MODELLING WITH HEC-RAS

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Introduction

HEC-RAS is based on the U.S. Army Corps of Engineers' HEC-RAS water surface profile model used for modeling both steady and unsteady, one-dimensional, gradually varied flow in both natural and man-made river channels. HEC-RAS also allows sediment transport/mobile bed computations and water temperature modeling.

- Steady and unsteady flow modeling
- Mixed flow regime analysis, allowing analysis of both subcritical and supercritical flow regimes in a single computer run
- Bridge and culvert analysis and design, including FHWA culvert routines for elliptical, arch, and semi-circular culverts
- Multiple bridge and culvert openings of different types and sizes at a roadway crossing
- Bridge scour computations following FHWA Publication HEC-18
- Bridge design editor and graphical cross section editor
- Floodplain and floodway encroachment modeling
- Multiple profile computations
- Lateral flow, split flow, over bank dendritic networks
- Sediment Transport/Movable Bed Modeling
- Sediment Impact Analysis Methods (SIAM)
- Water Quality Capabilities (Temperature Modeling)
- Tidal boundary conditions
- Reservoir and spillway analysis
- Levee overtopping
- User Defined Rules for Controlling Gate Operations
- Pumping of flooded areas
- Modeling Pressurized Pipe Flow
- Geometric model schematic can be placed over background maps and incorporate clickable scanned images of structures
- Inline weirs and gated spillways analysis, including both radial and sluice type gates and Ogee, broad and sharp crested weirs
- Tributary/diversion flow network capabilities, allowing for fully looped river system analysis in which reaches can be subdivided and combined
- Quasi 2-D velocity distributions
- X-Y-Z (pseudo 3-D) graphics of the river system

This lecture basically deals with the use of HEC-RAS. We will use HEC RAS 4.1 through practical exercises.

Ease of Use

The user interacts with HEC-RAS through a graphical user interface (GUI). The main focus in the design of the interface was to make it easy to use the software, while still maintaining a high level of efficiency for the user. The interface provides for the following functions:

- File Management
- Data Entry and Editing
- Hydraulic Analyses
- Tabulation and Graphical Displays of Input and Output Data
- Reporting Facilities
- Context Sensitive Help

Theoretical Calculations for One-dimensional Flow

The following paragraphs describe the methodologies used in performing the one-dimensional flow calculations within HEC-RAS. The basic equations are presented along with discussions of the various terms. Solution schemes for the various equations are described. Discussions are provided as to how the equations should be applied, as well as applicable limitations.

- General
- Steady Flow Water Surface Profiles
- Unsteady Flow Routing

Steady Flow Water Surface Profiles

HEC-RAS is currently capable of performing one-dimensional water surface profile calculations for steady gradually varied flow in natural or constructed channels. Subcritical, supercritical, and mixed flow regime water surface profiles can be calculated. Topics discussed in this section include: equations for basic profile calculations; cross section subdivision for conveyance calculations; composite Manning's n for the main channel; velocity weighting coefficient alpha; friction loss evaluation; contraction and expansion losses; computational procedure; critical depth determination; applications of the momentum equation; and limitations of the steady flow model. Figure- 1 depicts the terms of the energy equation representation

Equations for Basic Profile Calculations

Water surface profiles are computed from one cross section to the next by solving the Energy equation with an iterative procedure called the standard step method. The Energy equation is written as follows:

$$Z_2 + Y_2 + \frac{a_2 V^2}{2g} = Z_2 + Y_2 + \frac{a_2 V^2}{2g} + he$$

Z_1, Z_2= elevation of the main channel inverts

Y_1, Y_2= depth of water at cross sections

V_1, V_2= average velocities (total discharge/ total flow area)

a_1, a_2= velocity weighting coefficients

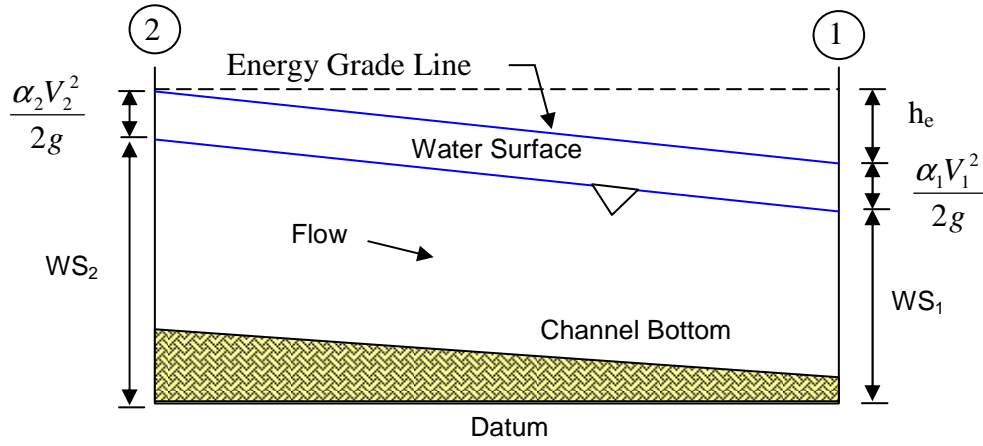g = gravitational acceleration, h_e=energy head loss

