Boundary and Initial Conditions

Objectives:

- Know requirements and options for *boundary conditions*
- Know *initial condition* requirements
- Review sources of data for both

References:

HEC-RAS River Analysis System, User's Manual, Chapter 8, Performing an Unsteady Flow Analysis, November 2002.

Unsteady Flow Data

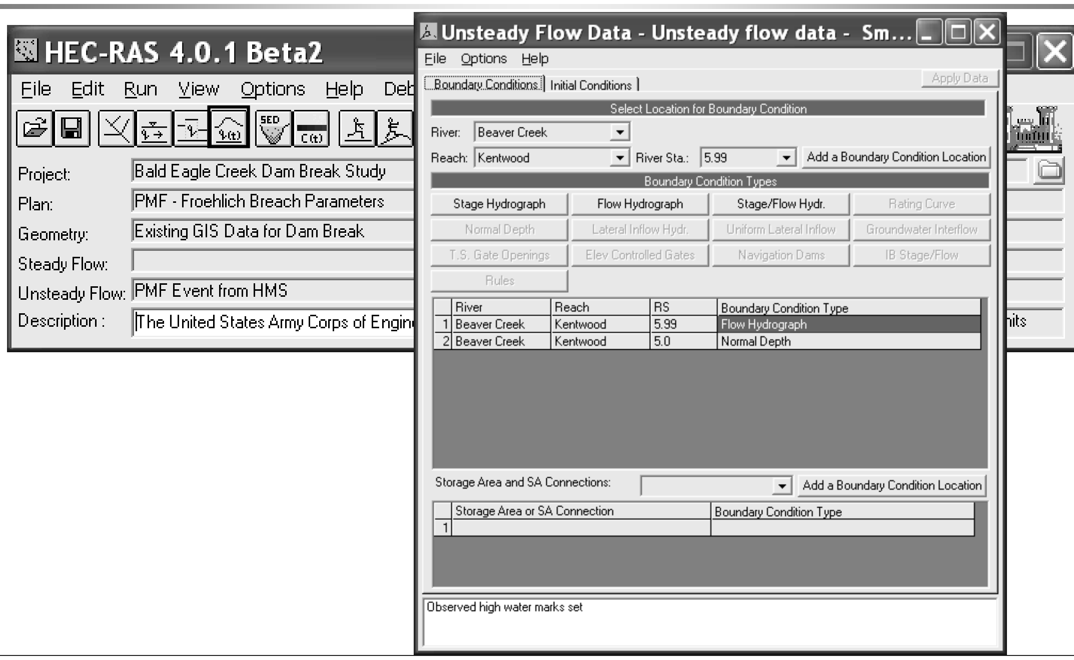
- Initial Conditions – Required
  - Establish flow and stage at all nodes at the start of simulation
- External Boundaries - Required
  - Upstream and Downstream ends of the river
  - Typically flow or stage hydrograph upstream
  - Typically rating or “normal depth” downstream
- Internal Boundaries - Optional
  - Add flow within the river system
  - Define gate operation

As with steady-flow applications, the Unsteady Flow data define flow and starting conditions for the simulation. The model simulates a dynamic hydraulic process on an segment of a river system network. To perform the hydraulic calculations within the segment, the time-varying “Boundary Conditions” must be defined for the “External Boundaries.”

The Unsteady Flow editor provides the options to defined:

- External boundary type and data
- Add internal boundary data
- Set the initial conditions for the start of the simulation

Unsteady Flow Data Editor



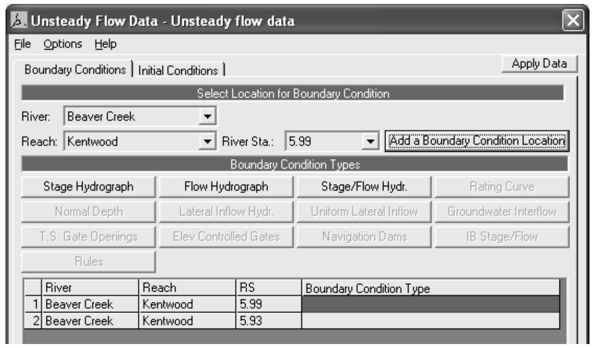
Once all of the geometric data are entered, the modeler can then enter any unsteady flow data that are required. To bring up the unsteady flow data editor, select **Unsteady Flow Data** from the **Edit** menu on the HEC-RAS main window. The Unsteady flow data editor should appear as shown above.

Unsteady Flow Data

The user is required to enter boundary conditions at all of the external boundaries of the system, as well as any desired internal locations, and set the initial flow and storage area conditions in the system at the beginning of the simulation period.

Boundary Conditions: Upstream

- Editor shows required external boundaries
- Boundary Type shows available options
- Upstream options:
  - Stage Hydrograph
  - Flow Hydrograph
  - Stage & Flow Hydrograph

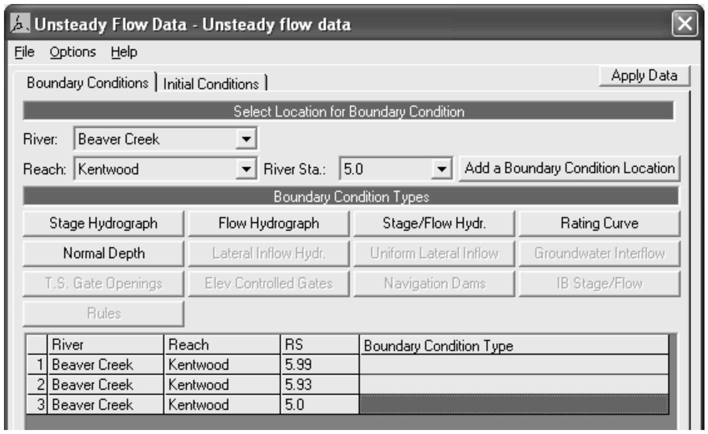


Boundary conditions are entered by first selecting the **Boundary Conditions** tab from the Unsteady Flow Data Editor. River, Reach, and River Station locations of the external bounds of the system will automatically be entered into the table.

Boundary conditions are entered by first selecting a cell in the table for a particular location, then selecting the boundary condition type that is desired at that location. Not all boundary condition types are available for use at all locations. The program will automatically gray-out the boundary condition types that are not relevant when the user highlights a particular location in the table.

Users can also add locations for entering internal boundary conditions. To add an additional boundary condition location, select the desired River, Reach, and River Station, then press the **Add a Boundary Condition Location** button.

