User's Manual for **BRI-STARS**

(BRIdge Stream Tube model for

Alluvial River Simulation)

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FOREWORD

This User's Manual provides guidelines for the installation, operation and usage of the BRI-STARS (Bridge Stream Tube model for Alluvial River Simulation) model. This manual presents the background on the methodologies used by the model, formulations of governing flow and sediment routing procedures used to develop the model and the optional local scour equations and sediment transport algorithms that are accessible through the model. This manual and the associated BRI-STARS software will be of interest to hydraulic engineers, bridge engineers, and geologists involved in bridge scour evaluations and modeling of general scour in alluvial streams in the vicinity of bridge crossings and highway encroachments. BRI-STARS is especially useful for sites where contraction scour and/or effects of in-stream mining activities are major concerns. This manual as an electronic document along with the down-loadable BRI-STARS software is available through the FHWA Bridge Technology web site at *www.fhwa.dot.gov/bridge* or through the Hydrau-Tech, Inc. web site at *www.hydrau-tech.com*.

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16. Abstract

BRI-STARS (BRIdge Stream Tube model for Alluvial River Simulation) model is a generalized semi-two-dimensional water and sediment-routing model with an integrated graphical interface for solving complicated river engineering problems with limited data and resources. This model is capable of computing alluvial scour/deposition through subcritical, supercritical, and a combination of both flow conditions involving hydraulic jumps. Unlike conventional water and sediment routing models, it is also capable of simulating channel widening/narrowing phenomena as well as local scour due to highway encroachments. It contains a subset of Federal Highway Administration's WSPRO subroutines for computing bridge hydraulics.

The first major component of **BRI-STARS** is the water surface profile and streambed variation computations using stream tubes for fixed-channel width under subcritical, supercritical, and the combination of both flow conditions. It is composed of three major computational blocks: backwater computations, stream tube computations, and sediment routing computations. These computational blocks are linked together during the operation of the model. Both energy and momentum equations are used so the water surface profile computation can be carried out through combinations of subcritical and supercritical flows without interruption. The stream tube concept is used in a semi-two-dimensional way, which allows the lateral and longitudinal variation of hydraulic conditions as well as sediment activity at various cross sections along the study reach. The sediment continuity equation and sediment transport capacity equations are used for sediment routing computations to simulate the general scour in the river bed elevation. The sediment routing is performed for each size fraction to account for the bed composition changes and the bed armoring processes. The second major component of the **BRI-STARS** is a variable width stream tube model. The minimum rate of energy dissipation theory is used for decisions as to whether the channel adjustments taking place at a given cross section due to scouring/deposition should advance in the lateral or vertical directions. Finally, the third component of **BRI-STARS** allows the computation of the hydraulic flow variables and the resulting local scour due to highway bridge encroachments. The WSPRO component allows modeling of bridge hydraulics.

This User's Manual provides a theoretical background on the methodologies used by the model as well as the formulations of governing flow and sediment routing procedures. Various records needed for the operation of the model, their description, format, and sequential positioning within the data structure are given. Example applications as well as practical guidelines for the use of the model are presented.

17. Key Words		18. Distribution Statement	
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³

NOTE: Volumes greater than 1000 l shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

ii

TABLE OF CONTENTS

APPENDICES:

LIST OF FIGURES

LIST OF TABLES

1. GETTING STARTED

1.1 GENERAL MODEL INFORMATION

There is a need for a generalized water and sediment-routing computer model for solving complicated river engineering problems with limited data and resources. This program should have the following capabilities:

- To compute hydraulic parameters for open channels with fixed as well as alluvial boundaries.

- To compute water surface profiles for subcritical, supercritical, and combinations of both flows without interruption.

- To compute and simulate the hydraulic and sediment conditions in the longitudinal and lateral directions.

- To compute and simulate the change of alluvial channel profile and geometry regardless of whether the channel width is variable or fixed.

- To compute the alluvial channel changes in the presence of highway encroachments and/or other man-made or natural structures.

- To compute channel changes in the presence of heavily sediment-laden flows.

- To compute bank failures due to the sediment activity in the presence of severe erosion problems.

Most of the sediment and water routing models, such as the HEC-6, were developed for solving simplified one-dimensional alluvial river problems. Although there are some truly two- or three-dimensional models, they require extensive amounts of computer time and data for calibration. Thus, truly two- or three-dimensional models may not be desirable for solving engineering problems with limited data and resources.

The development of **BRI-STARS** (BRIdge Stream Tube model for Alluvial River Simulation) consisted of three stages. The development of a stream tube model for alluvial channels with fixed width by Molinas was documented earlier. That model was successfully applied to simulate local scour and deposition processes at the Mississippi River Lock and Dam No. 26 replacement site near St. Louis. In the second stage of development, the theory of minimum rate of energy dissipation or its simplified version of minimum total stream power was used to incorporate the channel width as an unknown variable. Finally, in the last stage the bridge hydraulics and local pier scour component was added. Also, in this third stage the model's capabilities were enhanced by the inclusion of new sediment transport equations, graphical user interface, lateral water, and sediment inflow options. Both energy and momentum functions are used in the **BRI-STARS** model so the water surface profile computation can be carried out through combinations of subcritical and supercritical flows without interruption. The stream tube concept is used for hydraulic computations in a semi-two-dimensional way. Once the hydraulic parameters in each stream tube are computed, the scour or deposition in each stream tube determined by sediment routing will give the variation of channel geometry in the vertical direction.

BRI-STARS is flexible in its application. When only one stream tube is used, it becomes a one-dimensional model. When the sediment-routing subroutine is not used, it becomes a model for fixed-bed hydraulic computation. When the minimization subroutine is not used, it becomes a model for fixed-channel width. The selection of number of stream tubes and different combinations of subroutines depends on the site-specific conditions and an engineer's understanding and interpretation of the fluvial processes.

1.1.1   Model Description

The first major component of **BRI-STARS** is based on a stream tube computer model with fixed-channel width to simulate streambed variations in rivers for which sediment and hydraulic data are limited. Using stream tubes allows the lateral and longitudinal variation of hydraulic conditions as well as sediment activity at various cross sections along the study reach. The objective of the model is to study complicated sedimentation problems for which there is interaction between the flowing water-sediment mixture and the alluvial river channel boundaries. In order to accomplish this purpose, the water surface profile and other hydraulic variable computations for supercritical, subcritical, and the combination of both flow conditions must be carried out without interruption. The bed armoring and the breaking of the armor layer are incorporated to study longer periods of flow durations.

The stream tube computer program is a semi-two-dimensional program with the third dimension, depth, being intrinsically incorporated into the computations. As such, it has the basic limitations of every two-dimensional program; secondary flows cannot be simulated. The channel is divided into a preselected number of tubes. The bed elevation in each stream tube is allowed to move vertically up or down depending on the flow conditions. As a result, while one section of channel is eroding, another section might be aggrading. Depending on the number of stream tubes to be used, the channel cross section changes are averaged across different channel subsections of varying widths. Since the computer time and space are directly related to the number of stream tubes to be used, the user is required to decide on the optimum number of tubes. Bed forms are not simulated due to the lack of a generally accepted methodology for determining them. Even though provisions are made to expand the program to include river confluences and middle islands, at this point these options are not available. The channel boundaries are fixed in the lateral direction, and formation of meander bends cannot be simulated.

The computer model using stream tubes can be applied to a variety of river problems. It can be used as a fixed-bed model to compute water surface profiles for subcritical, supercritical, or the combination of both flow conditions involving hydraulic jumps. This option allows the applications involving the computation of water surface profiles in man-made channels with clear water, flow profiles over spillways, or flow profiles in natural river channels where the interaction between the sediment-water mixture and the channel bed are negligible. As a movable bed model, the computer program can be applied to route water and sediment through natural river channels. The use of stream tubes allows the variation of hydraulic conditions and sediment activity not only in the longitudinal, but also in the lateral direction. With the selection of a single stream tube, the model becomes one-dimensional. Average channel response to changes in certain riverflow or sediment conditions can be studied. With the selection of multiple stream tubes, the model becomes two-dimensional. The changes in the cross section geometries in the lateral direction can be simulated. Since the bed elevation changes are not averaged over the entire active channel widths as in one-dimensional models, more realistic channel erosion or aggradation can be simulated. This option provides valuable

information where certain navigation depths have to be maintained. It can also be used in bank stability problems to identify expected regions of bank instabilities. The armoring process provided in the program allows study of river sedimentation problems for longer periods of time.

The stream tube computer model for routing water and sediment is composed of three computational blocks: (1) backwater computations, (2) stream tube computations, and (3) sediment routing computations. These computational blocks are linked together during the operation of the model.

At each time step, first, backwater computations are carried out for the entire reach with the channel treated as a single tube. Second, with the computed water surface elevations, lateral locations of stream tubes at each cross section are determined. With each stream tube treated as an independent channel, the hydraulic variables along it are computed. Third, sediment is routed through each stream tube satisfying the sediment continuity equation. At the end of these computations, bed material compositions are revised and channel bed elevations are updated. An armoring procedure is incorporated into the sediment routing computations. Computations proceed in time through defined water and sediment discharge hydrographs.

The second major component of the **BRI-STARS** is a variable width stream tube model. **BRI-STARS** can be used for decisions as to whether the channel adjustments taking place at a given cross section due to scouring/deposition should advance in the lateral or vertical directions.

The basic tool for this decision-making component is the Minimum Rate of Energy Dissipation Theory developed by Yang and Song (1979, 1986) and Song and Yang (1979, 1980, 1982a, 1982b), and this general theory's special case Minimum Stream Power Theory used by Chang (1980b).

The Minimum Stream Power Theory states that

> *For all alluvial channels, the necessary and sufficient condition of equilibrium occurs when the stream power per unit length of channel, γQS, is a minimum subject to given constraints. Hence, an alluvial channel with water discharge Q and sediment load Q_s as independent variables, tends to establish its width, depth, and slope such that γQS is a minimum.*

To extend the minimization procedure to channel reaches experiencing gradually varied flows, stream power (γQS) should be integrated along the channel.

In **BRI-STARS**, selecting directions for channel adjustments is accomplished by this integral expression being minimized for total stream power at different stations. At a given time step, if alteration of the channel widths results in lower total stream power than raising or lowering of the channel, channel adjustments are made in the lateral direction. For the opposite case, the adjustments are made in the vertical direction.

At cross sections where sediment erosion is predicted following the sediment routing procedure, channel adjustments can proceed in either deepening or widening directions. The selected mode of channel adjustment in the computer model is the one resulting in the minimum total stream power for the reach.

Similarly, at cross sections where sediment accumulation is predicted, channel adjustments can proceed in raising the bed by sediment deposition on the bed or

along the banks. The selected mode of channel adjustment in **BRI-STARS** is the one resulting in the minimum total stream power for the reach. In both the aggrading and degrading channel cases, the sediment load is treated as a constriction in the minimization. In cases where geological or man-made restrictions are applied to the channel deepening or widening processes, computations are performed to accommodate these constrictions.

The amount of channel width adjustment during a time step is determined by the sediment continuity equation. However, for channel widening or narrowing computations, the wetted perimeter P is replaced by the hydraulic radius R. Channel widening of narrowing computations are carried out in the usual way using the sediment continuity equation. The amount of sediment eroded from the banks from a given reach is added into the sediment loads entering that reach in sediment-routing computations. This sediment load becomes influx for the following sections to conserve the mass balance.

Finally, the third component of **BRI-STARS** allows the computation of the hydraulic flow variables and the resulting scour due to highway bridge encroachments. **BRI-STARS** performs bridge hydraulics computations utilizing FHWA's WSPRO water surface profile computation program routines. The details of these computations are described in detail in the WSPRO User's Manual. Also, a second option which utilizes user supplied local loss coefficients at the bridge sections is available. In this simple bridge approach, the bridge loss coefficients can be calibrated with measured/computed water surface profiles for closer agreement with more accurate methods of computations. The simple bridge approach is applicable only for free-surface bridge hydraulics computations since it treats the bridge piers as a part of the channel geometry.

The local scour due to bridge piers in the **BRI-STARS** model is computed utilizing the following methods:

1.   Colorado State University/FHWA HEC-18 equation.
2.   Jain and Fisher equation.
3.   Laursen equation.
4.   Froehlich equations.
5.   User-supplied generic equation.

The local scour due to abutments in the **BRI-STARS** model is computed utilizing the following methods:

1.   Colorado State University equation.
2.   Laursen equation for clear-water scour.
3.   Laursen equation for live-bed scour.
4.   Froehlich equation for clear-water scour.
5.   Froehlich equation for live-bed scour.

The model computes and lists the local scour at bridge piers and abutments separately from the computed general stream aggradation/degradation values. The maximum potential local scour value computed during the simulation event is computed and used in the final estimation of cumulative scour at bridge sites. The **BRI-STARS** model also computes the potential contraction scour utilizing Laursen's simplified contraction scour equation and provides users this information for comparison purposes.

1.1.2 Potential Applications of BRI-STARS

Potential applications of **BRI-STARS** can be summarized as follows:

a)   The model can be used as a fixed-bed model to compute water surface profiles for subcritical, supercritical, or the combination of both flow conditions involving hydraulic jumps. These computations include, but are not limited to:

  • Flow profiles in man-made channels with no sediment.
  • Flow profiles over spillways and waterways.
  • Water surface profiles in rivers where bed elevation changes are negligible.

b)   The model can be used as a movable bed model to route water and sediment through alluvial channels.

c)   The use of stream tubes allows the model to compute the variation of hydraulic conditions and sediment activity not only in the longitudinal but also in the lateral direction.

d)   With the selection of a single stream tube, the model becomes one-dimensional. By selection of multiple stream tubes, changes in cross section geometries in the lateral direction can be simulated.

e)   The armoring option allows simulation of longer term riverbed changes.

f)   With the selection of the minimization procedure option, the model can simulate channel widening and narrowing processes.

g)   With the selection of the WSPRO bridge hydraulics option, the model utilizes specialized routines for the computation of flows through highway bridge openings.

h)   Maximum potential bridge pier scour for given flood hydrographs is computed through the use of several equations for various pier geometries.

i)   Flow diversion problems can be studied through the use of lateral inflow/outflow options.

j)   Aggregate mining studies can be conducted by simulating various mining alternatives (quantity and physical location).

k)   Dredging studies can be conducted by the use of the lateral sediment outflow option without any water outflow.

l)   Bank failures with known rates of bank regression can be simulated through the option of lateral sediment inflow without water inflow.

1.2   BRI-STARS PACKAGE

1.2.1   Contents of the BRI-STARS Package

The package includes:

1)   **BRI-STARS** User's Manual.

2)   Two 3-1/2 inch MS-DOS formatted high-density floppy disks containing:

●   Program Files:

BST50.EXE - interactive data entry module for **BRI-STARS**.
BSTPLOT.EXE - visual display program for **BRI-STARS**-generated thalweg
            and water surface profile output.
BSTXSEC.EXE - conversion program for **BRI-STARS**-generated cross-
            section output files to Corel Quattro-Pro-compatible
            format for the purpose of hard-copy plotting.
NPPLUS.EXE - Notepad Plus for Windows Text Editor for the integrated
            development environment.

●   Resource Files:

BRISTARS.RSC - default file names for BRISTARS.
BSTPLOT.RSC - default file name for BSTPLOT.
BSTXSECT.RSC - default file name for BSTXSECT.
BSTPLOT.WSP - default demo file for BSTPLOT.

●   Title Screen Files:

BSTIMAGE.SYS - title screen file for **BRI-STARS**.
BSTPLOT.SYS - title screen file for BSTPLOT.
BSTXSECT.SYS - title screen file for BSTXSECT.

●   Help Files:

BSTHELP.HLP - **BRI-STARS** help file.
BSTHELP.CNT - contents file for BSTHELP.
BSTTHALW.BMP - Bitmap image used in help file.
BSTTOPO.BMP - Bitmap image used in help file.
BSTTUBES.BMP - Bitmap image used in help file.
BSTCONTNTS.BMP - Bitmap image used in help file.

●   Examples:

EXMPL001.DAT - example problem 1 data file.
EXMPL002.DAT - example problem 2 data file.
WSPRO.DAT - WSPRO data used in conjunction with EXMPL002.DAT.
EXMPL003.DAT - example problem 3 data file.
EXMPL004.DAT - example problem 4 data file.
EXMPL005.DAT - example problem 5 data file.
EXMPL006.DAT - example problem 6 data file.
EXMPL007.DAT - example problem 7 data file.
EXMPL008.DAT - example problem 8 data file.
EXMPL009.DAT - example problem 9 data file.
EXMPL010.DAT - example problem 10 data file.

- BSTEMPLT Corel Quattro-Pro Worksheet Utility Files:

  BSTEMPLT.WB2 - Input Data Generator Template for **BRI-STARS.**
  I5INPUTH.WB2 - Input Data Generator Template for EXMPL009.DAT.
  BSTGEN.EXE - Quattro PRO-to-BRISTARS data translator program.

1.2.2 Organization of the Package

Organization of the **BRI-STARS** package is illustrated below:
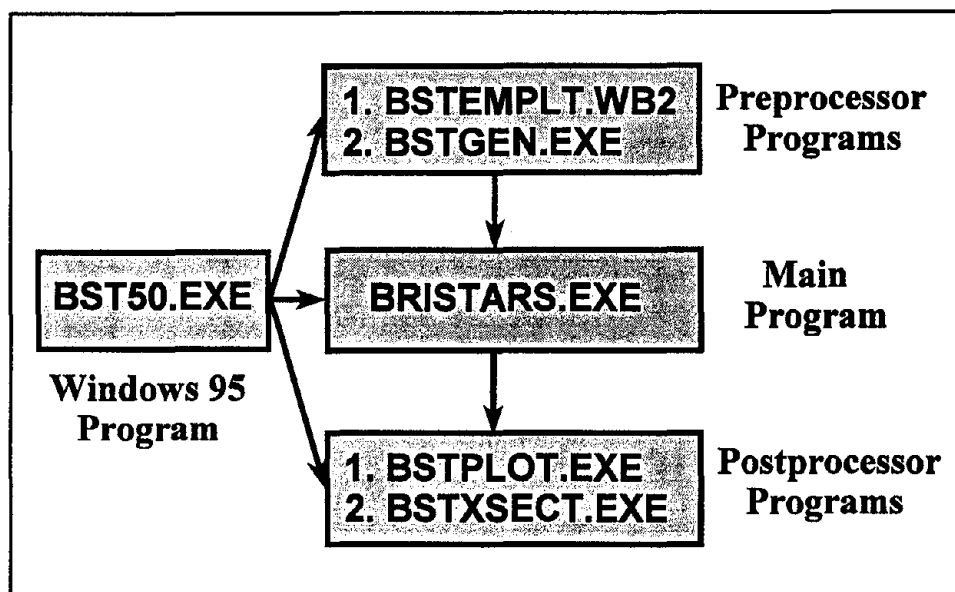
Figure 1. Organization of the **BRI-STARS** package.

1.2.3 Typographical Conventions

Throughout this User's Primer, when you see **Enter** you should press the **Enter** key (which is also called the **Return** key).

In the description of procedures, the items to be typed by the user are shown in upper case lettering. These commands can also be typed in any combination of upper and lower case lettering.

Throughout the User's Primer the computer hard disk is always assumed to be drive C. Drives A: and B: are assumed to be floppy disk drives.

In the explanations pertaining to output generation, it is assumed that the printing device is properly connected to the microcomputer and that the device driver for a plotting device is successfully installed for the plotting package. The user is expected to follow manufacturer's instructions in operating the printing devices to activate appropriate internal printing styles.

1.2.4 System Requirements

The system requirements for running the **BRI-STARS** model on a microcomputer are:

- **16 MB main memory (32 MB recommended).**

- Intel Pentium 66 Mhz or higher microcomputer.

- **Windows 95 Operating system.**

- Super VGA (800x600 at 256 color) or higher resolution screen for displaying computed plots.

- **Graphics printer such as HP LaserJet Series II or better.**

- Hard disk with enough room to hold the program, utilities, examples, and output files (Allow at least 10 Megabytes of hard disk space for applications).

1.3   INSTALLATION

To install **BRI-STARS** on the hard disk, use the automatic Windows 95/NT setup program provided on Diskette 1. The SETUP program is a utility program which automates the installation of **BRI-STARS** by creating a program and examples directory on the hard disk and by automatically copying the **BRI-STARS** model, utility programs, example problem input data, and output files contained in Diskettes 1-2 provided with the package.

1)   To run the SETUP program, place the Disk 1 into floppy drive A. From the main Windows 95 frame select **START** and then **RUN** options. Type **A:\SETUP** and then press the **Enter** key.

2)   A welcoming message describing the purpose of the program will be displayed. To continue with the installation press the **Next** key.

3)   At this point, the program licensing screen will be displayed. To continue with the installation, press the **Next** button.

4)   The user information screen requests user's name and affiliation. To continue with the installation press the **Next** button.

5)   The Destination Location Window requests the installation directory. To accept the default directory of **C:\BSTWIN95**, press the **Next** button. To change the directory name, press the Browse button and enter directory name in the **Path** line. If the directory does not exist, it will be automatically created.

6)   Program Folder Window requests the name of the program folder the **BRI-STARS** program is placed into. To accept the default folder name of **BRI-STARS**, press the **Next** button. Otherwise enter a new name. If the folder does not exist, it will be automatically created.

7)   The Confirmation Window requests the confirmation of installation information entered by the user. To confirm, press the **Next** button. To change the information, press the **Change** button and reenter information.

8)   At this point, the installation program copies all files into the specified **BRI-STARS** directory and prompts the user to complete installation by pressing the Finished button.

At this point, the **BRI-STARS** program group is created and the **BST50** icon is placed in the program group. To run the program, double click this icon.

1.4   OPERATION OF THE MODEL

The logical steps followed in the operation of the model can be listed as:
- Input data preparation.
- Execution of the model.
- Generating output:
  - computed formatted output.
  - cross section profile output.
  - water surface elevation and hydraulic output.

1.4.1   Input Data File Preparation

The **BRI-STARS** model operates in a batch mode in which the data needed by the model is provided through a separate data file. This data file can be prepared in several ways. They are:

- Using an ASCII text editor (such as **Wordpad** provided with Windows 95 or the **Notepad Plus** included in the **BRI-STARS** package) and by following the guidelines provided in chapter 6 for hydraulic data, chapter 7 for sediment data, chapter 8 for bridge scour data, and chapter 9 for minimization procedure data.

- By modifying an example problem provided in the package using an ASCII text editor.

- Using the **BSTEMPLT.WB2** template worksheet provided with the **BRI-STARS** package with **Corel Quattro Pro** for Windows.

- Using the **BSTDATA** data entry program provided with the earlier **DOS** version of the model.

1.4.2   Execution of the Model

After a successful installation, the executable **BRI-STARS** model and the utility programs are downloaded either into the **C:\BSTWIN95** directory on the hard disk or into a directory defined by the user. The example data files are also copied into the same directory.

In order to run the model, two procedures can be followed. The first procedure involves the use of the main Windows 95 frame, and the second procedure uses the Windows Explorer program.

Method 1 - Run BRI-STARS from the main Window:
1) Select **Start** and then **Programs**.
2) Point to the **BRI-STARS** program group from the program list.
3) Double click on the **BST50** icon.

Method 2 - Run BRI-STARS Using Windows Explorer:
1) Select the directory in which **BST50** is located.
2) Highlight **BST50.EXE** from the list of files.
3) Double click on the **BST50** icon.

Once the **BRI-STARS** model is activated, an opening screen with program information is presented. To run **BRI-STARS** with the **EXMPL009.DAT** file, the following procedure is suggested:

1)   Select **File** from the main menu.

2)   Specify the input file name by selecting **Input** from the drop-down menu and then by entering the desired file name (EXMPL009.DAT). Users may also browse through the directory tree using the standard Windows style file browsing utility, and may select other files by highlighting desired files.

3)   Specify names for other file menu items:

  •   **Output File** - file containing results.

  •   **X-Secs File** - file containing cross sections output.

  •   **WSP File** - water surface and thalweg elevations output.

  •   **Messages File** - file containing miscellaneous messages during execution.

  By default, **BRI-STARS** uses the user-supplied input file name with **.OUT, .XSC, .WSP, .MSG** extensions for naming these files. If these defaults are acceptable, move to next step.

4)   Select **Run** from the main **BRI-STARS** menu.

5)   Observe screen output:

  •   Observe thalweg and water surface elevation changes.

  •   Observe stream tubes and velocity distributions.

  •   Observe topographic changes during simulation.

6)   If results are acceptable, generate output for reporting results.

7)   Otherwise, edit the input file by selecting **Edit / Input File** from the main **BRI-STARS** menu and repeat steps 4-6.

8)   Continue until satisfactory results are obtained.

At the end of the **BRI-STARS** run described above, if the plotting option is requested for generating water surface profile plots and/or change cross section plots, two data files will be created containing plotting information. The default names for plot data files are XSECTS.XSC and WSPROFS.WSP. The file XSECTS.XSC contains the channel cross section information at each simulation time step, and WSPROFS.WSP contains the water surface profile information. In order to secure these files for future use and to provide proper identification, the user is urged to save these files under different names at run time by specifying unique file identification.

The procedure outlined above can be modified for different applications by altering the names of input and output data files. Since some of the output generated by the model could be very large, the use of floppy drives A: and B: for routing the output from long runs is not recommended. The user should ensure that there is enough storage space on the hard disk for the output (should allow 1-2 Megabytes of hard disk space for IPRLVL=0 for 100 time steps). As a good practice, the user is encouraged to create separate directories for different applications and save the output of each application in these individualized directories.

1.4.3 Generating Output

At the end of model execution, **BRI-STARS** results are stored in several output files. These files can be imported into a variety of commonly available word processors, desktop publishing programs, and spreadsheet and/or graphics packages for presenting results with varying levels of sophistication. In general:

1)   Import the ASCII formatted output file (OUTPUT.OUT) into a word processor to enhance the formatting of the document.

2)   Use the post-processor program BSTXSECT provided with the **BRI-STARS** package to manipulate the unformatted Cross Section Output (XSECTS.XSC) file. The BSTXSECT output can be used in conjunction with a variety of plotting/spreadsheet packages to generate report quality cross section plots at various simulation time steps.

3)   Import the ASCII formatted Water Surface and Thalweg Profile Output (WSPROFS.WSP) file into a spreadsheet or graphics program to generate tabulated profiles and water surface profile plots.

Formatted Numeric Output

The procedure for generating an output file from successful **BRI-STARS** run is described in the previous section. This output file can be routed to various dot matrix or laser printers for obtaining hardcopy printouts.

Most printers, as a default, operate using a fixed-width font on an 80-column page width in "portrait" orientation setting. **BRI-STARS** utilizes this default setting to format the printouts resulting from sediment routing applications involving up to 5 sediment size groups. For applications involving more than five sediment size groups, to obtain a legible output, a landscape (sideways) font or a 16.6-characters-per-inch compressed font should be used. The compressed and landscape fonts are available in HP LaserJet Series II™ internally. Additionally, by importing the ASCII **BRI-STARS** output into word processor and by using a fixed-width font (such as Letter Gothic or Courier fonts), users may utilize other text enhancements such as bolding, graphic lines, etc.

Cross Section Profile Plots

In order to improve the plotting capacity of **BRI-STARS**, a simple approach is taken. In this approach, the model results which are stored in the file XSECTS.XSC are transferred into a format compatible with widely used microcomputer graphics packages.

Step 1 Run the utility program BSTXSEC to convert the format of the cross section output file which is generated by **BRI-STARS** into spreadsheet program-compatible format. The assigned file name for the intermediate file is XSECTS.PRN to follow common file naming conventions.

Step 2 Import XSECTS.PRN into Quattro Pro for Windows or other spreadsheet programs, and create a graph.

Step 3 Generate hardcopy printouts through the spreadsheet or graphics programs.

Water Surface Profile Plots

In order to generate water surface profile plots to display **BRI-STARS** results, a simple procedure is followed. In this procedure, the Water Surface and Bottom Elevations Profile file which is generated at the end of the **BRI-STARS** run is imported into a spreadsheet program as an ASCII numeric file.

To create water surface plots following a successful **BRI-STARS** run, the following two-step procedure is needed.

Step 1 Import a copy of WSPROFS.WSP generated as an output into a spreadsheet program, and create an X-Y graph.

Step 2 Enhance and print the graph utilizing the graphics tools.

1.5   VISUAL OUTPUT FROM BRI-STARS

BRI-STARS visual output can be observed in the following screen windows:
1)   Thalweg profile window.
2)   Stream tubes and velocities window.
3)   Topographic changes window.

1.5.1   Thalweg and Water Surface Profile Window

The thalweg and water surface profile window displays the INITIAL (green line) and the CURRENT (red line) thalweg profiles as the main plot on the monitor. In this main plot, the computed water surface profile is indicated by a blue line. In the three vertically stacked minor frames, cross sections are displayed at user selected
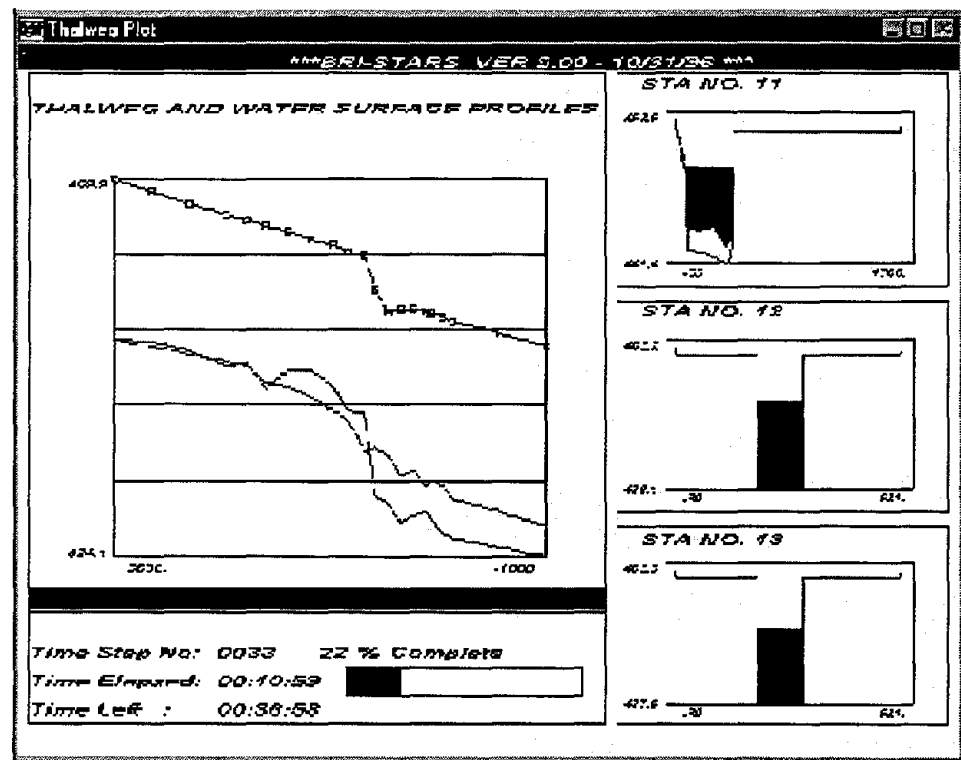
Figure 2. Thalweg and water surface profile window.

stations. In the cross section plots, the starting bottom elevations are identified by a green line and the current bottom elevations are shown by a red line. Depending on user options, the water surface line is omitted, shown as a blue line, or shown as a fill. The vertical and horizontal viewing limits of cross sections and the water surface profile viewing boundaries are specified in the PV record.

1.5.2 Velocities and Stream Tubes Window

The velocities and stream tubes window displays the current stream tube boundaries as the main plot on the monitor.. The color-coded contours show computed velocities in a reach by laterally and longitudinally interpolating stream tube velocities. In the three vertically stacked minor frames, discharge hydrographs at stations specified in the PV records are given. The upstream and downstream reach boundaries for screen viewing are controlled by the PV record.
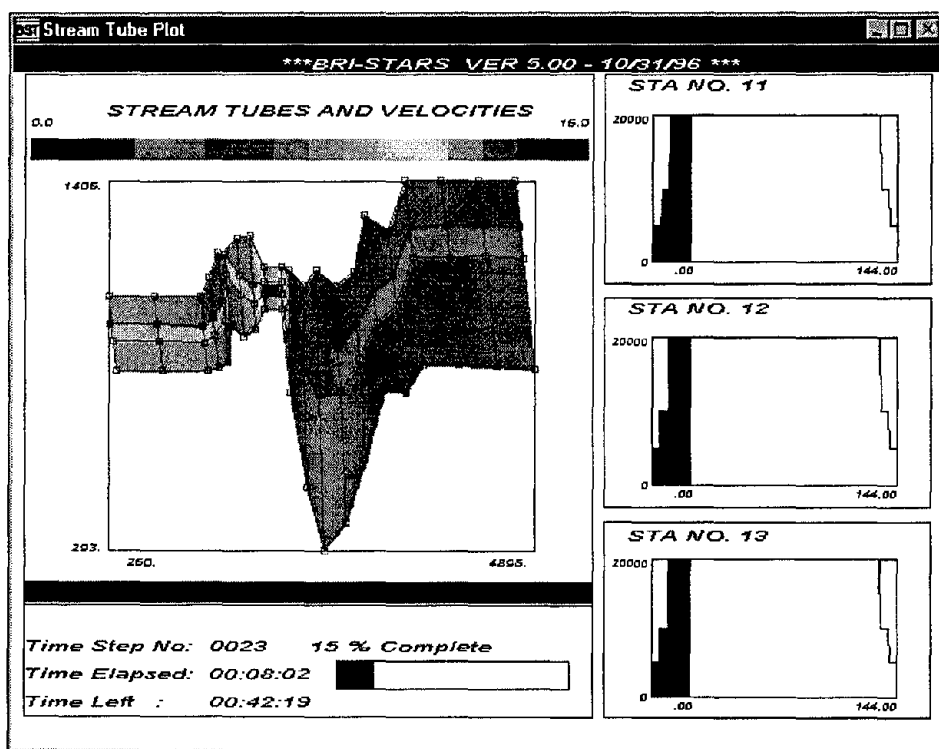
Figure 3. Velocities and stream tubes window.

1.5.3 Topographic Changes Window

The topographic changes window displays cumulative bed elevation changes up to the current simulation time step as the main plot on the monitor. The color-coded bed elevation change contours show computed scour/deposition at various longitudinal and lateral locations in the study reach. Stream tube boundaries are superimposed onto the screen plots to indicate the location of the main flow channel. In the three vertically stacked minor frames, bed-material size distributions are given at selected stations. Upstream and downstream reach boundaries and the stations for discharge hydrograph viewing are controlled by the PV record.
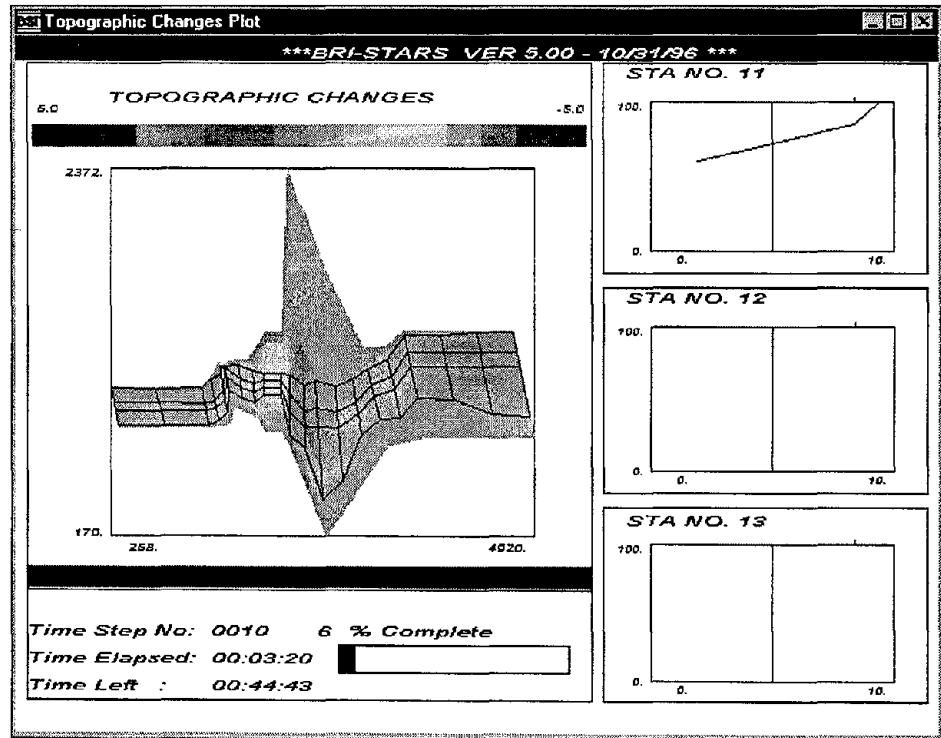
Figure 4. Topographic changes window.

1.6   ORDER OF BRI-STARS RECORDS

The **BRI-STARS** data file consists of a logical sequence of groups of data. These groups are:

- **Title information.**
- **Channel geometry.**
- **Roughness.**
- **Energy losses.**
- **Stream tube.**
- **Hydrologic information.**
- **Hydraulic boundary conditions.**
- **Sediment transport.**
- **Pier, abutment, and contraction scour.**
- **Printout.**
- **Streampower minimization.**

In general, **BRI-STARS** data files contain the following records in the order listed below:
- Title Information Records:

  TT   Title Records.

- Geometric Data Records:

  NS   Number of Sections.

  ST   Station.

- **ND**   Number of Sub-Division.
- **GP**   Global Positioning.
- **XS**   Cross Section.

- Roughness Data Records:

  RN   Roughness Equation.
  RH   (or **RB**) Roughness Values/Break Points.

- Energy Losses Data Records:

  CL   Coefficients of Local Losses Record.
  CE   Coefficients of Expansion/Contraction Energy Losses.

- Bottom Elevations Data Records:

  CB   Channel Bottom.

- Stream Tubes and Flow Distribution Data Records:

  NT   Number of Stream Tubes Record.

- Hydrologic and Time Step Data Records:

  IT   Number of Iterations Record.
  QQ   Discharge Record.
  SS   Stage Record.
  TL   Station Identification for Stage-Discharge Table Record.
  SQ   Stage-Discharge Table Record.
  DD   Discretized Discharge Record.
  RC   Rating Curve Record.
  TQ   Table of Discharge Record.
  QL   Lateral Water Inflow Record.

- Sediment Data Records:

  SO   Sediment Transport Option Record.
  QS   Sediment Discharge Record.
  SE   Sediment Transport Equation Record.
  TM   Water Temperature Record.
  SF   Number of Size Fraction Record.
  SG   Sediment Size Groups Record.
  SD   Sediment Size Distribution Record.
  SB   Sediment Size Breakpoint Record.
  SX   Size Distribution Across Channel Record.
  SL   Lateral Sediment Inflow Record.

- Bridge Scour Data:

  PS   Pier Stations Record.
  PE   Pier Scour Equation Record.
  PP   Pier Scour Parameters Record.
  PC   Pier Equation Coefficient Record.

- Screen Output Records:

  PV   Visual Screen Output Record.

- Output File Generation Records:

PR	Printout Record.	
PL	Plotting Option Record.	
PX	Channel Cross Section Plotting Record.	
PW	Water Surface Profile Plotting Record.	

● Minimization Data Records:

MN	Minimization Option Record.	
MI	Minimization Iterations Record.	
MR	Bed Elevation/Width Variation Record.	

1.7 DATA NEEDS FOR BRI-STARS

In order to generate a data file for a **BRI-STARS** simulation, the following data is needed:

● **Title Information.**
● **Geometric Data.**
● **Hydraulic Data.**
● **Roughness Data.**
● **Bottom Elevations Data.**
● **Energy Losses Data (Optional).**
● **Stream Tubes and Flow Distribution Data.**
● **Computational Time Step Data.**
● **Stage-Discharge Data.**
● **Sediment Data (Optional).**
● **Sediment Equation.**
● **Sediment Inflow Hydrograph.**
● **Sediment Size Data.**
● **Bridge Scour Data (Optional).**
● **Screen Output Control Data (Optional).**
● **Output File Control Data.**
● **Minimization Data (Optional).**

In the absence of a data group, engineering analysis may be required to extrapolate data from similar watersheds in the geographic region and/or estimations from similar flows.

1.8 BST-PLOT UTILITY PROGRAM

1.8.1 Introduction

The BST-PLOT (BRI-STARS Water Surface Profile Plotting) utility program is used to animate the water surface and bottom (thalweg) profiles computed by **BRI-STARS**. It can be activated at any time during the execution of **BRI-STARS** to view the current water surface profile output or an existing water surface output file generated earlier. By plotting the water surface and bottom profiles with this utility, the water and sediment routing processes can be quickly reviewed, and the simulation results can be visualized.

The menu bar in the BST-PLOT window uses pull-down menus in accordance with standard Windows applications. Each menu and its contents are explained in table 1. The steps in using the BST-PLOT utility program are given in the following.

Table 1. BST-PLOT main menu and its contents.

Menu	Contents	Explanation
File	**Input File**	Select a file for plotting
	Run	Start plotting water surface and bottom profiles
	Stop	Stop plotting
	Goto Frame	Go to a specified frame
	Single Frame Advance	Advance one frame
	Single Frame Reverse	Reverse one frame
	Exit	Exit BST-PLOT and go back to the **BRI-STARS** main window
Edit	**Select All**	Select all contents shown on the screen
	Select Graph	Select graph by highlighting an area on the screen
	Copy	Copy the contents selected by "Select All" or "Select Graph" into buffer
	Print	Print the contents stored in the buffer
View	**Superimpose Bottom Prof.**	Superimpose bottom profile plots
	Superimpose Surface Prof.	Superimpose water surface profile plots
	Grid On	Show grid lines on the screen
	Grid Off	Do not show grid lines on the screen
	Horizontal Axis	Change the minimum, maximum, and incremental values of horizontal axis
	Vertical Axis	Change the minimum, maximum, and incremental values of vertical axis
Speed	**Slow**	Use slow speed to plot the profiles
	Normal	Use the default normal speed to plot the profiles
	Fast	Use fast speed to plot the profiles
Status	**Pause**	Pause the plotting
Window	**Full Screen**	Use full screen to show the profile plotting window
	Status Bar	Hide the status bar at the bottom of the window
Help	**About**	Information about the **BRI-STARS** Water Surface Profile Plotting utility

1.8.2 Steps in Using BST-PLOT

Step 1 Activate the BST-PLOT utility program by choosing **View** from the main menu of **BRI-STARS** and then choosing **Animated WSP/Thalweg Profs.**

Step 2 BST-PLOT uses the current water surface and bottom profile output generated by **BRI-STARS** as the default input file for viewing. Users can select a different file to view by using **Input File** under **File** menu command.

Step 3 Choose **Run** under the **File** menu command to view the water and bottom profiles for the selected file.

Step 4 Choose **Exit** under **File** menu command to exit BST-PLOT and to return back to the main window of **BRI-STARS**.

1.8.3 Options for BST-PLOT

- **To view a specified frame (time step).** To view the water surface and bottom profiles for a specified frame (time step), choose **Goto Frame** under **File** menu, then specify the frame number in the "Goto Frame" dialog box. Click "OK" to view the specified frame. If you click "Cancel," the operation will be canceled.

- **To view the water surface or bottom profiles one frame at a time.** To view the water surface or bottom profiles one frame at a time, you can use the **Single Frame Advance** or **Single Frame Reverse** under the **File** menu. This option will advance or reverse plots by a single frame.

- **To superimpose the water surface or bottom profiles.** The previous water surface or bottom profile plots can be superimposed on the current screen plot for viewing the changes from preview steps. Click on **Superimpose Bottom Prof.** under the **View** menu to turn on or turn off the superimposing of bottom profiles. Similarly, click on **Superimpose Surface Prof.** under the **View** menu to turn on or turn off the superimposing of water surface profiles. By default, superimposing bottom profiles is chosen. Superimposing water surface profiles is not selected by default.

- **To show or hide grids on the screen.** Choose **Grid On** under the **View** menu to show grids on the screen, and choose **Grid Off** under the **View** menu to hide grids on the screen.

- **To specify the view range.** Choose **Horizontal Axis** under the **View** menu; then enter the upstream, downstream, and incremental values of horizontal axis in the "Horizontal Axis" dialog box. Click "OK" to change the horizontal axis to the specified values for viewing. By clicking "Reset," you can set the Horizontal Axis back to the default values determined by the program. Clicking "Cancel" cancels the operation. Similarly, choose **Vertical Axis** under the **View** menu to change and specify the vertical range for viewing.

- **To change the plotting speed.** You can change the plotting speed by using **Slow, Normal**, and **Fast** under the **View** menu. By clicking on **Normal** under the **View** menu, the plotting speed will be set to the normal speed, which is the default speed when you activate the BST-PLOT window. To plot the water surface and bottom profiles with slower speed than current plotting speed, choose **Slow** under the **View** menu. You can repeat click on **Slow** under the **View** menu to reduce the plotting speed. Similarly, you can use **Fast** under the **View** menu to increase the plotting speed. By repeat clicking on **Fast** under the **View** menu, the plotting speed will increase incrementally.

- **To print the water surface or bottom profile plotting.** Use **Select All** or **Select Graph** under the **Edit** menu to select the range of plotting, and then click **Copy** to copy the selected plotting to the buffer. Next, click on **Print** to

print the selected graph, or paste to other Window utilities, such as "MS-Paint," for editing.

- **To use full screen plotting.** Choose **Full Screen** under the **Window** menu to show the plotting window using full screen. To hide the status bar at the bottom of the plotting window, click on the **Status Bar** under the **Window** menu.

- **To pause the plotting.** To pause the plotting, click on **Pause** under **Status** menu. Clicking on **Resume** resumes the window and continues the plotting.

1.9   BST-XSECT UTILITY PROGRAM

1.9.1 Introduction

The BST-XSECT (BRI-STARS Cross Section Data Conversion) utility program is used to convert the unformatted cross section profiles output computed by **BRI-STARS** into series of x-y-z points for generating 2- and 3-dimensional cross section plots. This utility can be activated from the main menu of **BRI-STARS** at the end of a simulation run by first selecting the **View** option and then choosing the **X-Sectn Data Conversion** option from the pull-down menu. By converting the unformatted data into tabulated "station-distance across channel-elevation" series of points, the model output can be used in a variety of spreadsheet and graphics program, to display the simulation results.

Table 2. BST-XSECT main menu and its contents.

Menu	Contents	Explanation
File	**Input File**	Select a file for cross section conversion
	Run	Start data conversion
	Exit	Exit BST-XSECT and go back to the **BRI-STARS** main window
Edit	**Input File**	Use built-in Notepad Plus to view the unformatted cross section file
	Converted File	Use built-in Notepad Plus to view the converted cross section output file
	Print	Print the contents stored in the buffer

1.9.2 Steps in Using BST-XSECT

Step 1 Activate the BST-XSECT utility program by choosing **View** from the main menu of **BRI-STARS**, and then choosing **X-Sectn Data Conversion.**

Step 2 BST-XSECT uses the current cross section profiles output generated by **BRI-STARS** as the default input file for conversion. Users can select a different file for conversion by using **Input File** under the **File** menu command.

Step 3 Choose **Run** under the **File** menu command to activate the conversion process.

Step 4 Choose **Exit** under the **File** menu command to exit BST-XSECT and to return back to the main window of **BRI-STARS**.

1.9.3 Options for BST-XSECT

● **To generate cross-section profiles at a station at various time steps.** To generate a series of cross section profiles at a station, select **(C)hoose Parts** when prompted if **(E)ntire file** or parts are to be converted. Specify the station number when prompted, and depending on the graphics package format, insert spaces between time steps.

● **To generate cross-section profiles at all stations at various time steps.** To generate a series of cross section profiles at all stations, when prompted, select **(E)ntire file**.

● **To edit (or view) the converted file.** Select the **Edit** option from the main menu and then choose the **Converted File** from the pull-down menu.

1.10 BRI-STARS QUATTRO PRO EDITOR

1.10.1 Introduction

The BSTEMPLT is a Quattro Pro worksheet with specially programmed macros (sequences of commands which automate certain procedures) for editing and entering **BRI-STARS** input data. The worksheet is color-coded with cell definitions to facilitate data entry and manipulation. The macros provided in this worksheet allow users to generate data entry templates automatically. By following the instructions given for each cell, users can easily enter their data into the worksheet. If the geometry data, hydrology data, and sediment data are already in a separate worksheet file, these data can be imported into the current worksheet by the "cut-and-paste" facility provided by the Windows 95 environment. After entering the data into the Quattro Pro worksheet, the information can be transferred into the **BRI-STARS** input data format automatically.

The "BSTEMPL.WB2" was developed in Corel Quattro Pro for Windows. In order to use this worksheet, Quattro Pro V6.0 or later for Windows is required.

1.10.2 Steps in Using BSTEMPLT

As shown in figure 5, the three steps in using BSTEMPLT worksheet are: BUILDING A TEMPLATE, ENTERING DATA, and GENERATING BRI-STARS INPUT FILE. In the first step, using the built-in macros a data entry template for the specific problem is generated. This template reflects the basic layout of the data file with properly ordered records. In the second step, the data for each cell in the template is entered manually. In the last step, following the data entry the spreadsheet information is transferred into BRI-STARS input data format. The details of using BSTEMPLT are given in the following.
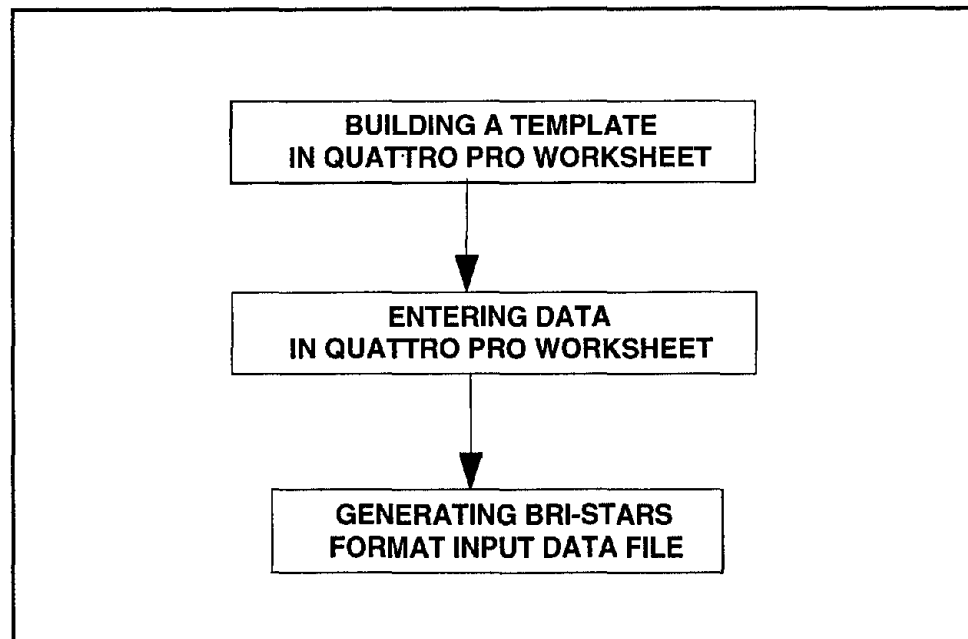
Figure 5. Steps in using BSTEMPLT.

STEP 1. BUILDING A TEMPLATE

1.   Get information about your data.

   a)   Unit system used in the data, i.e., English units or metric units.

   b)   Cross sectional data information, including the number of cross sections and the number of data points at each cross section.

   c)   The number of discretized data values for the stage-discharge data.

   d)   The number of discretized data values for the sediment discharge data.

   e)   The number of discretized data values for the water temperature data.

   f)   The number of sediment size groups.

   As an example, the BRI-STARS input file generated through BSTEMPLT for I5 Bridge data is listed in Examples. The data information collected for this example problem is given in the following.

   (i)   The unit system used in the example problem is English units.

   (ii)   Cross sectional data information, including the number of cross sections and the number of data points at each cross section, is listed in table 3.

   (iii) The number of discretized data values for the stage-discharge data is 144.

   (iv)   The sediment inflow discharge at upstream boundary is 300,000 tons/day for 144 time steps.

   (v)   The water temperature is 55°F for 144 time steps.

(vi)   The number of sediment size groups is 3.

Table 3. Cross sectional data information for I5 Bridge data.

No. of Cross Sections	No. of Data Points		No. of Cross Sections	No. of Data Points		No. of Cross Sections	No. of Data Points
1	29		8	26		15	26
2	29		9	24		16	22
3	29		10	26		17	17
4	29		11	18		18	26
5	26		12	18		19	13
6	28		13	18		20	13
7	26		14	20		21	13

2.   Open "BSTEMPLT.WB2" in Quattro Pro (Version 6.0 or later) for Windows to start a new data entry task and save it under a different name. Leave the original "BSTEMPLT.WB2" unchanged.

Note: For this step, the default startup macro \0 is needed. To check your startup macro, you may right-click on the Corel Quattro Pro title bar and choose Application Properties from the QuickMenu or pull down the Edit menu and choose Preferences. The window titled Startup Macro in the Macro tab displays the startup macro. This entry must be set to \0. If it is not \0, modify the entry and reopen the "BSTEMPLT.WB2."

For example, after "BSTEMPLT.WB2" is opened, you save it as "BSTINPUT.WB2". From now on, you will work in the Quattro Pro file "BSTINPUT.WB2".

3.   Click the quick button ▓Change Unit System▓ to specify the unit system. If the unit system in cell B6 is already in the one you need, then you can skip this step.

For the example problem, choose "English Unit System."

4.   Move the cursor down to the "NS" record line and enter the number of a cross section. Then click on the quick button ▓Generate Cross Section Template▓ to generate a cross sectional template for the specified number of cross sections.

For the example problem, you enter 21. Then click on the ▓Generate Cross Section Template▓ button and choose "GENERATE AND ADJUST SECTION TEMPLATE"; next choose 'USE SPECIFIED NO. OF SECTIONS: 21". For slower computers, this step may take a while. You should wait until finished.

5.   Move the cursor to the "ST" record for cross section number 1, and enter the number of data points. Then click on the quick button next to it to automatically adjust the number of "XS" records, so that the number of "XS" records matches the number of data points specified in "ST" record for section 1. Before you use the quick button, make sure the cell showing Number of Points at Station 1 is highlighted.

For the example problem, go to the cell requiring the number of data points for cross section no. 1 and change the default value of 50 to 29.

6.   Repeat step 5 for all cross sections to specify the number of data points and adjust the number of "XS" records for each cross section.

For the example problem, you enter the number of data points given in table 3 for other cross sections and adjust the number of "XS" record using the quick button.

7.   Move the cursor down to the "RH" record. Then click on the quick button **Adjust No. of "RH" Records if any No. of Sections or Points Changed** in order to automatically adjust the number of "RH" records for each cross section.

8   Move the cursor down to the "IT" record; enter the number of time iterations.

For the example problem, you enter 144 for the number of time iterations.

9.   Move the cursor down to the "SQ" record. Then click on the quick button **Generate & Adjust Stage-Discharge Record Template** to generate the stage-discharge data template.

For the example problem, you follow the Macro Menu and choose "GENERATE & ADJUST 'SQ' RECORD TEMPLATE." Then choose "USE THE VALUE SPECIFIED IN 'IT' RECORD: 144." You can choose "ENTER NEW VALUE" to specify a new value when needed.

10.   Move the cursor down to the "QS" record. Then click on the quick button **Generate & Adjust Sediment Discharge Record Template** to generate the sediment discharge data template.

For the example problem, you follow the Macro Menu and choose "GENERATE & ADJUST 'QS' RECORD TEMPLATE." Then choose "ENTER NEW NUMBER FOR SEDIMENT DISCHARGE RECORDS," enter 1, and click "OK." Choose "USE SPECIFIED NUMBER FOR 'QS' RECORD: 1."

11.   Move the cursor down to the "TM" record. Then click on the quick button **Generate & Adjust Water Temperature Record Template** to generate the temperature data template.

For the example problem, you follow the Macro Menu and choose "GENERATE & ADJUST 'TM' RECORD TEMPLATE." Then choose "ENTER NEW NUMBER FOR TEMPERATURE RECORDS", enter 1, and click "OK." Choose "USE SPECIFIED NUMBER FOR 'TM' RECORD: 1."

12.   Move the cursor down to the "SF" record. Then enter the number of size fractions. Click on the quick button next to it to adjust the number of "SG" records so that the number of "SG" records will match the number specified in the "SF" record.

For the example problem, you enter 3.

STEP 2. ENTERING DATA

Once the general data layout is generated, the specified data for each cell in the worksheet is entered according to the instruction for each cell. The instruction for each cell in the worksheet is labeled in red (required data) or green (optional data).

●   You can enter the data manually by following the instructions and entering the corresponding data for each cell.

●   Data from an existing spreadsheet file can also be imported by the cut and paste facility in the Windows environment into the current worksheet.

STEP 3. GENERATING BRI-STARS INPUT FILE

The information which has been entered into the Quattro Pro worksheet needs to be transferred into BRI-STARS input format. This is done by clicking on the button

Generate BRI-STARS Format Input File When Finished Filling BSTEMPLT.

For the example problem, when you click on the quick button, BRI-STARS input file "BSTINPUT.DAT" is generated. The Quattro Pro template file for I5 Bridge is provided in the BRI-STARS package under the file name "I5INPUT.WB2". You can compare your template file "BSTINPUT.WB2" for the I5 bridge data with "I5INPUT.WB2".

1.10.3 Notes

- Color codes used in the worksheet are as follows:

  Red — data field description.
  Blue — user instruction and tips.
  Green — optional fields which may be left unchanged.
  Black — fields which must be filed by the user.

- The macros are stored in pages MACRO and RESOURCES. Do not use these pages for data editing.

- If you create a block name, be sure not to overwrite existing block names.

- The default values provided in the template file "BSTEMPLT.WB2" are as follows:

  - English unit system.
  - 10 cross sections having trapezoidal shape with main channel and left/right floodplain.
  - 50 data points for each cross section.
  - 3 channel subsections.
  - Manning roughness value of 0.025.
  - Coefficients of contraction and expansion losses: 0.1 and 0.3.
  - 3 stream tubes.
  - 20 time iterations.
  - 20 discretized water discharges.
  - 20 discretized sediment discharges.
  - Yang's Sediment transport equation.
  - Active layer thickness multiplier of 50.
  - 20 discretized water temperatures.
  - 5 size fractions in the sand size range.

1.11 LIST OF BRI-STARS EXAMPLES

The **BRI-STARS** package is supplied with a series of examples to demonstrate the various options available in the model. The summary listing is given in table 4 with the feature of each example.

Table 4. Examples for **BRI-STARS** and their features.

Example File	Explanation and Features
EXMPL001.DAT	• CSU Laboratory study • Default Screen Plotting • RH record to change n=0.02 to 0.04 behind piers • IT record to set convergence limit to 0.0001 ft • CL record to set CL=1 • NT record to set number of tubes to 4
EXMPL002.DAT	• Dry Creek example with WSPRO input • IT to set convergence criteria to 0.1 ft • SF record to set single sediment size • WB to use WSPRO data directly
EXMPL003.DAT	• Hatchie Data (USGS) • 6 sediment time steps within one hydraulic time step • PV records • PX record for generating cross section files
EXMPL004.DAT	• CSU Laboratory Data • PE, PS records for local pier scour • PV records with zooming • RH record to change n=0.02 to 0.04 behind piers • CL set to 1 at U/S station • IT to set level of accuracy in hydraulic computations
EXMPL005.DAT	• CSU Data • CM Comment record • TM to set temperatures to 70°F • Simulation of piers by altering x-sections
EXMPL006.DAT	• Lower Tornillo study • RH to show natural channel roughness distribution • PR to control printout • NF, SG, SD records for sediment routing in graded beds
EXMPL007.DAT	• Red Fox • Global positioning records
EXMPL008.DAT	• Man-made channel • RC records for multiple rating curves • DD records for discretized discharges
EXMPL009.DAT	• I5-Bridge data • Global positioning • Natural river data
EXMPL010.DAT	• I5-Bridge data • Date-Time function for variable time increment step

2. STREAM TUBE MODEL FOR AGGRADATION AND DEGRADATION

2.1   STREAMLINES

A streamline is a line to which, at each instant, the velocity vectors are tangent. This concept is illustrated in figure 6.
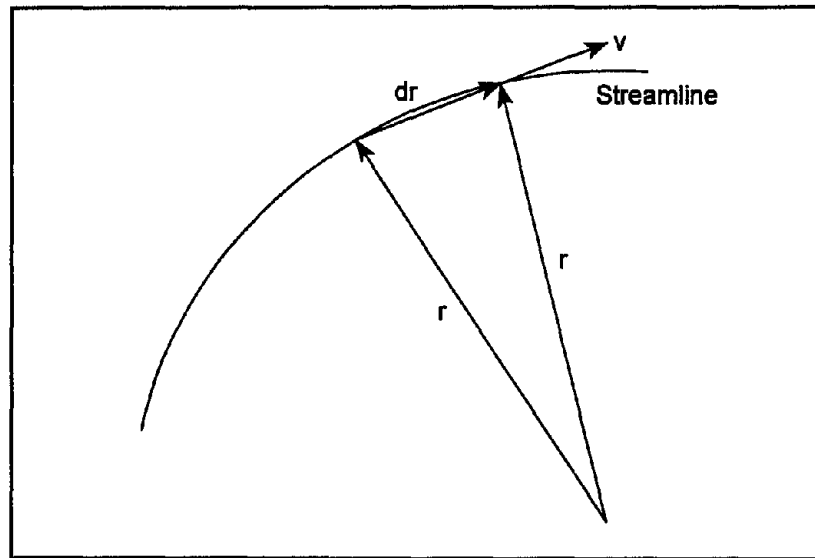
Figure 6. Streamline definition sketch.

