Steady Flow Data Requirements

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Hydraulic and Hydrologic Routing

- Hydrologic Routing (HEC-HMS)
  - Continuity Equation
  - Empirical or Analytical Storage-Discharge Relationship
- Hydraulic Routing (HEC-RAS)
  - Based on Solutions of Partial Differential Eqns.
  - St. Venant's equations (Dynamic Wave Eqns.)
    - Continuity Equation
    - Momentum Equation (Physics of the process)

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In general, routing techniques may be classified into two categories: hydraulic routing and hydrologic routing. Hydraulic routing techniques are based on the solution of the partial differential equations of unsteady open channel flow. These equations are often referred to as the St. Venant equations or the dynamic wave equations. Hydrologic routing employs the continuity equation and either an analytical or an empirical relationship between storage within the reach and discharge at the outlet as a replacement for the momentum equation.

This lecture describes several hydraulic and hydrologic routing techniques. Assumptions, limitations, and data requirements are discussed for each. The basis for selection of a particular routing technique are reviewed, and general guidelines to aid in the selection process are presented. This paper is limited to discussions on one dimensional flow routing techniques.

Froude number

$$F = \frac{V}{\sqrt{gD}}$$

Inertial Forces

Gravitational Forces

Where:

V = Mean velocity of flow (Q/A)
g = gravitational acceleration
D = Hydraulic Depth (A/T)

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The effect of gravity on the state of flow is represented by a ratio of inertial forces to gravity forces. This ratio is given by the Froude number.

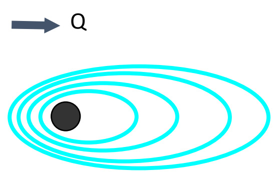
Subcritical flow has a low velocity and is often described as tranquil or streaming. In this state the role played by gravity forces is more pronounced. Supercritical flow has a high velocity and is often described as rapid, shooting, or torrential. In this state the inertial forces are dominant.

Flow Regime Types

- Subcritical Flow

$$V < \sqrt{gD}$$

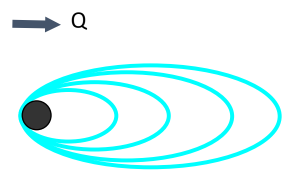
$$F < 1$$



- Supercritical Flow

$$V > \sqrt{gD}$$

$$F > 1$$



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Flow Regime Types

- Subcritical Flow $V < \sqrt{gD}$
- Critical Flow $V = \sqrt{gD}$
- Supercritical Flow $V > \sqrt{gD}$

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It is important to note that a gravity wave caused by a disturbance can propagate upstream in subcritical flow, but not supercritical flow. In subcritical flow, a disturbance that raises the water surface elevation at one location will cause the water surface to increase upstream for some distance. Because of this fact, when computing a subcritical water surface profile, the computations must start downstream and proceed in the upstream direction. For supercritical flow, disturbances only propagate in the downstream direction. The computation of supercritical water surface profiles starts upstream and continues in the downstream direction.

Usually, the flow in most natural channels is subcritical. However, some natural channels may have short reaches of supercritical flow. Constructed channels are either designed to flow in the subcritical or supercritical flow regime. On occasion natural or constructed channels may demonstrate flow in both regimes. This is a **mixed flow regime** situation, and requires special consideration when modeling the flow transitions.

Flow Transitions

- Establishment of Uniform Flow
- Definition of Uniform Flow
- Chezy equation: $V = C\sqrt{RS}$
- Manning's Equation: $V = \frac{1.49}{n} R^{2/3} S^{1/2}$

