Geometric Data Requirements for Water Surface Profile Calculations in HEC-RAS

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Overview

- Study Limit Determination
- River Network
- Cross Section Layout and Properties

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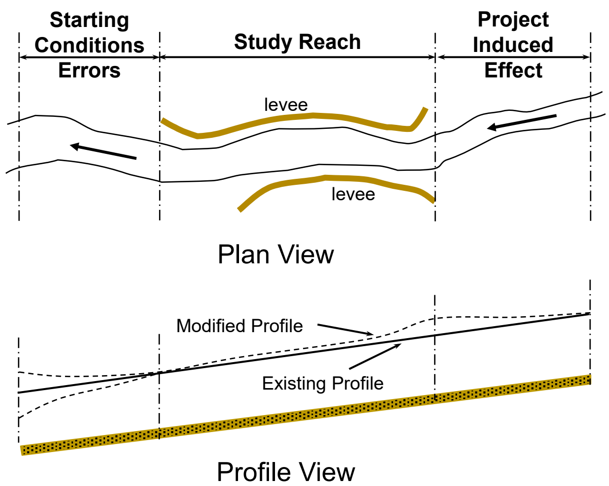
Study Limit Determination



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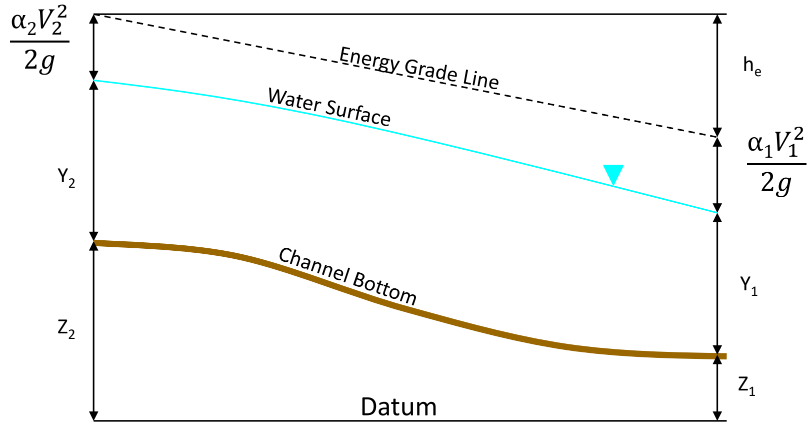
A hydraulic model should consider more than the immediate area of study.

The model should incorporate the river reach downstream of the study area and upstream in order to evaluate the impact of study alternatives. The upstream and downstream limits for study also define the limits for data collection.

The upstream limit is the upper study boundary, plus additional distance where the profile resulting from a structure-caused energy loss converges with the existing condition profile. For example, the water surface profile for some flow may rise if you put a bridge in across a river reach. At some point upstream, however, the effects of the bridge will no longer be seen. Your upstream study limits must incorporate this area.

The downstream limit must be started sufficiently far downstream to assure accurate results at the lower limit of the study reach. Amazingly, the equations used for water surface profile calculations are “self correcting”, so you just need to make sure that start your calculation far enough downstream to allow for the correcting to occur.

Energy Principles



$$Z_2 + Y_2 + \frac{\alpha_2 {V_2}^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 {V_1}^2}{2g} + h_e$$

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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 above.

where: Y_1 Y_2 = depth of water at cross sections

Z_1, Z_2 = elevation of the main channel inverts

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

α_1, α_2 = velocity weighting coefficients

g = gravitational acceleration

h_e = energy head loss

Energy Losses

- Energy Losses:

$$h_e = L\overline{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$

Friction losses + Contraction and Expansion

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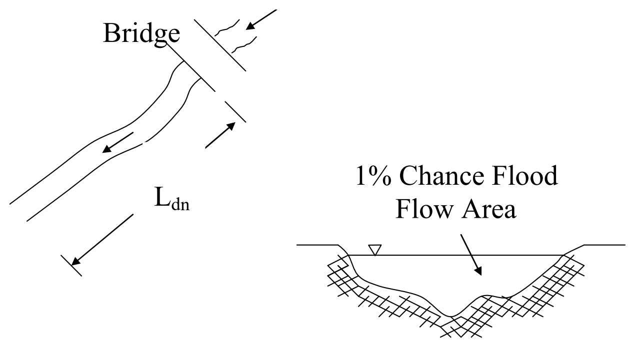
The energy head loss (h_e) between two cross sections is comprised of friction losses and contraction or expansion losses. The equation for the energy head loss is shown above.