Since v and dr are parallel, their cross product must be zero. Expansion of the cross product yields the equation of streamlines

$$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w} \tag{1}$$

where u, v, and w are the velocity components in the x, y, and z directions, respectively. Considering two-dimensional flow, the expression for the streamlines becomes

$$\frac{dx}{u} = \frac{dy}{v} \tag{2}$$

In many flow situations the pattern of the streamline represents very closely the field lines in a geometrically similar system. When this occurs, the analytical techniques of the branch of mathematics known as potential flow theory can be used to describe the flow situation. The potential flow theory assumes the quantity corresponding to rotation is zero; therefore, the flow must be irrotational. Under these conditions, the streamline patterns and the Bernoulli equation can be used to calculate the velocity and pressure variations throughout the flow field.

According to the mathematics of the potential flow theory, the equation of streamlines (Eq. (2)) defines a differential equation that is exact if there exists a function $\psi(xy)$ such that

---

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$$d\psi = -udy + vdx \tag{3}$$

The test for exactness is

$$-\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y} \tag{4}$$

which is the condition imposed by continuity. The total differential of ψ is

$$d\psi = \frac{\partial \psi}{\partial x}dx + \frac{\partial \psi}{\partial y}dy \tag{5}$$

and so, comparing Eqs. (3) and (4)

$$u = -\frac{\partial \psi}{\partial y} \quad and \quad v = \frac{\partial \psi}{\partial x} \tag{6}$$

Therefore, the x and y components of velocity can be obtained from ψ, defined as the stream function. Considering Eqs. (3) and (4), it is apparent that

$$d\psi = 0 \tag{7}$$

Therefore, streamlines are lines of constant stream function. Additionally, it can be shown that the rate of flow between two streamlines at successive sections is the difference between the value of the stream functions,

$$q = \int_A^B d\psi = \psi_B - \psi_A \tag{8}$$

where q is the discharge per unit width. Physically, this can be considered the definition of the stream function. Since the discharge between any two streamlines is equal to the difference between them, the velocities vary inversely with the streamline spacing. Therefore, visual inspection of the streamlines gives a qualitative picture, and differentiation of the stream function describes a two-dimensional flow field.

For unsteady incompressible flows, the equation of motion along a streamline is

$$\frac{1}{g}\frac{\partial V_s}{\partial t} + \frac{\partial}{\partial S}\left(\frac{P}{\gamma} + \frac{V^2}{2g} + h\right) = 0 \tag{9}$$

where t is the time; V_s is the velocity component along a streamline; P is the pressure; γ is the specific weight of water; V is the velocity; g is the gravitational acceleration; S is the distance along a streamline; and h is the hydraulic head. The equation of motion perpendicular to a streamline is

$$f_n = \frac{1}{g}\frac{\partial V_n}{\partial t} + \frac{\partial}{\partial n}\left(\frac{p}{\gamma} + h\right) = \frac{1}{g}\frac{V^2}{r} \tag{10}$$

where f_n is the force acting normal to a streamline; V_n is the velocity component normal to a streamline; n is the direction normal to a streamline; and r is the radius of curvature of a streamline.

For steady flow, Eq. (9) reduces to

$$\frac{P}{\gamma} + \frac{V^2}{2g} + h = H_s \tag{11}$$

where H_s is a constant along a streamline. For steady irrotational flow, this equation can be further simplified to

$$\frac{P}{\gamma} + \frac{V^2}{2g} + h = H \tag{12}$$

where H is a constant throughout the fluid.

2.2 STREAM TUBES

Stream tubes are imaginary tubes bounded by streamlines. Since the discharge between streamlines is constant, each stream tube carries a constant discharge along its length.
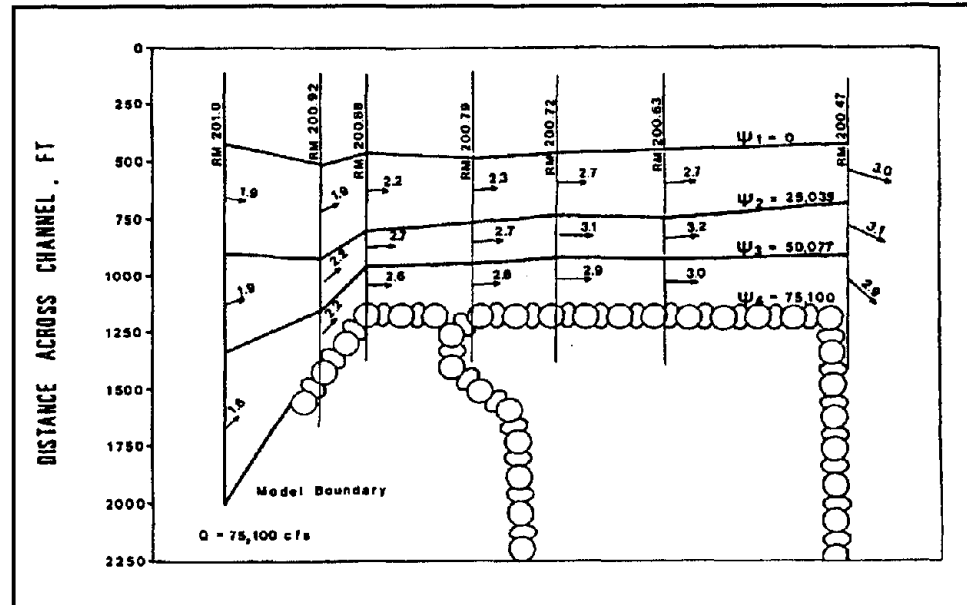
Figure 7. Plan view of a study reach using stream tubes.

For steady, incompressible flows, it is possible to write

$$\frac{P}{\gamma} + \frac{V^2}{2g} + h = H_t \tag{13}$$

where H_t is a constant along the stream tube. When applied to real fluids, the total head H_t is not a constant. Due to friction and other local losses, it is reduced in the direction of flow. Along a river, it is possible to determine the variation of this quantity. This is the basic assumption in the stream tube computation. The concept of stream tubes is illustrated in figure 7. In this figure, the stream tubes are shown in the plan view of a study reach.

2.3 GENERAL DESCRIPTION OF THE MODEL

The first major component of **BRI-STARS** is based on a stream tube computer model with fixed-channel width developed by Molinas (1983a) to simulate streambed variations in rivers for which sediment and hydraulic data are limited. Using stream tubes allows the lateral and longitudinal variation of hydraulic conditions as well as sediment activity at various cross sections along the study reach. The object of the model is to study complicated sedimentation problems for which there is interaction between the flowing water-sediment mixture and the alluvial river channel boundaries. In order to accomplish this purpose, the water surface profile and other

hydraulic variable computations for supercritical, subcritical, and the combination of both flow conditions must be carried out without interruption. The bed armoring and the breaking of the armor layer are incorporated to study longer periods of flow durations.

The stream tube computer program is a semi-two-dimensional program with the third dimension, depth, being intrinsically incorporated into the computations. As such, it has the basic limitations of every two-dimensional program: secondary flows cannot be simulated. The channel is divided into a preselected number of tubes. The bed elevation in each stream tube is allowed to move vertically up or down depending on the flow conditions. As a result, while one section of channel is eroding, another section might be aggrading. Depending on the number of stream tubes to be used, the channel cross section changes are averaged across different channel subsections of varying widths. Since the computer time and space are directly related to the number of stream tubes to be used, the user is required to decide on the optimum number of tubes. Bed forms are not simulated due to the lack of a generally accepted methodology for determining them. Even though provisions are made to expand the program to include river confluences and middle islands, at this point these options are not available. The channel boundaries are fixed in the lateral direction, and formation of meander bends cannot be simulated.

The computer model using stream tubes can be applied to a variety of river problems. It can be used as a fixed-bed model to compute water surface profiles for subcritical, supercritical, or the combination of both flow conditions involving hydraulic jumps. This option allows the applications involving the computation of water surface profiles in man-made channels with clear water, flow profiles over spillways, or flow profiles in natural river channels where the interaction between the sediment-water mixture and the channel bed are negligible. As a movable bed model, the computer program can be applied to route water and sediment through natural river channels. The use of stream tubes allows the variation of hydraulic conditions and sediment activity not only in the longitudinal, but also in the lateral direction. With the selection of a single stream tube, the model becomes one-dimensional. Average channel response to changes in certain riverflow or sediment conditions can be studied. With the selection of multiple stream tubes, the model becomes two-dimensional. The changes in the cross section geometries in the lateral direction can be simulated. Since the bed elevation changes are not averaged over the entire active channel widths as in one-dimensional models, more realistic channel erosion or aggradation can be simulated. This option provides valuable information where certain navigation depths have to be maintained. It can also be used in bank stability problems to identify expected regions of bank instabilities. The armoring process provided in the program allows study of river sedimentation problems for longer periods of time.

The stream tube computer model (Molinas, 1983a, 1983b, 1986; Molinas, Denzel, and Yang, 1986) for routing water and sediment is composed of three major components: (i) backwater computations, (ii) stream tube computations, and (iii) sediment routing computations. These computational blocks are linked together as shown in figure 8.

At each time step, first, backwater computations are carried out for the entire reach with the channel treated as a single tube. Second, with the computed water surface elevations, lateral locations of stream tubes at each cross section are determined. With each stream tube treated as an independent channel, the hydraulic variables along it are computed. Third, sediment is routed through each stream tube satisfying
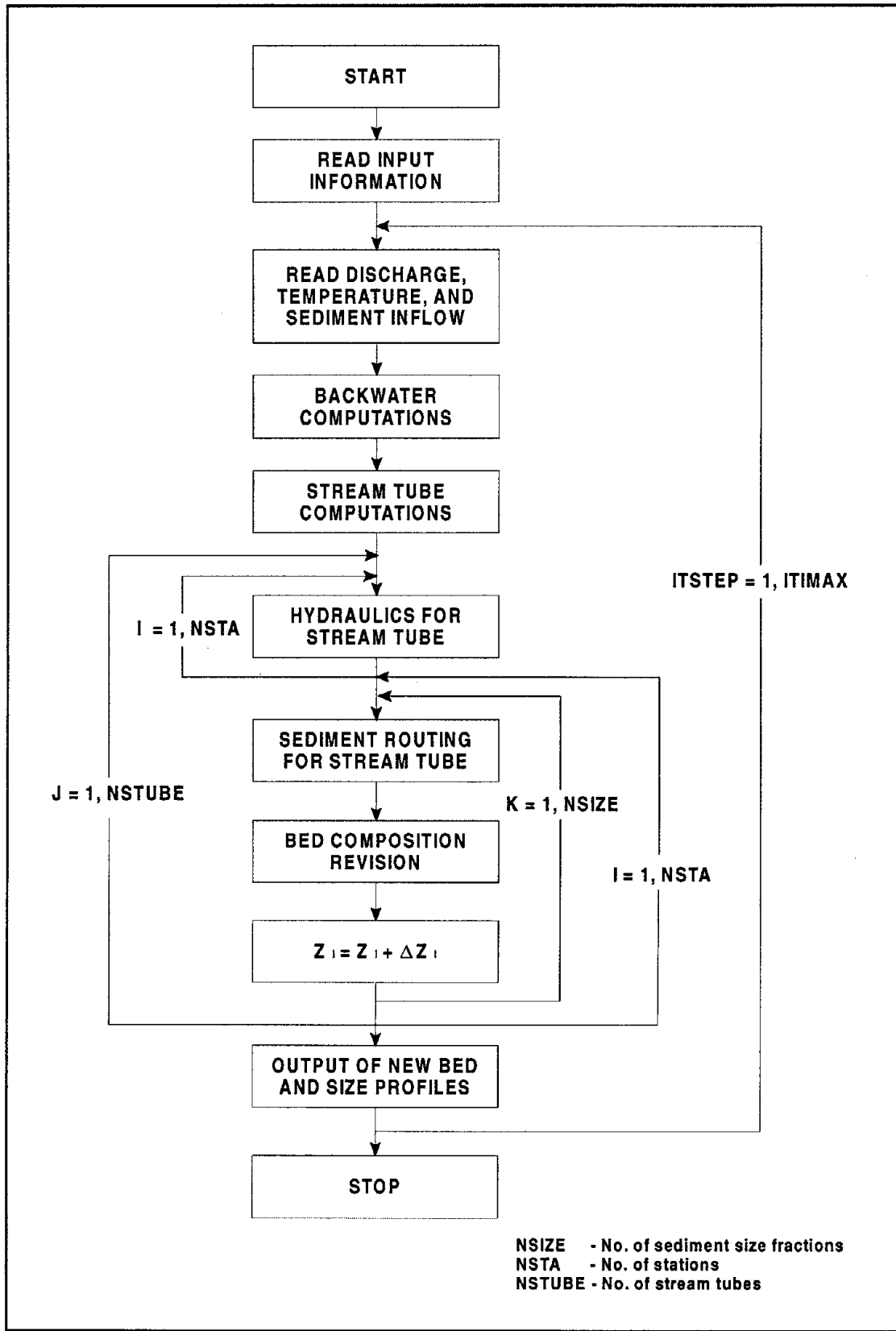
Figure 8. Flow chart for the tube computer model.

the sediment continuity equation. At the end of these computations, bed material compositions are revised and channel bed elevations are updated. An armoring procedure is incorporated into the sediment routing computations. Computations are proceeded in time through defined water and sediment discharge hydrographs.
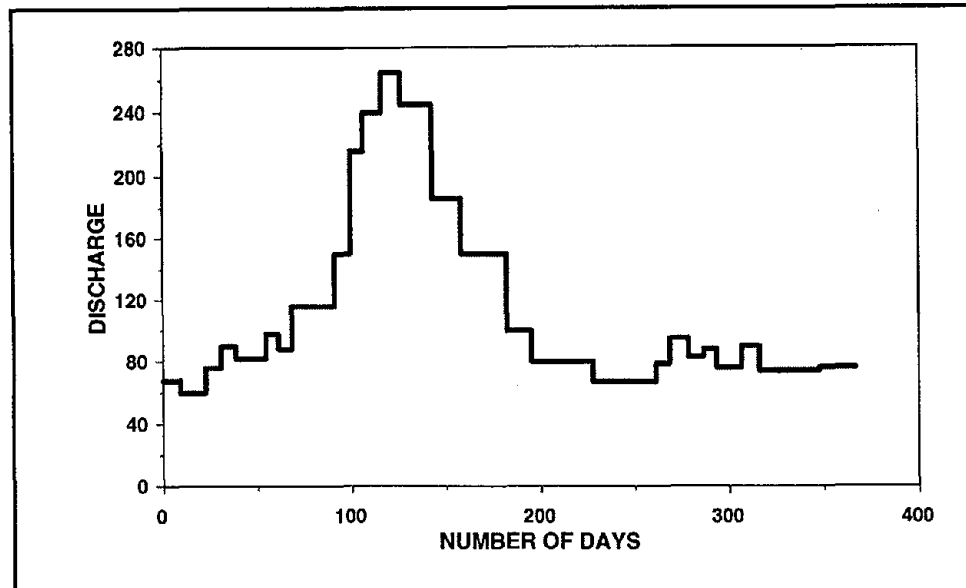
Figure 9. Approximated unsteady discharge hydrograph.

2.3.1 Backwater Computations

Water discharge hydrographs are approximated by bursts of constant discharges as shown in figure 9. During each constant discharge time block, backwater computations are carried out without interruptions for subcritical, supercritical, or a combination of both flow conditions involving hydraulic jumps. The basic approach is to solve the energy equation based on the standard-step method. The momentum equation is used when and where there is a change from supercritical to subcritical flow conditions involving the possibility of having hydraulic jumps. The details of these computations are presented in several publications (Molinas, 1983a; Molinas and Yang 1985).

These uninterrupted water surface profile computations are one of the most significant features of the **BRI-STARS** model. It is this unique component that makes the model applicable to water and sediment routing computations through complex flow conditions.

2.3.2 Stream Tube Computations

The use of stream tubes in routing water and sediment through alluvial channels is a unique feature of the **BRI-STARS** model. In the model, the total discharge carried through the channel is distributed equally among the preselected number of stream tubes. Along each stream tube, the water discharge remains constant. No lateral inflow into individual stream tubes from neighboring tubes is allowed. Due to the assumptions involved at a given station, water surface elevation across the channel should remain constant. Under these circumstances, the equal discharge locations and, therefore, lateral stream tube locations, correspond to equal channel conveyances. Following the initial backwater computations at each station, stream tube locations across the channel satisfying equal conveyance requirements are determined. To do this, the channel cross section is initially subdivided into 10

subsections of equal width. The incremental conveyance of each subsection is computed and summed. The conveyance of each stream tube is determined by dividing the total conveyance by the preselected number of stream tubes. The location of each stream tube can then be determined accordingly.

2.3.3 Sediment Routing Computations

Sediment routing computations in each stream tube are performed by satisfying the sediment continuity equation which is given as:

$$\frac{\partial Q_s}{\partial x} + n \frac{\partial A_d}{\partial t} + \frac{\partial A_s}{\partial t} - q_s = 0 \tag{14}$$

where n is the volume of sediment in a unit bed layer volume or one minus porosity. In this program, n is set equal to a commonly used value of 0.6. A_d is the volume of sediment deposition per unit length, A_s is the volume of sediment in suspension at the cross section per unit length. Q_s is the volumetric sediment discharge, and q_s is the lateral sediment inflow.

In the present computer program, the change in the average suspended sediment volume is set equal to 0 since this quantity is a function of location and flow velocity and since the change in velocity during a time step is assumed to be zero. Similarly, none of the parameters in the sediment transport function is allowed to change during a time set.

$$\frac{\partial Q_s}{\partial t} = 0 \quad or \quad \frac{\partial Q_s}{\partial x} = \frac{dQ_s}{dx} \tag{15}$$

Then the sediment continuity equation becomes:

$$n \frac{\partial A_d}{\partial t} + \frac{dQ_s}{dx} = 0 \tag{16}$$

The sediment continuity equation is discretized as follows:

$$n \frac{\partial A_d}{\partial t} = \frac{n (2P_i + P_{i+1} + P_{i-1}) \Delta Z_i}{4 \Delta t} \tag{17}$$

$$\frac{dQ_s}{dx} = \frac{Q_{s_i} - Q_{s_{i-1}}}{\dfrac{\Delta x_i + \Delta x_{i-1}}{2}} \tag{18}$$

where P is the wetted perimeter; Z is the bed elevation above a certain datum; and i is the cross-section index.

The change in bed elevation, ΔZ_i, can be obtained from the sediment continuity equation (Eq.16) with Eqs. (17) and (18), i.e.,

$$\Delta Z_i = \frac{8 \Delta t (Q_{s_{i-1}} - Q_{s_i})}{n (2P_i + P_{i-1} + P_{i+1})(\Delta x_i + \Delta x_{i-1})} \tag{19}$$

The total change in bed elevation at a given station i is computed from

$$\Delta Z_i = \sum_{k=1}^{NSIZE} \Delta Z_{i\,k} \tag{20}$$

where *NSIZE* is the number of size classes. This total bed elevation change is added to the old bed elevation and the new channel cross section at station *i* to be used at the next time iteration determined.
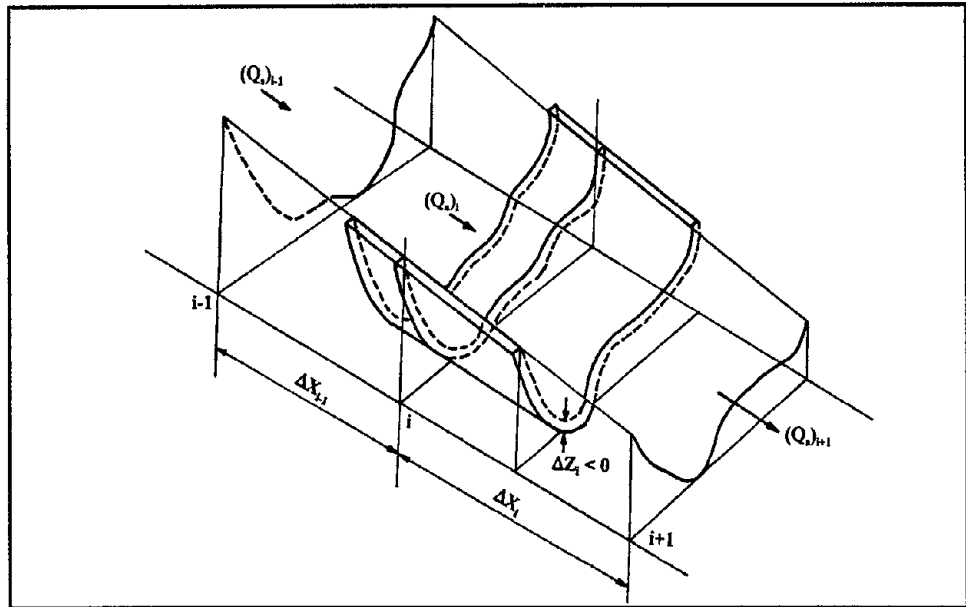
Figure 10. Definition of variables for computation.
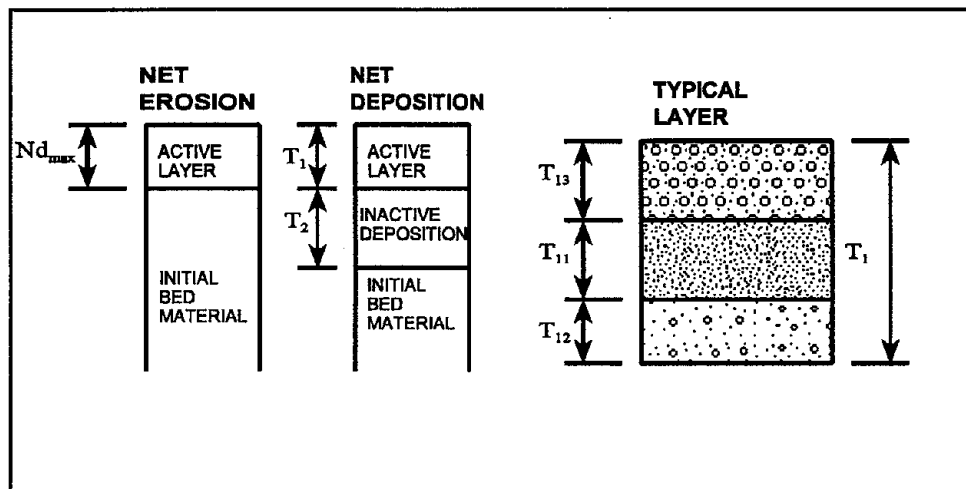
Figure 11. Bed composition accounting procedures.

The flow chart presented in figure 8 shows the process followed in computing the changes in bed elevation. Since the location of stream tubes across the channel changes with time and discharge, the changes in bed elevation as well as sediment size distribution at a given station for different stream tubes are translated to changes in bed elevation at each point across the channel.

For a given flow condition, due to a layer of large size sediment particles on the surface of the channel bed, the bed scouring may be limited. Under this condition,

the bed is said to be armored. Due to the armor layer formed on the surface of the channel bed, the underlying bed material cannot be transported. The sediment available for transport becomes limited to the amount of sediment entering the control volume. For the given flow condition, the armor layer may be formed either in a particular reach or over the entire study reach of river channel.

However, for flows of greater magnitude, this armor layer may be broken, and the bed material underneath this layer may become available for transport. Armoring events may also be experienced in a particular segment across the river channel.
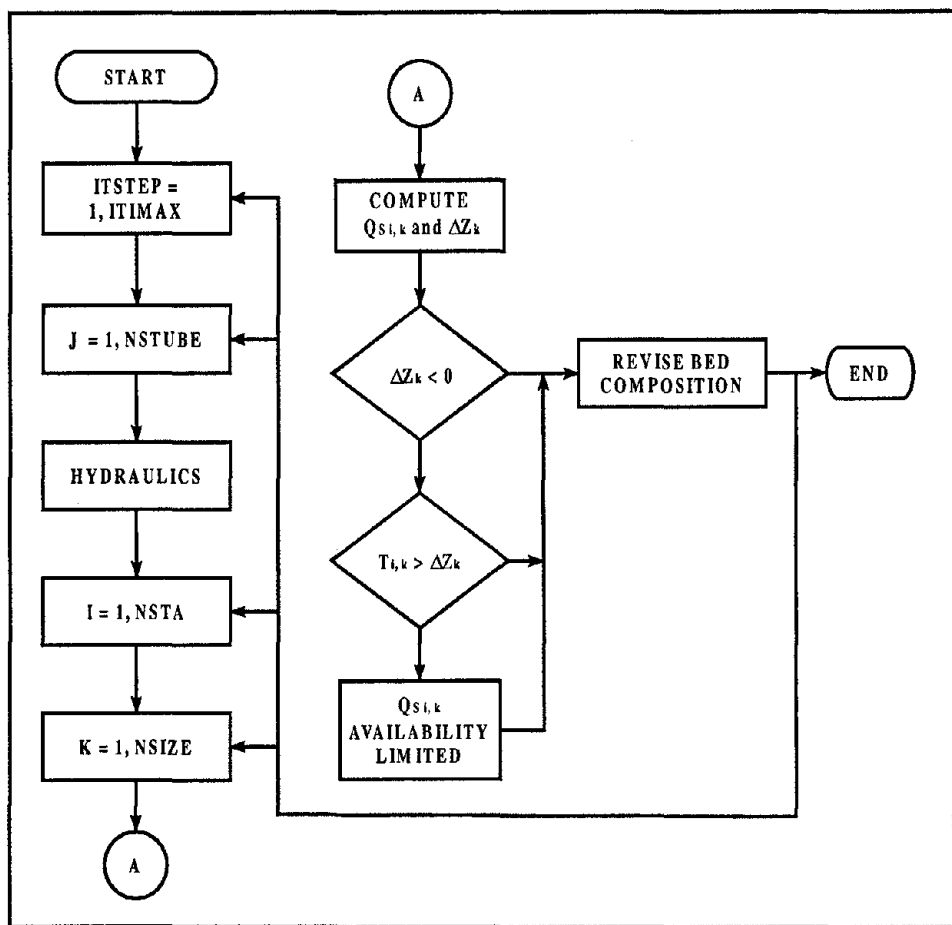
Figure 12. Logical chart for armoring process.

Mathematical simulation of the armoring process is a complicated task due to large combinations of possible sediment inflow conditions. A segment of river channel may be subjected to scouring and armoring during one time step, and may experience aggradation at the next time step. Therefore, it becomes necessary to keep an account of bed composition at each cross section. For this purpose, the bed is conceptually divided into layers. The active layer is the upper layer of the bed where sediment motion is experienced. The inactive layer (storage layer) is located beneath the active layer.

Currently, several armoring procedures are being used by various mathematical models. Almost all these procedures divide the bed into several conceptual layers of different thicknesses. Also, almost all these procedures utilize the active and inactive layer concept. However, in each armoring procedure, the sediment accounting for individual layers is handled differently. In **BRI-STARS**, the procedure is based on the one presented by Bennett and Nordin (1977).

Bed composition accounting in this procedure is accomplished through the use of two or three bed layers. The number of layers depends on whether scouring of deposition occurs at the cross section during the time step. Figure 6 shows the bed composition procedure described by Bennett and Nordin (1977) for deposition and scouring cases. According to this procedure the thickness of the active layer is set equal to a preselected parameter, N, times the geometric mean of the largest size class used in the simulation. The active layer in this approach is defined as the bed material layer that can be worked or sorted through by the action of the flowing water in the time step, t, to supply the volume of material necessary for erosion. Therefore, the parameter N defining the thickness of the active layer is related to the duration of the simulation time step. The value of parameter N should be increased for longer time steps.

The bed armoring in the mentioned procedure is achieved by the erosion of a particular size of material being limited to the amount of that size available in the active layer during a time step. Bennett and Nordin utilize the term "availability limited" to define the condition for which the sediment transport predicted by a selected transport equation is greater than the amount of sediment available for that size fraction. The term "capacity limited" is used to define the condition for which there is enough bed material present in the active layer to allow the transport indicated by the preselected sediment transport equation. Armoring is said to occur if the bed shear stress at a cross section is too low to transport any size present in the active layer (figure 12).

For the net deposition case, an inactive deposition layer is used. This layer is located beneath the active layer. When the deposition of a particular size fraction of certain thickness occurs, this thickness is added to the active layer. Also, an equal thickness of active layer is added to the inactive deposition layer. The size composition and the thickness of the inactive deposition layer is recomputed. Finally, the size computation of the active layer is recomputed and the channel bottom elevation is updated.

Due to the use of several stream tubes across the channel, the above outlined process has been slightly altered. The location of stream tubes changes with changing flow conditions and channel geometry. To account for bed material composition at the end of each time step bed material composition, active and inactive bed layer thicknesses for the stream tubes are transferred into point values across the channel.

At the beginning of the next time step, after the location of the stream tubes has been computed for the new flow conditions, cross sections are scanned. Points falling within each stream tube are identified. Within each stream tube, active and inactive layer thicknesses and bed material compositions are point averaged with respect to the distances across the channel according to the relations:

$$P_{i,k} = \frac{\left(\sum_{m=1}^{npts} P_{i,k,m} \cdot \Delta x_i \right)}{x_i} \tag{21}$$

$$TAL_{i,k} = \frac{\left(\sum_{m=1}^{npts} TAL_{i,k,m} \cdot \Delta x_i \right)}{x_i} \tag{22}$$

$$TIL_{i,k} = \frac{\left(\sum_{m=1}^{npts} TIL_{i,k,m} \cdot \Delta x_i \right)}{x_i} \tag{23}$$

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

The sediment transport capacity computations in the present mathematical model can be carried out by the use of:

- Molinas and Wu (1996).
- Ackers and White equation (1973).
- Engelund and Hansen's equation (1972).
- Yang's equations (1973, 1984).
- Yang, Molinas, and Wu equation (1996).
- Meyer-Peter Müller equation (1948).
- Generic user-supplied equation.

The user is allowed to use any one of these sediment computation methods by defining the variable *ISED* at the sediment input data.

Since Molinas and Wu's, Ackers and White's, Engelund and Hansen's, Yang's, and Yang, Molinas, and Wu's original equations compute the total load without breaking it into size fractions, these methods have been modified. Sediment load computations for these methods are carried for each size fraction as if the entire bed material is composed of just one size fraction. The resulting load is multiplied by the corresponding fraction to give the bed material load for a given size group. This method of fractional sediment transport computations is known in the literature as the Bed Material Fraction (BMF) method. The details of BMF formulations are presented in chapter 4. Also included in sediment transport equation options (in SE record) is the newly developed Transport Capacity Fraction (TCF) method which distributes the total load into fractional rates. This method is used in **BRI-STARS** in conjunction with Molinas and Wu (1996) equation. The details and development of the TCF method are given in chapter 4.

Sediment size distribution in the present program has been handled by the use of preselected size classes. The user is required to specify the number, lower and upper bounds of size classes, and the fraction of bed material falling within each size group. The number of size groups is limited to 10 in the **BRI-STARS**.

3. TOTAL STREAM POWER MINIMIZATION

The second major component of **BRI-STARS** is a variable width stream tube model. **BRI-STARS** can be used to decide whether the channel adjustments taking place at a given cross section due to scouring/deposition should advance in the lateral or vertical directions.

The basic tool for this decision-making component is the "Minimum Rate of Energy Dissipation Theory" developed by Yang and Song (1979, 1981, 1986) and Song and Yang (1979, 1980, 1982a, 1982b), and this general theory's special case "Minimum Stream Power Theory" used by Chang (1979, 1980a, 1980b, 1982a, 1982b, 1983) and Chang and Hill (1976, 1977, 1982).

The Minimum Stream Power Theory (Chang, 1980b) states that

> For all alluvial channels, the necessary and sufficient condition of equilibrium occurs when the stream power per unit length of channel, $\gamma\ QS$, is a minimum subject to given constraints. Hence, an alluvial channel with water discharge Q and sediment load Q_s as independent variables, tends to establish its width, depth, and slope such that γQS is a minimum.

To extend the minimization procedure to channel reaches experiencing gradually varied flows, stream power (γQS) should be integrated along the channel. This expression is defined as total stream power and is given by

$$\Phi_T = \int_x \Phi_S(x)\ dx \tag{24}$$

where $\Phi_S(x) = \gamma QS$ is the stream power at the location x along the river. This expression can be discretized as (Chang, 1982a):

$$\Phi_T = \sum_{i=1}^{N-1} \gamma \left(\frac{Q_i S_i + Q_{i+1} S_{i+1}}{2} \right) \Delta X_i \tag{25}$$

where N is the number of stations along the reach; ΔX_i is the reach length, or distance between stations i and $i+1$; and Q_i, S_i are discharge and slope at station i, respectively.

In **BRI-STARS**, selecting directions for channel adjustments is accomplished by this integral expression being minimized for total stream power at different stations.

At a given time step, if alteration of the channel widths results in lower total stream power than raising or lowering of the channel, channel adjustments are progressed in the lateral direction. For the opposite case, the adjustments are made in the vertical direction.

At cross sections where sediment erosion is predicted following the sediment routing procedure, channel adjustments can proceed in either deepening or widening directions. Figures 13 and 14 demonstrate the total stream power variation with channel width and change in bed elevation for constant water discharge and elevation (Molinas, 1984). Both channel widening and deepening reduce the total stream power for the study reach. The selected mode of channel adjustment in the

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computer model is the one resulting in the minimum total stream power for the reach.

CHANGING CHANNEL WIDTH AT STA. 11000

Q = 1960 cfs
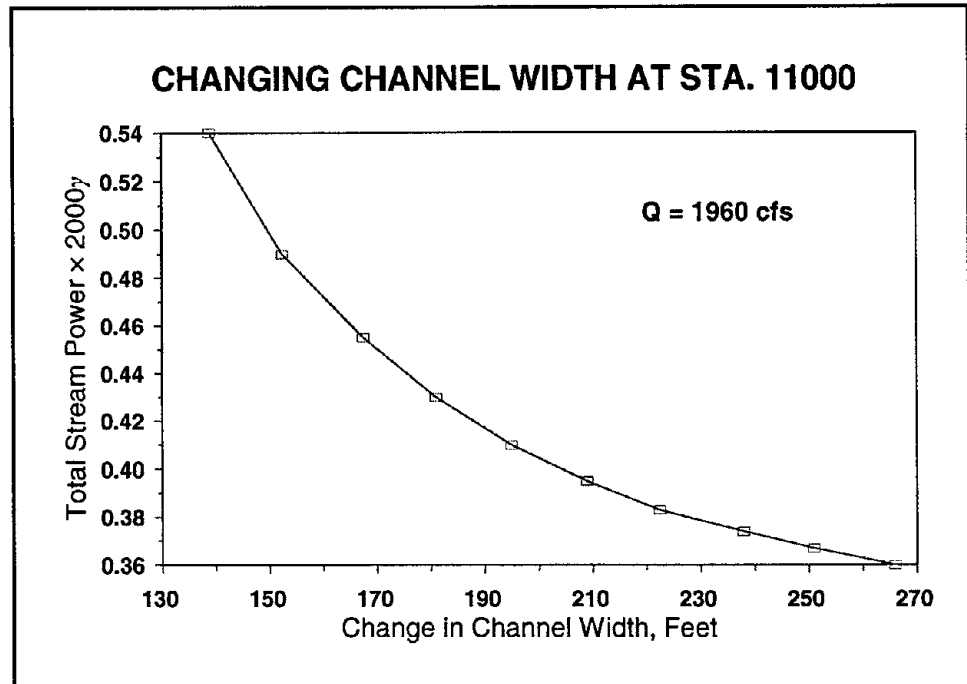
Figure 13. Plot of channel width versus total stream power.

CHANGING BED ELEVATIONS AT STA. 11000

Q = 1960 cfs
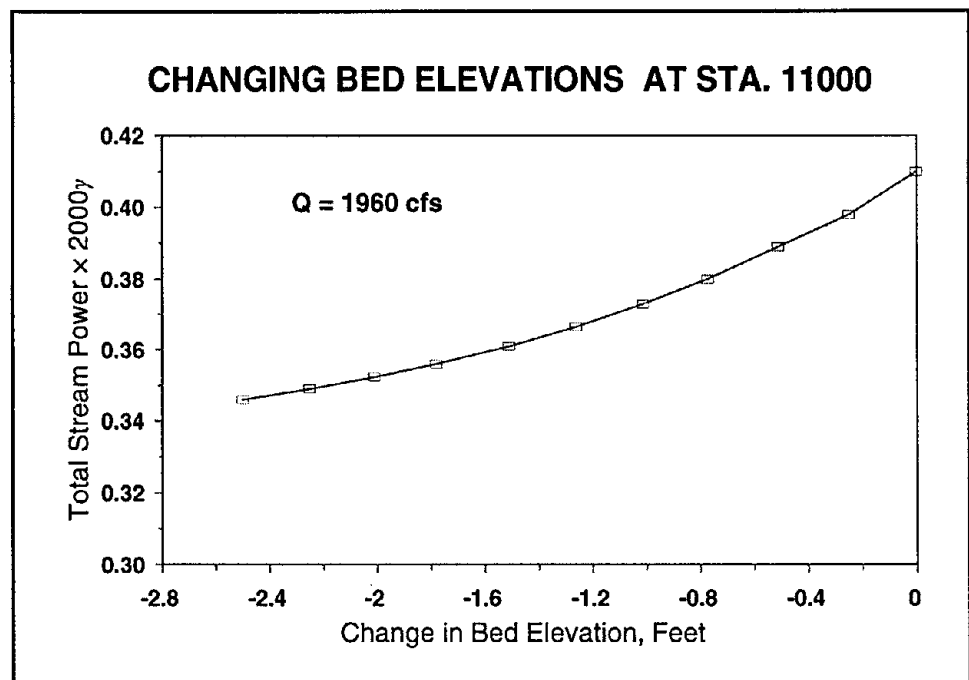
Figure 14. Channel bottom elevations versus total stream power.

Similarly, at cross sections where sediment accumulation is predicted, channel adjustments can proceed in raising the bed by sediment deposition on the bed or along the banks. The selected mode of channel adjustment in **BRI-STARS** is the

one resulting in the minimum total stream power for the reach. In both the aggrading and degrading channel cases, the sediment load is treated as a constriction in the minimization. In cases where geological or manmade restrictions are applied to the channel deepening or widening processes, computations are performed to accommodate these constrictions.

The amount of channel width adjustment during a time step is determined by the sediment continuity equation (Eq. (19)). However, for channel widening or narrowing computations, the wetted perimeter P in Eq. (19) is replaced by the hydraulic radius R. Channel widening or narrowing computations are carried out in the usual way using Eq. (19). The amount of sediment eroded from the banks from a given reach is added into the sediment loads entering that reach in sediment-routing computations. This sediment load becomes influx for the downstream sections that follow to conserve the mass balance.

4. SEDIMENT TRANSPORT EQUATIONS

4.1 INTRODUCTION

In alluvial river modeling, the water routing component is more reliable than sediment routing component. While hydraulic computations may achieve a high degree of accuracy, sediment scour/deposition estimations may be an order of magnitude in error. As a result, the overall accuracy of simulation may be significantly reduced. One of the reasons is due to the limitations of sediment transport capacity estimations. The selection of an appropriate sediment transport formula in a model is very important in order to accurately simulate the deformation process of a river.

Sediment transport is a complex subject because it involves many variables which are often interrelated. Therefore, prediction of transport rate has not been accomplished following a purely analytical method. All existing sediment transport formulas have been established relying on calibration using flume and field data collected under so-called steady uniform flow conditions. There are no universal equations which can be used under all conditions. It is suggested that the selection of the formulas should be based on: i) theoretical background; ii) extent of testing by original author and independent investigators; iii) extent of use by engineers and researchers. If measured sediment transport data are available, one may select the transport equation based on the comparison of computed transport rate with the measured values.

Sediments in natural rivers occur in the form of nonuniform mixtures. Their transport in open channels is more complicated than the transport of uniform sediments because both the condition for initiation of motion of a given size of sediment and its transport rate are affected by the presence of other sizes in the mixtures. Additional complexities are involved in the prediction of sediment transport capacity by size fractions. When different methods are applied to a given river, computed results may differ drastically from each other and from actual measurements.

Based on the general considerations given above, bed-material sediment transport equations currently included in **BRI-STARS** are

- Fine sand equation: Yang, Molinas, and Wu (1996).

- Sand equations: Engelund and Hansen (1972).

    Ackers and White (1973).

    Yang (1973).

    Molinas and Wu (1996).

- Gravel equations: Meyer-Peter and Müller (1948).

    Yang (1984).

- User supplied   Regression equations supplied by users.
  equations:

These sediment transport equations are discussed in this chapter. A comparison using sediment transport data in natural rivers is also presented.

For the computation of sediment transport by size fractions, two different methods are used in **BRI-STARS** in conjunction with bed-material load equations. These two methods are

●   Bed Material Fraction (BMF) method.

●   Transport Capacity Fraction (TCF) method.

A brief discussion and comparison of the BMF and TCF methods is also provided in this chapter.

4.2   BED-MATERIAL LOAD EQUATIONS

4.2.1 Fine Sediment Equations

Transport capacity of alluvial sediment by flowing water is inversely proportional to sediment size. Therefore, transport rate in a river with fine sediment sizes is usually very high. Large suspended sediment concentrations in heavily sediment-laden flows, such as those experienced in the Yellow River, increase the viscosity and reduce the fall velocity of sediment particles, which in turn increases the transport capacity. Taking into account the effects of high sediment concentrations on fall velocity, viscosity, and density in heavily sediment-laden flows, Yang's 1979 sand equation was modified by Yang, Molinas, and Wu (1996) as follows

$$
\log(C_{PPM}) = 3.710 - 0.157 \log\left(\frac{\omega_m d}{v_m}\right) - 1.097 \log\left(\frac{V_*}{\omega_m}\right)
$$
$$
+ \left[1.432 + 0.246 \log\left(\frac{\omega_m d}{v_m}\right) + 0.123 \log\left(\frac{V_*}{\omega_m}\right)\right] \log\left(\frac{\gamma_m}{\gamma_s - \gamma_m} \frac{VS}{\omega_m}\right)
$$

(26)

in which

$$
\begin{aligned}
\omega_m &= \omega(1 - C_{sv})^k \\
v_m &= v\,(\gamma/\gamma_m)\,e^{5.06 C_{sv}} \\
\gamma_m &= \gamma + (\gamma_s - \gamma)\,C_{sv}
\end{aligned}
$$

(27)

where C_{PPM} is the bed-material concentration by weight in PPM, C_{sv} is the suspended sediment concentration by volume, including wash load, d is the median bed material size, k is an exponent which varies with particle Reynolds number between 2 and 8, S is the energy slope, V is the mean flow velocity, V_* is the shear velocity, γ and γ_s are the specific weights of water and sediment, respectively, v is the kinematic viscosity of water, ω is the fall velocity of sediment particle d, and subscript m denotes the water-sediment mixture.

Coefficients for the fine sediment equation were determined by multiple regression analysis of 580 sets of Yellow River data with median diameter ranging from 0.013 mm to 0.091 mm, and suspended bed-material concentration from 0.05 to 477 kg/m^3 (50 PPM to 368,000 PPM).

4.2.2 Sand Equations

Engelund and Hansen Equation

Engelund and Hansen (1972) applied Bagnold's stream power concept and the similarity principle to obtain their sediment transport equation:

$$f' \Phi = 0.1 \theta^{5/2} \tag{28}$$

in which

$$\Phi = \frac{q_t}{\gamma_s \sqrt{g(s_g - 1)d^3}} \tag{29}$$

$$\theta = \frac{\tau_0}{(\gamma_s - \gamma)d} \tag{30}$$

$$f' = \frac{2gDS}{V^2} \tag{31}$$

where d is the median fall diameter of bed material, D is the mean flow depth, f' is the friction factor, g is the gravitational acceleration, q_t is the unit bed-material sediment discharge by weight, s_g is the specific gravity of sediment, τ_0 is the bed shear stress, Φ is the dimensionless transport function, and θ is the dimensionless shear stress. Substituting (29) - (31) into (28) yields

$$C_v = 0.05 \frac{V D^{1/2} S^{3/2}}{(s_g - 1)^2 g^{1/2} d} \tag{32}$$

where C_v is the sediment concentration by volume. The Engelund and Hansen formula was essentially developed using flume data of Guy, Simons, and Richardson (1966). Strictly speaking, it should be applied to streams with a dune bed in accordance with the similarity principle. However, it may be applied to upper flow regime with particle size greater than 0.15 mm without much loss of generality.

Ackers and White Equation

Ackers and White (1973) developed a general sediment discharge function in terms of three dimensionless groups: D_{gr} (sediment size), F_{gr} (mobility), and G_{gr} (sediment discharge). Based on Bagnold's stream power concept, they related the concentration of bed-material load as a function of the mobility number F_{gr}:

$$C_w = C_A s_g \frac{d}{D} \left(\frac{V}{V_*} \right)^n \left(\frac{F_{gr}}{A} - 1 \right)^m \tag{33}$$

where C_w is the sediment concentration by weight, C_A, A, n, and m are coefficients. The sediment mobility number is described by the parameter

$$F_{gr} = \frac{V_*^n}{\sqrt{gd(s_g - 1)}} \left[\frac{V}{\sqrt{32} \log \left(\frac{10D}{d} \right)} \right]^{1-n} \tag{34}$$

They defined the dimensionless grain diameter as

$$d_{gr} = d\left[\frac{g(s_g-1)}{v^2}\right]^{1/3} \tag{35}$$

where d is bed material size. For nonuniform sediment mixtures, Ackers and White suggested that d_{35} be used in replace of d.

The values of n, A, m, and C_A were obtained using 925 sets of flume data. For the intermediate size range, d_{gr} from 1 to 60 (0.04 to 2.5 mm sediment), these values are

$$\left.\begin{aligned}
n &= 1.0 - 0.56\log(d_{gr}) \\[2mm]
A &= \frac{0.23}{\sqrt{d_{gr}}} + 0.14 \\[2mm]
m &= \frac{9.66}{d_{gr}} + 1.34 \\[2mm]
\log(C_A) &= 2.86\log(d_{gr}) - [\log(d_{gr})]^2 - 3.53
\end{aligned}\right\} \tag{36}$$

The values of n, A, m, and C_A for the coarse size range with d_{gr} greater than 60 are given as

$$n = 0.0, \quad A = 0.17, \quad m = 1.5, \quad C_A = 0.025 \tag{37}$$

Yang's Sand Equation

Yang (1973) suggested that the bed-material concentration be related to unit stream power, which is expressed as the product of the velocity and slope. Yang and Molinas (1982) showed that the relationship between concentration and unit stream power can be derived from basic turbulent flow theories. Yang's dimensionless unit stream equation (Yang,1973) for sand is

$$\begin{aligned}
\log(C_{PPM}) &= 5.435 - 0.286\log\left(\frac{\omega d}{v}\right) - 0.457\log\left(\frac{V_*}{\omega}\right) \\[2mm]
&+ \left[1.799 - 0.409\log\left(\frac{\omega d}{v}\right) - 0.314\log\left(\frac{V_*}{\omega}\right)\right]\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right)
\end{aligned} \tag{38}$$

where the dimensionless critical velocity V_{cr}/ω at incipient motion can be expressed as

$$\frac{V_{cr}}{\omega} = \begin{cases} \dfrac{2.5}{\log\left(\dfrac{V_* d}{v}\right) - 0.06} & for\ 1.2 < \dfrac{V_* d}{v} < 70 \\[4mm] 2.05 & for\quad \dfrac{V_* d}{v} \geq 70 \end{cases} \tag{39}$$

The Yang equation is dimensionless. Coefficients for the sand equation were determined by multiple regression analysis of 463 sets of flume data with median diameter ranging from 0.15 mm to 1.71 mm.

Molinas and Wu Equation

Molinas and Wu (1996) defined a universal stream power, which was derived from dimensionless unit stream power and the universal law of velocity distribution, as follows

$$\psi = \frac{V^3}{(s_g - 1) g D \omega_{50} \left[\log\left(\dfrac{D}{d_{50}} \right) \right]^2} \tag{40}$$

Based on the universal stream power concept, Molinas and Wu obtained the following bed-material load equation

$$C_{PPM} = \frac{1430 \, (0.86 + \sqrt{\psi}) \, \psi^{1.5}}{0.016 + \psi} \tag{41}$$

By relating sediment concentration to water depth and relative roughness through ψ, this equation properly takes into account the effects of depth on the transport of sediment. It is applicable to natural rivers with sand bed. The coefficients for the equation were determined based on 513 sets of natural river data ranging from 0.091 mm to 1.15 mm for median diameter of bed material, and from 0.25 m to 62.3 m for flow depth.

4.2.3 Gravel Equations

Meyer-Peter and Müller Equation

Meyer-Peter and Müller (1948) developed an empirical equation for bed load discharge in natural streams. The general form of the equation in metric units is

$$\gamma \left(\frac{k_s}{k_r} \right)^{3/2} R_b S = 0.047 \, \gamma_s' d_m + 0.25 \rho^{1/3} q_{bw}'^{\,2/3} \tag{42}$$

in which

$$q_{bw}' = \gamma_s q_{bv} \, , \quad \gamma_s' = \gamma_s - \gamma \, , \quad k_r = 26 / d_{90}^{1/6} \, , \quad d_m = \sum p_{bk} d_k \tag{43}$$

where q_{bv} is the unit bed load discharge by volume, k_s is the Strickler's (1923) coefficient of bed roughness, and is equal to one divided by Manning's roughness coefficient n_s, d_{90} is the grain size of bed material for which 90% is finer by dry weight, in meters, and R_b is the hydraulic radius of the bed in meters. Units of ρ is in t·sec/m⁴; and γ, γ_s, and γ_s' are in t/m³.

Eq. (42) can be written as follows, as indicated by Chien (1954)

$$\Phi = 8 \, (\theta' - 0.047)^{3/2} \tag{44}$$

where $\theta' = \gamma R_b S / \gamma_s' d \, (k_s / k_r)^2 = \theta (k_s / k_r)^2$.

The experiments in developing the Meyer-Peter and Müller formula were made in laboratory flumes with widths ranging between 0.15 m and 2 m, water depth between 0.01 m and 1.20 m, effective diameter of sediments between 6.4 and 30 mm, and specific gravity for sediments from 1.25 to over 4. This formula is therefore more applicable to coarse sediments with little suspended load. Since the suspended load is usually only a very small portion of the sediment in transport in gravel bed, the bed load may be treated as total bed-material load.

Yang's Gravel Equation

Yang (1984), following the same dimensionless analysis and multiple regression methods used in deriving his sand equation (Yang, 1973), derived an equation to compute the bed-material concentration for gravel bed channels. Yang's dimensionless unit stream power equation for gravel is

$$\log(C_{PPM}) = 6.681 - 0.633\log\left(\frac{\omega d}{v}\right) - 4.816\log\left(\frac{V_*}{\omega}\right)$$
$$+ \left[2.784 - 0.305\log\left(\frac{\omega d}{v}\right) - 0.282\log\left(\frac{V_*}{\omega}\right)\right]\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \tag{45}$$

The dimensionless critical velocity V_{cr}/ω at incipient motion can also be computed by Eq. (39). Coefficients for the gravel equation were determined by multiple regression analysis of 166 sets of flume data with median diameter ranging from 2.46 mm to 7.01 mm.

4.2.4 User Supplied Equations

It has been common practice to assume that the rate of sediment transport or the magnitude of sediment concentration can largely be related to certain dominant variables such as water discharge, velocity, the energy gradient, shear stress, stream power, unit stream power, universal stream power, relative roughness, the Froude number, etc. Therefore, in cases where none of the existing sediment transport equations give satisfactory results, regression equations relating sediment transport to these parameters are developed. These equations use the existing data collected from a river station and plot sediment load or concentration against water discharge, velocity, slope, depth, shear stress, stream power, unit stream power, and universal stream power. The least scattered curve without systematic deviation from one-to-one correlation between dependent and independent variables is selected as the sediment rating curve for the station. Relations thus developed are often most reliable.

The basic form of user supplied equations in **BRI-STARS** is expressed as follows

$$Q_{s,k} = C_1 V^{C_2} S_f^{C_3} D^{C_4} d_k^{C_5} Q^{C_6} \tag{46}$$

where $Q_{s,k}$ is the sediment load for size fraction k by weight, Q is the water discharge, and $C_1 - C_6$ are user-supplied coefficients.

4.3 COMPARISON OF BED-MATERIAL LOAD EQUATIONS

There are numerous transport equations in literature to estimate sediment transport in alluvial rivers. Comparison and evaluation of transport equations can be found in American Society of Civil Engineers (1975), White, Milli, and Crabbe (1975), Alonso (1980), Brownlie (1981), Yang and Molinas (1982), Vetter (1989), and Yang and Wan (1991). However, the data bases used in these comparisons come mainly from flume experiments. Therefore, the conclusions made from these comparisons may not be appropriate for the field applications involving use of numerical modeling of natural rivers.

One of the most recent comparisons based on reliable field data was made by Molinas and Wu (1996). This new comparison emphasizes the behavior of the selected equations in natural rivers. The sediment transport data are collected from

small, medium, and large rivers. The wide range of flow conditions selected for the analysis is intended to show the effects of depth on the transport of sediment. Data from medium and large rivers include those from the Amazon and Orinoco River Systems (Posada, 1995), Mississippi River System (Posada, 1995), Atchafalaya River at Simmesport, Louisiana (Toffaleti, 1968), Mississippi River at Tarbert Landing, Mississippi (Toffaleti, 1968), Mississippi River at St. Louis, Missouri (Toffaleti, 1968), and Red River at Alexandria, Louisiana (Toffaleti, 1968). The small river data include the data from the Niobrara River near Cody, Nebraska (Colby and Hembree, 1955), Middle Loup River at Dunning, Nebraska (Hubbell and Matejka, 1959), Rio Grande River near Bernalillo, New Mexico (Toffaleti, 1968), and Rio Grande Conveyance Channel, New Mexico (Culbertson, Scott, and Bennett, 1972). A summary of these data is given in table 5. The total of 513 sets of data include flow depths in the ranges of 0.25m to 1.50m for small rivers and 1.10m to 62.33m for medium and large rivers.

Table 6 summarizes the comparisons of the equations of Engelund and Hansen, Ackers and White, Yang, and Molinas and Wu. The Toffaleti (1968) method is also included in comparisons since this equation was derived mainly from field data. For 432 sets of medium and large river data compared, the Molinas and Wu equation and Toffaleti's method give mean discrepancy ratios of 1.02 and 1.20, respectively. The Engelund and Hansen formula gives a mean discrepancy ratio of 2.28, which indicates that this method, on the average, overestimates the sediment transport rate. A similar conclusion for the Engelund and Hansen formula was arrived at by Posada (1995). Posada found that the Engelund and Hansen formula overpredicts the sediment transport rate by a factor of about two for deep rivers. The mean discrepancy ratios corresponding to the Ackers and White formula and the Yang formula are 0.69 and 0.66, respectively. This indicates that these two formulas underpredict the sediment transport rate in large rivers. This result is consistent with that of Brownlie (1981). The average geometric deviations and the mean normalized errors listed in table 6 quantify the range of errors for the computed quantities using various methods. The average geometric deviations are 1.62, 2.00, 2.49, 3.90, and 1.80, and the mean normalized errors are 47.8, 170.7, 61.5, 85.0, and 63.7 for Molinas and Wu, Engelund and Hansen, Ackers and White, Yang, and Toffaleti formulas, respectively. Among the selected equations, the best agreement between the computed and measured values is given by the universal stream power equation of Molinas and Wu. Toffaleti's method also gives reasonable predictions for medium and large rivers. The discrepancy ratios listed in table 6 also show the accuracy of each equation through another statistical method. The values of discrepancy ratios indicate that the Molinas and Wu equation ranks at the top of the five equations in all ranges.

For the 81 sets of small river data compared, the Molinas and Wu equation provides the most reliable estimation for total bed-material load. The Engelund and Hansen, Ackers and White, and Yang formulas, and Toffaleti's method can all predict the sediment transport rate with reasonable accuracy.

The comparison between computed and measured total bed-material concentrations for the five equations are also plotted in figures 15-19. Through the above comparison, the following conclusions are reached:

1.   The sediment transport equations developed based on a narrow range of flow depth from flume experiments do not properly account for depth effects on the transport of sediment, and they cannot be extrapolated to large or deep rivers. The use of dimensionless, homogeneous parameters in an equation is not sufficient to ensure its applicability to flow conditions where depth variation are significant

Table 5. Summary of river data.

Data Source (1)	Flow Discharge (m³/s) (2)	Flow Depth (m) (3)	Median diameter (mm) (4)	Geometric Standard Deviation (5)	Bed-Material Concentration (PPM) (6)	No. of Data (7)
(a) Medium and Large Rivers						
Amazon and Orinoco River Systems (Posada 1995)	8.6-235000.0	1.10-62.33	0.093-0.90	1.31-4.23	0.12-850	82
Mississippi River System (Posada 1995)	332.0-34100.0	2.92-21.8	0.18-0.99	1.32-5.53	0.23-370	85
Atchafalaya River at Simmesport (Toffaleti 1968)	382.3-14188.3	6.10-14.75	0.091-0.31	1.29-1.93	0.6-570	72
Mississippi River at Tarbert Landing (Toffaleti 1968)	4248.0-28829.8	6.74-16.40	0.18-0.33	1.38-2.0	12-260	53
Mississippi River at St. Louis (Toffaleti 1968)	1512.3-21608.2	4.66-17.28	0.18-1.15	1.33-3.73	7-510	111
Red River at Alexandria (Toffaleti 1968)	190.3-1537.8	3.00-7.38	0.10-0.22	1.33-2.60	7.9-500	29
Total of Medium and Large Rivers	8.6-235000.0	1.10-62.33	0.091-1.15	1.29-5.53	0.12-850	432
(b) Small Rivers						
Niobrara River near Cody (Colby and Hembree 1955)	5.86-16.06	0.42-0.58	0.22-0.35	1.51-2.35	260-1600	19
Middle Loup River at Dunning (Hubbell and Matejka 1959)	9.34-12.54	0.25-0.37	0.22-0.42	1.65-2.40	410-1830	15
Rio Grande River near Bernalillo (Toffaleti 1968)	35.1-286.0	0.33-1.46	0.21-0.39	1.62-1.88	460-4600	38
Rio Grande Conveyance Channel (Culbertson, et al. 1972)	25.2-36.53	0.89-1.50	0.18-0.29	1.38-1.86	910-3060	9
Total of Small Rivers	5.86-286.0	0.25-1.50	0.18-0.42	1.38-2.40	260-4600	81
(c) All Rivers						
Total of all River Data	5.86-235000.0	0.25-62.23	0.091-1.15	1.29-5.53	0.12-4600	513

Table 6. Summary of comparison between computed and measured bed-material concentrations.