Fig. 1 Representation of terms in energy equation

Friction losses

The energy loss term h_e in equation 1 is composed of friction loss h_f and form loss h_o. Only contraction and expansion losses are considered in the geometric form loss term.

$$h_e = h_f + h_o \tag{2}$$

To approximate the transverse distribution of flow of the river is divided into strips having similar hydraulic properties in the direction of flow. Each cross section is sub divided into portions that are referred to as subsections. Friction loss is calculated as shown below:

$$h_f = \left(\frac{Q}{K^1}\right)^2 \tag{3}$$

Where, $K^1 = \sum_{j=1}^{J}\left[\frac{1.49}{n_j}\right]\frac{\frac{(A_2 + A_1)}{2}\left[\frac{R_2 + R_1}{2}\right]^{1/2}}{L_j^{1/2}} \Bigg|_j \tag{4}$

$A_1, A_2 =$ downstream and upstream area, respectively of the cross sectional flow normal to the flow direction

J   =   total number of subsections

L_j =   length of the jth strip between subsections

n   =   Manning's roughness coefficient

Q   =   water discharge

$R_1, R_2 =$ down stream and upstream hydraulic radius

Other losses

Energy losses due to contractions and expansions are computed by the following equation:

$$h_0 = C_L\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \tag{5}$$

Where, C_L = loss coefficient for contraction and expansion. If the quantity within the absolute value notation is negative, flow is contracting, C_L is the coefficient for contraction; if is positive, flow is expanding and C_L is the coefficient of expansion. In the standard step method for water surface profile computations,

calculations proceed from the downstream to upstream based upon the reach's downstream boundary conditions and starting water surface elevation.

Exercise for you

The primary goal of this exercise is to introduce you to channel flow using the HEC River Analysis System (HEC-RAS). By the end of this exercise, you should be able to:

- Import and edit cross-sectional geometry data
- Import and edit flow data from HEC-HMS
- Perform a steady flow simulation
- View and analyze HEC-RAS output

HEC-RAS Hydraulics

HEC-RAS is a one-dimensional steady flow hydraulic model designed to aid hydraulic engineers in channel flow analysis and floodplain determination. The results of the model can be applied in floodplain management and flood insurance studies. If you recall from hydraulics, steady flow describes conditions in which depth and velocity at a given channel location do not change with time. Gradually varied flow is characterized by minor changes in water depth and velocity from cross-section to cross-section. The primary procedure used by HEC-RAS to compute water surface profiles assumes a steady, gradually varied flow scenario, and is called the direct step method. The basic computational procedure is based on

$$H = Z + Y + \frac{\alpha V^2}{2g}$$

an iterative solution of the energy equation: , which states that the total energy (H) at any given location along the stream is the sum of potential energy (Z + Y) and kinetic energy ($V^2/2g$). The change in energy between two cross-sections is called head loss (h_L). The energy equation parameters are illustrated in the following graphic:
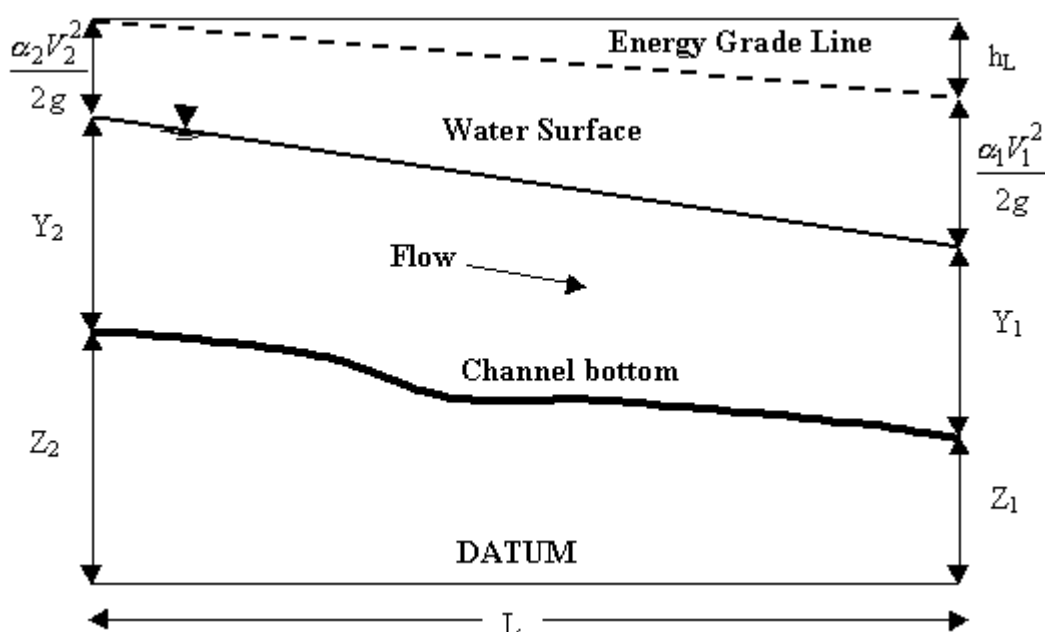
Given the flow and water surface elevation at one cross-section, the goal of the direct step method is to compute the water surface elevation at the adjacent cross-section. Whether the computations proceed from upstream to downstream or vice versa, depend on the flow regime. The dimensionless Froude number (Fr) is used to characterize flow regime, where:

- Fr < 1 denotes Subcritical flow
- Fr > 1 denotes Supercritical flow
- Fr = 1 denotes Critical flow

For a subcritical flow scenario, which is very common in natural and man-made channels, direct step computations would begin at the downstream end of the reach, and progress upstream between adjacent cross-sections. For supercritical flow, the computations would begin at the upstream end of the reach and proceed downstream.

Starting a Project

You may start the HEC-RAS program by clicking **Start/Programs/Hec/HEC-RAS 4.0**. The following window should subsequently appear:
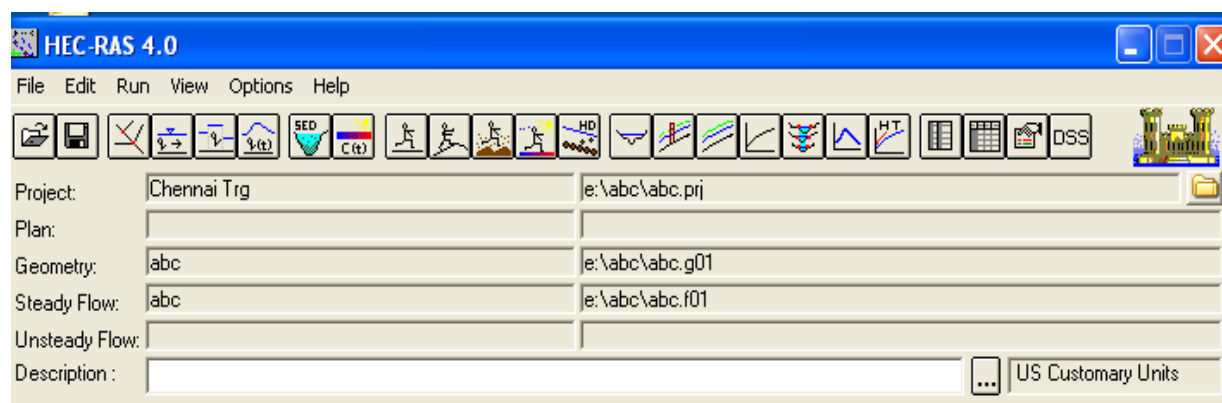
Henceforth, this window will be referred to as the main project window. A **Project** in RAS refers to all of the data sets associated with a particular river system. To define a new project, select **File/New Project** to bring up the main project window:
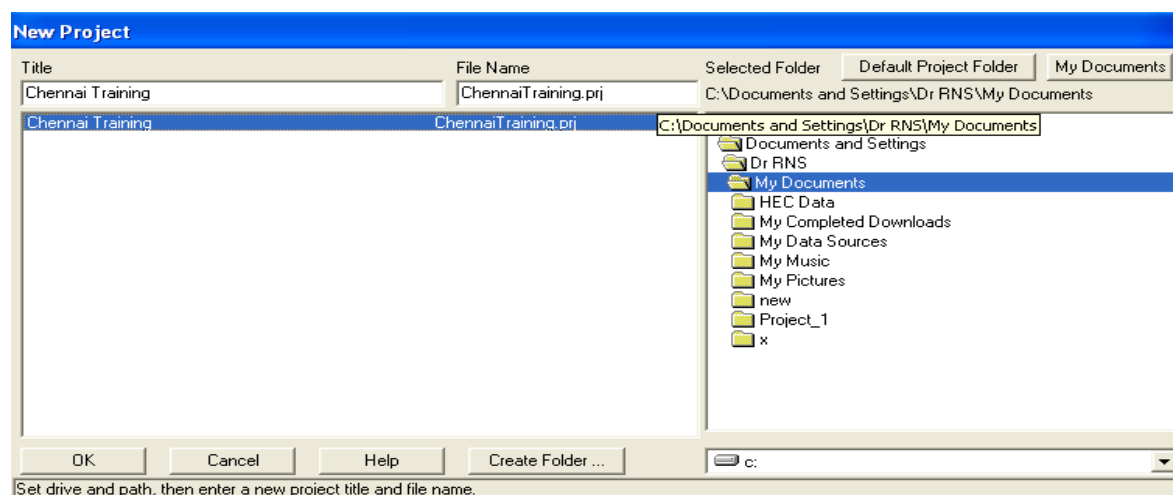
You will first need to select your working directory, and then a title (bbsr), and file name (BBSR.prj). All project filenames for HEC-RAS are assigned the extension ".prj". Click on the OK button and a window will open confirming the information you just entered. Again click the OK button. The project line in your main project window should now be filled in. The **Project Description** line at the bottom of the main project window allows you to type a detailed name for the actual short **Project** name. If desired, you may click on the ellipsis to the right of the **Description** bar, and additional space for you to type a lengthy **Description** will appear. Any time you see an ellipsis in a window in HEC-RAS, it means you may access additional space for writing descriptive text.