Friction losses are based on multiplying a flow weighted reach length by a representative friction slope for the reach.

Contraction and expansion losses are based on a user entered contraction or expansion loss coefficient times the absolute value of the change in velocity head. The program assumes that a contraction is occuring whenever the velocity head downstream is greater that upstream. Likewise, when the velocity head upstream is greater than the velocity head downstream, the program assumes an expansion is occurring.

Downstream Reach Length Determination



$$L_{dn} = 8000 \frac{HD^{0.8}}{S}$$

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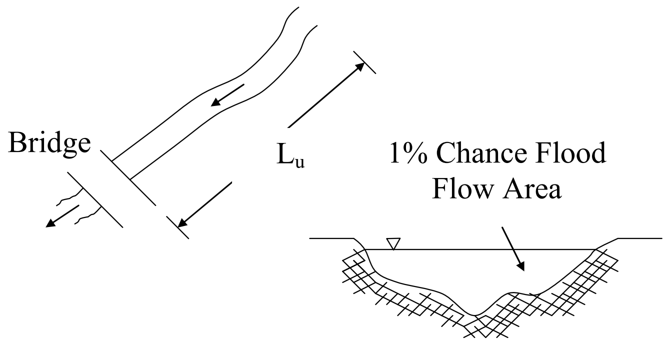
*Equation from RD-26, Accuracy of Computed Water Surface Profiles (1986), based on regression equations of 80 datasets.

Where:

L_{dn} = Downstream study length - normal depth starting condition (ft)
HD = Average reach hydraulic depth (1% chance flow) (ft)
S = Average reach slope (ft/mi)

Downstream Limits - Must be started sufficiently far downstream to assure accurate results at the lower limit of the study reach.

Upstream Reach Length Determination



$$L_u = 10000\, HD^{0.6} \frac{HL^{0.5}}{S}$$

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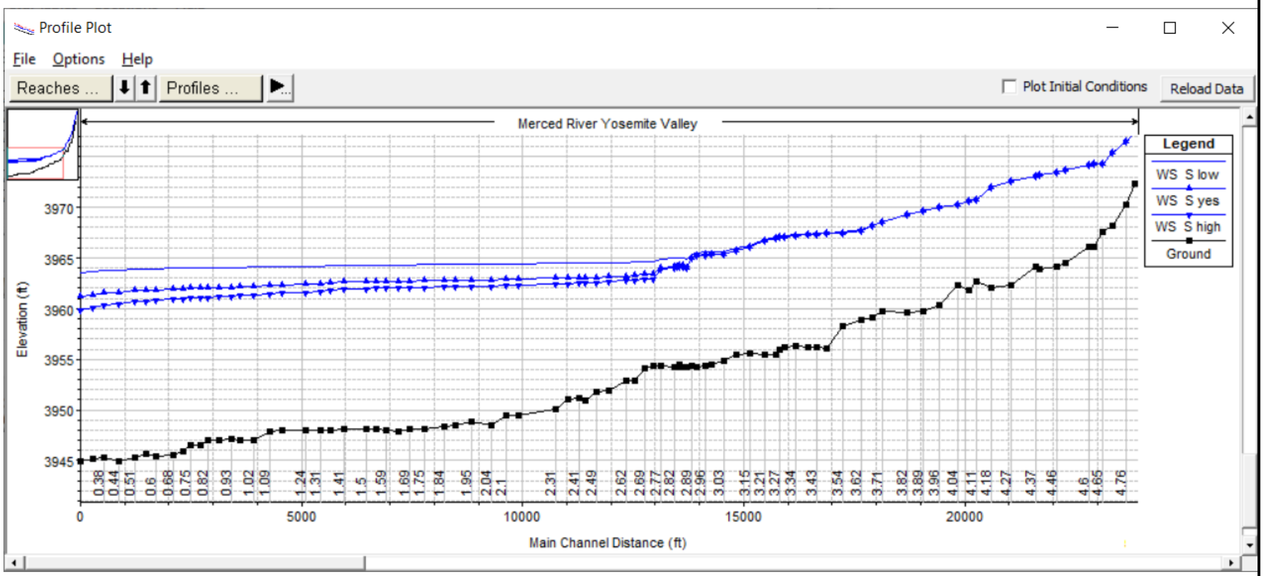
*Equation from RD-26, Accuracy of Computed Water Surface Profiles (1986), based on regression equations of 80 datasets.