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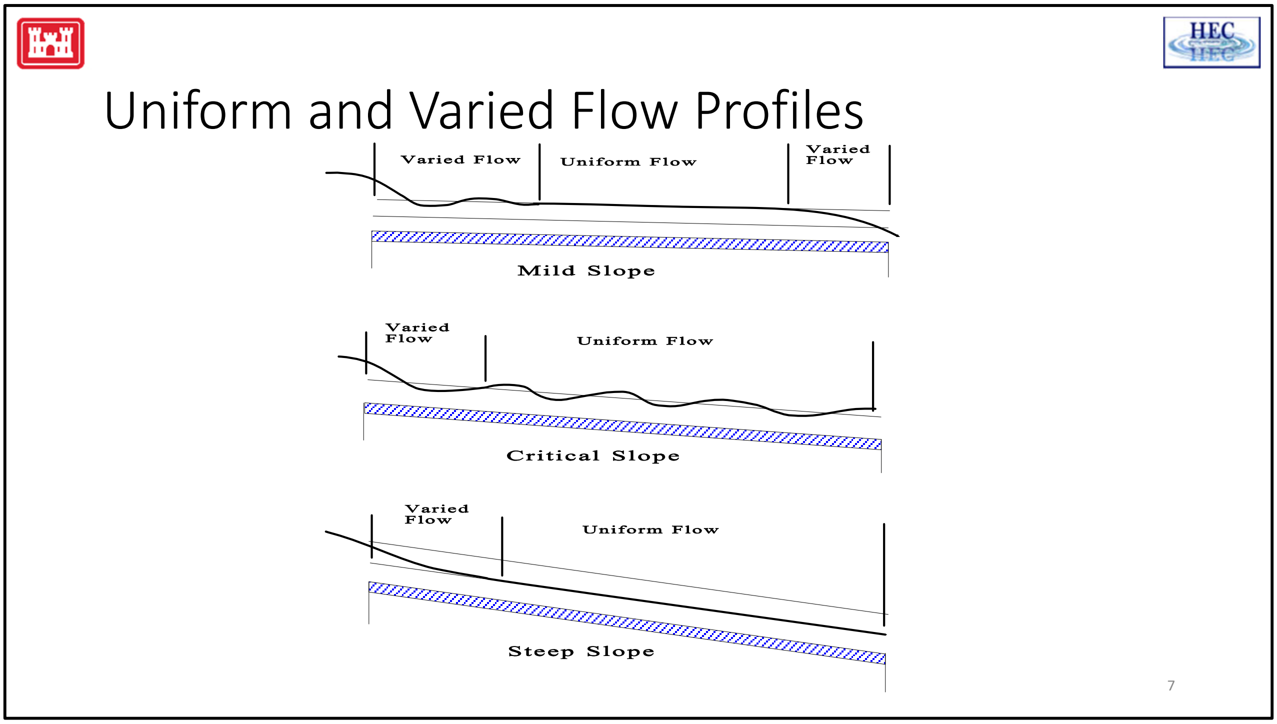
Understanding whether the flow is in the subcritical or supercritical flow regime, and how the flow transitions from one regime to another, is an important aspect of computing accurate water surface profiles.

When flow occurs in an open channel, resistance is encountered by the water as it flows downstream. This resistance is generally counteracted by the components of gravity forces acting on the body of the water in the direction of motion. Uniform flow will develop if the resistance is balanced by these gravity forces.



Mild Slope $Y_n > Y_c$
Critical Slope $Y_n = Y_c$
Steep Slope $Y_n < Y_c$

When evaluating how a water surface profile transitions among the three flow regions, the following rules must be applied:

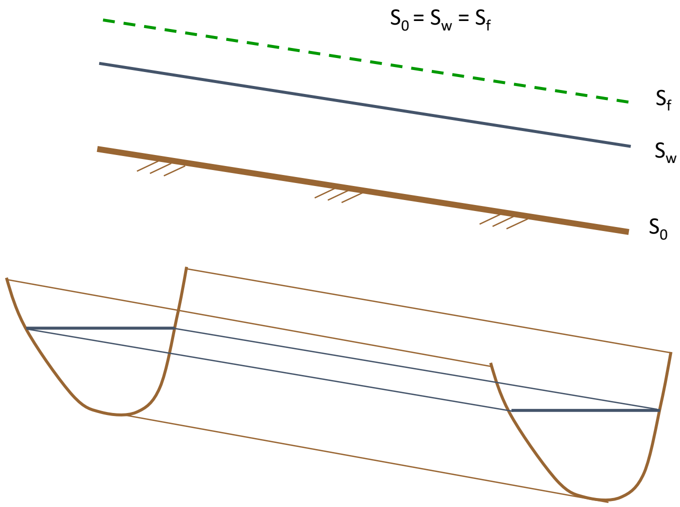
1. As the depth of water approaches normal depth, the slope of the water surface becomes asymptotic to the normal depth profile.

2. As the depth of water approaches critical depth, the slope of the water surface tends toward a perpendicular line to the critical depth line.

3. As the depth of water approaches zero, the slope of the water surface tends toward a perpendicular line with the channel bottom.

4. As the depth of water goes toward infinity ($Y > Y_n$ and $Y > Y_c$), the slope of the water surface approaches a horizontal line.

