6    68.0  4482.5    83.0
XS4488.7    95.0  4491.5   102.0  4493.2   106.0  4493.2   124.0  4491.6   129.0
XS4481.5   147.0  4480.0   178.0  4477.7   179.0  4473.3   182.0  4473.0   217.0
XS4473.1   237.0  4472.5   249.0  4473.5   264.0  4473.8   273.0  4473.5   288.0
XS4471.1   303.0  4471.8   321.0  4476.3   346.0  4478.8   355.0  4480.0   367.0
XS4480.3   470.0  4481.0   494.0  4480.0   526.0  4480.1   572.0  4480.4   696.0
XS4480.1   785.0  4482.2   804.0  4479.1   834.0  4480.1   861.0  4479.5   944.0
XS4479.4  1042.0  4478.4  1142.0  4477.9  1225.0  4479.4  1254.0  4478.9  1301.0
XS4478.8  1411.0  4479.1  1509.0  4478.2  1589.0  4475.9  1608.0  4479.1  1640.0
XS4478.4  1704.0  4478.6  1797.0  4482.6  1839.0  4487.9  1859.0  4488.1  1882.0
RH 0.080   0.024   0.080
*** Station #3
ST145471      35       0       0       0       0     0.0
ND     2  1012.0  2050.0
XS4478.5   298.0  4473.5   326.0  4472.7   333.0  4470.6   340.0  4463.8   346.0
XS4463.9   377.0  4469.3   391.0  4469.2   452.0  4468.6   551.0  4467.1   626.0
XS4464.5   635.0  4463.9   780.0  4464.5   810.0  4464.1   825.0  4463.2   830.0
XS4462.5   870.0  4462.6   890.0  4462.7   948.0  4462.3   972.0  4469.5   978.0
XS4469.7   981.0  4471.3  1012.0  4469.6  1043.0  4469.5  1121.0  4468.3  1196.0
XS4468.7  1290.0  4467.5  1390.0  4468.5  1494.0  4468.3  1587.0  4468.3  1693.0
XS4468.0  1794.0  4467.6  1904.0  4467.1  2010.0  4471.9  2041.0  4476.0  2050.0
RH 0.024   0.080
***
ST134151      47       0       0       0       0     0.0
ND     3  2021.0  2150.0  3119.0
XS4471.4  1521.0  4469.0  1561.0  4468.2  1610.0  4466.9  1654.0  4466.4  1690.0
XS4465.2  1734.0  4464.2  1762.0  4463.5  1809.0  4462.8  1836.0  4464.3  1873.0
XS4464.6  1910.0  4464.7  1943.0  4464.5  1968.0  4465.0  1991.0  4464.1  2003.0
XS4464.8  2021.0  4464.3  2028.0  4457.3  2037.0  4455.1  2057.0  4453.1  2074.0
XS4451.0  2089.0  4451.3  2107.0  4452.5  2119.0  4463.1  2140.0  4464.1  2144.0
XS4464.9  2150.0  4464.4  2219.0  4464.4  2286.0  4464.7  2355.0  4464.2  2427.0
XS4464.2  2502.0  4464.3  2573.0  4464.1  2642.0  4463.7  2706.0  4463.2  2786.0
XS4462.5  2847.0  4461.5  2867.0  4466.4  2898.0  4464.4  2914.0  4462.8  2981.0
XS4461.1  3013.0  4460.4  3056.0  4460.0  3072.0  4462.7  3087.0  4464.1  3097.0
XS4469.4  3112.0  4469.7  3119.0
RH 0.080   0.024   0.080
*** Station #5
ST133100      39       0       0       0       0     0.0
ND     3   199.0   319.0  1209.0
XS4468.0   111.0  4465.5   128.0  4463.7   164.0  4462.8   183.0  4464.1   199.0
XS4464.0   205.0  4454.8   220.0  4452.1   227.0  4450.4   240.0  4451.0   260.0
XS4450.8   276.0  4450.2   285.0  4461.8   302.0  4463.0   310.0  4463.5   319.0
XS4463.7   374.0  4463.5   451.0  4463.4   516.0  4463.4   587.0  4463.4   654.0
XS4463.2   710.0  4461.9   752.0  4461.6   808.0  4461.7   860.0  4461.7   901.0
XS4460.5   929.0  4462.2   970.0  4463.0  1013.0  4461.5  1031.0  4461.2  1072.0
XS4460.0  1116.0  4462.1  1138.0  4461.5  1147.0  4458.7  1170.0  4462.0  1184.0
XS4461.5  1189.0  4463.9  1197.0  4467.8  1206.0  4467.9  1209.0
```

```
RH 0.080   0.024   0.080
***
ST126460      44       0       0       0       0     0.0
ND     3   150.0   284.0  1226.0
XS4470.6    49.0  4463.6    61.0  4461.8    78.0  4458.9    90.0  4459.6    97.0
XS4459.3   117.0  4460.0   131.0  4459.9   150.0  4459.4   157.0  4459.4   161.0
XS4455.6   168.0  4451.6   171.0  4449.6   175.0  4454.2   203.0  4448.9   217.0
XS4448.2   238.0  4446.4   261.0  4454.2   268.0  4459.0   274.0  4460.1   284.0
XS4460.0   321.0  4459.9   355.0  4457.2   392.0  4458.1   419.0  4464.3   449.0
XS4459.9   499.0  4460.0   545.0  4457.7   568.0  4459.6   614.0  4460.4   664.0
XS4460.3   711.0  4460.2   766.0  4462.8   816.0  4460.5   868.0  4458.6   915.0
XS4461.2   975.0  4461.4  1027.0  4461.2  1073.0  4461.6  1119.0  4460.8  1163.0
XS4462.7  1195.0  4466.1  1202.0  4468.5  1213.0  4468.7  1226.0
RH 0.080   0.024   0.080
*** Station #7
ST124560      40       0       0       0       0     0.0
ND     2   181.0  1095.0
XS4468.0    55.0  4462.2    64.0  4461.5    72.0  4460.6    77.0  4457.3    81.0
XS4444.3    95.0  4444.9   106.0  4446.9   118.0  4447.6   135.0  4447.8   148.0
XS4449.4   151.0  4450.8   154.0  4458.5   181.0  4457.6   209.0  4461.5   231.0
XS4457.4   266.0  4456.0   281.0  4457.2   300.0  4460.4   337.0  4460.0   379.0
XS4457.2   411.0  4458.8   464.0  4459.0   521.0  4455.6   572.0  4457.6   606.0
XS4458.6   644.0  4458.1   697.0  4457.8   756.0  4458.1   805.0  4457.6   848.0
XS4456.2   872.0  4458.7   898.0  4458.5   910.0  4460.1   921.0  4458.6   937.0
XS4457.6   972.0  4459.6   994.0  4460.7  1048.0  4466.5  1088.0  4467.5  1095.0
RH 0.024   0.080
***
ST118694      29       0       0       0       0     0.0
ND     3    89.0   194.0  1147.0
XS4464.0    56.0  4457.4    67.0  4453.8    85.0  4454.2    89.0  4444.4   105.0
XS4444.1   121.0  4444.3   137.0  4444.2   155.0  4444.4   171.0  4444.5   176.0
XS4451.4   187.0  4451.6   194.0  4450.7   230.0  4452.3   262.0  4453.5   314.0
XS4454.1   386.0  4454.7   456.0  4454.6   530.0  4454.9   602.0  4456.1   669.0
XS4455.4   728.0  4455.8   776.0  4455.6   828.0  4454.8   897.0  4456.4   949.0
XS4456.8   997.0  4459.0  1068.0  4462.1  1123.0  4464.8  1147.0
RH 0.080   0.024   0.080
*** Station #9
ST111414      48       0       0       0       0     0.0
ND     3   222.0   371.0  1178.0
XS4462.5   163.0  4455.7   178.0  4451.5   185.0  4451.9   222.0  4451.8   227.0
XS4447.3   237.0  4444.4   247.0  4441.4   251.0  4441.9   272.0  4442.3   294.0
XS4440.7   321.0  4440.1   341.0  4441.5   344.0  4444.5   350.0  4446.8   355.0
XS4448.3   363.0  4451.5   368.0  4451.9   371.0  4451.7   375.0  4450.7   389.0
XS4452.0   401.0  4451.5   404.0  4451.8   409.0  4455.0   417.0  4455.4   423.0
XS4451.8   438.0  4451.2   478.0  4452.5   515.0  4450.7   565.0  4450.2   615.0
XS4451.2   654.0  4450.5   697.0  4451.0   745.0  4450.9   792.0  4450.7   837.0
XS4450.6   886.0  4451.0   921.0  4450.9   946.0  4450.5   994.0  4450.2  1029.0
XS4448.8  1064.0  4448.9  1090.0  4450.8  1101.0  4452.3  1129.0  4454.2  1141.0
XS4460.9  1152.0  4461.1  1155.0  4461.0  1178.0
RH 0.080   0.024   0.080
***
ST100814      89       0       0       0       0     0.0
ND     2  6218.0  9249.0
XS4463.5  4922.0  4460.8  4934.0  4460.9  4945.0  4456.0  4954.0  4451.2  4970.0
XS4445.5  4978.0  4443.5  4996.0  4443.9  5004.0  4446.1  5021.0  4447.2  5040.0
XS4446.9  5065.0  4442.8  5087.0  4441.9  5108.0  4441.4  5122.0  4441.5  5127.0
XS4433.9  5140.0  4430.7  5158.0  4430.5  5178.0  4430.0  5197.0  4429.5  5215.0
XS4434.4  5220.0  4440.0  5232.0  4440.2  5237.0  4439.0  5287.0  4442.0  5316.0
XS4446.0  5331.0  4447.0  5376.0  4446.9  5426.0  4446.5  5481.0  4445.9  5558.0
XS4445.2  5634.0  4444.2  5701.0  4443.5  5783.0  4443.0  5859.0  4442.6  5936.0
XS4442.2  5981.0  4443.0  6019.0  4442.0  6079.0  4441.5  6139.0  4442.6  6169.0
```