Where:

L_u = Upstream study length (ft)
HD = Average reach hydraulic depth (1% chance flow) (ft)
HL = Headloss at the channel crossing structure (1% chance flow) (ft)
S = Average reach slope (ft/mi)

Upstream Limits - Upper study boundary plus additional distance where profile resulting from a structure-caused energy loss converges with the existing condition profile.

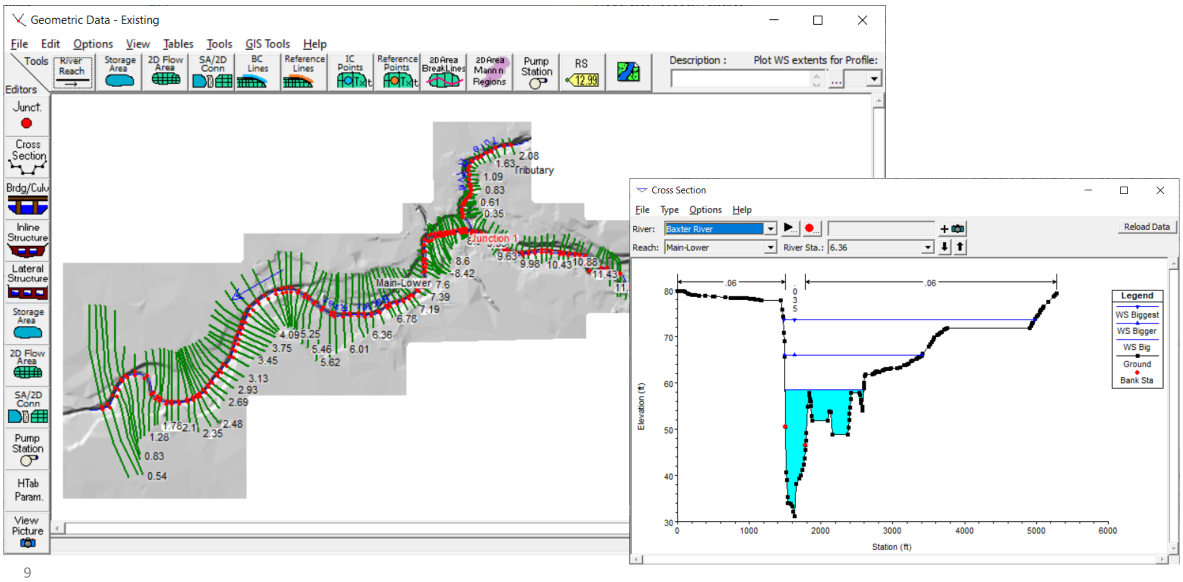
Example



L = 8000 * 4^0.8 / 2.5
L ends up being about 2 miles which matches the figure shown

Slope = 2.5ft/mile
HD ~3-5

Example Schematic



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The river system schematic is required for any geometric data set within the HEC-RAS system. The schematic defines how the various river reaches are connected, as well as establishing a naming convention for referencing all the other data.