Boundary Conditions: Downstream



- Downstream Boundary Options:
  - Stage Hydrograph
  - Stage & Flow Hydrograph
  - Rating Curve
  - Normal Depth

The downstream boundary can be:

- Stage Hydrograph - e.g., gage data on the stream, or tidal cycle
- Flow Hydrograph - e.g., gage data converted to flow
- Stage & Flow - e.g., combined observed stage and forecasted flow
- Rating Curve - e.g., rating at a gauged location, or steady-flow rating
- Normal Depth - e.g., average slope of stream to estimate energy slope

Flow Hydrograph

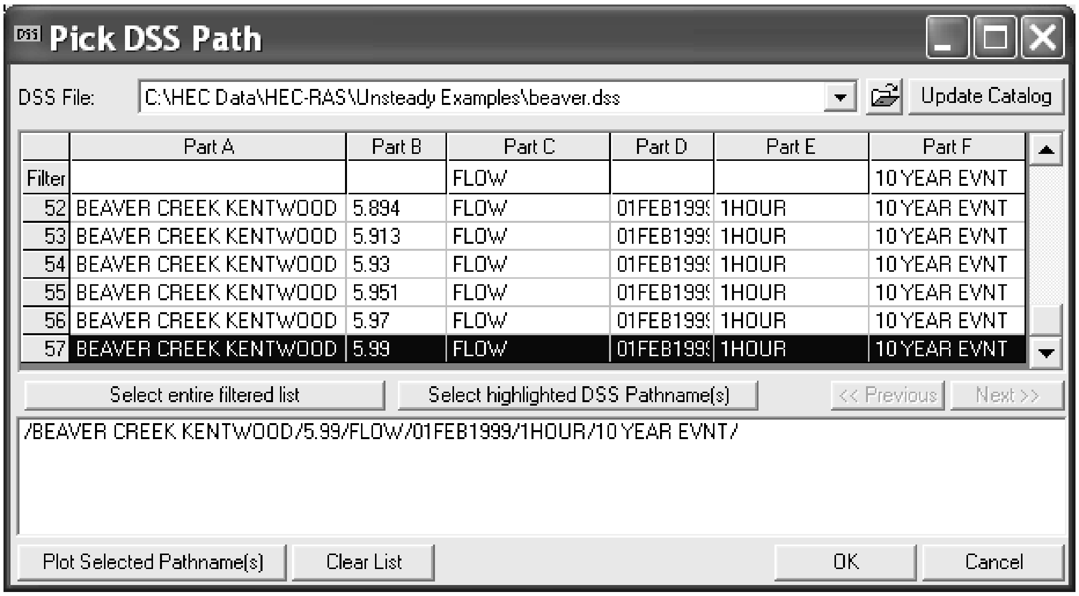
- Read from DSS
  - Select DSS file
  - Select Pathname
- Enter in Table
  - Select time interval
  - Select start date/time
  - Enter flow data - or cut & paste

Flow Hydrograph:

A flow hydrograph can be used as either an upstream boundary or downstream boundary condition, but is most commonly used as an upstream boundary condition. When the flow hydrograph button is pressed, the window shown above will appear. As shown, the user can either read the data from a HEC-DSS (HEC Data Storage System) file, or they can enter the hydrograph ordinates into a table.

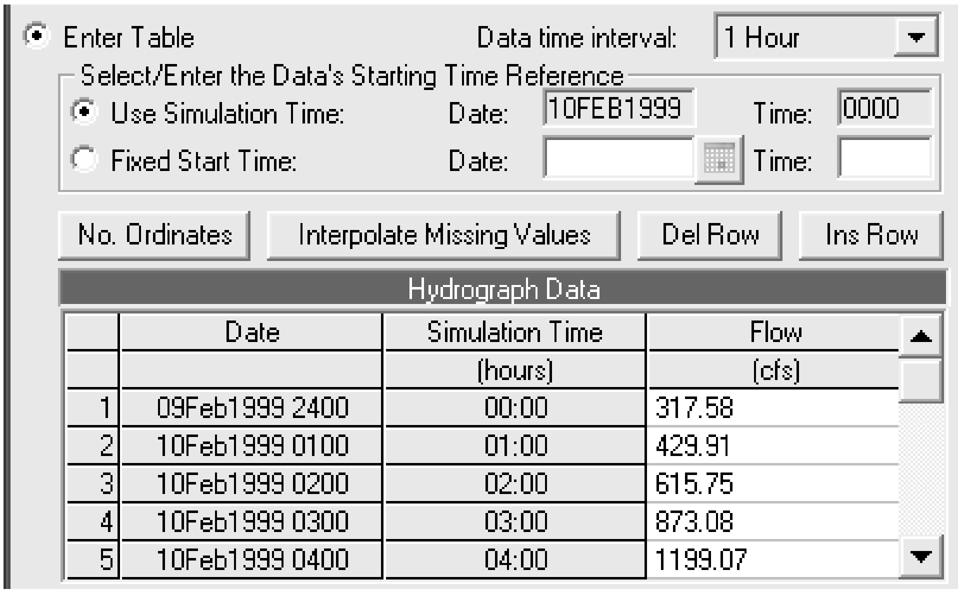
If the user selects the option to read the data from DSS, they must press the **Select DSS File and Path** button. When this button is pressed a DSS file and pathname selection screen will appear as shown on the next page. The user first selects the desired DSS file by using the browser button at the top. Once a DSS file is selected, a list of all of the DSS pathnames within that file will show up in the table. The user can use the pathname filters to reduce the number of pathnames shown in the table. The last step is to select the desired DSS Pathname and to close the window.

Select DSS file and Path



When the **Select DSS File and Path** button is pressed a DSS file and pathname selection screen will appear as shown above. First select the desired DSS file by using the browser button at the top. Once a DSS file is selected, a list of all of the DSS pathnames within that file will show up in the table. The user can use the pathname filters to reduce the number of pathnames shown in the table. The last step is to select the desired DSS Pathname and to close the window.

Enter Flow Data

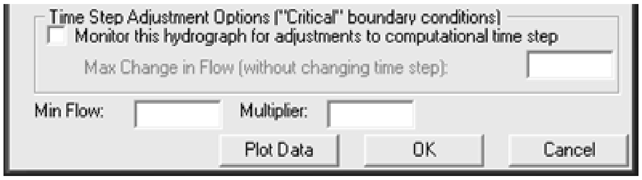


The user also has the option of entering a flow hydrograph directly into a table, as shown above. The first step is to enter a **Data time interval**. Currently the program only supports regular interval time series data. A list of allowable time intervals is shown in the drop down window of the data interval list box. To enter data into the table, the user is required to select either **Use Simulation Time** or **Fixed Start Time**.

If the user selects **Use Simulation Time**, then the entered hydrograph will always start at the beginning of the simulation time window. The simulation starting date and time is shown next to this box, but is grayed out.

If the user selects **Fixed Start Time** then the hydrograph is entered starting at a user specified time and date. Once a starting date and time is selected, the user can then begin entering the data.

Monitor Flow Rate-of-change



- Added option for Flow Hydrograph data
  - Set Maximum Flow Change in time step
  - If input data exceeds max, program will shorten computational time step
- Min Flow
- Multiplier

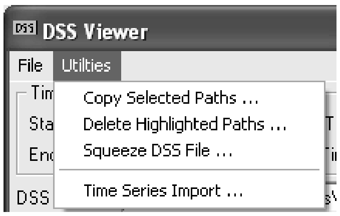
An additional option listed on the flow hydrograph boundary condition is to "**Monitor this hydrograph for adjustments to computational time step**." When you select this option, the program will monitor the inflow hydrograph to see if a change in flow rate from one time step to the next is exceeded. If the change in flow rate does exceed the user entered maximum, the program will automatically cut the time step in half until the change in flow rate does not exceed the user specified max. Large changes in flow can cause instabilities. The use of this feature can help to keep the solution of the program stable.

Also, the flow hydrograph for model boundaries can be monitored to ensure that the flow values do not drop below an input minimum value. If the value is less than the minimum, the value is set to the minimum.