```
XS4445.9  6192.0  4451.8  6208.0  4456.4  6218.0  4456.2  6245.0  4442.8  6284.0
XS4440.9  6299.0  4441.7  6336.0  4429.9  6359.0  4429.0  6373.0  4430.5  6392.0
XS4440.4  6413.0  4440.5  6416.0  4440.3  6455.0  4439.2  6458.0  4439.8  6463.0
XS4439.3  6512.0  4440.0  6528.0  4439.4  6615.0  4438.8  6704.0  4439.5  6795.0
XS4438.8  6884.0  4438.8  6977.0  4438.8  7061.0  4439.0  7151.0  4438.7  7250.0
XS4439.8  7350.0  4439.7  7446.0  4438.7  7548.0  4438.9  7648.0  4438.7  7746.0
XS4438.9  7845.0  4439.7  7944.0  4440.3  8039.0  4442.2  8077.0  4441.7  8184.0
XS4443.0  8279.0  4441.2  8334.0  4441.6  8380.0  4439.8  8435.0  4440.0  8515.0
XS4442.7  8615.0  4446.9  8669.0  4448.7  8717.0  4451.0  8820.0  4453.8  8917.0
XS4454.9  9011.0  4451.7  9179.0  4455.0  9194.0  4459.4  9249.0
RH 0.024   0.080
*** Station #11
ST96977.     102       0       0       0       0     0.0
ND     3  3673.0  4785.0  9392.0
XS4450.3  3434.0  4447.3  3439.0  4443.9  3448.0  4442.2  3462.0  4442.3  3502.0
XS4443.8  3542.0  4444.2  3580.0  4445.8  3617.0  4448.2  3653.0  4449.0  3673.0
XS4448.0  3680.0  4443.7  3688.0  4441.7  3696.0  4439.5  3703.0  4431.2  3706.0
XS4431.3  3725.0  4431.2  3745.0  4431.5  3762.0  4431.5  3773.0  4432.2  3778.0
XS4435.2  3780.0  4440.2  3790.0  4441.0  3802.0  4440.8  3834.0  4445.4  3849.0
XS4449.0  3867.0  4447.8  3885.0  4447.2  3943.0  4446.7  4000.0  4446.5  4064.0
XS4445.4  4116.0  4446.2  4160.0  4445.1  4224.0  4444.2  4299.0  4444.2  4373.0
XS4444.0  4450.0  4444.2  4520.0  4443.6  4570.0  4441.5  4600.0  4443.8  4622.0
XS4442.5  4639.0  4442.6  4699.0  4443.6  4749.0  4446.6  4769.0  4456.0  4785.0
XS4455.1  4815.0  4443.8  4836.0  4442.7  4880.0  4431.5  4900.0  4431.7  4935.0
XS4441.0  4951.0  4440.1  5062.0  4440.6  5154.0  4440.7  5247.0  4441.0  5338.0
XS4439.9  5436.0  4440.5  5531.0  4440.3  5629.0  4439.8  5728.0  4439.6  5823.0
XS4439.6  5914.0  4440.5  6002.0  4439.9  6112.0  4439.4  6202.0  4438.9  6297.0
XS4439.4  6391.0  4440.0  6491.0  4439.3  6582.0  4439.7  6677.0  4439.2  6795.0
XS4439.1  6882.0  4439.0  6965.0  4437.6  7052.0  4438.4  7157.0  4438.1  7252.0
XS4438.6  7345.0  4438.3  7442.0  4437.9  7534.0  4437.7  7630.0  4437.5  7724.0
XS4437.4  7814.0  4437.7  7906.0  4437.6  7930.0  4437.6  8023.0  4438.2  8119.0
XS4437.9  8206.0  4435.7  8242.0  4435.3  8337.0  4435.8  8431.0  4436.2  8527.0
XS4435.5  8550.0  4436.3  8573.0  4436.5  8669.0  4435.4  8763.0  4435.3  8858.0
XS4435.3  8955.0  4435.7  9051.0  4435.7  9146.0  4435.6  9240.0  4435.5  9329.0
XS4444.6  9382.0  4450.3  9392.0
RH 0.080   0.024   0.080
***
ST88577.     170       0       0       0       0     0.0
ND     3  1181.0  8926.0  9726.0
XS4450.3   168.0  4449.9   174.0  4447.3   210.0  4444.5   225.0  4444.4   233.0
XS4446.5   246.0  4448.1   266.0  4447.3   290.0  4446.4   314.0  4445.6   321.0
XS4441.8   331.0  4437.1   346.0  4436.1   398.0  4436.8   447.0  4437.0   510.0
XS4436.8   551.0  4436.8   591.0  4436.4   612.0  4436.9   638.0  4436.7   680.0
XS4436.5   721.0  4436.2   754.0  4435.9   804.0  4436.2   843.0  4436.4   887.0
XS4436.6   922.0  4437.3   954.0  4437.3   985.0  4435.8   990.0  4436.2  1008.0
XS4435.7  1042.0  4436.4  1090.0  4436.5  1094.0  4430.5  1098.0  4438.9  1101.0
XS4439.3  1146.0  4432.8  1170.0  4439.7  1181.0  4428.6  1214.0  4428.1  1269.0
XS4429.3  1277.0  4430.5  1282.0  4436.0  1319.0  4436.6  1329.0  4436.0  1336.0
XS4437.4  1342.0  4437.5  1347.0  4436.8  1378.0  4438.1  1401.0  4442.1  1423.0
XS4442.6  1431.0  4439.7  1444.0  4437.2  1466.0  4436.7  1502.0  4436.8  1569.0
XS4437.1  1637.0  4437.3  1703.0  4437.5  1770.0  4437.8  1847.0  4437.5  1917.0
XS4437.5  1987.0  4437.8  2056.0  4438.4  2122.0  4436.9  2157.0  4438.0  2187.0
XS4437.3  2213.0  4439.0  2240.0  4438.3  2301.0  4441.2  2325.0  4438.5  2341.0
XS4438.0  2368.0  4439.0  2398.0  4445.8  2428.0  4449.9  2480.0  4441.1  2499.0
XS4439.4  2536.0  4440.6  2575.0  4427.9  2600.0  4426.6  2651.0  4438.8  2681.0
XS4439.1  2759.0  4439.4  2763.0  4438.4  2776.0  4438.5  2900.0  4438.2  3001.0
XS4438.0  3108.0  4438.0  3235.0  4438.1  3336.0  4438.2  3437.0  4438.4  3541.0
XS4438.5  3642.0  4439.2  3743.0  4439.4  3902.0  4439.5  4013.0  4439.4  4100.0
XS4439.9  4205.0  4439.6  4309.0  4439.4  4391.0  4439.6  4490.0  4439.7  4597.0
XS4439.8  4681.0  4439.5  4701.0  4440.1  4811.0  4440.4  4904.0  4440.3  4995.0
XS4440.9  5098.0  4440.4  5199.0  4441.3  5313.0  4441.1  5407.0  4441.0  5515.0
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XS4440.6  5607.0  4441.8  5709.0  4442.3  5800.0  4441.3  5828.0  4441.2  5914.0
XS4440.6  5971.0  4439.9  6072.0  4440.5  6165.0  4440.1  6193.0  4439.6  6290.0
XS4439.3  6384.0  4438.5  6465.0  4438.1  6568.0  4438.2  6662.0  4437.2  6782.0
XS4438.2  6826.0  4437.6  6876.0  4437.2  6973.0  4436.3  7006.0  4437.5  7040.0
XS4434.6  7152.0  4433.2  7251.0  4433.7  7316.0  4433.1  7383.0  4435.4  7418.0
XS4435.7  7447.0  4436.3  7542.0  4435.8  7638.0  4435.5  7735.0  4435.1  7804.0
XS4435.9  7857.0  4435.7  7892.0  4435.7  7990.0  4435.2  8085.0  4434.2  8185.0
XS4433.9  8284.0  4434.2  8394.0  4435.8  8503.0  4437.5  8605.0  4438.9  8705.0
XS4438.2  8748.0  4439.2  8780.0  4439.3  8831.0  4441.4  8926.0  4436.6  9016.0
XS4435.6  9074.0  4434.0  9095.0  4433.9  9146.0  4435.3  9239.0  4438.5  9289.0
XS4438.1  9358.0  4439.3  9391.0  4438.7  9414.0  4439.3  9434.0  4438.1  9468.0
XS4440.3  9563.0  4445.0  9617.0  4446.8  9669.0  4448.9  9699.0  4450.3  9726.0
RH 0.080   0.024   0.080
*** Station #13
ST83227.     196       0       0       0       0     0.0
ND     2  9908.0 12710.0
XS4447.4  1423.0  4448.2  1434.0  4446.5  1452.0
XS4444.5  1483.0  4444.0  1527.0  4443.7  1667.0  4444.4  1720.0  4442.2  1764.0
XS4441.8  1778.0  4443.5  1789.0  4441.8  1805.0  4444.4  1825.0  4442.0  1849.0
XS4440.6  1885.0  4440.1  1919.0  4439.3  1975.0  4440.3  1997.0  4438.9  2022.0
XS4441.5  2055.0  4438.7  2125.0  4439.2  2147.0  4437.3  2180.0  4437.6  2212.0
XS4439.5  2284.0  4440.2  2305.0  4439.6  2325.0  4437.5  2406.0  4435.5  2435.0
XS4433.7  2464.0  4433.1  2498.0  4433.5  2507.0  4433.9  2630.0  4432.4  2725.0
XS4430.6  2730.0  4427.1  2738.0  4424.3  2749.0  4420.3  2766.0  4420.9  2779.0
XS4422.9  2797.0  4423.8  2805.0  4426.8  2811.0  4427.1  2815.0  4430.1  2818.0
XS4433.0  2827.0  4433.4  2857.0  4432.5  2875.0  4433.9  2925.0  4433.2  3010.0
XS4434.7  3029.0  4432.8  3055.0  4433.4  3194.0  4433.0  3330.0  4433.0  3433.0
XS4432.3  3500.0  4431.2  3559.0  4432.0  3605.0  4436.9  3680.0  4439.1  3697.0
XS4430.5  3753.0  4430.1  3763.0  4429.4  3765.0  4430.4  3773.0  4430.7  3796.0
XS4419.6  3815.0  4419.2  3829.0  4430.2  3869.0  4429.4  3911.0  4429.8  3913.0
XS4430.2  3922.0  4429.5  3941.0  4429.1  4021.0  4430.6  4039.0  4430.8  4145.0
XS4429.7  4173.0  4430.4  4185.0  4430.9  4267.0  4430.6  4382.0  4429.8  4502.0
XS4431.2  4524.0  4430.7  4532.0  4430.3  4632.0  4430.8  4661.0  4429.9  4729.0
XS4430.9  4759.0  4430.5  4816.0  4430.9  4861.0  4431.2  4912.0  4429.8  4958.0
XS4430.7  4980.0  4431.3  5028.0  4430.6  5042.0  4431.2  5091.0  4431.7  5166.0
XS4430.8  5186.0  4431.1  5314.0  4430.4  5331.0  4431.1  5355.0  4431.3  5495.0
XS4431.2  5678.0  4430.7  5791.0  4428.2  5835.0  4429.6  5862.0  4430.0  5893.0
XS4431.0  5904.0  4431.5  5917.0  4430.7  5938.0  4431.8  5964.0  4431.3  5968.0
XS4431.9  5985.0  4431.3  6035.0  4431.7  6053.0  4430.1  6140.0  4430.7  6155.0
XS4430.2  6166.0  4431.0  6184.0  4431.4  6227.0  4429.6  6314.0  4431.1  6330.0
XS4432.0  6506.0  4431.7  6607.0  4431.2  6705.0  4431.2  6815.0  4430.8  6864.0
XS4431.3  6897.0  4430.7  6923.0  4431.4  6962.0  4431.9  6980.0  4431.5  7069.0
XS4430.5  7079.0  4431.7  7089.0  4430.7  7158.0  4431.7  7162.0  4432.1  7290.0
XS4431.6  7397.0  4432.2  7467.0  4431.9  7555.0  4432.5  7575.0  4431.8  7666.0
XS4432.8  7762.0  4431.7  7780.0  4432.6  7792.0  4433.1  7925.0  4432.6  8014.0
XS4432.1  8114.0  4432.0  8308.0  4432.4  8606.0  4433.3  8707.0  4433.6  8802.0
XS4434.8  8920.0  4435.1  8986.0  4434.6  9081.0  4437.0  9126.0  4432.2  9168.0
XS4435.7  9216.0  4436.5  9319.0  4436.9  9421.0  4437.3  9522.0  4438.0  9620.0
XS4438.4  9718.0  4438.9  9814.0  4439.9  9908.0  4438.2  9959.0  4438.7 10017.0
XS4433.1 10057.0  4437.6 10099.0  4439.6 10118.0  4439.1 10170.0  4438.8 10210.0
XS4437.8 10394.0  4437.3 10484.0  4436.2 10530.0  4437.4 10558.0  4437.1 10671.0
XS4437.6 10860.0  4437.3 10955.0  4436.7 11141.0  4436.5 11337.0  4436.3 11437.0
XS4435.2 11535.0  4434.4 11544.0  4436.3 11600.0  4434.0 11695.0  4433.5 11712.0
XS4435.1 11734.0  4435.2 11884.0  4435.8 11913.0  4436.7 12003.0  4436.4 12106.0
XS4437.6 12206.0  4438.9 12305.0  4440.1 12400.0  4442.2 12500.0  4444.2 12568.0
XS4443.8 12578.0  4446.0 12616.0  4450.1 12710.0
RH 0.024   0.080
***
ST73142.     131       0       0       0       0     0.0
ND     1  7930.0
XS4450.3  2829.0  4442.3  2838.0  4429.0  2872.0  4426.9  2886.0  4425.9  2925.0
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XS4426.1  2964.0  4427.0  2980.0  4427.0  2980.0  4426.3  2986.0  4425.9  2989.0
XS4424.0  2997.0  4421.3  2998.0  4421.0  3005.0  4417.6  3009.0  4417.4  3046.0
XS4419.0  3076.0  4419.6  3102.0  4416.9  3122.0  4416.6  3139.0  4421.0  3144.0
XS4425.2  3152.0  4425.4  3154.0  4426.4  3174.0  4425.0  3210.0  4426.1  3247.0
XS4430.2  3275.0  4426.7  3302.0  4426.9  3398.0  4427.4  3497.0  4426.5  3575.0
XS4425.2  3613.0  4426.5  3667.0  4426.8  3760.0  4426.2  3835.0  4425.9  3916.0
XS4424.8  3974.0  4426.3  3991.0  4425.1  4067.0  4424.2  4132.0  4431.6  4175.0
XS4434.0  4193.0  4432.5  4244.0  4423.0  4270.0  4423.2  4301.0  4415.4  4315.0
XS4414.0  4347.0  4425.1  4370.0  4424.6  4402.0  4422.4  4423.0  4423.2  4471.0
XS4428.1  4481.0  4428.2  4488.0  4428.3  4497.0  4422.3  4511.0  4420.1  4561.0
XS4420.6  4576.0  4420.6  4649.0  4421.5  4741.0  4422.2  4757.0  4420.9  4772.0
XS4421.0  4864.0  4420.4  4929.0  4420.9  4949.0  4420.3  4970.0  4420.8  5007.0
XS4420.4  5095.0  4420.5  5143.0  4419.8  5165.0  4419.7  5207.0  4420.3  5223.0
XS4420.3  5314.0  4419.4  5342.0  4420.3  5375.0  4420.6  5448.0  4420.4  5544.0
XS4420.6  5635.0  4420.3  5659.0  4419.7  5720.0  4420.6  5773.0  4419.9  5843.0
XS4419.1  5863.0  4417.2  5896.0  4418.9  5921.0  4419.4  6018.0  4419.6  6110.0
XS4419.9  6203.0  4419.4  6295.0  4419.8  6335.0  4419.2  6378.0  4419.0  6402.0
XS4418.4  6413.0  4418.4  6471.0  4418.6  6513.0  4418.3  6542.0  4418.8  6628.0
XS4418.3  6642.0  4419.1  6664.0  4417.7  6685.0  4418.6  6702.0  4418.7  6743.0
XS4418.6  6828.0  4418.6  6882.0  4417.7  6903.0  4419.7  6921.0  4418.3  6953.0
XS4413.9  6978.0  4414.3  6999.0  4417.1  7034.0  4418.1  7052.0  4418.1  7116.0
XS4418.7  7143.0  4418.5  7230.0  4417.6  7267.0  4419.0  7287.0  4418.7  7335.0
XS4417.2  7369.0  4417.9  7395.0  4417.0  7432.0  4417.7  7471.0  4417.0  7513.0
XS4418.7  7571.0  4418.3  7664.0  4418.8  7737.0  4421.5  7777.0  4424.4  7839.0
XS4428.6  7861.0  4436.6  7887.0  4436.1  7900.0  4443.5  7910.0  4445.2  7916.0
XS4450.3  7930.0
RH 0.024
*** Station #15
ST69002.     110       0       0       0       0     0.0
ND     1  6187.0
XS4450.3  2062.0  4448.6  2062.0  4440.3  2077.0  4433.9  2089.0  4431.9  2096.0
XS4425.5  2113.0  4422.9  2138.0  4422.5  2173.0  4421.9  2193.0  4421.1  2217.0
XS4421.4  2250.0  4422.9  2266.0  4422.8  2291.0  4423.9  2316.0  4425.3  2341.0
XS4423.5  2351.0  4423.6  2378.0  4423.9  2408.0  4424.3  2428.0  4423.9  2441.0
XS4421.7  2444.0  4420.4  2448.0  4419.3  2450.0  4415.8  2454.0  4408.0  2484.0
XS4406.3  2499.0  4415.1  2520.0  4419.3  2526.0  4419.3  2546.0  4418.8  2574.0
XS4419.8  2576.0  4422.1  2581.0  4423.3  2586.0  4423.7  2614.0  4423.8  2645.0
XS4422.8  2671.0  4423.7  2691.0  4424.6  2712.0  4424.2  2748.0  4424.2  2784.0
XS4424.4  2819.0  4423.9  2861.0  4424.3  2901.0  4424.4  2948.0  4423.4  2981.0
XS4423.4  3024.0  4423.2  3066.0  4423.6  3109.0  4422.5  3144.0  4423.6  3177.0
XS4424.0  3211.0  4422.6  3242.0  4427.2  3271.0  4431.0  3293.0  4431.0  3332.0
XS4421.2  3351.0  4421.1  3377.0  4411.6  3391.0  4411.6  3422.0  4423.1  3442.0
XS4422.6  3474.0  4421.3  3494.0  4421.8  3516.0  4425.9  3546.0  4426.0  3557.0
XS4423.6  3567.0  4421.4  3651.0  4419.9  3694.0  4420.0  3752.0  4420.5  3863.0
XS4419.6  3972.0  4419.5  4069.0  4420.0  4166.0  4420.1  4266.0  4419.8  4364.0
XS4419.4  4434.0  4421.2  4474.0  4421.1  4517.0  4420.7  4618.0  4419.7  4717.0
XS4419.2  4814.0  4420.2  4855.0  4418.8  4900.0  4419.2  4962.0  4419.3  5056.0
XS4419.2  5081.0  4419.7  5147.0  4419.4  5247.0  4419.7  5346.0  4422.1  5431.0
XS4422.1  5495.0  4421.1  5531.0  4418.7  5622.0  4417.9  5719.0  4416.1  5779.0
XS4412.9  5801.0  4412.3  5821.0  4414.2  5865.0  4414.3  5902.0  4413.8  5917.0
XS4416.0  6002.0  4415.8  6042.0  4419.2  6080.0  4423.4  6098.0  4424.0  6115.0
XS4429.7  6126.0  4433.1  6138.0  4439.0  6161.0  4444.9  6173.0  4450.3  6187.0
RH 0.024
***
ST63722.     130       0       0       0       0     0.0
ND     1  4484.0
XS4450.3    75.0  4441.3    94.0  4427.4   120.0  4420.8   145.0  4420.3   171.0
XS4418.7   178.0  4418.5   187.0  4418.8   191.0  4417.9   197.0  4417.5   213.0
XS4418.2   231.0  4419.2   237.0  4419.5   269.0  4420.6   305.0  4420.8   324.0
XS4420.0   344.0  4418.9   350.0  4419.6   354.0  4418.7   367.0  4418.9   392.0
XS4418.4   429.0  4418.7   469.0  4418.5   501.0  4419.6   527.0  4418.7   530.0
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XS4419.4   533.0  4419.2   571.0  4420.1   607.0  4420.1   642.0  4421.1   674.0
XS4421.5   706.0  4421.6   737.0  4421.7   756.0  4421.6   779.0  4421.5   782.0
XS4420.6   783.0  4420.6   790.0  4418.6   793.0  4417.2   797.0  4415.7   801.0
XS4415.1   822.0  4414.1   844.0  4411.4   878.0  4417.2   885.0  4420.9   888.0
XS4421.2   924.0  4421.9   929.0  4421.5  1029.0  4421.1  1059.0  4421.4  1067.0
XS4420.9  1085.0  4419.3  1096.0  4418.2  1115.0  4416.8  1127.0  4417.4  1159.0
XS4419.8  1164.0  4418.5  1174.0  4416.0  1180.0  4416.5  1228.0  4420.3  1269.0
XS4427.0  1298.0  4426.2  1344.0  4417.1  1362.0  4417.4  1388.0  4408.9  1403.0
XS4408.4  1412.0  4407.6  1420.0  4409.0  1432.0  4420.6  1453.0  4419.8  1475.0
XS4416.9  1498.0  4417.9  1526.0  4423.5  1537.0  4422.9  1541.0  4415.3  1577.0
XS4413.9  1638.0  4412.0  1657.0  4414.6  1690.0  4415.5  1726.0  4414.2  1761.0
XS4415.2  1793.0  4414.4  1894.0  4413.5  1912.0  4414.5  1932.0  4414.0  2023.0
XS4414.0  2108.0  4413.7  2209.0  4414.2  2245.0  4413.2  2285.0  4413.8  2300.0
XS4413.9  2354.0  4413.3  2376.0  4414.1  2404.0  4413.9  2507.0  4413.4  2528.0
XS4414.5  2558.0  4415.1  2628.0  4414.6  2663.0  4415.0  2753.0  4413.8  2810.0
XS4414.0  2831.0  4414.0  2872.0  4413.1  2882.0  4414.0  2890.0  4414.4  2983.0
XS4414.1  3075.0  4415.0  3119.0  4414.1  3155.0  4415.3  3218.0  4414.3  3264.0
XS4415.0  3281.0  4414.7  3376.0  4415.5  3472.0  4415.7  3565.0  4416.8  3650.0
XS4416.9  3695.0  4415.5  3723.0  4414.6  3778.0  4413.7  3803.0  4411.6  3820.0
XS4419.6  4027.0  4419.8  4121.0  4419.9  4127.0  4421.3  4218.0  4423.5  4310.0
XS4425.2  4325.0  4427.9  4374.0  4446.0  4456.0  4450.1  4483.0  4450.3  4484.0
RH 0.024
*** Station #17
ST59883.     101       0       0       0       0     0.0
ND     1  5842.0
XS4450.3   157.0  4418.3   258.0  4413.7   359.0  4414.6   663.0  4415.2   865.0
XS4416.0  1068.0  4415.3  1119.0  4417.3  1341.0  4408.9  1372.0  4419.0  1380.0
XS4417.7  1393.0  4417.6  1403.0  4419.1  1419.0  4419.3  1508.0  4418.4  1541.0
XS4419.4  1547.0  4419.2  1573.0  4418.5  1578.0  4419.3  1589.0  4419.4  1627.0
XS4417.9  1635.0  4418.3  1666.0  4418.4  1763.0  4417.4  1769.0  4417.2  1794.0
XS4417.9  1805.0  4418.1  1846.0  4417.7  1886.0  4415.5  1917.0  4415.9  1972.0
XS4423.3  2001.0  4423.9  2025.0  4421.9  2033.0  4422.1  2054.0  4414.7  2072.0
XS4415.0  2095.0  4410.6  2100.0  4410.6  2146.0  4418.5  2158.0  4418.0  2190.0
XS4414.3  2224.0  4415.1  2260.0  4419.7  2272.0  4419.5  2281.0  4416.2  2287.0
XS4414.7  2295.0  4413.3  2309.0  4410.2  2343.0  4410.6  2396.0  4410.2  2434.0
XS4411.3  2514.0  4410.8  2589.0  4410.3  2708.0  4409.2  2741.0  4410.5  2765.0
XS4411.5  2861.0  4412.0  2956.0  4411.3  3003.0  4413.3  3084.0  4413.1  3141.0
XS4412.1  3221.0  4413.1  3274.0  4413.7  3389.0  4414.6  3514.0  4415.0  3633.0
XS4413.8  3723.0  4412.8  3839.0  4412.3  3872.0  4413.4  3924.0  4412.7  4029.0
XS4413.1  4135.0  4412.6  4256.0  4412.0  4369.0  4412.2  4485.0  4411.5  4596.0
XS4411.4  4700.0  4410.1  4773.0  4411.1  4815.0  4411.3  4892.0  4412.0  4938.0
XS4410.8  4968.0  4411.9  5010.0  4411.8  5035.0  4407.0  5116.0  4413.7  5184.0
XS4413.7  5240.0  4410.4  5312.0  4412.5  5343.0  4413.1  5366.0  4412.5  5405.0
XS4414.1  5485.0  4413.4  5559.0  4409.2  5605.0  4405.3  5657.0  4411.3  5719.0
XS4425.3  5767.0  4425.2  5774.0  4425.6  5779.0  4427.7  5783.0  4430.1  5794.0
XS4450.3  5842.0
RH 0.024
***
ST57665.      95       0       0       0       0     0.0
ND     1  3773.0
XS4450.3   210.0  4446.6   227.0  4438.3   250.0  4429.6   287.0  4421.4   344.0
XS4415.5   386.0  4414.1   479.0  4414.5   549.0  4417.1   636.0  4418.7   738.0
XS4417.5   793.0  4418.8   849.0  4419.1   901.0  4414.2   907.0  4407.9   912.0
XS4407.0   947.0  4412.2   983.0  4414.2   988.0  4418.9   999.0  4418.5  1071.0
XS4416.4  1088.0  4417.2  1102.0  4417.6  1115.0  4418.2  1124.0  4418.2  1167.0
XS4418.8  1173.0  4418.8  1228.0  4417.9  1235.0  4418.8  1241.0  4418.8  1315.0
XS4416.3  1361.0  4417.7  1431.0  4418.4  1451.0  4414.9  1483.0  4413.9  1519.0
XS4415.0  1529.0  4414.8  1587.0  4414.3  1595.0  4423.1  1631.0  4423.1  1649.0
XS4423.1  1681.0  4415.4  1697.0  4415.3  1749.0  4418.6  1753.0  4415.2  1758.0
XS4410.3  1777.0  4410.2  1785.0  4411.6  1800.0  4418.6  1811.0  4418.5  1824.0
XS4418.1  1838.0  4417.7  1856.0  4414.2  1901.0  4414.1  1928.0  4419.5  1952.0
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XS4419.7  1966.0  4414.1  1985.0  4414.3  2006.0  4412.9  2033.0  4413.3  2050.0
XS4411.9  2071.0  4413.3  2094.0  4413.9  2122.0  4412.9  2173.0  4414.4  2207.0
XS4414.7  2250.0  4414.4  2308.0  4414.7  2381.0  4416.2  2490.0  4414.2  2610.0
XS4412.7  2707.0  4412.0  2803.0  4410.8  2817.0  4411.1  2864.0  4411.2  2900.0
XS4409.3  2954.0  4410.0  2982.0  4410.2  3002.0  4409.4  3030.0  4411.1  3071.0
XS4410.4  3126.0  4410.9  3206.0  4411.4  3222.0  4412.0  3310.0  4410.1  3334.0
XS4410.9  3350.0  4410.5  3363.0  4410.5  3391.0  4411.8  3407.0  4410.4  3416.0
XS4424.4  3660.0  4424.8  3678.0  4436.1  3721.0  4448.0  3765.0  4450.3  3773.0
RH 0.024
*** Station #19
ST54321.     108       0       0       0       0     0.0
ND     1  5521.0
XS4450.3   180.0  4445.1   198.0  4443.8   198.0  4436.8   212.0  4429.7   243.0
XS4424.5   314.0  4417.4   410.0  4415.6   492.0  4414.0   543.0  4413.3   587.0
XS4413.1   659.0  4412.3   751.0  4412.3   823.0  4411.8   892.0  4411.7   993.0
XS4412.5  1059.0  4412.4  1090.0  4414.2  1121.0  4413.3  1182.0  4412.4  1192.0
XS4414.3  1209.0  4414.3  1271.0  4415.0  1327.0  4416.5  1402.0  4416.7  1494.0
XS4405.6  1505.0  4405.4  1523.0  4407.6  1555.0  4414.5  1568.0  4415.7  1576.0
XS4416.1  1634.0  4414.6  1648.0  4414.2  1664.0  4415.0  1677.0  4415.1  1699.0
XS4414.3  1776.0  4414.4  1830.0  4415.6  1859.0  4415.6  1958.0  4416.3  2045.0
XS4414.2  2082.0  4413.3  2176.0  4415.0  2200.0  4414.1  2249.0  4420.9  2280.0
XS4421.2  2300.0  4421.3  2317.0  4413.6  2349.0  4413.2  2385.0  4404.8  2395.0
XS4405.1  2425.0  4417.5  2447.0  4417.6  2449.0  4417.7  2458.0  4417.3  2469.0
XS4413.3  2508.0  4413.0  2545.0  4417.8  2559.0  4417.5  2586.0  4413.1  2605.0
XS4412.2  2618.0  4407.9  2644.0  4413.3  2672.0  4416.1  2727.0  4416.4  2759.0
XS4415.1  2774.0  4417.5  2789.0  4416.7  2860.0  4416.4  2886.0  4416.9  2903.0
XS4416.6  2993.0  4416.0  3036.0  4416.9  3086.0  4417.3  3198.0  4418.2  3288.0
XS4419.1  3376.0  4420.4  3478.0  4421.7  3578.0  4423.3  3657.0  4423.3  3743.0
XS4425.7  3878.0  4427.0  3992.0  4428.7  4085.0  4431.3  4209.0  4431.4  4293.0
XS4432.5  4388.0  4433.7  4476.0  4435.8  4594.0  4438.1  4700.0  4440.5  4731.0
XS4440.2  4756.0  4441.7  4784.0  4442.6  4832.0  4444.3  4866.0  4442.6  4917.0
XS4441.8  4975.0  4441.7  5000.0  4441.5  5021.0  4443.7  5145.0  4445.5  5243.0
XS4446.6  5303.0  4446.5  5349.0  4450.5  5418.0  4452.8  5469.0  4449.8  5498.0
XS4449.2  5511.0  4447.7  5516.0  4450.3  5521.0
RH 0.024
***
ST50167.     127       0       0       0       0     0.0
ND     1  8110.0
XS4450.3   210.0  4428.6   253.0  4417.6   311.0  4412.5   359.0  4411.6   451.0
XS4414.0   530.0  4413.7   534.0  4411.5   536.0  4410.3   558.0  4409.4   588.0
XS4408.4   616.0  4410.6   626.0  4412.7   629.0  4414.1   701.0  4412.6   761.0
XS4412.9   864.0  4412.8   964.0  4416.0  1054.0  4413.3  1080.0  4413.2  1188.0
XS4411.8  1247.0  4411.1  1299.0  4412.3  1329.0  4412.9  1434.0  4411.0  1481.0
XS4410.7  1536.0  4405.7  1572.0  4407.5  1596.0  4411.2  1634.0  4410.9  1686.0
XS4411.1  1715.0  4418.9  1747.0  4419.3  1765.0  4419.3  1781.0  4421.3  1810.0