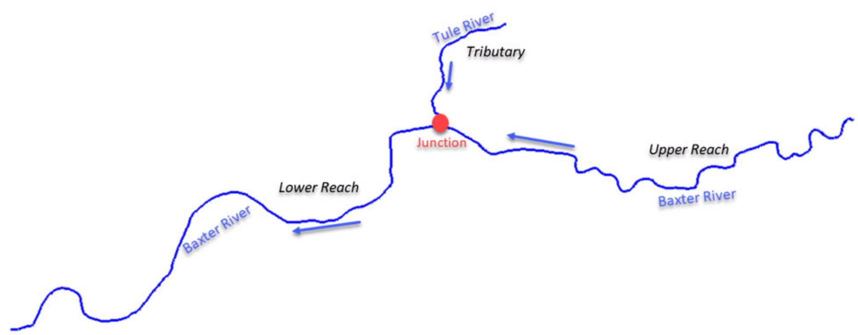
The connectivity of reaches is very important in order for the model to understand how the computations should proceed from one reach to the next. The user is required to draw each reach from upstream to downstream, in what is considered to be the positive flow direction. The connection of reaches are considered junctions. Junctions should only be established at locations where two or more streams come together or split apart. Junctions should not be established with a single reach flowing into another single reach, these two reaches should be defined as one reach.

HEC-RAS has the ability to model river systems that range from simple single reach models to complicated networks. A "network" model is where river reaches split apart and then come back together, forming looped systems. Arrows are automatically drawn on the schematic in the assumed positive flow direction. Junctions, which are shown as red circles, are automatically formed as reaches are connected.

The cross section is the other required piece of geometric data.

River Network

- Rivers and Reach network identifies how water moves through the system
- Junctions establish Reach connections



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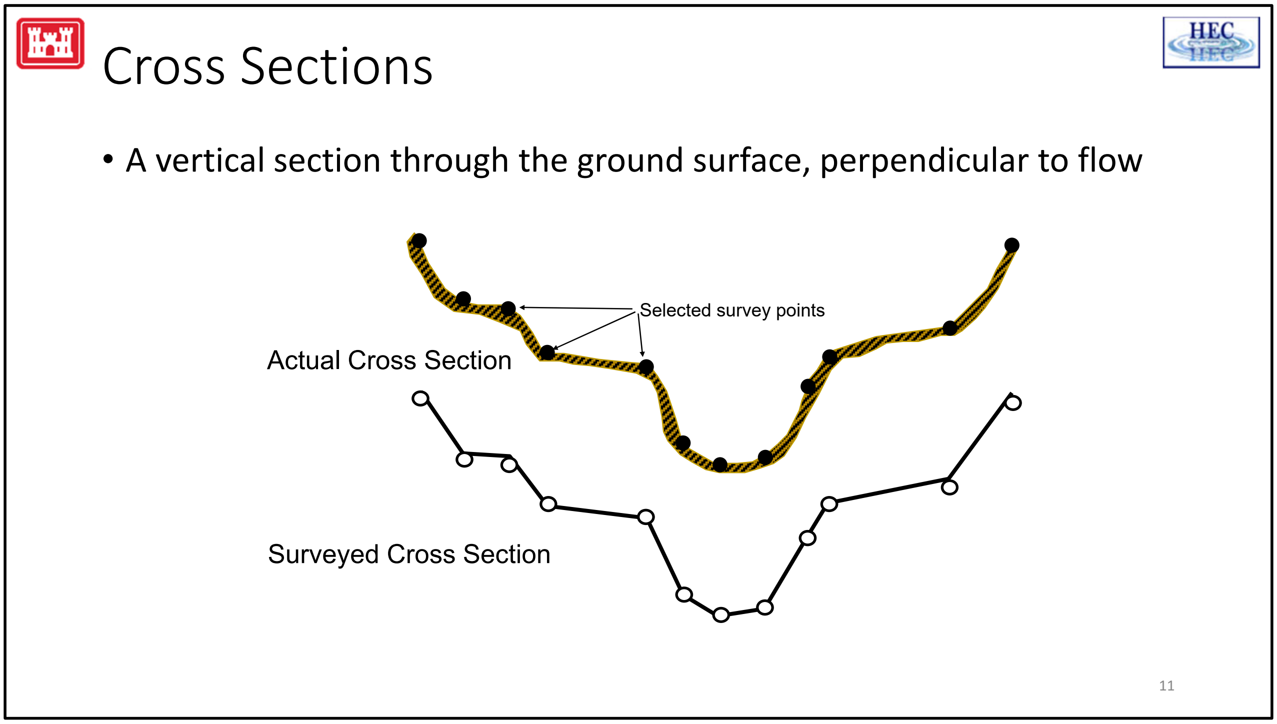
The River Schematic defines how water will move through the system. The River Network is comprised of Rivers which are drawn in the direction of flow from upstream to downstream. Each River name must be unique. Each Reach name (on the same river) must be unique. Each river contains reaches. A new reach is defined by a new river entering the river system and breaking up the river into multiple reaches. Each time a new river combines with another river, a junction is formed at the confluence.