Author of Formula	Data in Range of Discrepancy Ratio, $R^{(i)}$ (%)					Average Geometric Deviation $\sigma^{(iii)}$	Mean Normalized Error $MNE^{(iv)}$ (%)	Number of Data N
	0.75-1.25	0.5-1.5	0.25-1.75	0.5-2.0	$\overline{R}^{(ii)}$			
(a) Medium and Large Rivers								
Engelund and Hansen	22.2	47.2	68.1	58.6	2.28	2.00	170.7	432
Ackers and White	16.2	43.8	80.7	46.7	0.69	2.49	61.5	432
Yang	11.3	27.1	55.8	28.2	0.66	3.90	85.0	432
Molinas and Wu	36.3	69.7	87.1	77.1	1.02	1.62	47.8	432
Toffaleti	31.2	61.8	79.4	70.6	1.20	1.80	63.7	432
(b) Small Rivers								
Engelund and Hansen	29.6	56.8	77.8	76.5	1.23	1.62	55.3	81
Ackers and White	18.5	70.4	95.1	74.1	0.75	1.66	40.2	81
Yang	23.5	61.7	95.1	67.9	0.77	1.75	43.3	81
Molinas and Wu	51.9	84.0	95.1	87.7	0.92	1.42	33.3	81
Toffaleti	44.4	77.8	90.1	82.7	1.08	1.50	44.8	81
(c) All Rivers								
Engelund and Hansen	23.4	48.7	69.6	61.4	2.12	1.94	152.5	513
Ackers and White	16.6	48.0	83.0	51.1	0.70	2.34	57.8	513
Yang	13.3	32.6	62.0	34.5	0.68	3.44	78.4	513
Molinas and Wu	38.8	71.9	88.3	79.0	1.01	1.59	45.5	513
Toffaleti	33.3	64.3	81.1	72.5	1.18	1.75	60.80	513

Notes: (i) $R = C_{tc}/C_{tm}$ (ii) $\overline{R} = \dfrac{1}{N}\sum_i^N C_{tc}/C_{tm} = \dfrac{1}{N}\sum_i^N R$

(iii) $\sigma = \left(\prod_{i=1}^{N} r\right)^{1/N}$, $r = \begin{cases} C_{tc}/C_{tm} & for\ C_{tc}\le C_{tm} \\ C_{tm}/C_{tc} & for\ C_{tc}>C_{tm} \end{cases}$ (iv) $MNE = \dfrac{100}{N}\sum_{i=1}^{N}\left|\dfrac{C_{tc}-C_{tm}}{C_{tm}}\right|$
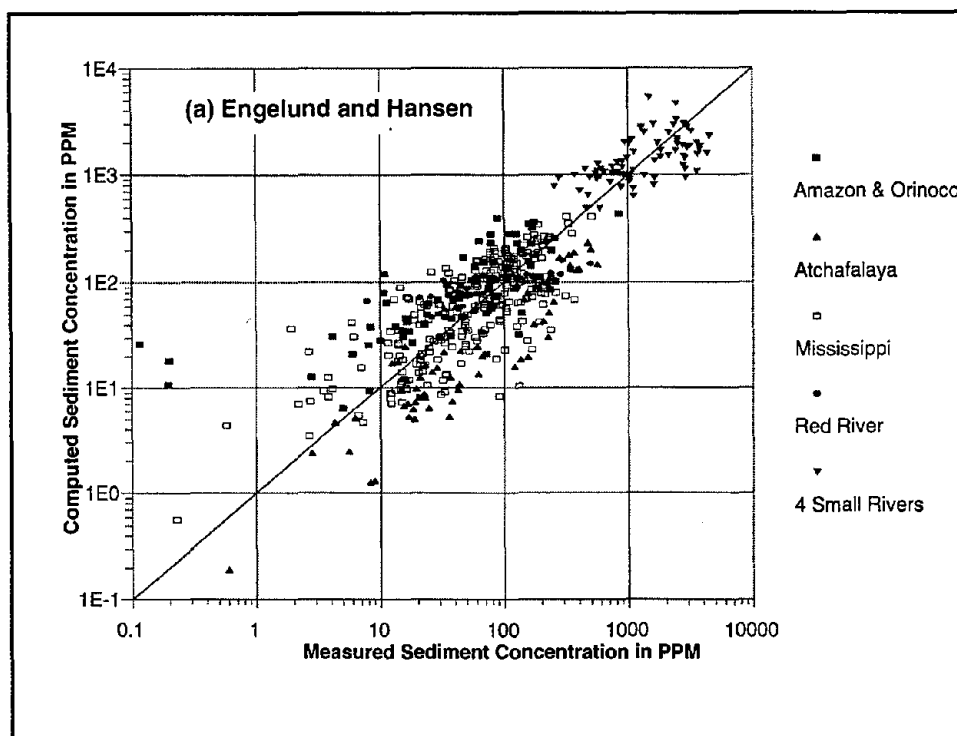
Figure 15. Comparison between computed and measured bed-material concentrations for Engelund and Hansen equation.
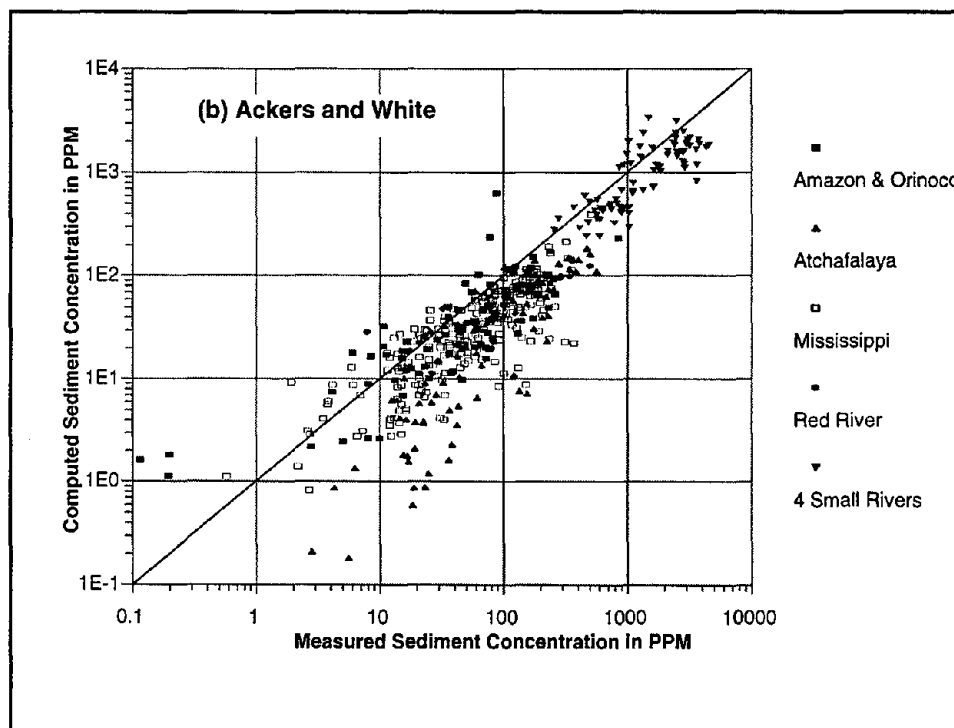
Figure 16. Comparison between computed and measured bed-material concentrations for Ackers and White equation.
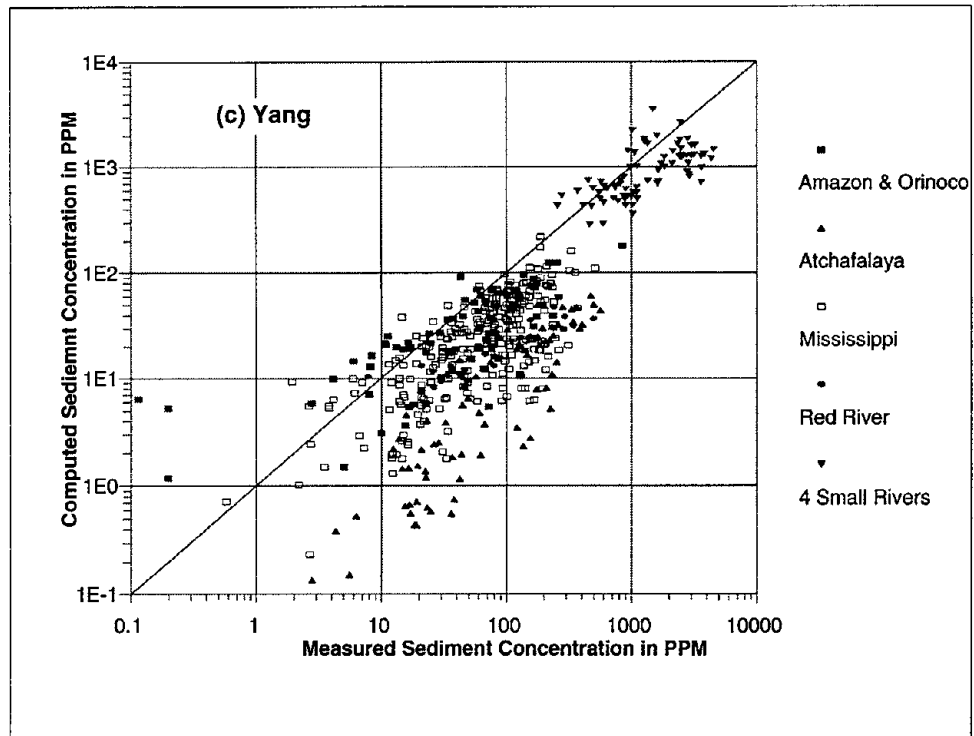
Figure 17. Comparison between computed and measured bed-material concentrations for Yang equation.
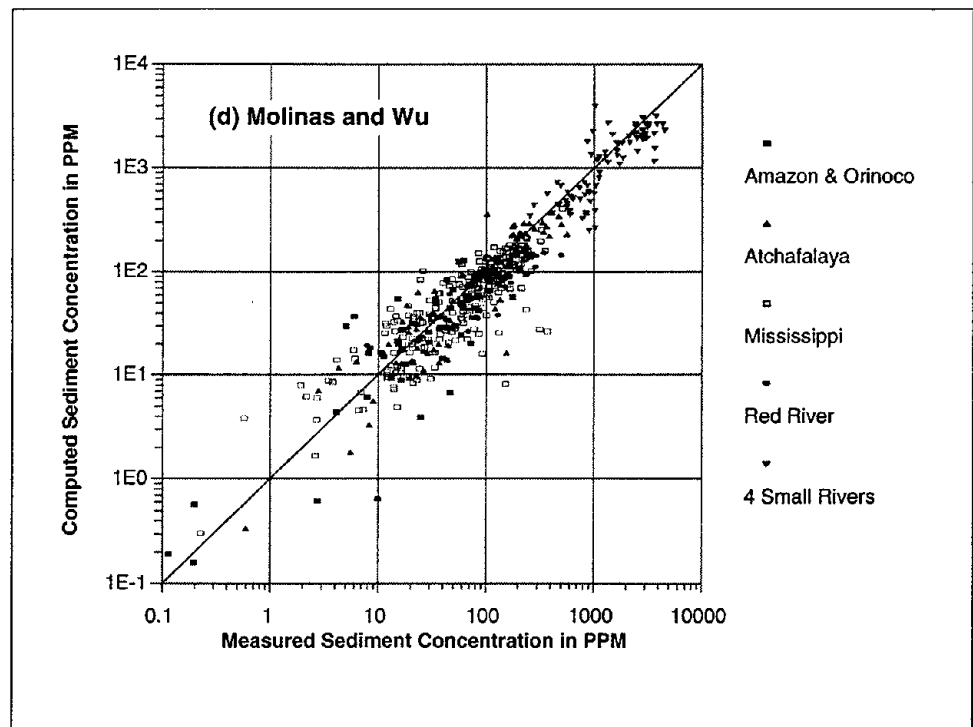
Figure 18. Comparison between computed and measured bed-material concentrations for Molinas and Wu equation.
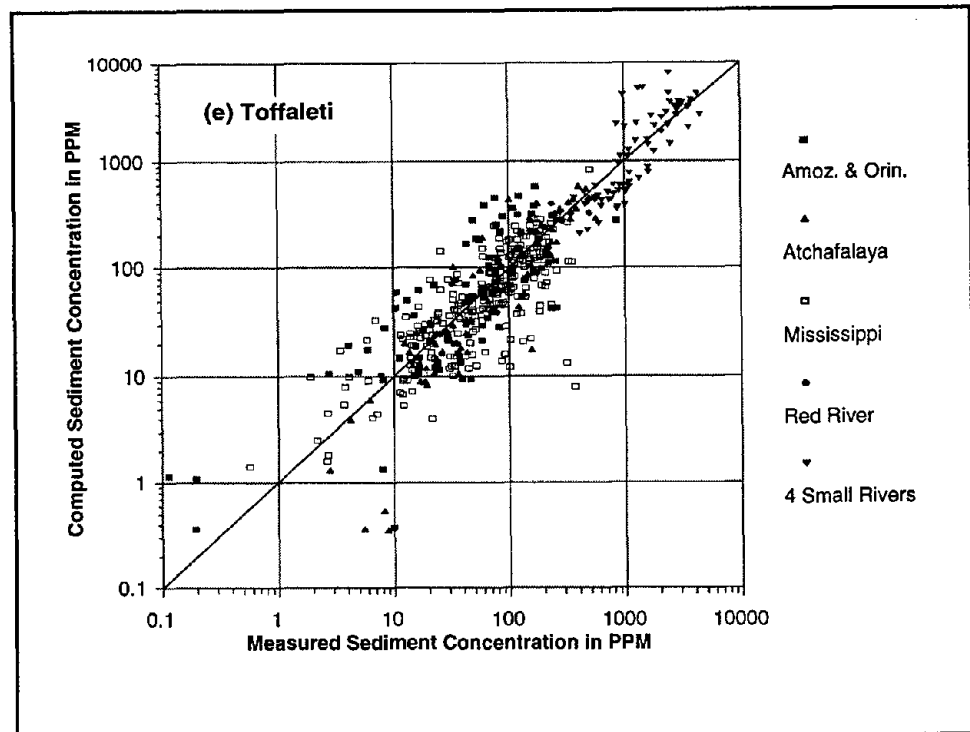
Figure 19. Comparison between computed and measured bed-material concentrations for Toffaleti equation.

2.   The Engelund and Hansen, Ackers and White, and Yang formulas are all applicable to small rivers with shallow flows. For medium and large rivers, Engelund and Hansen formula overpredicts the transport rate, while the Ackers and White, and Yang formulas underpredict the transport rate. For natural rivers, Toffaleti's method gives reasonable predictions of sediment transport rates.

3.   The relationship between C_t and universal stream power, Ψ, represents the sediment transport phenomena for natural rivers. The statistical analysis using 513 sets of measured data with large depth variation shows that the universal stream power equation proposed by Molinas and Wu is the most accurate predictor for estimating the total bed-material concentration in the sand range for all cases of natural rivers, including medium and large, and small rivers.

4.4   TRANSPORT CAPACITY BY SIZE FRACTIONS

Investigations of sediment transport capacity by size fractions can be classified into four groups (Wu and Molinas 1996): direct computation by size fraction method, correction of shear stress method, bed material fraction (BMF) method, and transport capacity fraction (TCF) method. They are described in the following.

Direct Computation by Size Fraction Method

The Direct Computation by Size Fraction Method includes those of Einstein (1950), Laursen (1958), and Toffaleti (1968, 1969), methods which were originally developed to compute the sediment transport rate by size fraction for nonuniform sediment mixtures. Generally speaking, this group of methods was found unsatisfactory in predicting transport rate by size fractions. This is due to the complexity of transport

of sediment mixtures and the lack of understanding of the motion of individual size and its effect on other sizes.

Correction of Shear Stress Method

Correction of Shear Stress Method focuses on extending a uniform sediment transport formula or a total transport rate formula to nonuniform sediment mixtures. In doing so, the actual shear stresses acting on each size fraction of the sediment mixture are corrected by introducing a correction factor. Relevant contributions following this approach are those of Ashida and Michiu (1973), Day (1980), Profitt and Sutherland (1983), Misri, et al. (1984), and Samaga, et al. (1986a, 1986b).

Bed Material Fraction Method

The Bed Material Fraction (BMF) Method assumes that the sediment transport rate by size fractions can be determined by multiplying the potential transport rate with the available fraction in the bed material, i.e.

$$C_{tk} = p_{bk} C_{pk} \tag{47}$$

in which C_{tk} is the sediment concentration of size fraction k, C_{pk} is the potential concentration of size fraction k in the case of uniform sediment in identical hydraulic conditions, P_{bk} is the fraction of bed material by weight, corresponding to the size fraction k, and k is the size fraction index. In using the BMF method given by Eq. (47), the potential concentration can be computed with any available bed-material formulas, such as those of Engelund and Hansen, Ackers and White, Yang, and Molinas and Wu, developed using a single representative size of bed material. As an example, the Engelund and Hansen formula may be used to determine the potential bed-material concentration for size group k from

$$C_{vk} = \left[p_{bk} \right] \left[0.05 \frac{VD^{1/2}S^{3/2}}{(s_g-1)^2 g^{1/2} d_k} \right] \tag{48}$$

where C_{vk} is the bed-material concentration of size fraction k by volume and d_k is the representative diameter of bed material of size fraction k.

This approach has been widely used in numerical models. However, it is generally considered to be too simple to account for the interactions of different size particles present in sediment mixtures. Molinas and Wu (1998) showed that the computed concentrations by size fractions are close to the measured values at the values of d_k/d_{50} around 1, and the computed values diverge from the measured ones at smallest and largest values of d_k/d_{50}.

Transport Capacity Fraction Method

The Transport Capacity Fraction (TCF) Method first computes the total sediment concentration by the use of a total sediment transport equation. Then the computed total concentration is broken into size fraction concentrations by a transport capacity size distribution function. This concept is expressed as

$$C_{tk} = p_{ck} C_t , \quad \sum_k p_{ck} = 1 \tag{49}$$

where p_{ck} is the fraction of sediment transport capacity by weight, corresponding to size fraction k. The total sediment concentration C_t can be determined by using the available bed-material transport formulas mentioned above. For the computation of transport capacity size fraction, several methods have been developed in the

literature, such as those of Karim and Kennedy (1981), Li (1988), and Molinas and Wu (1998).

By extending the concept of the BMF method and introducing a term to account for the sheltering and exposure effects on a given size fraction due to the presence of other sizes in the bed material, Molinas and Wu (1998) and Wu and Molinas (1996) obtained their transport capacity size fraction formula as follows

$$
p_{ck} = \frac{p_{bk}\left[\left(\dfrac{d_k}{d_n}\right)^{\alpha} + \zeta\left(\dfrac{d_k}{d_n}\right)^{\beta}\right]}{\sum\limits_k \left\{p_{bk}\left[\left(\dfrac{d_k}{d_n}\right)^{\alpha} + \zeta\left(\dfrac{d_k}{d_n}\right)^{\beta}\right]\right\}}
$$
(50)

in which

$$
\begin{aligned}
d_n &= \left[1 + (\sigma_g - 1)^{1.5}\right]d_{50} \\
\alpha &= -2.85\exp\left[-1000\left(\frac{V}{V_*}\right)^2\left(\frac{D}{d_{50}}\right)^{-2}\right] \\
\beta &= 0.2\sigma_g \\
\zeta &= 2.16F_r^{-1}
\end{aligned}
\Bigg\}
$$
(51)

where σ_g is the standard deviation of bed material size $(\sigma_g = \sqrt{d_{84}/d_{16}})$. The coefficients were determined with flume and field data ranging from 0.10 mm to 0.90 mm for median size of bed material, and from 1.25 to 3.0 for σ_g. This formula is applicable to the computation of bed-material transport capacity for size fractions falling in the sand range.

4.5   COMPARISON OF TRANSPORT CAPACITY BY SIZE FRACTIONS

The computations of sediment transport capacities by size fractions using the BMF and TCF methods were recently compared with flume and field data by Molinas and Wu (1998). This comparison requires the data including both bed-material size distribution and total bed-material load size distribution measurements. The available data which meet the requirement are the flume data of Einstein (1978), Einstein and Chien (1953), and Samaga, et al. (1986a, 1986b), and the field data from the Niobrara River near Cody, Nebraska (Colby and Hembree 1955) and the Middle Loup River at Dunning, Nebraska (Hubbell and Matejka 1959). A summary of these data is given in table 7. Data estimating unmeasured load near the bed surface by the use of indirect methods are not included in this paper. The complete data set incorporates 118 measurements containing 866 data points. The median diameter of the bed material falls in the sand range and the standard deviation is in the range 1.25 to 3.0.

According to the BMF method, the bed-material transport capacity by size fractions can be obtained by multiplying C_{pk} with P_{bk}. The bed-material concentrations for individual size fractions of sediment mixtures are computed by the use of Engelund and Hansen, Ackers and White, and Yang equations to compute the potential concentration, C_{pk}, respectively. The computed results for the 118 sets of laboratory

Table 7. Summary of laboratory and river data.

Data Source (1)	Flow Discharge (m^3/sec.) (2)	Flow Depth (m) (4)	Median Diameter (mm) (7)	Geometric Standard Deviation of Bed Size (8)	Bed-Material Concentration (kg/m^3) (9)	No. of Data Sets (10)
(a) Laboratory Data						
Einstein (1950)	0.019 -0.042	0.099 -0.139	0.108 -0.903	1.245 -2.158	1.32 -40.56	29
Einstein and Chien (1953)	0.043 -0.066	0.177 -0.237	0.104 -0.381	1.414 -2.968	2.12 -60.21	22
Samaga, et al. (1986)	0.0056 -0.015	0.056 -0.101	0.212 -0.404	1.480 -2.460	3.40 -10.08	33
(b) River Data						
Niobrara River near Cody (Colby and Hembree 1955)	5.86 -16.06	0.421 -0.576	0.215 -0.349	1.514 -2.345	0.26 -1.60	19
Middle Loup River at Dunning (Hubbell and Matejka 1959)	9.34 -12.54	0.250 -0.370	0.219 -0.424	1.651 -2.403	0.41 -1.83	15
Total of Laboratory and River Data	0.0056 -16.06	0.056 -0.576	0.104 -0.903	1.245 -2.968	0.56 -60.21	118

Table 8. Summary of comparison between computed and measured bed-material concentrations of individual size fractions.

Author of Formula (1)	Method of Computation (2)	Data in Range of Discrepancy Ratio, $R^{(i)}$ (%)				Standard Deviation $\sigma^{(ii)}$ (kg/m^3) (7)	Mean Normalized Error, $MNE^{(iii)}$ (%) (8)	Number of Data Points (9)
		0.75-1.25 (3)	0.5-1.5 (4)	0.25-1.75 (5)	0.5-2.0 (6)			
Engelund and Hansen	BMF	19	38	56	48	1.75	110.5	886
	TCF	25	48	68	57	1.62	84.4	886
Ackers and White	BMF	22	44	65	49	21.75	145.8	886
	TCF	24	49	74	55	1.38	66.2	886
Yang	BMF	19	40	56	52	2.01	133.9	886
	TCF	24	48	69	57	1.69	84.9	886

Notes: (i) $R = C_{tc}/C_{tm}$ (ii) $\sigma = \sqrt{\dfrac{\sum_i \sum_k (C_{tc}-C_{tm})^2}{N-1}}$ (iii) $MNE = \dfrac{100}{N} \sum_i \sum_k \left| \dfrac{C_{tc}-C_{tm}}{C_{tm}} \right|$

In which i = data set number, k = data point number in a set, and N = total number of data points.
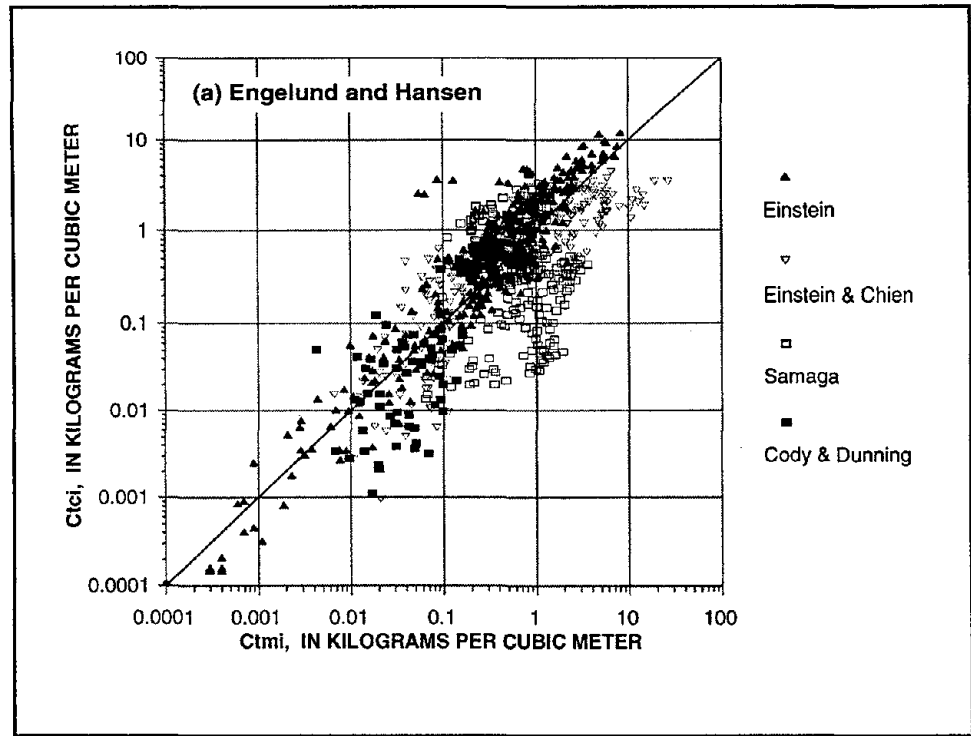
Figure 20. Computed and measured bed-material concentrations for individual size fractions by the BMF method using the Engelund and Hansen equation.
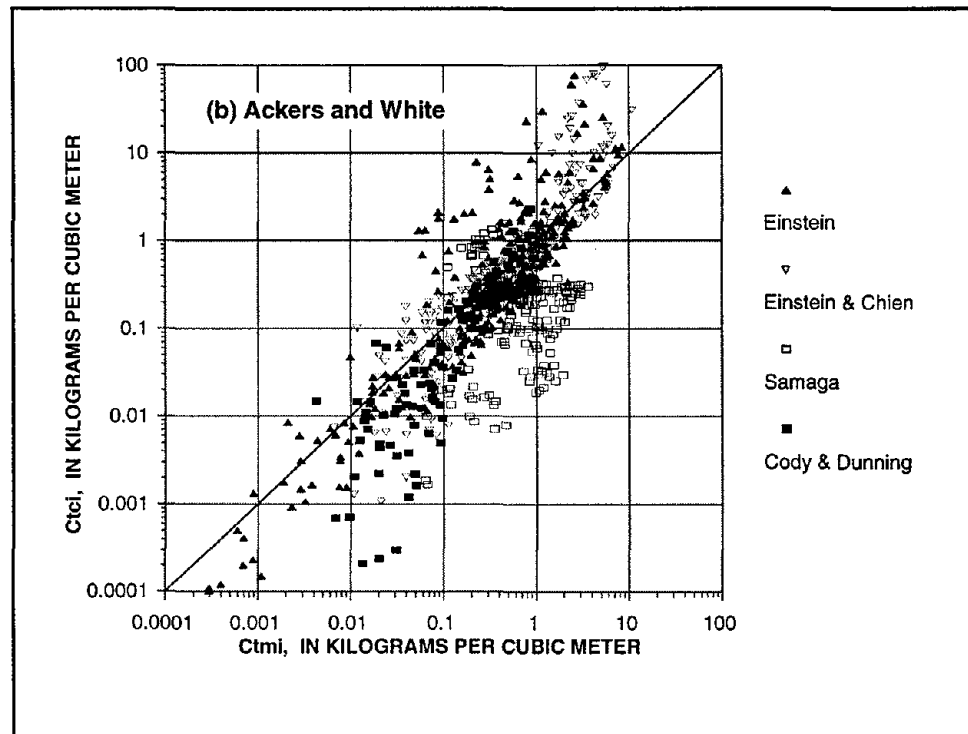
Figure 21. Computed and measured bed-material concentrations for individual size fractions by the BMF method using the Ackers and White equation.
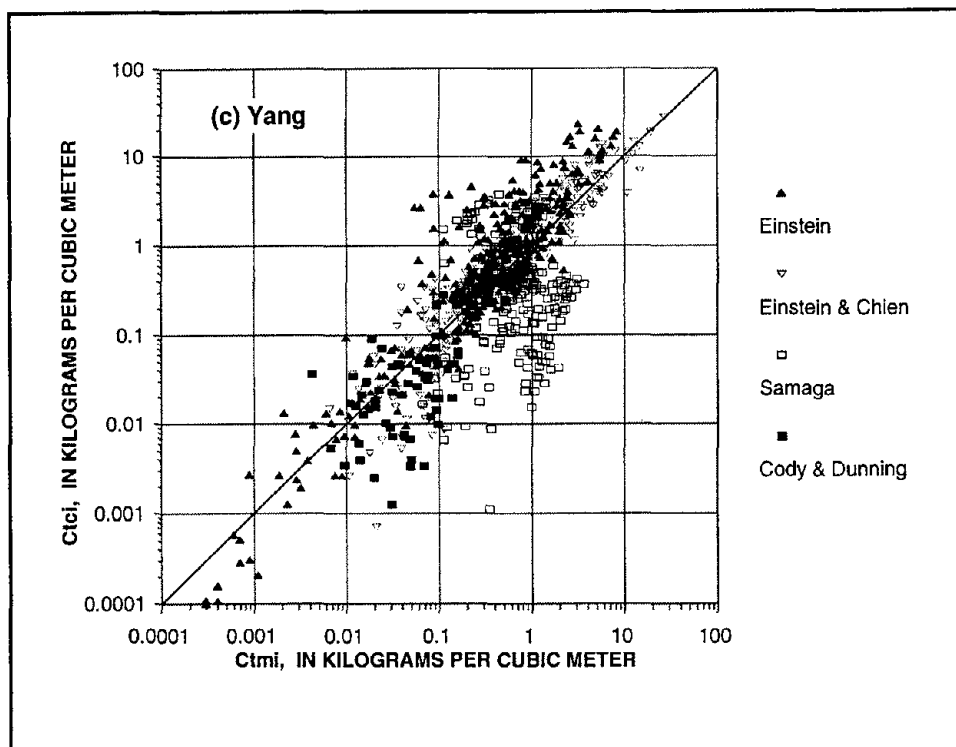
Figure 22. Computed and measured bed-material concentrations for individual size fractions by the BMF method using the Yang equation.

and river data are compared with the corresponding observed values in figures 20-22. In these figures, C_{ick} and C_{tmk} are computed and measured bed-material concentrations in kg/m³, respectively, corresponding to the size fraction, k. It can be seen that, even though on average the equations represent the data, a large scatter exists between computed bed-material concentrations of individual size fractions and measured values. The scatter is almost in the range of two logarithmic scales for all three formulas. The ratio of computed fractions of bed-material load to the measured fraction of bed-material load against the relative diameter of the bed material are shown in figure 23 by the use of the Engelund and Hansen equation. Values of P_{cck}/P_{cmk} equal to 1 indicate perfect agreement. Generally speaking, the values of P_{cck}/P_{cmk} are near perfect agreement at values of d_k/d_{50} around 1; and the values of P_{cck}/P_{cmk} diverge from the perfect agreement at smallest and largest values of d_k/d_{50}.

By applying the TCF method, the fractions of sediment transport capacity can be computed by Molinas and Wu equation. The ratio of computed fractions of transport capacity to the measured fractions of bed-material load for the 118 sets of data are plotted against d_k/d_{50} in figure 24. In can be seen that most of the points fall in around the perfect line of P_{cck}/P_{cmk} equal to 1.

Next, the total bed-material concentration, C_t, is computed by the use of the equations of Engelund and Hansen, Ackers and White, and Yang, respectively. Then the bed-material concentrations, C_{tk}, of individual size fractions can be obtained by multiplying C_t with P_{ck}. The results computed by the use of the Engelund and Hansen, Ackers and White, and Yang formulas are shown in figures 25-27, and are summarized in table 8 with the 118 sets of laboratory and river data.

(a) Einstein Flume Data

(c) Samaga et al. Data

(b) Einstein and Chien Flume Data

(d) Niobrara River & Middle Loup River
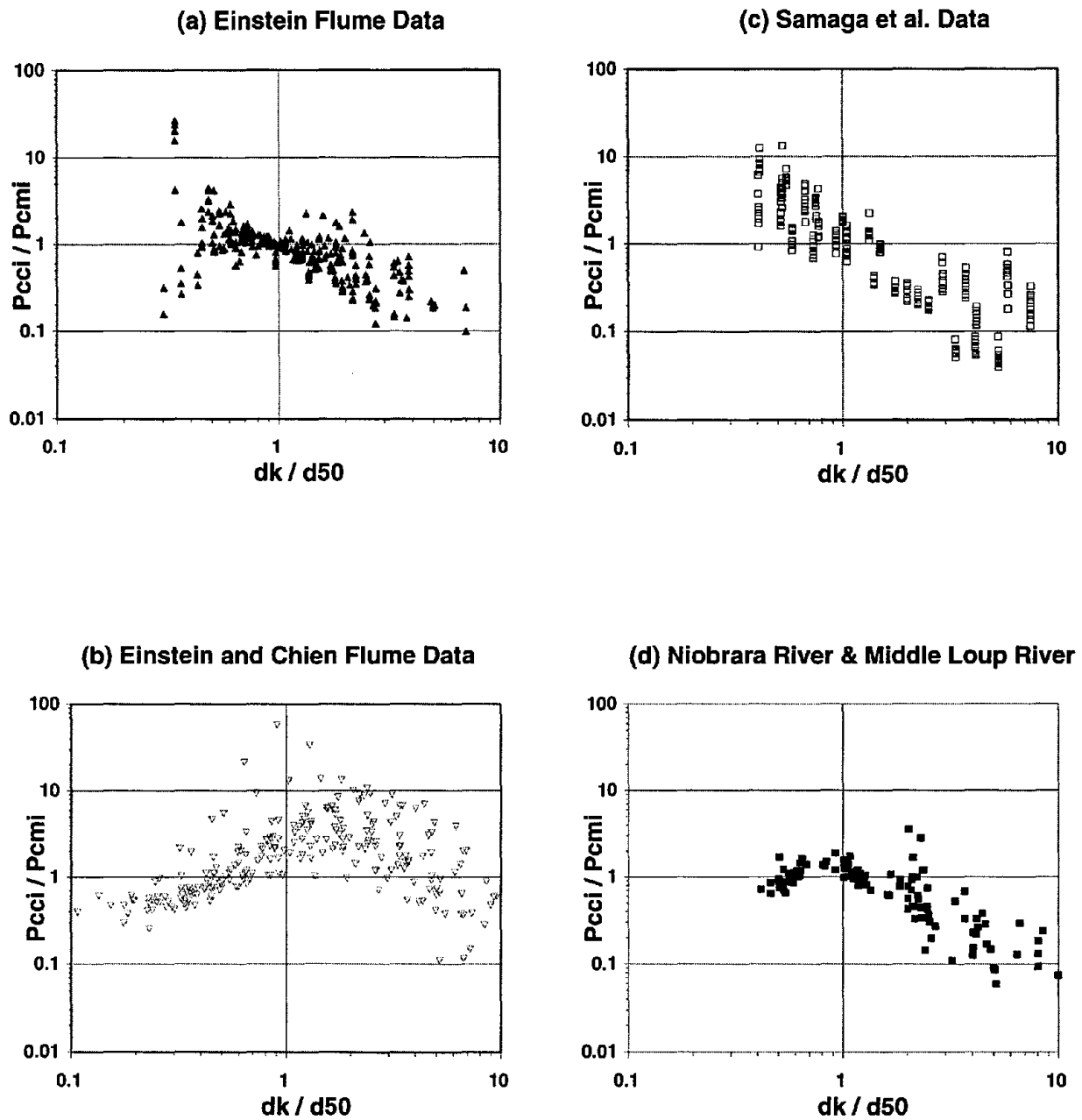
Figure 23. The variation of P_{cci} / P_{cmi} versus d_k / d_{50} for the Engelund and Hansen equation by the use of the BMF method.

(a) Einstein Flume Data

(c) Samaga et al. Flume Data

(b) Einstein and Chien Flume Data

(d) Niobrara River & Middle Loup River
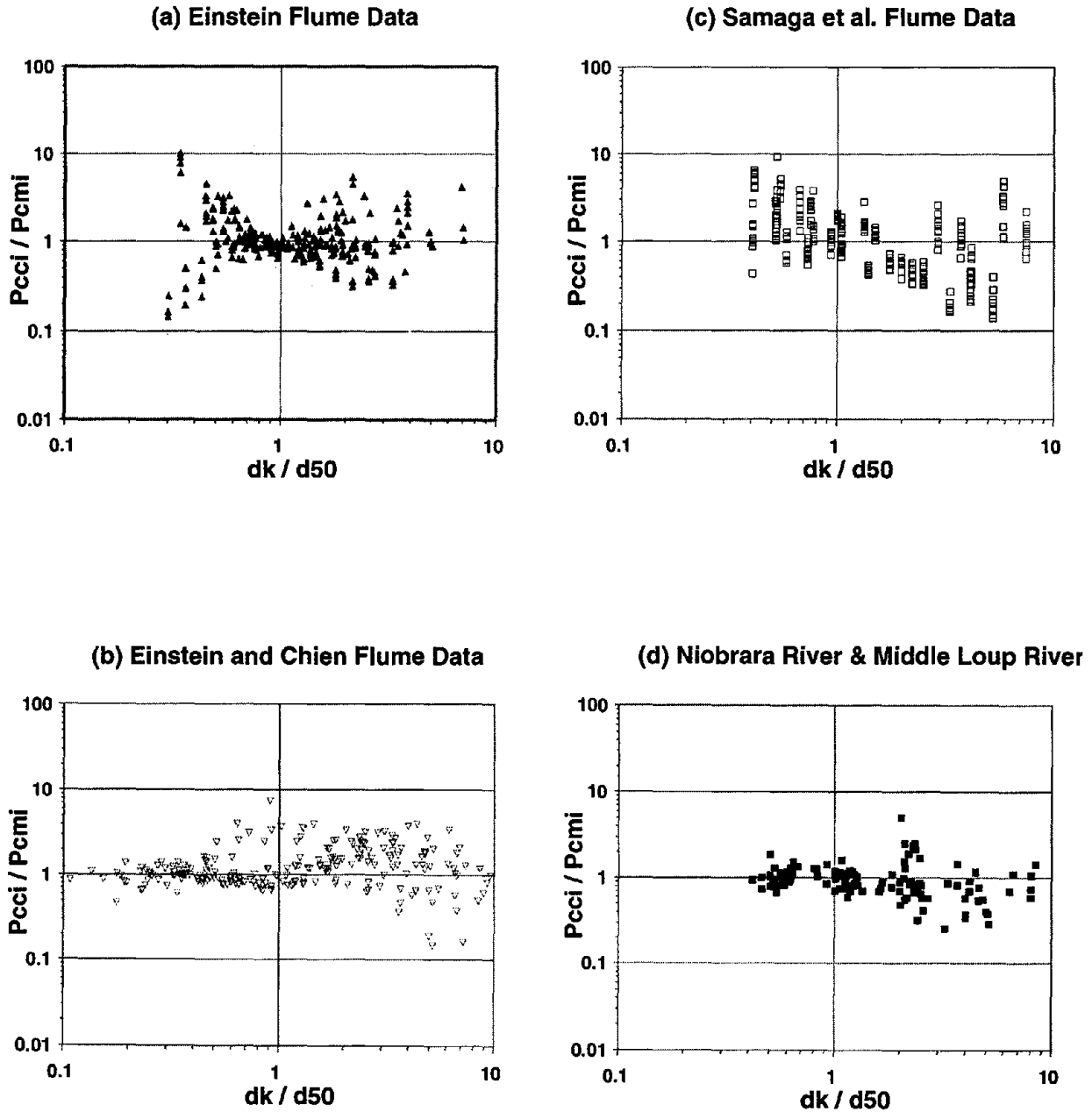
Figure 24. The variation of P_{cci} / P_{cmi} versus d_k / d_{50} for the Engelund and Hansen equation by the use of the TCF method.
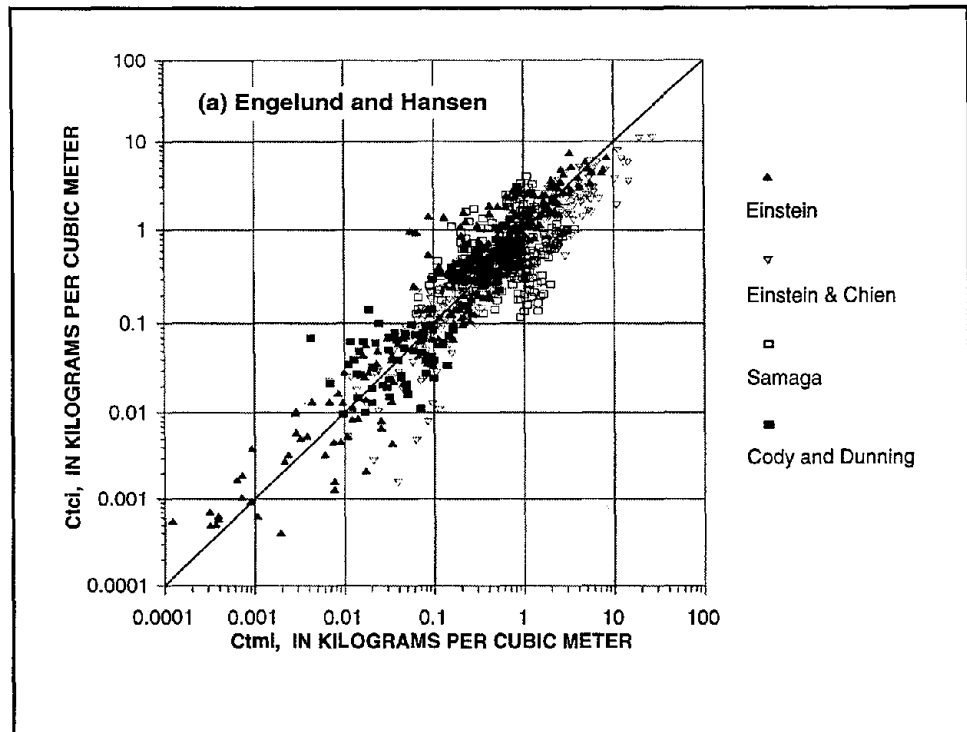
Figure 25. Computed and measured bed-material concentrations for individual size fractions by the TCF method using the Engelund and Hansen equation.
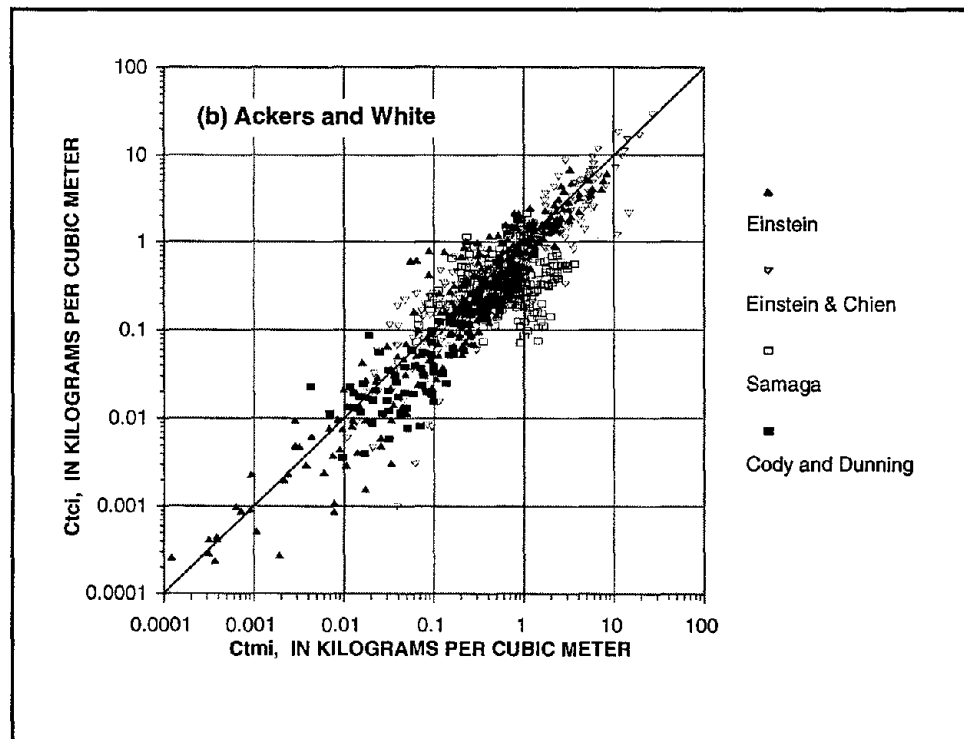
Figure 26. Computed and measured bed-material concentrations for individual size fractions by the TCF method using the Ackers and White equation.
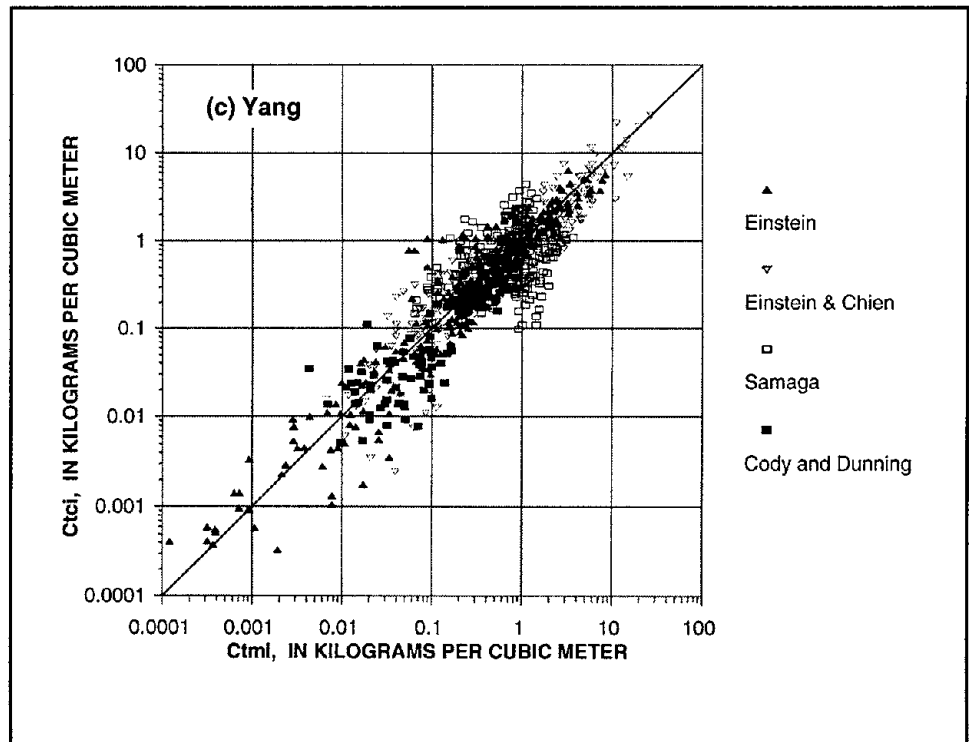
Figure 27. Computed and measured bed-material concentrations for individual size fractions by the TCF method using the Yang equation.

As shown in table 8, by using d_{50} (and d_{35}) for computing C_t and by using the Molinas and Wu equation for computing P_{ck}, the standard deviation between computed and measured bed-material concentrations of individual size fractions for the Engelund and Hansen, Ackers and White, and Yang formulas was reduced significantly from 1.75, 21.75, and 2.01 to 1.62, 1.38, and 1.69, respectively. The mean normalized error was also significantly reduced from 110.5, 145.8, and 133.9 to 84.4, 66.2 and 84.9, respectively.

The comparison demonstrates the limitations of the BMF method in calculating the transport rates of individual size fractions for nonuniform sediment mixtures because it neglects the effects due to the presence of the other size fractions. There is considerable scatter between computed and measured transport rates for individual size fractions. Generally speaking, the values of P_{cck}/P_{cmk} are near perfect agreement at values of d_k/d_{50} around 1; the values of P_{cck}/P_{cmk} diverge from perfect agreement at the smallest and largest values of d_k/d_{50}. Therefore, this method is only acceptable from a qualitative point of view.

Combining the concept of the TCF method with the use of the Molinas and Wu equation for the computation of the fraction of bed-material sediment transport capacity gives better prediction for the transport rates by size fractions. This is because the TCF method avoids any additional error in estimating the total bed-material load and also accounts for the effect on the transport of individual size fraction due to the presence of other size fractions in the sediment mixtures.

5. BRIDGE AND ABUTMENT SCOUR

If an obstruction is placed in a stream, the flow pattern in the vicinity of that obstruction will be modified. Since the transport capacity is a function of the flow characteristics, the transport capacity pattern will also be modified. In an area where the transport capacity is not equal to the rate at which material is supplied, scour or deposition must occur.

Scour can then be defined as the enlargement of a flow section by the removal of material composing the boundary through the action of fluid in motion.

The total scour at a river crossing is composed of three components that, in general, are additive:

● General scour, due to long-term changes in the river bed elevation (aggradation or degradation), which would occur whether an encroachment is present or not.

● Contraction scour, resulting from the constriction of the waterway, either natural or due to the bridge and its approaches.

● Local scour, a consequence of interference with flow by piers or abutments, which accelerate the flow-creating vortices that remove the material around them.

Laursen (1952) stated the general basic characteristics of any analysis of local scour, as follows:

1. The rate of scour will equal the difference between the capacity for transport out of the scoured area and the rate of supply of material.

2. The rate of scour will decrease as the flow section is enlarged.

3. There will be a limiting extent to scour.

4. This limit will be approached asymptotically.

Local scour can occur in one of two ways: clear-water scour or live-bed scour. Clear-water scour occurs when there is no bed material movement at the upstream of the stream crossing, but the acceleration of the flow and vortices created by the piers or abutments cause the material to move. The bed shear stresses away from the scour area are thus equal to or less than the critical or threshold shear stress necessary for the initiation of particle movement. The maximum scour depth is reached when the flow can no longer remove particles from the scour hole.

Live-bed scour (also referred to as scour with sediment transport) occurs when there is movement of the bed material upstream of the crossing. Live-bed scour fluctuates in response to passage of bed forms about an equilibrium scour depth. This equilibrium scour depth is reached when, over a period of time, the amount of material removed from the scour hole by the flow equals the amount of material supplied to the scour hole from the upstream boundary. Figure 28 shows diagrammatically the development of scour depth with time and the relationship between scour depth and approach velocity. Maximum depth of scour is about 30% larger than equilibrium depth of scour when the upstream channel bed form is

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classified as dunes. If the bed form upstream is classified as a plane bed, then the maximum depth of scour is equal to the equilibrium depth.
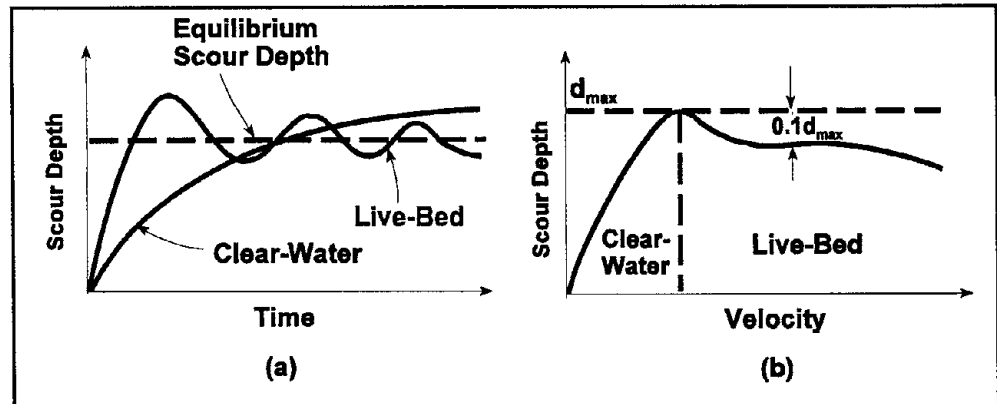
Figure 28. Scour depth for a given pier and sediment size as a function of time and of approach velocity (Raudkivi and Sutherland, 1981).

With antidunes occurring upstream and in the bridge crossing, the maximum depth of scour is not well known but is assumed to be about 20% greater than the equilibrium scour depth.

5.1   LOCAL SCOUR AT BRIDGE PIERS

5.1.1   Flow Field Around a Pier and Scour Process

The dominant feature of the flow near a pier is the large-scale eddy structure, or the system of vortices which develop around the pier. These vortex systems are the basic mechanism responsible for the local scour at bridge piers. Depending on the type of pier and the free-stream conditions, the eddy structure can exhibit any of three basic vortex systems: i) the horseshoe-vortex; ii) the wake-vortex; and iii) the trailing-vortex.

In the vertical plane, the flow velocity approaches zero in the vicinity of the upstream face of the pier, resulting in a downward pressure gradient. This gradient drives the downward flow of water at the upstream face of the pier. If the pressure field is sufficiently strong, it causes a three-dimensional separation of the boundary layer which rolls up ahead of the pier to form the horseshoe-vortex system. Then the horseshoe vortex develops as a result of flow separation at the upstream rim of the scour hole. This vortex extends downstream past the sides of the pier for a length comparable to a few pier widths before it diffuses and becomes part of the general turbulence. A pier inducing a sufficiently large pressure gradient to initiate the process described above is defined as blunt-nosed. All other piers are referred to as sharp-nosed. Some pier shapes, such as wedge or lenticular, may be considered either blunt-nosed or sharp-nosed depending upon the wedge angle and the angle of attack of the undisturbed flow.

The stagnation pressure causes not only a downward flow, but also lateral acceleration of flow past the pier. The separation of flow at the sides of the pier creates wake-vortices at the edge of the boundary layer. These vortices are translated downstream with the flow and interact with the horseshoe-vortex at the bed, causing it to oscillate laterally and vertically. The wake vortices also cause

disturbances which lift sediment from the bed. The strength of the vortices in the wake system varies significantly with pier shape and approach flow velocity. A streamlined pier will create a relatively weak wake, whereas a blunt body will produce a very strong one.
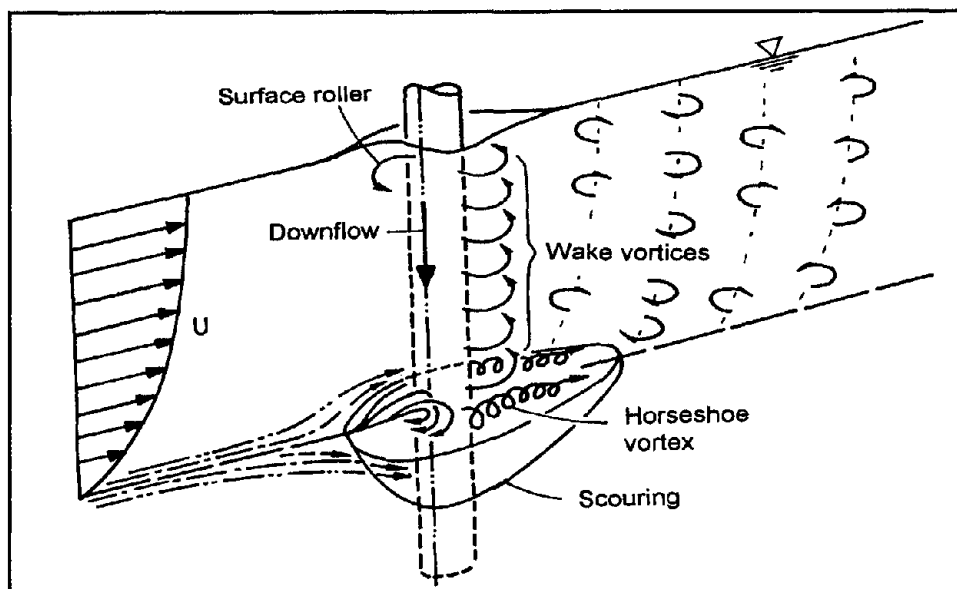
Figure 29. Flow pattern at a cylindrical pier (Raudkivi).

The trailing-vortex system usually occurs only on completely submerged piers, and is composed of one or more discrete vortices emanating from the top of the pier and extending downstream. These vortices form when finite pressure differences exist between two surfaces meeting at a corner, such as the edge at the top of the pier.

Finally, a bow wave develops at the surface, with rotation in the opposite direction of the horseshoe-vortex. The bow wave becomes important in relatively shallow flows, where it interferes with the approach flow and causes a reduction in the strength of the downward flow.

Figure 29 shows the flow pattern at a cylindrical pier. Several general characteristics shown in this figure are common to the scour patterns around all pier shapes. The upstream portion of the hole has the approximate form of an inverted cone, with side slopes equal to the angle of repose of the bed material. Deposition which occurs in the low velocity area behind the pier divides the downstream portion of the scour hole into two separate tails.

5.1.2 Analysis of Scouring Parameters

The parameters which influence scour around bridge piers can be arranged into four main groups:

1.   Fluid variables:

●   Density of fluid.

●   Kinematic viscosity of fluid.

2.   Streamflow variables:

- Depth of approach flow.
- Mean velocity of undisturbed flow.
- Roughness of the approach flow.

3.   Stream bed materials:

- Grain diameter and form.
- Grain size distribution.
- Density of the sediment.
- Cohesive properties.

4.   Bridge pier variables:

- Pier dimensions.
- Pier shape.
- Surface roughness.
- Number and spacing of the piers.
- Orientation of piers to approach flow.
- Pier protection.

Because of the complexities and costs of measurement, analysis, and evaluation of all of the above-mentioned variables, many investigators assume some restrictive conditions:

- The differences between the laboratory and field values for density, viscosity and acceleration due to gravity can be neglected.
- Channels can be considered sufficiently wide so that the bridge pier does not cause significant contraction of flows.
- Alluvial noncohesive (often uniform) bed material.
- Perfectly smooth piers without scour protection systems, such as riprap.

These assumptions and restrictions reduce the list of variables to:

- Density and kinematic viscosity of the fluid;
- Sediment diameter and density;
- Approach flow depth and mean velocity of the undisturbed flow;
- Pier width, shape, and orientation.

5.1.3 Influence of Parameters

Flow Depth

Several pier scour studies in the past have related depth of scour to the ratio of flow depth to the pier width (y / b). Experimental and field observations of pier scour, however, have shown that for $y / b > 3$ the influence of this parameter can be neglected. Due to the complex three-dimensional pattern of flow past the pier, analytical determination of the effect of flow depth is not possible. However, experimental and field observations indicate that for shallow flow depths the depth of scour increases with depth of flow. The effects of flow depth on pier scour diminish with increasing depth. For large flow depths, the depth of scour is almost independent of depth of flow.
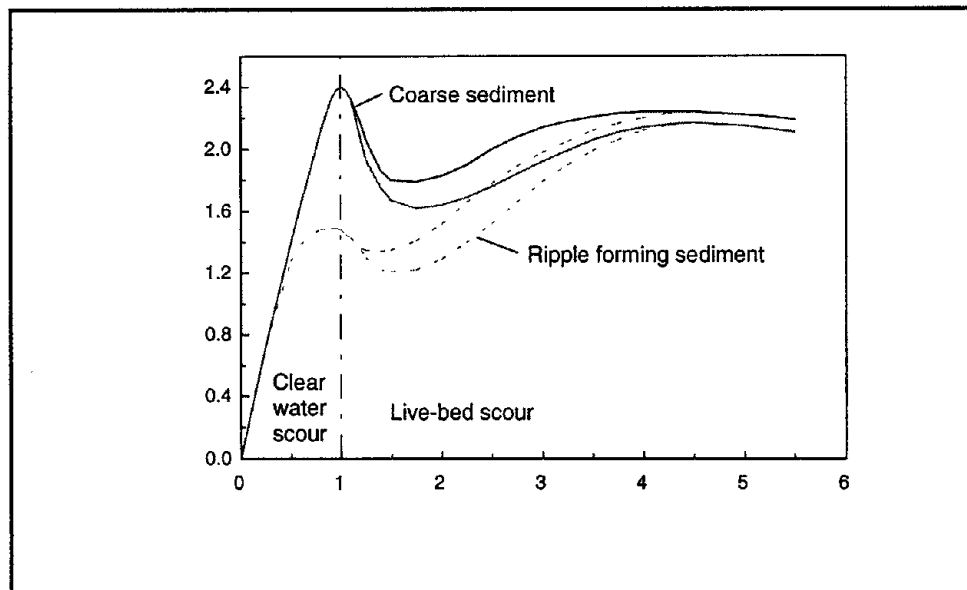
Figure 30. Scour depth vs. velocity (Melville, 1984)

Pier Size

The pier size primarily affects the time needed for the local clear-water scour to reach an equilibrium depth. Since the depth of scour varies proportionally with the pier width, the volume of the conical-shaped scour hole formed around the upstream half of the pier varies directly as the cube of the pier width (b^3). As the size of the pier increases, the scour volume and the time required to erode the bed around the pier at a given shear stress level also increase.

Velocity

For the case of clear-water scour, the scour depth increases almost linearly with velocity, with a reduction in the scour depth gradient near the maximum scour depth.

For pier scour with sediment motion, Laursen (1956) stated that the scour depth is not a function of velocity. He explained that the strength of the vortex forming the scour hole is a function of the mean velocity of the flow in such a way that a balance of transport capacity upstream of the crossing and in the scour hole is maintained without a change in the depth of scour. More recently, Melville (1984) obtained a generalized scour depth versus flow velocity relationship (figure 30) based upon laboratory studies. These studies showed maximum scour occurring at both the threshold condition from clear-water to live-bed scour and at the transition to a plane-bed condition.

Sediment Size

The effect of particle size was found to depend on whether or not the particular bed sediment forms ripples. Maximum depth of scour for nonuniform non-ripple-forming sediments occurs at the threshold of motion condition. For uniform ripple-forming sediments, the maximum scour depth occurs at the transition to the plane-bed condition. The data for circular piers show that maximum value of the scour depth to pier diameter ratio (y_s/b) is 2.5.

For clear-water scour, the equilibrium depth is not affected by the particle size for ratios of pier width to mean sediment size (b / D_{50}) greater than 25. For smaller

values of this ratio, sediment particles forming the bed at the base of the pier are relatively large compared to the size of the scour hole. Consequently, the erosion process is impeded and the scour depth is reduced.

For the case of scour with sediment motion, Laursen and Toch (1953) stated that for uniform sand size, since the sediment size will not have any effect on any existing balance of the transport capacities, the equilibrium depth of scour should not be affected by a change in sediment size.

Sediment Gradation

Raudkivi and Ettema (1977) stated that sediment gradation has a strong influence on the equilibrium depth of clear-water scour. The sediment gradation coefficient is an indicator of the sediment size uniformity, and is defined as $G = 0.5 \left(\dfrac{D_{84}}{D_{50}} + \dfrac{D_{50}}{D_{16}} \right)$.

D_{84}, D_{50}, and D_{16} are sediment sizes for which 84 percent, 50 percent, and 16 percent of the sediment in the bed is finer. Another measure of sediment size uniformity is the standard sediment size deviation, which is defined as $\sigma_g = \sqrt{D_{84} / D_{16}}$. Raudkivi and Ettema presented a relationship between the maximum clear-water scour depth and the geometric standard deviation of sediment sizes (figure 31). The ordinate (K_σ) in figure 31 is the ratio of equilibrium scour depth in graded sediment to that in uniform sediment. From this figure, it can be concluded that the scour in typical river gravels with $K_\sigma \approx 3.5$ is only about 20% of the depth of scour expected for uniform sediment conditions.
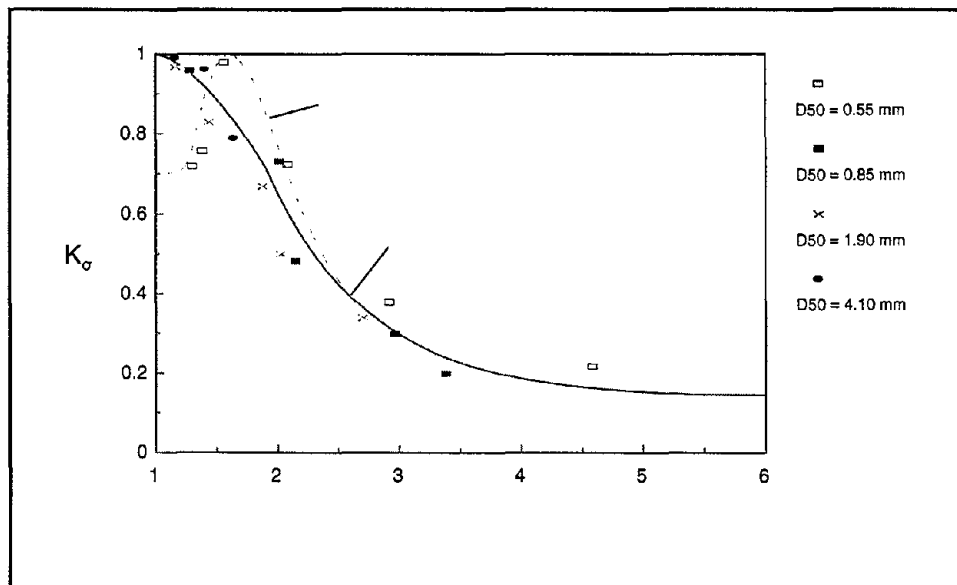
Figure 31. Effect of sediment gradation (Raudkivi and Ettema, 1977).

The effect of sediment gradation on the depth of live-bed scour is considerably more complex, as illustrated in figure 30. This figure shows the normalized scour depth versus flow velocity for nonuniform sediment $(K_\sigma \approx 3.5)$ and for coarse uniform sediment. In figure 30 experimental points are not shown, but the spread of data points was reportedly less than ($0.2\, d_s/b$) and even less for individual series. Since the data on sediment gradation for live-bed scour is very limited, a conclusive relationship between gradation and scour is yet to be determined.