Definition Sketch for Uniform Flow



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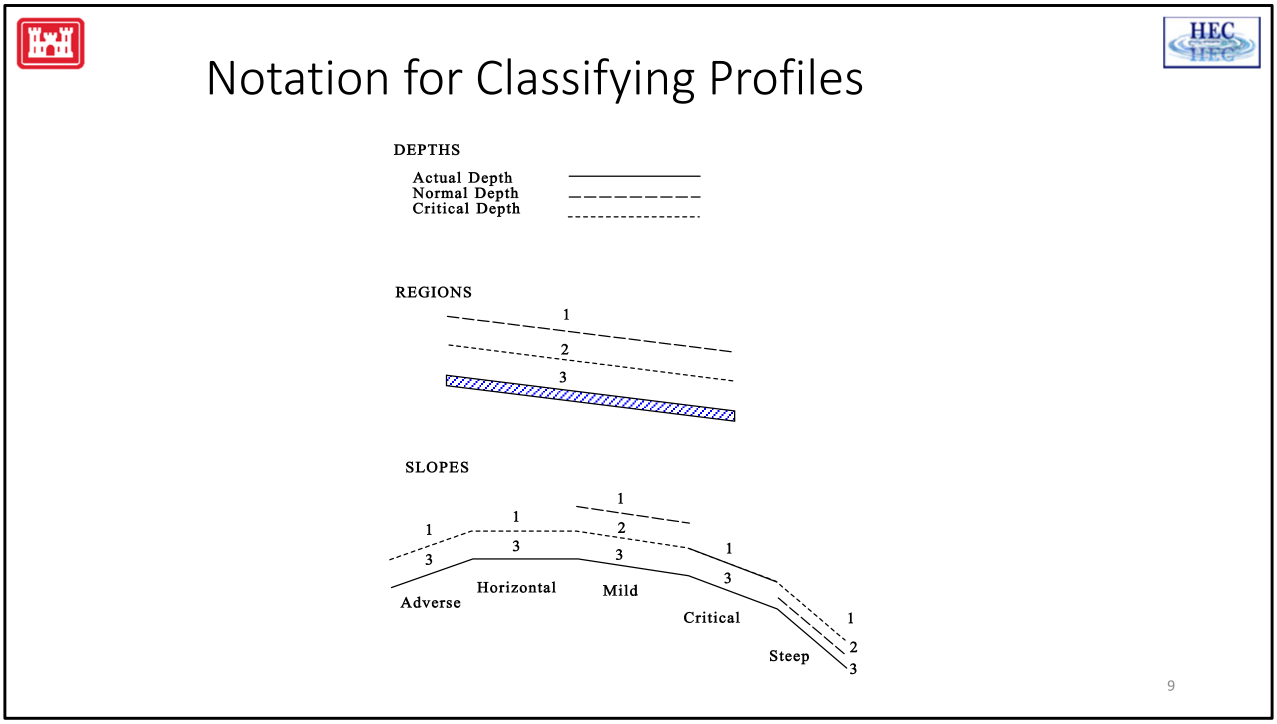
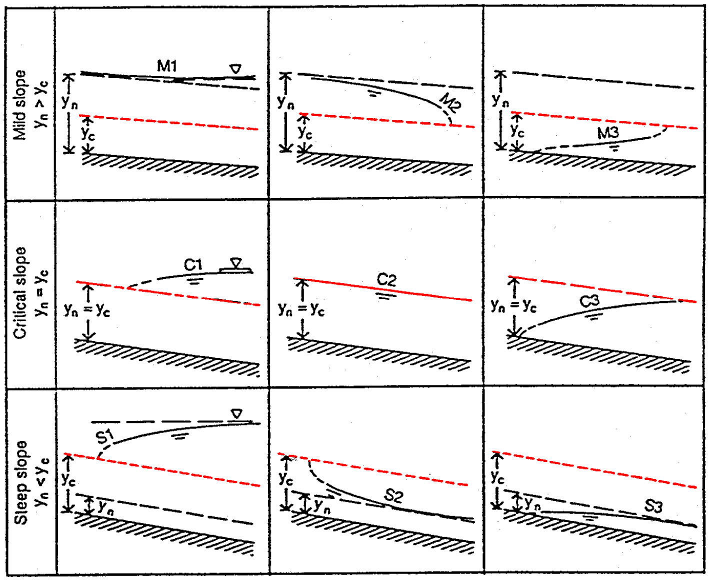
The gradually varied flow that we will discuss is steady flow whose depth varies gradually along the length of the channel. This definition requires that two conditions be met: (1) the flow is steady (i.e., all of the variables remain constant for the time interval under consideration), and (2) the streamlines are approximately parallel (i.e., the pressure distribution over the cross section can be considered hydrostatic).

Uniform flow has been established when: (1) the depth, water area, velocity, and discharge at every section of the channel reach are constant; and (2) the energy line, water surface, and channel bottom are all parallel (i.e., S_f=S_w=S_o). Manning’s equation is a uniform flow equation.



Five types of channel slopes exist: (1) adverse, (2) horizontal, (3) mild, (4) critical, and (5) steep. The mechanics of determining if a channel has an adverse or horizontal slope is quite simple. If the bed of the river has a positive slope, the slope is adverse; if the channel bottom lies in a horizontal plane, the slope is horizontal. To distinguish between mild, critical, and steep slopes is not as straightforward and comparison of normal and critical depth is probably the easiest way to categorize these slopes.

Possible Flow Profiles



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“The M1 profile represent the most well known backwater curve; it is the most important of all flow profiles from the practical point of view…occurs when the downstream end of a long mild channel is submerged.”

“The M3 profile starts theoretically from the upstream channel bottom…and terminates with a hydraulic jump at the downstream end…This type of flow usually occurs when a superciritcal flow enters a mild channel.”

“The S1 profile begins with a jump at the upstream end and becomes tangent to the horisonal pool level at the downstream end.”

“The S2 profile is a drawdown curve. It is usually very short …like a transition between a hydraulic drop and a uniform (super critical) flow.”