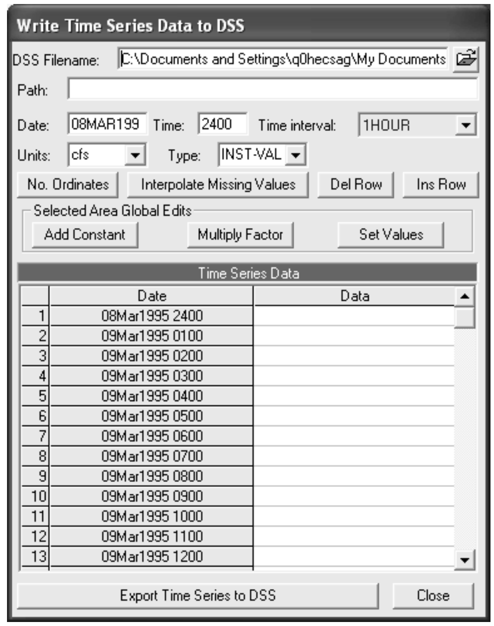
Additionally, the flow hydrograph for model boundaries can be easily modified by a constant ratio. This allows easy testing of model sensitivity to input flow values, or an analysis of model results with larger flood events.

These features appear on most flow input editors.

Enter Data to a DSS file



- Pathname
- Start date & time
- Time interval
- Units
- Data type
- Enter data, or
- Copy / Paste



Entering time-series data into a DSS file is an alternative to entering time-series data directly into the simulation. By entering the data into the file, it is available for use in other simulations. While DSS has DOS programs to accomplish data entry, this is the easiest Windows method at this time.

The function is a DSS Viewer Utility. The Write Time Series Data to DSS window provides for data entry of all the required pathname and header information. Then the data can be entered directly into the table. Or, if the data are available in a spreadsheet or similar table, the data can be copied and pasted into the input table.

Sources of Time-Series Data

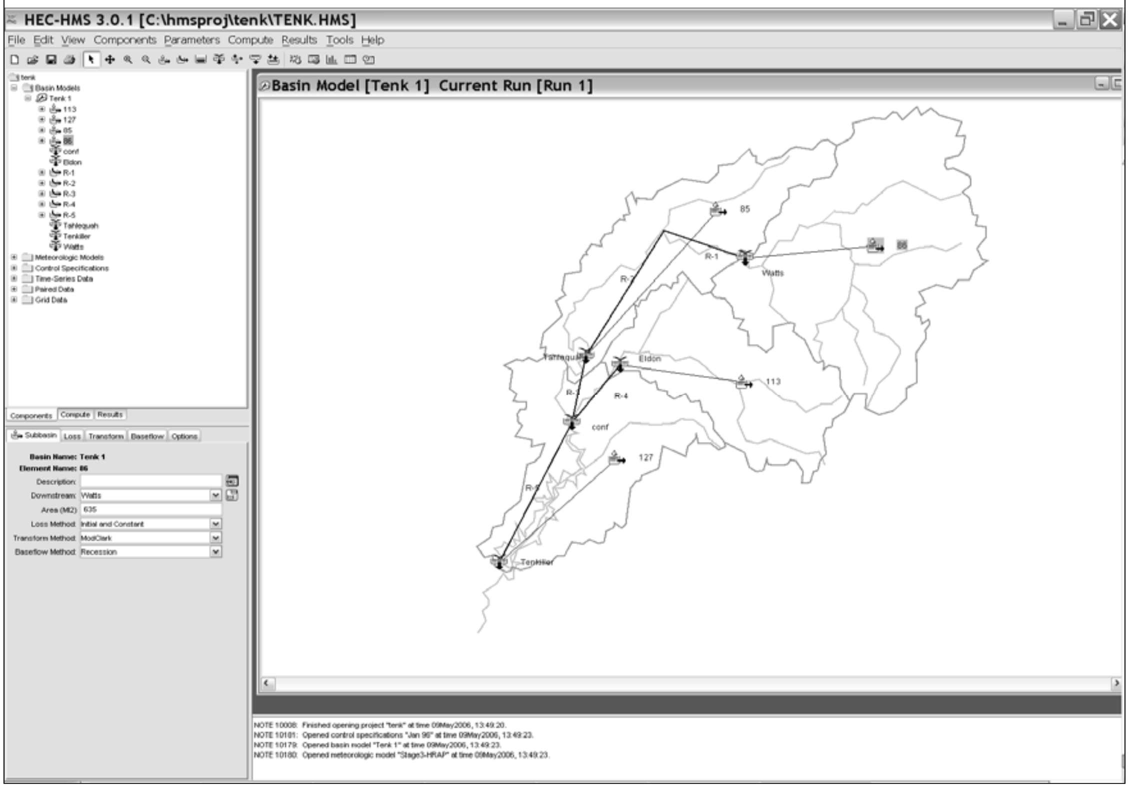
- Historic Records (USGS)
  - Stage Hydrographs
  - Flow Hydrographs
- Computed Synthetic Floods
- Peak Discharge with assumed time distribution
- Rainfall-runoff modeling

Unsteady-flow modeling provides a dynamic solution for stage and flow throughout the river network. The primary boundary data are time-series flow, typically for a flood event. Where do you get that flow data?

For most program user's, the simulation will route an upstream flow hydrograph, using a downstream rating curve or normal depth. The upstream hydrograph can be:

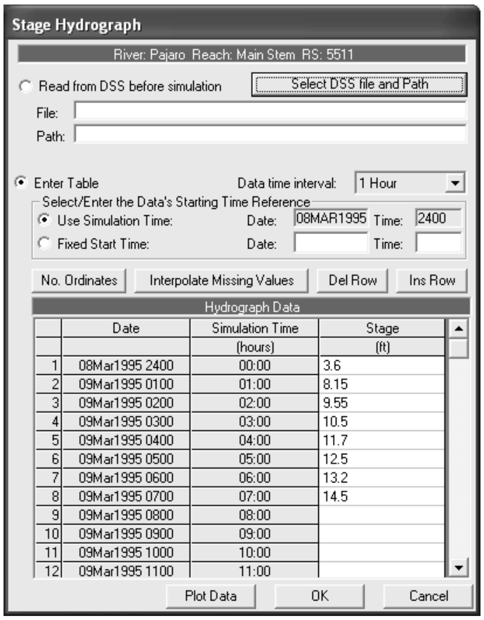
- Historic, like those obtained from the US Geologic Service.
- Synthetic, often, prior studies have computed and published synthetic floods like the Corps' Standard Project (SPF) or the Probable Maximum Flood (PMF).
- Modeling, using rainfall-runoff models like the Corps' Hydrologic Modeling System (HEC-HMS).
- Peak Discharge, and a time to peak estimate, can be used to provide a crude hydrograph using the HEC-RAS interpolation routine (Triangle hydrograph). If a Unit Hydrograph is available, that distribution can be used to develop a flow hydrograph.

HEC-HMS Basin Schematic



The HEC-HMS program can be used to model the rainfall-runoff process in the contributing watershed (catchment). Even when there are some gauged data in the watershed, the hydraulic model may require lateral inflow data and tributary flows where no gauged data exists. A basin model can be developed to provide the necessary data at all model locations. By careful coordination of study requirements and key information locations, the model nodes can be identified and modeled consistently among various computer programs. The data can be conveniently transferred through different models using the HEC-DSS file system.