A cross section is a vertical section through the ground surface perpendicular to flow. Cross sections must include the entire floodplain width!

Actual cross sections are curved and are approximated by a series of straight segments between entered points. There needs to be enough points so that the area and wetted perimeter are representative of the actual cross section.

Traditional methods require a survey team to go into the field and collect the cross-sectional data.
Another method is to take cross sections from topographic maps of the study area.

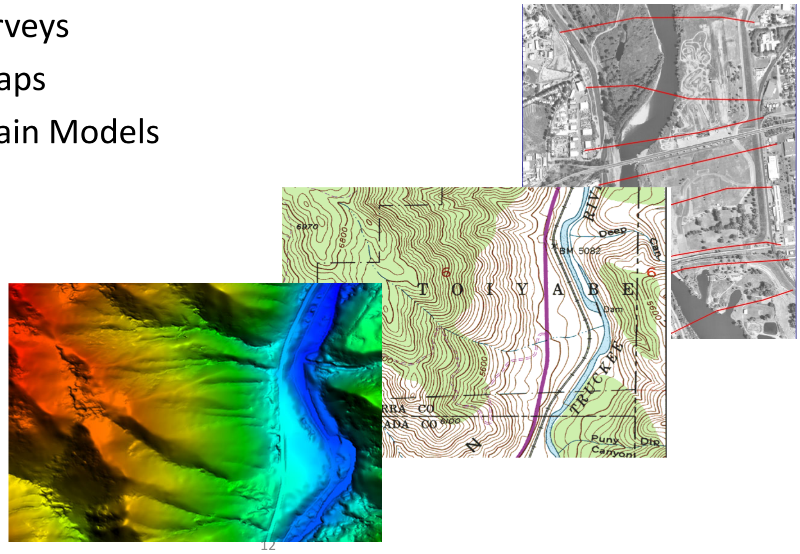
There are evolving methods use aerial data capture methods which are good for the floodplain areas but require additional data to represent the main flow channel.

Some costs. In a recent study conducted by the Philadelphia District aerial photography was used to collect ground surface data for approximately 100 miles of river, with a 1 mile wide floodplain, for about $600,000. This data was based on a 2ft contour interval, which results in all data points being +/- 1ft accuracy. This data did not include the main channel. Main channel data was surveyed about 1 cross section per mile (100 cross sections) at a cost of about $60,000.

Cross section spacing will be determined from slope and channel characteristics. From a hydraulic perspective, there is an "art" to laying them out.