For each HEC-RAS project, there are three required components--the **Geometry** data, **Flow** data, and **Plan** data. The **Geometry** data, for instance, consists of a description of the size, shape, and connectivity of stream cross-sections. Likewise, the **Flow** data contains discharge rates. Finally, **Plan** data contains information pertinent to the run specifications of the model, including a description of the flow regime. Each of these components is explored below individually.

Importing and Editing Geometric Data

The first of the components we will consider is the channel geometry. To analyze stream flow, HEC-RAS represents a stream channel and floodplain as a series of cross-sections along the channel. To create our geometric model of Waller Creek for example, we need to import the geometry file. In HEC-RAS main project window, use **File/Import HEC-RAS Data** and choose the file *NWA…*. This HEC-RAS geometry file contains physical parameters describing Waller Creek cross-sections. To view the data, select **Edit/Geometric Data** from the project window.
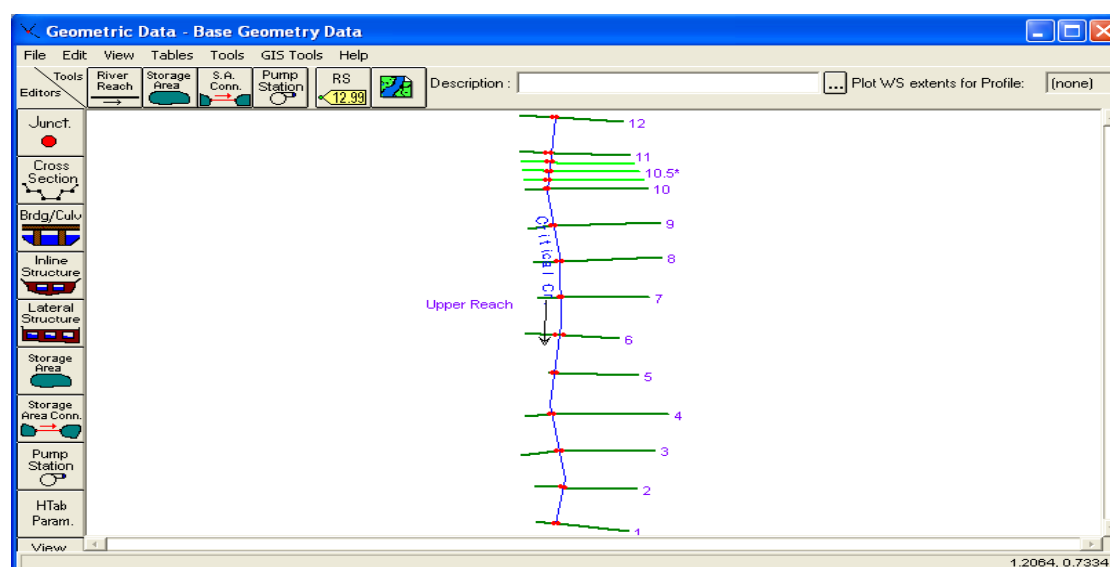
The resulting view shows a schematic of Waller Creek. This is the main geometric data editing window. The tick marks and corresponding numbers denote individual cross-sections. Choices under the **View** menu provide for zoom and pan tools. The six buttons on the left side of the screen are used to input and edit geometric data. The ![River Reach] and ![Junct.] buttons are used to create the reach schematic. A reach is simply a subsection of a river, and a junction occurs at the confluence of two rivers. Since our reach