Dashes indicate that the profile is leaving the realm of GVF

Required Boundary Conditions

- Subcritical Flow Regime
  - Downstream Boundary Conditions required
- Supercritical Flow Regime
  - Upstream Boundary Conditions required
- Mixed Flow Regime
  - Downstream and Upstream Boundary Conditions required

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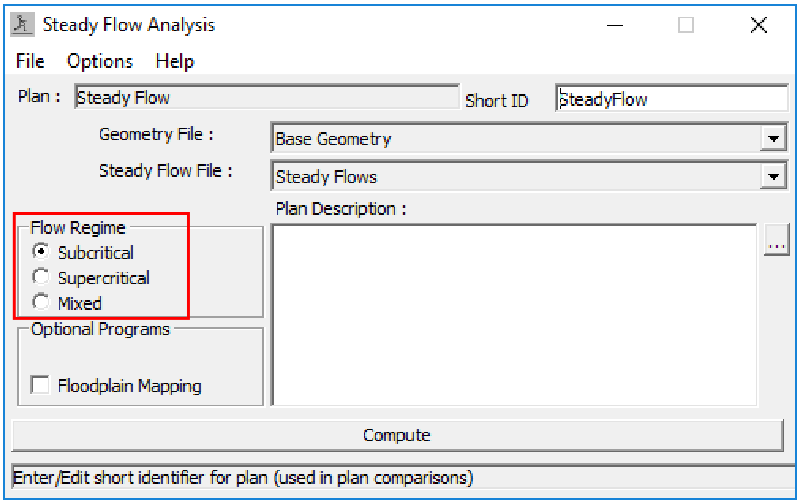
The modeler may be required to establish one or more boundary conditions for a given river system. The number and location of the boundary conditions will depend upon the extent of the river system being modeled, and the flow regime within the system.

Subcritical Flow Regime: boundary conditions are necessary at all of the external downstream ends of the river system.

Supercritical Flow Regime: boundary conditions are necessary at all of the external upstream ends of the river system.

Mixed Flow Regime: boundary conditions must be entered at all external ends of the river system.

Required Boundary Conditions



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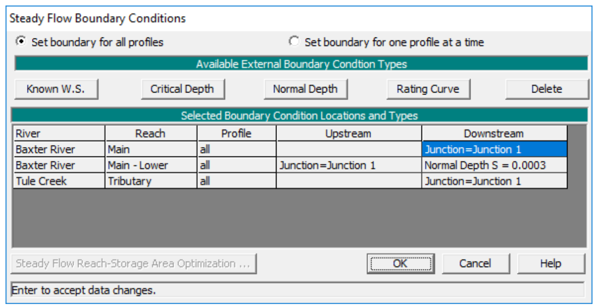
Types of External Boundary Conditions

- Known Water Surface Elevation
- Critical Depth
- Normal Depth (Slope Area - Manning's Eq.)
- Rating Curve



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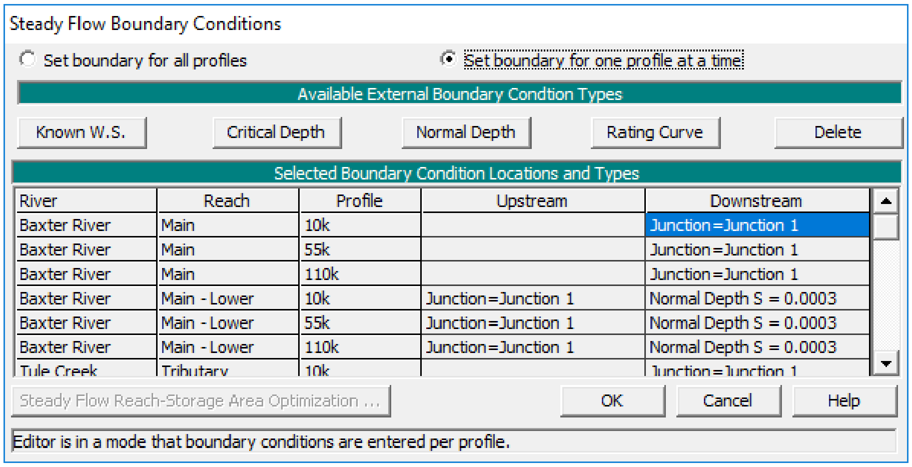
Known Water Surface Elevations - For this type of boundary condition the user must enter a known water surface elevation for each of the profiles to be computed.

Critical Depth - When this type of boundary condition is selected, the user is not required to enter any further information. The program will calculate critical depth for each profile and use that as the boundary condition.

Normal Depth - For this type of boundary condition, the user is required to enter an energy slope that will be used in calculating normal depth (using Manning's equation) at that location. A normal depth will be calculated for each profile based on the user entered energy slope. In general, the energy slope can be approximated by using the average slope of the channel or the average slope of the water surface in the vicinity of the cross section.

Rating Curve - When this type of boundary condition is selected, the user is required to enter an elevation versus flow rating curve. For each profile, the elevation is interpolated from the rating curve given the flow, using linear interpolation between the user entered points.