Stage Hydrograph

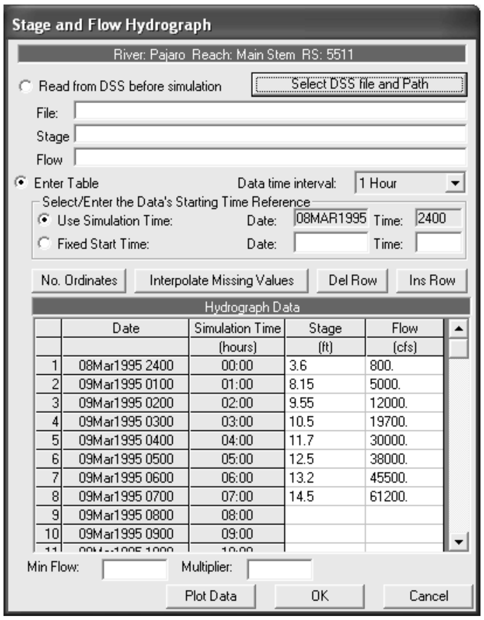


- Read from DSS
  - Select DSS file
  - Select Pathname
- Enter in Table
  - Select time interval
  - Select start date/time
    - Simulation time
    - Fixed starting time
  - Enter stage data - or cut & paste

Stage Hydrograph:

A stage hydrograph can be used as either an upstream or downstream boundary condition. The editor for a stage hydrograph is similar to the flow hydrograph editor shown above. The user has the choice of either attaching a HEC-DSS file and pathname or entering the data directly into a table.

Stage and Flow Hydrograph

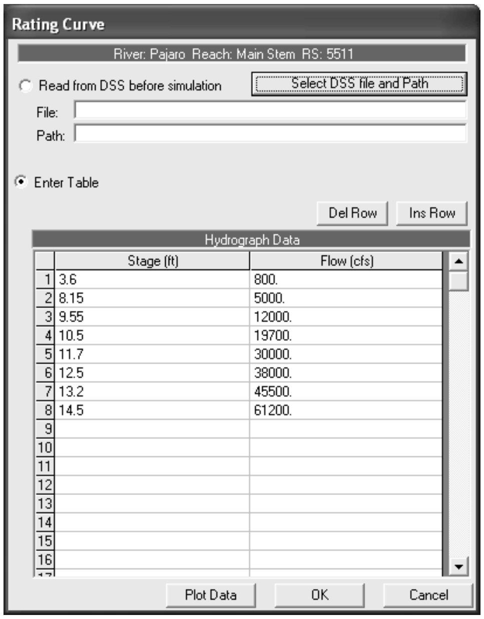


- Upstream Mixed
  - Stage used while defined
  - Flow used after
- Purpose:
  - Real-time use
  - Mix observed stage with
  - Forecasted flow

Stage and Flow Hydrograph:

The stage and flow hydrograph option can be used together as either an upstream or downstream boundary condition. The upstream stage and flow hydrograph is a mixed boundary condition where the stage hydrograph is inserted as the upstream boundary until the stage hydrograph runs out of data; at this point the program automatically switches to using the flow hydrograph as the boundary condition. The end of the stage data is identified by the HEC-DSS missing data code of “-901.0". This type of boundary condition is primarily used for forecast models where the stage is observed data up to the time of forecast, and the flow data is a forecasted hydrograph.

Rating Curve



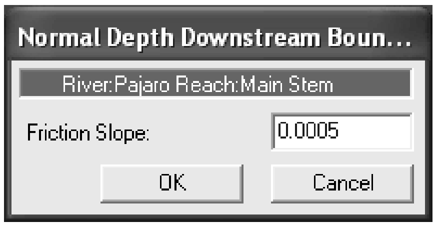
- Single value rating
- Downstream boundary
- Read from DSS
  - Select DSS file
  - Select Pathname
- Enter in Table
  - Enter stage- flow data - or
  - Cut & paste

Rating Curve:

The rating curve option can be used as a downstream boundary condition. The user can either read the rating curve from HEC-DSS or enter it by hand into the editor.

The downstream rating curve is a single valued relationship, and does not reflect a loop in the rating, which may occur during an event. This assumption may cause errors in the vicinity of the rating curve. The errors become a problem for streams with mild gradients where the slope of the water surface is not steep enough to dampen the errors over a relatively short distance. When using a rating curve, make sure that the rating curve is a sufficient distance downstream of the study area, such that any errors introduced by the rating curve do not affect the study reach.

Normal Depth



- Enter Friction (energy) Slope
- Program uses Manning's equation to compute stage
- Provides "Normal Depth" downstream boundary

Normal Depth:

The Normal Depth option can only be used as a downstream boundary condition for an open-ended reach. This option uses Manning's equation to estimate a stage for each computed flow. To use this method the user is required to enter a friction slope for the reach in the vicinity of the boundary condition. The slope of the water surface is often a good estimate of the friction slope.

As recommended with the rating curve option, when applying this type of boundary condition you should place it far enough downstream of the study reach, such that any errors it produces will not affect the results at the study reach.

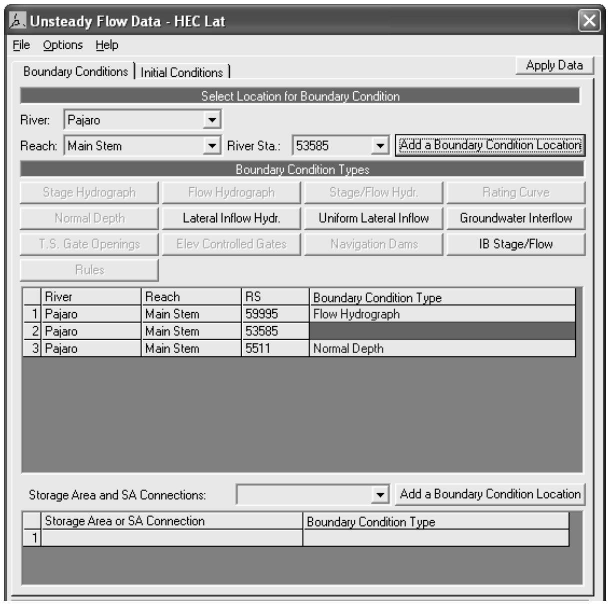
Adding an Internal Boundary

- Select:
  - River
  - Reach
  - River Station
- Add a Boundary Condition Location
- Location added to the list of Boundary Conditions

The Unsteady Flow Data editor automatically has the external boundaries defined, based on the geometric data model. The user can add internal boundary locations to define additional lateral flow. Also, when weirs with gates are added, the gate operation will be defined as an internal boundary.

Select the River, Reach and River Station where the data will be added. Then press **Add a Boundary Condition Location**. The location is added to the boundary condition table.

Internal Boundary Conditions



- Lateral Inflow Hydrograph
- Uniform Lateral Inflow
- Groundwater Interflow
- Also:
  - Gate openings
  - Navigation Dams
  - Internal Stage/Flow

Lateral Inflow Hydrograph: This internal boundary condition allows the user to bring in flow at a specific point along the stream.