XS4414.6  1823.0  4418.5  1840.0  4404.8  1854.0  4400.8  2038.0  4400.6  2050.0
XS4400.8  2068.0  4405.0  2076.0  4408.0  2091.0  4413.6  2107.0  4412.7  2131.0
XS4416.0  2154.0  4415.9  2207.0  4411.3  2240.0  4406.2  2267.0  4405.6  2303.0
XS4409.0  2327.0  4409.4  2372.0  4408.3  2433.0  4405.9  2468.0  4403.8  2505.0
XS4403.4  2555.0  4404.5  2636.0  4407.3  2697.0  4408.0  2763.0  4407.7  2817.0
XS4407.1  2889.0  4406.1  2984.0  4406.8  3058.0  4406.6  3138.0  4406.8  3211.0
XS4406.8  3215.0  4406.1  3289.0  4406.4  3370.0  4407.0  3453.0  4406.2  3471.0
XS4407.2  3496.0  4407.4  3559.0  4406.1  3602.0  4406.4  3634.0  4407.0  3729.0
XS4406.2  3848.0  4407.1  3929.0  4406.2  3962.0  4407.1  3979.0  4407.1  4053.0
XS4408.1  4114.0  4405.2  4170.0  4404.3  4260.0  4403.1  4293.0  4404.1  4317.0
XS4403.5  4333.0  4404.3  4356.0  4403.9  4432.0  4403.2  4484.0  4404.5  4508.0
XS4405.4  4559.0  4406.8  4609.0  4407.2  4630.0  4408.3  4657.0  4409.5  4716.0
XS4411.9  4791.0  4411.1  4933.0  4411.6  4998.0  4412.6  5072.0  4412.8  5171.0
XS4412.9  5255.0  4412.9  5385.0  4413.0  5470.0  4413.1  5599.0  4413.3  5712.0
XS4414.1  5818.0  4414.8  5913.0  4415.2  6026.0  4415.7  6129.0  4417.8  6235.0
XS4418.9  6353.0  4420.3  6466.0  4421.8  6590.0  4423.2  6696.0  4425.0  6804.0
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XS4426.2  6889.0  4426.0  6913.0  4426.8  6940.0  4429.1  7048.0  4430.7  7171.0
XS4433.1  7305.0  4435.3  7414.0  4438.7  7567.0  4441.4  7696.0  4445.3  7865.0
XS4448.3  8026.0  4450.3  8110.0
RH 0.024
*** Station #21
ST47263.      93       0       0       0       0     0.0
ND     1  6911.0
XS4450.3    62.0  4443.2    73.0  4412.8   134.0  4411.1   252.0  4412.5   336.0
XS4409.9   365.0  4409.7   389.0  4409.4   481.0  4408.8   579.0  4407.5   669.0
XS4407.1   713.0  4406.1   816.0  4406.3   902.0  4406.3   993.0  4405.8  1089.0
XS4406.2  1184.0  4404.7  1242.0  4405.8  1263.0  4405.3  1342.0  4413.1  1390.0
XS4413.1  1398.0  4410.1  1487.0  4407.9  1490.0  4403.0  1496.0  4399.8  1503.0
XS4399.7  1521.0  4399.3  1534.0  4399.4  1546.0  4407.9  1553.0  4410.6  1557.0
XS4411.2  1568.0  4410.9  1579.0  4408.8  1601.0  4411.0  1615.0  4410.6  1667.0
XS4401.7  1723.0  4400.9  1736.0  4402.0  1746.0  4403.9  1760.0  4404.7  1797.0
XS4407.2  1809.0  4405.1  1893.0  4404.6  1999.0  4402.5  2077.0  4402.7  2134.0
XS4404.2  2175.0  4403.4  2227.0  4402.1  2281.0  4404.1  2328.0  4404.5  2433.0
XS4403.3  2538.0  4403.5  2631.0  4403.5  2749.0  4405.1  3797.0  4399.5  3977.0
XS4402.0  4023.0  4404.8  4160.0  4403.5  4280.0  4403.7  4355.0  4403.1  4416.0
XS4403.0  4462.0  4402.7  4539.0  4402.8  4611.0  4402.4  4654.0  4408.2  4752.0
XS4409.0  4841.0  4410.8  4923.0  4412.5  5019.0  4413.5  5121.0  4413.5  5226.0
XS4414.1  5328.0  4415.4  5349.0  4415.8  5425.0  4415.5  5443.0  4417.6  5478.0
XS4418.1  5517.0  4420.4  5613.0  4420.8  5657.0  4421.9  5681.0  4423.5  5770.0
XS4424.7  5868.0  4427.3  5958.0  4427.8  6004.0  4430.5  6104.0  4430.7  6139.0
XS4433.0  6177.0  4434.7  6232.0  4435.3  6316.0  4437.1  6365.0  4440.3  6493.0
XS4442.2  6622.0  4446.4  6828.0  4450.3  6911.0
RH 0.024
***
ST32521.      89       0       0       0       0     0.0
ND     1  7370.0
XS4450.3  1362.0  4449.9  1370.0  4448.0  1401.0  4445.7  1430.0  4442.8  1457.0
XS4441.4  1480.0  4439.7  1493.0  4435.7  1514.0  4432.8  1523.0  4432.1  1532.0
XS4425.7  1549.0  4426.5  1553.0  4423.6  1562.0  4423.1  1571.0  4419.9  1583.0
XS4416.8  1586.0  4412.0  1603.0  4410.0  1612.0  4410.5  1612.0  4404.6  1876.0
XS4403.0  1941.0  4402.2  2024.0  4404.1  2057.0  4411.8  2257.0  4411.8  2268.0
XS4411.7  2280.0  4410.5  2281.0  4407.9  2291.0  4404.9  2296.0  4395.9  2328.0
XS4394.9  2424.0  4395.2  2432.0  4403.9  2480.0  4392.2  2529.0  4391.9  2551.0
XS4390.9  2664.0  4390.3  2720.0  4390.9  2777.0  4392.9  2834.0  4392.9  2891.0
XS4392.6  3006.0  4392.2  3122.0  4392.5  3239.0  4393.7  3357.0  4392.4  3477.0
XS4392.9  3597.0  4393.9  3699.0  4393.9  3802.0  4393.0  3843.0  4392.9  3968.0
XS4392.4  4095.0  4391.9  4224.0  4391.6  4355.0  4392.7  4487.0  4392.1  4622.0
XS4392.3  4760.0  4391.9  4900.0  4391.9  5042.0  4392.7  5188.0  4392.5  5336.0
XS4393.9  5488.0  4392.5  5643.0  4390.9  5801.0  4391.1  5964.0  4390.7  6130.0
XS4390.9  6238.0  4394.6  6524.0  4398.2  6596.0  4407.9  6737.0  4409.3  6746.0
XS4415.7  6802.0  4421.9  6845.0  4429.3  6891.0  4437.2  6910.0  4441.4  6925.0
XS4443.3  6934.0  4444.7  6960.0  4443.9  6982.0  4436.5  7021.0  4430.4  7056.0
XS4429.0  7076.0  4426.6  7118.0  4427.3  7161.0  4429.2  7239.0  4437.3  7295.0
XS4446.2  7344.0  4444.9  7347.0  4447.3  7351.0  4450.3  7370.0
RH 0.024
*** Station #23
ST30480.     111       0       0       0       0     0.0
ND     1  7975.0
XS4450.3   977.0  4446.8  1000.0  4444.9  1017.0  4441.1  1052.0  4439.1  1097.0
XS4436.8  1120.0  4433.9  1128.0  4436.7  1134.0  4439.1  1145.0  4442.0  1168.0
XS4442.5  1211.0  4443.4  1244.0  4442.5  1271.0  4440.7  1288.0  4440.0  1296.0
XS4439.1  1304.0  4435.9  1312.0  4433.2  1322.0  4428.4  1332.0  4424.5  1349.0
XS4423.0  1356.0  4419.0  1367.0  4416.8  1375.0  4415.5  1385.0  4411.0  1397.0
XS4409.6  1404.0  4403.9  1636.0  4398.4  1650.0  4397.6  1774.0  4397.4  1875.0
XS4398.1  1976.0  4407.9  2013.0  4405.9  2020.0  4392.9  2085.0  4392.6  2091.0
XS4392.7  2130.0  4403.7  2191.0  4405.4  2240.0  4392.7  2290.0  4394.4  2344.0
XS4392.7  2388.0  4394.4  2428.0  4392.9  2485.0  4393.9  2581.0  4392.4  2677.0
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XS4391.6  2772.0  4391.0  2866.0  4390.9  2959.0  4390.8  3052.0  4390.7  3145.0
XS4390.4  3237.0  4390.4  3329.0  4390.9  3421.0  4390.4  3513.0  4391.1  3604.0
XS4391.2  3695.0  4391.1  3786.0  4391.2  3878.0  4391.9  3969.0  4391.3  4060.0
XS4390.7  4152.0  4391.7  4244.0  4391.9  4336.0  4391.9  4428.0  4391.5  4513.0
XS4389.9  4521.0  4390.1  4614.0  4390.9  4708.0  4391.0  4803.0  4391.4  4874.0
XS4390.6  4898.0  4390.0  4993.0  4389.7  5025.0  4390.6  5090.0  4390.8  5187.0
XS4390.2  5286.0  4388.9  5385.0  4388.6  5427.0  4389.9  5486.0  4389.8  5587.0
XS4389.8  5690.0  4389.8  5794.0  4389.6  5900.0  4389.7  6007.0  4389.4  6116.0
XS4389.1  6226.0  4389.4  6339.0  4389.4  6453.0  4394.4  6505.0  4388.4  6569.0
XS4388.9  6688.0  4389.1  6808.0  4390.1  6932.0  4391.8  6992.0  4389.7  7058.0
XS4389.3  7186.0  4388.8  7318.0  4389.0  7453.0  4389.7  7511.0  4397.4  7591.0
XS4407.9  7697.0  4413.1  7721.0  4416.4  7754.0  4419.9  7776.0  4425.8  7804.0
XS4430.0  7833.0  4435.5  7849.0  4439.7  7877.0  4441.4  7899.0  4445.3  7923.0
XS4450.3  7975.0
RH 0.024
***
ST27647.     101       0       0       0       0     0.0
ND     1  8963.0
XS4450.3  2377.0  4449.2  2412.0  4447.8  2465.0  4445.4  2513.0  4444.5  2535.0
XS4443.6  2591.0  4441.7  2649.0  4439.9  2663.0  4439.4  2675.0  4439.5  2735.0
XS4438.3  2778.0  4436.7  2832.0  4434.4  2886.0  4433.2  2900.0  4433.6  2916.0
XS4433.1  2955.0  4431.6  3008.0  4429.7  3062.0  4428.3  3114.0  4425.9  3167.0
XS4424.1  3221.0  4421.8  3269.0  4420.2  3319.0  4417.3  3374.0  4415.8  3425.0
XS4414.3  3482.0  4412.8  3541.0  4411.3  3593.0  4407.9  3624.0  4409.6  3640.0
XS4404.4  3649.0  4409.6  3717.0  4402.6  3734.0  4403.8  3769.0  4403.1  3772.0
XS4395.9  3810.0  4404.9  3848.0  4403.9  3894.0  4403.1  3904.0  4403.3  3992.0
XS4405.4  4020.0  4407.9  4061.0  4407.1  4068.0  4411.0  4076.0  4410.6  4084.0
XS4407.9  4088.0  4399.6  4146.0  4394.6  4162.0  4395.1  4235.0  4401.9  4284.0
XS4401.4  4319.0  4394.9  4329.0  4391.4  4360.0  4392.9  4428.0  4392.7  4533.0
XS4390.9  4645.0  4390.7  4764.0  4390.4  4891.0  4389.9  5027.0  4389.4  5173.0
XS4389.2  5413.0  4389.4  5500.0  4389.4  5590.0  4389.4  5684.0  4389.1  5816.0
XS4389.1  5885.0  4388.9  5956.0  4388.4  6105.0  4388.4  6183.0  4388.4  6263.0
XS4388.1  6346.0  4388.1  6432.0  4388.1  6521.0  4388.1  6614.0  4388.1  6709.0
XS4388.1  6808.0  4388.3  6911.0  4388.3  7017.0  4388.1  7131.0  4387.9  7243.0
XS4388.1  7363.0  4387.9  7489.0  4387.7  7619.0  4387.9  7755.0  4388.4  7897.0
XS4388.9  8046.0  4389.9  8141.0  4393.3  8201.0  4407.9  8365.0  4409.7  8408.0
XS4415.1  8469.0  4416.5  8515.0  4419.1  8585.0  4422.2  8646.0  4425.3  8688.0
XS4431.3  8737.0  4436.9  8829.0  4436.0  8859.0  4437.5  8897.0  4443.2  8937.0
XS4450.3  8963.0
RH 0.024
*** Station #25
ST25059.      77       0       0       0       0     0.0
ND     1  5350.0
XS4450.3   836.0  4448.4   854.0  4449.0   879.0  4449.2   912.0  4448.4   959.0
XS4446.2  1015.0  4442.5  1052.0  4442.0  1090.0  4442.5  1111.0  4441.0  1150.0
XS4439.4  1182.0  4439.0  1185.0  4434.3  1207.0  4428.6  1229.0  4426.0  1246.0
XS4423.1  1262.0  4421.2  1276.0  4419.0  1306.0  4413.0  1355.0  4411.6  1379.0
XS4410.8  1393.0  4410.9  1419.0  4408.7  1454.0  4407.1  1481.0  4405.5  1550.0
XS4407.2  1577.0  4414.9  1607.0  4415.1  1636.0  4412.5  1665.0  4408.7  1700.0
XS4408.9  1707.0  4410.1  1708.0  4407.9  1731.0  4402.9  1751.0  4400.4  1807.0
XS4400.4  1889.0  4400.1  1972.0  4400.4  2055.0  4400.1  2139.0  4400.4  2225.0
XS4400.6  2311.0  4400.9  2366.0  4405.9  2764.0  4402.2  2832.0  4401.9  2855.0
XS4402.2  2871.0  4404.9  2950.0  4402.1  3048.0  4401.8  3147.0  4401.4  3234.0
XS4400.9  3248.0  4400.2  3267.0  4400.2  3306.0  4405.3  3339.0  4403.9  3352.0
XS4398.6  3371.0  4398.1  3457.0  4397.3  3565.0  4397.0  3675.0  4395.6  3788.0
XS4394.9  3904.0  4394.6  4023.0  4391.9  4145.0  4391.3  4270.0  4390.9  4399.0
XS4390.9  4531.0  4390.8  4668.0  4390.0  4809.0  4389.9  4955.0  4405.4  5063.0
XS4408.3  5107.0  4410.3  5122.0  4412.4  5156.0  4416.5  5184.0  4420.5  5249.0
XS4443.1  5319.0  4450.3  5350.0
RH 0.024
***
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ST23335.      44       0       0       0       0     0.0
ND     1  1707.0
XS4450.3   132.0  4447.3   138.0  4446.3   142.0  4443.3   142.0  4434.6   154.0
XS4418.6   156.0  4414.1   168.0  4413.2   175.0  4414.1   178.0  4411.4   182.0
XS4408.4   190.0  4402.2   281.0  4398.2   329.0  4402.8   395.0  4400.2   471.0
XS4403.4   547.0  4403.7   595.0  4402.2   663.0  4402.5   702.0  4399.4   779.0
XS4397.7   780.0  4397.8   826.0  4403.8   836.0  4403.8  1423.0  4408.8  1431.0
XS4419.3  1449.0  4422.7  1451.0  4423.2  1453.0  4426.2  1453.0  4426.7  1456.0
XS4432.0  1467.0  4435.9  1469.0  4437.9  1474.0  4439.7  1475.0  4441.4  1481.0
XS4443.8  1508.0  4445.6  1524.0  4446.5  1574.0  4445.1  1602.0  4445.6  1612.0
XS4445.5  1625.0  4445.2  1655.0  4447.1  1682.0  4449.9  1707.0
RH 0.024
*** Station #27
ST20325.      89       0       0       0       0     0.0
ND     1  4129.0
XS4450.3   651.0  4450.0   652.0  4447.4   687.0  4447.6   710.0  4447.8   736.0
XS4444.7   762.0  4439.1   781.0  4439.2   803.0  4443.5   831.0  4442.4   866.0
XS4439.0   902.0  4435.9   929.0  4436.1   947.0  4432.2   985.0  4430.1  1011.0
XS4426.8  1038.0  4427.2  1070.0  4427.6  1086.0  4424.0  1096.0  4421.2  1111.0
XS4420.7  1120.0  4417.8  1130.0  4411.6  1135.0  4410.7  1149.0  4410.0  1159.0
XS4410.0  1160.0  4408.4  1164.0  4403.1  1205.0  4401.3  1252.0  4400.8  1294.0
XS4399.6  1390.0  4400.0  1626.0  4399.9  1688.0  4399.7  1738.0  4399.3  1993.0
XS4400.3  2004.0  4396.9  2021.0  4396.1  2065.0  4398.9  2102.0  4402.4  2181.0
XS4399.4  2443.0  4399.5  2466.0  4397.3  2475.0  4397.9  2480.0  4398.2  2508.0
XS4398.7  2540.0  4398.7  2946.0  4398.4  2983.0  4398.4  3040.0  4398.3  3097.0
XS4397.9  3153.0  4397.8  3208.0  4397.8  3261.0  4398.1  3314.0  4397.6  3366.0
XS4397.5  3418.0  4397.3  3469.0  4397.4  3493.0  4398.9  3519.0  4402.9  3568.0
XS4407.9  3598.0  4411.9  3609.0  4412.6  3622.0  4409.1  3651.0  4409.7  3663.0
XS4408.3  3676.0  4407.9  3685.0  4405.9  3692.0  4403.8  3714.0  4399.3  3762.0
XS4398.9  3809.0  4399.1  3823.0  4404.3  3856.0  4408.5  3887.0  4411.5  3912.0
XS4411.9  3931.0  4412.4  3943.0  4412.1  3958.0  4410.5  3968.0  4410.6  3982.0
XS4411.9  4001.0  4409.2  4012.0  4411.2  4022.0  4414.4  4033.0  4412.7  4040.0
XS4420.8  4052.0  4426.7  4067.0  4427.4  4126.0  4450.3  4129.0
RH 0.024
***
ST17611.      36       0       0       0       0     0.0
ND     1  1536.0
XS4450.3   241.0  4447.0   266.0  4445.2   297.0  4440.3   332.0  4436.9   352.0
XS4433.4   381.0  4429.4   409.0  4426.3   441.0  4423.2   469.0  4420.6   489.0
XS4420.5   502.0  4418.4   512.0  4413.8   520.0  4407.9   526.0  4399.9   544.0
XS4399.0   586.0  4399.5   623.0  4401.7   713.0  4396.3   755.0  4393.9   788.0
XS4394.4   797.0  4397.9   801.0  4396.6   810.0  4398.1  1061.0  4395.7  1316.0
XS4394.9  1340.0  4393.0  1359.0  4396.0  1383.0  4395.6  1426.0  4395.9  1459.0
XS4407.9  1504.0  4408.4  1506.0  4411.4  1512.0  4420.6  1523.0  4427.5  1534.0
XS4450.3  1536.0
RH 0.024
*** Station #29
ST15288.      49       0       0       0       0     0.0
ND     1  1577.0
XS4450.3   199.0  4445.9   211.0  4439.1   229.0  4430.1   261.0  4425.9   273.0
XS4423.8   278.0  4426.2   287.0  4425.9   310.0  4422.5   346.0  4419.3   369.0
XS4416.0   389.0  4413.1   408.0  4410.1   424.0  4407.9   433.0  4399.9   468.0
XS4391.6   527.0  4391.2   533.0  4390.9   567.0  4393.2   617.0  4400.4   660.0
XS4400.2   668.0  4397.1   697.0  4396.1   806.0  4395.2   845.0  4395.8   896.0
XS4395.5   955.0  4395.3  1008.0  4395.7  1029.0  4395.9  1056.0  4395.9  1075.0
XS4396.7  1093.0  4404.9  1100.0  4409.9  1144.0  4413.1  1194.0  4415.3  1239.0
XS4418.3  1280.0  4418.9  1313.0  4418.3  1328.0  4420.5  1340.0  4424.0  1375.0
XS4425.3  1402.0  4425.5  1408.0  4429.9  1440.0  4434.6  1460.0  4438.8  1496.0
XS4438.6  1502.0  4440.7  1513.0  4446.7  1556.0  4450.3  1577.0
RH 0.024
***
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ST13070.      62       0       0       0       0     0.0
ND     2   605.0  1588.0
XS4440.0     0.0  4442.1     6.0  4440.0    19.0  4437.4    34.0  4436.4    43.0
XS4433.3    48.0  4431.6    75.0  4425.8   106.0  4425.2   136.0  4423.5   168.0
XS4422.7   198.0  4422.8   226.0  4422.5   257.0  4422.1   275.0  4423.4   322.0
XS4424.9   361.0  4426.7   394.0  4427.8   426.0  4425.1   460.0  4422.8   492.0
XS4422.7   518.0  4425.7   546.0  4436.8   578.0  4443.2   605.0  4442.4   617.0
XS4440.8   618.0  4437.2   630.0  4432.1   630.0  4428.5   653.0  4420.9   669.0
XS4416.9   685.0  4413.8   707.0  4412.7   712.0  4409.3   724.0  4408.0   725.0
XS4395.6   743.0  4394.8   791.0  4394.9   840.0  4395.3   890.0  4396.0   911.0
XS4395.9   946.0  4398.9  1017.0  4393.9  1046.0  4391.9  1072.0  4392.0  1099.0
XS4394.1  1154.0  4399.2  1181.0  4400.2  1210.0  4398.7  1236.0  4398.2  1264.0
XS4395.9  1277.0  4403.9  1322.0  4407.9  1325.0  4416.6  1347.0  4418.1  1365.0
XS4419.0  1385.0  4426.7  1433.0  4427.6  1468.0  4429.4  1501.0  4432.5  1542.0
XS4436.4  1571.0  4438.5  1588.0
RH 0.080   0.024
*** Station #31
ST10470.      22       0       0       0       0     0.0
ND     1  1536.0
XS4450.3   766.0  4449.1   768.0  4446.4   773.0  4442.4   776.0  4433.2   790.0
XS4428.7   796.0  4424.5   811.0  4419.3   813.0  4417.1   819.0  4411.4   826.0
XS4393.3   895.0  4394.4   944.0  4390.4   998.0  4391.1  1046.0  4392.7  1094.0
XS4394.6  1203.0  4393.4  1250.0  4393.9  1334.0  4393.9  1353.0  4393.1  1414.0
XS4431.1  1498.0  4450.3  1536.0
RH 0.024
***
ST 5630.      41       0       0       0       0     0.0
ND     1  1508.0
XS4450.3   288.0  4446.5   294.0  4438.9   311.0  4430.2   335.0  4421.0   367.0
XS4412.7   395.0  4408.7   413.0  4407.9   414.0  4405.9   418.0  4397.1   458.0
XS4390.9   493.0  4390.2   518.0  4389.7   576.0  4389.7   634.0  4389.9   690.0
XS4390.0   746.0  4390.5   801.0  4390.8   855.0  4391.1   908.0  4391.1   934.0
XS4391.1   956.0  4394.1   961.0  4395.3  1003.0  4397.1  1011.0  4393.9  1013.0
XS4393.4  1065.0  4391.5  1116.0  4391.5  1138.0  4396.9  1148.0  4396.1  1167.0
XS4391.6  1217.0  4390.6  1267.0  4390.2  1316.0  4390.9  1354.0  4394.3  1365.0
XS4408.1  1438.0  4417.2  1453.0  4425.2  1453.0  4439.3  1485.0  4444.9  1504.0
XS4450.3  1508.0
RH 0.024
*** Station #33
ST 2709.      48       0       0       0       0     0.0
ND     1  2345.0
XS4450.3   853.0  4449.1   854.0  4442.4   861.0  4437.7   864.0  4434.2   871.0
XS4423.7   873.0  4417.0   880.0  4409.8   890.0  4408.0   893.0  4404.5   900.0
XS4389.3   915.0  4389.2   934.0  4389.5  1010.0  4391.8  1041.0  4393.5  1094.0
XS4387.4  1120.0  4386.6  1181.0  4386.8  1202.0  4391.5  1237.0  4391.7  1293.0
XS4390.4  1404.0  4389.0  1424.0  4389.2  1502.0  4390.8  1516.0  4398.0  1628.0
XS4403.6  1741.0  4405.0  1752.0  4405.2  1782.0  4400.5  1804.0  4401.0  1815.0
XS4408.5  1829.0  4409.5  1837.0  4410.1  1863.0  4407.5  1901.0  4409.8  1938.0
XS4408.4  1957.0  4409.3  2110.0  4411.9  2145.0  4417.1  2177.0  4422.4  2211.0
XS4428.3  2239.0  4434.5  2267.0  4438.3  2294.0  4440.6  2309.0  4440.9  2315.0
XS4441.3  2327.0  4449.3  2344.0  4450.3  2345.0
RH 0.024
***  Outlet
ST   0.0      46       1       1       0       0     0.0
ND     1  3289.0
XS4453.3  1890.0  4450.3  1920.0  4450.3  1920.0  4447.5  1925.0  4436.5  1932.0
XS4427.9  1951.0  4421.6  1969.0  4414.0  1986.0  4410.8  1992.0  4390.2  2084.0
XS4390.1  2110.0  4389.7  2157.0  4393.4  2347.0  4388.0  2373.0  4387.0  2396.0
XS4385.8  2446.0  4385.8  2472.0  4389.5  2494.0  4392.0  2496.0  4393.1  2504.0
XS4391.5  2547.0  4390.2  2599.0  4389.8  2622.0  4389.3  2651.0  4389.2  2705.0
XS4389.3  2759.0  4389.3  2814.0  4389.8  2871.0  4388.0  2877.0  4388.6  2928.0
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XS4389.4  2973.0  4388.7  2987.0  4388.7  3000.0  4386.9  3010.0  4386.9  3027.0
XS4389.1  3037.0  4389.1  3047.0  4388.0  3108.0  4387.4  3166.0  4403.3  3211.0
XS4408.0  3228.0  4409.0  3230.0  4431.3  3266.0  4441.5  3287.0  4449.9  3288.0
XS4450.3  3289.0
RH 0.024
***  Number of stream tubes
NT     3
***
IT  2460       5     1.0     DAY
***
***  Boundary conditions: table with stage and discharge
***
QQ      TABLE OF DISCHARGES
SS      STAGE DISCHARGE TABLE
TL    33
SQ 1190.  4408.2       1
SQ 1010.  4408.2       1
...
...
SQ  965.  4449.9       1
SQ  965.  4449.9       1
***
***  Sediment transport data ***************************************************
***
SE     6     0.0
***
***  Non-equilibrium transport parameters
***
N0 94900    0.25     1.0
N0 95000    0.01     1.0
N0124000    0.01     1.0
N0125000   0.001     1.0
***
***  Sediment rating curve
***
QR 0.890   1.411
***
***  Temperature records
***
TM    31    37.4   F
TM    29    48.2   F
...
...
TM    31    50.0   F
TM    29    50.9   F
***
***  Bed sorting information
***
SF     9    99.3
SG.00025    .004    41.0
SG  .004    .008    50.0
SG  .008    .016    50.0
SG  .016    .031    50.0
SG  .031    .062    50.0
SG  .062    .125    74.0
SG  .125    .250    74.0
SG  .250    .50     74.0
SG  .50    2.0      74.0
***
***  Bed gradation using interpolated values from known stations.
***
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***  Rangelines 59 and 24 have the same bed gradations
NB100814
BG.16800  .03635  .03635  .03468  .03635  .26545  .33341  .08469  .00472
***  Rangeline 20
NB111414
BG.21700  .04965  .04965  .04738  .04965  .24563  .26711  .06977  .00417
***  Rangeline 18
NB118694
BG.16300  .01734  .01734  .01655  .01734  .16472  .44834  .14730  .00806
***  Rangeline 17
NB124560
BG.05600  .01307  .01307  .01247  .01307  .17262  .53313  .17377  .01282
***  Rangeline 16
NB126460
BG.11700  .02756  .02756  .02629  .02756  .15085  .46832  .14821  .00665
***  Rangeline 14
NB133100
BG.15600  .03706  .03706  .03536  .03706  .21470  .36961  .10850  .00465
***  Rangeline 13
NB134151
BG.15100  .03587  .03587  .03423  .03587  .15747  .40906  .13405  .00658
***  Rangeline 10
NB145471
BG.12700  .02257  .02257  .02153  .02257  .25894  .39618  .12186  .00679
***
***  Cohesive sediment data
***
CS 0.021    0.10    2.40    0.63   0.250    0.10
***
***  Distribution of incoming sediment
***
IQ     9     20.    225.    425.    700.   1175.   2000.   3250.   4750.   8000.
IS  clay    .398    .176    .228    .149    .202    .209    .113    .213    .172
IS vfslt    .051    .093    .062    .041    .045    .049    .023    .038    .027
IS  fslt    .052    .093    .062    .042    .046    .050    .022    .040    .028
IS  mslt    .032     .08     .10    .089    .091    .140    .158    .134    .100
IS  cslt    .036     .08    .101    .094    .098    .142    .157    .137    .100
IS vfsnd    .136    .087    .179    .236    .206    .201    .306    .249    .334
IS  fsnd    .252    .344    .215    .291    .270    .191    .202    .174    .218
IS  msnd    .042    .043    .051    .057    .041    .018    .019    .015    .021
IS other    .001    .004    .002    .001    .001    .000    .000    .000    .000
***
***  Angle of repose
***
AR  40.0    40.0
***
***  Output options
***
PR     0    2460
PX  2460
PW  2460
END
```

4.2 Output Data Files

Due to the extent of the output data files generated by GSTARS 2.1 for example 4, only the main output file (.OUT file) and the debug file (.DBG file) are listed here. All other output files are included in the GSTARS 2.1 distribution under directory Example4.

4.2.1 Main Output File (.OUT)