schematic is already defined, we have no need to use these buttons. The ![Cross Section button], ![Brdg/Culv button], and ![Inline Weir Spillway button] buttons are used to input and edit geometric descriptions for cross-sections, and hydraulic structures such as bridges, culverts, and weirs. The ![View Picture button] allows you to associate an image file (photograph) with a particular cross-section. Click on the ![Cross Section button] button to open the cross-section data window:
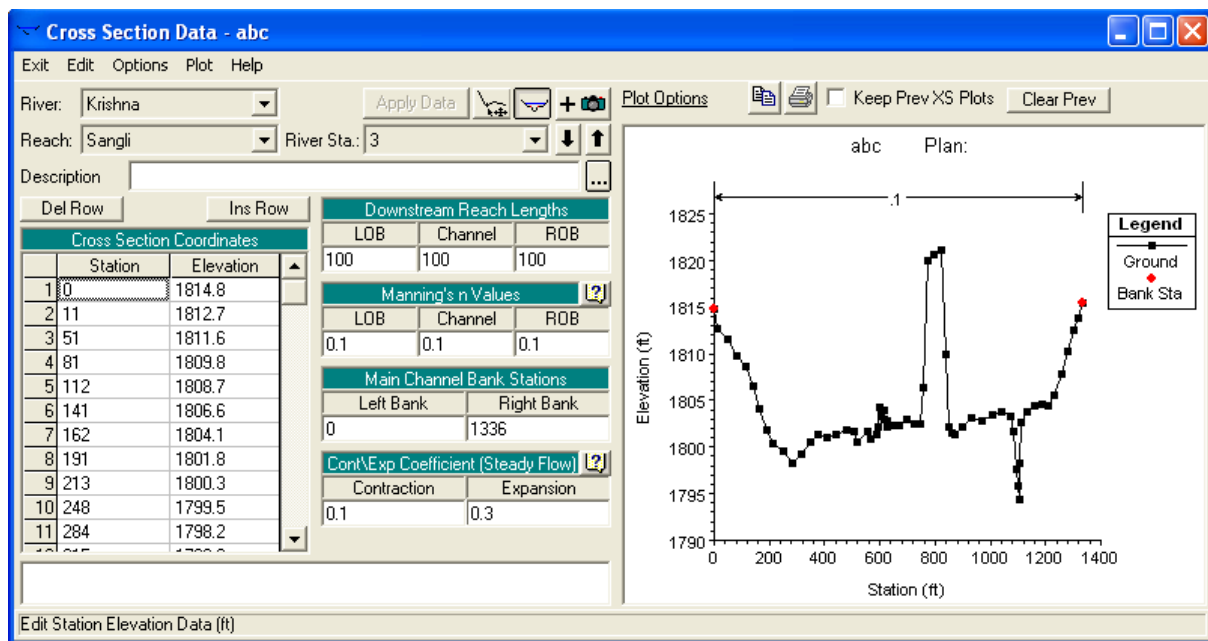
The data used to describe the cross-sections include the river station/cross-section number (26780 in the figure), lateral and elevation coordinates for each terrain point (station & elevation columns), Manning's roughness coefficients (n), reach lengths between adjacent cross-sections, left and right bank station, and channel contraction and expansion coefficients. These data are typically obtained by field surveys. The ![down arrow][up arrow] buttons can be used to toggle between different cross-sections. To edit data, simply double-click on the field of interest. As an example, double-click on station 779, change the value to 778, and hit the enter key. You may notice that this action caused all of the data fields to turn red and it enabled the "Apply Data" button. Whenever you see input data colored red in HEC-RAS, it means that you are in edit mode. There are two ways to leave the edit mode (you can do whichever you like):

1. Click the "Apply Data" button. The data fields will turn black, indicating you're out of edit mode, and the data changes are applied.
2. Select **Edit/Undo Editing**. You'll leave the edit mode without changing any of the data.

To actually see what the cross-sections look like, select the **Plot/Plot Cross-Section** menu item.
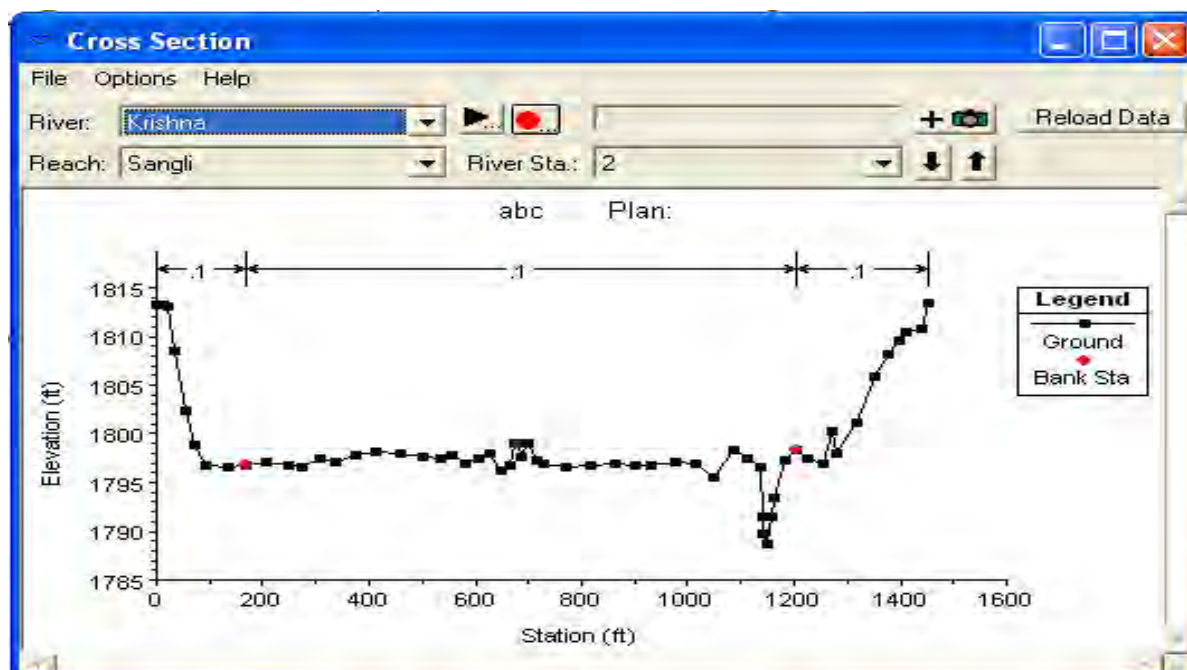
The cross-section points appear black and bank stations are denoted with red. Manning roughness coefficients appear across the top of the plot. Again, the [↓][↑] buttons can be used to maneuver between different cross-sections. Any solid black areas occurring in a cross-section represent blocked obstructions. These are areas in the cross-section through which no flow can occur. Some cross-sections contain *green arrows and gray areas*. This symbolism is indicative of the presence of a bridge or culvert. Input data and plots specifically associated with bridges and culverts can be accessed from the main geometric data editor window by clicking on the [Brdg/Culv] button. Take a little time to familiarize yourself with the geometric data by flipping through some different cross-sections and bridges/culverts. When you are finished, return to the geometric editor window and select **File/Save Geometric Data**. Return to the main project window using **File/Exit Geometry Data Editor**. At this point, save your HEC-RAS project just in case the program crashes for some reason or another.