Uniform Lateral Inflow Hydrograph: This internal boundary condition allows the user to bring in a flow hydrograph and distribute it uniformly along the river reach between two specified cross sections.

Groundwater Interflow: This option allows the user to identify a reach that will exchange water with a groundwater reservoir.

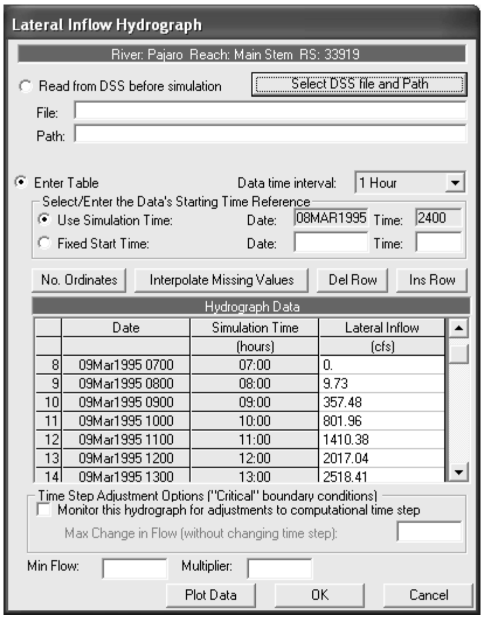
<u>THE FOLLOWING WILL BE PRESENTED IN THE GATE LECTURE</u>

Time Series of Gate Openings. This option allows the user to enter a time series of gate openings for an inline gated spillway, lateral gated spillway, or a spillway connecting two storage areas.

Elevation Controlled Gate. Define the opening and closing of gates based on the elevation of the water surface elevation upstream from the structure.

Navigation Dams: Simulate the gate operations for navigation dams attempting to maintain navigation depths.

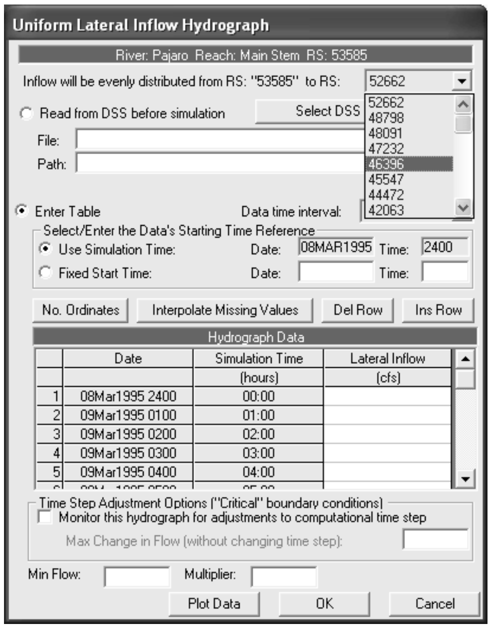
Lateral Inflow Hydrograph



- Lateral flow downstream from a Cross Section
- Read from DSS
  - Select DSS file
  - Select Pathname
- Enter in Table
  - Select time interval
  - Select start date/time
  - Enter flow data - or cut & paste

Lateral Inflow Hydrograph: This internal boundary condition allows the user to bring in flow at a specific point along the stream. The user attaches this boundary condition to the river station of the cross section just upstream of where the lateral inflow will come in. The actual change in flow will not show up until the next cross section downstream from this inflow hydrograph. The user can either read the hydrograph from DSS or enter it by hand.

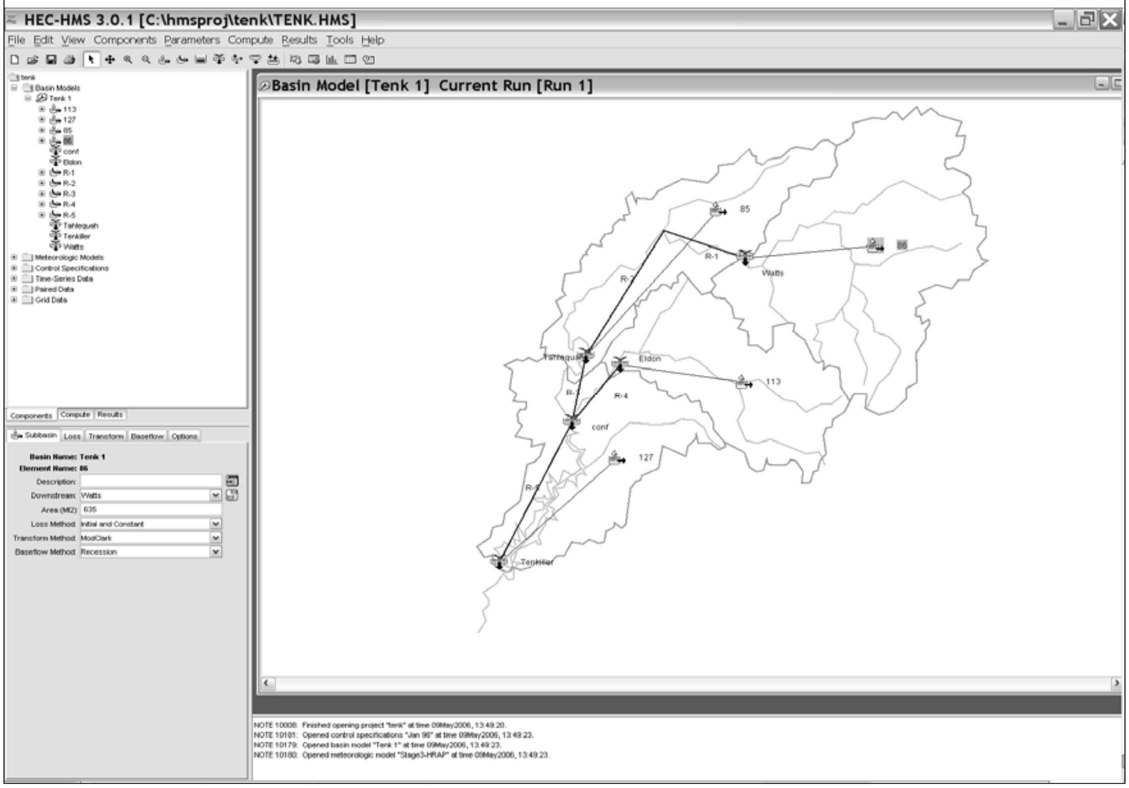
Uniform Lateral Flow Hydrograph



- Uniform Lateral flow to a reach element
- Add Internal Location at Upstream River RS
- Set Downstream RS
- Read from DSS
- Enter in Table

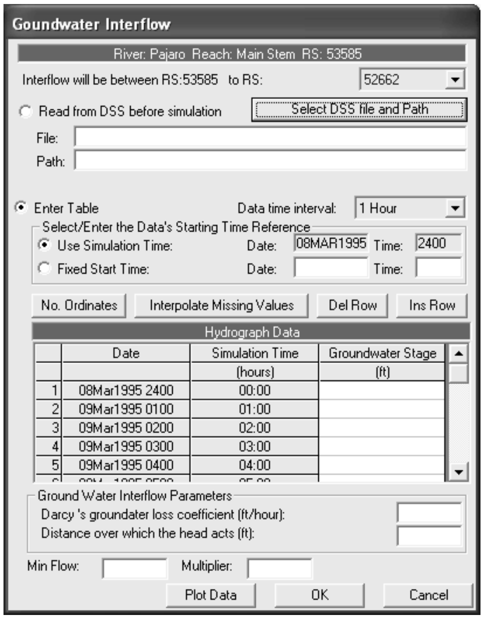
Uniform Lateral Inflow Hydrograph: This internal boundary condition allows the user to bring in a flow hydrograph and distribute it uniformly along the river reach between two specified cross sections. The hydrograph for this boundary condition type can be either read from DSS, or entered into a table.