Selecting Boundary Conditions



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Discharge Information

- Tributary Inflows
- Local Inflow
- Hydrograph Attenuation
- Lateral Structure

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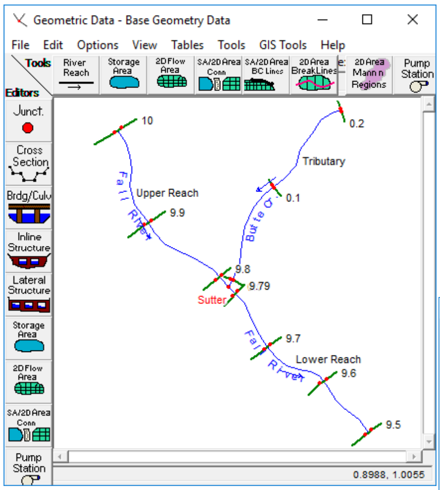
1. If a model only represents the main stem of a river system (tributaries are not being modeled), the user will be required to enter a flow change at each of the cross sections that are just downstream of a tributary inflow point.

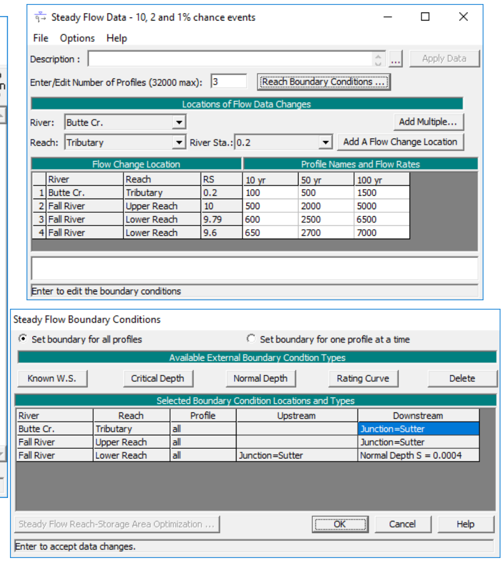
2. If the peak flow increases significantly along the stream, due to local runoff inflows, the modeler should enter flow changes intermittently, as required to account for the local inflow.

3. If the peak flow decreases significantly as the flood wave travels downstream (hydrograph attenuation), the modeler should intermittently decrease the flows, as required to account for the hydrograph attenuation.

4. If flow is taken out of the river system due to a lateral weir; pumping station; or other mechanism, the modeler should reduce the flow between the relevant cross sections to account for the lost discharge.

Tributary Inflows and Junctions





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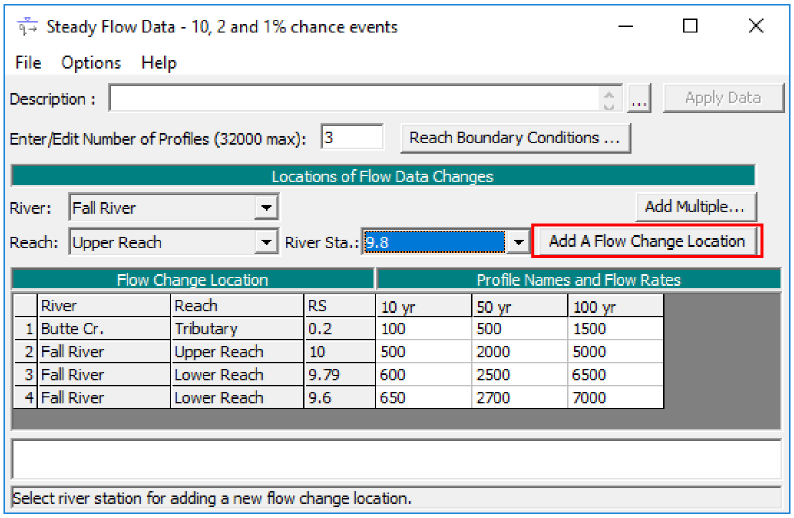
Local Inflow