Importing and Editing Flow Data

Enter the flow editor using **Edit/Steady Flow Data** from the main project window. Instead of importing an existing HEC-RAS flow file, we'll use stream flow output from an HEC-HMS model run similar to the one completed for the Introduction to HMS Exercise. The resulting flows are based on the 100-year design storm on Waller Creek, between its junction with the Hemphill Branch, and the Colorado River.

Output data from the HEC-HMS model are stored in files with a .dss extension. DSS stands for the HEC **D**ata **S**torage **S**ystem, which is essentially a database for storing time-series information. To use these data, select **File/Set Locations for DSS Connections** from the main flow data window. To open the DSS file, click on the [📂] button and select the Waller.dss file from your working directory. The window should now look like this:

The DSS data are stored in table records, each one representing a 24-hour increment of time-series flow data. Each record is described by several parameters, some of which are shown in the columns titled Part A, Part B, etc., as follows:

Column	Description
A	????
B	HMS hydrologic element (subbasin, junction, etc.) identifier
C	Flow type (baseflow, floodflow)
D	Date
E	Model Time Step
F	HMS Run ID

HEC-RAS allows you to view the hydrograph of any DSS record. Since the highest flows for our model run occur on February 1, we'll concentrate on the data from this day. Click on any record with Column C = FLOW and Column D = 01FEB1999 and then click on [Plot Selected Pathname] to see the associated hydrograph:
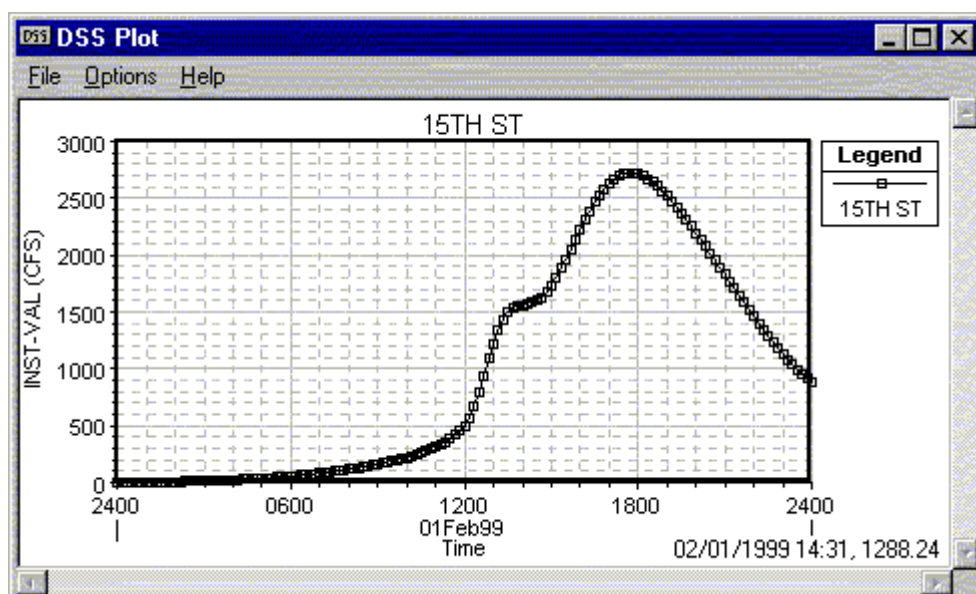
The coordinates of the cursor (time,flow rate) are displayed in the bottom right corner of the plot. Gridlines can be shown by invoking the **Options/Grid** menu item.