HEC-HMS Basin Schematic



HMS provides individual watershed flows locations. If a reach flows through a watershed the hydrograph can be distributed along the reach with the distributed flow boundary condition.

Groundwater Interflow



- Add Internal Location at Upstream River RS
- Set Downstream RS
- Input Groundwater Stage
  - Read from DSS
  - Enter in Table
- Darcy's Loss Coefficient
- Distance between stages of river & groundwater

Groundwater Interflow: This option allows the user to identify a reach that will exchange water with a groundwater reservoir. The stage of the groundwater reservoir is assumed to be independent of the interflow from the river, and must be entered manually or read from DSS. The groundwater interflow is similar to a uniform lateral inflow in that the user enters an upstream and a downstream river station, in which the flow passes back and forth. The computed flow is proportional to the head between the river and the groundwater reservoir. The computation of the interflow is based on Darcy's equation. The user is required to enter Darcy's groundwater loss coefficient (hydraulic conductivity), as well as a time series of stages for the groundwater aquifer.

The groundwater algorithm is simplistic; simulating flow in only one direction, laterally, perpendicular to the river. The groundwater aquifer is assumed to be very large such the the interchange of water with the river has no impact on the groundwater level.

Darcy's Law

$V = K\ S$

V = Velocity (ft/hour)

K = Hydraulic Conductivity (ft/hour)

S = Slope (ft/ft) = Stage difference / Distance

$Q = V\ A$

Q = Flow (cfs)

A = Area, perpendicular to the flow (ft^2)

- – Top width x length, if groundwater below channel
- – Valley width x length plus channel depth x length, if groundwater is above channel invert

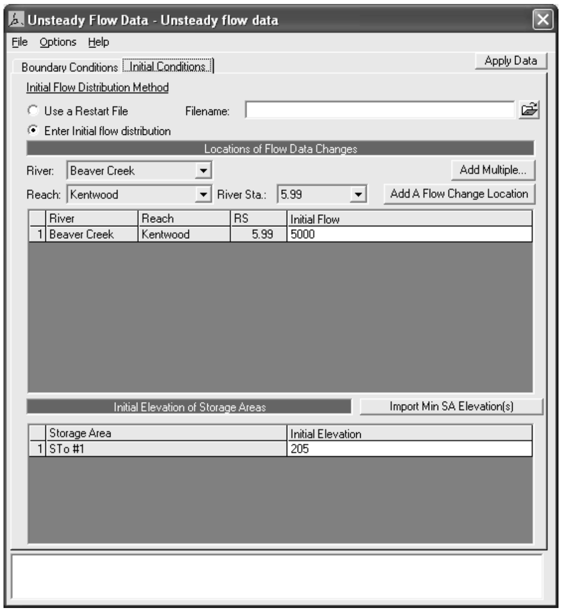
Darcy's Law (1856) applied the principles of fluid flow to the flow of water in a permeable media. The velocity of flow equals the product of a coefficient times the hydraulic gradient. The flow equals the velocity times the effective area = gross area times porosity of the media. (*Hydrology for Engineers, by LKP*)

- In RAS, the slope is computed by the difference between the water elevation at the cross section and the input groundwater elevation, divided by the input Distance.
- The area is length times the flow width.
- The length is the channel length for the reach element (between upstream and downstream River Stations).
- The flow width depends on the groundwater level.

  If the groundwater level is below the invert of the channel, the flow is down from the channel and the width is the average top width.

  If the groundwater level is above the invert, the width is the overbank width plus the channel depth, estimated by the average channel water elevation minus the groundwater elevation.

Initial Conditions



- Requires an initial flow for all reaches
- Enter steady-flow at upstream boundary
- Can add a flow-change location
- Pool elevation for storage areas
- Use system status from previous simulation (restart)

Initial Conditions In addition to the boundary conditions, the user must establish the initial conditions of the system at the beginning of the unsteady flow simulation. Initial conditions consist of flow and stage information at each of the cross sections, as well as elevations for any storage areas defined in the system. Select the **Initial Conditions** tab to bring up the data editor, shown above. There are two options for establishing the initial conditions.

The first option is to enter flow data for each reach and have the program perform a steady flow backwater run to compute the corresponding stages at each cross section. This option also requires the user to enter a starting elevation for any storage areas in the system. This is the most common method for establishing initial conditions.

A second method is to read a file of stages and flows written from a previous run, which is called a “Restart File”. This is often used when running a long simulation time that must be divided into shorter periods. The output from the first period is used as the initial conditions for the next period, and so on. However, the RAS model has a dynamic allocation procedure to overcome the time-dimension limit.

Initial Conditions Data

- Initial Flow data
  - Should be nearly steady-state conditions
  - Starting flow from upstream hydrograph
  - Flow distribution from Steady Flow profile
- Initial Elevation in Storage areas
  - Stage from historic data
  - Initial early in event, dry conditions
- Hot Start file from previous simulation

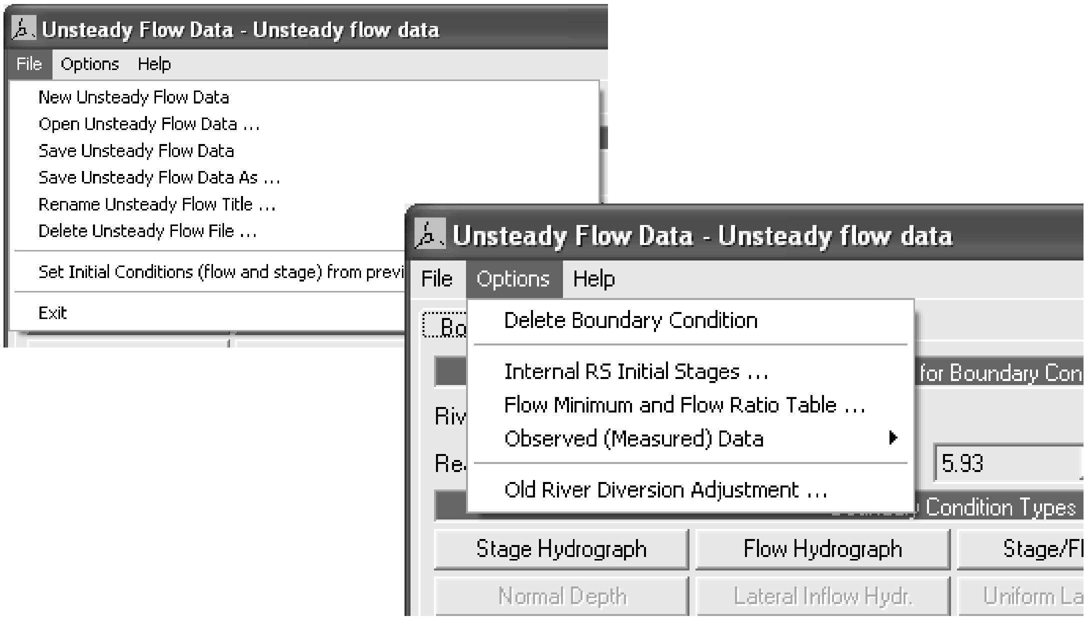
In most applications, the initial condition is a steady-flow water surface profile throughout the river system. If a constant flow is defined for each river reach, that flow should represent a condition when flows are fairly stable, i.e., a period prior to the start of the flood. The initial value should be the starting flow in the inflow hydrograph. You do not want a large change in flow between the initial flow and the first inflow value.