Shape of the Pier

Piers can be classified into two categories:

● Blunt-nosed piers, where a strong horseshoe-vortex system—and thus the maximum scour depth—occurs at the pier nose. If the pier is aligned with the flow, the upstream pier shape has a strong influence on the scour depth, whereas the pier length and the downstream pier shape have a minimal effect.

● Sharp-nosed piers, where the horseshoe-vortex system is very weak and the maximum scour depth occurs near the downstream end.

Laursen and Toch (1953, 1956) found that the shape coefficient is defined as the ratio of the scour depth caused by a particular shaped pier to the scour depth caused by a rectangular pier. This coefficient varies with the shape of the pier as tabulated in figure 32. From this figure, the maximum reduction in scour depth that can be achieved by pier shape selection is approximately 30%. Selecting a simple round-shaped pier causes only a 10% reduction in scour. It should be noted that if the pier is not aligned with the flow, the pier shape effect may be lost.

Nose Form	Length-Width Ratio	K
Rectangular		1.00
Semicircular		0.90
Elliptical	2:1	0.80
	3:1	0.75
Lenticular	2:1	0.80
	3:1	0.70
Abutment		
Vertical wall		1.00
Wing wall		0.90
Spill-through		0.80

Figure 32. Effect of pier shape on scour (Laursen and Toch, 1953 and 1956).

Angle of Attack

For pier shapes other than circular, the depth of local scour depends upon the alignment of the pier with flow. The local scour depth is related to the projected width of the pier, and this width increases with the flow angle of attack. With an increasing angle of attack, the location of maximum scour moves along the exposed side of the pier from the front to the rear end of the pier. The influence of the angle of attack has been studied by Laursen and Toch (1956), who developed a correction factor for angle of attack. They defined an empirical coefficient (K_α), which is the ratio between scour depth at an angle of attack α to that at zero angle of attack. The relation between K_α and angle of attack is given in figure 33.

To accommodate the effects of the angle of attack, use of the projected width in pier scour equations has also been proposed.
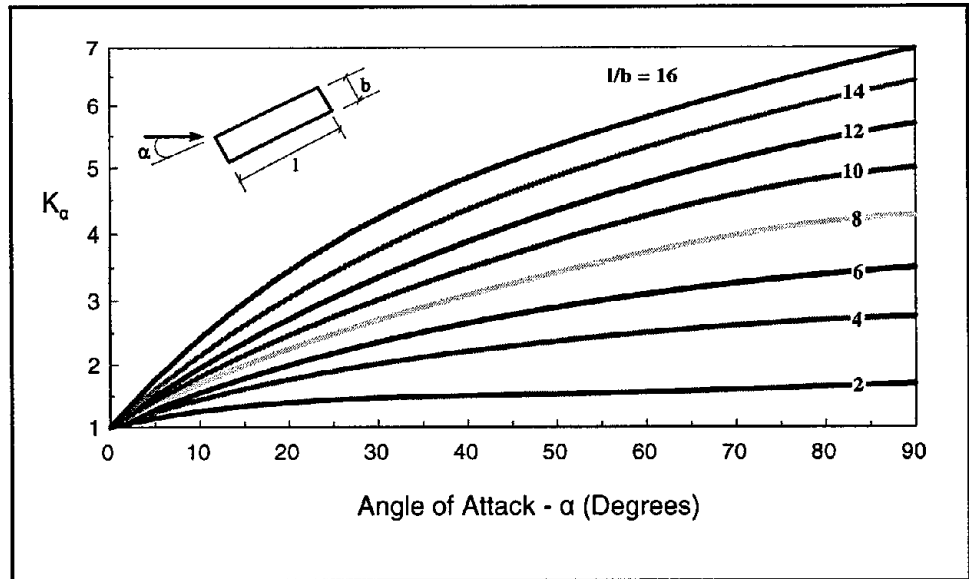
Figure 33. Correction factor for angle of attack.

Bed Material Density

Some experimental studies have been carried out to determine the effect of varying bed material densities under otherwise identical flow conditions. The conclusion reached from these studies is that the scour depth increases with decreasing bed material density.

Flow Duration

Maximum scour depth caused by flood events occurs in the flow recession phase when the river bed has been eroded to its lowest level and the general sediment transport is reduced so that clear-water scour conditions prevail. In this phase, the rate of scour development can have an important influence on the maximum scour depth. Theoretically, the terminal scour depth can only be reached during floods of infinitely long duration. For flooding events of shorter duration, the time of exposure to excess-shear conditions is important in determining the maximum scour depth. In other words, the longer the flooding duration, the greater the scour depth caused by the individual event. A comprehensive study of this phenomenon is not presently available.

5.2   DESCRIPTION OF MODELS

A large number of equations for predicting scour have been proposed by various researchers. Although the approaches and the parameters considered are varied, some general comments on pier scour equations can be made:

- There is a difference between clear-water and live-bed scour, and a scour equation should specify which case it pertains to.

- For a given pier geometry, the depth of scour increases with the depth of flow.

- The depth of scour increases with the pier size.

- The effect of pier spacing is negligible unless scour holes from adjacent piers overlap.

- In clear-water scour, the particle boundary shear and the critical tractive force affect scour depth as a ratio.

- For scour by sediment transport flow, the velocity and sediment size do not measurably matter except for low rates of sediment movement (just above the critical tractive force), and then the small effect is to have less scour with a higher velocity.

A list of formulae developed to predict the anticipated depth of local scour at intermediate bridge piers follows.

The Inglis-Poona equation (1938) is given as:

$$\frac{D_s}{b} = 1.70 \left(\frac{q^{2/3}}{b} \right)^{0.78} \tag{52}$$

where D_s is the depth of scour measured from water surface (= $d_s + y$); b = pier width; and q is the discharge per unit width in m²/s. It is based on a series of model tests run without general movement of the bed. The use of the discharge per unit width in the contraction implies greater scour depths at each pier as more piers are introduced into the cross section.

Chitale's formula (1944) is given as:

$$\frac{d_s}{y} = -5.49\,Fr^2 + 6.65\,Fr - 0.51 \tag{53}$$

where y is the upstream flow depth and Fr is the approach flow Froude number, which is based on the results of an extension of the original Poona model tests using rectangular piers. Most of the tests were for the case of clear-water scour, but for some where coarse sand was laid around the pier, the finer sand from upstream moved down to the scoured area.

The Inglis-Lacey relationship (1949) is given as:

$$d_s = 0.946\left(\frac{Q}{f} \right)^{1/3} - y \tag{54}$$

where Q is the total discharge in m³ /sec; f is the silt factor (= $1.76\sqrt{D_{50}}$, D_{50} in mm); and d_s and y are given in meters. The depth of scour relative to the water surface ($d_s + y$) computed from this equation is equal to twice the Lacey regime depth. This relationship applies to a regime channel and ignores the pier size, shape, and alignment.

Blench's equation (1957) is defined as:

$$\frac{y + d_s}{y_r} = 1.8\left(\frac{b}{y_r} \right)^{1/4} \tag{55}$$

where y_r is the regime depth (= $1.48\,(q^2/F_d)^{1/3}$); F_d = $1.9\sqrt{D}$; D is in mm; and q is in m²/s. This equation can be obtained from the Inglis-Poona equation if the exponent 0.78 is changed to 0.75. The limitation of the Poona equation therefore still

applies, and there exists a contradiction because the conditions of the Poona tests were those of clear-water scour, whereas regime theory implies a low to moderate rate of sediment movement.

The Laursen relationship (1960)

$$\frac{b}{y} = 5.5 \; \frac{d_s}{y} \left[\left(\frac{d_s}{11.5 \; y} + 1 \right)^{1.7} - 1 \right]$$

(56)

was based on an analysis using long bridge contraction hydraulics. A balance of sediment transport capacity in the normal and contracted sections was used in the derivation of this equation. It is valid for subcritical flow with a significant rate of sediment movement. This equation represents a conservative approximation of the pier scour by enveloping the available data. The pier scour value obtained from Eq. (56) must be increased using the coefficients representing the effects of pier shape and alignment, as shown in figures 32 and 33. A second relationship

$$\frac{b}{y} = 5.5 \; \frac{d_s}{y} \left[\left(\frac{d_s}{11.5 \; y} + 1 \right)^{7/6} \left(\frac{\tau_o'}{\tau_c} \right)^{1/2} - 1 \right]$$

(57)

where $\tau_0' / \tau_c = V^2 / 120 \, D^{2/3} \, y^{1/3}$ was similarly adapted from an analysis of long contraction. In this case, the contraction was assumed to scour to reach a boundary shear equal to the critical tractive force for the bed material. The shear in the approach is assumed to be less than the critical value (clear-water scour).

The Ahmad formula (1962)

$$d_s = K q^{2/3} - y$$

(58)

in which K is a multiplying factor that varies from 1.9 to 3.4 depending on the pier shape. It is based on field experience and model studies and was derived for bridges crossing alluvial rivers in deep sand fills.

Neill's equation (1964)

$$\frac{d_s}{b} = 1.5 \left(\frac{y}{b} \right)^{0.3}$$

(59)

is based on physical model data and computes the maximum scour that can occur at any velocity. For round-nosed piers, the coefficient should be changed to 1.2, whereas for all nonaligned shapes the coefficient 1.5 is used. For oblique piers the width is taken as the projected width. When plotted, the predicted scour depths computed by using Neill's equation correspond almost exactly to the first Laursen and Toch graphic relationship (1956).

Larras found that

$$d_{se} = 1.42 \, K b^{0.75}$$

(60)

in which K is the coefficient depending on pier shape and d_{se} is the equilibrium scour depth below mean bed level. K is suggested to be equal to 1 for circular piers and to 1.4 for rectangular piers aligned with the flow. The equation was obtained from available scour data from various rivers following flood events.

Blench (1962) converted the original Inglis-Poona equation to

$$\frac{y_r + d_s}{y_r} = 1.8 \left(\frac{b}{y_r}\right)^{1/4} \tag{61}$$

and Arunachalam (1965) obtained another form of the equation:

$$\frac{y_r + d_s}{y_r} = 1.95 \left(\frac{b}{y_r}\right)^{1/6} \tag{62}$$

Breusers (1964) proposed

$$d_{se} = 1.4\,b \tag{63}$$

for scour with continuous sediment motion for circular piers.

Hancu (1965) utilized experimental results for circular piers, and for natural sands obtained

$$\frac{d_s}{b} = 3.3 \left(\frac{d}{b}\right)^{0.2} \left(\frac{y}{b}\right)^{0.13} \tag{64}$$

Shen's equations

$$\frac{d_{se}}{b} = 11.0\,Fr^2 \tag{65}$$

$$\frac{d_{se}}{b} = 3.4\,Fr^{0.67} \tag{66}$$

are based on model studies conducted at CSU and elsewhere and apply to clear-water scour. Velocity effects are considered, but sediment size effects are excluded.

Shen, Schneider, and Karaki (1966) stated that, since the horseshoe-vortex system is the mechanism of local scour and the strength of the horseshoe-vortex system is a function of the pier Reynolds number, the equilibrium depth of scour should be functionally related to the pier Reynolds number, i.e.,

$$d_{se} = f(Re) \tag{67}$$

Experimental work with circular piers resulted in the following relation:

$$d_{se} = 0.00073\,Re^{0.619} \tag{68}$$

This equation was also tested for non-circular pier shapes. If dunes are present on the bed at the design velocity, it is suggested to add one half the expected height of these dunes to the estimated equilibrium depth of scour to get the maximum probable depth of scour.

Coleman (1971) analyzed available data from experiments using circular piers in sand under conditions of continuous sediment transport. The correlation obtained was

$$\frac{d_s}{b} = 1.49 \left(\frac{V^2}{g\,y}\right)^{0.1} \tag{69}$$

where V is the mean approach velocity; g is the gravitational acceleration.

A prediction equation was developed at CSU in 1975 for equilibrium scour depth:

$$\frac{d_s}{y} = 2.0 \; K_1 \; K_2 \left(\frac{b}{y}\right)^{0.65} Fr^{\,0.43} \tag{70}$$

The exponents were derived from laboratory data. The coefficients K_1 and K_2 are functions of pier shape and flow angle of attack. Their values are given in tables 9 and 10 for various pier types, flow angles of attack, and pier length-to-width ratios.

Table 9. Pier shape correction factor (K_1).

Type of Pier	Factor
(a) Square nose	1.1
(b) Round nose	1.0
(c) Circular cylinder	1.0
(d) Sharp nose	0.9
(e) Cylinder group	1.0

Table 10. Flow alignment correction factor (K_2).

Angle	$L/b = 4$	$L/b = 8$	$L/b = 12$
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.5	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0
Angle = skew angle of flow; L = length of pier; b = pier width			

The CSU equation was derived from laboratory data and is the one recommended in FHWA's publications "Interim Procedures for Evaluating Scour at Bridges" (1988) and "Highways in the River Environment" (Richardson et al., 1987). "Highways in the River Environment" also supports the use of Jain and Fisher's equation (1980) for higher flow velocities $(Fr - Fr_c \geq 0.15$):

$$\frac{d_s}{b} = 1.86 \left(\frac{y}{b}\right)^{0.5} (Fr - Fr_c)^{0.25} \tag{71}$$

where Fr_c is the critical Froude number. The equation was obtained first in a general form as a result of dimensional analysis, and then the numeric coefficients were determined with a multiple-linear regression analysis of experimental data.

Basak, Basamily, and Ergun (1975) performed tests with square piers in coarse sand. The water depths were low, and for most of the tests the flow velocity was greater than critical velocity $(V > V_c)$, where critical velocity is the velocity beyond which sediment motion is initiated. Since both depth and velocity were varied simultaneously, no independent variation of parameters was obtained. The results were correlated with the equation

$$d_s = 0.558 \, b^{\,0.586} \tag{72}$$

Jain (1981), using experimental data from previous studies, formulated an equation for maximum clear-water scour around cylindrical piers:

$$\frac{d_s}{b} = 1.84 \left(\frac{y}{b}\right)^{0.3} (Fr_c)^{0.25} \tag{73}$$

This equation is very similar to Laursen and Toch's equation, but accounts for the effect of sediment size on scour depth through the use of Fr_c.

Baker (1981), following a theoretical and experimental study of the mechanism of the vortex in the scour hole for $V/V_c \leq 1$, arrived at the formula

$$\frac{d_s}{b} = \left[g_1 \frac{V}{V_c} \right] \left[k_1 \tanh\left(k_2 \frac{y}{b} \right) \right] \left[g_2 g_3 \right] \tag{74}$$

in which k_1 and k_2 are functions of $G = \left(\rho_s - \rho \right) g D^3 / \left(\rho v^2 \right)$; g_1 is a function of V/V_c; g_2 and g_3 are functions of shape and incidence to the flow.

Raudkivi and Ettema (1977, 1983) found that the maximum depth of clear-water scour, for a cylindrical pier in a uniform grain-size sediment, in the absence of relative flow depth or relative grain size effects, is

$$\frac{d_{se}}{b} = 2.3 \tag{75}$$

For nonuniform sediment, this equation becomes

$$\frac{d_{se}}{b} = 2.3 \, K_\sigma \tag{76}$$

where K_σ is a coefficient whose value is a function of σ_g.

Froehlich (1987) used multiple-linear-regression analysis to develop a prediction equation for local live-bed scour

$$\frac{d_s}{b} = 0.32 \, \varphi \left(\frac{b'}{b} \right)^{0.62} \left(\frac{y}{b} \right)^{0.46} Fr^{0.20} \left(\frac{b}{D} \right)^{0.08} + 1 \tag{77}$$

where b' is the pier width projected normal to the approach flow ($b \cos\alpha + L \sin\alpha$); α is the angle of attack; and φ is the pier shape correction factor with values of 1.3 for a square-nosed pier, 1.0 for a round-nosed pier, and 0.7 for a sharp-nosed pier. It should be noted that Froehlich's equation increases the computed depth of scour to pier width ratio by a factor of safety equal to 1.0.

Melville and Sutherland (1988) presented a flow chart that allows the calculation of a predicted scour depth relative to the pier width as the product of six coefficients. These coefficients are functions, respectively, of flow intensity, flow depth, sediment size (as a ratio to the pier width), sediment gradation, pier shape and pier alignment.

5.3   DIMENSIONAL ANALYSIS

As stated in a previous section, depth of scour is a function of a number of parameters. In general, the relationship can be expressed as

$$d_s = f\left(y, \, b, \, V, \, D_{50}, \, \sigma_g, \, \varphi, \, \alpha, \, \gamma_s, \, t, \, g, \, \rho, \, v \right) \tag{78}$$

where y is the flow depth; b is the pier width; V is the mean approach velocity; D_{50} is the mean sediment size; σ_g is the sediment gradation; φ is the pier shape factor; α is the angle of attack; γ_s' is the submerged weight of the sediment; t is the time; g is the gravitational acceleration; ρ is the water density; and v is the kinematic viscosity.

The effect of viscosity is considered negligible in the scour process. By nondimensionalizing Eq. (78), the following relationship is obtained:

$$\frac{d_s}{b} = f\left(\frac{y}{b}, \ \frac{V}{\sqrt{g\,y}}, \ \frac{D_{50}}{y}, \ \sigma_g, \ \varphi, \ \alpha, \ \frac{V_t}{b}, \ \frac{\rho\,V^2}{\gamma_s'\,D_{50}} \right) \tag{79}$$

Furthermore,

$$\frac{\rho V^2}{\gamma_s'\,D_{50}} = \frac{\rho V^2}{(\rho_s - \rho)\,g\,D_{50}} \tag{80}$$

where ρ_s is sediment density. If ρ_s is assumed to be a constant, then this last term is in effect a particle Froude number where the characteristic length is the mean particle size. This term differs from the flow Froude number ($= V/\sqrt{g\,y}$) only by a constant, and therefore can be eliminated as redundant.

Neglecting the term representing the development of the scour hole with time, Eq. (79) can be rewritten as

$$\frac{d_s}{b} = f\left(\frac{y}{b}, \ \frac{V}{\sqrt{g\,y}}, \ \frac{D_{50}}{y}, \ \sigma_g, \ \varphi, \ \alpha \right) \tag{81}$$

The general form of the existing equations suggests that the relationship between scour depth and sediment gradation is vague (only Raudkivi and Ettema [1977] presented a relationship which takes into account the effects of σ_g, but even this gave only a maximum expected value, as a function of the uniformity characteristics of the sediment). If the effect of σ_g is neglected, Eq. (80) becomes

$$\frac{d_s}{b} = f\left(\frac{y}{b}, \ Fr, \ \frac{D_{50}}{y}, \ \varphi, \ \alpha \right) \tag{82}$$

Referring to the structure of most of the developed models, the functional relationship in Eq. (80) might be expressed as

$$\frac{d_s}{b} = \kappa \ K_1 \ K_2 \left(\frac{y}{b} \right)^a (Fr)^b \left(\frac{D_{50}}{y} \right)^c \tag{83}$$

where κ is a proportionality constant; K_1 is a shape factor; K_2 is the alignment factor; and a, b, and c are exponents to be determined through regression analysis.

Taking into account the time effect, Eq. (82) becomes

$$\frac{d_s}{b} = \kappa \ K_1 \ K_2 \left(\frac{y}{b} \right)^a (Fr)^b \left(\frac{D_{50}}{y} \right)^c \left(\frac{Vt}{b} \right)^d \tag{84}$$

where d is exponent to be determined through regression analysis. Eq. (82) is implemented in **BRI-STARS** as a generic equation for which the user is allowed to enter κ, K_1, K_2, and the exponents a, b, and c.

5.4   LOCAL SCOUR AT ABUTMENTS

The mechanism causing local scour at abutments doesn't differ from that of local scour at piers. The same systems of vortices take place, removing material from the bed in the vicinity of the abutment. Therefore, the same qualitative considerations on the nature and development of the process previously described still apply.

Very few field data are available to help derive or test prediction models. Available equations are mostly based on laboratory data and theoretical considerations derived from sediment continuity laws or dimensional analysis. Abutment scour computations in **BRI-STARS** are performed coupled with water and sediment routing computations and assume that the local scour does not alter the bridge hydraulics.

5.4.1 Description of Models

Garde, et al. (1961), proposed a formula based on dimensional analysis. Neglecting the effect of the width of the channel, sediment size, and gradation, and considering the angle of incidence equal to 90° and a constant average drag coefficient in their study, they obtained the following relationship for maximum scour depth:

$$\frac{y + d_s}{y} = 4.0 \; \frac{1}{\beta} \; Fr^{2/3} \tag{85}$$

in which β is the contraction ratio caused by the embankment $((B - a) / B)$; and B is channel width.

Liu, et al. (1961), and Gill (1972) derived the following equation for equilibrium scour depth in sand-bed channels for subcritical flows:

$$\frac{d_s}{y} = \kappa \left(\frac{a}{y} \right)^{0.4} Fr^{0.33} \tag{86}$$

where d_s is the equilibrium depth of abutment scour measured from mean bed level; a is the abutment and embankment length; and κ is a shape factor with values of 1.1 for spill-through abutments and 2.15 for vertical abutments.

Laursen (1980) suggested two relationships for vertical wall abutments. In the case of live-bed scour,

$$\frac{a}{y} = 2.75 \; \frac{d_s}{y} \left[\left(\frac{1}{11.5} \; \frac{d_s}{y} + 1 \right)^{1.7} - 1 \right] \tag{87}$$

should be used. An approximate, simplified form of Eq. (86) is also presented:

$$\frac{d_s}{y} = 1.5 \left(\frac{a}{y} \right)^{0.48} \tag{88}$$

For clear-water scour, the equation for abutment scour is given as:

$$\frac{a}{y} = 2.75 \; \frac{d_s}{y} \left[\frac{\left(\frac{1}{11.5} \; \frac{d_s}{y} + 1 \right)^{7/6}}{\left(\frac{\tau}{\tau_c} \right)^{1/2}} - 1 \right] \tag{89}$$

In the case of interruption of flood plain flow by the embankment-abutment combination, Eq. (89) reduces to:

$$\frac{Q_o}{q_w \, y} = 2.75 \; \frac{d_s}{y} \left[\left(\frac{d_s}{4.1 \, y} + 1 \right)^{7/6} - 1 \right] \tag{90}$$

where q_w is the discharge per unit width in the approach channel (Q_w / w); Q_o is the interrupted discharge on the single flood plain; y_0 is the approach flow depth; w is the width of flow influenced by the abutment (is $2.75 \, d_s$).

Froehlich (1987), on the basis of a dimensional analysis, obtained

$$\frac{d_s}{y} = 0.78 \, K_s \, K_\theta \left(\frac{a'}{y}\right)^{0.63} Fr^{1.16} \left(\frac{y}{D_{50}}\right)^{0.43} \left(\sigma_g\right)^{-1.87} + 1.0 \qquad (91)$$

for clear-water scour, and

$$\frac{d_s}{y} = 2.27 \, K_s \, K_\theta \left(\frac{a'}{y}\right)^{0.43} Fr^{0.61} + 1.0 \qquad (92)$$

for live-bed scour. In these equations, a' is the flow area of approach cross section obstructed by embankment divided by depth of flow at abutment ($= A_e / y$); K_s is the shape correction factor, with values of 1.0 for vertical abutments with square or rounded corners, 0.82 for vertical abutments with wing walls and sloped approach, and 0.55 for spill-through abutments and sloped approach embankment; K_θ is the angle correction factor ($= (\theta/90)^{0.13}$); θ is the angle of embankment to flow.

Some last quantitative remarks can be made. It is not practical to assume that the scour depth would continue to increase indefinitely with an increase in abutment length. Therefore a limit of $a/y = 25$ is assumed in using the previous equations. For $a/y > 25$, "Highways in the River Environment" suggests the following relationship:

$$\frac{d_s}{y} = 4.0 \, Fr^{0.33} \qquad (93)$$

Eq. (92) is based on field data collected at rock dikes on the Mississippi. It should be noted that for sand beds the maximum depth of scour will be 30% greater than the equilibrium scour depth.

The lack of field data and the variety of different cases that are possible suggest the need for discretion in choosing the proper abutment scour equation. FHWA's "Interim Procedures for Evaluating Scour of Bridges" is recommended as a reference guide.

5.4.2 Effect of Angle of Inclination

When the embankment is skewed, the angle of incidence has a strong effect on the depth of scour. If it is angled downstream, the scour depth is reduced because of the streamlining effect. If the embankment is angled upstream, there is an increase in the value of d. The curve presented in figure 34, obtained from Ahmad (1953), should be used to adjust the depth of scour computed by the chosen scour equation if the equation does not account for this parameter.
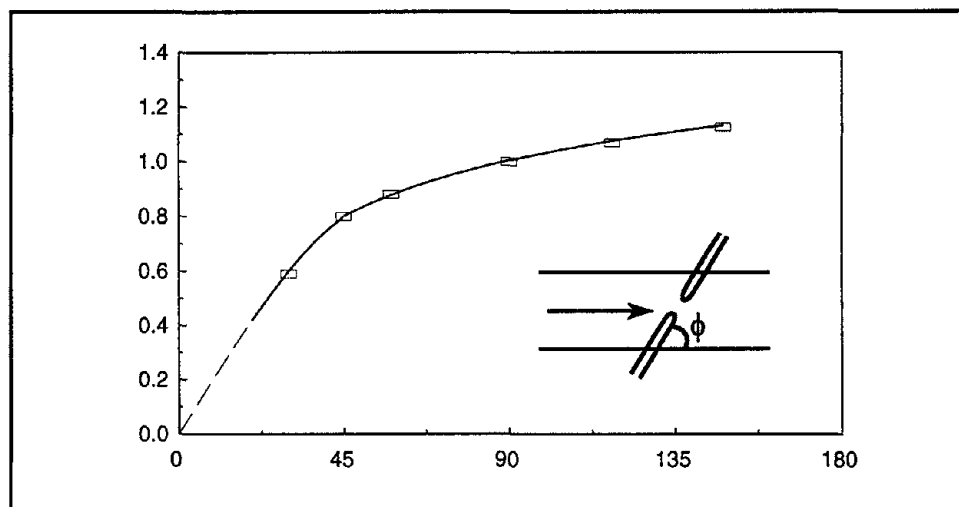
Figure 34. Scour estimation adjustment for skew

5.5 NOTATION

The following symbols are used in this chapter:

a	embankment length.
b	pier or abutment width.
B	channel width.
d_s	depth of scour below mean bed level.
d_{se}	equilibrium scour depth below mean bed level.
d_{sm}	maximum equilibrium scour depth below mean bed level.
D, D_{50}	mean sediment size.
f	friction factor.
Fr	Froude number.
Fr_c	critical Froude number.
g	gravitational acceleration.
L, l	length of the pier.
q	discharge per unit width.
Q	total discharge.
Re	pier Reynolds number.
V	mean approach flow velocity.
V_c	critical mean approach flow velocity.
y	upstream flow depth.
y_r	regime depth.
α	angle of attack of the flow.
v	kinematic viscosity of the water.
ρ	water density.
ρ_s	bed material density.
σ_g	geometric standard deviation of particle size distribution.
τ_c	critical shear stress.
τ	bed shear stress.

6. HYDRAULIC DATA

In this section, input data requirements pertaining to channel geometry and flow properties will be presented. First, channel geometry data and the required data records for the computer runs will be discussed. Second, channel roughness and loss coefficient data requirements will be presented. Finally, data requirements pertaining to the discharges and the corresponding stages for water surface profile computations will be discussed. Unless otherwise specified, all units will be in the English system.

6.1   CHANNEL GEOMETRY DATA

The various input data records are defined in Appendix B of this manual, and typical input data for the program are given in Appendix C. For geometric properties data, the distance between cross sections, channel cross section shapes, and the location of sub-channels or subsections should be provided. Stations should be identified by their distance from a reference downstream station. The computer program determines the distance between two cross sections from the difference in the station identification numbers. Channel cross sections are input by entry of the X- and Y-coordinate pairs for each data point across the channel, starting from the left-hand side of the channel looking downstream. The locations of channel subsections at a given station are entered by their end points being defined going from left to right across the channel.

The data records for defining the channel geometries and station locations along the study reach are: NS, ST, ND, and XS.

The NS record defines the number of measured stations to be used in the study. It is the first record following the title (TT) records. Only one NS record per job is required.

The ST records identify the location of each cross section and the number of points defining the channel geometry at this location.

The ND record defines the number of subsections or subchannels at a given station and their corresponding lateral locations across the river.

The XS record is used to define the channel geometry at a given station.

The ST, ND, and XS records should be provided for each measured cross section along the study reach.

6.2   CHANNEL ROUGHNESS AND LOSS COEFFICIENT DATA

Following the channel geometry data, the type of flow equation should be selected by the variable *EQROUGH* being defined in the RE record. The available options are: Manning, Darcy-Weisbach, and Chezy equations. Depending on the selection, one of these flow roughness equations will be used for energy slope and conveyance computations. Roughness coefficients corresponding to each point across the channel at different stations should be provided following the RE record. These values are entered using the RH records. Roughness coefficients for each station are entered using the RN records. Roughness coefficients for each station should be defined starting from the furthest upstream station and progressing in the downstream direction. For each station, up to 27 roughness values can be assigned across the channel.

The normal, critical, and sequent depth computations require representative bottom elevations along the study reach. For the computation of these elevations, two options are provided through the CB record. They are: THALWEG and READ. If the THALWEG option is selected, no further information is required. For the READ option, the manually computed channel bottom elevations must be entered with the BE record.

Next, local energy loss coefficients should be provided by the CL record. These coefficients are for the bends, natural and man-made structures, etc., along the study reach. The coefficient of loss is internally set equal to 0.1 for contractions and to 0.3 for expansions. These coefficients can be selected by the user in the CE (coefficients of expansion and contraction loss) record.

6.3   INPUTTING THE DISCHARGES AND CORRESPONDING STAGES

The discharges and the corresponding stages to be used in the water surface profile computations should be provided following the number of stream tube data (NT record). The required data records for this purpose are: IT, QQ, SS, DD, SQ, TL, TQ, RC, and NC records. Depending on the option selected in entering stage and discharge values, some of these records are omitted.

In general, the discharges can be entered either as a table or as a series of discretized discharges by specifying the IOPTQ value in the QQ record. The corresponding stages can be input either in the form of a rating curve or as a stage-discharge table by specifying the IOPTSTQ value in the SS record.

Depending on the nature and format of the available data, several options for inputting the stage-discharge values are provided. These options are given below:

CASE 1: Discharge Hydrograph and a Stage-Discharge Rating Curve are Available

If the discharges are given in the form of a hydrograph, a discretization procedure is necessary. In this procedure, the user first selects a fixed duration. Next, the hydrograph is broken into discrete steps of constant discharges. The duration of each constant discharge event is expressed in whole multiples of the selected duration. A sample discretization procedure is given in figure 35. In this example, the actual hydrograph is approximated by a 1-time step of Q1, 1-time step of Q2, 1-time step of Q3, 2-time step of Q4, 1-time step of Q5, 2-time step of Q6, and 1-time step of Q7 discharges. These discretized discharges and the number of time steps are input with the DD records. If the duration of the entire hypothetical event was assumed to be 18 days, the fixed-time interval used in this example would have been 2 days (= 18/9). Smaller time steps would result in closer approximation of the hydrograph. However, the number of time steps to be used in the simulation, and therefore the computation time, will be higher. Selecting the optimum number of time steps and the degree of accuracy is dependent upon the user's experience in discretization. Once the input hydrograph at a general station is discretized, the corresponding stages can be computed from the given rating curve. The rating curve in this program is assumed to be given in the form:

$$Stage\ in\ feet\ =\ C1\ (discharge\ in\ ft^3/sec)^{C3}\ +\ C3 \qquad (94)$$
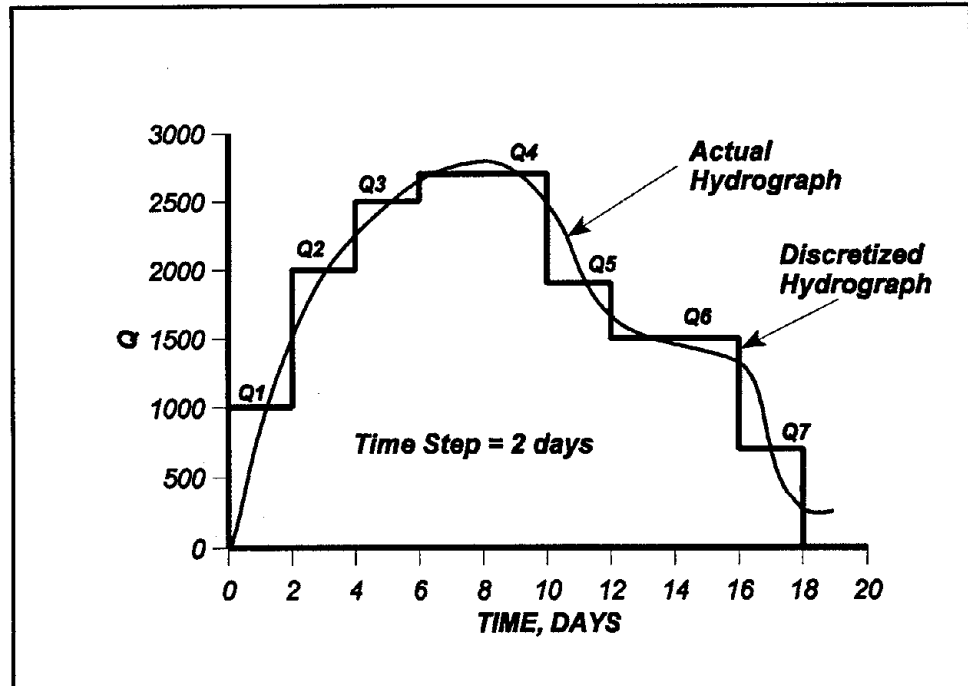
Figure 35.   Discretization of input discharge hydrograph.

where $C1$, $C2$, and $C3$ are coefficients to be supplied by the user in the RC record. If, for the example hydrograph given in figure 35, a stage-discharge rating curve:

$$Stage = 0.9 \, Q^{0.2} + 1000 \tag{95}$$

is given at station No. 10 of a hypothetical reach, the input data records would be:

FIELD NUMBERS										
0	1	2	3	4	5	6	7	8	9	10

```
IT    9.       1.       2.
QQ       DISCRETIZED DISCHARGES
SS       RATING CURVE
DD    1.    1000.
DD    1.    2000.
DD    1.    2500.
DD    2.    2700.
DD    1.    1900.
DD    2.    1500.
DD    1.     700.
NC    1.
RC   10.       0.9      0.2    1000.
```

Note that the sum of NDAYS in field 1 of DD records is equal to ITIMAX in the IT record.

CASE 2: Table of Daily Discharges and a Rating Curve at the Control Section Are Available

In some instances, periodic discharge records for a study reach are available in the form of a table. The stage-discharge rating curve for the control section might also

be available. In this case, the input stage-discharge data are entered on the IT, QQ, SS, TQ, NC, and RC records. For the example reach described in CASE 1, the discharge table is given as:

Days	Discharge (ft³ / sec)
0	500
2	1600
4	2250
6	2650
8	2800
10	2250
12	1750
14	1500
16	1250

and the stage-discharge rating curve for Station No. 10 is in the form:

$$Stage = 0.9\,Q^{0.2} + 1000 \tag{96}$$

the input data records would be:

FIELD NUMBERS										
0	1	2	3	4	5	6	7	8	9	10

```
IT    9.       1.       2.
QQ         TABLE OF DISCHARGES
SS         RATING CURVE
TQ   500.   1600.   2250.   2650.   2800.   2250.   1750.   1500.   1250.
NC    1.
RC   10.      0.9      0.2   1000.
```

CASE 3: Stage-Discharge Values Are Available for the Control Section

In the case where periodic discharges and the corresponding stage values are available for the control section in tabular format, this information is input with the QQ, SS, IT, TL, and SQ records. The number of SQ records should be equal to the *ITIMAX* value given in the IT record. For the example problem given in CASE 1, if the discharges and stages are:

Day	Discharge	Stage
0	500.	1003.1
2	1600.	1003.9
4	2250.	1004.2
6	2650.	1004.4
8	2800.	1004.4
10	2250.	1004.2
12	1750.	1004.0
14	1500.	1003.9
16	1250.	1003.7

the input data records would be:

FIELD NUMBERS										
0	1	2	3	4	5	6	7	8	9	10

```
IT    9.        1.                        2.
QQ        TABLE OF DISCHARGES
SS        STAGE DISCHARGE TABLE
TL   10.
SQ  500.   1003.1
SQ 1600.   1003.9
SQ 2250.   1004.2
SQ 2650.   1004.4
SQ 2800.   1004.4
SQ 2250.   1004.2
SQ 1750.   1004.0
SQ 1500.   1003.9
SQ 1250.   1003.7
```

7. SEDIMENT DATA

In this section, the input data for computing sediment transport capacities associated with different flow and channel geometry conditions are presented. Sediment transport capacity computations in the computer program are activated by selection of "SEDIMENT TRANSPORT REQUESTED" in the SO record. Following the SO record, depending upon the availability of sediment characteristics data, the user is requested to provide some or all of the SO, QS, SE, TM, SF, SG, and SD records. The definitions of the above mentioned records are given in Appendix B of this manual. In the current version of the computer program, sediment transport capacities can be determined by (1) the Molinas and Wu equation with bed material fraction (BMF) method for fractional load, (2) the Molinas and Wu equation with transport capacity fraction (TCF) method for fractional load, (3) the Ackers and White equation with the BMF method for fractional load, (4) the Engelund and Hansen equation with the BMF method for fractional load, (5) Yang's equation with the BMF method for fractional load, (6) the Yang, Molinas, and Wu equation with the BMF method for fractional load, (7) the Meyer-Peter Müller equation with the BMF method for fractional load, and (8) a generic sediment transport equation (defined through SP record).

The above-mentioned methods were chosen because of their accuracy and the short computational times associated with them. The sediment transport methods to be used in the program require the water temperature data for kinematic viscosity computations. These data are input on the TM record following the SE record. Water temperatures are input in the form of a table with number of time iterations in the first column and the corresponding temperatures in the second column. The total of time iterations should be equal to $ITIMAX$ specified in the IT record. Desired sediment transport equations can be selected by the variable $ISED$ in the SE record.

The thickness of the active layer (a conceptual layer in which sediment can be sorted in a single time step) is controlled by the $NALT$ variable in the SE record. This variable controls the maximum allowable erosion in a given time step and is set equal to $50D_k$ by default. D_k is the geometric mean size corresponding to the last size group specified in the SG records.

The sediment inflow hydrograph into the study reach at the farthest upstream station must be supplied in the form of discretized sediment discharges on QS records. Data generation for the QS records follows exactly the same format as the DD records described in chapter 6 and figure 35. The sediment discharge hydrograph is first broken into discrete steps of constant discharges. The duration of each constant sediment discharge event is expressed in whole multiples of the preselected duration. These sediment discharges and the number of time steps are input on the QS records. The sum of $NDAY$ in field 1 of QS records should be equal to $ITIMAX$ in the IT record.

The sediment transport equations available for routing computations are applicable only to particle sizes of 0.0625 mm (sand) and greater. For Yang's Method of computations, sediment routing can be performed for sediments up to 10 mm gravel sizes. The Meyer-Peter Müller method is available for larger sediments. The sediment gradation curve can be input through the SF, SG, and SD records following the TM (Temperatures Record). The SF record is used to define the number of size fractions, the SG record identifies different sediment size groups falling into sand and gravel sizes, and the SD record is used to input the bed material size fractions falling within each size group defined by SC records at different stations.

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Data records for inputting hypothetical sediment characteristics data are given in table 11. The hypothetical gradation curve used in constructing table 11 is shown in figure 36.
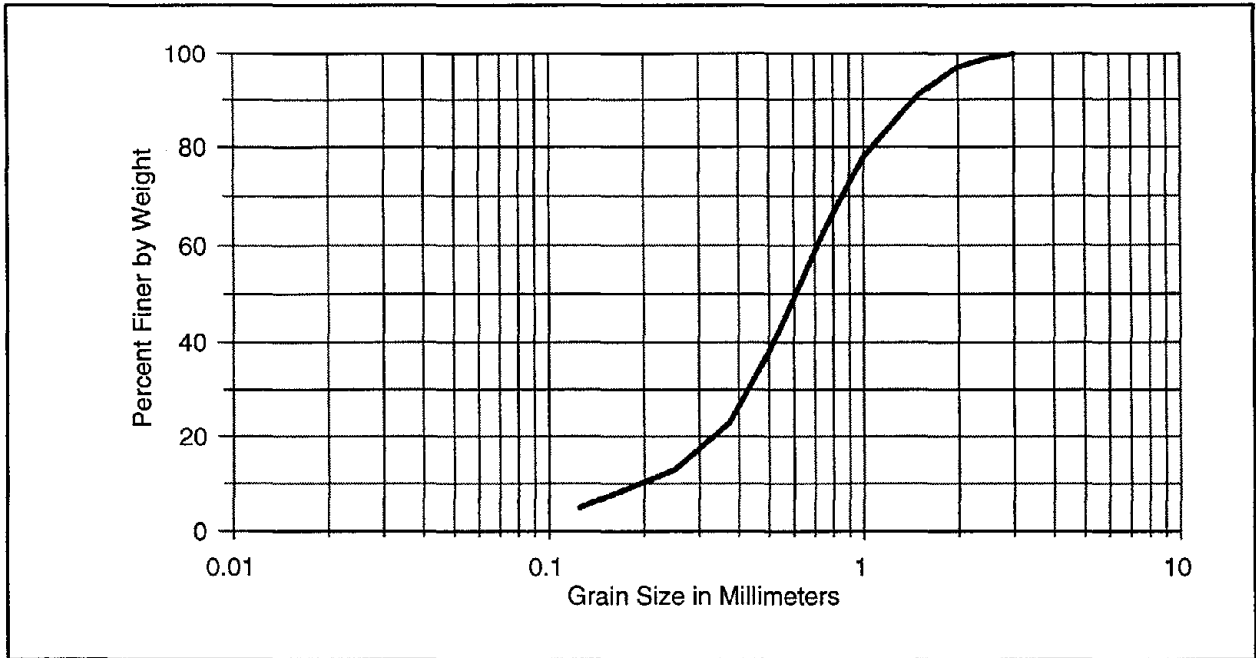
Figure 36. Hypothetical sediment size gradation curve.

Table 11. Inputting sediment characteristics data by discretizing the small sediment gradation curve.

FIELD NUMBERS										
0	1	2	3	4	5	6	7	8	9	10

```
SO        SEDIMENT TRANSPORT REQUESTED
QS      9    100.
SE      1.
TM      9.       70.
SF     10
SG 0.0625   0.1250
SG 0.1250   0.2500
SG 0.2500   0.3750
SG 0.3750   0.5000
SG 0.5000   0.7500
SG 0.7500   1.0000
SG 1.0000   1.5000
SG 1.5000   2.0000
SG 2.0000   2.5000
SG 2.5000   3.0000
SD    0.05    0.08    0.10    0.15    0.25    0.15    0.13    0.06    0.02    0.01
SD    0.05    0.08    0.10    0.15    0.25    0.15    0.13    0.06    0.02    0.01
SD    0.05    0.08    0.10    0.15    0.25    0.15    0.13    0.06    0.02    0.01
SD    0.05    0.08    0.10    0.15    0.25    0.15    0.13    0.06    0.02    0.01
SD    0.05    0.08    0.10    0.15    0.25    0.15    0.13    0.06    0.02    0.01
```

8. BRIDGE SCOUR DATA

8.1 BRIDGE PIER SCOUR DATA

In the presence of bridge piers in the study reach, the user is given the option to compute local scour due to piers by activating pier scour computations. The user is given the option of selecting the local pier scour equation to be used in the simulations from a list of equations. The general overview of pier scour equations was presented in chapter 5. Local pier scour equations available in the **BRI-STARS** model are: i) CSU equation; ii) Laursen equation; iii) Froehlich equation; iv) Jain and Fisher equation; v) generic equation. For the pier scour computations, data pertaining to the number of stations containing bridge piers and the number of piers at each station along with the location of pier center locations across the channel must be supplied to the **BRI-STARS** model. Also, depending upon the selection of bridge pier scour equation, additional information such as the bridge pier type and dimensional characteristics, the properties of the approach flow, and representative sediment size at the pier location for each individual pier must be supplied to the model.

The records needed for pier scour computations are: PE, PS, and PP records. These records are entered into the data file following the sediment transport data, after SD (Sediment Size Distribution) records. The PE record defines the pier scour equation to be used in the study and the number of stations containing piers in the study reach. The PS record specifies the pier station numbers and the number of piers at the corresponding stations. Finally, the PP record specifies the center location of the piers, the width, type, approach flow angle of attack, pier length, and the representative sediment size at the pier location. A set of Pier Scour Parameters (PP) records are needed for each Pier Station (PS) record. For each pier station one set of PS and PP records must be supplied.

An example set of pier records for a hypothetical reach are given in table 12 below. The Froehlich equation for local pier scour computations is chosen in the first field of the PE record. The number of stations containing piers are specified as (2) in the second field of PE record. The first set of PS-PP records defines the first pier station as station no. 3 (first field of PS record) containing 4 piers (second field of PS record). The PP records used in the first set of PS-PP records define the center locations of the 4 piers to be at stations 10, 50, 90, 150 ft across the channel (first field of PP records). The width, type, angle of attack, length, and representative

Table 12. Example set of pier scour records for a hypothetical reach.

				FIELD NUMBERS						
0	1	2	3	4	5	6	7	8	9	10
PE	3.0	2.0								
PS	3.0	4.0								
PP	10.0	10.0	1.0	20.0	40.0	5.0				
PP	50.0	10.0	1.0	20.0	40.0	5.0				
PP	90.0	10.0	1.0	20.0	40.0	5.0				
PP	150.0	10.0	1.0	20.0	40.0	5.0				
PS	10.0	1.0								
PP	10.0	10.0	1.0	20.0	40.0	5.0				

sediment size corresponding to each of the piers in station 3 are defined in fields 2-6 of PP records, respectively. The second set of PS-PP records define the station no. 10 to be the second pier station containing a single pier (fields 1 and 2 of PS record). The pier at station no. 10 is located at station 50 ft across channel (first field of PP record). It is 10 ft wide (second field of PP record), of type 1 (third field of PP record), the approach flow angle of attack is 20 degrees (fourth field), the pier length is 40 ft (fifth field), and the representative sediment size at pier location is 5 mm (sixth field).

If the optional generic pier scour equation is selected for predicting maximum potential local pier scour, each PP record must be followed by a PC (Pier equation Coefficients) record. The fields of the PC record specify values used in the generic pier equation. Since each pier is allowed its own set of coefficients, it is possible to use more than 1 pier scour formula across the channel. This option is useful in cases where the variation in the geomorphology across the channel is significant and the application of different local pier scour equations is needed. Table 13 shows an example set of pier scour records for a hypothetical reach with user-provided pier equation coefficients.

Table 13. Example set of pier scour records for a hypothetical reach.

					FIELD NUMBERS					
0	1	2	3	4	5	6	7	8	9	10
PE	3.0	2.0								
PS	3.0	4.0								
PP	10.0	10.0	1.0	20.0	40.0	5.0				
PC	2.0	1.0	1.0	-0.65	0.43	0.0	5.0			
PP	50.0	10.0	1.0	20.0	40.0	5.0				
PC	2.0	1.0	1.0	-0.65	0.43	0.0				
PP	90.0	10.0	1.0	20.0	40.0	5.0				
PC	2.0	1.0	1.0	-0.65	0.43	0.0	5.0			
PP	150.0	10.0	1.0	20.0	40.0	5.0				
PC	2.0	1.0	1.0	-0.65	0.43	0.0	5.0			
PS	10.0	1.0								
PP	10.0	10.0	1.0	20.0	40.0	5.0				
PC	2.0	1.0	1.0	-0.65	0.43	0.0	5.0			

8.2   BRIDGE ABUTMENT SCOUR DATA

In the presence of bridge abutments in the study reach, the user is given the option to compute local scour due to abutments by activating abutment scour computations. The user is given the option of selecting the local abutment scour equation to be used in the simulations from a list of equations. The general overview of abutment scour equations was presented in Chapter 5. Local abutment scour equations available in the **BRI-STARS** model are: i) CSU (Liu) equation; ii) Laursen equations; and iii) Froehlich equations. For the abutment scour computations, data pertaining to the number of stations containing bridge abutments, and the number of abutments at each station along with the location of abutment center locations across the channel must be supplied to the **BRI-STARS** model. Also, depending upon the selection of bridge abutment scour equation, additional information such as the bridge abutment type and dimensional characteristics, the properties of the approach flow, and representative sediment size at the abutment location for each individual abutment must be supplied to the model.

The records needed for abutment scour computations are: AE, AS, and AP records. These records are entered into the data file following the sediment transport data, after SD (Sediment Size Distribution) records and the optional local pier scour data records (PE, PS, PP, PC). The AE record defines the abutment scour equation to be used in the study and the number of stations containing abutments in the study reach. The AS record specifies the abutment station numbers and the number of abutments at the corresponding stations. Finally, the AP record specifies the center location of the abutments, the width, type, approach flow angle of attack, abutment length, and the representative sediment size at the abutment location. A set of Abutment Scour Parameters (AP) records are needed for each Abutment Station (AS) record. For each abutment station, one set of AS and AP records must be supplied.

An example set of abutment records for a hypothetical reach are given in table 14 below. The Laursen equation for local abutment scour computations is chosen in the first field of the AE record. The number of stations containing abutments are specified as (2) in the second field of AE record. The first set of AS-AP records defines the first abutment station as station no. 4 (first field of AS record) containing 2 abutments (second field of AS record). The AP records used in the first set of AS-AP records define the locations of the 2 abutments to be from stations 0 to 30 ft across the channel and from 90 to 120 ft across the channel (first two fields of AP records). The abutment type, angle of embankment inclination, abutment elevation at the flood plain, representative sediment size, geometric standard deviation for sediment size, and the fine sand concentration index corresponding to each of the abutments in station 4 are defined in fields 3-8 of the AP records, respectively. The second set of AS-AP records define the station no. 10 to be the second abutment station containing a single abutment (fields 1 and 2 of AS record). The abutment at station no. 10 has the following characteristics: it is located between stations 0 ft and 50 ft across the channel (first two fields of AP record); it is of type 1 (third field of AP record); the angle of inclination of the approach embankment is 20 degrees (fourth field); the abutment elevation is 1040 ft (fifth field); the representative sediment size at abutment location is 5 mm (sixth field); the geometric standard deviation $(G = \sqrt{D_{84} / D_{16}})$ of the bed material is 2.3 (seventh field); and the fine sand concentration index for estimating shear stress is medium (given as 2 in the eighth field).

Table 14. Example set of abutment scour records for a hypothetical reach.

					FIELD NUMBERS					
0	1	2	3	4	5	6	7	8	9	10
AE	3.0	2.0								
AS	4.0	2.0								
AP	0.0	30.0	1.0	20.0	1040.0	5.0	2.3	2.0		
AP	90.0	120.0	1.0	20.0	1040.0	5.0	2.3	2.0		
AS	10.0	1.0								
AP	0.0	50.0	1.0	20.0	1020.0	5.0	2.3	2.0		

8.3   CONTRACTION SCOUR DATA

For the **BRI-STARS** model, Laursen's contraction scour equations have been chosen for the purpose of determining local scour due to contractions. The scour computed from Laursen equations can be used for the purpose of comparing the simulation results with hand calculations. Since **BRI-STARS** utilizes the sediment

continuity equation in which transport capacities are determined by various equations, it intrinsically computes the contraction scour during simulations. For long-term simulations, if the transport equation selected for the simulation is in agreement with Laursen's simplified transport function, the computed contraction scour is expected to be in agreement with simulated contraction scour values. Laursen (1980) provides contraction scour equations for two scenarios: i) live-bed scour (where approach shear stress is greater than critical shear stress); and ii) clear-water scour (where approach shear stress is less than critical shear stress).

LIVE-BED SCOUR

For contraction scour in a live-bed situation, Laursen gives the following equation:

$$\frac{y_1}{y_2} = \frac{Q_{mc2}}{Q_{mc1}} \left(\frac{W_{c1}}{W_{c2}} \right)^{K_1} \left(\frac{n_2}{n_1} \right)^{K_2} \tag{97}$$

and

$$y_s = y_2 - y_1 \quad [Average \ scour \ depth] \tag{98}$$

where y_1 is the depth in the main channel (average); y_2 is the depth in the contracted section (average); W_{c1} is the bottom width of the main channel; W_{c2} is the bottom width of the contracted section; Q_{mc1} is the flow in the approach channel; Q_{mc2} is the flow in the contracted section; n_1, n_2 are the Manning's coefficients for the main channel and contracted section; and K_1, K_2 are exponents for which

$$K_1 = \frac{6(2 + e)}{7(3 + e)} \ ; \quad K_2 = \frac{6}{7} \frac{e}{(3 + e)} \tag{99}$$

where K_1, K_2 are computed as follows:

1. Compute $V_{*c} = \sqrt{g \, Y_1 \, S_{E1}}$.

2. Compute ω_{50} (fall velocity) for the D_{50} size material.

3. Compute V_{*c} / ω_{50} .

4. If:

$V_{*c} / \omega_{50} < 0.5$ then   e = 0.25; (bed-load).

                                        $K_1 = 0.59; K_2 = 0.066.$

$0.5 \le V_{*c} / \omega_{50} \le 2.0$ then   e = 1.0; (suspended, bed-load).

                                         $K_1 = 0.64; K_2 = 0.21.$

$V_{*c} / \omega_{50} \ge 2.0$ then   e = 2.25; (suspended load).

                                         $K_1 = 0.69; K_2 = 0.037.$

CLEAR-WATER SCOUR

For contraction scour in a clear-water situation, Laursen gives the following equation:

$$\frac{y_1}{y_2} = \left(\frac{W_{c1}}{W_{c2}} \right)^{6/7} \left(\frac{V_1^2}{120 \, y_1^{1/3} D_{50}^{2/3}} \right)^{3/7} \quad [variables \ defined \ above] \tag{100}$$

The critical shear stress can be estimated from the figure given below for various inflowing fine sediment concentrations.
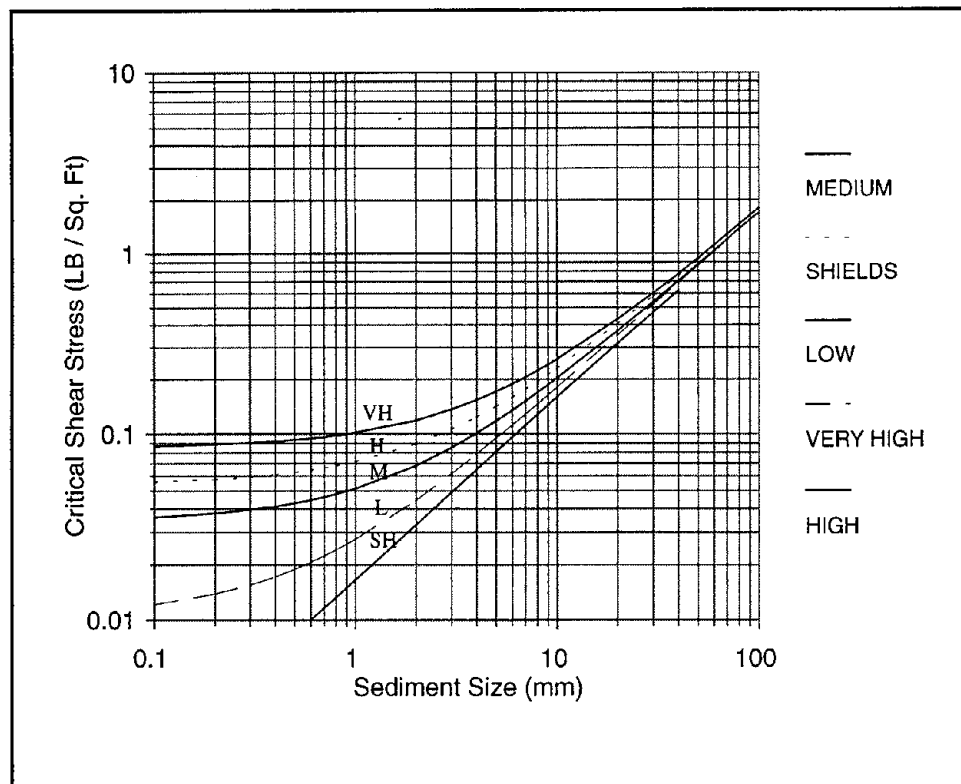
Figure 37. Critical shear stresses versus bed material.

8.4   BRIDGE HYDRAULICS DATA

A portion of the WSPRO (Shearman, 1990) model has been incorporated as an option in version 3.0 of **BRI-STARS**. If the use of WSPRO bridge routines is requested, the preparation of cross-section data files for **BRI-STARS** must comply with restrictions imposed in WSPRO. The spacing of and the definition of APPROACH, BRIDGE, FULL VALLEY, and EXIT cross-sections are in accordance with WSPRO. The **BRI-STARS** bridge station identified in WB (WSPRO Bridge Station record) corresponds to the bridge (BR) section in WSPRO. The WSPRO records which are used in version 3.0 of **BRI-STARS** are limited to a minimum definition. The WSPRO records recognized in **BRI-STARS** are the AB, AS, BP, BR, CD, and PW records. The comprehensive definition of input data parameters are given in the WSPRO manual and for the sake of brevity are not reproduced in this manual. However, the WSPRO tables for these records are reproduced in tables 15-20 below. Currently, applications are limited to a single WSPRO bridge station in fixed geometry mode. Design mode is not supported. Other bridge stations in the reach may be approximated using the simplified **BRI-STARS** pier stations. To avoid any syntactic errors and conflicting record identification problems, the WSPRO data are prepared separately and are stored in a different data file. If the WSPRO bridge option is chosen, the user is prompted for the appropriate file name. An example problem is given in appendix C.

Table 15. Table 4.3 from the WSPRO Users Manual.

AB Record

Purpose: Mandatory record to specify abutment slope(s) for Type 3 openings in design mode (not used for other opening types in design mode). Mandatory record to specify abutment toe elevations for Type 2 openings in fixed-geometry mode (not used for other opening types in fixed-geometry model).

Format:

Columns	Format	Contents	
1-2	A2	AB	
3-10	8x	blank	
11-80	free	Either	ABSLPL [,ABSLPR]
		or	*, *, YABLT, YABRT

Definition of variables:

ABSLPL, ABSLPR — Slope (horizontal distance per foot change in elevation) of the left and right abutments, respectively. Required only for Type 3 openings when using the design mode for defining bridge section. If both abutments have the same slope, only ABSLPL is required. See figure 4-9 for illustration of these parameters.

YABLT, YABRT — Ground elevation at the toe of the left and right abutments, respectively. Required only for Type 2 openings when using fixed-geometry mode (in design mode the model determines these elevations). The depths of water at the toes of the abutments are used to compute an adjustment factor for the coefficient of discharge. See figure 4-8 for illustration of these parameters.

Table 16. Table 4.4 from the WSPRO Users Manual.

AS Record

Purpose: Header record for approach cross section.

Format:

Columns	Format	Contents
1-2	A2	AS
3-5	3x	blank
6-10	A5	SECID
11-80	free	SRD [, SKEW, EK, CK, VSLOPE]

Definition of variables:

SECID — Unique cross-section identification code (see discussion of SECID is
   section 4.1).

SRD — Section reference distance. A cumulative distance, in feet, along the
   stream measured from any arbitrary zero reference point (SRD may be
   negative). Unless an FL record is coded for the approach section, the
   difference in the full valley section SRD and the approach section SRD
   is used as the flow length for computing the friction loss in the
   unconstricted profile computations. The effective flow length
   (Schneider, et al., 1977) is used for friction loss computations for
   bridge backwater regardless of SRD or FL record data. The SRD values
   for the approach section should be approximately equal to the SRD
   values of the full valley section plus the bridge width plus the bridge
   length (plus the length of spur dikes if they exist). See Section 4.3
   and figure 3-8 and 3-11 for additional information.

SKEW — The actual angle that cross section must be rotated to locate the
   cross section normal to the flow direction. The model applies the
   cosine of SKEW to the horizontal dimensions of the section to compute
   the correct cross-section properties. Default is zero degrees.

EK,CK — Coefficients to be used for expansion and contraction losses,
   respectively, in the energy equation. These coefficients do not apply
   to the bridge backwater computations. However, they are used in the
   computation of the unconstricted profile in upstream computations (for
   the full valley to approach section subreach) and would be used in the
   approach to bridge section subreach in downstream computations.
   Default values are 0.5 for EK and 0.0 for CK or the last values input
   for a previous cross section.

VSLOPE — Valley slope in feet/foot. Used for adjusting elevations of
   propagated geometry data. Also used for elevation adjustments of
   approach cross-section data used to fabricate intermediate approach
   cross sections when the approach section is the upstream match section
   for a multiple-opening situation. Default value is either zero or the
   last valley slope that was input for a previous cross section.

Table 17. Table 4.7 from the WSPRO Users Manual.

BP Record

Purpose: Specifying relation of bridge opening horizontal datum to the
            horizontal datum of road and (or) approach section(s) (only
            applicable to single-opening situations).

Format:

Columns	Format	Contents
1-2	A2	BP
3-10	8x	blank
10-80	free	XREFLT [, XREFRT, FDSTLT, FDSTRT]

Definition of variables:

   XREFLT — Horizontal station on the road grade or approach section which
        coincides with the projection of a reference point from the bridge
        section. The reference point in the bridge section is either (1)
        XCONLT (or BL record) for DESIGN MODE or (2) minimum x-coordinate of
        the bridge section for FIXED-GEOMETRY MODE. The reference point is
        projected vertically to the road grade section and along a line
        parallel to the flow to the approach section. XREFLT is the only
        parameter needed to provide a common horizontal datum for bridge and
        road grade sections. Figures 4-4 illustrates use of the BP record for
        the bridge/road grade adjustment. It also is sufficient to use only
        XREFLT for marking necessary horizontal adjustments for bridge and
        approach sections when their stationing is not alined properly and (or)
        when either (or both) the bridge or (and) approach sections are skewed
        to the bridge/approach section adjustment.