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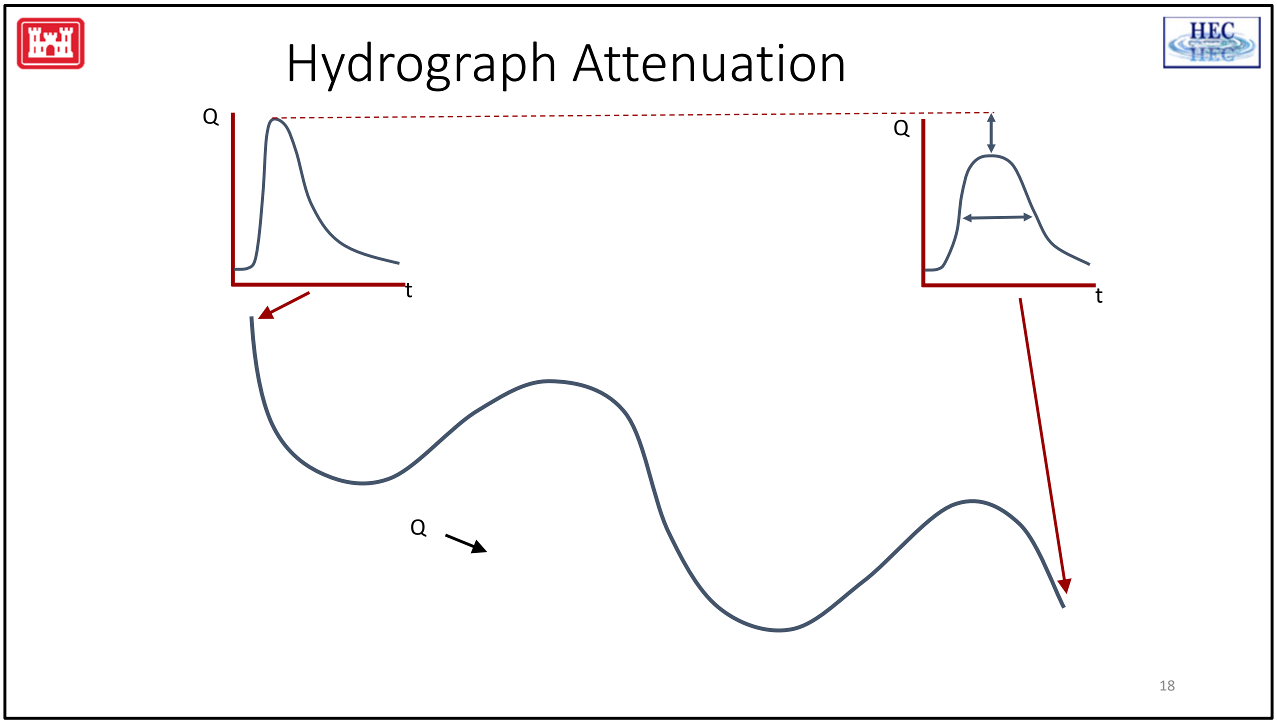
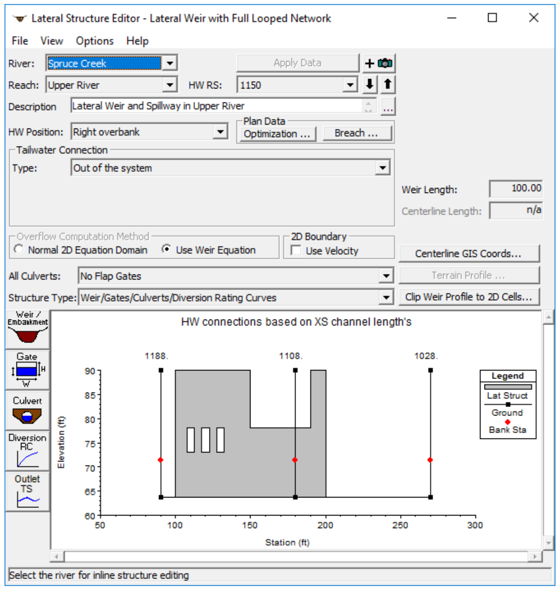
In a steady flow analysis local inflows are specified by defining a new total discharge at the cross section downstream of the inflow.



Since steady flow profiles often do not represent a “snapshot” in time but the max flow throughout the system, the peak flow for the event is often specified for each cross section. If the system is long enough, however a hydrograph will attenuate which, while conserving the volume of flow will reduce the peak.

Lateral Structure



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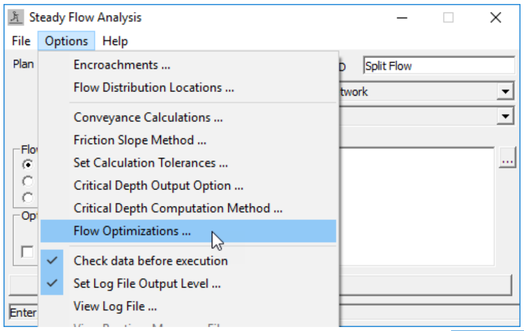
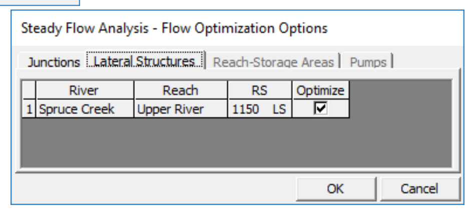
Lateral Weir can be used to calculate a flow which would be removed from the channel laterally. The water removed can be taken out of the model or sent to a storage area or another cross section. The use of lateral weirs and storage areas can sometimes be awkward in steady flow as they are intrinsically unsteady processes.

Lateral Structure Optimization





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Since flows removed via lateral weirs and culverts are a function of the elevation head which are in turn a function of the flow RAS must iterate to achieve a solution. In order to make this happen you must turn the optimization function on for the lateral structure. If the optimization function is not turned on, no flow will be removed and lateral flows will be reported based on the backwater profile. These reported flows will likely overestimate the actual lateral flows since the water surface is higher than it would be if flows were removed.