Exit the plot window and return to the "Set Locations for DSS Connections" window. We're now going to link the HEC-RAS cross-sections with their calculated DSS flows from HEC-HMS. The following table shows the relationship between the junctions in the HEC-HMS basin model and cross-sections in the HEC-RAS geometry file:

HEC-HMS Junction	HEC-RAS Cross-Section
Junction with Hemphill Branch	12609
MLK Blvd	8916
15th Street	7089
7th Street	3591
1st Street	1157
Colorado River	0

The procedure for linking the DSS records with their associated cross-sections is as follows:

1. Choose the river station from the drop-down list
2. Click on the button "Add selected location to table"
3. Click on the DSS record in which the Part B corresponds to the selected cross-section. Ensure that Part B column reads "FLOW" and Part C says "01FEB1999". Click on "Select DSS Pathname" to link the data.
4. Repeat for each of the junctions (click OK when finished with all junctions).

After the DSS records for the six junctions have been set, return to the main steady flow data window and select **File/DSS Import**. Fill in the fields as shown below:

Click on the "Import Data" button, and the flows from HEC-HMS will be imported into your HEC-RAS model.

As discussed earlier, the direct step method uses a known water surface elevation (and several hydraulic parameters) to calculate the water surface elevation at an adjacent cross-section. We'll assume a subcritical flow regime for our model, so the computations will begin at the downstream end. As such, the water surface elevation at the downstream boundary must be known. To establish this value, click on the

Reach Boundary Conditions button from the steady flow data window. HEC-RAS allows the user to set the water surface elevation boundary condition by four methods:

1. Known water surface - based on observed data
2. Critical depth - the program will calculate critical depth
3. Normal depth - the program will calculate normal depth
4. Rating curve - elevation determined from an existing stage-discharge relationship curve

For this tutorial, we'll use the critical depth option. Click in the box in the "Downstream" column and then click on the critical depth button.

Click OK to return to the main steady flow window. You'll notice that each of the junctions have now been assigned peak flow values from the HMS DSS output. For cross-sections falling between HMS junctions, the flow value of the upstream junction is applied. However, the most upstream cross-section, number 32093, hasn't been assigned a flow value. You will need to input a number here, but its magnitude is really inconsequential because the computations will proceed from downstream to upstream (subcritical flow). And for this tutorial, we are mainly interested in water surface profiles between U.T. and the Colorado River. Input a value of 2700. All of the required flow parameters have now been entered into the model! From the file menu, select **Save Flow Data** and save the flow data under the name "100 year flows." To leave the flow data editor and return to the HEC-RAS project window, choose **File/Exit Flow Data Editor**.

Executing the Model

With the geometry and flow files established, the HEC-RAS model can be executed. Select **Simulate/ Steady Flow Analysis** from the project window. But before running the model, one final step is required: definition of a plan. The plan specifies the geometry and flow files to be used in the simulation. To define a plan, select **File/New Plan**. You'll be subsequently asked to provide a plan title and a 12 character short identifier.


To execute the model, first ensure that the flow regime radio button is set to "Subcritical" and then click the compute button. All of the HEC-RAS windows you've used to this point are simply graphical user interfaces used to input data for the model. The computations are actually performed by a FORTRAN program named SNET. Clicking the compute button starts SNET and opens a DOS window that shows the progress of the simulation. When the computations are complete, the **PROGRAM TERMINATED NORMALLY** message should appear.

```
     XSEC  29307  =   658.77     657.57     657.57
     XSEC  29717  =   661.80     660.99     660.99
     XSEC  29948  =   662.97     662.32     662.11
BRIDGE
     XSEC  29955  =   663.03     662.79     662.09
     XSEC  29955  =   663.07     662.84     662.09
     XSEC  29962  =   663.14     662.74     662.12
     XSEC  29987  =   663.27     662.73
     XSEC  30157  =   665.10     663.76     663.76
     XSEC  30442  =   667.16     666.33     666.33
     XSEC  30812  =   669.42     668.77
     XSEC  31057  =   671.10     670.32
     XSEC  31107  =   673.07     672.23     672.23
CULVERT
     XSEC  31166  =   673.22     670.94     670.32
     XSEC  31249  =   674.54     672.03     672.03
     XSEC  31485  =   676.85     675.09     674.25
     XSEC  31576  =   677.32     677.01
     XSEC  31806  =   678.42     677.45
     XSEC  31961  =   679.72     679.22
     XSEC  32093  =   682.09     681.09     681.09


PROGRAM TERMINATED NORMALLY
```

Dismiss the DOS window by clicking the X in the upper right corner.