An additional three parameters are required to account for curvilinear flow
between bridge and approach cross sections. A typical situation is illustrated
in figure 4-6. The input data for the bridge and approach sections must be
alined normal to the flow. The variable flow length due to nonparallel
sections is described by the additional parameters:

   XREFRT — Horizontal station of the approach section which coincides with the
        projection (parallel to the flow) of a right-hand reference point in
        the bridge section. This reference point is either (1) XCONRT (on BL
        record) for FIXED-GEOMETRY MODE.

   FDSTLT, FDSTRT — The flow distances measured along the left and right
        projection lines, respectively.

A BP record for datum correction between the road grade and the bridge must be
include in the road grade input data. A BP record for datum correction between
in the bridge and approach section or to account for curvilinear flow must be
included with the approach section input data.

Table 18. Table 4.8 from the WSPRO Users Manual.

BR Record

Purpose: Header record for bridge cross section.

Format:

Columns	Format	Contents
1-2	A2	BR
3-5	3x	blank
5-10	A5	SECID
10-80	free	SRD [, LSEL, SKEW, EK, CK, USERRCD]

Definition of variables:

SECID — Unique cross-section identification code (see discussion of SECID is section 4.1).

SRD — Section reference distance; must be assigned the same value as the full valley section.

LSEL — Elevation of the low chord of the bridge opening. Should be coded for fixed geometry mode if there is any chance for submerged flow. The model cannot check for, or compute, pressure flow without this elevation. The model computes a low chord elevation in design mode. An average elevation is computed for sloping decks. Users may override the design mode computed value by coding LSEL. See Section 4-3 for additional discussion of LSEL.

SKEW — The actual angle that the cross section must be rotated to locate the cross section normal to the flow direction. The model applies the cosine of SKEW to the horizontal dimensions of the section to obtain the correct cross-sectional properties (Default value is zero).

EK,CK — Coefficients to be used for computing expansion and contraction losses, respectively, in the energy equation. These coefficients are not used to the bridge backwater computations. They would apply to supercritical flow computations from the bridge section to the exit section. Default values are 0.5 for EK and 0.0 for CK or the last values input for a previous cross section.

USERCD — User-specified coefficient of discharge for a bridge. Model will use this override value rather than computing the coefficient of discharge.

Table 19. Table 4.11 from the WSPRO Users Manual.

CD Record

Purpose: Mandatory record for ALL bridge openings to specify parameters used for computing the flow length and the coefficient of discharge for a bridge.

Format:

Columns	Format	Contents
1-2	A2	BR
3-10	8x	blank
10-80	free	BRTYPE, BRWIDTH, EMBSS, EMBELV, WWANGL, WWWID, ENTRND

Definition of variables:

BRTYPE — Indicates the type of bridge opening, as follows:

1 — Vertical embankments and vertical abutments with or without wingwalls (figure 4-7).

2 — Sloping embankments and vertical abutments without wingwalls (figure 4-9).

3 — Sloping embankments and sloping spillthrough abutments (figure 4-8).

4 — Sloping embankments and vertical abutments with wingwalls (figure 4-10).

BRWIDTH — Total width (in direction of flow) of the bridge deck. For type 1 openings BRWIDTH should include the length of the upstream wingwalls. For the other types BRWIDTH should reflect only the deck dimension. The model computes the x-components using the values coded for EMBSS and EMBELV.

EMBSS — Embankment side slope, expressed in the horizontal change in feet per foot change of elevation (e.g., 3 to 1 may be expressed as 3.0 or 2 and 2 ½ to 1 would be expressed as 2.5). Default value is 0. This parameter must be specified for BRTYPE 2, 3, and 4.

EMBELV — Embankment elevation must be coded for BRTYPE 2, 3, and 4. A representative elevation in the vicinity of the bridge opening should be used when the top of the embankment is not horizontal. EMBELV and EMBSS are used to compute the x-component (s) of the flow length through the bridge (see figure 4-11).

WWANGL — Wingwall angle, in degrees. Required only for type 1 openings with wingwalls (figure 4-7) and type 4 openings (figure 4-10). Default is zero degrees.

Table 19. Table 4.11 from the WSPRO Users Manual (continued).

WWWID — Wingwall width, in feet. Required only for type 1 openings with
    wingwalls (see figure 4-7). Default is 0.

ENTRND — Radius of entrance rounding, in feet. Required only for type 1
    opening with rounded entrance corners. Default is 0.

Additional notes:

BRTYPE and BRWIDTH must be coded for all opening types.

For BRTYPE 1, additional parameters may be applicable as follows:

(a) WWANGL and WWWID (both parameters must be specified when wingwalls
     are present);
(b) ENTRND (if wingwalls are not present and entrance corners are
     rounded); or
(c) No additional parameters when neither wingwalls nor entrance
     rounding exists.

When coding a Type 1 bridge opening, EMBSS and EMBLV should be allowed to
default.

EMBSS and EMBELV must be coded for BRTYPE 2, 3, and 4.

There are no additional parameters for BRTYPE 2 and 3.

WWANGL should be coded for BRTYPE 4.

Table 20. Table 4.27 from the WSPRO Users Manual.

PW Record

Purpose: Specify pier or pile data.

Format:

Columns	Format	Contents
1-2	A2	PW
3	1x	blank
4	I1	PPCD
5-10	6x	blank
10-80	free	PELV(1), PWIDTH(1), PELV(2), PWDTH(2)...PELV(NPW), PWDTH(NPW)

Definition of variables:

The parenthetical notation indicates the order number, i, assigned by the model to each PELV and PWDTH data pair; i = 1 and i = NPW for the lowest and highest PELV values with NPW ≤ 25.

PPCD — Code to indicate whether the obstruction is in the form of piers (PPCD = 0 or blank) or piles (PPCD = 1). The adjustment to the coefficient of discharge for piers requires this distinction.

PELV(i) — The elevation, in feet above the common elevation datum, of the ith pair of elevation-width data.

PWDTH(i) — The gross width, in feet, of all piers (or pile bents) for the ith pair of elevation-width data.

Figure 4-15 illustrates coding requirements for pier data. The model creates an elevation-area relationship from the elevation-width data. Straight-line interpolation is used to obtain pier (pile) area between specified elevations. A constant pier (pile) area is assumed between the highest elevation coded and the maximum bridge opening elevation is a fatal error.

The minimum pier (pile) data requirement is one elevation-width pair at the minimum elevation that pier (pile) area begins. No additional data are required if the gross pier (pile) width is constant for the entire elevation range between the specified PELV and maximum bridge opening elevation (see figure 4-15a).

If the gross pier (pile) width should happen to vary uniformly over the elevation range between minimum and maximum bridge-opening elevations, a second elevation-width pair at the maximum elevation will suffice (see figure 4-15b).

For nonuniform variation of gross pier (pile) width, two elevation-width pairs are required at each elevation where there is an abrupt change in gross pier (pile) width.

An abrupt change can be: (1) additional piers coming into effect with increasing elevation; (2) change in pier dimensions; and (3) loss of piers with increasing elevation (sloping low chord). Figures 4-15c and 4-15d illustrate the above features.

9. MINIMIZATION PROCEDURE DATA

Minimization computations in the **BRI-STARS** are activated by setting the variable *IOPTMN* in the second field of the MN record to "MINIMIZATION REQUESTED." To bypass these computations, the "NO MINIMIZATION REQUESTED" option should be used.

Once the minimization computations are activated, total stream power computations are performed at the end of the first time step and then at the end of specified periodic time intervals. The frequency of these computations is controlled by the variable *ITERMN* in the first field of the MI record. Depending on the application, the user might select these computations to be spaced apart in time or at every time step. The selection of total stream power minimization frequency is to save computer time in applications where no appreciable changes in channel configurations are expected within a time block. These types of applications involve either very low sediment transport rates or very short time intervals. The range of allowable width and depth variation at different cross sections along a study reach is defined by MR records. Starting from the farthest upstream station, a single MR record should be supplied for each cross section. In cross sections where no man-made or geological constraints are present, the corresponding channel boundaries can be set beyond the existing channel boundaries or possible scour or deposition elevations.

Geological boring data and knowledge of man-made restrictions imposed on the study reach are required in a definition of the range of width and depth variations in the MR records.

Table 21 presents the minimization procedure records for a hypothetical study reach. This reach contains three stations. Existing channels extend between the lateral locations of 50 feet and 200 feet. Station No. 2 contains a lateral constraint at 210 feet (clay plug or rock formation) on the right-hand side of the channel looking downstream. The scour depths at station No. 3 are controlled by another rock formation at the elevation 2100.0 feet. No other channel constraints are present than those described above. Minimization computations are requested at every fifth time step.

Table 21. Minimization procedure data for a hypothetical study reach with three stations.

FIELD NUMBERS										
0	1	2	3	4	5	6	7	8	9	10

MN		MINIMIZATION REQUESTED								
MI	5.									
MR	-999.	999.	0.	3000.						
MR	-999.	210.	0.	3000.						
MR	-999.	999.	2100.	3000.						

10. SENSITIVITY ANALYSIS

10.1 INTRODUCTION

In the numerical modeling of river systems, a large number of parameters require value assignments to properly carry out the computational tasks. The values of these parameters often lack rigorous verification, and thus require value assignments based on heuristic knowledge of the systems. Due to a lack of regularity of real phenomena and operating conditions in physical experiments, these parameters may assume a varying range of acceptable values. The uncertainties in approximating these values in engineering applications mandate the adoption of tolerances and safety factors in order to minimize risk of design failure. These tolerances or safety factors are often obtained by introducing parameter variability into the system and observing the change in the system's performance. This process is referred to as sensitivity analysis.

The general definition of sensitivity is the rate of change in an output factor with respect to a rate of change of an input factor. The input factors used in sensitivity analysis are grouped into two categories. The first category is input parameter values. The sensitivity analysis may aim toward seeking the variation of output according to variation in this category. The second category is theoretical formulations and equations. The selection of various formulations and equations for the solution of the problem may also be the target of sensitivity analysis.

If the sensitivity analysis indicates a low level of variation with respect to a certain input parameter or algorithm, then the simulation model user may choose tolerance or safety factors to reflect this observation. However, if the system outputs are very sensitive to variation in a parameter, the modeler may wish to reduce variability either by additional research (to obtain higher confidence in the value) or by introducing the appropriate tolerance or safety factor to compensate for the parameter uncertainty. Sensitivity information is therefore very important in the mathematical simulation of alluvial rivers because it can reduce the burden of additional costs associated with applying arbitrary tolerance or safety factors to all of the modeling variables. This information can also reduce modeling data requirements.

10.2 MATHEMATICAL FORMULATION

In the model, the objective function value can be described as a function of independent parameters

$$Y_o = F\left(x_1, x_2, ..., x_i, ..., x_n\right) \tag{101}$$

in which Y_o is the objective function value corresponding to a given base simulation parameter and x_i is the independent parameter. In **BRI-STARS**, the variations of water surface elevation and channel bed elevation are the objective function values. Roughness coefficients, time steps, sediment size distribution, etc., are considered independent parameters.

The objective function value corresponding to a perturbed parameter (x_i) can be written as:

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$$Y_i = F\left(x_1, x_2, ..., x_i + \Delta x_i, ..., x_n\right) \tag{102}$$

in which Y_i is objective function value; and Δx_i is the perturbation of the parameter x_i. In this equation, the parameters other than x_i remain unchanged. Using the two equations given above, the coefficient of sensitivity can be formulated as:

$$\alpha_i = \frac{Y_i - Y_o}{Y_o} * 100 \, (\%) \tag{103}$$

and

$$\beta_i = Y_i - Y_o \tag{104}$$

in which α is rate of change of the objective function value corresponding to variation (Δx_i) of the base simulation parameter; and β is change of the objective function value.

10.2.1 Base Simulation

Parameters for the base simulation are mainly determined by data observed in the field in a certain event. In case of a lack of observed data, the base simulation may be determined based on physical model studies or heuristic knowledge of the project engineers.

10.2.2 Selection of Parameters

Parameters for sensitivity analysis may be selected depending upon the objectives of simulations, useful data, etc. The parameters used in sensitivity analysis of the sediment routing models can be grouped under two main categories: physical and operational parameters. These parameters and their relative importance are given in table 22.

Table 22. Parameters of the sediment routing models.

Description of Data		Relative Importance of Data		
		High	Medium	Low
Physical parameters	Sediment inflow	x		
	Discharge inflow	x		
	Variation of bed elevation		x	
	Sediment size distribution		x	
	Water temperature			x
	Cross-section geometry	x		
	Active layer thickness	x		
	Coefficients of losses			x
Operational parameters	Sediment transport equation	x		
	Pier scour equation		x	
	Time step	x		
	Number of stream tubes		x	
	Number of iterations			x
	Stream power minimization			x
	Roughness equation	x		

10.2.3 Limitation of Parameter Variability

For the physical parameters, parameter variability can be limited to the variations experienced in the natural or experimental channel. For the operational parameters, the limitation of the parameter variability can be chosen through analysis, based on the objectives of the model application. Factors which influence the determination of time step, for example, include simulation objective, accuracy required, computational speed of the computer, etc. The relative sensitivity of parameters can be found by varying each one by an equal percentage and comparing corresponding percentage changes in output.

10.3 APPLICATION

To study the sensitivity of **BRI-STARS** to various modeling parameters, a series of microcomputer runs were performed. For these runs a stable uniform reach of Rangpur Canal, Pakistan was chosen. Using the existing cross section and hydrologic data, various modeling parameters were altered. The computational results were analyzed with respect to the amount of variation in the base parameters chosen for sensitivity analysis. Tables 23 through 26 provide a partial list of the computer runs performed in the course of the sensitivity analysis. In these computer runs the effects of selecting the following parameters were studied:

- Roughness coefficient.

- Sediment transport equation.

- Duration of simulation time step.

- Number of stream tubes.

In addition to the computer runs given in tables 23 through 26, a number of test runs to study the effects of selecting the active layer thickness and the boundary conditions were performed. In the tables 23 through 26 the test conditions used for comparison are referred to as "base conditions." Differences in computed results using the altered modeling parameters from their respective base values are presented as nondimensional percentage variations whenever possible. In several test cases the computed results corresponding to the base conditions were very small. For these cases, since expressing the results as percentage variations from these near zero values overamplified the importance of the parameter under investigation, deviations were presented as dimensional quantities.

Table 23. Sensitivity analysis runs for roughness coefficient selection.

RUN NO.	DESCRIPTION
1 - 9	Effects of selecting Manning's n Roughness Coefficient on water and sediment routing results (using Yang's Sediment Transport Equation).
10 - 18	Effects of selecting Manning's n Roughness Coefficient on water and sediment routing results (using Acker and White's Sediment Transport Equation).
19 - 27	Effects of selecting Manning's n Roughness Coefficient on water and sediment routing results (using Engelund and Hansen's Sediment Transport Equation).

*n = 0.02 used as a base condition for each Sediment Transport Equation; 3 stream tubes.

Table 24. Sensitivity analysis runs for selecting the duration
of computational time steps.

RUN NO.	DESCRIPTION
28	Duration of time step (days) = 0.125
29	Duration of time step (days) = 0.250
30	Duration of time step (days) = 0.500
31	Duration of time step (days) = 2.000
32	Duration of time step (days) = 4.000
33	Duration of time step (days) = 5.000
34	Duration of time step (days) = 6.000
35	Duration of time step (days) = 10.00
36	Duration of time step (days) = 20.00

* 1 day is used as a base condition with Yang's equation and Manning's n coefficient
of 0.02; 3 stream tubes.

Table 25. Sensitivity analysis runs for longer time (1.5- and 8-year) simulations.

RUN NO.	DESCRIPTION
37	Number of time steps = 480 and duration of each time step is 1 day
38	Number of time steps = 480 and duration of each time step is 6 days

*Using Yang's equation and Manning's n coefficient of 0.02; 3 stream tubes.

Table 26. Sensitivity analysis runs for the number of stream tube selection.

RUN NO.	DESCRIPTION
39	Water and Sediment Routing using 1 stream tube
40	Water and Sediment Routing using 2 stream tubes
41	Water and Sediment Routing using 4 stream tubes
42	Water and Sediment Routing using 5 stream tubes

*3 stream tubes used as a base condition, using Yang's equation and Manning's n
coefficient of 0.02.

The results of sensitivity analysis are presented in figures 38 through 46. Figure 38
demonstrates the effects of varying roughness coefficients and sediment transport
equations. In this analysis, for each of the three sediment transport functions
available in the model, 9 runs were performed for a total of 27 computer runs. The
Manning's roughness coefficients were varied through a range from 0.005 to 0.05.
The base condition for the computer runs was chosen as n=0.020. Sediment routing
computations were conducted using three stream tubes and a single sediment size
group of 0.125 mm - 0.250 mm. In figure 38, the scour/deposition of cross sections
6000 ft, 7000 ft, 8000 ft, and 10000 ft downstream from the canal entrance were
plotted for various roughness values. These scour/deposition values correspond to
computations utilizing 60 time steps of one-day duration. Results from the analysis
are summarized as:

● Changing roughness coefficient changes the computed scour and
deposition significantly.

● Different sediment transport equations have significant effects.

These conclusions can be observed by using values corresponding to a roughness
coefficient of n=0.02. Comparing scour/deposition values at 8000 ft, Yang's equation
predicts 0.1 ft of deposition; whereas the Ackers & White equation predicts 0.27 ft
of scour and Engelund & Hansen equation predicts 0.15 ft of scour. Similar results
can be obtained throughout the entire range of roughness values.
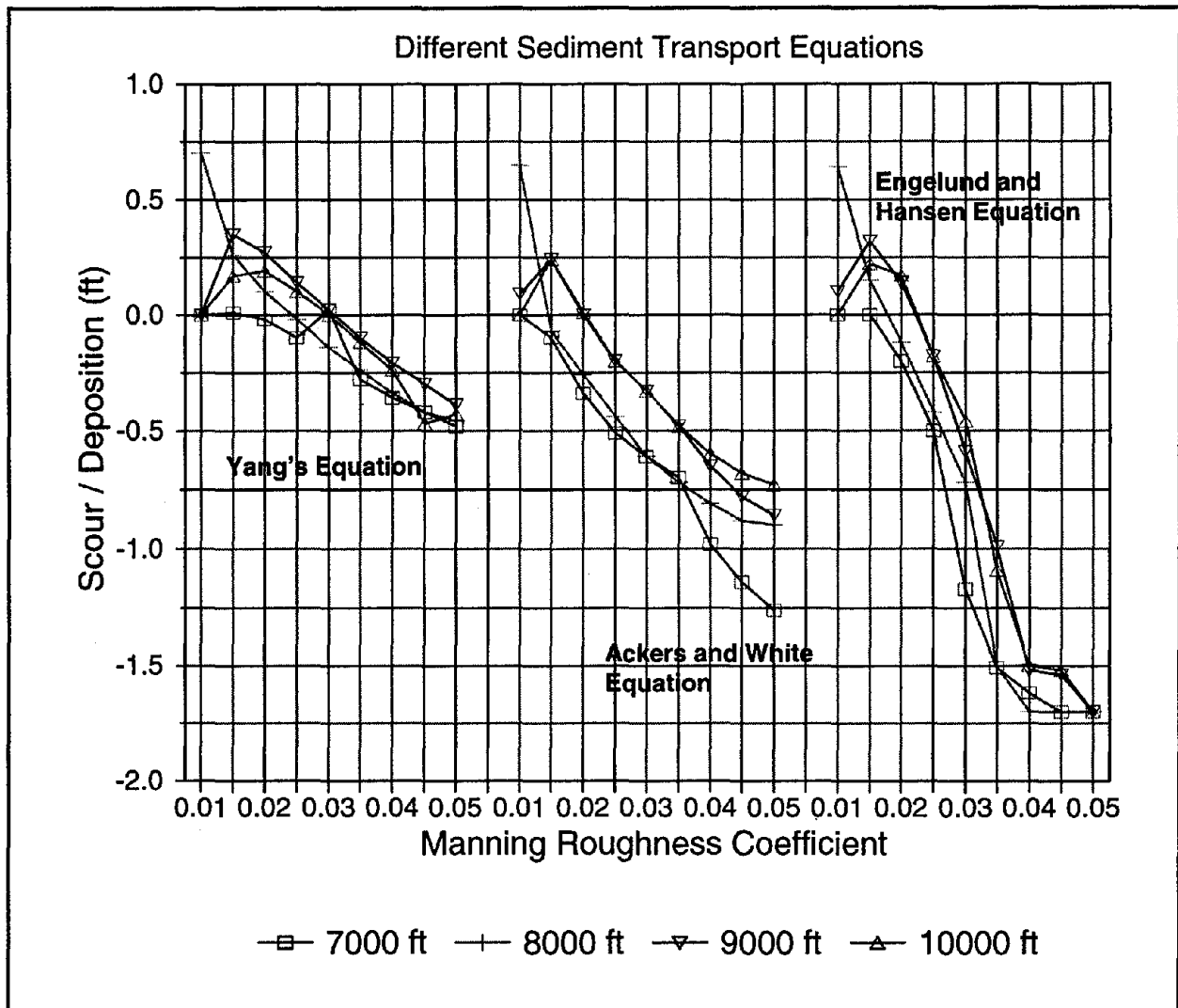
Figure 38. Roughness sensitivity analysis.

Figures 39 through 43 demonstrate the sensitivity of sediment routing computations to the duration of time step utilized in numerical computations at various locations along the study reach. The conclusions from these figures are:

● Proper selections of time steps are necessary for the convergence of results. In figures 39 through 43 for time steps of up to 3 days computed results are almost unaffected. For time step durations larger than 20 days the discrepancies with the base condition of one-day time step increase with the length of simulation (unstable and nonconvergent).

● Since the finite difference scheme used for approximating the sediment continuity equation is an approximation method, the accuracy of the results rely on the duration of time step even within the stable range.

● Proper selection of simulation time step should be made following a sensitivity analysis.
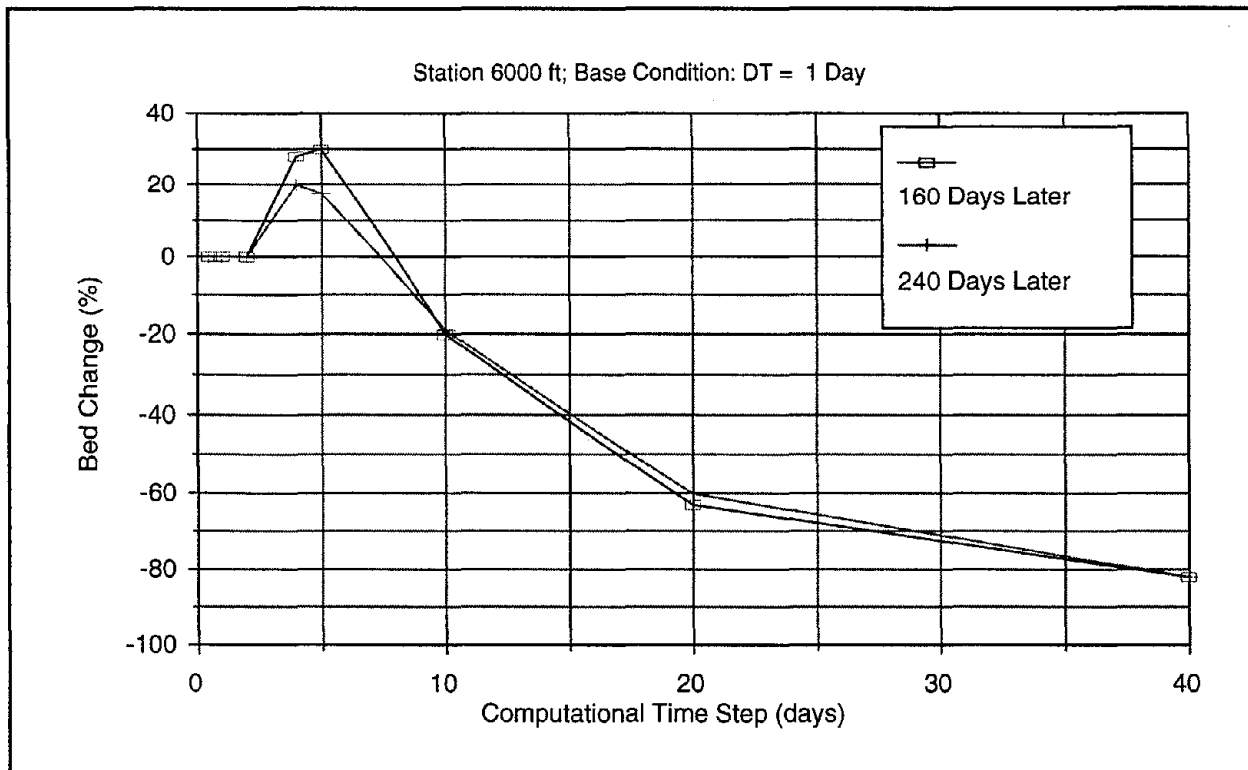
Figure 39.   Time step sensitivity analysis at Station 6000.
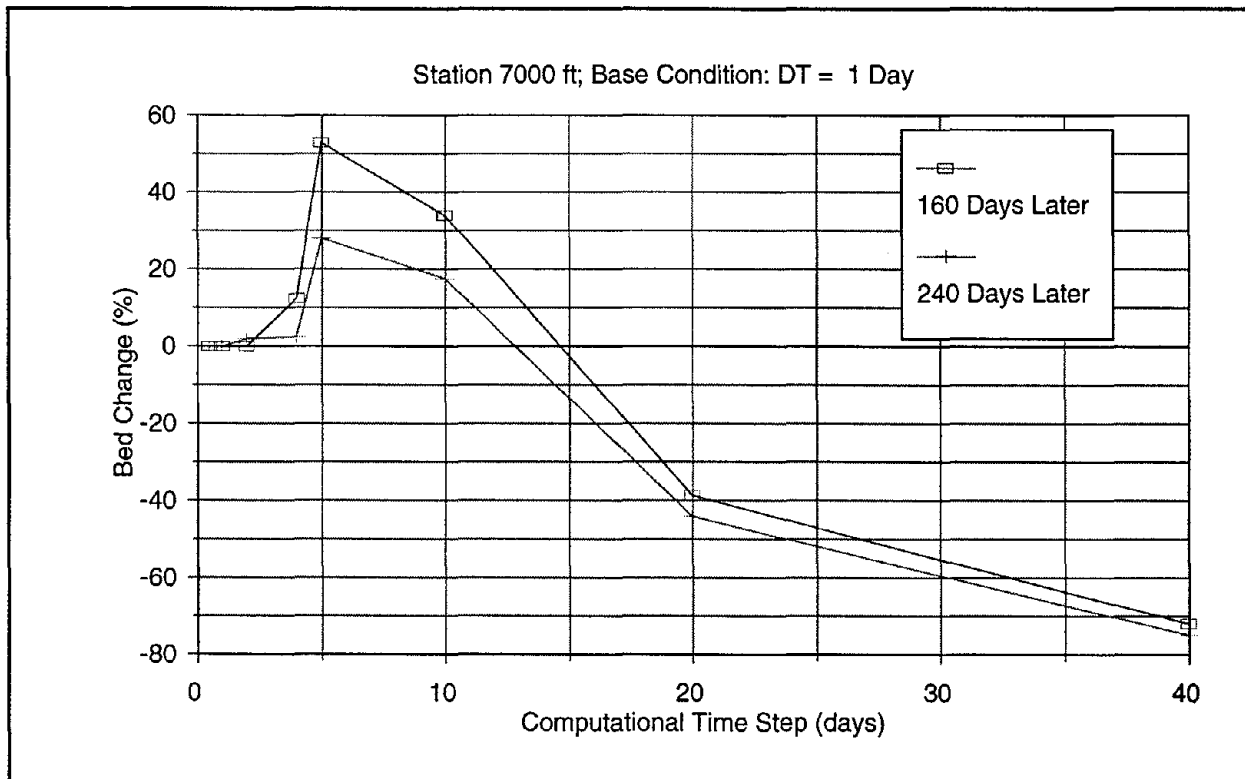
Figure 40.   Time step sensitivity analysis at Station 7000.
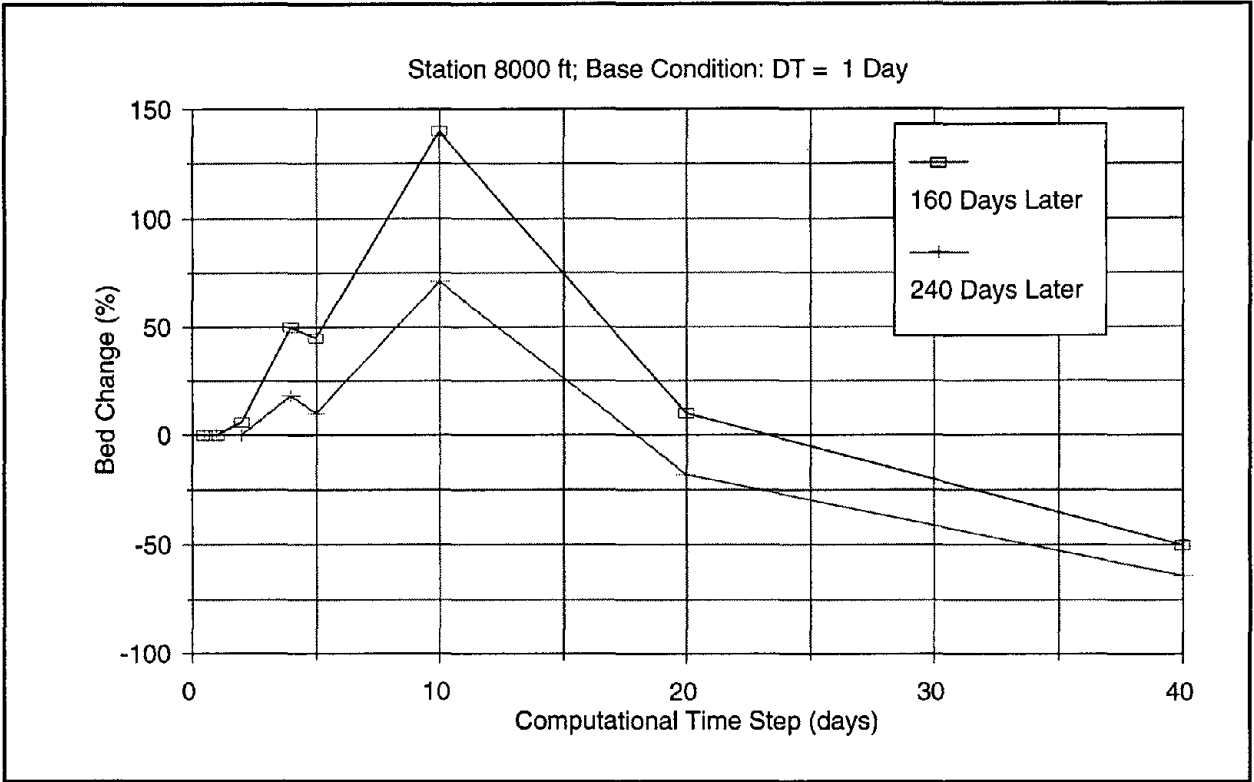
Figure 41. Time step sensitivity analysis at Station 8000.
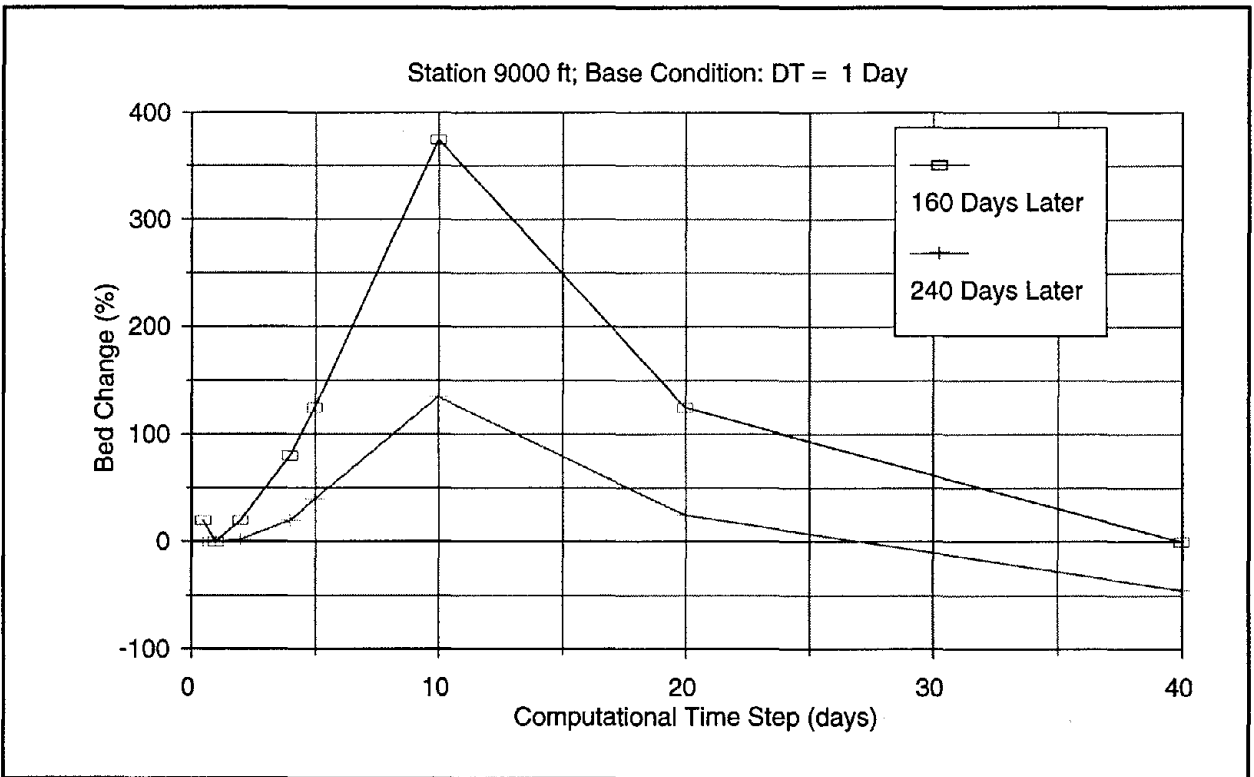
Figure 42. Time step sensitivity analysis at Station 9000.
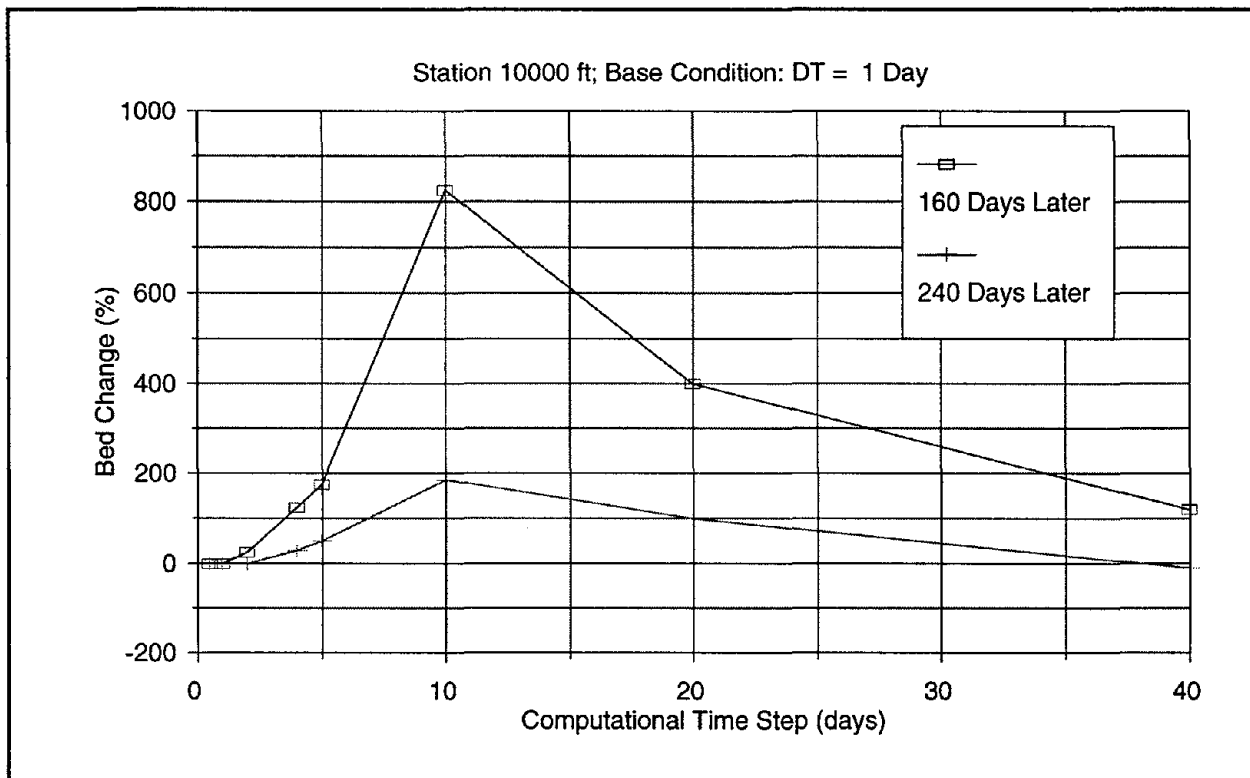
Figure 43. Time step sensitivity analysis at Station 10000.

Figures 44 and 45 demonstrate the sensitivity of computed results to number of stream tubes selected for the **BRI-STARS** simulation. The computer runs for studying the stream tube sensitivity were performed using one-day time steps and a single sediment size. The scour depths shown in figures 44 and 45 pertain to thalweg elevations. The analysis presented in this report was based on point values rather than total sediment volume removed from the study reach. Figure 44 demonstrates the computed scour depths at various locations along the study reach for one, two, three, four, and five stream tubes. Figure 45 shows the same results in terms of relative scour variation with the number of stream tubes. The base condition used in figure 45 for computing relative scour depths was the computed scour depths corresponding to three stream tubes. Figures 44 and 45 show that the number of stream tube selection is not a factor in scour depth computations. This is highly desirable since the stream tubes are merely utilized to obtain the variation of flow conditions across the channel for higher model output resolution. Figure 46 shows the variation of execution times with the number of stream tubes selected for the **BRI-STARS** simulation. For a single sediment size, the computation times are only 8 percent higher for simulations utilizing five stream tubes than simulation runs utilizing only one stream tube, indicating the efficiency of the **BRI-STARS'** stream tube computations.
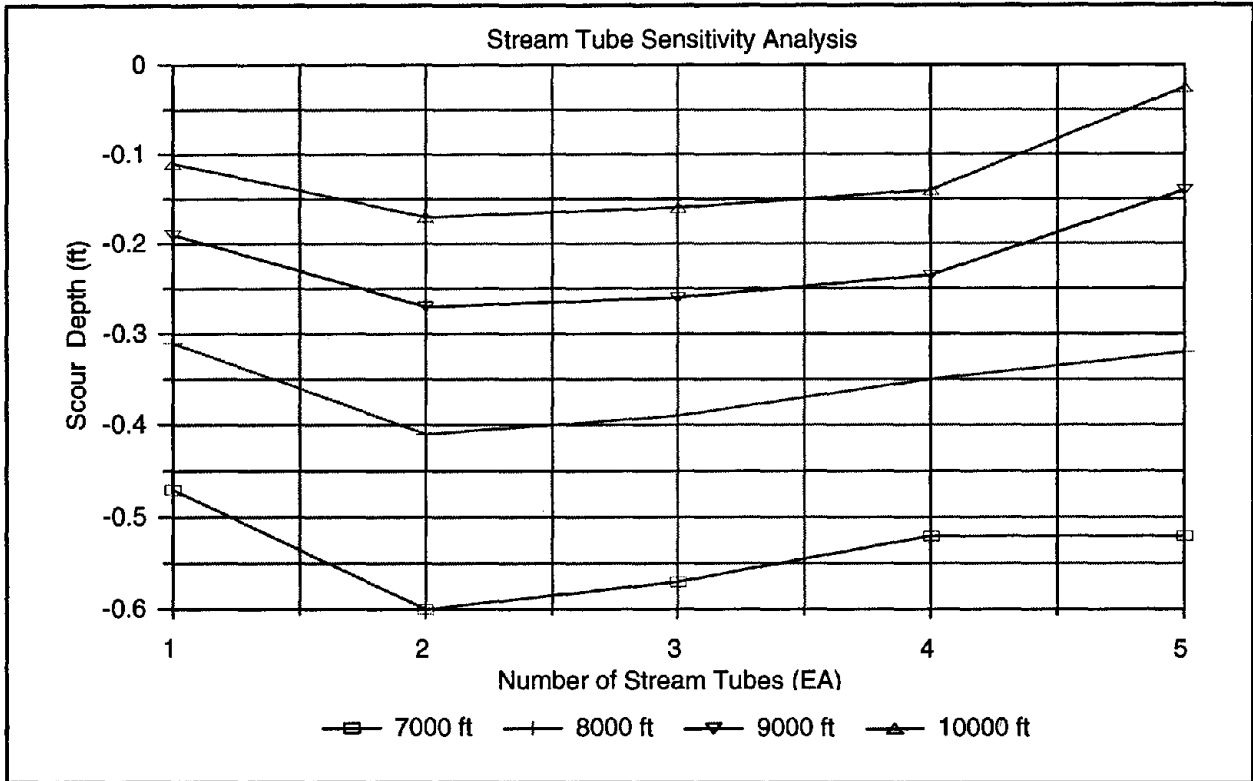
Figure 44. Scour/deposition versus number of stream tubes.
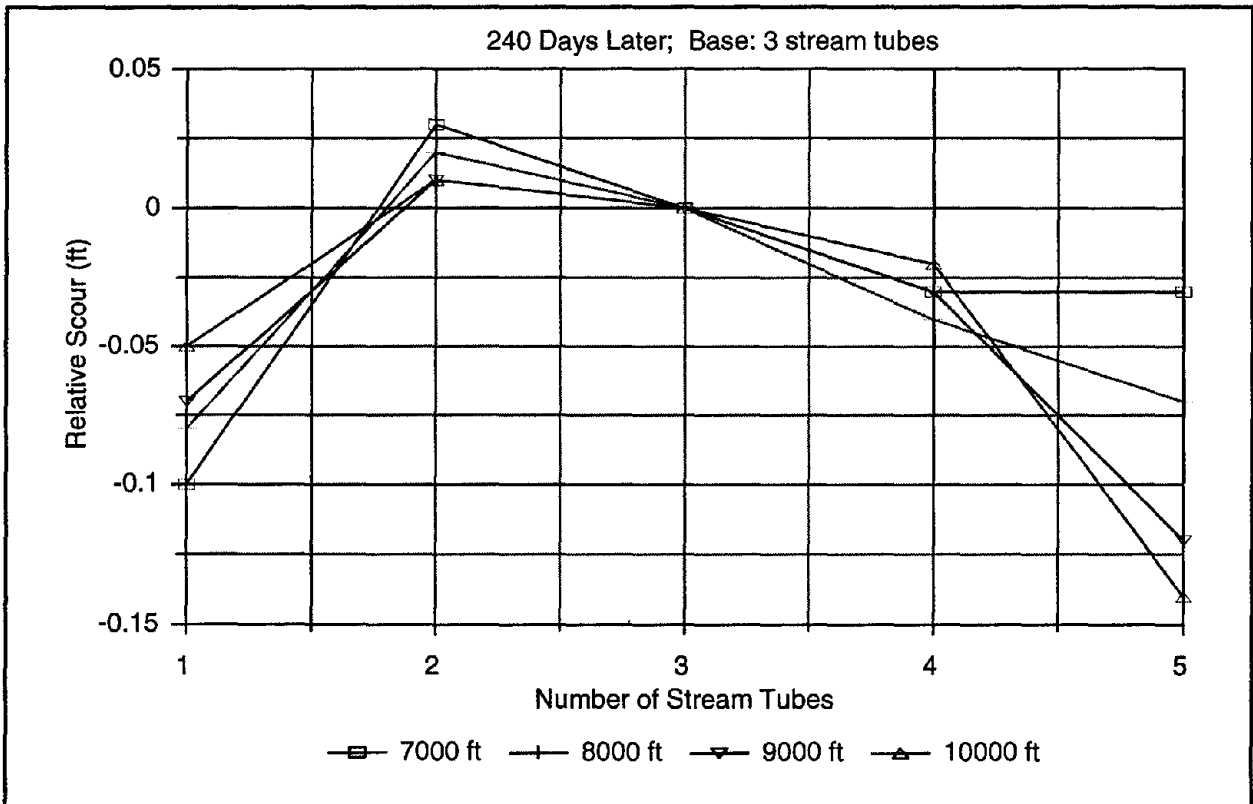
Figure 45. Varying scour depth with number of stream tubes.
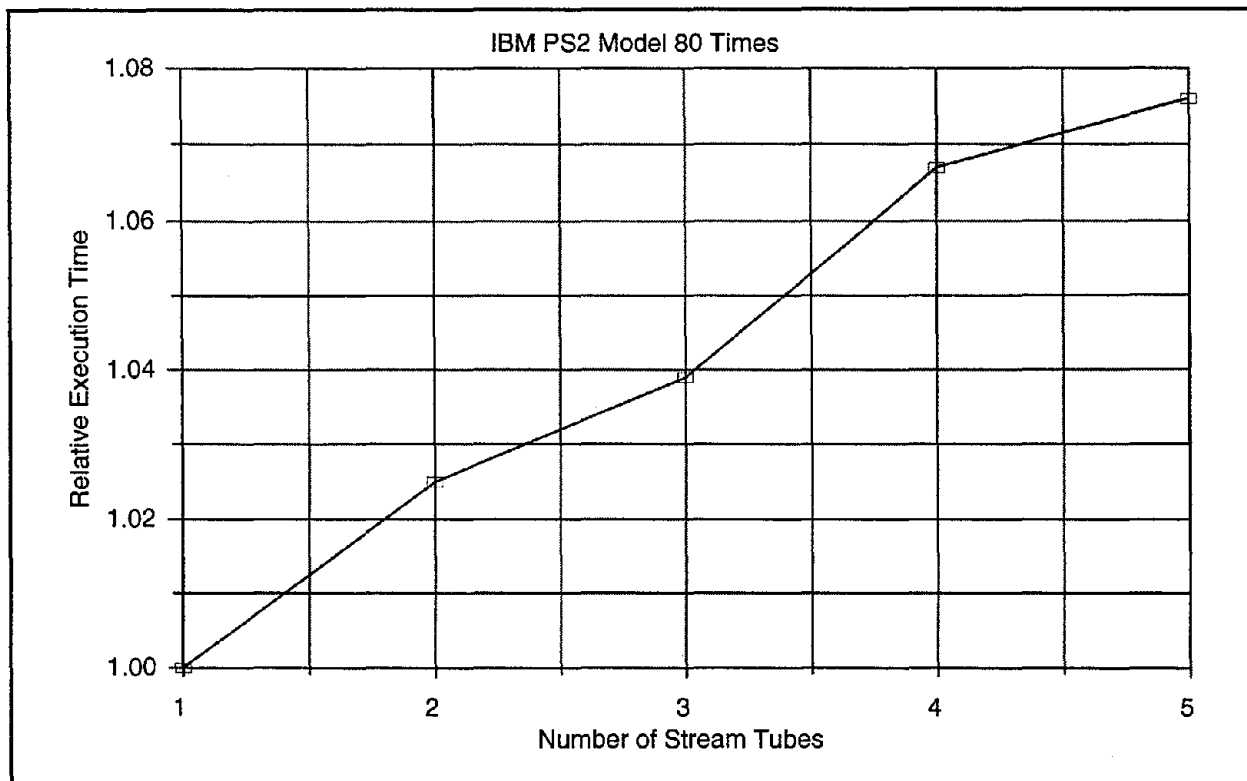
Figure 46. Execution time versus number of stream tubes.

10.4 CONCLUSIONS

The sensitivity analysis of the parameters used in the **BRI-STARS** for simulation of a stable uniform reach of the Rangpur Canal in Pakistan reached the following conclusions:

1.   The magnitude of scour or deposition at a given cross-section is sensitive to the selection of sediment transport equation and Manning's roughness coefficient.

2.   Proper selection of computation time step based on sensitive analysis is important to the accuracy and convergence of the computational results.

3.   The computed average depth of scour is not sensitive to the selection of number of stream tubes.

4.   The increase of number of stream tubes used in the computation does not increase the computational time significantly.

10.5 CALIBRATION GUIDELINES

Any numerical modeling effort of an alluvial system is conducted in three basic stages:

●   Calibration.
●   Verification.
●   Prediction.

The first stage, calibration, aims at preparing the model of the type of system to be modeled. Any past record of water and sediment flows and/or changes in channel geometry can be used in the calibration process. These past records provide the modeler with some initial indication of modeling parameters important in replicating the past behavior of the system to be modeled. A sensitive analysis as presented above aids in determining which parameters are more important to calibrate for modeling behavior of a particular system. For example, in a large, flat-slope river, the downstream water surface elevation is very significant, whereas in a small, steep channel, selection of the downstream elevation may be less crucial. Once the significant parameters are identified, they may be calibrated (assigned values) to fit the observed past behavior of the system. The parameters selected during calibration must be realistic and verifiable for other flow conditions.

The second stage, verification, involved application and comparison of the model to a different, known real-life case. The results of this comparison determine the validity and quality of the calibration. Ideally, a model properly calibrated with one real-life scenario should accurately model a different situation in the same system. Verification rarely yields exact agreement between the model and the real-life case, but the level of agreement in general provides a range of confidence in calibrated parameters.

Finally, once the model is calibrated and verified, predictions may be made concerning system behavior for which there are no data. This step is the goal of the modeling effort, wherein design decisions are made. These decisions are also subject to sensitivity analysis to determine the level of confidence of the results.

For the **BRI-STARS** model, the calibration procedure is conducted in two phases: i) calibration of hydraulic parameters; and ii) calibration of sediment transport parameters.

In phase 1, calibration of hydraulic parameters aims at defining such parameters as channel roughness, coefficients for energy loss due to expansion and contraction and other factors such as bend losses, and control water surface elevations. In order to accomplish this calibration, the modeler is advised to deactivate sediment routing computation (select NO SEDIMENT TRANSPORT REQUESTED in the SO record and skip all sediment transport records for the simulation) and focus solely on hydraulic computations. Any past hydraulic records (such as velocity measurements, water surface elevation data, or high water marks) may be used for calibrating the model. In the absence of useful data, visual descriptions may even prove useful to the modeler.

For phase 2, calibration of the sediment transport parameters aims at defining such parameters as active layer thickness, optimum sediment transport equation to use, and sediment inflow into the study reach. In order to accomplish this calibration, the modeler must activate the sediment transport computation by selecting SEDIMENT TRANSPORT REQUESTED in the SO record and must provide pertinent sediment data. In the absence of reliable data, the modeler may use information from neighboring watersheds or other similar river reaches. Sediment transport should then be simulated and checked for numerical stability with variation in the simulation time step and cross section spacing. These parameters were discussed in the previous sections along with other parameters significant to model calibration. As a general rule, to ensure numerical stability in calibration time steps, smaller active layer thicknesses (thickness of sediment layer which can be sorted in one time step) should be chosen (second field of the SE record). Also, for closely spaced cross sections, smaller time steps should be chosen to allow for the detection of the passage of a sand wave during a single time step.

Once the hydraulic and sediment transport calibration has been accomplished, the modeler may then move on to verification and ultimately prediction of the behavior of the river system. In design cases where no data is available, calibration and verification are conducted based on the realism of the simulation results. For these cases, the sensitivity analysis plays a more pronounced role in the modeling effort.

APPENDIX A - LIST OF REFERENCES

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APPENDIX B - INPUT DATA RECORDS

In this appendix **BRI-STARS** input records are listed. Their general format, sequential order, and detailed description are provided.

B.1   LIST OF DATA RECORDS

Data records used in **BRI-STARS** input file are listed in table 27 in alphabetical order. The detailed information for each data record is given at the page indicated in this table.

Table 27. **BRI-STARS** input records

Preceding Page Blank

Table 27. **BRI-STARS** input records (continued)

B.2 FORMAT OF DATA RECORDS

BRI-STARS input is supplied through a data file composed of series of 80-column-wide records. Each **BRI-STARS** record contains a 2-character record identification field and 10 fixed-width data fields. The model documentation refers to the data fields through their numeric sequence (e.g., Field 1, Field 5, etc.).

The width of **BRI-STARS** records are:

Field 0	Columns 1-2 for record identification
Field 1	Columns 3-8
Fields 2-10	Columns 9-16, 17-24, 25-32, ..., 73-80

The general layout of **BRI-STARS** data records is shown in table 28.

Table 28. General layout of **BRI-STARS** data records

		1	2	3	4	5	6	7	8
Column Nos.: 12345678	90123456	78901234	56789012	34567890	12345678	90123456	78901234	56789012	34567890
Fields: 0	FIELD 1	FIELD 2	FIELD 3	FIELD 4	FIELD 5	FIELD 6	FIELD 7	FIELD 8	FIELD 9	FIELD 10

Note: Blank columns in each field are treated as zeros.

B.3   ORDER OF DATA RECORDS

SS - Stage Record

QQ - Discharge Record

Lateral Water Inflow Hydrograph

QI - Water Inflow Hydrograph Record

QL - Lateral Water Inflow Record

IT - Number of Iterations Record

NT - Number of Stream Tubes Record

BE* - Bottom Elevation Record

CB - Channel Bottom Record

CL - Coefficients of Losses Record

CE* - Coefficients of Expansion/Contraction Record

RB* - Roughness Breakpoint Record

RH - Roughness Coefficients Record

RE - Roughness Equation Record

XS - Cross Section Geometry Record

XS - Cross Section Geometry Record

ND - Number of Subchannels/Subsections Record

GP - Global Positioning Record

ST - Cross Section Identification Record

NS - Number of Stations Record

TT - Title Record No. 3

TT - Title Record No. 2

TT - Title Record No. 1

* - Denotes an optional record

Figure 47. Illustration of **BRI-STARS** record order.

SI* - Sediment Inflow Hydrograph Record

SL* - Lateral Sediment Inflow Record

SX* - Size Distribution Across Channel Record

SB* - Sediment Size Breakpoint Record

SD - Sediment Size Distribution Record

SG - Sediment Size Groups Record

SF - Number of Size Fractions Record

TM - Temperatures Record

SP* - Sediment Transport Eq. Parameters Record

SE - Sediment Transport Equation Record

QS - Sediment Discharge Record

SO - Sediment Transport Option Record

RC* - Rating Curve Record

NC* - Number of Rating Curves Record

TQ* - Table of Discharges Record

Table of
Discharge and
Rating Curve

RC* - Rating Curves Record

NC* - Number of Rating Curves Record

DD* - Discretized Discharges Record

Discretized
Discharges and
Rating Curve

SQ* - Stage Discharge Table Record

TL* - Station Identification for Stage-Discharge
Table Record

Stage-Discharge
Pairs

* - Denotes an
optional record

Figure 47. Illustration of **BRI-STARS** record order (continued).

CM(or [*])* - Comment Record (place anywhere)

MR* - Bed Elevation/Width Variation Record

MI* - Minimization Iterations Record

MN - Minimization Option Record

PW* - Water Surface Profile Plotting Record

PX* - Channel Cross Section Plotting Record

PL - Plotting Options Record

PV* - Visual Screen Output Record

PV* - Visual Screen Output Record

PV* - Visual Screen Output Record

PR - Printout Record

CS - Contraction Scour Record

PC* - Pier Equation Coefficients Record

PP/AP* - Pier/Abutment Scour Parameters Record

PS/AS* - Pier/Abutment Stations Record

PE/AE* - Pier/Abutment Scour . Equation Record

WB* - WSPRO Bridge Option Record

* - Denotes an
optional record

Figure 47. Illustration of **BRI-STARS** record order (continued).

B.4 DESCRIPTION OF DATA RECORDS

In this section, detailed description of individual data record used in **BRI-STARS** are presented. For each record following general description and use of the record, different data fields are identified, variable names, allowed values for these variables, (numeric or alphabetic information), range of acceptable values, and descriptions are given. Finally, the typical use of the record in a data file is illustrated by an example. In the Value section of each record, a "+" indicates a nonnegative number, a "-" signifies that a negative number should be chosen, a "+/-" means that a nonzero number should be chosen. All other values are self-explanatory (e.g., "0" means 0, "1.1" means 1.1, etc.).

ABUTMENT SCOUR EQUATION RECORD

Record AE—REQUIRED for Local Bridge Abutment Scour Computations

The AE record defines the local bridge abutment scour equation to be used in estimating potential local bridge abutment scour. Options that are available in the computer model are: CSU equation, the Laursen equations, and the Froehlich equations.

Field	Variable	Value	Description
0	ID	AE	Record Identification.
1	IABUT	"+" or blank	Variable to select the abutment scour equation.
		1	Use CSU (Liu) equation.
		2	Use Laursen clear-water equation.
		3	Use Laursen live-bed equation.
		4	Use Froehlich clear-water equation.
		5	Use Froehlich live-bed equation.
2	NABUTST	"+"	Number of stations containing bridge abutments. Maximum value of NABUTST is number of stations.

Example:

```
AE    3.0      2.0
AS    4.0      2.0
AP    0.0     30.0     1.0   20.0   1040.0    5.0    2.3    2.0
AP   90.0    120.0     1.0   20.0   1040.0    5.0    2.3    2.0
AS   10.0      1.0
AP    0.0     50.0     1.0   20.0   1020.0    5.0    2.3    2.0
```

Related Records: AS, AP

ABUTMENT SCOUR PARAMETERS RECORD

RECORD AP—REQUIRED for Local Bridge Abutment Scour Computations

The AP record is used to define the location of bridge abutments across the channel at a given bridge station. This record defines the various parameters (such as abutment location, type, etc.) necessary for the computation of local scour due to bridge abutments in various equations. The appropriate fields of the AP record are activated depending upon the abutment scour equation in the AE record. The number of AP records for each abutment station should be equal to NABUT defined in the 2nd field of the Abutment Station AS record. A set of (AP) records should be provided for each station containing bridge abutments.

Field	Variable	Value	Description
0	ID	AP	Record Identification.
1	ABUTLFT	"+/-"	Left end of abutment across channel facing downstream at the station specified in the AS record.
2	ABUTRGT	"+/-"	Right end of abutment facing downstream.
3	ABUTTYP	"+"	Abutment shape number for scour equations.
		1	Vertical-wall abutment.
		2	Vertical-wall abutment with wing walls.
		3	Spill-through abutment.
4	THETA	"+"	Angle of inclination of approach embankment.
5	ABUTELV	"+/-"	Elevation of abutment at flood plain.
6	D50	"+"	Sediment size at abutment location for which 50% of the sediment is finer by dry weight (mm).
7	SIGMAG	"+"	Geometric standard deviation of bed material at abutment $[=(D84/D16)^{1/2}]$.
8	SEDINDX	"+"	Fine sediment concentration index to determine critical shear stress for the Laursen equation.
		0	Clear water flow (Shield's criteria).
		1	Low concentration.
		2	Medium concentration.
		3	High concentration.
		4	Very high concentration.

Example:

```
AE    3.0      2.0
AS    4.0      2.0
AP    0.0     30.0    1.0    20.0   1040.0    5.0    2.3    2.0
AP   90.0    120.0    1.0    20.0   1040.0    5.0    2.3    2.0
AS   10.0      1.0
AP    0.0     50.0    1.0    20.0   1020.0    5.0    2.3    2.0
```

Related Records: AE, AS

ABUTMENT STATIONS RECORD

RECORD AS—REQUIRED for Local Bridge Abutment Scour Computations

The AS record identifies stations containing bridge abutments, and defines the number of bridge abutments at these stations. The geometric and flow parameters corresponding to the abutments are specified in the Abutment Parameters (AP) record. The number of AS records should be equal to NABUTST value specified in the second field of the Abutment Scour Equation (AE) record.

Field	Variable	Value	Description
0	ID	AS	Record Identification.
1	ABUTST	"+"	Station number containing bridge abutments. Stations are numbered in the downstream direction, starting with the furthest upstream station as 1.
2	NABUT	"+"	Number of abutments at station no. ABUTST. The geometric and flow parameters corresponding to these abutments are specified in the appropriate fields of the Abutment Parameters (AP) records. The maximum number of abutments allowed at a given abutment station is 10.

Example:

```
AE    3.0      2.0
AS    4.0      2.0
AP    0.0     30.0      1.0     20.0   1040.0      5.0      2.3      2.0
AP   90.0    120.0      1.0     20.0   1040.0      5.0      2.3      2.0
AS   10.0      1.0
AP    0.0     50.0      1.0     20.0   1020.0      5.0      2.3      2.0
```

BOTTOM ELEVATIONS RECORD

Record BE—OPTIONAL

The BE record is activated by the READ option on the CB record. This record defines the representative channel bottom elevations at different stations along the study reach. These bed elevations are entered in the downstream direction starting from the farthest upstream station. For each station, only one channel bed elevation is utilized.

Field	Variable	Value	Description
0	ID	BE	Two-character Record Identification.
1-10	Z	"+/-"	Bottom elevations at different stations given as a distance from the sea level or a set datum. Only one representative elevation at each station is required. The number of Z values are limited to the number of stations defined in the NS record (in feet).

Example:

```
BE 944.0   942.0   940.0   938.0   936.0   934.0   932.0   930.0   928.0   926.0
BE 924.0   922.0   920.0   918.0   916.0   914.0   912.0   910.0   908.0
```

CHANNEL BOTTOM RECORD

RECORD CB—REQUIRED

This record defines the type of channel bottom elevation computation. Based on these bottom elevations, different reaches are classified as subcritical, critical, and/or supercritical at the beginning of water surface profile computations. The two options allowed in the program are: READ and THALWEG.

Field	Variable	Value	Description
0	ID	**CB**	Record Identification.
1	IOPTZI	**"+" or blank**	Channel bottom elevations computation method.
		1	Use thalweg elevation for bottom slope estimation.
		2	Use user supplied elvs. For bottom slope estimation.
2	IOPTZ	**text or blank**	Optional if Field 1 is specified.
		THALWEG	Channel bottom elevation at each station is set equal to the lowest elevation at that station. This option is recommended for study reaches for which the mode of flow is not known or for reaches in which a combination of supercritical and subcritical flows is expected.
		READ	Channel bottom elevations at each station are read in manually. The user, after plotting the thalweg elevations manually, decides on the representative bottom elevations at different stations. These values are entered on the optional BE records. This option is recommended for strictly subcritical or supercritical study reaches to save computer time.