Steady Flow Data Options

- Specify a Change in Energy
- Specify a Change in Water Surface
- Insert a Known Water Surface
- Enter and Additional Energy Loss

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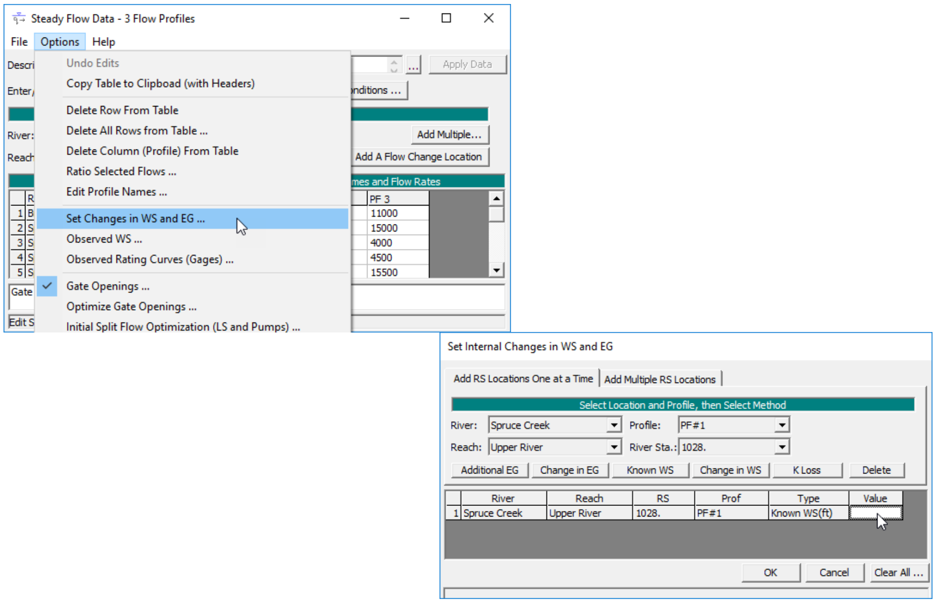
Specify a Change in Energy - This option allows the user to force a specific change in energy between any two cross sections in the model. The change in energy can be set for a specific profile in a multiple profile model. The user can set several changes in energy within the model, for various locations. During the computations, the program will apply the specified change in energy between two cross sections, and then compute a water surface for the corresponding energy. This option is useful for modeling a complex hydraulic structure that cannot be directly handled with the available options in the program. If the change in energy for the complex structure can be computed external to HEC-RAS, then that change in energy can be applied between the two bounding cross sections. This allows the modeler to keep the whole system in one model, without breaking it into separate pieces.

Specify a Change in Water Surface - This option allows the user to force a specific change in the water surface elevation between two cross sections. This option works the same as the "Change in Energy" option described previously. The user can specify changes in water surface elevations at multiple locations for various profiles.

Insert a Known Water Surface - This option allows the user to force a specific water surface at a given cross section. The known water surface elevations can be specified at multiple locations for various profiles. During the computations, the program will not compute a water surface elevation for any cross section where a known water surface elevation has been entered. The program will use the known water surface elevation and then move to the next section.

Enter an Additional Energy Loss - This option allows the user to enter an additional energy loss between two cross sections. This energy loss gets added to any computed energy losses that occur during the balancing of the energy equation. The additional energy loss can be specified at multiple locations for various profiles.

Steady Flow Data Options



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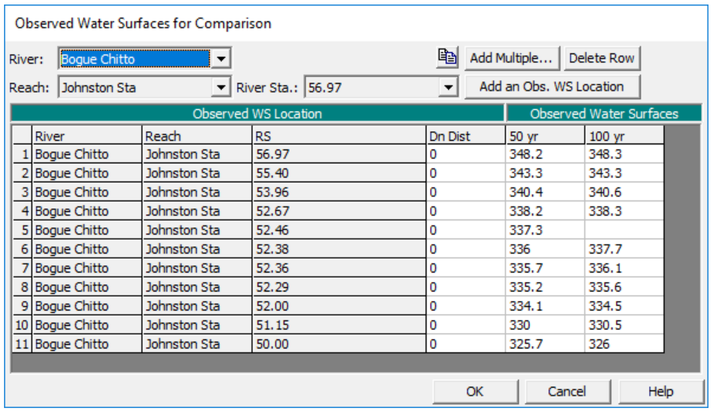
Steady Flow Data Options

- Enter Observed Water Surfaces for Comparison



Observed WS Location					Observed Water Surfaces	
	River	Reach	RS	Dn Dist	50 yr	100 yr
1	Bogue Chitto	Johnston Sta	56.97	0	348.2	348.3
2	Bogue Chitto	Johnston Sta	55.40	0	343.3	343.3
3	Bogue Chitto	Johnston Sta	53.96	0	340.4	340.6
4	Bogue Chitto	Johnston Sta	52.67	0	338.2	338.3
5	Bogue Chitto	Johnston Sta	52.46	0	337.3	
6	Bogue Chitto	Johnston Sta	52.38	0	336	337.7
7	Bogue Chitto	Johnston Sta	52.36	0	335.7	336.1
8	Bogue Chitto	Johnston Sta	52.29	0	335.2	335.6
9	Bogue Chitto	Johnston Sta	52.00	0	334.1	334.5
10	Bogue Chitto	Johnston Sta	51.15	0	330	330.5
11	Bogue Chitto	Johnston Sta	50.00	0	325.7	326