```
              GGGGG     SSSSS   TTTTTTTT     A     RRRRRR     SSSSS
             GGGGGGG   SSSSSSS  TTTTTTTT    AAA    RRRRRRR   SSSSSSS
            GG     GG SS     SS    TT      AA AA   RR    RR SS     SS
            GG        SS           TT     AA   AA  RR    RR SS
            GG  GGGGG  SSSSSSS     TT    AA     AA RRRRRRR   SSSSSSS
            GG  GGGGG   SSSSSSS    TT    AAAAAAAAA RRRRRR     SSSSSSS
            GG     GG        SS    TT    AAAAAAAAA RR RR           SS
            GG     GG SS     SS    TT    AA     AA RR  RR   SS     SS
             GGGGGGG   SSSSSSS     TT    AA     AA RR   RR   SSSSSSS
              GGGGG     SSSSS      TT    AA     AA RR    RR   SSSSS


GSTARS Version 2.1 - Dec 2000                        U.S. Bureau of Reclamation
INPUT FILE:  RioGrande.dat                           Technical Service Center
DATE OF RUN: 17 Apr 2001                             Denver, Colorado
TIME OF RUN: 13:15:53



********************************************************************************
*  GSTARS version 2.1  -  Example data file for Appendix B of user's manual    *
*  Middle Rio Grande, 1980 survey data, rangelines 9 to 59                     *
*  Simulation of nonequilibrium and cohesive sediment transport                *
********************************************************************************


* * * * * * *   SUMMARY OF INPUT PARAMETERS   * * * * * * *

Number of cross sections:..........................    33
Number of stream tubes:............................     3
Number of time steps:..............................  2460
Number of sediment time steps (NITRQS):............     5
Duration of time step (days):......................  1.0000E+00
Formula selected for conveyance calculations:........  MANNING
Formula selected for friction slope:...............  average
Formula for sediment transport: .............  Yang (1973) with gravel (1984)
Non-equilibrium coefficient for scour:.............  1.0000E+00
Non-equilibrium coefficient for deposition:..........  1.0000E-03
NALT for active layer thickness:...................    14
Transport parameter CFACTOR:.......................  1.00
Angle of repose above the water surf. (deg):.........  40.0
Angle of repose below the water surf. (deg):.........  40.0
Silt/clay: threshold for deposition (lb/ft^2):.......  2.1000E-02
Silt/clay: threshold for particle erosion (lb/ft^2):.  1.0000E-01
Silt/clay: threshold for mass erosion (lb/ft^2):.....  2.4000E+00
Silt/clay: slope of erosion rate curve (1/h):........  6.3000E-01
Silt/clay: erosion rate ERSTME (lb/ft^2/h):..........  2.5000E-01
Silt/clay: ERLIM threshold (%):......................  10.0
Printout control is  0; print interval:.............  2460
Number of time steps to generate x-sec plots:........  2460
Number of time steps for thalweg plots:.............  2460
No minimization requested.

Sect.  Location   ISWITCH  ITYP   Thalweg     Bed slope   Loss  NDIVI NPOINTS
   #     (ft)                       (ft)                  Coef.
```

```
------------------------------------------------------------------------------
   1   1.4801E+05    0        0   4.4711E+03   3.4646E-03  0.00     3      50
   2   1.4547E+05    0        0   4.4623E+03   3.4646E-03  0.00     2      35
   3   1.3415E+05    0        0   4.4510E+03   9.9823E-04  0.00     3      47
   4   1.3310E+05    0        0   4.4502E+03   7.6118E-04  0.00     3      39
   5   1.2646E+05    0        0   4.4464E+03   5.7229E-04  0.00     3      44
   6   1.2456E+05    0        0   4.4443E+03   1.1053E-03  0.00     2      40
   7   1.1869E+05    0        0   4.4441E+03   3.4095E-05  0.00     3      29
   8   1.1141E+05    0        0   4.4401E+03   5.4945E-04  0.00     3      48
   9   1.0081E+05    0        0   4.4290E+03   1.0472E-03  0.00     2      89
  10   9.6977E+04    0        0   4.4312E+03  -5.7336E-04  0.00     3     102
  11   8.8577E+04    0        0   4.4266E+03   5.4762E-04  0.00     3     170
  12   8.3227E+04    0        0   4.4192E+03   1.3832E-03  0.00     2     196
  13   7.3142E+04    0        0   4.4139E+03   5.2553E-04  0.00     1     131
  14   6.9002E+04    0        0   4.4063E+03   1.8357E-03  0.00     1     110
  15   6.3722E+04    0        0   4.4076E+03  -2.4621E-04  0.00     1     130
  16   5.9883E+04    0        0   4.4053E+03   5.9911E-04  0.00     1     101
  17   5.7665E+04    0        0   4.4070E+03  -7.6646E-04  0.00     1      95
  18   5.4321E+04    0        0   4.4048E+03   6.5789E-04  0.00     1     108
  19   5.0167E+04    0        0   4.4006E+03   1.0111E-03  0.00     1     127
  20   4.7263E+04    0        0   4.3993E+03   4.4766E-04  0.00     1      93
  21   3.2521E+04    0        0   4.3903E+03   6.1050E-04  0.00     1      89
  22   3.0480E+04    0        0   4.3884E+03   9.3092E-04  0.00     1     111
  23   2.7647E+04    0        0   4.3877E+03   2.4709E-04  0.00     1     101
  24   2.5059E+04    0        0   4.3899E+03  -8.5008E-04  0.00     1      77
  25   2.3335E+04    0        0   4.3977E+03  -4.5244E-03  0.00     1      44
  26   2.0325E+04    0        0   4.3961E+03   5.3156E-04  0.00     1      89
  27   1.7611E+04    0        0   4.3930E+03   1.1422E-03  0.00     1      36
  28   1.5288E+04    0        0   4.3909E+03   9.0400E-04  0.00     1      49
  29   1.3070E+04    0        0   4.3919E+03  -4.5086E-04  0.00     2      62
  30   1.0470E+04    0        0   4.3904E+03   5.7692E-04  0.00     1      22
  31   5.6300E+03    0        0   4.3897E+03   1.4463E-04  0.00     1      41
  32   2.7090E+03    0        0   4.3866E+03   1.0613E-03  0.00     1      48
  33   0.0000E+00    1        1   4.3858E+03   2.9531E-04  0.00     1      46
------------------------------------------------------------------------------

Coefficients used in Exner equation and in
computing hydraulic properties for sediment capacity
-------------------------------------------------------------------------
      C1WP      C2WP      C3WP      C1WPU     C2WPU
     0.250     0.500     0.250     0.750     0.250
      C1Q       C2Q       C3Q        C1QD      C2QD      C1QU      C2QU
     0.000     1.000     0.000     0.000     1.000     1.000     0.000
-------------------------------------------------------------------------