Example:

```
RH    .020      .020      .020      .020      .020
CL    0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
CB          THALWEG
NT    3.0
IT    15.0      1.0     .00833
```

COEFFICIENTS OF EXPANSION/CONTRACTION RECORD

RECORD CE—OPTIONAL

This record defines the expansion or contraction loss coefficients to use in hydraulic computations. The default values of expansion and contraction loss coefficients which are internally set to 0.3 and 0.1, respectively, can be altered through the use of this record.

Field	Variable	Value	Description
0	ID	CE	Record Identification.
1	COEFC	"+" or blank	Contraction loss coefficient value. The default value is 0.1.
2	COEFE	"+" or blank	Expansion loss coefficient value. The default value is 0.3.

Example:

```
RH    .020    .020    .020    .020    .020    .020    .020    .020    .020    .020
RH    .020    .020    .020    .020    .020
CE    0.1     0.8
CL    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
CB          THALWEG
NT    3.0
IT    15.0    1.0    .00833
```

COEFFICIENTS OF LOSSES RECORD

RECORD CL—REQUIRED

This record defines the local energy loss coefficients at various stations along the study reach. Loss coefficient values are entered in the downstream direction starting from the farthest upstream station. At each station, only one loss coefficient across the channel is allowed. The number of loss coefficients along the study reach is controlled by the variable NSTA in the NS record.

Field	Variable	Value	Description
0	ID	CL	Record Identification.
1-10	CLOSS	"+" or blank	Energy loss coefficients. One for each station, starting from the farthest upstream station.

Example:

```
RH   .020    .020    .020    .020    .020    .020    .020    .020    .020    .020
RH   .020    .020    .020    .020    .020
CL   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
CB        THALWEG
NT   3.0
```

COMMENT RECORD

RECORD CM (or *)—OPTIONAL

This record can be used to insert comments or other information which the user wishes to have ignored by **BRI-STARS** (same as the [*] record employed by WSPRO).

Field	Variable	Value	Description
0	ID	CM (or *)	Record Identification.
1	COMMNT	text or blank	User comments such as station numbers, hints, and text which can be used to identify a certain feature.

Example:

```
CM**********************THIS IS A TYPICAL COMMENT RECORD********************
```

CONTRACTION SCOUR RECORD

RECORD CS—OPTIONAL

This record provides information to compute local scour using Laursen's contraction scour equations. The scour computed from Laursen's equations can be used for the purpose of comparing the simulation results with hand calculations. Since BRI-STARS utilizes the sediment continuity equation in which transport capacities are determined by various equations, it intrinsically computes the contraction scour during simulations. For long-term simulations, if the transport equation selected for the simulation is in agreement with Laursen's simplified transport function, the computed contraction scour is expected to be in agreement with simulated contraction scour values.

Field	Variable	Value	Description
0	ID	CS	Record Identification.
1	ISTA	"+"	Station number at which Laursen's contraction scour estimate is requested. Stations are numbered in the downstream direction, with Station No. 1 being the farthest upstream station.
2	QRATIO	"+/-"	The ratio of main channel flow to contracted section flow (the default value is 1.0).
3	WIDRAT	"+"	The ratio of bottom widths for the main channel and the contracted section (default = 1—no contraction).
4	RNRAT	"+"	The ratio of average Manning's Roughness coefficients for the main channel and the contracted section (default = 1).
5	D50CNTR	"+/-"	The sediment size at the contraction site for which 50 percent by weight of the material is finer (in mm.).

Example:

```
CS    7.0    1.0    1.3    1.0    2.1
```

DISCRETIZED DISCHARGES RECORD

RECORD DD—OPTIONAL

This record is activated if the second and third fields of the QQ record are set equal to "DISCRETIZED DISCHARGES." The DD record is used to input the discretized discharges defined in time blocks. The discharge hydrograph is first approximated by a series of constant discharges. The number of time increments in each time interval pertaining to a constant discharge block is determined. These values are input in a table format. The sum of all time increments should be equal to the maximum number of time iterations, ITIMAX, defined in the IT record.

Field	Variable	Value	Description
0	ID	DD	Record Identification.
1	NDAY	"+"	Number of time increments corresponding to a given discharge defined in field 2. The sum of all NDAY values in DD records should be equal to ITIMAX in the IT record (no dimension).
2	QI	"+/-"	Discretized discharge value for the number of time increments, NDAY, defined in Field 1. For the duration of NDAY, the discharge hydrograph is approximated by the constant QI value (in cfs).

Example:

```
IT    9.0      1.0      2.0
QQ        DISCRETIZED DISCHARGES
SS        RATING CURVE
DD    1.0   1000.0
DD    1.0   2000.0
DD    1.0   2500.0
DD    2.0   2700.0
DD    1.0   1900.0
DD    2.0   1500.0
DD    1.0    700.0
NC    1.0
RC   10.0      0.9      0.2  1000.0
```

GLOBAL POSITIONING RECORD

RECORD GP—OPTIONAL

This record is for the global positioning of channel cross sections in order to display the actual plan views of color-coded topographic changes and stream tube/velocity distributions. Through the GP record, plan views of the actual cross section locations and their orientations with respect to a coordinate axis are specified. This is accomplished by specifying series of Easting and Northing locations corresponding to the start and end points of channel cross sections and the break-points. Each global positioning record contains information regarding the scale used in reporting measurements, the starting location of the plan view with respect to lateral station across the channel, and Easting and Northing pairs for the start and end points of cross sections from plan view. A minimum of two pairs of GE-GN values are required: one pair for the starting and the other pair for the ending point of the cross section in the plan view. In cases where the cross section follows a broken line across the channel, the start of only the first segment is defined by a GE-GN pair; from that point on only the end points of each segment is entered. The ending of a segment is used as the start of the next segment. GP record allows one starting, and up to 3 ending points (3 segments).

Field	Variable	Value	Description
0	ID	GP	Record Identification.
1	GSCALE	0 or blank	Default scaling factor of 1 to be applied to all global coordinate locations specified in fields 3 through 10 (GE and GN values).
		"+"	User-supplied scaling factor to be applied to all global coordinate locations specified in fields 3 through 10 (GE and GN values).
2	GCLOC	1	Starting reference point across channel corresponding to the first Easting and Northing coordinate pair in fields 3 and 4 (in feet).
3	GE	"+/-"	Easting coordinate for the start of the first channel segment (in feet).
4	GN	"+"	Northing coordinate for the start of the first channel segments (in feet).
5,7,9	GE	"+/-"	Easting coordinate for the ending points of channel segments 1, 2, and 3, respectively (in feet).
6,8,10	GN	"+"	Northing coordinate for the ending points of channel segments 1, 2, and 3, respectively (in feet).

Example:

```
ST3600.0    29.00     0.00     0.00    1.50    1.00
GP    1.0      0.0   4920.0    765.0  4680.0  1414.0
ND    1.0    693.03
```

NUMBER OF ITERATIONS RECORD

RECORD IT—REQUIRED

This record defines the number of iterations and the duration of the time step used in the water- and sediment-routing computations. The duration of time increments between hydraulic computations, DTIME, is determined from division of the total duration of water discharge hydrograph (in days) by the number of iterations, ITIMAX. The time increment between each successive sediment routing computation is then determined by the program by division of DTIME by the number of sediment routing computations within each hydraulic time step, NITRQS.

Field	Variable	Value	Description
0	ID	IT	Record Identification.
1	ITIMAX	"+"	The maximum number of time iterations.
2	NITRQS	1	Perform only one sediment routing computation in each time step.
		"+/-"	The number of sediment routing computations to be performed within each hydraulic time step. During each time step, hydraulic conditions are assumed to remain constant. At a given time step, the variable NITQRS allows the sediment routing computations to be performed at intermediate times.
3	DTIME	"+"	Duration of time step for which hydraulic conditions are assumed to remain constant (in days).
4	EPS	0 or blank	Default. Use 0.001 ft for convergence criteria in water surface computation (in feet).
		"+"	User-supplied value for convergence criteria in the normal depth, critical depth, sequent depth, and energy balance equations (feet).
5	KM	0	Default. Use a maximum of 20 iterations in the water surface convergence computations.
		"+"	User-supplied maximum number of iterations allowed in normal depth, critical depth, sequent depth, and energy balance computations.

Example:

```
CB        THALWEG
NT    3.0
IT   15.0      1.0   .00833
QQ        TABLE OF DISCHARGES
SS        STAGE DISCHARGE TABLE
```

MINIMIZATION ITERATIONS RECORD

RECORD MI—REQUIRED for Minimization

The MI record defines the frequency of minimization computations. If minimization is not requested, this record may be omitted. Total stream power computations are performed at the end of the first time step, and subsequently, at the end of each (1 + ITERMN) time step. These total stream power minimization computations are used in the program's logic to decide whether to make the channel scouring/deposition adjustments at the proceeding ITERMN time iterations in the lateral or in the vertical directions. In order to save computational time, minimization computations are activated only at specified time intervals.

Field	Variable	Value	Description
0	ID	MI	Record Identification.
1	ITERMN	"+"	The frequency of total stream power minimization computations.
		1	Perform minimization computations at each time step.
		2	Perform minimization computations at time steps 1, 3, 5, etc.

Example:

```
PW        WATER SURFACE PROFILE PLOTS         1.
MN        MINIMIZATION IS REQUESTED
MI    5.0
MR -50.0    900.0   2270.0   2310.0
MR -50.0    900.0   2270.0   2310.0
```

MINIMIZATION OPTION RECORD

RECORD MN—REQUIRED

The MN record activates total stream power minimization computations. With the selection of "NO MINIMIZATION REQUESTED," the model operates as the Stream Tube Computer Model for routing water and sediment through alluvial channels. This Stream Power Minimization option increases computational times substantially and therefore should be activated following the calibration runs (to check the direction of channel evolution).

Field	Variable	Value	Description
0	ID	**MN**	Record Identification.
1	IMN	**blank**	Unused (in earlier DOS versions).
		1	Use the model only for routing water and sediment.
		2	Activate stream power minimization computations.
2	IOPTMN	**text**	If Field 1 is specified, Field 2 is OPTIONAL.
		NO MINIMIZATION REQUESTED	Use the model only for routing water and sediment.
		MINIMIZATION IS REQUESTED	Activate total stream power minimization computations.

Example:

```
PX        CHANNEL CROSS SECTION PLOTS        3.
PW        WATER SURFACE PROFILE PLOTS        1.
MN        MINIMIZATION IS REQUESTED
MI    5.0
MR  -50.0    900.0   2270.0   2310.0
```

RANGE OF BED ELEVATION AND WIDTH VARIATION RECORD

RECORD MR—REQUIRED for Minimization

This record defines the allowable range of bed elevation and width variations at each station along the study reach for the minimization computations. If minimization is not requested, it can be omitted. The lateral and vertical channel restrictions (such as geological or man-made) at different locations along the study reach should be defined on the MR records. One record for each station should be supplied starting from the farthest upstream station.

Field	Variable	Value	Description
0	ID	MR	Record Identification.
1	XLFTI	"+/-"	The lateral location at the left-hand side of the channel looking downstream beyond which no channel expansion is allowed (in ft).
		-9999	No left-hand side boundary.
2	XRGHTI	"+/-"	The lateral location at the right-hand side of the channel looking downstream beyond which no channel expansion is allowed (in ft).
		+9999	No right-hand side boundary.
3	CBLI	0 or blank	No channel controls for scouring in the vertical direction.
		"+/-"	Channel bottom elevation beyond which no scouring is allowed (in ft).
4	CBHI	0 or blank	No channel controls for deposition in the vertical direction.
		"+/-"	Channel bottom elevation beyond which no deposition is allowed (in ft).

Example:

```
MN      MINIMIZATION IS REQUESTED
MI    5.0
MR -50.0    900.0  2270.0   2310.0
MR -50.0    900.0  2270.0   2310.0
```

NUMBER OF RATING CURVES RECORD

RECORD NC—OPTIONAL

This record defines the number of rating curves to be used in defining the stage-discharge values throughout the study reach. The NC record is activated by selecting the "RATING CURVE" option in the SS record. It is placed right before the RC records.

Field	Variable	Value	Description
0	ID	NC	Record Identification.
1	NCURVES	"+"	Number of user-supplied rating curves.

Example:

```
IT   9.0     1.0     2.0
QQ       TABLE OF DISCHARGES
SS       RATING CURVE
TQ 500.0  1600.0  2250.0  2650.0  2800.0  2250.0  1750.0  1500.0  1250.0
NC   1.0
RC  10.0     0.9     0.2  1000.0
```

NUMBER OF SUBCHANNELS/SUBSECTIONS RECORD

RECORD ND—REQUIRED

This record defines the number of channel subsections and/or the number of subchannels at a given station and the lateral locations corresponding to these subsections/subchannels across the river. All the channel subsections, except the first subsection, are confined by the lateral locations defined in this record. The first subsection is bounded by CROSLOC(ISTA,1) and DL(ISTA,1). The computer program allows the user to define up to ten subsections/subchannels across the river at each station (using 9 DL values).

Field	Variable	Value	Description
0	ID	**ND**	Record Identification.
1	NDIVI	"+"	Number of subchannels or subsections across the river at a given station (up to 10).
2-10	DL	"+"	End point locations of channel subsections with respect to a given reference location at a given station. These values are entered starting from the left side of the channel looking downstream. The first channel subsection is bounded by the first CROSLOC value on the XS record on the left and the first DL value on the right (in ft).
			If the river channel consists of only a main channel and no overbanks, NDIVI is set equal to 1. DL is set equal to the last CROSLOC value on the XS record. The channel extends between the first and last CROSLOC values on the XS record.
			If the river consists of a main channel and right overbank, NDIVI is set equal to 2. The first DL value corresponds to the end point of the main channel across the river. The second DL value is set equal to the last CROSLOC value on the XS record.
			In the case of a left overbank, a main channel and a right overbank, NDIVI are set equal to 3. The first DL value corresponds to the end point of left overbank. The left overbank is bounded by the first CROSLOC value and the first DL value. The second DL value corresponds to the end point of the main channel. The main channel is bounded by the first and second DL values. The third DL value corresponds to the end of the right overbank section. The right overbank extends between the second and third DL values

Example:

```
ST4365.0    14.0     0.0     0.0  2000.0     1.0
ND    3.0   461.0   539.0   540.0
XS 309.7   460.0   299.7   461.0   299.7   470.0   299.7   485.0   299.7   488.0
```

NUMBER OF STATIONS RECORD

RECORD NS—REQUIRED

This record defines the number of measured stations to be used by the program. The total number of stations allowed in Version 5.0 of the program is 50.

Field	Variable	Value	Description
0	ID	NS	Record Identification.
1	NSTA	"+"	Number of stations for which channel cross sections are defined.

Example:

```
TT                          EXAMPLE PROBLEM
TT        SILVERCROFT WASH CHANNEL 100-YEAR FLOOD - SUPERCRITICAL FLOWS
TT                        JULY 1992, ALBERT MOLINAS
NS   10.0
ST4365.0     14.0     0.0     0.0  2000.0     1.0
ND   3.0    461.0   539.0   540.0
```

NUMBER OF STREAM TUBES RECORD

RECORD NT—REQUIRED

The NT record defines the number of stream tubes to be used in hydraulic and sediment-routing computations. Since the number of water surface profile and sediment-routing computations is directly proportional to the number of stream tubes selected, the user should use his judgment and experience in selecting the number of tubes. For large numbers of stream tubes, the coordinate pairs defining the cross section geometries should be spaced closely across the channel. For most studies, the use of three stream tubes would provide adequate information across the channel. However, the program allows the use of up to 10 stream tubes. With the selection of one stream tube, the model treats the entire channel as a single tube.

Field	Variable	Value	Description
0	ID	NT	Record Identification.
1	NSTUBE	1-10	Number of stream tubes to be used in the hydraulic and sediment-routing computations.
2-10	PRCTFLW	blank	Default. Equal flow distribution in each of the stream tubes.
		0-1.0	Percent flow distribution for each of the stream tubes. Sum of the percentage flows must be equal to 1.0.

Example:

```
CL    0.0      0.0      0.0      0.0     0.0     0.0     0.0     0.0     0.0     0.0
CB        THALWEG
NT    3.0      0.35     0.45     0.2
IT   15.0      1.0    .00833
QQ        TABLE OF DISCHARGES
```

PIER EQUATION COEFFICIENTS RECORD

RECORD PC—OPTIONAL

The PC record defines the coefficients in the specified generic bridge pier equation. This record is activated if the variable IPIER in the PE record is set equal to 5. The fields of the PC record define the generic local scour equation, which is in the form of:

$$\frac{ds}{b} = \kappa\, K_1\, K_2 \left(\frac{y}{b}\right)^{\alpha} (Fr)^{\beta} \left(\frac{D_M}{y}\right)^{\gamma}$$

in which kappa = proportionality constant; K_1 = shape factor; K_2 = alignment factor; alpha, beta, gamma = exponents; y = flow depth; b = pier width; D_M = dominant sediment size; Fr = Froude number [= $V/\sqrt{gy}$]; V = mean approach velocity; g = gravitational acceleration; and ds = depth of scour. If the generic pier scour equation is selected, the user must provide a PC record for each of the piers in the study reach. This is done by supplying a PC record after every PP (Pier scour Parameters) record.

Field	Variable	Value	Description
0	ID	PC	Record Identification.
1	KAPPA	"+"	User-supplied value of proportionality constant (κ).
2	K1	"+"	User-supplied value of shape factor K1.
3	K2	"+"	User-supplied value of alignment factor K2.
4	ALPHA	"+"	User-supplied exponent for (y /b).
5	BETA	"+"	User-supplied exponent for Froude Number, Fr.
6	GAMMA	"+/-"	User-supplied exponent for (DM / y).
7	DM	"+"	Dominant sediment size (D50, D65, or D90).

Example:

```
PE    3.0     2.0
PS    3.0     4.0
PP   10.0    10.0    1.0    20.0    40.0    5.0
PC    2.0     1.0    1.0   -0.65    0.43    0.0     5.0
PP   50.0    10.0    1.0    20.0    40.0    5.0
PC    2.0     1.0    1.0   -0.65    0.43    0.0
PP   90.0    10.0    1.0    20.0    40.0    5.0
PC    2.0     1.0    1.0   -0.65    0.43    0.0     5.0
PP  150.0    10.0    1.0    20.0    40.0    5.0
PC    2.0     1.0    1.0   -0.65    0.43    0.0     5.0
PS   10.0     1.0
PP   10.0    10.0    1.0    20.0    40.0    5.0
PC    2.0     1.0    1.0   -0.65    0.43    0.0     5.0
```

PIER SCOUR EQUATION RECORD

RECORD PE—REQUIRED for Local Bridge Pier Scour Computations

The PE record defines the local bridge pier scour equation to be used in estimating potential local bridge pier scour. Options that are available in the computer model are: CSU equations, the Laursen equation, the Jain and Fisher equation, Froehlich equations, or a generic bridge scour equation.

Field	Variable	Value	Description
0	ID	PE	Record Identification.
1	IPIER	"+"	Variable to choose the local bridge pier scour equation to be used.
		1	Use CSU equation.
		2	Use Laursen equation.
		3	Use Froehlich equation for live-bed scour.
		4	Use Jain and Fisher equation.
		5	Use generic equation.
2	NPIERST	"+"	No. of cross sections containing bridge piers (limited to total number of stations specified in NS record).

Example:

```
PE    3.0      2.0
PS    3.0      4.0
PP   10.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0     5.0
PP   50.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0
PP   90.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0     5.0
PP  150.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0     5.0
PS   10.0      1.0
PP   10.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0     5.0
```

PLOTTING OPTION RECORD

RECORD PL—REQUIRED

This record allows the user the option of creating internal files to be used later in generating plots. These files are stored internally with the default file names TAPE8 and/or TAPE9. During the execution of the model, the user may select different names for these files. These files contain the summary of hydraulic and sediment routing computations, and may be used in plotting and tabulating the results. If the "PLOTTING IS REQUESTED" option is selected, the user must provide both the PX and PW records.

Field	Variable	Value	Description
0	ID	PL	Record Identification.
1	IPL	blank or "+"	Variable to activate the plot file generation option. This field was unused in DOS versions.
		blank	Use Field 2-4 selection.
		1	Use the plot file generation option.
		2	Do not generate plot files.
2-4	IOPTPL	NO PLOTTING IS REQUESTED	Do not use the plot generation option.
		PLOTTING IS REQUESTED	Use the plot generation option. Specify whether cross section or water surface profile plots, or both, are requested in the PX and PW records. If this option is selected, both the PX and PW records should be provided.

Example:

```
PV   5.0      0.0      0.0      0.0      0.0      0.0    1.0
PV   9.0      0.0      0.0      0.0      0.0      0.0    1.0
PL        PLOTTING IS REQUESTED
PX        CHANNEL CROSS SECTION PLOTS          3.
PW        WATER SURFACE PROFILE PLOTS          1.
```

PIER SCOUR PARAMETERS RECORD

RECORD PP—REQUIRED for Local Bridge Scour Computations

The PP record is used to define the location of bridge piers across the channel at a given bridge pier station. This record also defines the various parameters (such as pier width, flow angle of attack, etc.) necessary for the computation of local scour due to bridge piers in various equations. The appropriate fields of the PP record are activated depending upon the pier scour equation in the PE record. The number of PP records for each pier station should be equal to NPIER defined in the 2nd field of the Pier Station (PS) record. A set of PP records should be provided for each station containing bridge piers.

Field	Variable	Value	Description
0	ID	PP	Record Identification.
1	PIERCT	"+/-"	Pier center location across channel at the bridge pier station specified in the PS record.
2	B	"+"	Pier width (used in all equations).
3	PIERTYP	"+" 1 2 3 4 5	Pier shape correction factor in CSU equation. Square-nosed pier. Round-nosed pier. Sharp-nosed pier. Cylinder. Group of cylinders.
4	THETA	"+"	Angle of attack used in Froehlich equation.
5	PLEN	"+"	Pier length used in Froehlich equation.
6	D50	"+"	Sediment size at pier location for which 50% of the sediment is finer (mm).

Example:

```
PE    3.0      2.0
PS    3.0      4.0
PP   10.0     10.0      1.0     20.0     40.0     5.0
PC    2.0      1.0      1.0    -0.65     0.43     0.0      5.0
PP   50.0     10.0      1.0     20.0     40.0     5.0
PC    2.0      1.0      1.0    -0.65     0.43     0.0
PP   90.0     10.0      1.0     20.0     40.0     5.0
PC    2.0      1.0      1.0    -0.65     0.43     0.0      5.0
PP  150.0     10.0      1.0     20.0     40.0     5.0
PC    2.0      1.0      1.0    -0.65     0.43     0.0      5.0
PS   10.0      1.0
PP   10.0     10.0      1.0     20.0     40.0     5.0
PC    2.0      1.0      1.0    -0.65     0.43     0.0      5.0
```

PRINTOUT CONTROL RECORD

RECORD PR—REQUIRED

This record defines the amount of printout and the interval of printing. In the current version of the program, four different levels of printout are provided to allow the user to follow computations. The user can also control the interval of printing. This option is to enable the user to get detailed information only at specified time intervals.

Field	Variable	Value	Description
0	ID	PR	Record Identification.
1	IPRLVL	-1	No printout pertaining to hydraulic and sediment computations.
		0	Limited printout. Only water surface profile tables are generated.
		1	Normal and critical depth tables in addition to Level 0 printout are generated.
		2	Debugging option. All hydraulic computations are printed to allow the user to follow the computations.
2	INTPR	"+"	Interval of printing. If a printout is desired at each time interval, INTPR should be set equal to 1. Setting INTPR equal to a very large number has the same effect as generating no printout.
3	IPRBGN	0 or blank	Default. Start from time step no. 1.
		"+"	Starting time step for printout.
4	IPREND	0 or blank	Default. Ending time step for printout is set to ITIMAX (maximum time step).
		"+"	Ending time step for printout.

Example:

```
SD    .14    .14    .14    .28    .30
SD    .14    .14    .14    .28    .30
PR    0.0    5.0
PV    3.0    0.0    0.0    0.0    0.0    0.0    1.0
PV    5.0    0.0    0.0    0.0    0.0    0.0    1.0
```

PIER STATIONS RECORD

RECORD PS—REQUIRED for Local Bridge Scour Computations

The PS record identifies stations containing bridge piers, and defines the number of bridge piers at these stations. The geometric and flow parameters corresponding to the piers are specified in the Pier Parameters (PP) record. The number of PS records should be equal to NPIERST value specified in the second field of the Pier Scour Equation (PE) record.

Field	Variable	Value	Description
0	ID	PS	Record Identification.
1	PIERST	"+"	Station number containing bridge piers. Stations are numbered in the downstream direction, starting with the furthest upstream station as 1.
2	NPIER	"+"	Number of piers at station no. PIERST. The geometric and flow parameters corresponding to these piers are specified in the appropriate fields of the Pier Parameters (PP) records. The maximum number of piers allowed at a given pier station is 10.

Example:

```
PE    3.0      2.0
PS    3.0      4.0
PP   10.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0     5.0
PP   50.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0
PP   90.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0     5.0
PP  150.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0     5.0
PS   10.0      1.0
PP   10.0     10.0     1.0    20.0    40.0    5.0
PC    2.0      1.0     1.0   -0.65    0.43    0.0     5.0
```

VISUAL SCREEN OUTPUT RECORD

RECORD PV—OPTIONAL

This record specifies the boundaries of the three stacked cross section plot windows appearing on the right-hand side of the screen. These windows provide the user a visual means of monitoring the progress of computations during the execution of the model. They also allow the user to qualitatively inspect the results of scouring/ deposition computations through time without generating extensive hard-copy plots and printouts.

The cross-section plot windows indicate two lines: the original channel cross section and the computed cross section at a given time step. A separate program status window indicates the simulation time step. The plotting procedure in the model is compatible with existing graphics hardware (VGA, Super VGA, and above).

In the absence of graphics capability, the model turns-off screen plotting. In the presence of a graphics card, the user may choose between graphic- and text-mode output (in order to speed up simulation) by specifying the appropriate value of ISCTYP variable in the 6th field.

Field	Variable	Value	Description
0	ID	PV	Record Identification.
1	ST	"+/-"	Station for which a cross section plot window is requested.
2	XMIN	0	Compute the minimum X-position across the channel.
		"+/-"	Use the user-supplied left boundary across the channel.
3	XMAX	0	Compute the maximum X-position across the channel.
		"+/-"	Use the user-supplied right boundary across the channel.
4	YMIN	0	Compute the minimum bottom elevation across the channel for station ST.
		"+"	Use the user-supplied minimum bottom elevation across the channel.
5	YMAX	0 or blank	Compute the maximum bottom elevation across the channel.
		"+"	Use the user-supplied maximum bottom elevation across the channel.
6	ISCTYP	0 or blank	Graphics card is present (VGA and above).
		1	Use text-mode graphics irrespective of the graphics capability.
7	IUPST	0 or blank	Default. Use station no. 1 as the upstream boundary of the thalweg profile plot on screen.

Field	Variable	Value	Description
		1 - 50	User-supplied upstream station number bounding the thalweg profile plot.
8	**IDWST**	**0 or blank**	Default. Use the furthest downstream station as the lower boundary of the thalweg profile plot.
		1 - 50	User-supplied downstream station number bounding the thalweg profile plot.
9	**IWTRLV**	**0 or blank**	Default. Do not indicate the water surface line in the channel for the cross-section screen plots.
		1	Draw the water surface line across the channel in the cross section screen plots.
		2	Show the water surface line across the channel as a FILL in the cross section screen plots.

Example:

```
SD   .14      .14      .14      .28      .30
PR   0.0      5.0
PV   3.0      0.0      0.0      0.0      0.0      0.0      1.0
PV   5.0      0.0      0.0      0.0      0.0      0.0      1.0
PV   9.0      0.0      0.0      0.0      0.0      0.0      1.0
PL        PLOTTING  IS  REQUESTED
PX        CHANNEL  CROSS  SECTION  PLOTS           3.
PW        WATER  SURFACE  PROFILE  PLOTS           1.
```

WATER SURFACE PROFILE PLOTTING RECORD

RECORD PW—OPTIONAL

This option is activated by "PLOTTING IS REQUESTED" in the PL record. The PW record allows the user to generate water surface profile plots at desired time intervals. Upon the selection of this option, the data required for generating plots are extracted at the specified time intervals and stored internally in the default file name FILE9. During the execution of the program, the user may rename FILE9. This file contains summary information for each station. The location of stations, corresponding thalweg, water surface elevations, and velocities are stored in free format.

Field	Variable	Value	Description
0	ID	PW	Record Identification.
1	-	blank	Not used.
2-5	IOPTPL2	**WATER SURFACE PROFILE PLOTS**	Water surface profile plotting.
		"+/-"	Use the user-supplied left boundary across the channel.
6	INTPL2	0	Do not generate water surface profile plots.
		>0	Generate water surface profile plots at time intervals of INTPL2.
7	IPL2BGN	0	Default. Use time step number 1 as the first time step for water surface profile plotting.
		>0	User-supplied time step value for initiating water surface profile plotting.
8	IPL2END	0	Default. Use time step ITIMAX as the last time step for water surface profile plotting.
		>0	User-supplied time step value for ending water surface profile plotting.

Example:

```
PL      PLOTTING IS REQUESTED
PX      CHANNEL CROSS SECTION PLOTS          3.
PW      WATER SURFACE PROFILE PLOTS          1.
MN      MINIMIZATION IS REQUESTED
MI   5.0
```

CHANNEL CROSS SECTION PLOTTING RECORD

RECORD PX—OPTIONAL

This option is activated by "PLOTTING IS REQUESTED" in the PL record. The PX record allows the user to generate cross section plots at desired time intervals. Upon the selection of this option, the data required for generating plots are extracted at the specified time intervals and stored internally under the default file name FILE8. During the execution of the program, the user may rename FILE8. This file contains summary information for each station. The location of stations, the number of points defining the channel geometries, and the pairs of bottom elevation-location across channel values corresponding to these data points are stored in free format.

Field	Variable	Value	Description
0	ID	PX	Record Identification.
1	-	blank	Not used.
2-5	IOPTPL1	CHANNEL CROSS SECTION PLOTS	Channel cross section plotting.
6	INTPL1	0	Do not generate cross section plots.
		>0	Generate cross section profile plots at time intervals of INTPL1.
7	IPL1BGN	0	Default. Use time step number 1 as the first time step for cross section plotting.
		>0	User-supplied time step value for initiating cross section plotting.
8	IPL1END	0	Default. Use time step ITIMAX as the last time step for cross section plotting.
		>0	User-supplied time step value for ending cross section plotting.

Example:

```
PV    9.0      0.0      0.0      0.0      0.0      0.0     1.0
PL         PLOTTING IS REQUESTED
PX         CHANNEL CROSS SECTION PLOTS           3.
PW         WATER SURFACE PROFILE PLOTS           1.
MN         MINIMIZATION IS REQUESTED
```

WATER INFLOW HYDROGRAPH RECORD

RECORD QI—REQUIRED for Lateral Water Inflow

The QI records are used to input the lateral water inflow hydrographs at given stations. The lateral inflow stations are specified through the use of QL records. Water discharge values entered in fields 1 through 10 of each QI record correspond to discharges for each of the simulation time steps. The total number of discharge values entered using QI records should be equal to the ITIMAX value which is defined in the IT record. In case of no later water inflow, QI records can be omitted. The water discharges specified in the fields of QI records are in cubic feet per second.

Field	Variable	Value	Description
0	ID	QI	Record Identification.
1-10	QLATERL	"+/-"	Water inflow values corresponding to various simulation time steps (cubic feet per second).

Example:

```
IT  15.0      1.0   .00833
CM **** ENTER DISCHARGES STARTING FROM U/S STATION - INFLOW AT STA. 5... ***
QL   1.0      5.0
TL   1.0
QI2750.0   4500.0   6100.0   7000.0   6600.0   6000.0   4200.0   2950.0   2250.0   1550.
QI1450.0   1100.0    850.0    750.0    700.0
TL   5.0
QI 500.0    600.0    700.0    800.0    900.0   1000.0   1100.0   1200.0   1100.0   1000.
QI 500.0    400.0    300.0    200.0    100.0
QQ       TABLE OF DISCHARGES
SS       STAGE DISCHARGE TABLE
TL  10.0
SQ 3250. 2283.50
SQ 5100. 2284.90
SQ 6800. 2286.05
SQ 7800. 2286.30
SQ 7500. 2286.40
```

LATERAL WATER INFLOW RECORD

RECORD QL—REQUIRED for Lateral Water Inflow

QL records are used to indicate the lateral water inflow stations within the study reach. In case of no lateral water inflow they can be omitted. The fields 2 through 10 of the first, and 1 through 10 of the second and following QL records contain station numbers for which water inflow hydrographs are to be input. The maximum number of water inflow stations are limited to the total number of stations used in the simulation.

Field	Variable	Value	Description
0	ID	QL	Record Identification.
1	ANL	"+"	Number of water inflow stations.
2-10 (1-10 after first QL record)	LATERAL	"+"	Station numbers indicating lateral water inflow stations. If the value of ANL in field 1 exceeds 9, more than one record will be needed.
			In the second QL record and thereafter, Field 1 is also used for entering lateral inflow values.

Example:

```
IT  15.0     1.0  .00833
CM **** ENTER DISCHARGES STARTING FROM U/S STATION - INFLOW AT STA. 5... ***
QL   1.0     5.0
TL   1.0
QI2750.0  4500.0  6100.0  7000.0  6600.0  6000.0  4200.0  2950.0  2250.0  1550.
QI1450.0  1100.0   850.0   750.0   700.0
TL   5.0
QI 500.0   600.0   700.0   800.0   900.0  1000.0  1100.0  1200.0  1100.0  1000.
QI 500.0   400.0   300.0   200.0   100.0
QQ      TABLE OF DISCHARGES
SS      STAGE DISCHARGE TABLE
TL  10.0
SQ 3250. 2283.50
SQ 5100. 2284.90
SQ 6800. 2286.05
SQ 7800. 2286.30
SQ 7500. 2286.40
```

DISCHARGE RECORD

RECORD QQ—REQUIRED

This record defines the discharge input options. The discharge values can be entered either in tabular form as daily discharges, or in time blocks as discretized discharges. The program allows up to 1000 discharge values. The number of discharges to be used for a given study is limited by the variable ITIMAX in the IT record.

Field	Variable	Value	Description
0	ID	QQ	Record Identification.
1	IQQ	blank or "+"	Variable to activate the plot file generation option. This field was unused in DOS versions.
		blank	Use Field 2-4 selection.
		1	Use TABLE OF DISCHARGES option.
		2	Use DISCRETIZED DISCHARGES option.
2-4	IOPTQ	TABLE OF DISCHARGES	The discharges are entered in tabular form. Discharge values corresponding to each time step are provided.
		DISCRETIZED DISCHARGES	The discharges will be entered in time blocks as discretized discharges.

Example:

```
NT    3.0
IT   15.0      1.0   .00833
QQ        TABLE OF DISCHARGES
SS        STAGE DISCHARGE TABLE
TL   10.0
```

SEDIMENT DISCHARGE RECORD

RECORD QS—REQUIRED for Sediment Transport

The QS record defines the sediment discharges entering the study reach at the farthest upstream station. These sediment discharges are entered as a series of constant bursts of discharges. The sediment discharge hydrograph is first approximated by a series of constant discharges. The number of preselected computational time increments in each time interval pertaining to a constant sediment discharge block is determined. These values are input in a table format. The sum of all time increments should be equal to the maximum number of time iterations ITIMAX defined in the IT record.

Field	Variable	Value	Description
0	ID	QS	Record Identification.
1	NDAY	"+"	Number of time increments corresponding to the sediment discharge defined in field 2. The sum of all NDAY values in QS records should be equal to ITIMAX in the IT record (dimensionless).
2-4	QSI	TABLE OF DISCHARGES	Discretized sediment discharge value for the number of time increments, NDAY, defined in field 1. For the duration of NDAY, the sediment discharge hydrograph is approximated by the constant QSI value (in tons per day).

Example:

```
SQ   800. 2280.25
SO        SEDIMENT TRANSPORT IS REQUESTED
QS   15.0      0.0
SE    1.0
TM   15.0     70.0
```

ROUGHNESS BREAKPOINT RECORD

RECORD RB—OPTIONAL

The RB record specifies the roughness breakpoint locations across the channel and the associated roughness values at a given station. Roughness breakpoints are points at which the coefficient of roughness exhibits a distinctive change in value. Generally, such breakpoints are observed in natural channels at the junction of flood plains with the main channel, with higher roughness values occurring on the flood plains and lower roughness values occurring in the main channel regions. The RB record allows users to specify up to 5 roughness breakpoints and the associated roughness values at a station. Only one RB record is allowed for each station along the study reach. Stations are numbered in the downstream direction, with station number 1 being the furthest upstream station. The location of roughness breakpoints across the channel are relative to the left-hand side of the channel facing downstream. Location definitions follow the same specifications as the channel geometry points across the station.

Field	Variable	Value	Description
0	ID	RB	Record Identification.
1, 3, 5, 7, 9	RBV	"+"	Roughness value associated with the roughness breakpoint in the following field of the RB record.
2, 4, 6, 8, 10	RBX	"+"	Roughness breakpoint across channel. The roughness coefficient for the channel segment bounded by the first RBX value and the start of the channel is assigned the first RBV value in the RB record.
			For the following segments, the roughness coefficient for the channel points following within consecutive RBX values are assigned the RBV value associated with the right-hand value of the segment.
			Points falling beyond the last RBX value are assigned the last RBV value.

Example:

```
RB   0.04   100.0   0.025   200.0   0.04   400.0
```

For this record, the channel cross-section points falling between the beginning of the channel and the 100 ft station across the channel (facing downstream) are assigned a roughness value of 0.04. Points falling within the segment 100.0 and 200.0 ft across the channel are assigned a value of 0.025, and the channel points falling between locations 200.0 and 400.0 ft across the channel are assigned the value of 0.04.

RATING CURVE RECORD

RECORD RC—OPTIONAL

This record identifies the station number for which the rating curve is given and also for definition of the coefficients of the stage discharge function. The assumed stage-discharge function is in the form of:

$$Stage \ in \ feet = C1(Discharge \ in \ ft^3/sec)^{C2} + C3$$

The coefficients C1, C2, C3 are expected to be derived by the user following a data analysis. This option is activated by the "RATING CURVE" option in the SS record. The number of rating curves provided for the study reach should be defined in the NC record just before the RC record.

Field	Variable	Value	Description
0	ID	RC	Record Identification.
1	ISTA	"+"	Station number for which the rating curve is provided. Stations are numbered starting from the upstream-most station. The interpolated cross sections are included in the numbering process.
2	C1	"+/-"	Value of the coefficient C1.
3	C2	"+/-"	Value of the coefficient C2.
4	C3	"+/-"	Value of the coefficient C3.

Example:

```
IT    9.0       1.0      2.0
QQ         TABLE OF DISCHARGES
SS         RATING CURVE
TQ 500.0  1600.0  2250.0  2650.0  2800.0  2250.0  1750.0  1500.0  1250.0
NC   1.0
RC  10.0      0.9      0.2  1000.0
```

ROUGHNESS EQUATION RECORD

RECORD RE—REQUIRED

This record is used to select the roughness equation to be used throughout the hydraulic computations. The available options are the Manning, Darcy-Weisbach, or Chezy equations.

Field	Variable	Value	Description
0	ID	RE	Record Identification.
1	-	blank	Not used.
2	EQROUGH	text	The flow equation to use in relating roughness to velocity.
		MANNING	Use Manning's flow equation with Manning's roughness coefficients.
		DARCY	Use Darcy-Weisbach equation with Darcy's friction factors.
		CHEZY	Use Chezy's equation with Chezy's resistance coefficients.

Example:

```
XS 278.0    520.0    278.0    525.0    280.0    530.0    282.0    535.0    286.0    545.0
XS 290.0    555.0    290.3    562.0    290.9    576.0    291.0    605.0    290.0    635.0
RE         MANNING
RH  .020     .020     .020     .020     .020     .020     .020     .020     .020     .020
RH  .020     .020     .020     .020
```

ROUGHNESS COEFFICIENT RECORD

RECORD RH—REQUIRED FOR EACH STATION

This record defines the channel roughness at given station coefficients, friction factors, or resistance coefficients which correspond to the roughness equation selected on the RE record. Roughness values at a station are entered across the channel for each data point defining the geometry at that cross section. The computer model limits the number of roughness values at a station to 27. RH records for each station are entered starting from the farthest upstream station and progressing in the downstream direction.

Field	Variable	Value	Description
0	ID	RH	Record Identification.
1-10	RN	"+"	Roughness coefficients at station STA corresponding to each data point across the channel used in order to define the geometry. At each station up to 200 RN values are allowed.

Example:

```
XS 290.0    555.0    290.3    562.0    290.9    576.0    291.0    605.0    290.0    635.0
RE      MANNING
RH  .020     .020     .020     .020     .020     .020     .020     .020     .020     .020
RH  .020     .020     .020     .020
RH  .020     .020     .020     .020     .020     .020     .020     .020     .020     .020
```

SEDIMENT SIZE BREAKPOINT RECORD

RECORD SB—OPTIONAL

This record is utilized to input the sediment size variation across the channel at a given station. Breakpoints at which sediment size gradation lines distinctively change are indicated in the fields of the SB record. For each of the SBX values identified in the SB record, an SX record must be supplied.

Field	Variable	Value	Description
0	ID	SB	Record Identification.
1-10	SBX	"+"	Locations of breakpoints in sediment size gradations across the channel at a given station.

Example:

```
SF    3.0
SG 0.250    0.500
SG 0.500    1.000
SG 1.000    2.000
SB 100.0    400.0
SX  0.33    0.33    0.33
SX  0.25    0.50    0.25
```

SEDIMENT SIZE DISTRIBUTION RECORD

RECORD SD—REQUIRED

The SD record inputs the bed material size fractions falling within each size group defined by SG records at different stations along the study reach. An SD record should be provided for each cross section starting from the farthest upstream station. The number of SD records should be equal to the total number of cross sections.

Field	Variable	Value	Description
0	ID	SD	Record Identification.
1-10	P	$0 \le P \le 1$	Bed material size fraction falling within each of the NF size groups. The P value in the first field corresponds to the smallest size group defined in the SG records. The number of P values on each SD record is determined by the variable, NF, in the SF record.

Example:

```
SG    .60    1.80
SG   1.80    5.00
SD    .14     .14     .14     .28     .30
SD    .14     .14     .14     .28     .30
SD    .14     .14     .14     .28     .30
```

SEDIMENT TRANSPORT EQUATION RECORD

RECORD SE—REQUIRED for Sediment Transport

This record defines the sediment transport method or equation to be used in the sediment load computations. Options that are available in the computer model are: (1) the Molinas and Wu equation with bed material fraction (BMF) method for fractional load, (2) the Molinas and Wu equation with transport capacity fraction (TCF) method for fractional load, (3) the Ackers and White equation with the BMF method for fractional load, (4) the Engelund and Hansen equation with the BMF method for fractional load, (5) Yang's equation with the BMF method for fractional load, (6) the Yang, Molinas, and Wu equation with the BMF method for fractional load, (7) the Meyer-Peter Müller equation with the BMF method for fractional load, and (8) a generic sediment transport equation. For the generic sediment transport equation option, the user is required to provide the coefficients C1-C6 for the equation

$$Q_{s,i} = C1\,(V)^{C2}\,(S_f)^{C3}\,(d)^{C4}\,(Di)^{C5}\,(Q)^{C6} \tag{105}$$

in which $Q_{s,i}$ = sediment load for size group i in tons/day (by dry weight); V = velocity in ft/sec; Sf = friction slope in ft/ft; d = depth in ft; Di = geometric mean sediment size corresponding to size group i in mm; and Q = discharge in cfs. These coefficients are defined by the user through the SP records.

Field	Variable	Value	Description
0	ID	SE	Record Identification.
1	ISED	"+"	Variable to choose the sediment transport equation or method to be used.
		1	Use Molinas and Wu (1996) equation with the BMF method for fractional load (natural rivers and sand sizes only).
		2	Use Molinas and Wu (1996) equation with the TCF method for fractional load (natural rivers and sand sizes only).
		3	Use Ackers and White (1973) equation with the BMF method for fractional load (sand sizes only).
		4	Use Engelund and Hansen (1972) equation with the BMF method for fractional load (sand sizes only).
		5	Use Yang's (1973, 1984) equation with the BMF method for fractional load (sand and gravel sizes).
		6	Use Yang, Molinas, and Wu (1996) equation with the BMF method for fractional load (silt and fine sand sizes).
		7	Use Meyer-Peter Müller (1948) equation with the BMF method for fractional load (sand, gravel, and larger sizes).
		8	Use a generic sediment transport equation in the form of Eq. (105).

Field	Variable	Value	Description
2	**NALT**	**0 or blank**	Use the default active layer thickness of 50*D(NF) where D(NF) is the geometric mean sediment size corresponding to the size group NF specified in the SF record.
		"+"	User-specified multiplication factor for defining the thickness of the active layer given by: TAL = NALT*D(NF).

Example:

```
SO        SEDIMENT TRANSPORT IS REQUESTED
QS  15.0       0.0
SE   1.0      50.0
TM  15.0      70.0
SF   5.0
SG 0.062     0.125
SG 0.125     0.250
SG 0.250     0.500
SG 0.500     1.000
SG 1.000     2.000
```

NUMBER OF SIZE FRACTIONS RECORD

RECORD SF—REQUIRED

The SF record defines the number of size fractions to be used in the sediment transport capacity computations. In the computer program the number of size fractions is limited to 10.

Field	Variable	Value	Description
0	ID	SF	Record Identification.
1	NF	1<=NF<=10	Number of size fractions to be used in the sediment transport capacity computations.

Example:

```
SE    1.0
TM   15.0      70.0
SF    5.0
SG    .08       .29
SG    .29       .50
SG    .50      1.0
SG   1.0       2.0
SG   2.0       4.0
```

SEDIMENT SIZE GROUPS RECORD

RECORD SG—OPTIONAL

The SG record defines the sediment size groups to be used in the sediment transport capacity computations. With SG records, up to 10 sand (also gravel, if Yang's Method is used) size groups can be defined. These records are ordered with increasing sediment sizes. For each size fraction, one SG record is required. The number of SG records is limited by the variable NF (number of size fractions) in the SF record.

Field	Variable	Value	Description
0	ID	SG	Record Identification.
1	DRL	"+"	Lower bound of the size group i (i=1,NF) (in millimeters). The lowest allowable size is 0.0625 mm.
2	DRU	"+"	Upper bound of the size group i (i=1,NF) (in millimeters). The highest allowable size is 2 mm for Ackers and White and 10 mm for Yang's Method.

Example:

```
SE    1.0
TM   15.0      70.0
SF    5.0
SG    .08       .29
SG    .29       .50
SG    .50      1.0
SG   1.0       2.0
SG   2.0       4.0
```

SEDIMENT INFLOW HYDROGRAPH RECORD

RECORD SI—REQUIRED for Lateral Sediment Inflow

The SI records are used to input the lateral sediment inflow hydrographs for a given stream tube at a given station. The lateral sediment inflow stations are specified through the use of SL records. Sediment discharge values entered in each SI record correspond to lateral sediment inflow values for a given time step. Fields 1 through 10 in SI records contain sediment discharges in cubic feet corresponding to various size groups specified in SG records. The total number of SI records needed for a given lateral inflow station is:

(Total number of time steps) x (Number of stream tubes)

The order of SI records follow the increasing order of stream tubes. In other words, the first ITIMAX (total number of simulated time steps specified in the IT record) number of SI records corresponds to the first stream tube, the second ITIMAX number of SI records corresponds to the second stream tube, and so on. In case of no lateral sediment inflow, SI records can be omitted. The sediment discharges specified in the fields of SI records are in cubic feet per second.

Field	Variable	Value	Description
0	ID	SI	Record Identification.
1-10	QSLATRL	"+"	Lateral sediment inflow values corresponding to various size groups specified in SG records (cubic feet).

Example:

```
CM    ****  SEDIMENT INFLOW AT STATION 5 - FIRST 5 VALUES FOR TUBE NO.1 ***
SL    1.0      5.0
TL    5.0
SI 100.0    100.0    100.0    100.0   100.0
SI 200.0    200.0    200.0    200.0    200.0
SI 200.0    200.0    200.0    200.0    200.0
SI 200.0    200.0    200.0    200.0    200.0
SI 300.0    300.0    300.0    300.0    300.0
```

LATERAL SEDIMENT INFLOW RECORD

RECORD SL—REQUIRED for Lateral Sediment Inflow

SL records are used to indicate the lateral sediment inflow stations within the study reach. In case of no lateral sediment inflow they can be omitted. In fields 2 through 10 of the first, and 1 through 10 of the second and following, QL records contain the station numbers for which sediment inflow hydrographs are to be input. The station numbering convention assumes the furthest upstream station to be station 1. The maximum number of sediment inflow stations are limited to the total number of stations used in the simulation.

Field	Variable	Value	Description
0	ID	SL	Record Identification.
1	ANL	"+"	Number of sediment inflow stations.
2-10 (1-10 after first SL record)	LATERLS	"+"	Station numbers indicating lateral water inflow stations. If the value of ANL in field 1 exceeds 9, more than one record is needed.

Example:

```
CM    **** SEDIMENT INFLOW AT STATION 5 - FIRST 5 VALUES FOR TUBE NO.1 ***
SL    1.0     5.0
TL    5.0
SI 100.0    100.0    100.0    100.0    100.0
SI 200.0    200.0    200.0    200.0    200.0
SI 200.0    200.0    200.0    200.0    200.0
SI 200.0    200.0    200.0    200.0    200.0
SI 300.0    300.0    300.0    300.0    300.0
```

SEDIMENT TRANSPORT OPTION RECORD

RECORD SO—REQUIRED

This record activates sediment transport computations. These computations are carried out at each time step with the computed hydraulic parameters.

Field	Variable	Value	Description
0	ID	SO	Record Identification.
1	-	-	Not used.
2-5	SEDOPT	SEDIMENT TRANSPORT REQUESTED	Activate sediment transport equations.
		NO SEDIMENT TRANSPORT	Do not use sediment transport equations.

Example:

```
SQ  950. 2280.60
SQ  800. 2280.25
SO      SEDIMENT TRANSPORT IS REQUESTED
QS  15.0     0.0
SE   1.0
TM  15.0    70.0
```

SEDIMENT TRANSPORT EQUATION PARAMETERS RECORD

RECORD SP—OPTIONAL

This record is used to provide the coefficients C1-C6 for the user-supplied generic sediment transport equation:

$$Q_{s,i} = C1\,(V)^{C2}\,(S_f)^{C3}\,(d)^{C4}\,(D_i)^{C5}\,(Q)^{C6}$$

in which $Q_{s,i}$ = sediment load for size group i in tons/day (by dry weight); V = velocity in ft/sec; S_f = friction slope in ft/ft; d = depth in ft; Di = geometric mean sediment size corresponding to size group i in mm; and Q = discharge in cfs. For each size group, one SP record must be supplied. This equation assumes that the given size group is the only sediment group present in the bed. **BRI-STARS** internally multiplies the load resulting from this equation by the fraction of the bed material associated with the given size group (defined in the SD records).

Through the use of SP records, different sediment equations for different size groups can be selected. Doing this, however, requires conversion of particular equations to power forms through regression analysis.

Field	Variable	Value	Description
0	ID	SP	Record Identification.
1	ISIZE	"+"	Sediment size group number i. The size group number specified in this field corresponds to the sediment size groups specified through the SG cards.
2	C1	"+"	Coefficient for the generic sediment transport equation.
3	C2	"+"	Velocity (V) exponent.
4	C3	"+"	Friction slope (S_f) exponent.
5	C4	"+/-"	Hydraulic depth (d) exponent.
6	C5	"+"	Discharge (Q) exponent.

Example:

```
SE    5.0
SP    1.0    0.1333    3.32    0.0    -1.30    -0.61    1.0
SP    2.0    0.1333    3.32    0.0    -1.30    -0.61    1.0
SP    3.0    0.1333    3.32    0.0    -1.30    -0.61    1.0
TM   15.0      70.0
SF    3.0
SG    .08       .29
SG    .29       .60
SG    .60      5.00
```

STAGE-DISCHARGE TABLE RECORD

RECORD SQ—OPTIONAL

The SQ record defines a sequence of discharges and the corresponding stage values to be used at different time steps. This option of stage and discharge tabulation is activated by both the "TABLE OF DISCHARGES" in the QQ record and the "STAGE DISCHARGE TABLE" in the SS record. The number of stage-discharge pairs is limited by the variable ITIMAX defined in the IT record. In order to use this option, the station number for which the table is given should be defined in the TL record. The number of stage discharge pairs which can be entered is limited by the users hard disk space.

Field	Variable	Value	Description
0	ID	SQ	Record Identification.
1	QQ	"+"	Discharge value (cfs).
2	STAGE	"+"	Stage value corresponding to QQ defined in field 1 (in ft).
3	DATE	IYR:IMO:IDAY (or blank)	Starting date of hydrograph step. IYR, IMO, IDAY are 2-digit integer values of year, month, and day corresponding to the start of flows at discharge Q.
4	TIME	IHR:IMIN:ISEC (or blank)	Starting time of hydrograph using 24-hour clock. IHR, IMIN, ISEC are 2-digit integer values of hour, minute, and second (optional) corresponding to the start of flow at discharge Q.
5	DT	"+"	Computational time increment for the time period specified by consecutive SQ (Date-Time) values.
		(0 or blank)	Use the time increment value specified in IT record.

Example:

```
IT  15.0      1.0  .00833
QQ        TABLE OF DISCHARGES
SS        STAGE DISCHARGE TABLE
TL  10.0
SQ 3250. 2283.50
SQ 5100. 2284.90
SQ 6800. 2286.05
SQ 7800. 2286.30
SQ 7500. 2286.40
SQ 7000. 2286.00
SQ 5300. 2284.85
SQ 4150. 2284.05
SQ 3350. 2283.30
SQ 2550. 2282.55
SQ 1950. 2281.95
SQ 1500. 2281.40
SQ 1150. 2281.05
SQ  950. 2280.60
SQ  800. 2280.25
```

STAGE RECORD

RECORD SS—REQUIRED

This record defines the stage input options at control sections. The available options use either a stage-discharge rating curve or a table of stage versus discharge values. The number of stage values is limited by the number of time iterations.

Field	Variable	Value	Description
0	ID	SS	Record Identification.
1	-	blank	Not used.
2-3	IOPTSTQ	text	Specify method of providing stage values at the boundaries.
		RATING CURVE	A stage discharge rating curve relationship in the form of: Stage = C1 (Discharge)^ C2 + C3 is provided. The values of C1, C2, and C3 are defined in the RC record. Stage is in feet and discharge is in cubic feet per second.
		STAGE DISCHARGE TABLE	Use Darcy-Weisbach equation with Darcy's friction factors.

Example:

```
QQ      TABLE OF DISCHARGES
SS      STAGE DISCHARGE TABLE
TL  10.0
SQ 3250. 2283.50
SQ 5100. 2284.90
SQ 6800. 2286.05
```

CROSS SECTION IDENTIFICATION RECORD

RECORD ST—REQUIRED

This record identifies the location of each cross section and the number of points defining the channel geometry at this location. The cross sections are entered in the downstream direction starting from the furthest upstream station.

Field	Variable	Value	Description
0	ID	ST	Record Identification.
1	STA	"+/-"	Station identification. Location of the cross section expressed in terms of distance from a downstream reference station, in feet.
2	NPTS	"+"	Number of coordinate pairs to define the geometry of the cross section at the station STA.
3	ISWITCH	0	Current station, STA, is not a control section. Water surface elevation is not given.
		1	Station STA is a control section. Water surface elevation is defined either as a given elevation or as a rating curve.
4	ITYP	"+"	Index to identify type of control.
		0	If ISWITCH is equal to 0.
		1	If ISWITCH = 1 and the channel control is a natural control.
		2	If ISWITCH = 1 and the channel control is a lake.
		3	If ISWITCH = 1 and the channel control is a weir.
		4	If ISWITCH = 1 and the channel control is a gate.
5	BEC	0	Leave the given bed elevations across the channel at station STA unchanged.
		"+/-"	Add the constant elevation BEC to the given bed elevations across the channel at station STA (in ft).
6	XSWF	1	Leave the given lateral locations of the data points across the river at station STA unchanged.
		"+"	Apply the multiplication factor XSWF to the lateral location of data points across the river at station STA.

Example:

```
ST3865.0     14.0      0.0      0.0   2000.0      1.0
ND    3.0   461.0    539.0    540.0
XS  307.5   460.0    297.5    461.0    297.5    470.0    297.5    485.0    297.5    488.0
XS  297.5   490.0    297.5    495.0    297.5    500.0    297.5    505.0    297.5    510.0
XS  297.5   515.0    297.5    530.0    297.5    539.0    307.5    540.0
```

SIZE DISTRIBUTION ACROSS CHANNEL RECORD

RECORD SX—OPTIONAL

This record is used to input sediment size distribution across channel at a given station at various ground elevation points. The number of SX records needed for a given station is determined by the number of ground points used to define the cross section at that station. User is expected to supply the exact number of SX records for each of the desired stations. For stations where such resolution is not available or not necessary, SD (Size Distribution) records can still be used. In other words, SD and SX records can be combined in the definition of the bed material along the study reach.

Field	Variable	Value	Description
0	ID	SX	Record Identification.
1-10	PNN	0 - 1.0	Bed material size fraction falling within each of the NF size groups. The PNN valued in the first field corresponds to the smallest size group given in the SG records. The number of PNN values in each SX record is determined by the variable NF (no. of size groups) in the SF record.
			The number of SX records needed for each station (cross section) is equal to the number of ground elevation points at that section.
			SX records can be used along with SD records in the same data set.

Example:

```
SF    3.0
SG 0.250    0.500
SG 0.500    1.000
SG 1.000    2.000
CM *************STATION 1 SEDIMENT SIZE DISTRIBUTION DATA*********
SB 100.0    400.0
SX  0.33     0.33     0.33
SX  0.25     0.50     0.25
CM *************STATION 2 SEDIMENT SIZE DISTRIBUTION DATA*********
SD   0.4      0.4      0.2
```

STATION IDENTIFICATION FOR STAGE-DISCHARGE TABLE RECORD

RECORD TL—OPTIONAL

This record identifies the station number for which the pairs of stage-discharge values are given using SQ records. The station number corresponding to a cross section is determined by the number of cross sections upstream from that location including the current cross section.

Field	Variable	Value	Description
0	ID	TL	Record Identification.
1	ITABLE	"+" (1 <ITABLE < NSTA)	Station number for which pairs of stage-discharge values are given. Stations are numbered starting from the upstream-most section.
2	SQMTHD	0 (or blank)	Stage-discharge pairs defined in the SQ records averaged values for the time interval specified by consecutive SQ record.
		1	Stage-discharge pair defined in the SQ record are point values measured at the time specified on each SQ record. In this method, in the time interval falling between two measurements, linear variation of stage and discharge is assumed and these interpolated values are used in simulations.
3	DTUNITS	DAYS (or blank)	Unit of computational time increments in SQ records is days.
		HOURS	Unit of computational time increments in SQ records is hours.
		MINUTES	Unit of computational time increments in SQ records is minutes.
		SECONDS	Unit of computational time increments in SQ records is seconds.

Example:

```
QQ       TABLE OF DISCHARGES
SS       STAGE DISCHARGE TABLE
TL  10.0
SQ 3250. 2283.50
SQ 5100. 2284.90
SQ 6800. 2286.05
```

WATER TEMPERATURES RECORD

RECORD TM—REQUIRED for Sediment Transport

The TM record defines water temperatures corresponding to each time iteration. These temperatures are input in tabular form with the number of time iterations occupying the first column and the corresponding temperatures, the second column. The format of the TM record is identical to DD records used in discretizing water discharge hydrograph. Therefore, if the water temperatures are given in terms of a hydrograph, TM records can be generated following the procedure outlined in Chapter 6 for discretized discharges.

Field	Variable	Value	Description
0	ID	TM	Record Identification.
1	NDAY	"+"	Number of time iterations for which water temperature is equal to TEMP value specified in field 2.
2	TEMP	"+"	Water temperature in degrees Fahrenheit.

Example:

```
SQ  950. 2280.60
SQ  800. 2280.25
SO      SEDIMENT TRANSPORT IS REQUESTED
QS  15.0      0.0
SE   1.0
TM  15.0     70.0
```

TABLE OF DISCHARGES RECORD

RECORD TQ—OPTIONAL

The TQ record defines a sequence of discharges to be used at different time steps. This option of discharge tabulation is activated by selecting both the "TABLE OF DISCHARGES" in the QQ record and the "RATING CURVE" in the SS record. The stage values corresponding to the tabulated discharges are computed using the stage-discharge function defined in the record SQ. The number of tabulated discharge values are limited by the variable ITIMAX defined in the IT record.

Field	Variable	Value	Description
0	ID	TQ	Record Identification.
1-10	QQ	"+"	Discharge values corresponding to each time step. The number of discharge values is limited to ITIMAX, defined in the IT record. In the program unlimited number of discharges as can be entered using TQ records (in cfs).

Example:

```
IT    9.0      1.0      2.0
QQ        TABLE OF DISCHARGES
SS        RATING CURVE
TQ 500.0  1600.0   2250.0   2650.0   2800.0   2250.0   1750.0   1500.0   1250.0
NC    1.0
RC   10.0      0.9      0.2  1000.0
```

TITLE RECORD

RECORD TT—REQUIRED

This record defines the title of the study. Each job is identified with three TT records inserted at the beginning of the data set. The date of the study, purpose, and the source of data should be indicated in these title records to specify the data set for future references.

Field	Variable	Value	Description
0	ID	TT	Record Identification.
1-7	TITLE	text	Data set identification should include date, source of data, and purpose of study. The titles should be centered in TT records as they are requested to appear in the computer plots and the printout.