The flows in the river system should be consistent. For a complex river network, resolve the flow distribution using steady-flow analysis. The new option for optimizing the flow distribution could be used to help develop a consistent flow set.

If flow is not steady at the start of simulation, you can use hydrologic routing to estimate the flows through the river system. Flow changes can be input in the initial condition, just like steady flow data. An HMS model could be used for this purpose. Remember, the initial flow in the hydrologic model is steady flow.

The Hot Start file can be saved from a simulation. Additionally, this option may be used when the software is having stability problems at the beginning of a run. Run the model with all the inflow hydrographs set to a constant flow, and set the downstream boundaries to a high tailwater condition. Run the model with decreasing tailwater down to a normal stage over time. Once the tailwater is a reasonable value for the constant flow, those conditions can be written out to a file, and then used as the starting conditions.

File and Options Menus

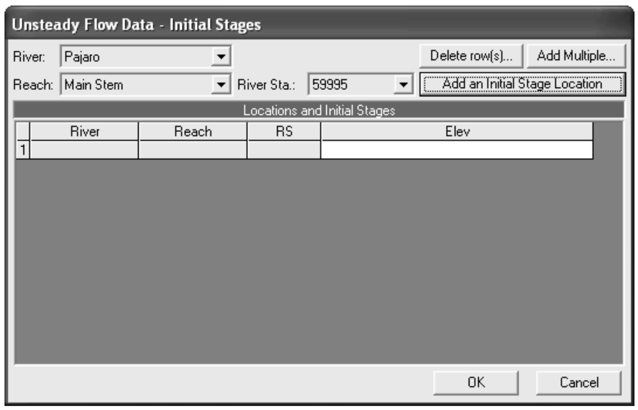


The Unsteady Flow Window has the standard **File Menu** options. It is a good idea to save the data before going on to the next step.

The **Options Menu** has four options:

- Delete an added Boundary Condition. You cannot delete external boundaries because they are required.
- Internal RS Initial Stages to set a stage at the start of simulation.
- Flow Minimum and Flow Ratio Table
- Add Observed Data - this option is helpful when calibrating model to simulate an historic flood event.

Internal RS Initial Stages

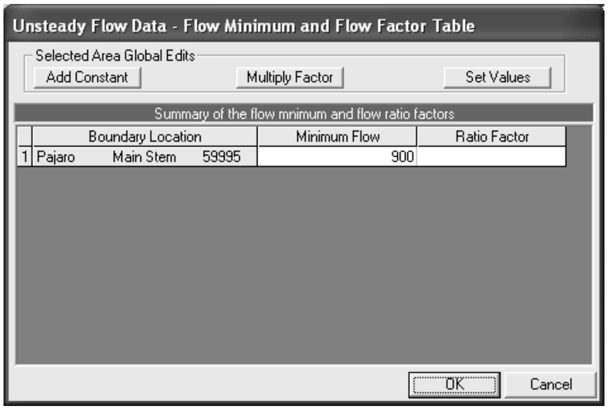


- Select:
  - River
  - Reach
  - River Station
- Add Location to table below
- Define Initial Elevation

The initial stage can be set for a river station. Normally, this would be defined by the computed water surface profile during the initial conditions stage of the computation process. This option is useful at locations upstream from a control structure where the initial stage is NOT the 'normal' backwater elevation.

Select the River, Reach and River Station where the initial stage is to be defined. Then 'click' the **Add an Initial Stage Location** button. The location will be added to the table below. Then you can enter the initial stage for that location.

Flow Minimum & Flow Ratio Table



- Global Editing to:
  - Add constant,
  - Multiply values, or
  - Set Values
- Minimum Flow value for boundary
- Multiplying factor to modify hydrograph for boundary

The boundary hydrographs can be modified with global editing to:

Add a constant value to the input

Multiply input values by a factor

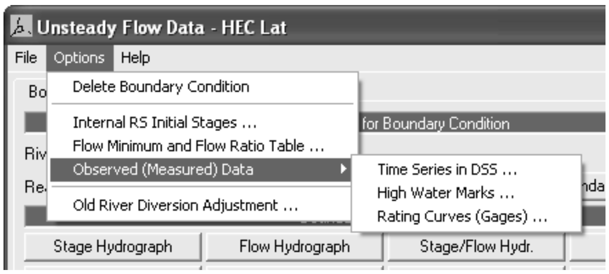
Set values to an input value

The following two options are also available on all flow hydrograph input windows.

1. The flow hydrograph for model boundaries can be monitored to ensure that the flow values do not drop below an input minimum value. If the value is less than the minimum, the value is set to the minimum.

2. The flow hydrograph for model boundaries can be easily modified by a constant ratio. This allows easy testing of model sensitivity to input flow values, or an analysis of model results with larger flood events.

Observed (Measured) Data

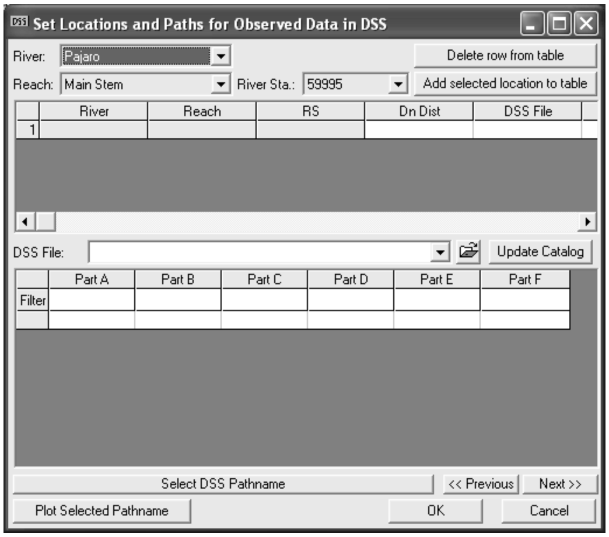


- Time Series in DSS
- High Water Marks
- Rating Curve (Gage)

There are 3 options available to enter observed data:

1. Time-series data can be entered to define observed stage or flow data. There data must be in a DSS file.
2. High-water marks can be defined
3. A Rating Curve can be defined