Viewing the Results

There are several methods available with which to view HEC-RAS output, including cross-section profiles, perspective plots, and data tables. From the project window, select **View/Cross-Sections**.
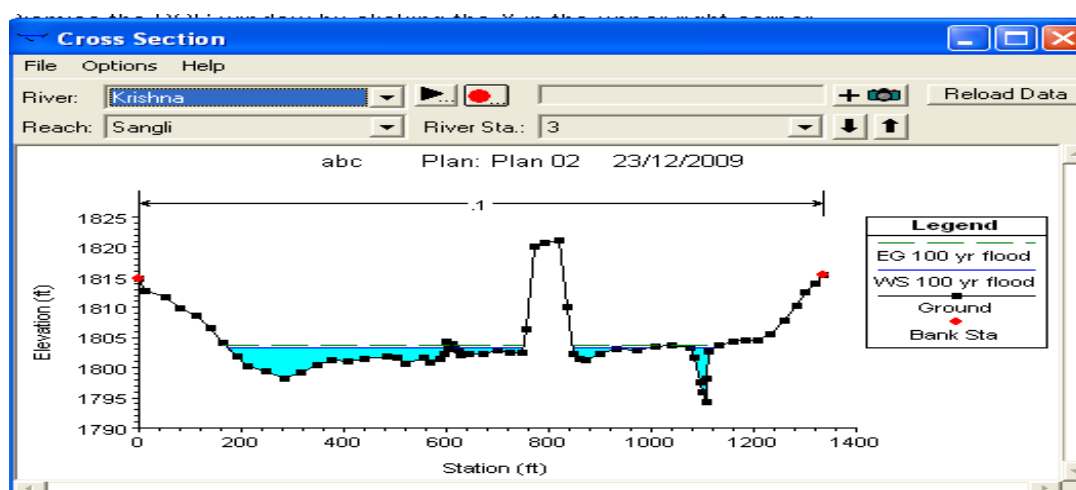
The cross-section view is similar to the one shown when we edited the cross-section data. However, the output view also shows the elevation of the total energy head line (shown in the legend as "EG 100yr flood"), the water surface ("WS 100 yr flood"), and critical depth ("Crit Peak Flows"). As with the cross-section geometry editor, you can use the ⬇⬆ to scroll to other cross-sections. For a profile of the entire reach, select **View/Water Surface Profiles** from the project window.
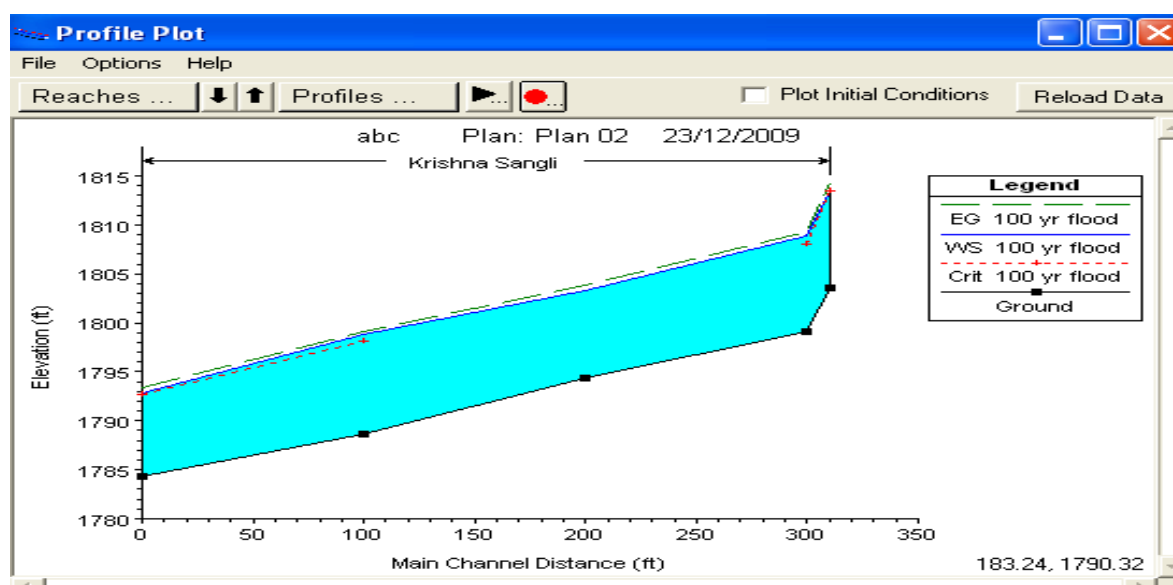
Using the **Options/Zoom In** menu option, you can focus on a particular stretch of reach to see how the water surface relates to structures in the channel such as bridges. Other available options for graphical display of output data include plots of velocity distribution (**View/Cross-Sections/Options/Velocity Distribution**) and pseudo 3D plots (**View/X-Y-Z Perspective Plots**). Spend a little time playing around with some of the display options.

For hydraulic design, it is often useful to know the calculated values of various hydraulic parameters. HEC-RAS offers numerous options for tabular output data display. From project window, choose **View/ Cross Section Table**.

The resulting table includes a number of hydraulic parameters, including water surface elevation, head losses, and cross-sectional area. At the bottom of the window, error and notes (if any) resulting from the steady flow computations are shown. As you scroll through the cross-sections, take a look at some of the error messages. For our model, it looks like the primary areas of concern is too few cross-sections. Additional tabular output data can be accessed from the invoking **View/Profile Table** from the main project window. Numerous formats and data types can be viewed by selecting different tables from the **Std. Tables** menu.

References:

1. Sankhua, R N, (2009), Lecture on Hydraulic modelling, 23rd ITP, NWA Pune
2. HEC-RAS manual
3. HEC RAS technical reference guide