Example:

```
TT                EXAMPLE  PROBLEM FOR THE  BRI-STARS MODEL
TT   SILVERCROFT WASH 100 YEAR FLOOD FLOWS - LATERAL WATER & SED. INFLOW
TT                JULY 1992, ALBERT MOLINAS
NS  10.0
ST4365.0    14.0     0.0     0.0  2000.0     1.0
```

WSPRO BRIDGE OPTION RECORD

RECORD WB—OPTIONAL

This record, placed following sediment data and just before pier scour data, directs BRI-STARS to use WSPRO bridge routines. The fields of this record identify the station number of the WSPRO bridge cross section and the name of the file containing the WSPRO data records for the bridge.

Field	Variable	Value	Description
0	ID	WB	Record Identification.
1	BRSTA	"+/-"	Bridge station number for which WSPRO hydraulic computations are desired.
2	BRFILE	alphanumeric	Up to 64 character name of file containing information needed to perform WSPRO hydraulic computations. The path of the file may be included as a part of the name. If the path name is not included, BRI-STARS will assume that the file is in the current directory.

Example:

```
SD 1.000
SD 1.000
SD 1.000
WB   3.0        WSPRO.DAT
PR   1.0    1.0
```

CROSS SECTION GEOMETRY RECORD

RECORD XS—REQUIRED

This record defines the channel geometry at a given station. The channel is described by pairs of lateral location and bed elevation values across the width. The data points should be entered starting from the left-hand side of the channel looking downstream and should progress towards the right-hand side.

Field	Variable	Value	Description
0	ID	RB	Record Identification.
1, 3, 5, 7, 9	BOTTOM	"+/-"	Bottom elevations of the data points defining the channel geometry across the river at station STA. Maximum number of BOTTOM values at a given station is limited to 200 (in ft).
2, 4, 6, 8, 10	CROSLOC	"+/-"	Lateral locations of the data points defining the channel geometry across the river at station STA. Maximum number of CROSLOC values at a given station is limited to 200 (in ft).

Example:

```
ST   0.0    25.0     0.0     0.0  2000.0     1.0
ND   3.0   390.0   555.0   635.0
XS 291.0     0.0   291.0   390.0   290.5   418.0   290.3   433.0   290.0   445.0
XS 287.0   455.0   284.0   465.0   281.0   475.0   278.0   485.0   278.0   490.0
XS 278.0   495.0   278.0   500.0   278.0   505.0   278.0   510.0   278.0   515.0
XS 278.0   520.0   278.0   525.0   280.0   530.0   282.0   535.0   286.0   545.0
XS 290.0   555.0   290.3   562.0   290.9   576.0   291.0   605.0   290.0   635.0
```

APPENDIX C - EXAMPLE INPUT FILES

The **BRI-STARS** package is supplied with a set of 10 examples to demonstrate the various options available in the model. The summary listing is given in table 4 with features of each example. In appendix C, printouts of input data files are provided for three of the example applications. These listings show typical format of **BRI-STARS** input files and introduce some of the commonly used records and their sequential positioning within data files.

The input files selected for listing are:

- Dry Creek, near Barren Hills example with WSPRO input
  (EXMPL002.DAT and WSPRO.DAT)

- Colorado State University Hydraulics Laboratory study of Schoharie Creek bridge pier scour
  (EXMPL005.DAT)

- Lower Tornillo Creek, Big Bend National Park, Texas
  (EXMPL006.DAT)

C.1 DRY CREEK, NEAR BARREN HILLS EXAMPLE WITH WSPRO INPUT (EXMPL002.DAT and WSPRO.DAT)

Main **BRI-STARS** data file for Dry Creek near Barren Hills (EXMPL002.DAT):

```
TT      DRY CREEK NEW BARREN HILLS
TT      SIMPLE BRIDGE EXAMPLE, FIXED GEOMTRY MODE
TT      ALBERT MOLINAS,  APRIL 1990
NS   5.0
*************************** STATION 1 ****************************************
ST 49000    25.0     0.0     0.0    0.50    1.00
ND   1.0   575.0
XS1106.7    0.00 1105.70    75.00 1104.80   140.00 1100.10   165.00 1096.60   185.0
XS1098.3  225.00 1097.50   235.00 1097.40   245.00 1093.70   275.00 1093.70   290.0
XS1094.4  310.00 1094.40   330.00 1097.10   345.00 1098.00   350.00 1097.50   370.0
XS1096.9  390.00 1095.80   405.00 1095.80   435.00 1094.50   450.00 1094.00   465.0
XS1097.1  485.00 1099.20   490.00 1100.00   515.00 1102.00   550.00 1109.00   575.0
*************************** STATION 2 (APPROACH) ***************************
ST 48100    25.0     0.0     0.0    0.00    1.00
ND   1.0   575.0
XS1106.7    0.00 1105.70    75.00 1104.80   140.00 1100.10   165.00 1096.60   185.0
XS1098.3  225.00 1097.50   235.00 1097.40   245.00 1093.70   275.00 1093.70   290.0
XS1094.4  310.00 1094.40   330.00 1097.10   345.00 1098.00   350.00 1097.50   370.0
XS1096.9  390.00 1095.80   405.00 1095.80   435.00 1094.50   450.00 1094.00   465.0
XS1097.1  485.00 1099.20   490.00 1100.00   515.00 1102.00   550.00 1109.00   575.0
*************************** STATION 3 (BRIDGE) ***************************
ST 47900     9.0     0.0     0.0    0.00    1.00
ND   1.0   137.01
XS1108.3    0.00 1105.50     0.00 1099.20    16.00 1093.10    50.00 1093.30    68.0
XS1093.5   95.00 1097.10   117.00 1104.30   137.00 1106.90   137.00
*************************** STATION 4 (EXIT) ***************************
ST 47750    26.0     0.0     0.0    0.00    1.00
ND   1.0   549.0
XS1107.6    0.00 1105.90    70.00 1104.50   145.00 1099.50   161.00 1096.40   187.0
XS1098.1  223.00 1097.50   233.00 1097.10   243.00 1094.60   258.00 1093.60   273.0
XS1093.6  288.00 1094.20   308.00 1094.40   328.00 1096.90   344.00 1097.80   350.0
XS1097.3  367.00 1096.70   390.00 1095.60   407.00 1095.60   433.00 1094.30   447.0
XS1093.8  465.00 1096.90   486.00 1099.00   489.00 1099.50   515.00 1102.00   549.0
XS1108.0  567.00
*************************** STATION 5 ***************************************
ST 47500    26.0     1.0     1.0    0.00    1.00
ND   1.0   567.0
XS1107.6    0.00 1105.90    70.00 1104.50   145.00 1099.50   161.00 1096.40   187.0
XS1098.1  223.00 1097.50   233.00 1097.10   243.00 1094.60   258.00 1093.60   273.0
XS1093.6  288.00 1094.20   308.00 1094.40   328.00 1096.90   344.00 1097.80   350.0
XS1097.3  367.00 1096.70   390.00 1095.60   407.00 1095.60   433.00 1094.30   447.0
XS1093.8  465.00 1096.90   486.00 1099.00   489.00 1099.50   515.00 1102.00   549.0
XS1108.0  567.00
*************************** ROUGHNESS DATA ***************************
RE      MANNING
*************************** STATION 1 ****************************************
RH0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.040
RH0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.040
RH0.0400  0.0400  0.0400  0.0400  0.0400
*************************** STATION 2 (APPROACH) ***************************
RH0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.040
RH0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.040
RH0.0400  0.0400  0.0400  0.0400  0.0400
*************************** STATION 3 (BRIDGE) ***************************
RH0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400
*************************** STATION 4 (EXIT) ***************************
RH0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.0400  0.040
```

```
RH0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.040
RH0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
************************* STATION 5 *****************************************
RH0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.040
RH0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.040
RH0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
******************** COEFFICIENTS OF LOSSES DATA **************************
CL0.0000   0.0000   1.2000   0.0000   0.0000
CB       THALWEG
NT   3.0
IT   16.0      1.0 0.10000
QQ       TABLES OF DISCHARGES
SS       STAGE-DISCHARGE TABLE
TL   5.0
**************************DISCHARGE-STAGE DATA PAIRS **********************
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
SQ   52001104.400
***************************** SEDIMENT ROUTING DATA ************************
SO       SEDIMENT TRANSPORT IS REQUESTED
QS   16.0      0.00
SE   1.0
TM   16.0     60.00
SF   1.0
SG 0.300    0.500
SD 1.000
SD 1.000
SD 1.000
SD 1.000
SD 1.000
***************************** WSPRO INTERFACE DATA ************************
WB   3.0          WSPRO.DAT
***************************** PRINTOUT AND PLOTTING DATA ******************
PR   1.0      1.0
PV   2.0      0.0      0.0      0.0      0.0      0.0      1.0      5.0      2.0     10.0
PV   3.0      0.0      0.0      0.0      0.0      0.0      1.0      5.0      2.0     10.0
PV   4.0      0.0      0.0      0.0      0.0      0.0      1.0      5.0      2.0     10.0
PL       PLOTTING IS REQUESTED
PX       CHANNEL CROSS SECTION PLOTS          1.0
PW       WATER SURFACE PROFILE PLOTS          1.0
MN       NO MINIMIZATION IS REQUESTED
```

WSPRO input data file (WSPRO.DAT) for the single-opening bridge in fixed-geometry mode referenced in EXMPL002.DAT, WP record:

```
T1              DRY CREEK NEAR BARREN HILLS
T2              SIMPLE BRIDGE EXAMPLE, FIXED-GEOMETRY MODE
T3              WSPRO MANUAL, P. 157  EXAMPLE NO. 2
XS 0 EXIT       47750
*               EXIT CROSS SECTION
*               GR DATA (X-Y COORDINATES) ARE DEFINED IN BRI-STARS FILE...
*               N DATA (MANNING N-VALUE) DEFINED IN BRI-STARS DATA FILE...
XS    FULLV     47900
*               FULL VALLEY
BR    BRIDG     47900   1118.3      30
*                SRD      LSEL      SKEW  (HEADINGS FOR BR RECORD)
*               BRIDGE SECTION (FIXED-GEOMETRY MODE)
*               GR RECORDS ARE DEFINED IN BRI-STARS FILE...
*               PIER DATA  - ELEV, WIDTH PAIRS
PW 1            1094,2.3   1105.3,2.3     1105.3,6     1118.3,6
*
*               BRTYPE    BRWDTH    EMBSS    EMBELV
CD                2        60.4      1.0     1121.5
*
*               ABUTMENT TOE ELEVATIONS (TYPE 2 ONLY)
AB               *   *    1105.5    1104.3
*               ------------------------------------------------------------
AS    APPRO     48100
*               APPROACH SECTION
*               GR DATA SPECIFIED IN BRI-STARS DATA FILE...
BP              225.
```

C.2 CSU HYDRAULICS LABORATORY STUDY OF SCHOHARIE CREEK BRIDGE PIER SCOUR (EXMPL005.DAT)

```
TT        SCHOHARIE CREEK PHYSICAL MODEL PIER SCOUR EXPERIMENTS AT CSU
TT        16 CFS RUN IN 8-FT WIDE EXPERIMENTAL FLUME.  SLOPE=0.055 %
TT        C. SANTORO AND A. MOLINAS (COMMENT RECS AND SCREEN PLOTTING)
CM*********************************************************************************
NS   9.0
CM*************************** 1ST STATION ******************************************
ST  41.0    19.0     0.0      0.0  100.00    1.00
ND   1.0     8.0
XS  10.0    0.00   0.0316    0.01  0.0316    0.50   0.0316    1.00   0.0316    1.50
XS0.0316    2.00   0.0316    2.50  0.0316    3.00   0.0316    3.50   0.0316    4.00
XS0.0316    4.50   0.0316    5.00  0.0316    5.50   0.0316    6.00   0.0316    6.50
XS0.0316    7.00   0.0316    7.50  0.0316    7.99  10.00      8.00
CM*************************** 2ND STATION ******************************************
ST  34.0    19.0     0.0      0.0  99.9961    1.00
ND   1.0     8.0
XS  10.0    0.00   0.0316    0.01  0.0316    0.50   0.0316    1.00   0.0316    1.50
XS0.0316    2.00   0.0316    2.50  0.0316    3.00   0.0316    3.50   0.0316    4.00
XS0.0316    4.50   0.0316    5.00  0.0316    5.50   0.0316    6.00   0.0316    6.50
XS0.0316    7.00   0.0316    7.50  0.0316    7.99  10.00      8.00
CM*************************** 3RD STATION ******************************************
ST  26.0    19.0     0.0      0.0  99.9918    1.00
ND   1.0     8.0
XS  10.0    0.00   0.0316    0.01  0.0316    0.50   0.0316    1.00   0.0316    1.50
XS0.0316    2.00   0.0316    2.50  0.0316    3.00   0.0316    3.50   0.0316    4.00
XS0.0316    4.50   0.0316    5.00  0.0316    5.50   0.0316    6.00   0.0316    6.50
XS0.0316    7.00   0.0316    7.50  0.0316    7.99  10.00      8.00
CM*************************** 4TH STATION ******************************************
ST  24.0    19.0     0.0      0.0  99.9907    1.00
ND   1.0     8.0
XS  10.0    0.00   0.0316    0.01  0.0316    0.50   0.0316    1.00   0.0316    1.50
XS0.0316    2.00   0.0316    2.50  0.0316    3.00   0.0316    3.50   0.0316    4.00
XS0.0316    4.50   0.0316    5.00  0.0316    5.50   0.0316    6.00   0.0316    6.50
XS0.0316    7.00   0.0316    7.50  0.0316    7.99  10.00      8.00
CM*************************** 5TH STATION ******************************************
ST  22.0    22.0     0.0      0.0  100.00    1.00
ND   1.0     8.0
XS  10.0    0.00   0.0212    0.01  0.0212    0.50   0.0212    1.00   0.0212    1.50
XS0.0212    2.00   0.0212    2.50  0.0212    3.00   0.0212    3.35   0.0212    3.68
XS  10.0    3.69   10.00     4.27  0.0212    4.28   0.0212    4.65   0.0212    5.00
XS0.0212    5.50   0.0212    6.00  0.0212    6.50   0.0212    7.00   0.0212    7.50
XS0.0212    7.99   10.00     8.00
CM*************************** 6TH STATION ******************************************
ST  20.0    22.0     0.0      0.0  99.9989    1.00
ND   1.0     8.0
XS  10.0    0.00   0.0212    0.01  0.0212    0.50   0.0212    1.00   0.0212    1.50
XS0.0212    2.00   0.0212    2.50  0.0212    3.00   0.0212    3.35   0.0212    3.68
XS  10.0    3.69   10.00     4.27  0.0212    4.28   0.0212    4.65   0.0212    5.00
XS0.0212    5.50   0.0212    6.00  0.0212    6.50   0.0212    7.00   0.0212    7.50
XS0.0212    7.99   10.00     8.00
CM*************************** 7TH STATION ******************************************
ST  19.0    22.0     0.0      0.0  99.9981    1.00
ND   1.0     8.0
XS  10.0    0.00   0.0212    0.01  0.0212    0.50   0.0212    1.00   0.0212    1.50
XS0.0212    2.00   0.0212    2.50  0.0212    3.00   0.0212    3.35   0.0212    3.68
XS  10.0    3.69   10.00     4.27  0.0212    4.28   0.0212    4.65   0.0212    5.00
XS0.0212    5.50   0.0212    6.00  0.0212    6.50   0.0212    7.00   0.0212    7.50
XS0.0212    7.99   10.00     8.00
CM*************************** 8TH STATION ******************************************
ST  17.0    19.0     0.0      0.0  99.9869    1.00
ND   1.0     8.0
XS  10.0    0.00   0.0316    0.01  0.0316    0.50   0.0316    1.00   0.0316    1.50
```

```
XS0.0316    2.00   0.0316    2.50   0.0316    3.00   0.0316    3.50   0.0316    4.00
XS0.0316    4.50   0.0316    5.00   0.0316    5.50   0.0316    6.00   0.0316    6.50
XS0.0316    7.00   0.0316    7.50   0.0316    7.99   10.00    8.00
CM****************************** 9TH STATION ************************************
ST   0.0     19.0     1.0      1.0  99.9774    1.00
ND   1.0      8.0
XS  10.0     0.00   0.0316    0.01   0.0316    0.50   0.0316    1.00   0.0316    1.50
XS0.0316    2.00   0.0316    2.50   0.0316    3.00   0.0316    3.50   0.0316    4.00
XS0.0316    4.50   0.0316    5.00   0.0316    5.50   0.0316    6.00   0.0316    6.50
XS0.0316    7.00   0.0316    7.50   0.0316    7.99   10.00    8.00
RE       MANNING
CM****************************** 1ST STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
CM****************************** 2ND STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
CM****************************** 3RD STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
CM****************************** 4TH STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
CM****************************** 5TH STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200
CM****************************** 6TH STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200
CM****************************** 7TH STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200
CM****************************** 8TH STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0400   0.0400   0.0400   0.0400
RH0.0400   0.0400   0.0400   0.0400   0.0200   0.0200   0.0200   0.0200   0.0200
CM****************************** 9TH STATION ************************************
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
RH0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200   0.0200
CM****************************** LOSS COEFFS ************************************
CL   0.0      0.0      0.0      1.0      0.0      0.0      0.0      0.0      0.0
CB       THALWEG
NT   4.0
IT  48.0      1.0   0.0069   0.0001     20.0
QQ       TABLE OF DISCHARGES
SS       STAGE DISCHARGE TABLE
TL   9.0
CM********************** DISCHARGE-STAGE DATA PAIRS **********************
SQ    4.0 100.419
SQ    8.0 100.649
SQ   12.0 100.839
SQ   16.0 100.949
SQ   16.0 100.949
SQ   16.0 100.949
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SQ  16.0 100.949
SQ  16.0 100.949
CM*****************************SEDIMENT ROUTING DATA****************************
SO        SEDIMENT TRANSPORT REQUESTED
QS  48.0      0.
SE   1.0     10.
TM  48.0     70.
SF   6.0
SG0.0625  0.5000
SG0.5000  1.0000
SG1.0000  2.0000
SG2.0000  4.0000
SG4.0000  6.0000
SG6.0000 16.0000
SD 0.000    0.000    0.172   0.510   0.248    0.07
SD 0.000    0.000    0.172   0.510   0.248    0.07
SD 0.075    0.049    0.097   0.461   0.248    0.07
SD 0.075    0.049    0.097   0.461   0.248    0.07
SD 0.075    0.049    0.097   0.461   0.248    0.07
SD 0.075    0.049    0.097   0.461   0.248    0.07
SD 0.075    0.049    0.097   0.461   0.248    0.07
SD 0.075    0.049    0.097   0.461   0.248    0.07
SD 0.075    0.049    0.097   0.461   0.248    0.07
CM
CM************************PRINTOUT AND PLOTTING DATA***********************
CM
PR   0.0    24.0     1.0    48.0
***************************************************************************
CM  STA    XMIN.    XMX    YMN    YMX    IVIDEO   UPSTR   DWNSTR  WTR LINE VMAX
***************************************************************************
PV   4.0     0.1     7.9   99.70  100.20   0.0     1.0     9.0     2.0     3.0
PV   6.0     0.1     7.9   99.70  100.20   0.0     1.0     9.0     2.0     3.0
PV   8.0     0.1     7.9   99.70  100.20   0.0     1.0     9.0     2.0     3.0
PL     PLOTTING IS REQUESTED
PX     CHANNEL CROSS SECTION PLOTS            4.0     1.0    48.0
PW     WATER SURFACE PROFILE PLOTS            1.0     1.0    48.0
MN     NO MINIMIZATION REQUESTED
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C.3 LOWER TORNILLO CREEK, BIG BEND NATIONAL PARK, TEXAS (EXMPL006.DAT)

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T1              LOWER TORNILLO CREEK - BIG BEND NATIONAL PARK, TEXAS
T2                X-SECTIONS INPUT FROM UPSTREAM TO DOWNSTREAM
T3                   PROVIDED BY DR. LARRY ARNESON, FHWA
NS  29.0
ST 19430     22     0.0     0.0     0.0     1.0
ND   1.0   2397
XS  2070    1.0   2060     36   2058     40   2056    123   2056    257
XS  2054    311   2054    500   2054    691   2054    900   2054   1100
XS  2054   1300   2054   1440   2054   1583   2052   1597   2052   1812
XS  2052   2027   2050   2033   2050   2100   2050   2243   2050   2385
XS  2060   2391   2070   2397
ST 18750     18     0.0     0.0     0.0     1.0
ND   1.0   2496
XS  2060    1.0   2056    212   2054    330   2052    426   2050    530
XS  2050    650   2050    850   2050   1074   2048   1318   2046   1346
XS  2046   1500   2046   1688   2044   1752   2044   2000   2044   2200
XS  2044   2448   2050   2478   2060   2496
ST 18100     19     0.0     0.0     0.0     1.0
ND   1.0   2250
XS  2050    1.0   2048     94   2046    160   2044    280   2044    500
XS  2044    718   2042    744   2040    762   2040    940   2038    954
XS  2038   1100   2038   1300   2038   1506   2040   1614   2040   1800
XS  2040   2086   2042   2110   2044   2170   2050   2250
ST 17470     23     0.0     0.0     0.0     1.0
ND   1.0   2454
XS  2050    1.0   2040     24   2036     44   2036     84   2034    288
XS  2032    370   2032    500   2032    600   2032    750   2032    854
XS  2034    908   2034   1100   2034   1300   2034   1469   2034   1638
XS  2036   1648   2038   1796   2040   1894   2042   1988   2044   2080
XS  2046   2196   2048   2324   2050   2454
ST 16870     22     0.0     0.0     0.0     1.0
ND   1.0   2042
XS  2040    1.0   2032     24   2030     76   2028    172   2028    210
XS  2026    218   2026    400   2026    600   2026    816   2028    912
XS  2028   1100   2028   1300   2028   1400   2028   1520   2030   1556
XS  2030   1672   2030   1788   2032   1818   2034   1898   2036   1952
XS  2038   2024   2040   2042
ST 16200     23     0.0     0.0     0.0     1.0
ND   1.0   1890
XS  2032    1.0   2030      2   2022     16   2022     88   2020     94
XS  2020    100   2020    200   2020    300   2020    406   2022    470
XS  2022    600   2022    700   2022    800   2022    964   2024    970
XS2024.3   1100 2024.86   1300 2025.5   1546   2024   1606   2026   1714
XS  2028   1770   2030   1856   2032   1890
ST 15480     17     0.0     0.0     0.0     1.0
ND   1.0   1758
XS  2030    1.0   2020      8   2014     16   2014    150   2014    320
XS  2016    328   2016    500   2016    664   2018    732   2018    800
XS  2018    900   2018   1100   2018   1324 2019.2   1550   2020   1696
XS  2022   1732   2030   1758
ST 14750     25     0.0     0.0     0.0     1.0
ND   1.0   1732
XS  2020    1.0   2018     14   2016     52 2015.2     96   2014    190
XS  2008    220   2008    379   2008    538   2008    642   2008    746
XS  2010    756   2010    866   2008    872   2008   1008   2010   1100
XS  2010   1208   2010   1320   2010   1398   2010   1498   2012   1538
XS  2012   1618   2014   1674   2016   1718   2018   1728   2020   1732
ST 13910     18     0.0     0.0     0.0     1.0
ND   1.0   1572
XS  2014    1.0   2012     58   2010     70   2002    108   2002    300
XS  2002    500   2002    680   2002    818   2000    870   2000   1000
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XS    2000    1142    2002    1170    2002    1321    2002    1472    2004    1520
XS    2006    1548    2008    1558    2014    1572
ST   13310      15     0.0     0.0     0.0     1.0
ND    1.0     1388
XS    2010     1.0    2000      54    1996      72 1995.94     200 1995.86     400
XS1995.8       600  1995.7     758  1995.8     900    1996    1046    1994    1136
XS1994.1      1258    1996  1258.2    2000    1298    2002    1338    2010    1388
ST   12740      25     0.0     0.0     0.0     1.0
ND    1.0     2602
XS    2010     1.0    2000      42 1999.32     200 1998.48     400 1997.62     600
XS1996.6       800  1995.5    1000 1995.07    1200 1994.54    1326    1994    1452
XS    1990    1538    1990    1712    1990    1726    1990    1776    1990    1798
XS    1990    1858    1992    1864    1992    1918    1990    1924    1990    2062
XS    1990    2200    1990    2357    1990    2514    2000    2528    2010    2602
ST   12010      13     0.0     0.0     0.0     1.0
ND    1.0     1426
XS    2000     1.0    1990      14    1988      18    1986      38    1984      58
XS    1984     200    1984     400    1984     600    1984     800    1984    1000
XS    1984    1236    1990    1252    2000    1426
ST   11410      17     0.0     0.0     0.0     1.0
ND    1.0     1608
XS    2000     1.0    1990      26    1982      60    1980     170    1980     264
XS    1978     268    1978     350    1978     500    1978     700    1978     900
XS    1978    1000    1978    1186    1980    1196    1980    1350    1980    1510
XS    1990    1568    2000    1608
ST   10640      17     0.0     0.0     0.0     1.0
ND    1.0     1372
XS    1990     1.0    1980      18    1970      32    1970     200    1970     400
XS    1970     521    1970     642    1972     666    1972     800    1972     994
XS    1974    1068    1974    1166    1974    1264    1972    1298    1972    1356
XS    1980    1362    1990    1372
ST   10050      16     0.0     0.0     0.0     1.0
ND    1.0     1034
XS    1980     1.0    1970       8    1968      14    1966      18    1966     150
XS    1966     278  1966.9     464    1968     528    1968     685    1968   763.5
XS    1968     842    1966     878    1966     962    1968     966    1970     994
XS    1980    1034
ST    9340      17     0.0     0.0     0.0     1.0
ND    1.0     1026
XS    1980     1.0    1970      20    1964      40    1964      98    1962     128
XS    1960     164    1960     282    1960     400    1960     592    1958     666
XS    1958     722    1960     796    1960     856    1962     866    1962     958
XS    1964     996    1980    1026
ST    8720      15     0.0     0.0     0.0     1.0
ND    1.0     1154
XS    1966     1.0    1964      82    1962     188  1961.3     322    1960     402
XS    1958     434    1956     446    1954     486    1954     596    1955     770
XS    1954     936    1952     982    1952    1062    1954    1068    1966    1154
ST    8170      18     0.0     0.0     0.0     1.0
ND    1.0     1218
XS    1960     1.0    1956     100    1954     214    1952     406    1950     506
XS    1948     514    1948     550    1950     612    1950     700    1950     826
XS    1948     840    1948     979    1948    1118    1950    1124    1956    1138
XS    1956    1180    1958    1212    1960    1218
ST    7350      16     0.0     0.0     0.0     1.0
ND    1.0     1460
XS    1960     1.0    1950     116    1948     150    1946     164    1944     180
XS    1944     204    1944     372    1942     378    1942     490    1942     600
XS    1942     800    1942    1000    1942    1200    1942    1412    1950    1426
XS    1960    1460
ST    6550      19     0.0     0.0     0.0     1.0
ND    1.0     1650
XS    1950     1.0    1940      20    1938      26    1938     173    1938     320
XS    1936     330    1934     338    1934     450    1936     566    1936     700
XS    1936     900    1936    1100    1936    1330    1938    1334    1938    1410
XS    1938    1606    1940    1616    1942    1634    1950    1650
ST    5930      20     0.0     0.0     0.0     1.0
```

ND	1.0	2024							
XS	1950	1.0	1940	26	1934	56	1932	112	1931.56	200
XS1930.6	400	1930	516	1930	658	1930	800	1930	1000
XS	1930	1200	1930	1400	1930	1642	1932	1648	1934	1704
XS	1936	1720	1936	1848	1938	1958	1940	2006	1950	2024
ST	5160	21	0.0	0.0	0.0	1.0			
ND	1.0	1840							
XS	1940	1.0	1930	10	1924	26	1922	48	1922	200
XS	1922	400	1922	560	1922	720	1922	778	1922	842
XS	1922	1014	1922	1086	1922	1162	1922	1222	1924	1282
XS	1926	1292	1928	1402	1930	1584	1932	1658	1934	1718
XS	1936	1840							
ST	4490	18	0.0	0.0	0.0	1.0			
ND	1.0	2288							
XS	1930	1.0	1920	26	1916	32	1916	196	1916	270
XS	1916	318	1916	534	1916	750	1918	762	1918	916
XS	1920	976	1920	1088	1920	1200	1920	1400	1920	1600
XS	1920	1800	1920	2036	1930	2288			
ST	3850	17	0.0	0.0	0.0	1.0			
ND	1.0	2170							
XS	1920	1.0	1910	18	1910	200	1910	343	1910	486
XS1910.2	600	1910.6	800	1911	1036	1912	1048	1912	1200
XS	1912	1381	1912	1562	1914	1698	1914.8	1828	1916	1966
XS	1918	2074	1918.2	2170					
ST	3110	17	0.0	0.0	0.0	1.0			
ND	1.0	2030							
XS	1916	1.0	1910	8	1904	14	1904	200	1904	400
XS	1904	554	1906	562	1906	850	1906	985	1906	1120
XS	1908	1196	1909	1308	1910	1420	1912	1580	1913	1713
XS	1914	1846	1916	2030					
ST	2200	20	0.0	0.0	0.0	1.0			
ND	1.0	1996							
XS	1908	1.0	1900	30	1898	36	1896	40	1896	200
XS	1896	400	1896	600	1896	768	1898	772	1898	900
XS	1898	1026	1900	1036	1900	1068	1900	1144	1902	1270
XS	1903	1417	1904	1564	1905	1671	1906	1778	1908	1996
ST	1520	17	0.0	0.0	0.0	1.0			
ND	1.0	2184							
XS	1900	1.0	1890	14	1890	200	1890	400	1890	600
XS	1890	752	1892	768	1892	900	1892	1072	1894	1126
XS	1894	1300	1894	1468	1894	1556	1894.5	1744	1896	1930
XS	1898	2028	1900	2184					
ST	500	18	0.0	0.0	0.0	1.0			
ND	1.0	2044							
XS	1894	1.0	1890	18	1884	34	1882	108	1882	200
XS	1882	400	1882	600	1882	800	1882	978	1884	990
XS	1884	1100	1884	1316	1886	1364	1886	1560	1888	1666
XS	1890	1846	1892	1952	1894	2044			
ST	1.0	17	1.0	1.0	0.0	1.0			
ND	1.0	2226							
XS	1890	1.0	1880	8	1878	14	1878	100	1878	300
XS	1878	500	1878	700	1878	900	1878	928	1880	942
XS	1880	1150	1880	1384	1882	1458	1884	1626	1886	1626.1
XS	1888	2062	1890	2226					
RE	MANNING								
RH	.050	.050	.050	.050	.050	.050	.050	.050	.050	.050
RH	.050	.050	.050	.050	.050	.050	.032	.032	.032	.032
RH	.050	.050							
RH	.050	.050	.050	.050	.050	.050	.050	.050	.050	.050
RH	.050	.050	.032	.032	.032	.032	.050	.050		
RH	.050	.050	.050	.050	.050	.050	.050	.032	.032	.032
RH	.032	.032	.032	.032	.032	.032	.050	.050	.050	
RH	.050	.050	.050	.050	.032	.032	.032	.032	.032	.032
RH	.032	.032	.032	.032	.032	.050	.050	.050	.050	.050
RH	.050	.050	.050						
RH	.050	.050	.050	.032	.032	.032	.032	.032	.032	.032

RH	.032	.032	.032	.032	.050	.050	.050	.050	.050	.050
RH	.050	.050								
RH	.050	.050	.050	.032	.032	.032	.032	.032	.032	.032
RH	.032	.032	.032	.032	.050	.050	.050	.050	.050	.050
RH	.050	.050	.050							
RH	.050	.050	.032	.032	.032	.050	.050	.050	.050	.050
RH	.050	.050	.050	.050	.050	.050	.050			
RH	.050	.050	.050	.050	.050	.032	.032	.032	.032	.032
RH	.050	.050	.050	.050	.050	.050	.050	.050	.050	
RH	.050	.050	.050	.050	.050					
RH	.050	.050	.050	.032	.032	.032	.032	.032	.032	.032
RH	.032	.032	.050	.050	.050	.050	.050	.050		
RH	.050	.050	.032	.032	.032	.032	.032	.032	.032	.032
RH	.032	.032	.050	.050	.050					
RH	.050	.050	.050	.050	.050	.050	.050	.050	.050	.032
RH	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032
RH	.032	.032	.032	.050	.050					
RH	.050	.050	.050	.050	.032	.032	.032	.032	.032	.032
RH	.032	.050	.050							
RH	.050	.050	.050	.050	.050	.032	.032	.032	.032	.032
RH	.032	.032	.050	.050	.050	.050	.050			
RH	.050	.050	.032	.032	.032	.032	.032	.050	.050	.050
RH	.050	.050	.050	.050	.050	.050	.050			
RH	.050	.050	.050	.032	.032	.032	.050	.050	.050	.050
RH	.050	.050	.050	.050	.050	.050				
RH	.050	.050	.050	.050	.050	.032	.032	.032	.032	.032
RH	.032	.032	.032	.050	.050	.050	.050			
RH	.050	.050	.050	.050	.050	.050	.050	.032	.032	.032
RH	.032	.032	.032	.032	.050					
RH	.050	.050	.050	.050	.050	.032	.032	.032	.032	.032
RH	.032	.032	.032	.050	.050	.050	.050	.050		
RH	.050	.050	.050	.050	.050	.050	.050	.032	.032	.032
RH	.032	.032	.032	.032	.050	.050				
RH	.050	.050	.050	.050	.050	.032	.032	.032	.032	.032
RH	.032	.032	.032	.050	.050	.050	.050	.050	.050	
RH	.050	.050	.050	.050	.050	.050	.032	.032	.032	.032
RH	.032	.032	.032	.050	.050	.050	.050	.050	.050	.050
RH	.050	.050	.050	.032	.032	.032	.032	.032	.032	.032
RH	.032	.032	.032	.032	.050	.050	.050	.050	.050	.050
RH	.050									
RH	.050	.050	.032	.032	.032	.032	.032	.032	.050	.050
RH	.050	.050	.050	.050	.050	.050	.050	.050		
RH	.050	.032	.032	.032	.032	.050	.050	.050	.050	.050
RH	.050	.050	.050	.050	.050	.050	.050			
RH	.050	.050	.032	.032	.032	.032	.050	.050	.050	.050
RH	.050	.050	.050	.050	.050	.050	.050			
RH	.050	.050	.032	.032	.032	.032	.032	.032	.032	.050
RH	.050	.050	.050	.050	.050	.050	.050	.050	.050	.050
RH	.050	.032	.032	.032	.032	.032	.050	.050	.050	.050
RH	.050	.050	.050	.050	.050	.050	.050			
RH	.050	.050	.032	.032	.032	.032	.032	.032	.032	.032
RH	.050	.050	.050	.050	.050	.050	.050	.050		
RH	.050	.032	.032	.032	.032	.032	.032	.032	.032	.032
RH	.050	.050	.050	.050	.050	.050	.050			
CL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL	0..0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
CB	THALWEG									
NT	3.0									
IT	60.0		1.0	.004167						
QQ	TABLE OF DISCHARGES									
SS	STAGE DISCHARGE TABLE									
TL	29.0									
SQ	7000	1879.40								
SQ	7000	1879.40								
SQ	7000	1879.40								
SQ	7000	1879.40								

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SQ   7000 1885.40
SQ   7000 1885.40
SQ   7000 1885.40
SQ   7000 1885.40
SO         SEDIMENT TRANSPORT REQUESTED
QS  60.0      0.0
SE   1.0     10.0
TM  60.0     72.0
SF   8.0
SG  .075     .200
SG  .200     .500
SG  .500    1.00
SG  1.00    2.00
SG  2.00    5.00
SG  5.00   10.00
```

```
SG 10.00   30.00
SG 30.00   80.00
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
SD    .14      .22      .16      .15      .08      .08      .08      .09
PR   0.0     15.0      1.0     60.0
PV   2.0      0.0      0.0      0.0      0.0      0.0
PV   4.0      0.0      0.0      0.0      0.0      0.0
PV  11.0      0.0      0.0      0.0      0.0      0.0
PL       PLOTTING IS REQUESTED
PX       CHANNEL CROSS SECTION PLOTS              15.
PW       WATER SURFACE PROFILE PLOTS               1.
MN       NO MINIMIZATION REQUESTED
```

APPENDIX D - BRI-STARS SIMULATION OF CALIFORNIA I5 BRIDGE SITE

The California I5 Bridge site is located at the Los Gatos Creek study reach downstream from I-5. Severe scouring happened in this study reach during the flood on March 11, 1995. This study aims at estimating the contraction scour at the California I5 bridge site during the flood by applying **BRI-STARS** with limited available data. Figure 48 is the plan view of the study reach. The locations of the eight cross sections and the high water edges measured by U.S. Geological Survey (USGS) on March 20 and 21, 1995, are shown in this figure.

D.1 SELECTION OF SIMULATION DATA

The data needed for the numerical simulation of the study reach can be classified into the following categories: i) channel geometry data, ii) roughness and energy losses data, iii) hydrology data, and iv) sediment data.

The available channel geometry data are the channel cross sectional data measured after the flood on March 20 and 21, 1995. There are four measured cross sections (USGS sections nos. 9, 8, 7, and 6) at upstream of the bridge and four measured cross sections (USGS sections nos. 3, 2, 1.5, and 1) at the downstream of the bridge. Locations of the measured cross sections are shown in figure 48. The cross section profiles of these measured sections are plotted in figures 49-56. It is assumed that these cross sections represent the boundary conditions before the flood. There are no cross sections measured at the bridge location. Two cross sections are generated for the bridge contraction using USGS sections nos. 6 and 3 and the plan view (figure 48) of the reach. These two generated cross sections are shown in figures 57-58.

Figure 59 is the plan view of the location of cross sections used for simulation. In this figure, cross sections nos. 12 and 13 are the two cross sections generated for the bridge location; cross sections nos. 1-3 and 20-21 are propagated cross sections extending the existing bottom slope using sections nos. 4 and 19 (USGS sections nos. 9 and 1), respectively. Sections 5, 7-8, 10, 15, and 18 are cross sections interpolated using the corresponding upstream and downstream measured sections. These cross sections are also listed in table 29.

The available hydrology data is the hydrography measured at D.W.R. Station, Los Gatos Creek at Eldorado Avenue, shown in figure 60, and the high water surface elevation shown in figure 61. From figure 60, it can be seen that the time duration of the flood that occurred in March 11, 1995, was about one day. The average peak flow discharge is about 20,000 cfs (cubic feet per second) according to the estimation of J. Sterling Jones (Federal Highway Administration). From figure 61, it can be seen that the high water surface elevation at station no. 19 (USGS station no. 1) is about 450.5 feet. The water surface elevation at downstream control station no. 1, which is 1000 feet downstream from section 19 (USGS station no. 1), was determined to be 448.5 feet.

There are no available roughness and energy losses data. The Manning roughness values in the main channel of the reach are about 0.04, according to J. Sterling Jones' estimation. The local energy loss coefficients at bridge location are calibrated according to the high water surface shown in figure 61.

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The bed material size was determined to be 0.2-0.3 millimeters, according to J. Sterling Jones. The inflowing sediment discharge into the study reach was determined to be 300,000 tons per day (6,000 parts per million) through calibration.

Table 29. Measured, interpolated, and propagated cross sections.

Cross Section No.	Distance along the Channel (ft)	USGS Measured Section	Interpolated or Propagated Section
1	3600.0		Propagated
2	3200.0		Propagated
3	2800.0		Propagated
4	2398.5	SEC-9	
5	2187.0		Interpolated
6	1976.5	SEC-8	
7	1740.0		Interpolated
8	1502.0		Interpolated
9	1265.5	SEC-7	
10	1098.0		Interpolated
11	932.4		Interpolated
12	830.5		Interpolated
13	675.5		Interpolated
14	543.0	SEC-3	
15	412.0		Interpolated
16	281.5	SEC-2	
17	221.2	SEC-1.5	
18	110.2		Interpolated
19	0.0	SEC-1	
20	-5000.0		Propagated
21	-1000.0		Propagated

D.2   NUMERICAL SIMULATION

An input data file is generated according to the information discussed above. The listing of this data file is given in section D.3. In the simulation, a total of 21 cross sections, including 8 USGS measured sections, 2 bridge sections, and 11 interpolated and propagated sections, are used. The number of discretized stage-discharge values is 144, and the time increment is 0.00694 day (10 minutes). For the sediment routing, the Molinas and Wu formula is used to compute the sediment transport rates. The model output is given in section D.4 and computed water surface and bottom profiles at time steps 1, 48, 96, and 144 are plotted in figure 62. In this figure, the variations of water surface and bottom profiles versus time are shown.

Simulation results by **BRI-STARS** indicate severe scouring due to bridge contraction for the simulated flooding event. Upstream from the bridge, sediment is deposited at the initial phase of the flooding due to the blockage of flows by the contracted bridge opening. This deposition is reduced with the progress of time and finally is reverted to scouring. Maximum scour occurs at the bridge location; the maximum simulated scour depth is about 9 feet.
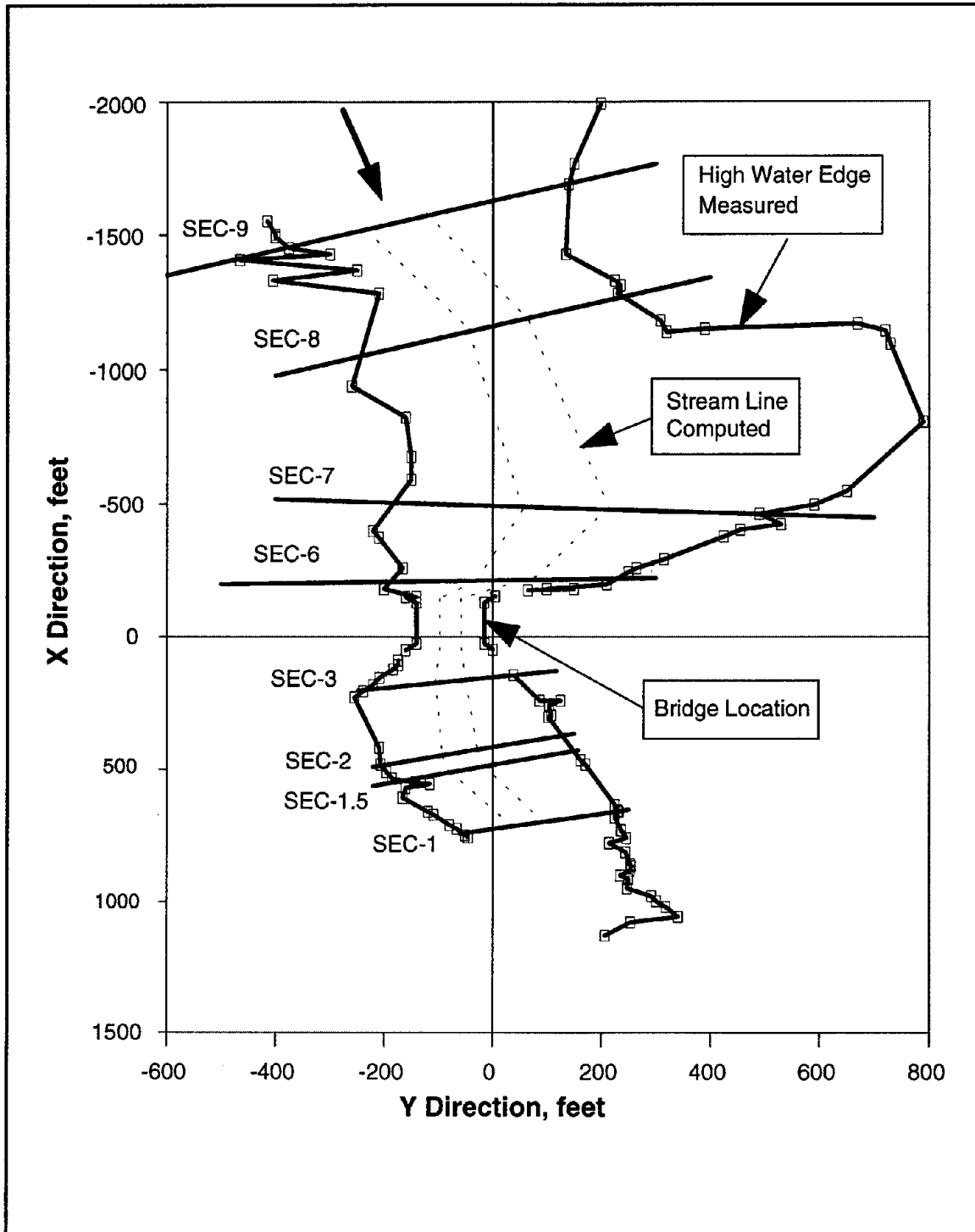
Figure 48. Plan view of the study reach at California I5 bridge.
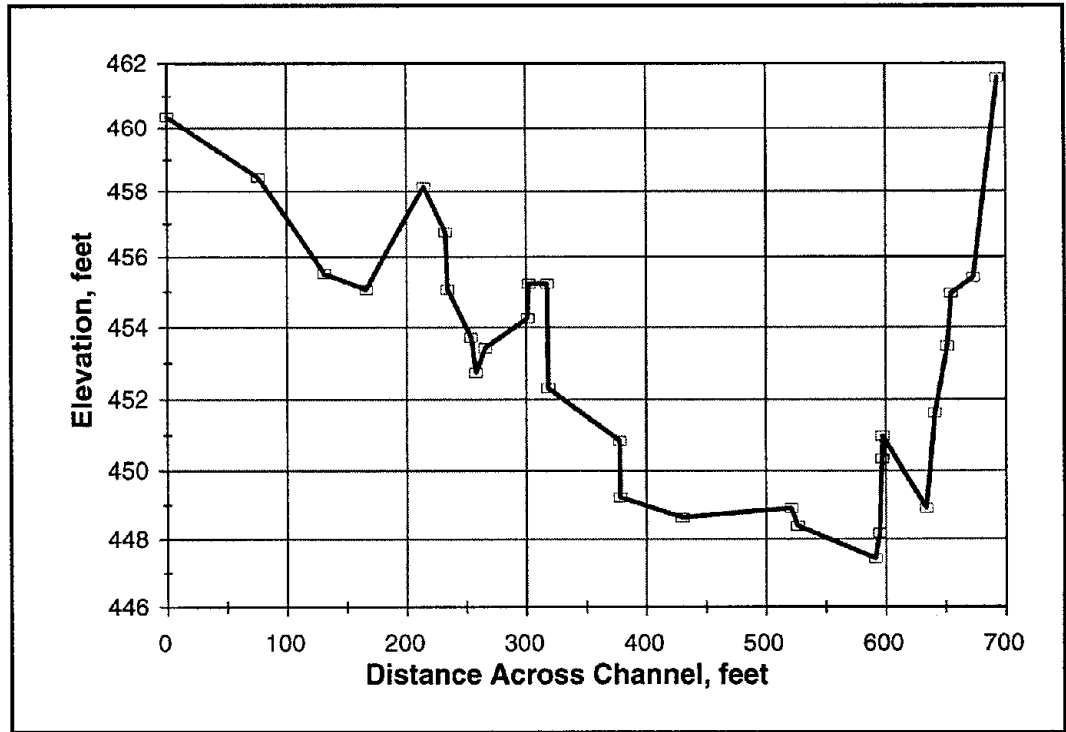
Figure 49. USGS measured cross section no. 9.
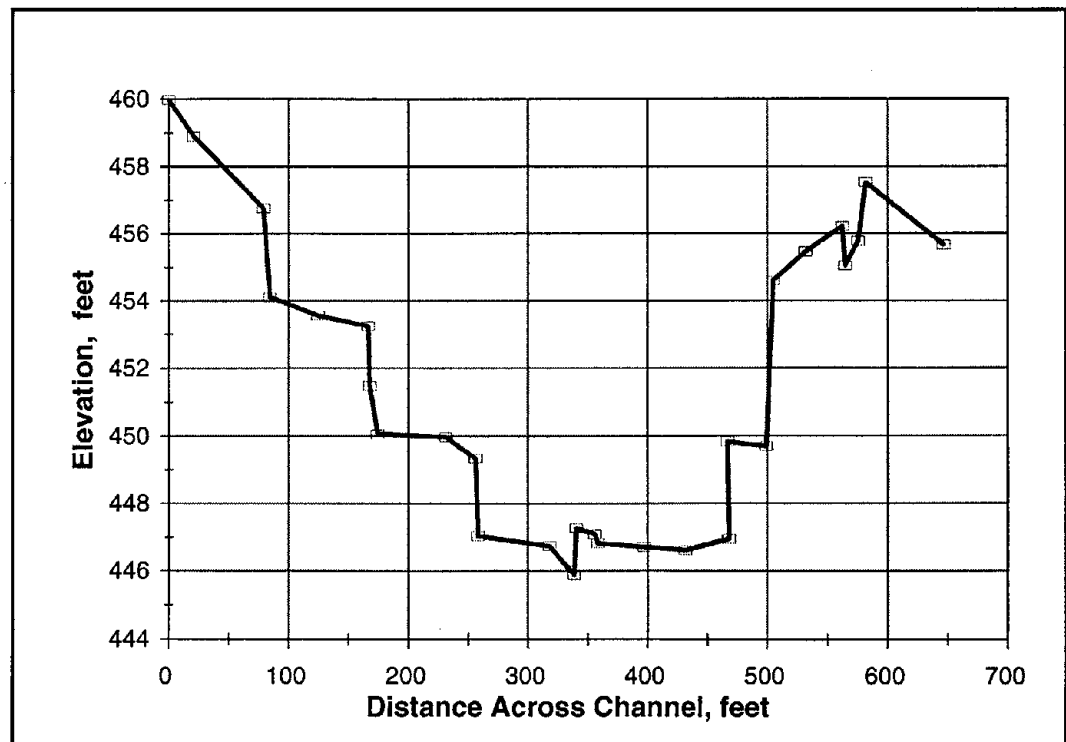
Figure 50. USGS measured cross section no. 8.
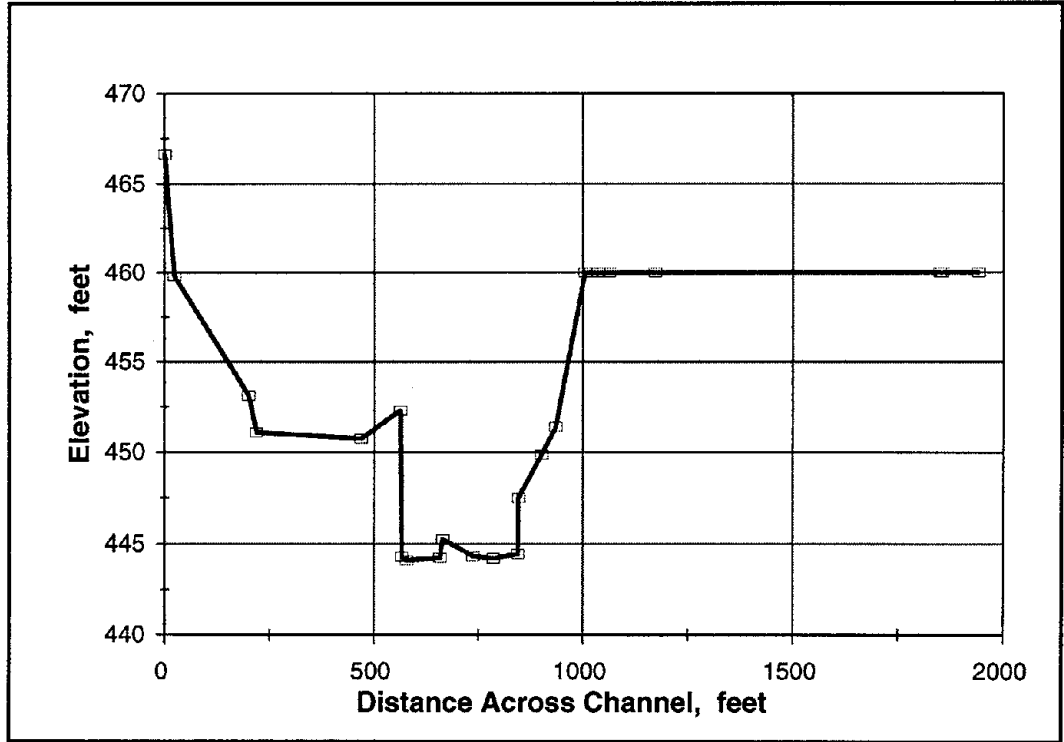
Figure 51. USGS measured cross section no. 7.
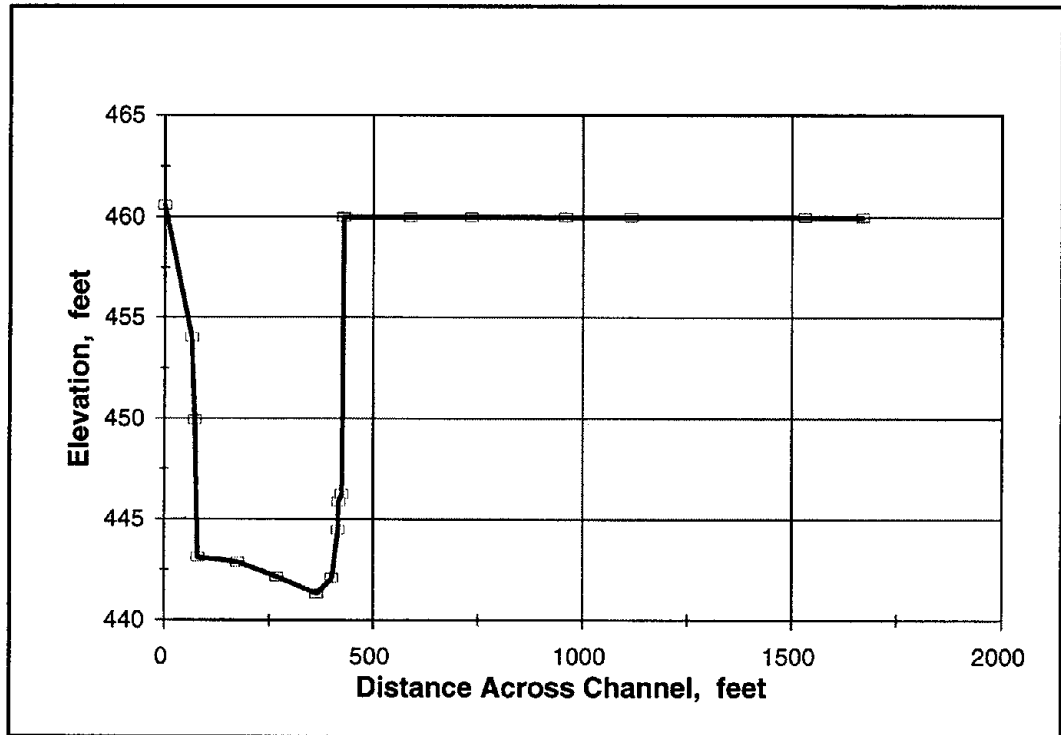
Figure 52. USGS measured cross section no. 6.
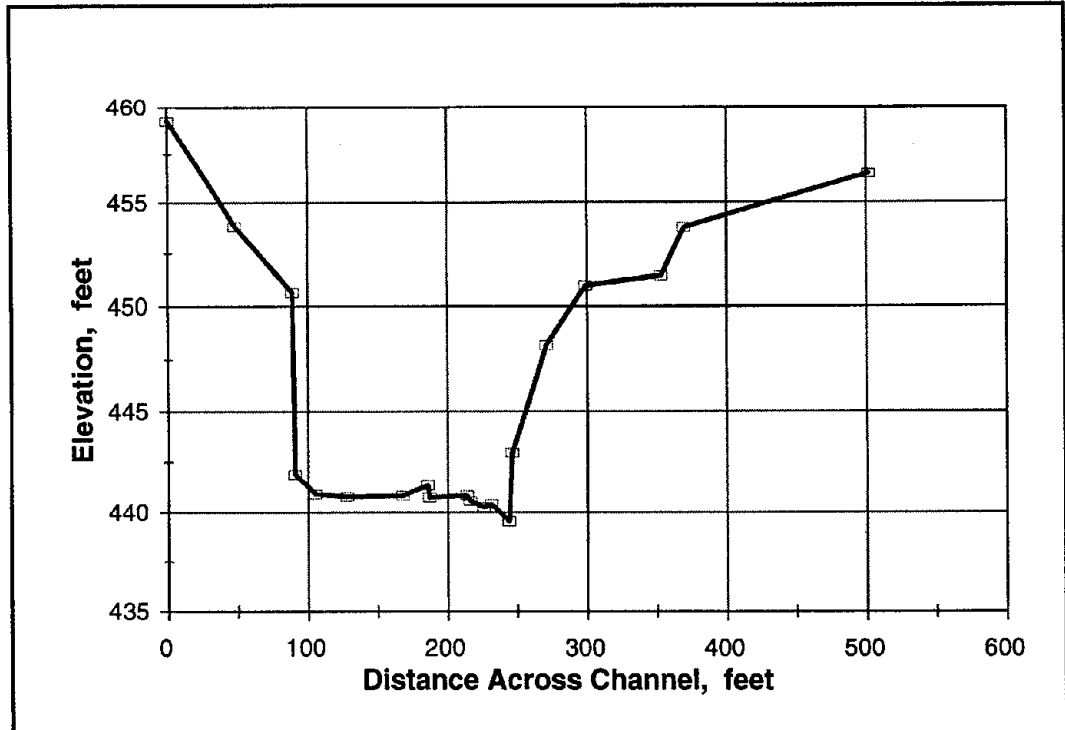
Figure 53. USGS measured cross section no. 3.
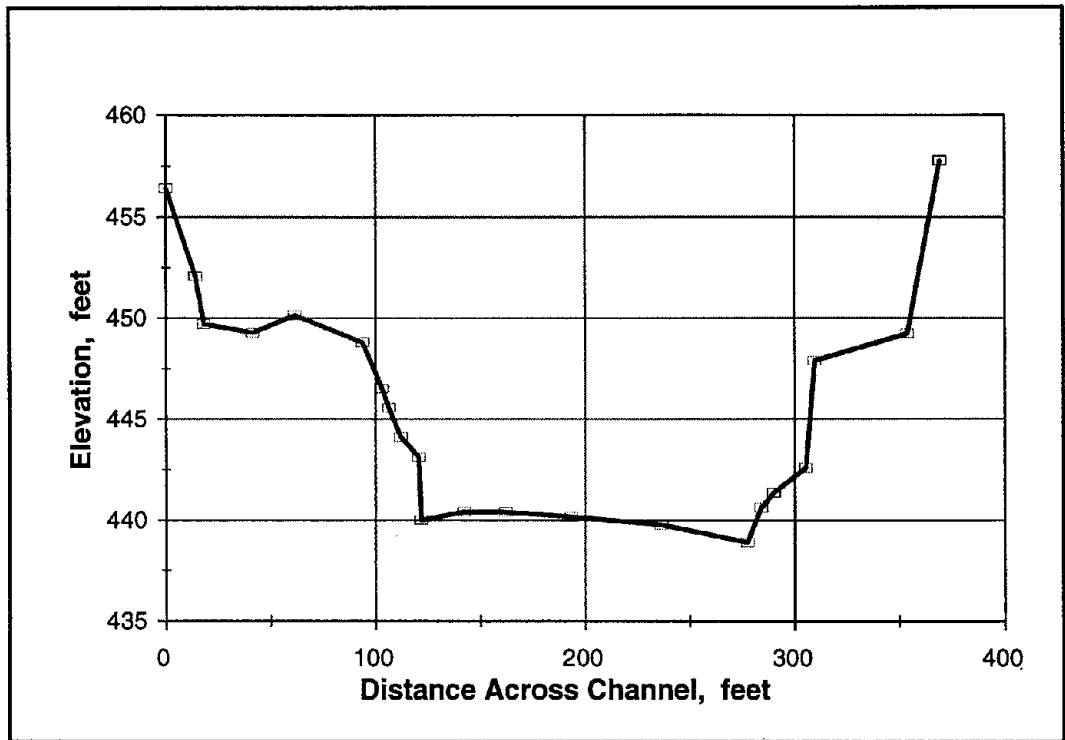
Figure 54. USGS measured cross section no. 2.
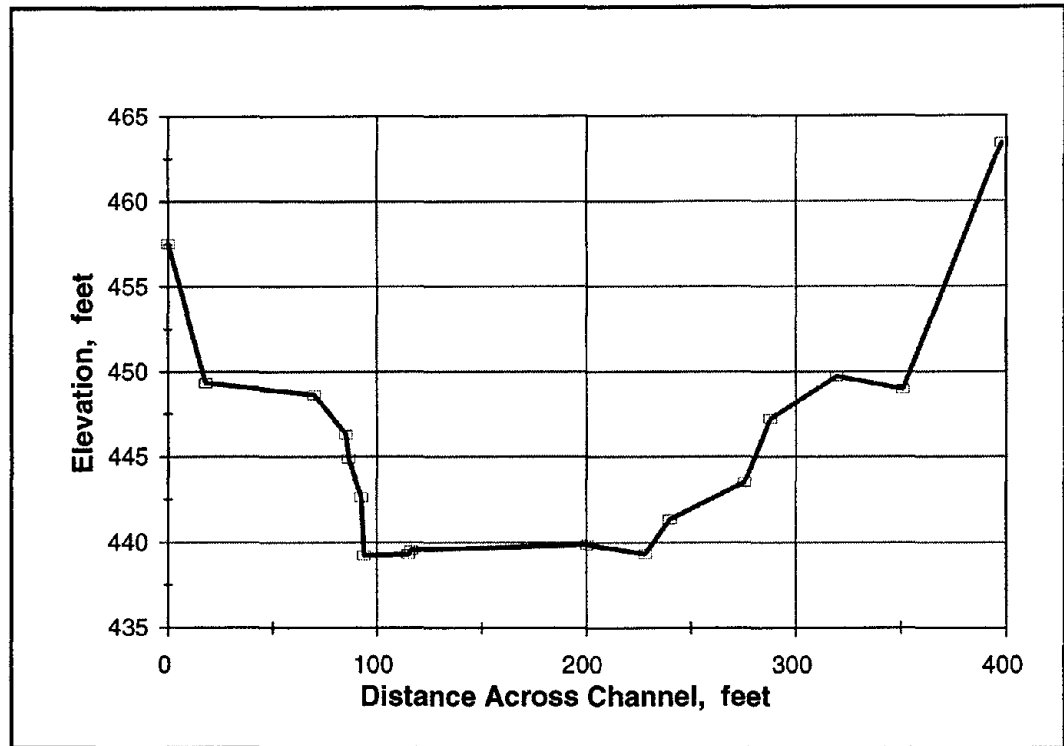
Figure 55. USGS measured cross section no. 1.5.
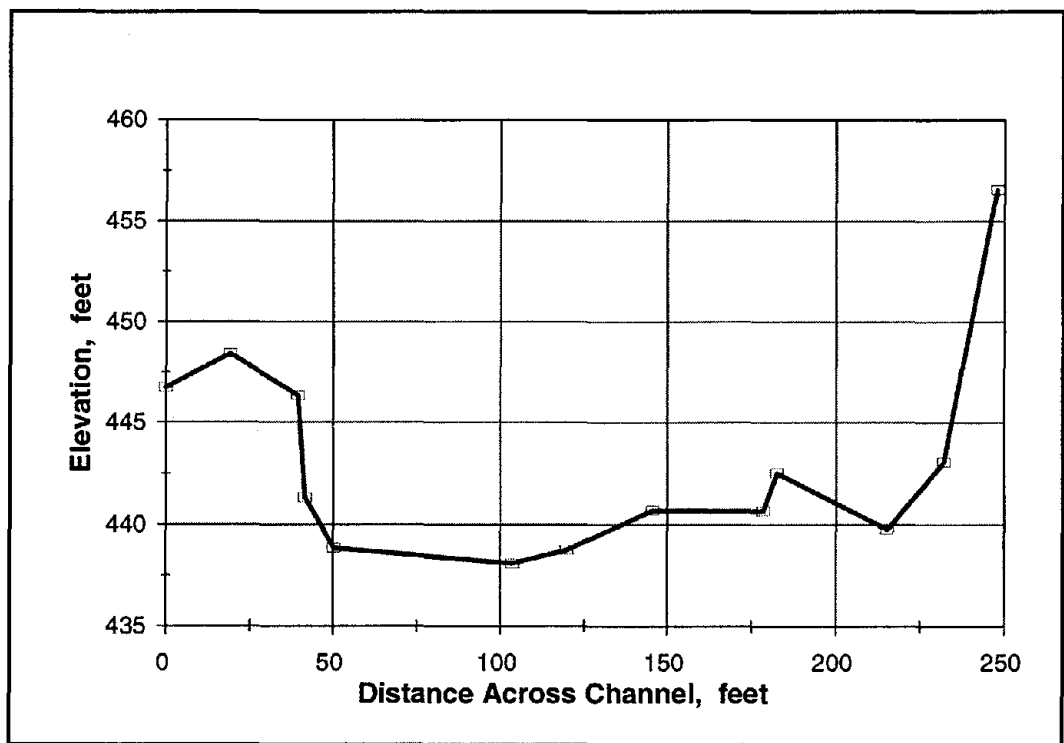
Figure 56. USGS measured cross section no. 1.
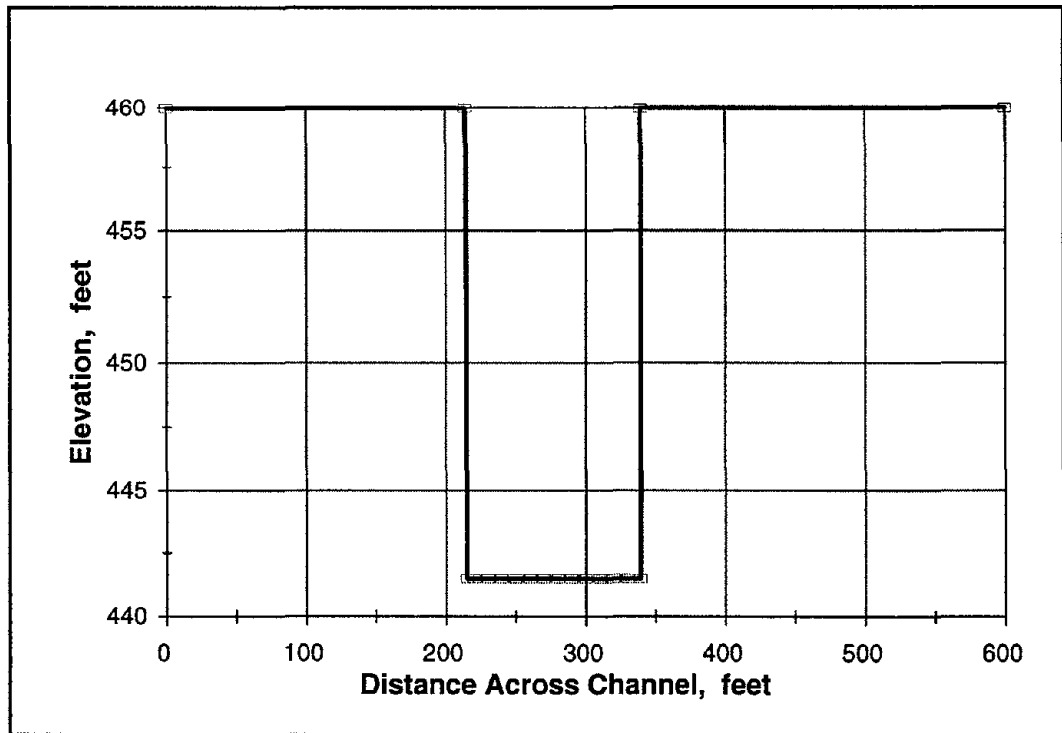
Figure 57. Generated cross section for bridge location at 830.3 ft.
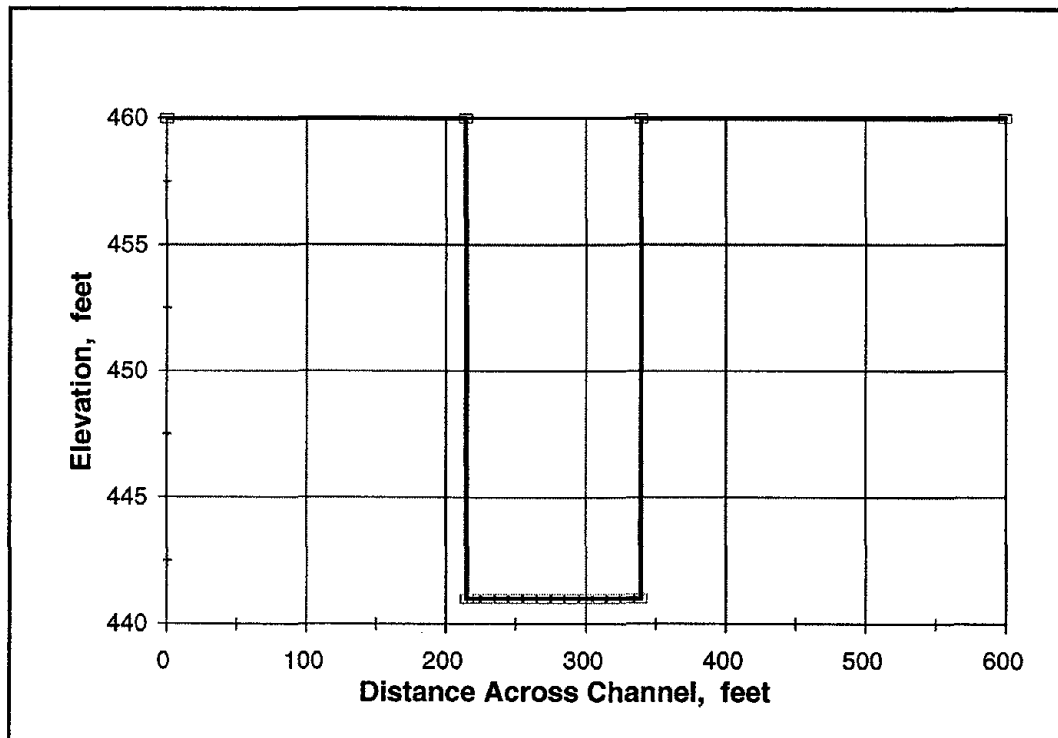
Figure 58. Generated cross section for bridge location at 675.5 ft.
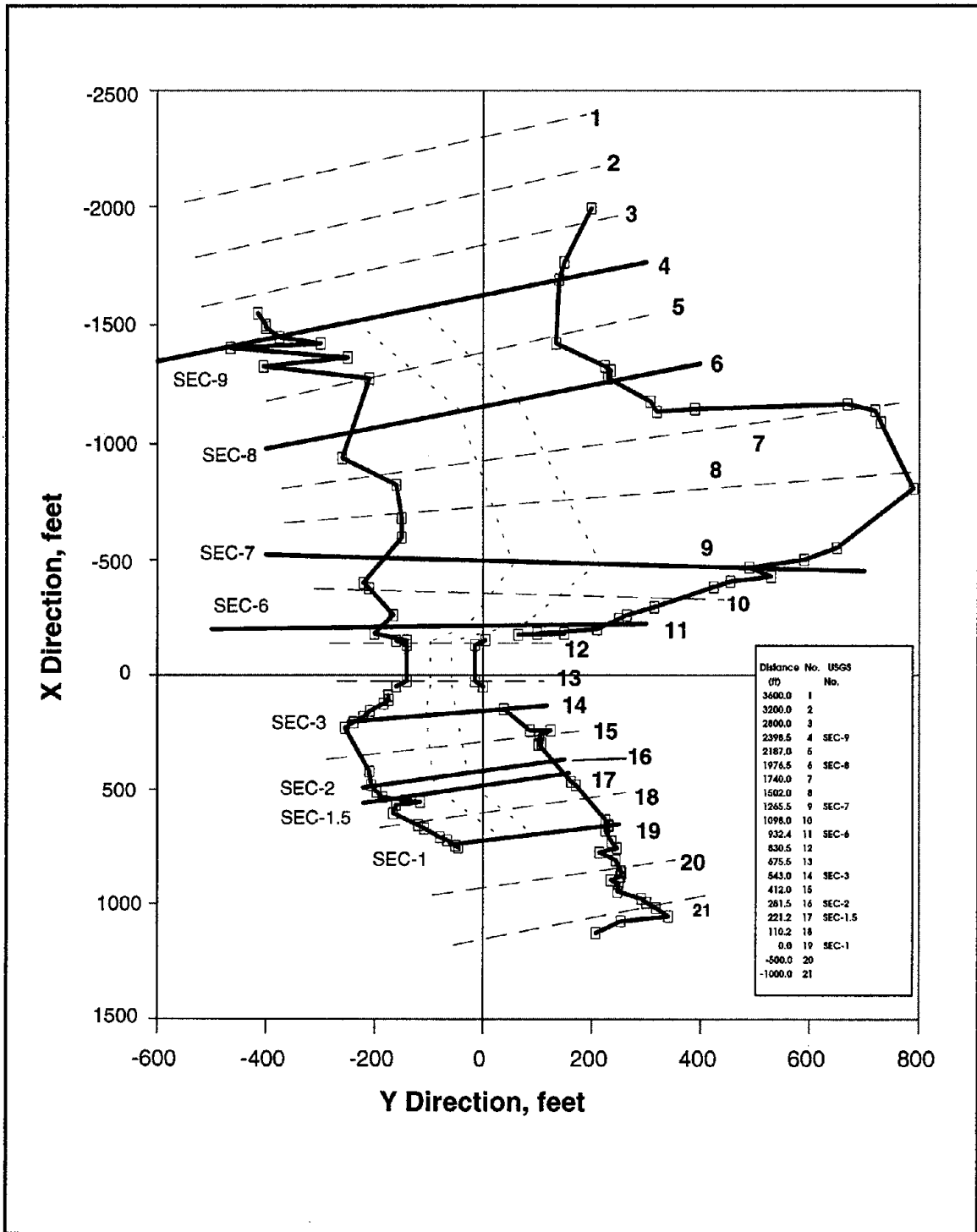
Figure 59. Plan view showing locations of interpolated and propagated cross sections.
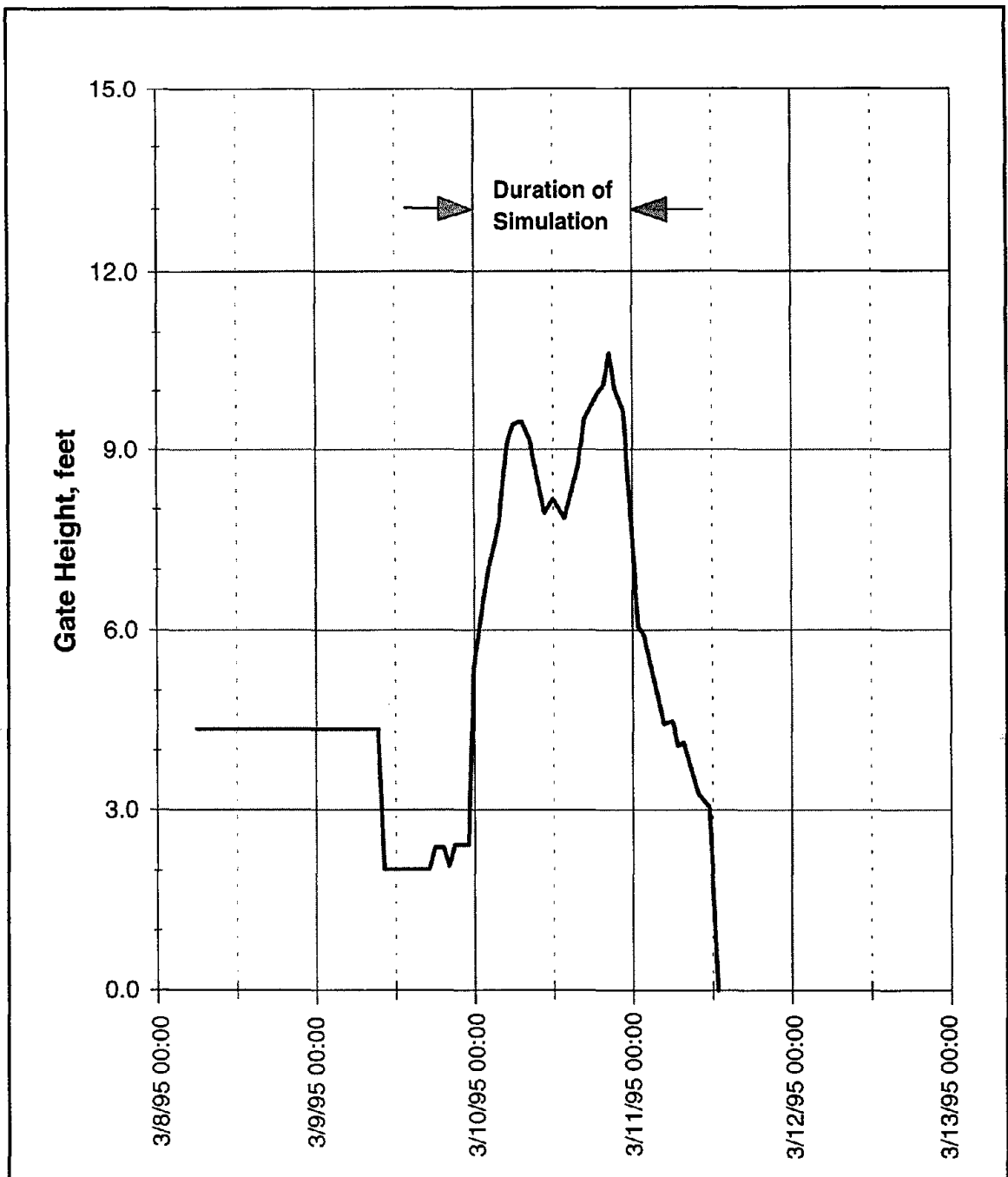
Figure 60. Hydrograph at D.W.R. station, Los Gatos Creek at Eldorado Avenue.
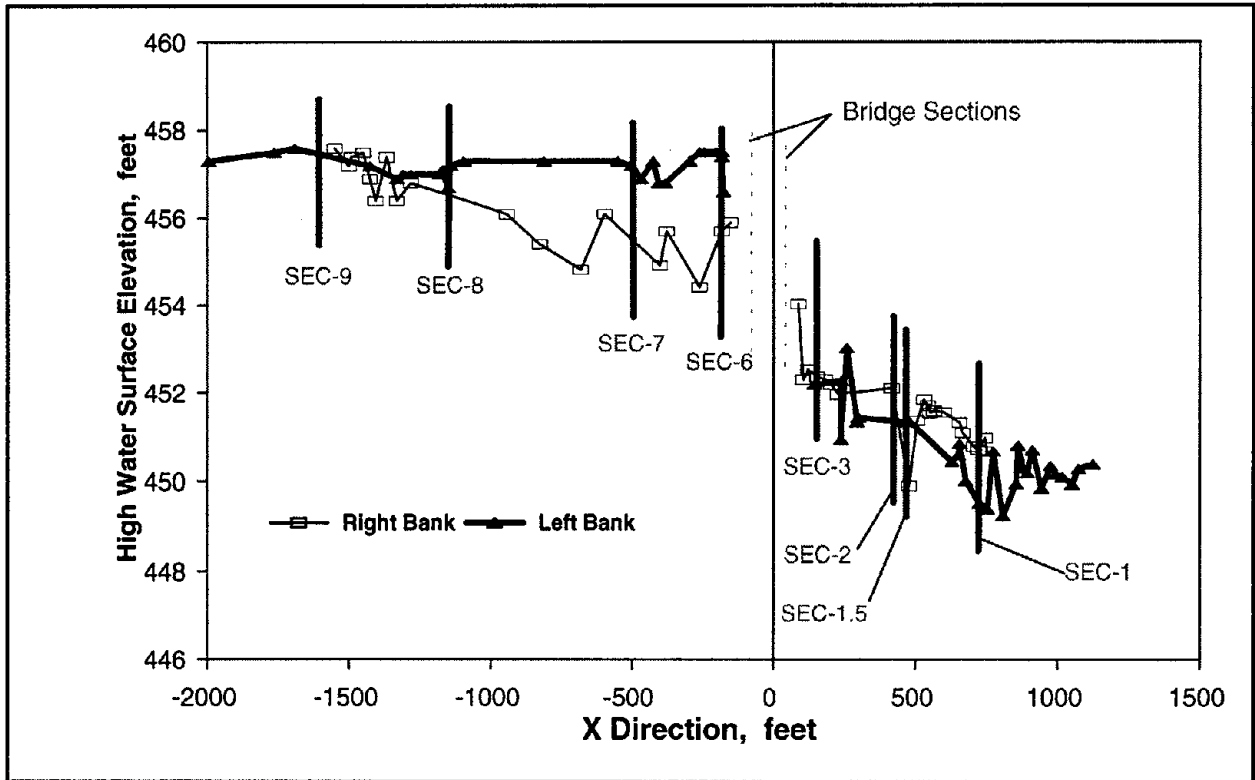
Figure 61. High water surface elevation measured on March 20 and 21, 1995.
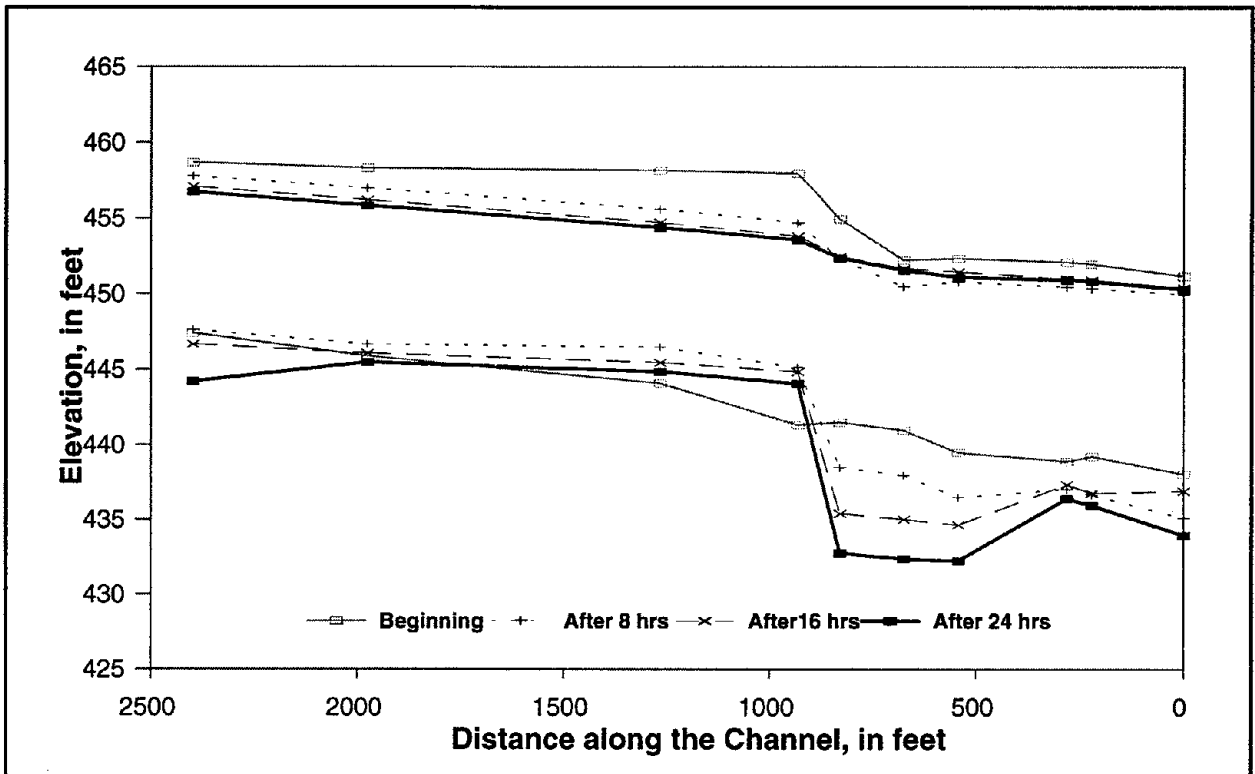
Figure 62. Water surface and bottom profiles at different times

D.3   LISTING OF INPUT DATA FILE (EXMPL009.DAT)