Number of particle size classes:   9
                                 Geometric  Dry specific
Class      DRL          DRU         mean       weight
  #        (mm)         (mm)        (mm)      (lb/ft^3)
--------------------------------------------------------
  1   2.5000E-04   4.0000E-03   1.0000E-03   4.1000E+01
  2   4.0000E-03   8.0000E-03   5.6569E-03   5.0000E+01
  3   8.0000E-03   1.6000E-02   1.1314E-02   5.0000E+01
  4   1.6000E-02   3.1000E-02   2.2271E-02   5.0000E+01
  5   3.1000E-02   6.2000E-02   4.3841E-02   5.0000E+01
  6   6.2000E-02   1.2500E-01   8.8034E-02   7.4000E+01
  7   1.2500E-01   2.5000E-01   1.7678E-01   7.4000E+01
  8   2.5000E-01   5.0000E-01   3.5355E-01   7.4000E+01
  9   5.0000E-01   2.0000E+00   1.0000E+00   7.4000E+01
--------------------------------------------------------
```

Percentage of bed material for each size fraction and for each cross section

Section #	1	2	3	4	5	6	7	8	9
1	12.7	2.3	2.3	2.2	2.3	25.9	39.6	12.2	0.7
2	12.7	2.3	2.3	2.2	2.3	25.9	39.6	12.2	0.7
3	15.1	3.6	3.6	3.4	3.6	15.7	40.9	13.4	0.7
4	15.6	3.7	3.7	3.5	3.7	21.5	37.0	10.8	0.5
5	11.7	2.8	2.8	2.6	2.8	15.1	46.8	14.8	0.7
6	5.6	1.3	1.3	1.2	1.3	17.3	53.3	17.4	1.3
7	16.3	1.7	1.7	1.7	1.7	16.5	44.8	14.7	0.8
8	21.7	5.0	5.0	4.7	5.0	24.6	26.7	7.0	0.4
9	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
10	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
11	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
12	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
13	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
14	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
15	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
16	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
17	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
18	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
19	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
20	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
21	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
22	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
23	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
24	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
25	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
26	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
27	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
28	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
29	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
30	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
31	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
32	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5
33	16.8	3.6	3.6	3.5	3.6	26.5	33.3	8.5	0.5

(Column header: Bed material size fraction for each group)

Nonequilibrium recovery factors for each cross section

Station #	Location	Deposition	Scour
1	1.4801E+05	1.0000E-03	1.0000E+00
2	1.4547E+05	1.0000E-03	1.0000E+00
3	1.3415E+05	1.0000E-03	1.0000E+00
4	1.3310E+05	1.0000E-03	1.0000E+00
5	1.2646E+05	1.0000E-03	1.0000E+00
6	1.2456E+05	4.9600E-03	1.0000E+00
7	1.1869E+05	1.0000E-02	1.0000E+00
8	1.1141E+05	1.0000E-02	1.0000E+00
9	1.0081E+05	1.0000E-02	1.0000E+00
10	9.6977E+04	1.0000E-02	1.0000E+00
11	8.8577E+04	2.5000E-01	1.0000E+00
12	8.3227E+04	2.5000E-01	1.0000E+00
13	7.3142E+04	2.5000E-01	1.0000E+00
14	6.9002E+04	2.5000E-01	1.0000E+00
15	6.3722E+04	2.5000E-01	1.0000E+00
16	5.9883E+04	2.5000E-01	1.0000E+00
17	5.7665E+04	2.5000E-01	1.0000E+00
18	5.4321E+04	2.5000E-01	1.0000E+00
19	5.0167E+04	2.5000E-01	1.0000E+00

20	4.7263E+04	2.5000E-01	1.0000E+00
21	3.2521E+04	2.5000E-01	1.0000E+00
22	3.0480E+04	2.5000E-01	1.0000E+00
23	2.7647E+04	2.5000E-01	1.0000E+00
24	2.5059E+04	2.5000E-01	1.0000E+00
25	2.3335E+04	2.5000E-01	1.0000E+00
26	2.0325E+04	2.5000E-01	1.0000E+00
27	1.7611E+04	2.5000E-01	1.0000E+00
28	1.5288E+04	2.5000E-01	1.0000E+00
29	1.3070E+04	2.5000E-01	1.0000E+00
30	1.0470E+04	2.5000E-01	1.0000E+00
31	5.6300E+03	2.5000E-01	1.0000E+00
32	2.7090E+03	2.5000E-01	1.0000E+00
33	0.0000E+00	2.5000E-01	1.0000E+00

```
********************************************************************************
********************************************************************************
    TIME STEP NO.  2460 AFTER  2.4600E+03 DAYS; DISCHARGE IS  9.6500E+02 CFS
********************************************************************************
********************************************************************************
```

```
*********************************************
*     RESULTS OF BACKWATER COMPUTATIONS     *
*       DISCHARGE =  9.6500E+02 C.F.S.      *
*********************************************
```

STA. #	STATION (ft)	WATER SURFACE ELEVATION(ft)	FLOW AREA (ft^2)	FLOW VELCTY (ft/s)	ENERGY GRADE LINE ELEV(ft)	FROUDE NUMBER
1	1.4801E+05	4.48587E+03	4.68472E+03	2.05989E-01	4.48587E+03	4.70957E-02
2	1.4547E+05	4.48369E+03	6.76115E+02	1.42727E+00	4.48373E+03	1.86059E-01
3	1.3415E+05	4.47292E+03	4.20319E+02	2.29587E+00	4.47303E+03	2.25791E-01
4	1.3310E+05	4.47207E+03	3.66333E+02	2.63422E+00	4.47247E+03	5.91173E-01
5	1.2646E+05	4.46828E+03	3.24999E+02	2.96924E+00	4.46849E+03	3.60575E-01
6	1.2456E+05	4.46705E+03	2.52171E+02	3.82677E+00	4.46735E+03	4.14504E-01
7	1.1869E+05	4.46298E+03	2.16807E+02	4.45097E+00	4.46337E+03	3.93042E-01
8	1.1141E+05	4.45875E+03	2.20162E+02	4.38314E+00	4.45911E+03	3.66059E-01
9	1.0081E+05	4.45342E+03	4.79162E+02	2.01393E+00	4.45357E+03	7.45406E-01
10	9.6977E+04	4.45250E+03	3.83207E+03	2.51822E-01	4.45250E+03	4.82760E-02
11	8.8577E+04	4.45210E+03	4.29720E+04	2.24565E-02	4.45210E+03	2.48957E-03
12	8.3227E+04	4.45200E+03	1.77855E+05	5.42576E-03	4.45200E+03	2.82781E-04
13	7.3142E+04	4.45190E+03	1.24790E+05	7.73296E-03	4.45190E+03	2.78544E-04
14	6.9002E+04	4.45180E+03	1.12910E+05	8.54665E-03	4.45180E+03	2.90820E-04
15	6.3722E+04	4.45170E+03	1.33552E+05	7.22567E-03	4.45170E+03	2.33904E-04
16	5.9883E+04	4.45160E+03	1.85511E+05	5.20186E-03	4.45160E+03	1.61869E-04
17	5.7665E+04	4.45150E+03	1.18639E+05	8.13392E-03	4.45150E+03	2.51478E-04
18	5.4321E+04	4.45140E+03	1.48251E+05	6.50924E-03	4.45140E+03	2.26441E-04
19	5.0167E+04	4.45130E+03	2.62121E+05	3.68150E-03	4.45130E+03	1.15437E-04
20	4.7263E+04	4.45120E+03	2.56348E+05	3.76442E-03	4.45120E+03	1.11352E-04
21	3.2521E+04	4.45110E+03	2.98790E+05	3.22969E-03	4.45110E+03	8.25031E-05
22	3.0480E+04	4.45100E+03	3.78025E+05	2.55274E-03	4.45100E+03	6.21451E-05
23	2.7647E+04	4.45090E+03	3.21128E+05	3.00503E-03	4.45090E+03	7.86793E-05
24	2.5059E+04	4.45080E+03	2.06609E+05	4.67066E-03	4.45080E+03	1.24726E-04
25	2.3335E+04	4.45070E+03	6.33029E+04	1.52442E-02	4.45070E+03	4.34404E-04
26	2.0325E+04	4.45060E+03	1.53585E+05	6.28317E-03	4.45060E+03	1.70562E-04
27	1.7611E+04	4.45050E+03	5.75035E+04	1.67816E-02	4.45050E+03	4.57557E-04
28	1.5288E+04	4.45040E+03	5.47095E+04	1.76386E-02	4.45040E+03	5.20625E-04

29	1.3070E+04	4.45030E+03	5.58681E+04	1.72728E-02	4.45030E+03	6.56810E-04
30	1.0470E+04	4.45020E+03	3.76289E+04	2.56452E-02	4.45020E+03	6.65019E-04
31	5.6300E+03	4.45010E+03	6.30226E+04	1.53120E-02	4.45010E+03	3.84171E-04
32	2.7090E+03	4.45000E+03	7.09447E+04	1.36021E-02	4.45000E+03	3.60155E-04
33	0.0000E+00	4.44990E+03	7.61147E+04	1.26782E-02	4.44990E+03	2.14368E-01

```
**************************************************************
*       SEDIMENT ROUTING RESULTS FOR TIME STEP    2460       *
**************************************************************
```

INCOMING SEDIMENT DISTRIBUTION PER SIZE FRACTION

SIZE FRACTION	PERCENT	QSED (TON/DAY)
1	17.86	2.5844E+03
2	4.32	6.2569E+02
3	4.42	6.4016E+02
4	9.01	1.3042E+03
5	9.62	1.3928E+03
6	21.93	3.1734E+03
7	27.93	4.0421E+03
8	4.81	6.9577E+02
9	0.10	1.4473E+01
TOTAL		1.4473E+04

```
***************************************************************
*                    STREAM TUBE NO.   1                      *
***************************************************************
```

STA	DISTANCE	TOTAL LOAD (TONS)	(FT**3)	CHANGE (FT)	DIRECTION
1	1.4801E+05	9.5602E+02	1.1558E+04	0.001	VERTICAL
2	1.4547E+05	8.6393E+02	1.0445E+04	0.002	VERTICAL
3	1.3415E+05	8.3837E+02	1.0136E+04	0.001	VERTICAL
4	1.3310E+05	8.3635E+02	1.0111E+04	0.000	VERTICAL
5	1.2646E+05	8.3133E+02	1.0050E+04	0.001	VERTICAL
6	1.2456E+05	8.2088E+02	9.9241E+03	0.003	VERTICAL
7	1.1869E+05	8.0282E+02	9.7058E+03	0.004	VERTICAL
8	1.1141E+05	7.7496E+02	9.3690E+03	0.001	VERTICAL
9	1.0081E+05	6.0611E+02	7.3277E+03	0.001	VERTICAL
10	9.6977E+04	4.3357E+02	5.2417E+03	0.001	VERTICAL
11	8.8577E+04	1.9697E+02	2.3813E+03	0.001	VERTICAL
12	8.3227E+04	1.7718E+02	2.1421E+03	0.000	VERTICAL
13	7.3142E+04	1.7359E+02	2.0987E+03	0.000	VERTICAL
14	6.9002E+04	1.7266E+02	2.0874E+03	0.000	VERTICAL
15	6.3722E+04	1.7204E+02	2.0799E+03	0.000	VERTICAL
16	5.9883E+04	1.7161E+02	2.0747E+03	0.000	VERTICAL
17	5.7665E+04	1.7143E+02	2.0725E+03	0.000	VERTICAL
18	5.4321E+04	1.7120E+02	2.0698E+03	0.000	VERTICAL
19	5.0167E+04	1.7082E+02	2.0651E+03	0.000	VERTICAL
20	4.7263E+04	1.6993E+02	2.0544E+03	0.000	VERTICAL
21	3.2521E+04	1.6909E+02	2.0443E+03	0.000	VERTICAL
22	3.0480E+04	1.6890E+02	2.0420E+03	0.000	VERTICAL
23	2.7647E+04	1.6876E+02	2.0402E+03	0.000	VERTICAL
24	2.5059E+04	1.6870E+02	2.0395E+03	0.000	VERTICAL
25	2.3335E+04	1.6869E+02	2.0394E+03	0.000	VERTICAL
26	2.0325E+04	1.6866E+02	2.0391E+03	0.000	VERTICAL
27	1.7611E+04	1.6865E+02	2.0390E+03	0.000	VERTICAL
28	1.5288E+04	1.6865E+02	2.0389E+03	0.000	VERTICAL

```
 29   1.3070E+04   1.6864E+02   2.0388E+03     0.000   VERTICAL
 30   1.0470E+04   1.6864E+02   2.0387E+03     0.000   VERTICAL
 31   5.6300E+03   1.6863E+02   2.0387E+03     0.000   VERTICAL
 32   2.7090E+03   1.6863E+02   2.0386E+03     0.000   VERTICAL
 33   0.0000E+00   1.6862E+02   2.0386E+03     0.000   VERTICAL


*************************************************************
*                    STREAM TUBE NO.   2                    *
*************************************************************
 STA  DISTANCE          TOTAL LOAD          CHANGE   DIRECTION
                     (TONS)      (FT**3)       (FT)
*************************************************************
  1   1.4801E+05   9.6125E+02   1.1621E+04     0.001   VERTICAL
  2   1.4547E+05   9.3946E+02   1.1358E+04     0.002   VERTICAL
  3   1.3415E+05   9.3571E+02   1.1312E+04     0.001   VERTICAL
  4   1.3310E+05   9.3743E+02   1.1333E+04    -0.002   VERTICAL
  5   1.2646E+05   9.3617E+02   1.1318E+04     0.001   VERTICAL
  6   1.2456E+05   9.4233E+02   1.1392E+04    -0.006   VERTICAL
  7   1.1869E+05   9.3260E+02   1.1275E+04     0.006   VERTICAL
  8   1.1141E+05   9.2263E+02   1.1154E+04     0.004   VERTICAL
  9   1.0081E+05   8.8492E+02   1.0698E+04     0.006   VERTICAL
 10   9.6977E+04   7.5273E+02   9.1002E+03     0.000   VERTICAL
 11   8.8577E+04   1.9816E+02   2.3957E+03     0.001   VERTICAL
 12   8.3227E+04   1.7607E+02   2.1286E+03     0.000   VERTICAL
 13   7.3142E+04   1.7282E+02   2.0894E+03     0.000   VERTICAL
 14   6.9002E+04   1.7191E+02   2.0784E+03     0.000   VERTICAL
 15   6.3722E+04   1.7134E+02   2.0714E+03     0.000   VERTICAL
 16   5.9883E+04   1.7092E+02   2.0663E+03     0.000   VERTICAL
 17   5.7665E+04   1.7075E+02   2.0643E+03     0.000   VERTICAL
 18   5.4321E+04   1.7053E+02   2.0617E+03     0.000   VERTICAL
 19   5.0167E+04   1.7015E+02   2.0571E+03     0.000   VERTICAL
 20   4.7263E+04   1.6931E+02   2.0469E+03     0.000   VERTICAL
 21   3.2521E+04   1.6869E+02   2.0394E+03     0.000   VERTICAL
 22   3.0480E+04   1.6856E+02   2.0378E+03     0.000   VERTICAL
 23   2.7647E+04   1.6850E+02   2.0371E+03     0.000   VERTICAL
 24   2.5059E+04   1.6847E+02   2.0367E+03     0.000   VERTICAL
 25   2.3335E+04   1.6846E+02   2.0366E+03     0.000   VERTICAL
 26   2.0325E+04   1.6844E+02   2.0364E+03     0.000   VERTICAL
 27   1.7611E+04   1.6844E+02   2.0364E+03     0.000   VERTICAL
 28   1.5288E+04   1.6844E+02   2.0363E+03     0.000   VERTICAL
 29   1.3070E+04   1.6844E+02   2.0363E+03     0.000   VERTICAL
 30   1.0470E+04   1.6843E+02   2.0363E+03     0.000   VERTICAL
 31   5.6300E+03   1.6843E+02   2.0362E+03     0.000   VERTICAL
 32   2.7090E+03   1.6843E+02   2.0362E+03     0.000   VERTICAL
 33   0.0000E+00   1.6842E+02   2.0361E+03     0.000   VERTICAL


*************************************************************
*                    STREAM TUBE NO.   3                    *
*************************************************************
 STA  DISTANCE          TOTAL LOAD          CHANGE   DIRECTION
                     (TONS)      (FT**3)       (FT)
*************************************************************
  1   1.4801E+05   8.9060E+02   1.0767E+04     0.001   VERTICAL
  2   1.4547E+05   8.9677E+02   1.0842E+04     0.000   VERTICAL
  3   1.3415E+05   8.8890E+02   1.0746E+04     0.001   VERTICAL
  4   1.3310E+05   8.5864E+02   1.0381E+04     0.002   VERTICAL
  5   1.2646E+05   8.4705E+02   1.0240E+04     0.001   VERTICAL
  6   1.2456E+05   8.1572E+02   9.8617E+03     0.005   VERTICAL
  7   1.1869E+05   7.8739E+02   9.5193E+03     0.004   VERTICAL
```

8	1.1141E+05	7.6492E+02	9.2476E+03	0.000	VERTICAL
9	1.0081E+05	5.5064E+02	6.6570E+03	0.002	VERTICAL
10	9.6977E+04	5.2379E+02	6.3324E+03	0.000	VERTICAL
11	8.8577E+04	2.1705E+02	2.6240E+03	0.001	VERTICAL
12	8.3227E+04	1.7235E+02	2.0836E+03	0.000	VERTICAL
13	7.3142E+04	1.7061E+02	2.0625E+03	0.000	VERTICAL
14	6.9002E+04	1.7013E+02	2.0567E+03	0.000	VERTICAL
15	6.3722E+04	1.6973E+02	2.0520E+03	0.000	VERTICAL
16	5.9883E+04	1.6948E+02	2.0489E+03	0.000	VERTICAL
17	5.7665E+04	1.6938E+02	2.0478E+03	0.000	VERTICAL
18	5.4321E+04	1.6905E+02	2.0438E+03	0.000	VERTICAL
19	5.0167E+04	1.6858E+02	2.0381E+03	0.000	VERTICAL
20	4.7263E+04	1.6742E+02	2.0241E+03	0.000	VERTICAL
21	3.2521E+04	1.6661E+02	2.0142E+03	0.000	VERTICAL
22	3.0480E+04	1.6648E+02	2.0126E+03	0.000	VERTICAL
23	2.7647E+04	1.6641E+02	2.0118E+03	0.000	VERTICAL
24	2.5059E+04	1.6639E+02	2.0115E+03	0.000	VERTICAL
25	2.3335E+04	1.6638E+02	2.0115E+03	0.000	VERTICAL
26	2.0325E+04	1.6636E+02	2.0112E+03	0.000	VERTICAL
27	1.7611E+04	1.6636E+02	2.0112E+03	0.000	VERTICAL
28	1.5288E+04	1.6635E+02	2.0112E+03	0.000	VERTICAL
29	1.3070E+04	1.6635E+02	2.0111E+03	0.000	VERTICAL
30	1.0470E+04	1.6635E+02	2.0111E+03	0.000	VERTICAL
31	5.6300E+03	1.6634E+02	2.0110E+03	0.000	VERTICAL
32	2.7090E+03	1.6633E+02	2.0109E+03	0.000	VERTICAL
33	0.0000E+00	1.6633E+02	2.0109E+03	0.000	VERTICAL