Observed Time Series Data

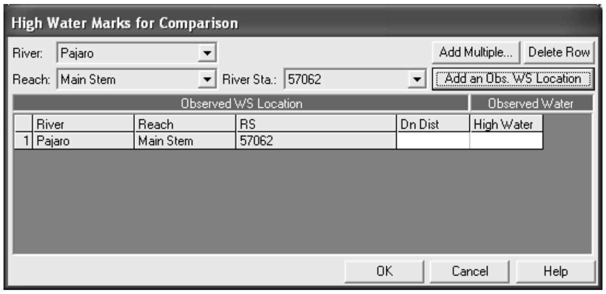


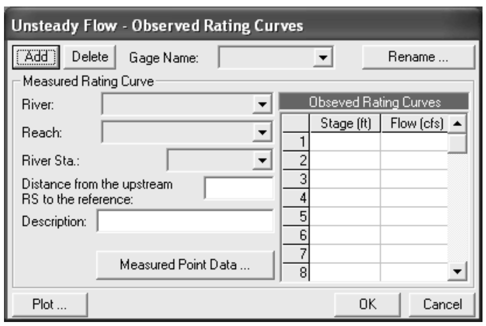
- Add Selected location
  - River
  - Reach
  - River Station
- Select DSS File
- Select Pathname to read Observed Data

Observed time-series data can be added to the unsteady flow data set. First select the model location where the observed data would apply. Select River, Reach, and River Station and press **Add selected location**. The location will appear in the table below. Several locations can be selected.

The second step is the selection of DSS records to read the observed data. The lower half of the window has the standard DSS file and record selection features. Filters can be selected for pathname parts to facilitate record selection. A DSS Record should be selected for each Location selected. Remember the time window set for the simulation will be used to extract the observed data, so be sure there is observed data for the time window.

High Water & Rating Curves





- High Water
  - Select location
  - Add an Obs. WS
  - Define Distance downstream & stage
- Observed Rating
  - Select location
  - Distance downstream
  - Stage – Flow data

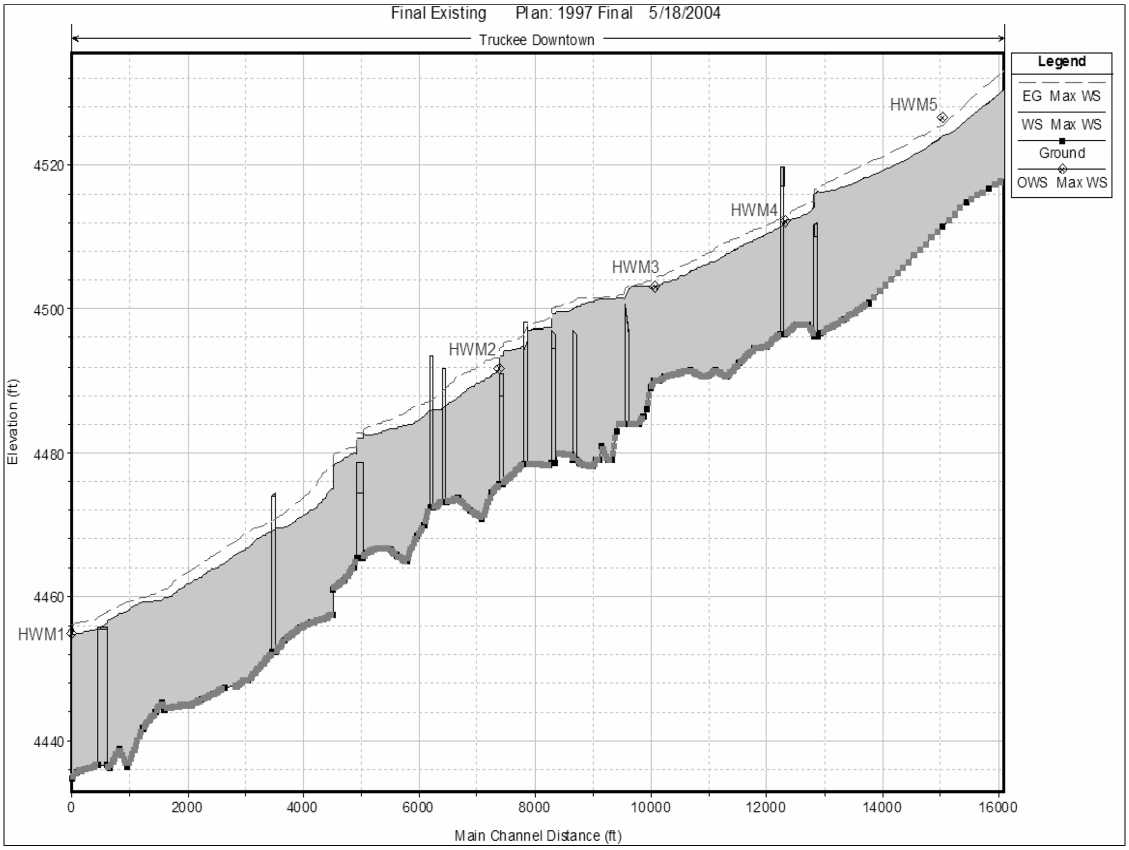
High Water Marks can be defined for locations along the river reach.

First the nearest upstream cross section is selected and added to the Observed Water Surface Locations. The distance downstream from the section and the observed stage are then entered in the table.

Observed Rating provides for a Rating Curve or Measured Flow Data to be entered.

1. The Rating curve is defined in typical Stage – Flow relationship, starting from the lowest stage and sequentially increasing.
2. The Measured Point Data is entered by pressing that button and entering the observed stage and flow, along with optional description. These data do not have to define a complete rating.

Boundary & Initial Conditions



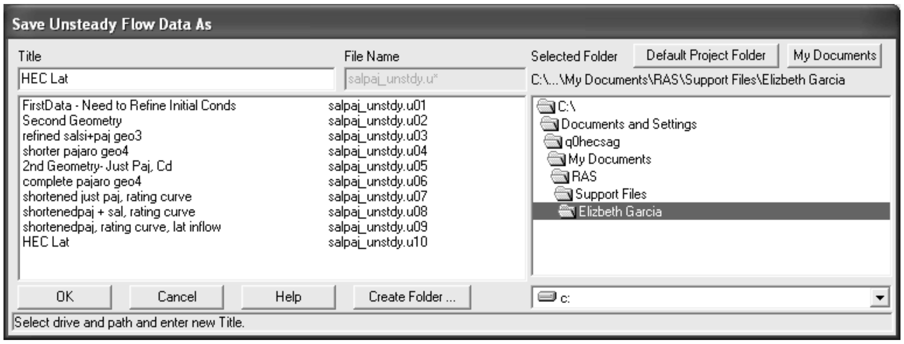
High Water Marks can be defined for locations along the river reach.

First the nearest upstream cross section is selected and added to the Observed Water Surface Locations. The distance downstream from the section and the observed stage are then entered in the table.

Observed Rating provides for a Rating Curve or Measured Flow Data to be entered.

1. The Rating curve is defined in typical Stage – Flow relationship, starting from the lowest stage and sequentially increasing.
2. The Measured Point Data is entered by pressing that button and entering the observed stage and flow, along with optional description. These data do not have to define a complete rating.

File Unsteady Flow Data



- Save Unsteady Flow Data
- Provide Descriptive Title
- Ready for Unsteady Simulation

After entering all required data, save the file to permanently write the data to disk. Once complete, the next step is to set up an unsteady flow simulation. As with steady-flow simulation, a Plan is established using a Geometry and Unsteady Flow file.