```
TT       Bridge Scour Example with Global Positioning and Date-Time
TT       Natural Channel With Constriction and Bridge on I5 in California
TT       Data surveyed on March 20, 1995. Simulation by Wu and Molinas
NS   21.0
CM*************************STATION NO.  1 ************************************
ST3600.0   29.00     0.00     0.00     1.50     1.00
GP    1.0      0.0  4920.0    765.0   4680.0   1414.0
ND   1.0   693.03
XS460.36      0.00   458.44    76.19   455.51   131.29   455.06   166.30   458.16   214.42
XS456.74    232.66   455.06   234.14   453.71   254.01   452.74   257.94   453.43   265.87
XS454.25    301.37   455.23   302.30   455.23   317.66   452.32   318.35   450.85   378.23
XS449.23    378.43   448.64   430.03   448.91   521.50   448.38   526.82   447.43   591.61
XS448.17    594.93   450.34   597.00   450.99   597.70   448.91   633.85   451.63   640.99
XS453.48    651.65   454.95   654.61   455.41   673.05   461.57   693.03
CM*************************STATION NO.  2 ************************************
ST3200.0   29.00     0.00     0.00     1.00     1.00
GP    1.0      0.0  4520.0    765.0   4280.0   1414.0
ND   1.0   693.03
XS460.36      0.00   458.44    76.19   455.51   131.29   455.06   166.30   458.16   214.42
XS456.74    232.66   455.06   234.14   453.71   254.01   452.74   257.94   453.43   265.87
XS454.25    301.37   455.23   302.30   455.23   317.66   452.32   318.35   450.85   378.23
XS449.23    378.43   448.64   430.03   448.91   521.50   448.38   526.82   447.43   591.61
XS448.17    594.93   450.34   597.00   450.99   597.70   448.91   633.85   451.63   640.99
XS453.48    651.65   454.95   654.61   455.41   673.05   461.57   693.03
CM*************************STATION NO.  3 ************************************
ST2800.0   29.00     0.00     0.00     0.50     1.00
GP    1.0      0.0  4120.0    765.0   3880.0   1414.0
ND   1.0   693.03
XS460.36      0.00   458.44    76.19   455.51   131.29   455.06   166.30   458.16   214.42
XS456.74    232.66   455.06   234.14   453.71   254.01   452.74   257.94   453.43   265.87
XS454.25    301.37   455.23   302.30   455.23   317.66   452.32   318.35   450.85   378.23
XS449.23    378.43   448.64   430.03   448.91   521.50   448.38   526.82   447.43   591.61
XS448.17    594.93   450.34   597.00   450.99   597.70   448.91   633.85   451.63   640.99
XS453.48    651.65   454.95   654.61   455.41   673.05   461.57   693.03
CM*************************STATION NO.  4 ************************************
ST2398.5   29.00     0.00     0.00     0.00     1.00
GP    1.0      0.0  3722.0    765.0   3481.0   1414.0
ND   1.0   693.03
XS460.36      0.00   458.44    76.19   455.51   131.29   455.06   166.30   458.16   214.42
XS456.74    232.66   455.06   234.14   453.71   254.01   452.74   257.94   453.43   265.87
XS454.25    301.37   455.23   302.30   455.23   317.66   452.32   318.35   450.85   378.23
XS449.23    378.43   448.64   430.03   448.91   521.50   448.38   526.82   447.43   591.61
XS448.17    594.93   450.34   597.00   450.99   597.70   448.91   633.85   451.63   640.99
XS453.48    651.65   454.95   654.61   455.41   673.05   461.57   693.03
CM*************************STATION NO.  5 ************************************
ST2187.0   26.00     0.00     0.00     0.00     1.00
GP    1.0      0.0  3510.0    737.0   3260.0   1357.0
ND   1.0   621.50
XS458.60      0.00   456.48    48.40   455.26    96.79   453.59   145.19   454.24   193.58
XS450.90    216.72   450.59   239.87   449.50   263.01   448.35   286.16   447.79   309.30
XS447.77    332.44   447.60   355.59   448.02   378.73   447.57   401.88   447.36   425.02
XS447.16    448.16   448.80   471.31   448.23   494.45   451.13   517.60   455.03   540.74
XS458.51    563.88   458.79   575.41   458.96   586.93   459.27   598.45   458.94   609.98
XS458.61    621.50
CM*************************STATION NO.  6 ************************************
ST1976.5   28.00     0.00     0.00     0.00     1.00
GP    1.0      0.0  3298.0    708.0   3038.0   1300.0
ND   1.0   646.86
XS459.98      0.00   458.90    20.83   456.76    78.97   454.10    84.39   453.56   124.84
XS453.25    166.64   451.48   168.08   450.06   174.65   449.97   231.54   449.33   256.32
XS447.04    258.84   446.75   318.05   445.89   338.89   447.28   340.41   447.09   356.11
XS446.83    358.37   446.71   397.03   446.62   431.89   446.95   468.11   449.83   466.92
XS449.69    499.16   454.60   505.05   455.47   531.90   456.22   562.82   455.04   564.89
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XS455.79  576.01  457.52  581.75  455.67  646.86
CM*****************************STATION NO.  7 ***********************************
ST1740.0   26.00    0.00    0.00    0.00    1.00
GP   1.0     0.0  3074.0   529.0  2826.0  1570.0
ND   1.0 1017.84
XS457.76     0.00  455.17   59.79  452.90  119.57  452.59  179.35  452.93  239.14
XS448.07   263.56  448.06  287.98  448.00  312.40  446.94  336.82  446.22  361.25
XS446.03   385.67  445.70  410.09  446.19  434.51  445.97  458.93  445.95  483.35
XS447.24   507.78  447.67  532.20  448.22  556.62  450.41  581.04  453.93  605.46
XS460.00   629.88  460.00  707.48  460.00  785.07  460.00  862.66  460.00  940.25
XS460.00 1017.84
CM*****************************STATION NO.  8 ***********************************
ST1502.0   26.00    0.00    0.00    0.00    1.00
GP   1.0     0.0  2850.0   350.0  2614.0  1840.0
ND   1.0 1424.70
XS457.08     0.00  453.12   86.40  451.91  172.81  451.68  259.22  452.62  345.62
XS446.09   371.65  446.11  397.67  446.10  423.70  446.03  449.72  445.49  475.75
XS445.23   501.77  444.99  527.79  445.20  553.82  445.14  579.84  445.18  605.87
XS447.84   631.89  448.65  657.92  449.54  683.94  451.07  709.97  453.12  735.99
XS460.00   762.02  460.00  894.55  460.00 1027.09  460.00 1159.63  460.00 1292.16
XS460.00 1424.70
CM*****************************STATION NO.  9 ***********************************
ST1265.5   24.00    0.00    0.00    0.00    1.00
GP   1.0     0.0  2627.0   170.0  2402.0  2110.0
ND   1.0 1941.87
XS466.63     0.00  459.80   22.78  453.10  200.39  451.08  220.07  450.75  469.36
XS452.30   564.31  444.30  567.36  444.10  579.28  444.24  658.73  445.24  665.50
XS444.33   737.99  444.22  787.13  444.44  845.41  447.50  846.77  449.86  901.35
XS451.39   935.06  460.00 1006.19  460.00 1020.13  460.00 1038.37  460.00 1063.79
XS460.00 1172.91  460.00 1850.97  460.00 1855.57  460.00 1941.87
CM*****************************STATION NO. 10 ***********************************
ST1098.0   26.00    0.00    0.00    0.00    1.00
GP   1.0     0.0  2430.0   437.0  2301.0  2241.0
ND   1.0 1748.18
XS458.51     0.00  455.86   56.09  455.79  112.18  455.72  168.28  456.47  224.37
XS451.07   251.56  449.76  278.76  443.66  305.95  444.09  333.15  443.89  360.35
XS443.70   387.54  443.61  414.74  443.55  441.93  443.44  469.13  443.29  496.32
XS445.16   523.52  445.64  550.71  446.14  577.91  446.60  605.11  447.21  632.30
XS460.00   659.50  460.00  877.23  460.00 1094.97  460.00 1312.71  460.00 1530.44
XS460.00 1748.18
CM*****************************STATION NO. 11 ***********************************
ST 932.5   18.00    0.00    0.00    0.00    1.00
GP   1.0     0.0  2234.0   704.0  2200.0  2372.0
ND   1.0  296.32
XS460.60     0.00  454.02   66.18  449.93   73.01  443.12   81.28  442.88  175.70
XS442.15   269.94  441.32  365.67  442.10  401.22  444.46  416.66  445.87  417.84
XS446.27   425.57  460.00  428.46  460.00  588.42  460.00  734.79  460.00  960.15
XS460.00 1117.07  460.00 1531.42  460.00 1668.32
CM*****************************STATION NO. 12 ***********************************
ST 830.5   18.00    0.00    0.00    0.00    1.00
GP   1.0     0.0  2140.0   800.0  2140.0  1400.0
ND   1.0  600.00
XS460.00     0.00  460.00  214.50  441.50  215.00  441.50  220.00  441.50  230.00
XS441.50   240.00  441.50  250.00  441.50  260.00  441.50  270.00  441.50  280.00
XS441.50   290.00  441.50  300.00  441.50  310.00  441.50  320.00  441.50  330.00
XS441.50   339.50  460.00  340.00  460.00  600.00
CM*****************************STATION NO. 13 ***********************************
ST 675.5   18.00    0.00    0.00    0.00    1.00
GP   1.0     0.0  1950.0   800.0  1950.0  1400.0
ND   1.0  600.00
XS460.00     0.00  460.00  214.50  441.00  215.00  441.00  220.00  441.00  230.00
XS441.00   240.00  441.00  250.00  441.00  260.00  441.00  270.00  441.00  280.00
XS441.00   290.00  441.00  300.00  441.00  310.00  441.00  320.00  441.00  330.00
XS441.00   339.50  460.00  340.00  460.00  600.00
CM*****************************STATION NO. 14 ***********************************
ST 543.0   20.00    0.00    0.00    0.00    1.00
GP   1.0     0.0  1872.0   884.0  1798.0  1245.0
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ND    1.0    502.00
XS459.27      0.00    453.83    48.00    450.66    89.08    441.87    90.57    440.90   105.20
XS440.78    127.89    440.83   167.85    441.36   185.85    440.74   186.94    440.84   213.97
XS440.56    216.29    440.26   225.84    440.40   231.14    439.53   244.05    442.96   246.43
XS448.19    271.12    450.98   299.24    451.44   353.45    453.76   369.88    456.47   502.00
CM****************************STATION NO.  15 ***********************************
ST 412.0     26.00     0.00     0.00     0.00     1.00
GP    1.0      0.0   1736.0    917.0   1654.0   1232.0
ND    1.0    414.77
XS453.27      0.00    451.89    20.83    451.40    41.66    450.16    62.48    443.72    83.31
XS442.03     99.39    440.54   115.48    440.61   131.56    440.59   147.64    440.75   163.72
XS440.43    179.81    440.38   195.89    440.06   211.97    440.05   228.06    442.49   244.14
XS444.76    260.22    446.28   276.31    449.62   292.39    449.94   308.47    450.26   324.55
XS454.62    340.64    455.91   355.46    456.21   370.29    456.52   385.12    456.82   399.94
XS457.13    414.77
CM****************************STATION NO.  16 ***********************************
ST 281.5     22.00     0.00     0.00     0.00     1.00
GP    1.0      0.0   1600.0    950.0   1510.0   1220.0
ND    1.0    369.44
XS456.42      0.00    452.07    14.03    449.71    18.10    449.29    41.41    450.15    61.50
XS448.82     93.84    446.52   103.07    445.58   106.33    444.13   112.16    443.12   120.68
XS440.00    121.85    440.42   142.28    440.40   162.15    440.17   193.58    439.77   236.52
XS438.91    277.72    440.64   284.17    441.35   290.13    442.60   305.53    447.89   309.67
XS449.25    353.81    457.78   369.44
CM****************************STATION NO.  17 ***********************************
ST 221.2     17.00     0.00     0.00     0.00     1.00
GP    1.0      0.0   1572.0    842.0   1440.0   1220.0
ND    1.0    397.69
XS457.54      0.00    449.32    18.10    448.62    70.10    446.27    84.92    444.85    86.40
XS442.63     92.64    439.24    93.90    439.32   115.01    439.55   116.40    439.85   200.43
XS439.33    228.23    441.34   240.13    443.48   275.61    447.20   288.01    449.72   319.55
XS448.97    351.06    463.40   397.69
CM****************************STATION NO.  18 ***********************************
ST 110.2     26.00     0.00     0.00     0.00     1.00
GP    1.0      0.0   1459.0    835.0   1349.0   1140.0
ND    1.0    309.04
XS448.72      0.00    448.72    13.51    448.08    27.02    446.59    40.53    442.54    54.04
XS438.98     66.18    438.95    78.32    439.02    90.47    438.98   102.61    438.94   114.75
XS438.98    126.90    439.20   139.04    439.48   151.18    439.70   163.32    440.44   175.47
XS441.27    187.61    441.72   199.75    442.51   211.90    444.96   224.04    445.29   236.18
XS445.29    248.33    444.71   260.47    445.07   272.61    448.29   284.75    453.60   296.90
XS459.97    309.04
CM****************************STATION NO.  19 ***********************************
ST   0.0     13.00     0.00     0.00     0.00     1.00
GP    1.0      0.0   1345.0    828.0   1258.0   1060.0
ND    1.0    247.96
XS446.74      0.00    448.43    19.13    446.34    39.50    441.32    41.59    438.84    50.31
XS438.09    103.66    438.76   119.99    440.70   145.65    440.67   178.55    442.53   182.58
XS439.75    215.37    443.07   232.31    456.56   247.96
CM****************************STATION NO.  20 ***********************************
ST-500.0     13.00     0.00     0.00    -1.00     1.00
GP    1.0      0.0    850.0    828.0    758.0   1060.0
ND    1.0    247.96
XS446.74      0.00    448.43    19.13    446.34    39.50    441.32    41.59    438.84    50.31
XS438.09    103.66    438.76   119.99    440.70   145.65    440.67   178.55    442.53   182.58
XS439.75    215.37    443.07   232.31    456.56   247.96
CM****************************STATION NO.  21 ***********************************
ST-1000.     13.00     1.00     1.00    -2.00     1.00
GP    1.0      0.0    345.0    828.0    258.0   1060.0
ND    1.0    247.96
XS446.74      0.00    448.43    19.13    446.34    39.50    441.32    41.59    438.84    50.31
XS438.09    103.66    438.76   119.99    440.70   145.65    440.67   178.55    442.53   182.58
XS439.75    215.37    443.07   232.31    456.56   247.96
CM************************** ROUGHNESS DATA ***********************************
RE      MANNING
CM****************************STATION NO.  1 ***********************************
RH0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600
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RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0600   0.0600   0.0600
CM****************************STATION NO.  2 **********************************
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600
RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0600   0.0600   0.0600
CM****************************STATION NO.  3 **********************************
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600
RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0600   0.0600   0.0600
CM****************************STATION NO.  4 **********************************
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600
RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0600   0.0600   0.0600
CM****************************STATION NO.  5 **********************************
RHO.0600   0.0550   0.0500   0.0500   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0480   0.0600
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0600
CM****************************STATION NO.  6 **********************************
RHO.0600   0.0500   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600
CM****************************STATION NO.  7 **********************************
RHO.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0420   0.0530
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0600
CM****************************STATION NO.  8 **********************************
RHO.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0410   0.0470
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0600
CM****************************STATION NO.  9 **********************************
RHO.0600   0.0600   0.0450   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0600   0.0600   0.0600   0.0600
RHO.0600   0.0600   0.0600   0.0600
CM****************************STATION NO.10 **********************************
RHO.0600   0.0600   0.0600   0.0600   0.0500   0.0500   0.0450   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0600
CM****************************STATION NO.11 **********************************
RHO.0600   0.0600   0.0564   0.0520   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600   0.0600
CM****************************STATION NO.12 **********************************
RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0350   0.0600   0.0600
CM****************************STATION NO.13 **********************************
RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0600   0.0600
CM****************************STATION NO.14 **********************************
RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0600   0.0600   0.0600
CM****************************STATION NO.15 **********************************
RHO.0600   0.0600   0.0600   0.0480   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0460   0.0500   0.0500   0.0500
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0600
CM****************************STATION NO.16 **********************************
RHO.0600   0.0600   0.0600   0.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0600
RHO.0600   0.0600
CM****************************STATION NO.17 **********************************
RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0600   0.0600   0.0600
CM****************************STATION NO.18 **********************************
RHO.0600   0.0600   0.0590   0.0510   0.0500   0.0400   0.0400   0.0400   0.0400   0.0400
RHO.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0420
RHO.0400   0.0500   0.0500   0.0500   0.0500   0.0600
CM****************************STATION NO.19 **********************************
RHO.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
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RH0.0600   0.0600   0.0600
CM****************************STATION NO.20 **********************************
RH0.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RH0.0400   0.0400   0.0600
CM****************************STATION NO.21 **********************************
RH0.0600   0.0600   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400   0.0400
RH0.0400   0.0400   0.0600
CM********************** COEFFICIENTS OF LOSSES ***************************
CL  0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
CL  0.00      0.30      0.30      0.30      0.00      0.00      0.00      0.00      0.00      0.00
CL  0.00
CB      THALWEG
NT   3.0
IT 144.0      1.0 0.00694
QQ       TABLE OF DISCHARGES
SS       STAGE DISCHARGE TABLE
TL  21.0
CM********************* DISCHARGE-STAGE DATA PAIRS  ***********************
SQ  5000 444.000
SQ  5000 444.240
SQ  5000 444.480
SQ  5000 444.720
SQ  5000 444.960
SQ 10000 445.200
SQ 10000 446.500
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SQ 10000 446.500
SQ 20000 448.500
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SQ 10000 446.500
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SQ  5000 444.500
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SQ  5000 444.500
CM**************************** SEDIMENT ROUTING DATA ************************
SO       SEDIMENT TRANSPORT IS REQUESTED
QS 144.0 50000.0
SE   1.0    4.00
TM 144.0   55.00
SF   4.0
SG 0.200   0.300
SG 0.300   4.000
SG  4.00    6.0
SG  6.00   10.0
SD 1.000   0.000   0.000   0.000
SD 0.000   0.000   0.000   1.000
SD 0.000   0.000   0.000   1.000
SD 1.000
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CM************************* PRINTOUT AND PLOTTING DATA *********************
PR   0.0    48.0     1.0    144.0
PV  12.0     0.0     0.0    000.0    000.0    0.0    1.0    21.0    1.0    16.0
PV  13.0     0.0     0.0    000.0    000.0    0.0    1.0    21.0    1.0    16.0
PV  14.0     0.0     0.0    000.0    000.0    0.0    1.0    21.0    1.0    16.0
PL       PLOTTING IS REQUESTED
PX       CHANNEL CROSS SECTION PLOTS         24.0    1.0    144.0
PW       WATER SURFACE PROFILE PLOTS          1.0    1.0    144.0
```

MN   NO MINIMIZATION IS REQUESTED

D.4   LISTING OF OUTPUT DATA FILE (EXMPL009.OUT)

Sample of the level "0" output generated at a frequency of 48 time steps is given below:

```
************************************************************************
            Bridge Scour Example with Global Positioning and Date-Time
          Natural Channel With Constriction and Bridge on I5 in California
          Data surveyed on March 20, 1995. Simulation by Wu and Molinas
                             Run at 16:19:55.76
                             Date   07/22/1998
************************************************************************




                  ************************************************
                  *         BRI-STARS VER  5.03   OUTPUT         *
                  ************************************************



                         TIME STEP NO    :         48
                         SIMULATION DATE :   01/01/00
                         SIMULATION TIME :   07:59:41
                         DISCHARGE (CFS) :   20000.00
                         TIME INCR.(DAYS):      .0069



                  ********************************************
                  *    RESULTS OF BACKWATER COMPUTATIONS    *
                  *       DISCHARGE =  20000.00   C.F.S.     *
                  ********************************************
```

STA NO.	STATION (FT)	BOTTOM ELEVATN	WATER SURF. ELEVATION	FLOW AREA	AVERAGE VELOCITY	ENER. GRADE ELEVATION	FROUDE NUMBER
1	3600.0	448.93	459.56	3533.8	5.66	460.188	.46
2	3200.0	448.34	458.87	3494.1	5.72	459.513	.46
3	2800.0	447.76	458.06	3287.3	6.08	458.767	.50
4	2398.5	447.01	457.20	3198.3	6.25	457.946	.51
5	2187.0	447.08	456.69	3039.0	6.58	457.479	.52
6	1976.5	446.09	456.24	3056.9	6.54	457.020	.52
7	1740.0	446.36	455.75	3108.4	6.43	456.495	.52
8	1502.0	445.94	455.41	3688.4	5.42	455.965	.46
9	1265.5	444.57	455.24	4622.3	4.33	455.598	.36
10	1098.0	442.95	455.03	4037.8	4.95	455.438	.32
11	932.5	441.85	454.89	3933.7	5.08	455.307	.28
12	830.5	436.72	453.13	2045.8	9.78	454.631	.43
13	675.5	436.32	452.24	1962.6	10.19	453.858	.45
14	543.0	436.96	452.22	2808.1	7.12	453.157	.45
15	412.0	437.10	452.01	2794.2	7.16	452.965	.47
16	281.5	437.00	451.78	2784.1	7.18	452.759	.49
17	221.2	438.07	451.67	2762.7	7.24	452.656	.50
18	110.2	436.45	451.29	2579.8	7.75	452.436	.51
19	.0	435.62	450.85	2414.7	8.28	452.185	.52
20	-500.0	437.20	449.77	2332.2	8.58	451.013	.51
21	-1000.0	435.48	448.50	2292.2	8.73	449.803	.52

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********************************************************************
*      SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  1      *
********************************************************************
```

STA NO.	TOT. LOAD (TONS)	CHANGE (FT)	DIRECTN. OF CHANGE	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT) 1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	135.1	.00	DEPTH	1398.	0.	0.	235.
3	143.2	.00	DEPTH	1398.	0.	0.	333.
4	205.9	-.01	DEPTH	2212.	0.	0.	277.
5	239.2	-.01	DEPTH	2650.	0.	0.	242.
6	206.4	.01	DEPTH	2385.	0.	0.	111.
7	224.9	-.01	DEPTH	2648.	0.	0.	71.
8	140.8	.02	DEPTH	1694.	0.	0.	8.
9	77.3	.02	DEPTH	934.	0.	0.	0.
10	111.7	-.02	DEPTH	1350.	0.	0.	0.
11	66.9	.05	DEPTH	809.	0.	0.	0.
12	120.4	-.10	DEPTH	1455.	0.	0.	0.
13	170.3	-.10	DEPTH	2058.	0.	0.	0.
14	178.4	-.01	DEPTH	2157.	0.	0.	0.
15	196.4	-.02	DEPTH	2374.	0.	0.	0.
16	199.7	.00	DEPTH	2415.	0.	0.	0.
17	214.4	-.02	DEPTH	2592.	0.	0.	0.
18	229.7	-.02	DEPTH	2777.	0.	0.	0.
19	273.0	-.03	DEPTH	3300.	0.	0.	0.
20	285.8	-.01	DEPTH	3455.	0.	0.	0.
21	302.1	-.01	DEPTH	3653.	0.	0.	0.

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********************************************************************
*      SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  2      *
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STA NO.	TOT. LOAD (TONS)	CHANGE (FT)	DIRECTN. OF CHANGE	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT) 1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	142.4	-.01	DEPTH	1398.	0.	0.	323.
3	148.0	.00	DEPTH	1398.	0.	0.	391.
4	159.3	-.01	DEPTH	1543.	0.	0.	382.
5	164.7	-.01	DEPTH	1587.	0.	0.	404.
6	167.7	.00	DEPTH	1632.	0.	0.	396.
7	171.8	.00	DEPTH	1684.	0.	0.	393.
8	181.8	-.01	DEPTH	1991.	0.	0.	208.
9	94.3	.07	DEPTH	1120.	0.	0.	20.
10	83.7	.01	DEPTH	1008.	0.	0.	4.
11	79.3	.01	DEPTH	958.	0.	0.	1.
12	114.3	-.10	DEPTH	1381.	0.	0.	1.
13	144.3	-.10	DEPTH	1744.	0.	0.	1.
14	166.0	-.07	DEPTH	2007.	0.	0.	0.
15	182.5	-.05	DEPTH	2206.	0.	0.	0.
16	200.1	-.07	DEPTH	2418.	0.	0.	0.
17	206.3	-.03	DEPTH	2494.	0.	0.	0.
18	224.3	-.07	DEPTH	2712.	0.	0.	0.
19	280.2	-.07	DEPTH	3388.	0.	0.	0.
20	282.8	.00	DEPTH	3419.	0.	0.	0.
21	299.9	-.01	DEPTH	3626.	0.	0.	0.

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        *****************************************************
        *     SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  3    *
        *****************************************************
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STA NO.	TOT. LOAD (TONS)	CHANGE (FT)	DIRECTN. OF CHANGE	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT) 1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	138.4	-.01	DEPTH	1398.	0.	0.	274.
3	143.8	.00	DEPTH	1398.	0.	0.	340.
4	166.8	-.01	DEPTH	1689.	0.	0.	327.
5	187.9	-.01	DEPTH	1927.	0.	0.	344.
6	259.5	-.03	DEPTH	2787.	0.	0.	350.
7	209.8	.02	DEPTH	2409.	0.	0.	127.
8	152.5	.03	DEPTH	1816.	0.	0.	28.
9	88.6	.03	DEPTH	1068.	0.	0.	2.
10	67.7	.02	DEPTH	819.	0.	0.	0.
11	71.8	-.01	DEPTH	868.	0.	0.	0.
12	119.6	-.10	DEPTH	1445.	0.	0.	0.
13	181.8	-.10	DEPTH	2197.	0.	0.	0.
14	166.6	.02	DEPTH	2015.	0.	0.	0.
15	175.2	-.01	DEPTH	2118.	0.	0.	0.
16	181.4	-.01	DEPTH	2193.	0.	0.	0.
17	193.8	-.02	DEPTH	2343.	0.	0.	0.
18	197.5	.00	DEPTH	2388.	0.	0.	0.
19	165.5	.02	DEPTH	2000.	0.	0.	0.
20	226.2	-.03	DEPTH	2735.	0.	0.	0.
21	234.8	.00	DEPTH	2838.	0.	0.	0.

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           *********************************************
           *        BRI-STARS VER  5.03   OUTPUT        *
           *********************************************
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              TIME STEP NO     :        96
              SIMULATION DATE :  01/01/00
              SIMULATION TIME :  15:59:23
              DISCHARGE (CFS) :  20000.00
              TIME INCR.(DAYS):     .0069
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           *********************************************
           *     RESULTS OF BACKWATER COMPUTATIONS     *
           *       DISCHARGE =  20000.00   C.F.S.      *
           *********************************************
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STA NO.	STATION (FT)	BOTTOM ELEVATN	WATER SURF. ELEVATION	FLOW AREA	AVERAGE VELOCITY	ENER. GRADE ELEVATION	FROUDE NUMBER
1	3600.0	448.93	459.30	3379.4	5.92	459.979	.48
2	3200.0	447.97	458.63	3495.3	5.72	459.263	.46
3	2800.0	447.63	457.72	3160.6	6.33	458.484	.52
4	2398.5	446.89	456.82	3122.4	6.41	457.594	.52
5	2187.0	446.83	456.36	3088.1	6.48	457.121	.50
6	1976.5	444.68	455.90	3147.9	6.35	456.671	.51
7	1740.0	446.05	455.41	3111.6	6.43	456.160	.52
8	1502.0	445.80	454.86	3218.9	6.21	455.594	.56
9	1265.5	445.25	454.30	3315.7	6.03	455.022	.57
10	1098.0	443.68	453.80	2894.3	6.91	454.616	.48
11	932.5	442.30	453.51	2955.1	6.77	454.269	.43

12	830.5	433.69	452.52	2293.2	8.72	453.716	.36
13	675.5	432.92	451.97	2273.5	8.80	453.175	.36
14	543.0	436.66	451.76	2882.7	6.94	452.653	.43
15	412.0	435.28	451.55	2844.1	7.03	452.474	.46
16	281.5	434.84	451.33	2831.1	7.06	452.288	.48
17	221.2	436.60	451.26	2848.5	7.02	452.195	.48
18	110.2	433.82	450.88	2656.7	7.53	451.998	.49
19	.0	431.79	450.47	2491.4	8.03	451.785	.50
20	-500.0	436.43	449.64	2432.7	8.22	450.785	.48
21	-1000.0	434.87	448.50	2379.1	8.41	449.713	.50

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***********************************************************
*      SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  1      *
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STA NO.	TOT. LOAD (TONS)	CHANGE (FT)	DIRECTN. OF CHANGE	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT)			
				1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	134.5	.00	DEPTH	1398.	0.	0.	227.
3	148.9	.00	DEPTH	1398.	0.	0.	402.
4	161.4	.00	DEPTH	1543.	0.	0.	408.
5	174.1	.00	DEPTH	1704.	0.	0.	401.
6	180.3	.00	DEPTH	1791.	0.	0.	389.
7	242.3	-.02	DEPTH	2618.	0.	0.	311.
8	241.4	.00	DEPTH	2711.	0.	0.	208.
9	229.6	.00	DEPTH	2647.	0.	0.	129.
10	233.4	.00	DEPTH	2733.	0.	0.	89.
11	153.6	.09	DEPTH	1840.	0.	0.	18.
12	142.3	.02	DEPTH	1712.	0.	0.	9.
13	147.1	-.01	DEPTH	1771.	0.	0.	7.
14	167.0	-.03	DEPTH	2014.	0.	0.	5.
15	182.1	-.02	DEPTH	2198.	0.	0.	4.
16	189.0	-.01	DEPTH	2282.	0.	0.	3.
17	191.7	.00	DEPTH	2315.	0.	0.	2.
18	201.9	-.02	DEPTH	2439.	0.	0.	2.
19	228.5	-.02	DEPTH	2761.	0.	0.	1.
20	245.1	-.01	DEPTH	2963.	0.	0.	0.
21	264.0	-.01	DEPTH	3191.	0.	0.	0.

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*      SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  2      *
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STA NO.	TOT. LOAD (TONS)	CHANGE (FT)	DIRECTN. OF CHANGE	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT)			
				1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	141.6	-.01	DEPTH	1398.	0.	0.	313.
3	151.8	-.01	DEPTH	1398.	0.	0.	437.
4	153.9	.00	DEPTH	1416.	0.	0.	445.
5	151.3	.00	DEPTH	1416.	0.	0.	414.
6	149.4	.00	DEPTH	1416.	0.	0.	390.
7	154.4	.00	DEPTH	1472.	0.	0.	395.
8	161.7	-.01	DEPTH	1546.	0.	0.	409.
9	170.9	-.01	DEPTH	1642.	0.	0.	424.
10	167.9	.00	DEPTH	1642.	0.	0.	387.
11	161.8	.01	DEPTH	1643.	0.	0.	313.
12	155.9	.02	DEPTH	1643.	0.	0.	242.
13	156.9	.00	DEPTH	1660.	0.	0.	237.
14	156.5	.00	DEPTH	1674.	0.	0.	218.

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15      159.8     -.01    DEPTH    1717.      0.      0.     215.
16      163.8     -.02    DEPTH    1767.      0.      0.     213.
17      169.2     -.03    DEPTH    1832.      0.      0.     213.
18      175.9     -.03    DEPTH    1918.      0.      0.     209.
19      207.0     -.05    DEPTH    2336.      0.      0.     167.
20      253.0     -.03    DEPTH    2957.      0.      0.     101.
21      272.5     -.01    DEPTH    3240.      0.      0.      55.
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***********************************************************
*      SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  3    *
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STA	TOT. LOAD	CHANGE	DIRECTN.	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT)			
NO.	(TONS)	(FT)	OF CHANGE	1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	137.7	-.01	DEPTH	1398.	0.	0.	267.
3	147.7	.00	DEPTH	1398.	0.	0.	387.
4	152.9	.00	DEPTH	1456.	0.	0.	392.
5	151.2	.00	DEPTH	1456.	0.	0.	372.
6	181.9	-.02	DEPTH	1842.	0.	0.	357.
7	197.1	-.01	DEPTH	2015.	0.	0.	368.
8	227.9	-.01	DEPTH	2363.	0.	0.	392.
9	251.8	-.01	DEPTH	2701.	0.	0.	343.
10	194.2	.04	DEPTH	2235.	0.	0.	112.
11	179.6	.02	DEPTH	2111.	0.	0.	59.
12	134.7	.10	DEPTH	1614.	0.	0.	15.
13	137.2	.00	DEPTH	1647.	0.	0.	12.
14	152.4	-.02	DEPTH	1832.	0.	0.	10.
15	168.2	-.02	DEPTH	2026.	0.	0.	8.
16	173.0	-.01	DEPTH	2084.	0.	0.	7.
17	177.3	-.01	DEPTH	2137.	0.	0.	6.
18	171.5	.01	DEPTH	2069.	0.	0.	4.
19	147.9	.01	DEPTH	1786.	0.	0.	2.
20	203.3	-.02	DEPTH	2457.	0.	0.	1.
21	208.6	.00	DEPTH	2522.	0.	0.	0.

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*          BRI-STARS VER  5.03   OUTPUT       *
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TIME STEP NO      :        144
SIMULATION DATE :   01/01/00
SIMULATION TIME :   23:59:04
DISCHARGE (CFS) :   5000.00
TIME INCR.(DAYS):      .0069
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*********************************************
*      RESULTS OF BACKWATER COMPUTATIONS    *
*        DISCHARGE =   5000.00   C.F.S.     *
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STA	STATION	BOTTOM	WATER SURF.	FLOW	AVERAGE	ENER. GRADE	FROUDE
NO.	(FT)	ELEVATN	ELEVATION	AREA	VELOCITY	ELEVATION	NUMBER
1	3600.0	448.93	454.49	1192.7	4.19	454.784	.41
2	3200.0	447.98	453.80	1279.1	3.91	454.066	.37

3	2800.0	447.46	453.03	1170.9	4.27	453.338	.42
4	2398.5	446.74	452.17	1161.7	4.30	452.486	.42
5	2187.0	446.84	451.70	1145.0	4.37	452.012	.42
6	1976.5	444.29	451.31	1241.5	4.03	451.598	.39
7	1740.0	445.90	450.77	1105.0	4.52	451.109	.45
8	1502.0	445.53	450.02	1025.8	4.87	450.416	.50
9	1265.5	444.98	448.93	885.0	5.65	449.442	.57
10	1098.0	442.97	447.77	755.0	6.62	448.509	.68
11	932.5	441.21	445.82	577.0	8.67	447.078	.91
12	830.5	436.29	445.60	901.5	5.55	446.105	.37
13	675.5	433.78	445.59	1318.7	3.79	445.811	.21
14	543.0	435.93	445.45	1357.6	3.68	445.673	.25
15	412.0	435.00	445.33	1310.3	3,82	445.582	.28
16	281.5	434.33	445.25	1357.6	3.68	445.490	.26
17	221.2	435.54	445.21	1315.4	3.80	445.447	.27
18	110.2	432.48	445.05	1230.2	4.06	445.362	.31
19	.0	430.53	444.96	1249.7	4.00	445.287	.34
20	-500.0	435.96	444.77	1444.4	3.46	444.958	.23
21	-1000.0	434.14	444.50	1529.9	3.27	444.679	.23

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*************************************************************
*     SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  1     *
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STA NO.	TOT. LOAD (TONS)	CHANGE (FT)	DIRECTN. OF CHANGE	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT) 1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	26.3	.03	DEPTH	316.	0.	0.	2.
3	29.2	.00	DEPTH	316.	0.	0.	37.
4	36.4	.00	DEPTH	399.	0.	0.	41.
5	39.6	.00	DEPTH	434.	0.	0.	45.
6	28.8	.01	DEPTH	337.	0.	0.	10.
7	41.0	-.01	DEPTH	461.	0.	0.	35.
8	49.2	-.01	DEPTH	536.	0.	0.	59.
9	84.2	-.04	DEPTH	915.	0.	0.	103.
10	117.3	-.05	DEPTH	1260.	0.	0.	158.
11	155.5	-.08	DEPTH	1757.	0.	0.	123.
12	29.9	.32	DEPTH	350.	0.	0.	12.
13	9.0	.06	DEPTH	108.	0.	0.	0.
14	11.4	-.01	DEPTH	137.	0.	0.	1.
15	14.9	-.01	DEPTH	179.	0.	0.	1.
16	12.2	.01	DEPTH	147.	0.	0.	0.
17	13.5	.00	DEPTH	162.	0.	0.	0.
18	15.4	.00	DEPTH	185.	0.	0.	1.
19	19.6	.00	DEPTH	236.	0.	0.	1.
20	11.1	.00	DEPTH	134.	0.	0.	0.
21	11.7	.00	DEPTH	142.	0.	0.	0.

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*     SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  2     *
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STA NO.	TOT. LOAD (TONS)	CHANGE (FT)	DIRECTN. OF CHANGE	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT) 1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	26.3	.06	DEPTH	318.	0.	0.	0.
3	30.7	.00	DEPTH	318.	0.	0.	53.
4	33.8	.00	DEPTH	354.	0.	0.	54.
5	34.2	.00	DEPTH	354.	0.	0.	59.

6	30.8	.00	DEPTH	337.	0.	0.	36.
7	44.8	-.02	DEPTH	475.	0.	0.	66.
8	55.5	-.01	DEPTH	575.	0.	0.	97.
9	81.9	-.03	DEPTH	855.	0.	0.	135.
10	98.8	-.03	DEPTH	959.	0.	0.	235.
11	111.1	-.04	DEPTH	1205.	0.	0.	138.
12	39.7	.35	DEPTH	453.	0.	0.	27.
13	11.6	.11	DEPTH	139.	0.	0.	1.
14	13.1	-.01	DEPTH	156.	0.	0.	3.
15	14.6	-.01	DEPTH	171.	0.	0.	6.
16	14.0	.00	DEPTH	164.	0.	0.	5.
17	15.7	-.01	DEPTH	190.	0.	0.	0.
18	16.3	.00	DEPTH	192.	0.	0.	5.
19	14.6	.00	DEPTH	170.	0.	0.	5.
20	12.0	.00	DEPTH	143.	0.	0.	2.
21	10.3	.00	DEPTH	123.	0.	0.	2.

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*     SEDIMENT ROUTING RESULTS FOR STREAM TUBE NO.  3     *
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STA NO.	TOT. LOAD (TONS)	CHANGE (FT)	DIRECTN. OF CHANGE	SEDIMENT LOAD FOR SIZE FRACTIONS (CU.FT) 1	2	3	4
1	115.7	.00	DEPTH	1398.	0.	0.	0.
2	24.8	.04	DEPTH	299.	0.	0.	1.
3	28.3	.00	DEPTH	299.	0.	0.	43.
4	32.8	.00	DEPTH	352.	0.	0.	44.
5	33.0	.00	DEPTH	352.	0.	0.	46.
6	26.6	.01	DEPTH	296.	0.	0.	25.
7	40.0	-.01	DEPTH	432.	0.	0.	52.
8	67.4	-.02	DEPTH	705.	0.	0.	109.
9	83.3	-.01	DEPTH	879.	0.	0.	128.
10	107.1	-.03	DEPTH	1070.	0.	0.	225.
11	134.5	-.06	DEPTH	1485.	0.	0.	141.
12	30.3	.27	DEPTH	350.	0.	0.	17.
13	8.2	.05	DEPTH	99.	0.	0.	0.
14	12.6	-.01	DEPTH	151.	0.	0.	2.
15	16.1	-.01	DEPTH	192.	0.	0.	2.
16	12.9	.01	DEPTH	155.	0.	0.	1.
17	15.0	-.01	DEPTH	180.	0.	0.	1.
18	17.5	.00	DEPTH	210.	0.	0.	1.
19	17.5	.00	DEPTH	212.	0.	0.	0.
20	9.9	.00	DEPTH	119.	0.	0.	0.
21	7.5	.00	DEPTH	91.	0.	0.	0.