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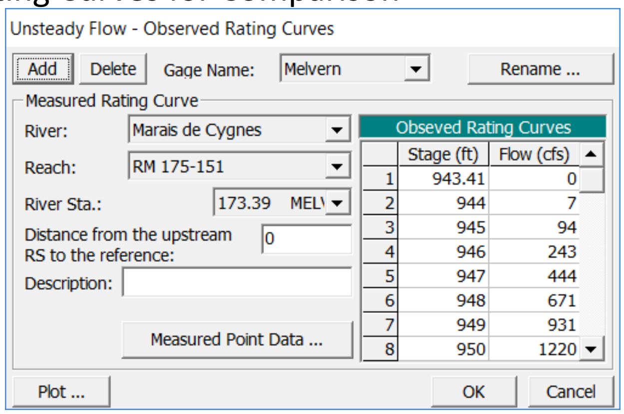
Enter Observed Water Surfaces For Comparison - This option allows the user to enter observed water surface elevations for comparison purposes. The user can enter observed water surface elevations at any cross section and for all the profiles. When these data are entered, the user can then display the observed water surfaces in the profile plots, as well as the profile tables.

Steady Flow Data Options

- Observed Rating Curves for Comparison



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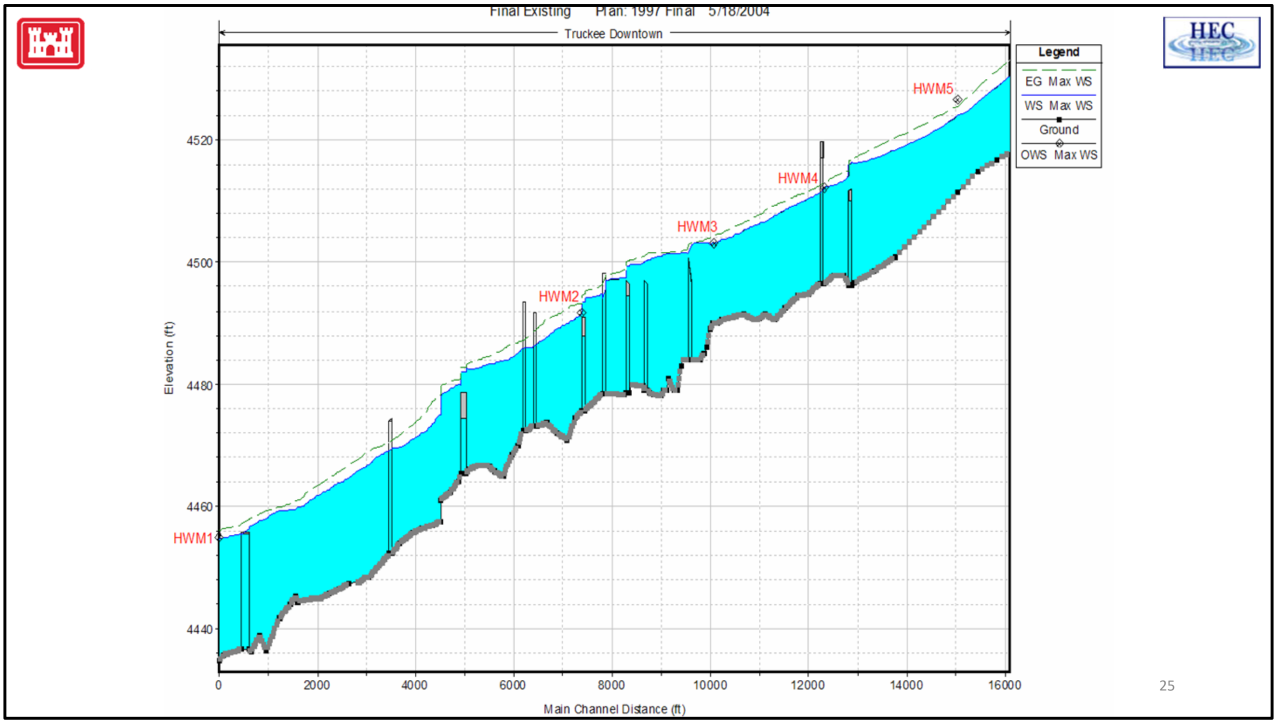
Final Existing Plan: 1997 Final 5/18/2004
Truckee Downtown
Legend
EG Max WS
WS Max WS
Ground
OWS Max WS
HWM1
HWM2
HWM3
HWM4
HWM5
Elevation (ft)
4440
4460
4480
4500
4520
0
2000
4000
6000
8000
10000
12000
14000
16000
Main Channel Distance (ft)
25

Questions?

US Army Corps of Engineers