```
************************************************
*** ACCUMMULATED DEPOSITION FOR WHOLE STREAM ***
************************************************
```

STA NO.	ACCU.DEPS. (TONS)	ACCU DEPS. (FT^3)	ACCU. DEPS. FOR DIFFRNT SIZE GROUPS (FT^3) 1	2	3	4
1	3.1000E+05	8.4985E+06	-2.9269E+03	-1.4734E+02	3.0722E+03	6.5682E+04
2	5.2101E+06	1.4521E+08	7.6166E+04	1.0006E+06	1.8740E+06	4.9252E+06
3	3.6084E+06	9.8794E+07	9.9582E+03	2.9554E+04	5.9520E+04	6.8416E+05
4	1.7994E+06	5.1624E+07	4.3658E+03	6.2662E+04	3.3582E+05	3.6385E+06
5	1.3708E+06	3.7379E+07	1.8985E+04	7.3263E+04	1.2216E+05	6.2943E+05
6	2.0143E+06	5.5032E+07	-2.6868E+03	1.7617E+04	9.9494E+04	5.3873E+05
7	2.4481E+06	6.5260E+07	1.0451E+04	3.9978E+04	7.4083E+04	4.8593E+05
8	3.6209E+06	9.8266E+07	5.4673E+04	1.0132E+05	1.8251E+05	7.1001E+05
9	9.7474E+06	2.7019E+08	2.5949E+05	4.6785E+05	8.1218E+05	4.5410E+06
10	1.0291E+07	2.9533E+08	1.9216E+04	3.1534E+05	1.1374E+06	1.2085E+07
11	1.4551E+07	5.4355E+08	7.8562E+05	1.8494E+07	4.3361E+07	2.0142E+08
12	3.0485E+06	1.1457E+08	1.3340E+06	2.0728E+07	1.9114E+07	3.7270E+07
13	3.9103E+06	1.3832E+08	4.3102E+05	6.1456E+06	7.0592E+06	3.7535E+07
14	1.0532E+06	4.0090E+07	1.9960E+05	2.8202E+06	4.2469E+06	1.5794E+07
15	1.5886E+06	5.7546E+07	2.0513E+05	2.5865E+06	4.0641E+06	1.6931E+07
16	1.3672E+06	5.1603E+07	1.5281E+05	2.1622E+06	3.6094E+06	1.7294E+07
17	4.6403E+05	1.7259E+07	7.3276E+04	8.7171E+05	1.3830E+06	5.7945E+06
18	3.1742E+05	1.1866E+07	8.9689E+04	1.2208E+06	1.3529E+06	4.3798E+06
19	1.6733E+06	6.2867E+07	2.1198E+05	2.9545E+06	4.9142E+06	2.1964E+07
20	2.6557E+06	1.0329E+08	8.3364E+05	9.8521E+06	1.4470E+07	4.1362E+07
21	1.2939E+06	5.1477E+07	8.7491E+05	1.1378E+07	1.2972E+07	1.8260E+07
22	1.7147E+05	6.8405E+06	2.1842E+05	2.9119E+06	2.3616E+06	1.1897E+06
23	7.3044E+04	2.8726E+06	1.1284E+05	1.5552E+06	1.0333E+06	1.7105E+05
24	2.8272E+04	1.1059E+06	4.8915E+04	6.7300E+05	3.6199E+05	2.1981E+04
25	-4.5038E+03	-2.1559E+05	8.1162E+03	7.7252E+04	1.3711E+04	-1.3274E+04

26	1.1872E+04	4.3753E+05	2.4888E+04	2.4959E+05	1.1219E+05	3.0987E+03
27	6.9966E+03	2.4300E+05	7.2287E+03	1.0173E+05	6.1431E+04	7.5040E+03
28	3.5659E+03	1.1678E+05	2.8237E+03	3.6493E+04	2.1653E+04	3.2651E+03
29	1.5403E+03	5.5541E+04	3.5465E+03	3.9618E+04	1.7577E+04	2.4701E+03
30	3.4045E+03	1.1522E+05	3.0140E+03	4.3461E+04	2.8559E+04	3.7588E+03
31	6.7258E+03	2.4939E+05	7.2784E+03	1.1953E+05	8.8299E+04	1.0229E+04
32	5.1621E+03	1.9353E+05	7.1712E+03	1.0597E+05	7.3558E+04	5.9595E+03
33	4.6923E+03	1.7668E+05	6.0479E+03	9.6960E+04	6.6417E+04	4.7345E+03
SUM	7.2656E+07	2.3302E+09	6.0896E+06	8.7332E+07	1.2549E+08	4.4772E+08

ACCUMULATED DEPOSITION FOR DIFFERENT SIZE GROUPS (CONT.)

STA	5	6	7	8	9
1	2.5721E+05	2.0244E+06	4.8904E+06	1.2374E+06	2.3419E+04
2	3.1501E+06	3.8277E+07	7.9583E+07	1.6136E+07	1.8978E+05
3	2.2485E+06	3.2602E+07	5.4984E+07	8.1222E+06	5.3695E+04
4	4.0348E+06	1.4816E+07	2.4924E+07	3.7708E+06	3.6999E+04
5	8.2523E+05	1.2988E+07	2.0003E+07	2.6968E+06	2.2485E+04
6	1.1040E+06	2.4438E+07	2.6435E+07	2.3938E+06	7.2738E+03
7	1.2826E+06	3.2215E+07	2.8879E+07	2.2623E+06	1.0607E+04
8	1.1913E+06	4.4834E+07	4.7077E+07	4.0873E+06	2.8234E+04
9	1.2091E+07	1.4920E+08	9.5181E+07	7.5888E+06	5.1954E+04
10	2.9898E+07	1.6175E+08	8.5800E+07	4.3121E+06	1.5870E+04
11	1.9156E+08	7.2577E+07	1.5124E+07	2.4330E+05	-8.3681E+03
12	2.2018E+07	9.1018E+06	4.6553E+06	3.5452E+05	-2.8450E+02
13	4.5832E+07	2.8073E+07	1.2466E+07	7.6582E+05	9.0287E+03
14	1.3629E+07	2.5349E+06	7.8704E+05	7.8523E+04	2.3420E+02
15	2.0217E+07	1.0206E+07	3.1875E+06	1.4689E+05	2.3419E+03
16	2.1548E+07	5.5399E+06	1.2522E+06	4.3984E+04	6.4167E+02
17	5.6360E+06	2.5624E+06	9.0627E+05	3.1480E+04	1.2738E+02
18	4.1461E+06	7.9731E+05	-5.1310E+04	-6.4860E+04	-3.9618E+03
19	2.3201E+07	7.5677E+06	1.9423E+06	1.0776E+05	3.4890E+03
20	2.8940E+07	6.6680E+06	1.0970E+06	6.2198E+04	2.0778E+03
21	7.3344E+06	6.1766E+05	3.8463E+04	8.5509E+02	8.8992E+00
22	1.5638E+05	2.4424E+03	5.1159E+01	4.9709E-01	2.5725E-03
23	2.2082E+02	-1.8039E-07	-3.5775E-06	-2.2055E-05	-1.4598E-03
24	1.5096E+00	-6.5503E-03	-1.0138E-01	-5.5876E+00	-6.5326E-02
25	-1.4749E+04	-1.1002E+05	-1.3943E+05	-3.5231E+04	-1.9537E+03
26	2.8489E+03	4.9661E+03	2.1135E+04	1.7535E+04	1.2772E+03
27	3.0383E+03	2.7044E+04	2.9818E+04	5.1127E+03	8.8099E+01
28	5.9966E+02	1.5862E+04	3.3993E+04	2.0496E+03	3.9459E+01
29	3.4234E+02	-3.3144E+03	-2.9450E+03	-1.6541E+03	-9.9383E+01
30	8.2652E+02	2.5982E+04	8.1369E+03	1.3856E+03	9.9865E+01
31	2.1093E+03	1.1495E+04	9.2435E+03	1.1997E+03	5.2870E+00
32	6.6499E+02	1.2349E+03	-1.0348E+03	1.0445E+01	-7.3716E-01
33	4.9565E+02	7.1855E+02	1.3426E+03	-3.4226E+01	8.0924E-01
SUM	4.4029E+08	6.5936E+08	5.0912E+08	5.4368E+07	4.4511E+05

ACCUMULATED SEDIMENT DISTRIBUTION THAT EXITED THE REACH (TONS)

SIZE FR	TOTAL	TUBE #1	TUBE #2	TUBE #3	TUBE #
1	1.5871E+07	5.2968E+06	5.2949E+06	5.2795E+06	
2	1.0593E+06	3.2887E+05	4.0121E+05	3.2917E+05	
3	9.8610E+04	1.8246E+04	4.4196E+04	3.6168E+04	
4	7.0868E+02	6.3789E+01	2.1262E+02	4.3228E+02	
5	9.3735E+00	1.1775E+00	6.4185E+00	1.7774E+00	
6	1.5387E+00	7.6651E-01	1.3720E-01	6.3497E-01	
7	1.1925E+01	1.0330E+01	1.2058E+00	3.8989E-01	
8	1.7294E+00	4.7586E-01	6.0077E-01	6.5278E-01	

```
   9    4.6213E-03    1.0329E-03  2.4792E-03  1.1092E-03
 TOTAL  1.7030E+07    5.6440E+06  5.7405E+06  5.6453E+06
--------------------------------------------------------------------------------


* * * * * *  GSTARS run completed successfully  * * * * * *
```

4.2.2 Debug File (.DBG)

```
GSTARS Version 2.1 - Dec 2000                        U.S. Bureau of Reclamation
INPUT FILE:  RioGrande.dat                           Technical Service Center
DATE OF RUN: 17 Apr 2001                             Denver, Colorado
RUN STARTED: 13:15:53:00

               ************ Limits for this version ************
               Maximum number of cross sections:............101
               Maximum number of points per cross section:...197
               Maximum number of particle size fractions:.... 10
               Maximum number of stream tubes:................ 5
               *************************************************



********************************************************************************
***                                                                          ***
***  NOTE: this is a simplified version of the datafile used to simulate     ***
***  the Rio Grande floodway between San Marcial and the upper reach of the  ***
***  Elephant Butte Reservoir (to The Narrows).  It may not contain an       ***
***  accurate representation of the actual flow and geological conditions    ***
***  at the site.  This data file should be viewed only as an example of     ***
***  input data as it might be used in a GSTARS version 2.1 simulation.      ***
***  This file was constructed for didactic purposes only.                   ***
***                                                                          ***
********************************************************************************
***
********************************************************************************
*  GSTARS version 2.1  -  Example data file for Appendix B of user's manual    *
*  Middle Rio Grande, 1980 survey data, rangelines 9 to 59                     *
*  Simulation of nonequilibrium and cohesive sediment transport                *
********************************************************************************
  Cross section coordinate order is Y-X
*** Station #2
*** Station #3
***
*** Station #5
***
*** Station #7
***
*** Station #9
***
*** Station #11
***
*** Station #13
***
*** Station #15
***
*** Station #17
***
*** Station #19
***
*** Station #21
```

```
***
*** Station #23
***
*** Station #25
***
*** Station #27
***
*** Station #29
***
*** Station #31
***
*** Station #33
***  Outlet
***  Number of stream tubes
***
***
***  Boundary conditions: table with stage and discharge
***
***
***  Sediment transport data **************************************************
***
***
***  Non-equilibrium transport parameters
***
***
***  Sediment rating curve
***
***
***  Temperature records
***
***
***  Bed sorting information
***
***
***  Bed gradation using interpolated values from known stations.
***
***  Rangelines 59 and 24 have the same bed gradations
***  Rangeline 20
***  Rangeline 18
***  Rangeline 17
***  Rangeline 16
***  Rangeline 14
***  Rangeline 13
***  Rangeline 10
***
***  Cohesive sediment data
***
***
***  Distribution of incoming sediment
***
***
***  Angle of repose
***
***
***  Output options
***

********************************************************************************
********************************************************************************
    TIME STEP NO.  2460 AFTER  2.4600E+03 DAYS; DISCHARGE IS  9.6500E+02 CFS
********************************************************************************
```

```
********************************************************************************

RUN ENDED: 13:25:28:81
```

4.3 Final Remarks

In this section we present a brief discussion of the simulation results. The data used to set-up the input data files was based on a survey of 1980. Since we also have access to survey data of 1988, corresponding to the end of the span of the GSTARS 2.1 simulation in this example, that data is used for comparison purposes. Note that this example does not constitute a detailed sedimentation study of the region. It is included here for didactic purposes only. A more detailed analysis was presented in Yang et al. (1998).

The results of the simulation are shown in figures 4.6 and 4.7 for two random but representative cross sections. Figure 4.8 shows the thalweg for the run. The match between computations and measurements for the 8 year period is approximate, and the thalweg plot indicates that the match is better at the upstream sections. There is a bias towards underpredicting the sedimentation effects at the downstream reach. This may not be important because most of the sedimentation effects take place at the upstream reaches, i.e., at the delta. A better match of the deposition pattern in the lower reach could perhaps be obtained by a more careful calibration of the model.

Figure 4.6 Computed and measured cross sections at rangeline 17, which is located at a distance of approximately 124,560 ft from the downstream boundary.

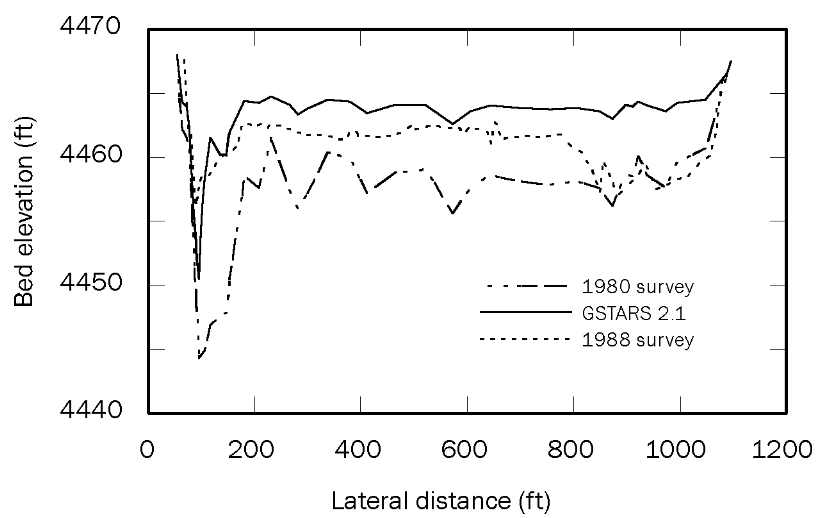


Figure 4.7 Computed and measured cross sections at rangeline 24, which is located at a distance of approximately 100,810 ft from the downstream boundary.

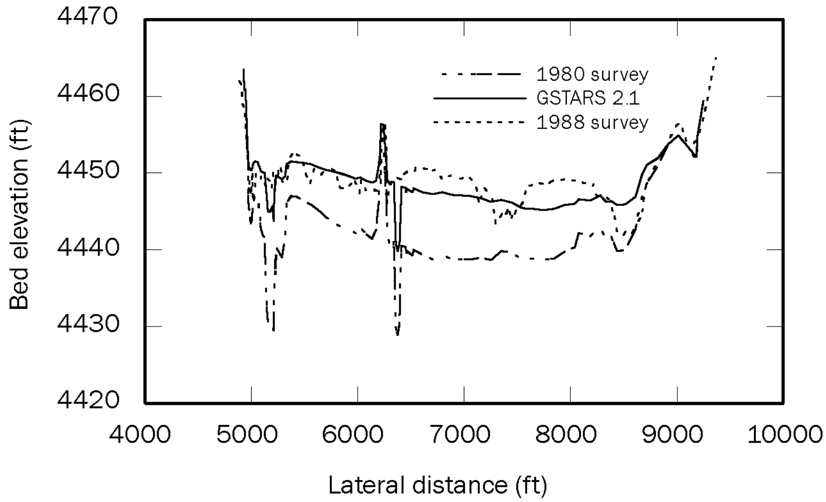
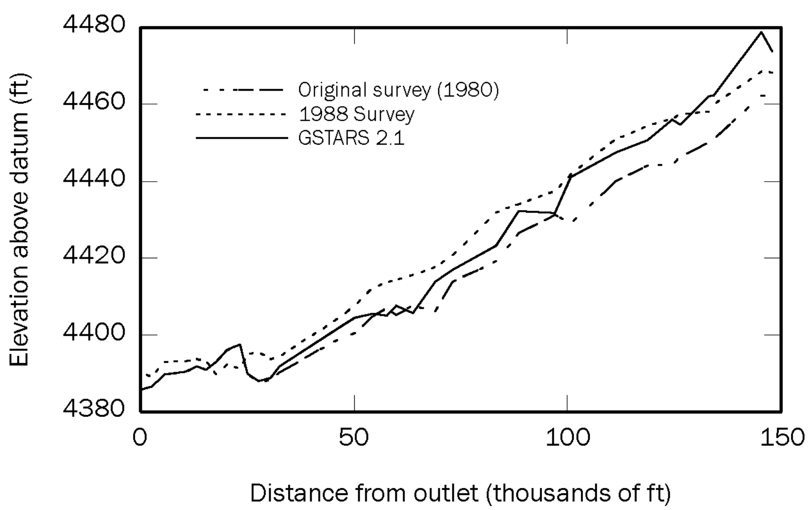


Figure 4.8 Thalweg elevations for the simulated reach.



4.4 References

Yang, C.T., Treviño, M.A., and Simões, F.J.M. (1998). *User's manual for GSTARS 2.0 (Generalized Stream Tube model for Alluvial River Simulation version 2.0)*. U.S. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

APPENDIX C

Reprint of the paper by A. Molinas and C. T. Yang, "Generalized water surface profile computation," ASCE Journal of Hydraulic Engineering, Vol. 111, No. 3, March 1985, pages 381–387.

Generalized Water Surface Profile Computations

By Albert Molinas,[1] A. M. ASCE and Chih Ted Yang,[2] M. ASCE

Abstract: A computer model based on both the energy and momentum equations is developed. This generalized model can be used for the computation of water surface profiles through hydraulic jumps. It also allows computation of water surface profiles regardless of whether the bed slope is steep, mild, horizontal, adverse or a combination of these. The control section can be a lake, weir, gate or a natural river section. The Manning, Chezy or Darcy-Weisbach equations can be used for head loss computation. A detailed description of methods used and a step-by-step computation procedure is given. Examples are used to demonstrate the applications of this generalized model for water surface profile computations.

Introduction

Most of the computer programs for water surface profile computations are based on the application of energy equations for gradually varied open-channel flows. These types of programs cannot be directly applied to open-channel flows with hydraulic jumps. The most commonly used model of this type is the HEC-2 Water Surface Profiles Computer Program developed by the U.S. Army Corps of Engineers (3). The generalized computer program introduced in this paper employs both the energy and momentum equations so the computation of water surface profile can go through hydraulic jumps without interruption. This capability allows computation of water surface profiles through a study reach, regardless of whether the bed slope is steep, mild, horizontal, adverse or a combination of these. The control section can be a lake, weir, gate or a natural river section. This paper provides a step-by-step description of the methods and procedures used in the generalized water surface profile computation program. Examples of computations are used to demonstrate the capability of the generalized program.

Basic Equations

The basic equation used in most of the water surface profile computations is the energy equation (1):

$$z_1 + y_1 + \alpha_1 \frac{V_1^2}{2g} = z_2 + y_2 + \alpha_2 \frac{V^2}{2g} + h_t \qquad (1)$$

in which z = bed elevation; y = water depth; V = velocity; α = velocity distribution coefficient; h_t = total energy loss between sections 1 and 2;

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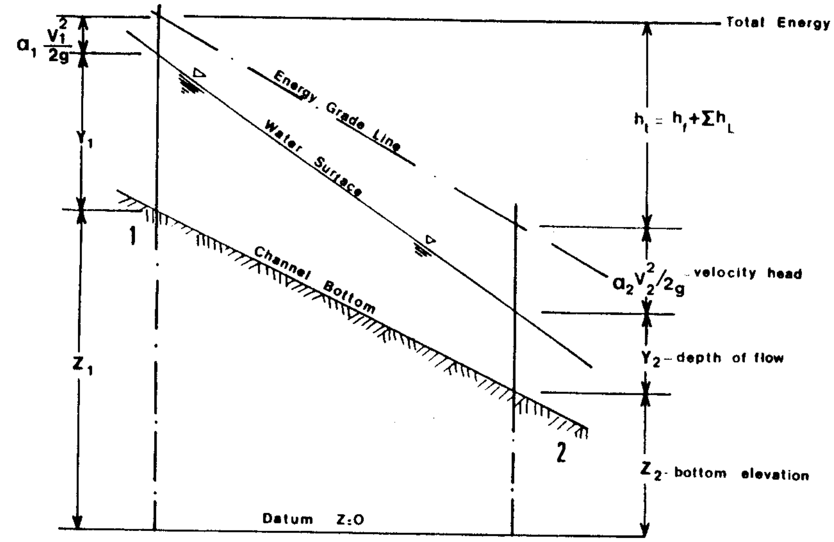

FIG. 1.—Definition of Variables

g = gravitational acceleration; and subscripts 1 and 2 denote sections 1 and 2, respectively. Fig. 1 shows these definitions.

The standard procedure for water surface profile computation is a trial-and-error procedure to balance Eq. 1. The computer program used in this paper utilizes the method described by Henderson (2) for making estimated guesses to shorten the trial-and-error procedure. This procedure, after the initial water surface elevation is guessed, computes the next guessed water surface elevation for faster convergence according to the equation

$$(Z_{ass})_{new} = (Z_{ass})_{old} - \frac{(H_{ass} - H_{comp})}{1 - F_{ass}^2 (1 \mp 0.5C_L) \mp \left(\frac{3}{2}\right)\left(\frac{h_f}{R}\right)} \quad \text{(2)}$$

in which $(Z_{ass})_{old}$, $(Z_{ass})_{new}$ = initial and improved assumed water surface elevations, respectively; $(F)_{ass}$, $(R)_{ass}$, $(h_f)_{ass}$, H_{ass} = Froude number, hydraulic radius, friction loss, and total head, respectively, computed by use of the initial assumed depth; H_{comp} = total head computed by subtraction or addition of head losses to the total head of the cross section at which flow conditions are known; and C_L = energy loss coefficient. The total head at a given cross section is

$$H = \frac{\alpha V^2}{2g} + y + z \quad \text{(3)}$$

For irregular channels, the Froude number can be computed by

$$(F)_{ass} = \frac{Q}{A_{ass}\left(\frac{g y_d \cos\theta}{\alpha}\right)^{1/2}} \quad \text{(4)}$$

in which Q = water discharge; A = cross-sectional area; y_d = hydraulic depth = area/top width; and θ = angle of inclination of channel bed.

Before starting water surface profile computations, the normal and critical depths for different reaches along the study reach are computed to determine whether the flow conditions are supercritical, subcritical or critical. The computation is carried out in the upstream direction for subcritical flow; while for supercritical flows, it is in the downstream direction. In the case of horizontal or adverse slope reach, the normal depth is set equal to a very large value. The preceeding method is valid for gradually varied open-channel flows without hydraulic jump.

Whenever the flow condition changes from supercritical to subcritical, the occurrence of hydraulic jumps must be considered. The governing equation for hydraulic jumps is the momentum equation (1), i.e.

$$\frac{Q\gamma}{g}(\beta_2 V_2 - \beta_1 V_1) = P_1 - P_2 + W \sin\theta - F_f \quad (5)$$

in which γ = unit weight of water; β = momentum coefficient; P = pressure acting on a given cross section; W = weight of water enclosed between sections 1 and 2; and F_f = total external friction force acting along the channel boundary. Assuming the value of θ is small and $\beta_1 = \beta_2 = 1$, Eq. 5 can be reduced to

$$\frac{Q^2}{A_1 g} + A_1\bar{y}_1 = \frac{Q^2}{A_2 g} + A_2\bar{y}_2 \quad (6)$$

in which $\bar{y}$ = depth measured from water surface to the centroid of cross section, A, containing flow. For an irregular channel cross section consisting of m subsections, $\bar{y}$ can be computed by

$$\bar{y} = \frac{\sum_{i=1}^{m} A_i\bar{y}_i}{A} \quad (7)$$

and the specific force is defined as

$$SF = \frac{Q^2}{Ag} + A\bar{y} \quad (8)$$

Since the sequent depths of a hydraulic jump are the depths before and after the jump with the same specific force, a trial-and-error computation can be made to satisfy Eq. 6. Thus, a combined utilization of Eqs. 2 and 6 should enable us to carry out water surface profile computations to and through hydraulic jumps.

Computation Methods

Normal, Critical and Sequent Depth Computations.—Before water surface profile computations are started, the normal and critical depths for different reaches along the study reach are computed to determine whether the flow conditions are supercritical, subcritical or critical. For supercritical flows, the computations are progressed in the downstream direction. For subcritical flows, the computations are progressed in the upstream direction. The normal depth computation is made in conjunction with conveyance by satisfying the equation

$$g(d) = Q - K(d)\sqrt{S_0} = 0 \quad (9)$$

in which $K(d)$ = conveyance which is a function of depth, d; and S_0 = bottom slope. For adverse and horizontal slopes, a normal depth value of 999.9 ft is assigned.

Critical depth is the depth of minimum specific energy with a Froude number of 1 for a given discharge. Thus, the critical depth can be computed by satisfying the equation

$$f(d) = 1 - \alpha(d)\frac{Q^2 T(d)}{gA^3(d)} = 0 \quad (10)$$

in which $T(d)$ = top channel width at a given elevation or depth, d; and $A(d)$ = channel cross-sectional area at a given elevation or depth, d. The computational procedure for critical depth is similar to that just described for normal depth by satisfying Eq. 10.

Sequent depths for a given discharge are the depths with equal specific forces. Sequent depth in the present program is computed if the flow changes from supercritical to subcritical and results in a hydraulic jump. The specific force of a natural channel can be expressed by

$$SF(d) = \frac{Q^2}{A_t g} + A_m \bar{y} \quad (11)$$

in which $SF(d)$ = specific force corresponding to a water surface elevation or depth, d; A_t = total flow area; A_m = flow area in which there is motion; and $\bar{y}$ = distance from water surface to the centroid of the cross section, i.e.

$$\bar{y} = \frac{\sum_{i=1}^{m} A_i \bar{y}_i}{A_t} \quad (12)$$

In this program, it is assumed that $A_t = A_m$, and Eq. 12 is solved in the channel geometry subroutine.

Sequent water surface elevation computations for a given supercritical water surface elevation are started with two initial guesses. The first one is the critical water surface elevation with the theoretical minimum specific force. The second guess is the maximum bottom elevation for the cross section. The subcritical sequent water surface elevation should be within these two limitations. Once the interval for the sequent depth is defined, the bisection method is used to get the elevation, d_b, for which

$$SF(d_a) - SF(d_b) = 0 \quad (13)$$

in which d_a = computed supercritical water surface elevation; and d_b = desired subcritical sequent water surface elevation. The accuracy level of Eq. 13 is a user defined value.

Geometric Computations.—For natural channels, the channel is divided into subchannels. The geometric variables are computed for each subchannel. Later on, these values are summed to obtain the total area,

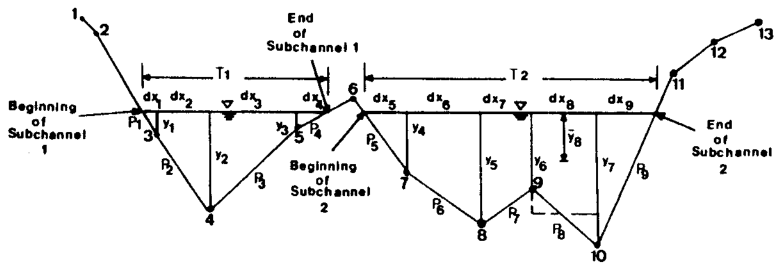

FIG. 2.—Assumed Natural Channel Cross Section

wetted perimeter and top width. The hydraulic radius, hydraulic depth and the centroid of the cross section are determined from these values. For the channel cross section shown in Fig. 2, these values are computed with the following equations:

$$A_i = 0.5(y_i + y_{i+1})dX_i \qquad (14)$$

$$p_i = [dX_i^2 + (y_i - y_{i+1})^2]^{1/2} \qquad (15)$$

$$R_i = \frac{A_i}{p_i} \qquad (16)$$

$$\bar{y}_i = 0.25(y_i + y_{i+1}); \quad \text{if not adjacent to channel wall} \qquad (17)$$

$$\bar{y}_i = \frac{1}{3} y_i; \quad \text{if adjacent to channel wall} \qquad (18)$$

$$A_t = \sum_{i=1}^{m} A_i, \quad i = 1, 2, \ldots, m \qquad (19)$$

$$p_t = \sum_{i=1}^{m} p_i, \quad i = 1, 2, \ldots, m \qquad (20)$$

$$R = \frac{A_t}{p_t} \qquad (21)$$

$$T = \sum_{j=1}^{N} T_j \qquad (22)$$

$$\bar{y} = \frac{\sum_{i=1}^{m} A_i \bar{y}_i}{A_t} \qquad (23)$$

in which A_i, p_i, R_i, $\bar{y}_i$ = area, wetted perimeter, hydraulic radius, and centroid of a subsection, respectively; T_j = top width of a subchannel; A_t, p_t, R, T, $\bar{y}$ = area, wetted perimeter, hydraulic radius, top width, and centroid of the whole cross section; m = number of subsections; and N = number of subchannels. The beginning of a subchannel is identified when the bottom elevation of the channel drops below the water surface. The end of a subchannel is identified when the bottom elevation emerges above the water surface elevation.

Conveyance and Friction Slope Computations.—The conveyance, K, is a measure of a channel's flow-carrying capacity. Any one of the following three formulas can be used in this program for discharge computation:

Manning's formula

$$Q = KS_f^{1/2} = \left(\frac{CM}{n} AR^{2/3}\right) S_f^{1/2} \qquad (24)$$

Chezy's formula

$$Q = KS_f^{1/2} = (CAR^{1/2})\, S_f^{1/2} \qquad (25)$$

or Darcy-Weisbach's formula

$$Q = KS_f^{1/2} = \left[\left(\frac{8gR}{f}\right)^{1/2} A\right] S_f^{1/2} \qquad (26)$$

in which n, C, f = roughness coefficient in Manning, Chezy, and Darcy-Weisbach's formula, respectively; A = cross-sectional area; R = hydraulic radius, and S_f = friction slope; and CM = coefficient in Manning's formula. It is equal to 1.0 for SI units and 1.486 for U.S. units. The conveyance of each subsection is computed first and the sum of them is the total conveyance of the cross section. The total conveyance is used for the determination of friction slope, S_f, of a given discharge, Q, i.e.

$$S_f = \left(\frac{Q}{K}\right)^2 \qquad (27)$$

α **Value Computation.**—The velocity distribution coefficient, α, is a measure of flow uniformity across a channel. For uniform flow across a channel, $\alpha = 1$. For nonuniform flow across a channel

$$\alpha = \frac{\sum_{i=1}^{m} V_i^3 A_i}{A_t \bar{V}^3}, \quad i = 1, 2, \ldots, m \qquad (28)$$

in which V_i, A_i = velocity and area of subsection, i, respectively; and $\bar{V}$ = average velocity for the total cross-sectional area, A_t. The velocity in each subsection can be computed by

$$V_i = \frac{K_i S_f^{1/2}}{A_i} \qquad (29)$$

Thus, the velocity distribution coefficient can be computed by

$$\alpha = \frac{\sum_{i=1}^{m} \left(\frac{\alpha_i K_i^3}{A_i^2}\right)}{\left(\frac{K_t^3}{A_t^2}\right)} \qquad (30)$$

in which α_i, K_i = velocity distribution coefficient and conveyance of each substation, respectively; and K_t = total conveyance of the cross section. If the subsection is small enough, α_i can be assumed to be 1. The velocity distribution coefficients are computed automatically in this program when the conveyance and area are computed in the channel geometry subroutine.

Energy Loss Computation.—The friction loss, h_f, through a reach is the product of energy slope, S_f, and reach length, L. There are different ways to determine average friction slope based on the friction slopes at the two ends of a given reach. Any one of the following equations can be used in this program for the computation of energy loss:

$$h_f = \left[\frac{(S_f)_1 + (S_f)_2}{2}\right] L \qquad (31)$$

$$h_f = [\sqrt{(S_f)_1 (S_f)_2}]\, L \qquad (32)$$

$$h_f = \left[\frac{Q}{\dfrac{CM}{n}\dfrac{(A_1 + A_2)}{2}\left(\dfrac{R_1 + R_2}{2}\right)^{2/3}}\right]^2 L \qquad (33)$$

$$h_f = \left(\frac{2Q}{K_1 + K_2}\right)^2 L \qquad (34)$$

in which K_1, K_2 = conveyance at the beginning and end of the reach, respectively.

Local loss due to channel expansion and contraction, h_E, is computed according to the equation:

$$h_E = C_E \left|\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right| \qquad (35)$$

in which C_E = energy loss coefficient due to channel expansion or contraction. C_E is set equal to 0.1 for contractions, and to 0.3 for expansions.

Local loss occurring due to channel bends, h_B, is computed using the equation

$$h_B = C_b \frac{V_2^2}{2g} \qquad (36)$$

in which C_b = energy loss coefficient due to channel bends. C_b is a user supplied coefficient and can be defined as a function of Froude number. Total energy loss is the sum of friction loss and the local losses.

Computation Procedures

There are six possible transitions from one type of flow to another. These are:

1. From subcritical to supercritical.
2. From supercritical to subcritical.
3. From subcritical to critical.

4. From critical to subcritical.
5. From critical to supercritical.
6. From supercritical to critical.

The program checks for these transitions during the water surface profile computations at each each cross section. If a water surface profile at the transition can change rapidly, it is called a rapidly varied flow profile. To obtain more accurate profiles for rapidly varied flows, shorter length computations are required. However, in the program, irrespective of the reach length, computations are not interrupted for the sake of continuity.

The transitions from subcritical to supercritical flow and from subcritical to critical flow are handled in the same way. The cross section where the change occurs is set as a control section with critical depth/w.s.e. (water surface elevation) as a control depth/w.s.e. Subcritical water surface profile computations are performed in the upstream direction, and supercritical flow profile computations are performed in the downstream direction.

The transition from supercritical to subcritical flow and from critical to subcritical flow are handled the same way when the variable indicating the existence of a hydraulic jump (HYDJUMP) is set equal to "YES" and hydraulic jump computations are started. These computations are explained in the following paragraph in greater detail. However, here we will mention the fact that in case of a transition from critical to subcritical flow, the computations are carried out starting from the next downstream control, proceeding in the upstream direction to obtain a Cl type profile with no hydraulic jump. The transition from critical to supercritical does not cause an interruption in the computations. Supercritical water surface profile computations are started from the cross section where this transition occurs.

If during the supercritical flow computations proceeding in the downstream direction, a mild, adverse or horizontal reach is encountered, the variable indicating the existence of a hydraulic jump (HYDJUMP) is set equal to "YES." The supercritical water surface computations are continued until either the critical depth/w.s.e. or the next subcritical or critical downstream control is met. If in the course of computations, the critical depth/w.s.e. is reached before the next control section, the variable to initiate the search for a control section (SEARCH) is set equal to "YES" to stop further computation. The next natural or artificial control section in the downstream direction is located. If in the course of computations, the computed depths/w.s.e. remain below the critical depths/w.s.e., depending on the downstream controls, a possibility for an M3, A3 or H3 type profile exists. As soon as the variable "HYDJUMP" becomes "YES," the sequent depth computations are initiated.

Sequent depth computations continue until either the variable "SEARCH" becomes equal to "YES" or the variable "HYDJUMP" is reset to "NO."

The steps followed in location of the hydraulic jump can be summarized as:

1. Compute the upstream supercritical water surface profile up to the

junction where the transition from supercritical to subcritical flow occurs.

2. Continue the supercritical water surface profile computations downstream from the junction. At the same time, compute the corresponding sequent water surface profile.

3. Starting from the subcritical or critical downstream control, compute the subcritical water surface profile in the upstream direction.

4. While computing the subcritical water surface profile at each cross section, compare the subcritical depth/w.s.e. with the sequent depth/w.s.e.

   a. If the sequent depth/w.s.e. is greater than the subcritical depth/w.s.e., the toe of the hydraulic jump is between the current cross section and the next cross section in the downstream direction.
   b. If the sequent depth/w.s.e. is equal to the subcritical depth/w.s.e., the toe of the hydraulic jump is located at the current cross section.

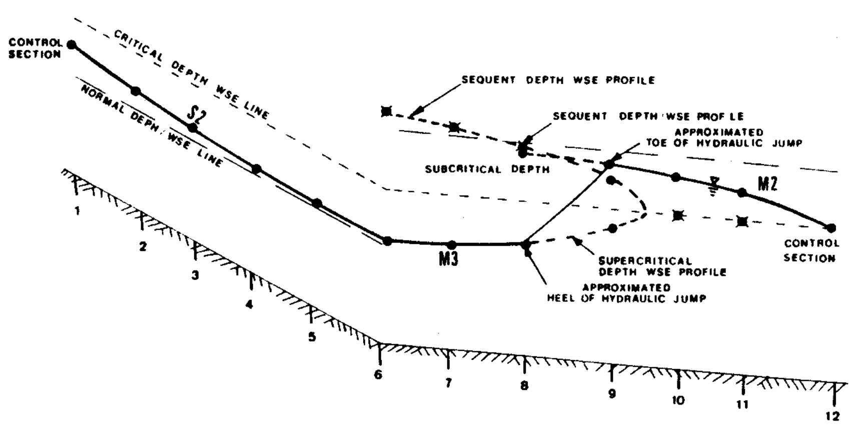

FIG. 3.—Locating Hydraulic Jump on Subcritical Slope

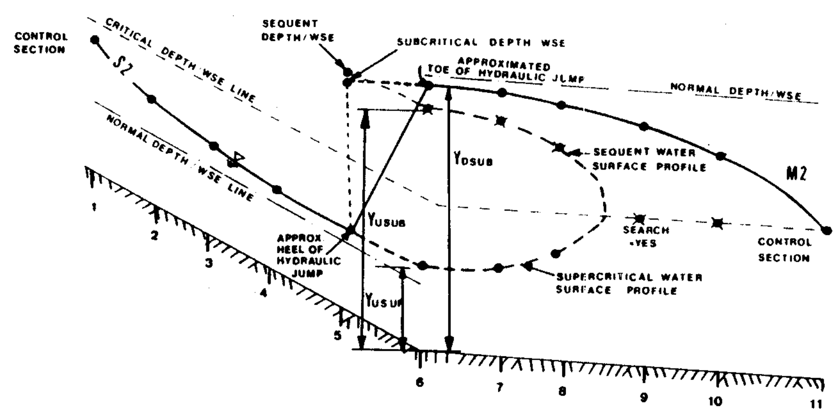

FIG. 4.—Locating Hydraulic Jump on Supercritical Slope

c. If the sequent depth/w.s.e. if less than the subcritical depth/ w.s.e., subcritical water surface profile computations should be continued in the upstream direction. If the sequent depth/w.s.e. is greater than or equal to subcritical depth/w.s.e., the hydraulic jump computations are ended and the variables "HYDJUMP" and "SEARCH" are reset to "NO." If not, subcritical water sur-

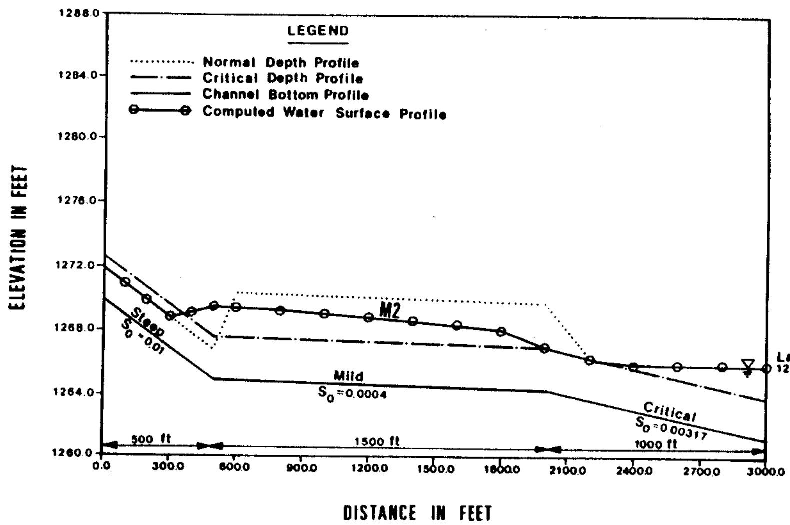

FIG. 5.—Computed Water Surface Profile with Transitions from Steep to Mild Slope and from Mild to Critical Slope in Sequence

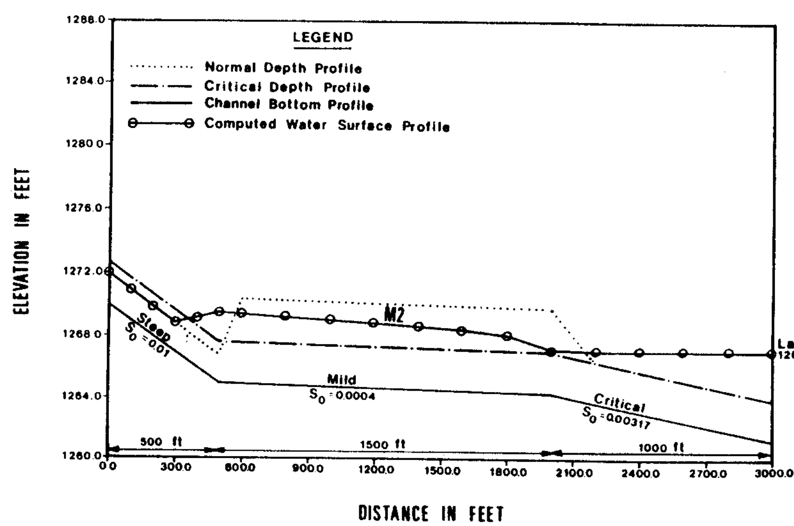

FIG. 6.—Computed Water Surface Profile with Transitions Stated in Fig. 5, Except Lake Level Is Raised from 1,266 ft to 1,267 ft

face computations are continued until the junction is reached.

5. At the junction of subcritical and supercritical slopes, the sequent depth/w.s.e. to the depth/w.s.e. determined from the supercritical water surface profile computations is compared with the subcritical depth/w.s.e. determined from the subcritical water surface profile computations.

a. If $Y_{usub} > Y_{dsub}$, the hydraulic jump takes place downstream from

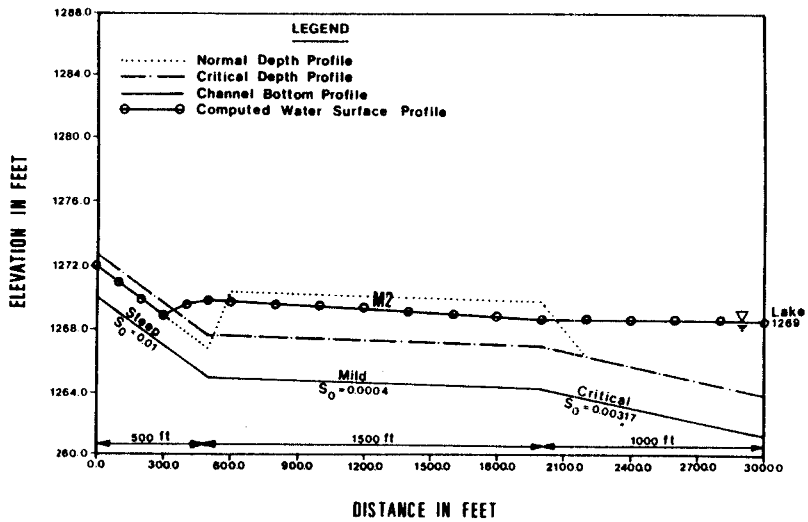

FIG. 7.—Computed Water Surface Profile with Transitions Stated in Fig. 5, Except Lake Level is Raised to 1,269 ft

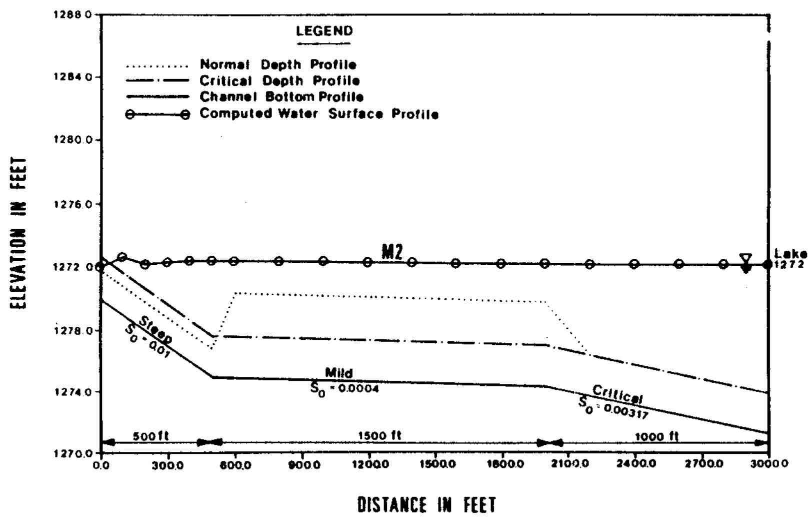

FIG. 8.—Computed Water Surface Profile with Transitions Stated in Fig. 5, Except Lake Level is Raised to 1,272 ft

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the junction. The heel of the jump is set to be located at the junction, and the toe at the next downstream cross section.

b. If $Y_{usub} = Y_{dsub}$, the hydraulic jump takes place at the junction.

c. If $Y_{usub} < Y_{dsub}$, the hydraulic jump takes place upstream from the junction.

Here, Y_{usub} = sequent depth/w.s.e. for the supercritical depth/w.s.e., determined from the supercritical water surface profile computations upstream from the junction; Y_{dsub} = subcritical depth/w.s.e. determined from the subcritical water surface profile computations downstream from the junction.

If Y_{usub} is greater than or equal to Y_{dsub}, the heel of the hydraulic jump is set at the junction and the toe at the next downstream cross section. This approximation is to give the user an idea where the jump would be located. For better results, intermediary cross sections computed from measured cross sections should be utilized.

If Y_{usub} is less than Y_{dsub}, subcritical water surface computations are continued in the upstream direction for a possible S1 profile. At each cross section upstream from the junction, the sequent depth/w.s.e. is computed, and a comparison between Y_{usub} and Y_{dsub} is done. The computations are terminated when either $Y_{usub} \geq Y_{dsub}$ or Y_{dsub} becomes less than critical depth/w.s.e. Theoretically, Y_{dsub} becomes less than critical depth/w.s.e. in the case of $Y_{dsub} \leq Y_{usub}$. However, due to reasons explained in the sequent water surface elevation computations, there might be cases where the computed Y_{usub} is less than critical depths/w.s.e.

Fig. 3 shows an example of computed results of locating the hydraulic jump on a subcritical slope. At cross section 8, the subcritical depth/w.s.e. is less than the sequent depth/w.s.e. So the heel of the jump is

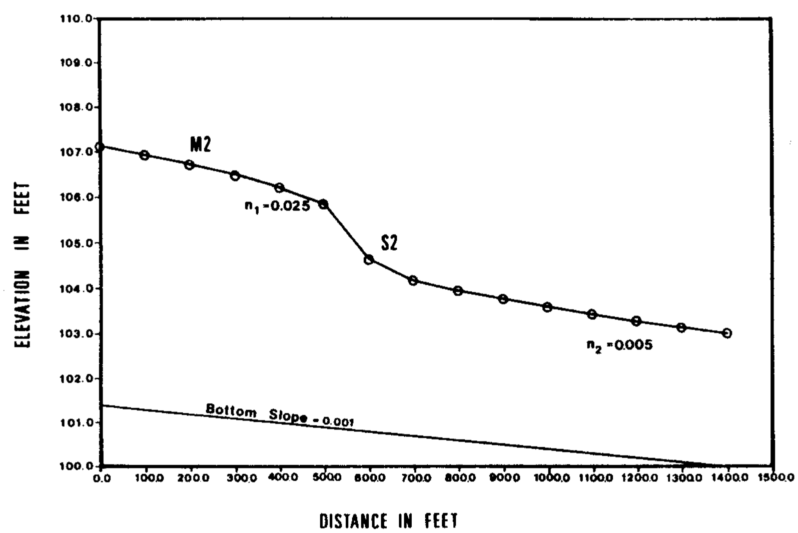

FIG. 9.—Computed Water Surface Profile with Transition from Subcritical to Supercritical by Changing Channel Bottom Roughness

at section 8 and the toe is at section 9. Fig. 4 shows an example of locating the hydraulic jump on a steep slope. At section 6, $Y_{d\text{sub}} > Y_{u\text{sub}}$. At section 5, the subcritical depth/w.s.e. is less than the sequent depth/w.s.e. The heel of the jump is at section 5 and the toe at section 6.

Examples

To show the capability of the generalized water surface computation program, problem 9-8 in the "Open-Channel Hydraulics," by Chow (1) is slightly modified and used as an example. The example problem is a rectangular channel, 20-ft wide, and consists of steep, mild and critical slopes as shown in Figs. 5–8. The entrance flow has a normal depth on a supercritical slope. The channel has a Manning's roughness coefficient of $n = 0.015$ and carries a discharge of 500 ft^3/sec. The normal depth water surface elevation at station "0" on the supercritical slope is 1,272 ft. The downstream control is a lake. In order to demonstrate the change of water surface profile, the lake water surface is allowed to change between elevation 1,266 and 1,272 ft. With the lake level at 1,266 ft, as shown in Fig. 5, the profile goes through supercritical flow, critical depth,

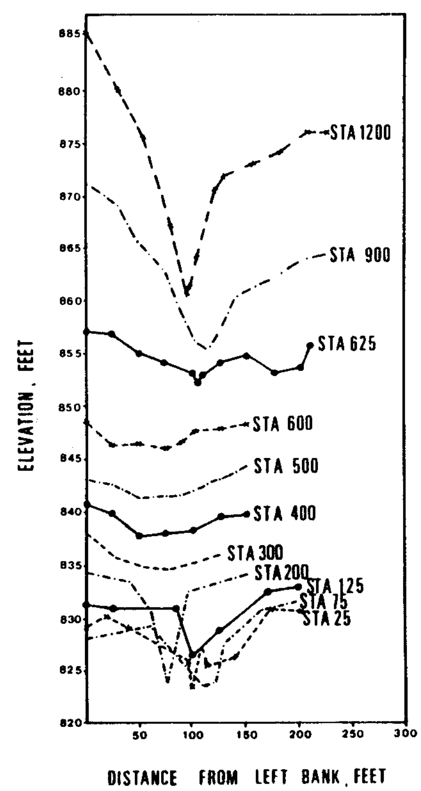

FIG. 10.—Channel Cross Sections of Different Stations Along Priest Rapids Lateral and Wasteway, Columbia River Basin, Wash.

hydraulic jump, M2 curve and critical depth, and ends up with a horizontal profile at the lake level of 1,266 ft. As the lake level is raised to 1,267 ft, as shown in Fig. 6, the critical depth profile after the M2 profile disappears. With lake level at 1,269 ft, as shown in Fig. 7, the hydraulic jump is directly influenced by the backwater effect due to high lake level. With the lake level further raised to 1,272 ft, as shown in Fig. 8, the hydraulic jump moves toward the upstream gate control and basically eliminates the hydraulic jump.

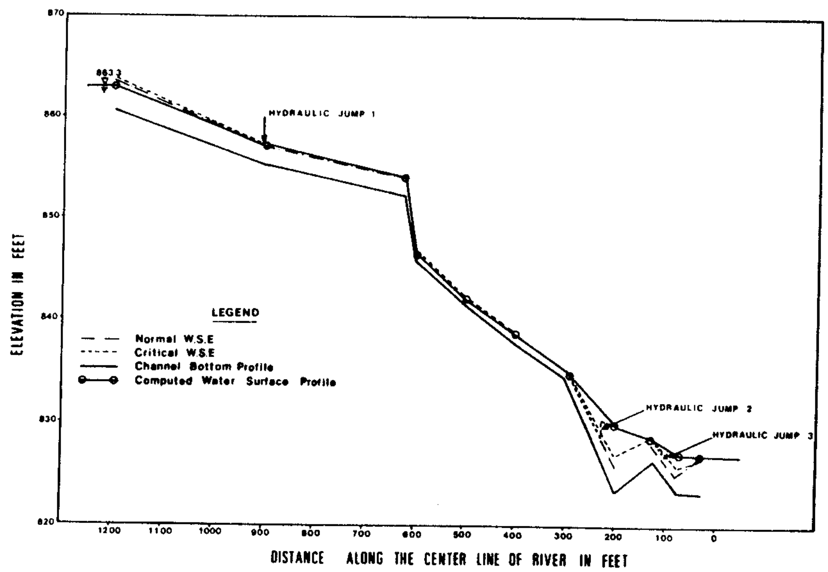

FIG. 11.—Computed Water Surface Profile Along Priest Rapids Lateral and Wasteway, Columbia River Basin, Wash.

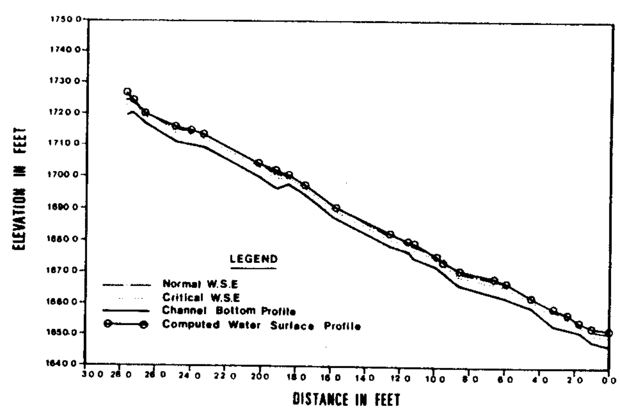

FIG. 12.—Computed Water Surface Profile Along Trinity River Below Grass Valley Creek, Calif.

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The change from one type to another type of water surface profile can occur not only due to the change of channel bottom slope or upstream or downstream controls; it could also be caused by the change of roughness along the course of flow. Fig. 9 shows the computed water surface profile for a rectangular channel with a channel bottom slope of 0.001. A change of Manning's roughness coefficient from 0.025 to 0.005 can change the water surface from an M2 to an S2 profile.

To demonstrate the application of the program to a natural river with mild, steep and adverse slopes, the Priest Rapids Lateral and Wasteway, Columbia Basin Project, Washington, is utilized. The channel cross sections at different stations along the Priest Rapids are shown in Fig. 10. The water discharge used in the computation is 200 ft^3/sec. The Manning's roughness coefficient is 0.035. The accuracy level for backwater computations and sequent water surface elevation computations are 0.001 ft and 0.01 ft, respectively. The upstream and downstream controls are set at elevation 863.3 ft and 827.0 ft, respectively. The computed water surface profile is shown in Fig. 11. The computed profile has three hy-

TABLE 1.—Comparison Between Generalized Computer Program and U.S. Bureau of Reclamation's (USBR) Program for Gradually Varied Flows: Trinity-River Below Grass Valley Creek

Station identification (1)	Q = 300 Cubic Feet per Second USBR (2)	General-ized (3)	Differ-ence (4)	Q = 1,000 Cubic Feet per Second USBR (5)	General-ized (6)	Differ-ence (7)	Q = 3,000 Cubic Feet per Second USBR (8)	General-ized (9)	Differ-ence (10)
1		1,724.75		1,726.6	1,726.65	−0.1	1,729.4	1,729.56	−0.2
2	1,722.9	1,722.85	0.0	1,724.2	1,724.08	+0.1	1,726.2	1,726.00	−0.2
3	1,718.8	1,718.75	0.0	1,720.1	1,720.04	+0.1	1,722.4	1,722.32	+0.1
4	1,714.3	1,714.17	+0.1	1,715.9	1,715.85	+0.0	1,718.4	1,718.33	0.0
5	1,713.4	1,713.29	+0.1	1,714.7	1,714.64	+0.1	1,717.0	1,716.95	0.0
6	1,712.1	1,711.98	+0.1	1,713.4	1,713.43	0.0	1,715.7	1,715.69	0.0
7	1,702.9	1,702.76	+0.1	1,704.5	1,704.39	+0.1	1,707.1	1,706.99	+0.1
8	1,700.9	1,700.90	0.0	1,702.2	1,702.12	+0.1	1,704.5	1,704.41	+0.1
9	1,699.6	1,699.57	0.0	1,700.9	1,700.85	0.0	1,702.8	1,702.80	0.0
10	1,696.4	1,696.38	0.0	1,697.7	1,697.63	+0.1	1,699.5	1,699.46	0.0
11	1,689.3	1,689.29	0.0	1,690.6	1,690.60	0.0	1,692.8	1,692.81	0.0
12	1,681.3	1,681.49	−0.2	1,682.6	1,682.64	0.0	1,685.2	1,685.17	0.0
13		1,678.73		1,680.3	1,680.17	+0.1	1,682.6	1,682.49	+0.1
14		1,677.26		1,679.7	1,678.66	+0.0	1,682.0	1,682.05	−0.1
15		1,674.37		1,675.5	1,675.47	0.0	1,677.4	1,677.28	+0.1
16	1,672.5	1,672.45	0.0	1,673.7	1,673.61	0.1	1,675.9	1,675.80	+0.1
17	1,669.2	1,669.09	+0.1	1,670.9	1,670.90	0.0	1,674.1	1,674.05	0.0
18	1,666.8	1,666.60	+0.2	1,668.5	1,668.41	+0.1	1,671.1	1,671.02	+0.1
19	1,666.0	1,665.88	+0.1	1,667.2	1,667.07	+0.1	1,669.1	1,668.96	+0.1
20	1,661.3	1,661.17	+0.1	1,662.4	1,662.42	0.0	1,664.7	1,664.66	0.0
21	1,657.0	1,656.88	+0.1	1,658.9	1,658.85	0.0	1,661.9	1,661.83	+0.1
22		1,656.01		1,657.3	1,657.34	0.0	1,659.6	1,659.52	+0.1
23	1,653.3	1,653.24	+0.1	1,654.7	1,654.80	+0.1	1,657.2	1,657.02	+0.2
24	1,650.9	1,650.96	0.0	1,652.8	1,652.75	0.0	1,655.7	1,655.70	0.0
25	1,650.1	1,640.10	0.0	1,651.9	1,651.88	0.0	1,654.8	1,654.80	0.0
	Average: +0.045 feet			Average: +0.040 feet			Average: +0.028 feet		

draulic jumps and goes through steep, mild and adverse bed slope profiles without any interruptions.

A comparison between the generalized computer program with the Bureau of Reclamation's Water Surface Profile Computer Program (4) is made on the Trinity River below the Grass Creek Valley. The computed results by the Bureau program were verified by field measurements and observations. A comparison of the computed results from these two programs is summarized in Table 1. The computed water surface by generalized program along the Trinity River is shown in Fig. 12. The results shown in Table 1 indicate that the results computed by these two programs are in close agreement.

Summary and Conclusion

A generalized computer program for the computation of water surface profiles of natural rivers is introduced in this paper. A step-by-step description of the methods and procedures used in the program is made. Examples are used to show the capability of the program. This study has reached the following conclusions:

1. The energy equation can be used in conjunction with the momentum equation for the computation of water surface profiles through gradually varied, as well as rapidly varied open-channel flows.
2. The computer program developed in this paper can be used to compute water surface profiles through hydraulic jumps or the change from subcritical to supercritical flows without any interruptions.
3. The generality of the theories used and the field conditions considered in the computer program make it a powerful and useful tool for engineering computations of water surface profiles in natural rivers and man-made channels.

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Appendix I.—References

1. Chow, V. T., *Open-Channel Hydraulics*, McGraw-Hill Book Co., New York, N.Y., 1959.
2. Henderson, F. M., *Open-Channel Flow*, Macmillan Co., New York, N.Y., Chap. 5, 1966.
3. U.S. Army Corps of Engineers, Hydrologic Engrg. Center, "HEC-2, Water Surface Profiles," Users Manual, Nov., 1976.
4. U.S. Bureau of Reclamation, Sedimentation Section, Hydrology Branch, "Guide for Application of Water Surface Profile Computer Program," Dec., 1968, Denver, Colo.

Appendix II.—Notation

The following symbols are used in this paper:

A	=	cross-sectional area;
$A(d)$	=	channel cross-sectional area at given elevation or depth, d;
A_m	=	flow area in which there is motion;
A_t	=	total flow area;
C_L, C_E, C_b	=	energy loss coefficient due to velocity variation, expansion or contraction, and bend, respectively;
CM	=	coefficient in Manning's formula; it is equal to 1.0 for SI units and 1.486 for U.S. units;
d_a	=	computed supercritical water surface elevation;
d_b	=	desired subcritical sequent water surface elevation;
$(F)_{ass}, (R)_{ass}, (h_f)_{ass}, H_{ass}$	=	Froude number, hydraulic radius, friction loss, and total head, respectively, computed by use of initial assumed depth;
F_f	=	total external friction force;
H_{comp}	=	total head computed by subtraction or addition of head losses to total head of cross section at which flow conditions are known;
h_f, h_t	=	friction loss and total energy loss, respectively;
$K(d)$	=	conveyance which is a function of depth, d;
n, C, f	=	roughness coefficient in Manning, Chezy, and Darcy Weisbach's formula, respectively;
P	=	pressure;
p	=	wetted perimeter;
Q	=	water discharge;
R	=	hydraulic radius;
S_f	=	friction slope;
S_0	=	bottom slope;
$SF(d)$	=	specific force corresponding to water surface elevation or depth, d;
$T(d)$	=	top channel width at given elevation or depth, d;
V	=	velocity;
W	=	weight of water;
Y_d	=	hydraulic depth;
y	=	water depth;
$\bar{y}$	=	depth measured from water surface to centroid of cross section;
Z	=	bed elevation;
$(Z_{ass})_{old}, (Z_{ass})_{new}$	=	initial and improved assumed water surface elevations, respectively;
α	=	velocity distribution coefficient;
β	=	momentum coefficient;
γ	=	unit weight of water; and
θ	=	angle of inclination of channel bed.