Sources of Ground Data

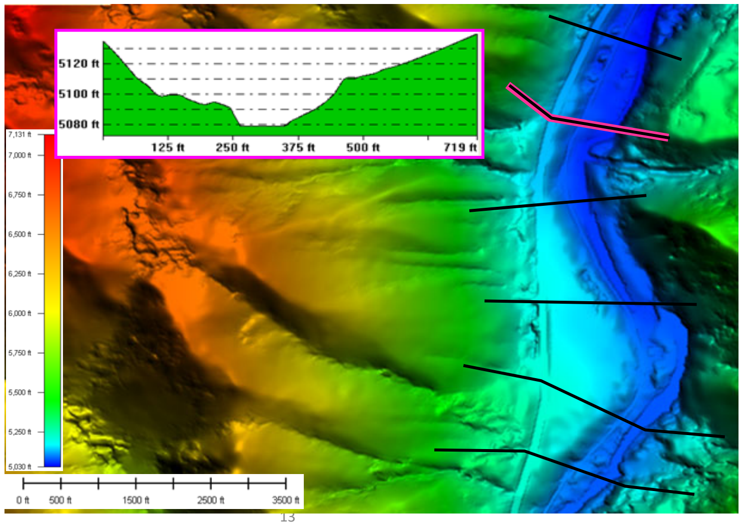
- Ground Surveys
- Contour Maps
- Digital Terrain Models



There are several ways to capture the geometry of the floodplain.

1. Traditional ground surveys are a good way to get very accurate cross sections for a small area.
2. You can get cross sections from previously published contour maps. However, these data are typically not as accurate and may be out of date.
3. There are aerial methods for data capture. The older (standard) method of using stereo orthophotos (stereophotogrammetry) to create digital terrain models has given way to LiDAR (Light Detection and Ranging). Photogrammetry requires overlapping pairs of aerial photos to identify elevation points for creation of the ground surface. LiDAR typically uses airborne lasers to compute the distance to the ground thousand of times per second during an overflight. The processed data is then used to create a ground surface model of the bare earth. Often, however, vegetation impairs the accuracy of the final bare earth product.
4. Typically, bathymetric data must be added to the overbank terrain data to complete the cross section information.

Elevation Extraction



Elevation extraction from digital terrain models is now commonplace. Using RAS Mapper or another geospatial data program allows you to easily extract information, but more importantly, update the information as you refine your hydraulic model.

Rules!

- Left to right, when looking downstream
- Perpendicular to flow
  - Main Channel
  - Overbanks
- Representative of the channel and floodplain area (conveyance)
- Spaced such that there is smooth transition in floodplain properties
- Capture the entire floodplain extent

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HEC-RAS is founded on the solving the energy equation from cross section to cross section. The energy equation is solved using Manning's equation assumes uniform flow (uniform flow assumes an average velocity for the cross section). Because uniform flow is assumed, cross sections must be oriented perpendicular to flow in the main channel and in the overbanks thereby being representative of the channel and floodplain area available for conveyance.

Further, cross sections should be located often enough that they smoothly represent changes to the floodplain geometry. And, of course, they must capture the extent of the floodplain in it's entirety.

Specific Guidelines

- Change of width (expansion, contraction)
- Change of roughness (land use, Manning's n value)
- Change of channel slope
- Bridges and other hydraulic structures
- Control points – such as critical depth
- Change in discharge (flow)
- Maximum distance for hydraulic computations (friction losses)

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Specific considerations when laying out cross sections include locating a new cross section when there is a change in:

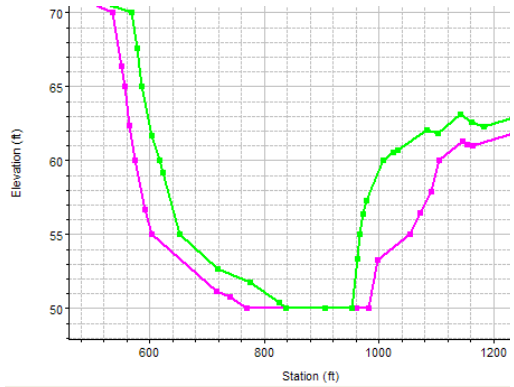
floodplain width
roughness (due to vegetation or bed roughness
channel slope

A new cross section should also be located:

at hydraulic structures
where a flow change will occur
at critical flow change locations
to properly account for the hydraulic compuations

Conveyance

- Cross section must capture the proper cross section conveyance.



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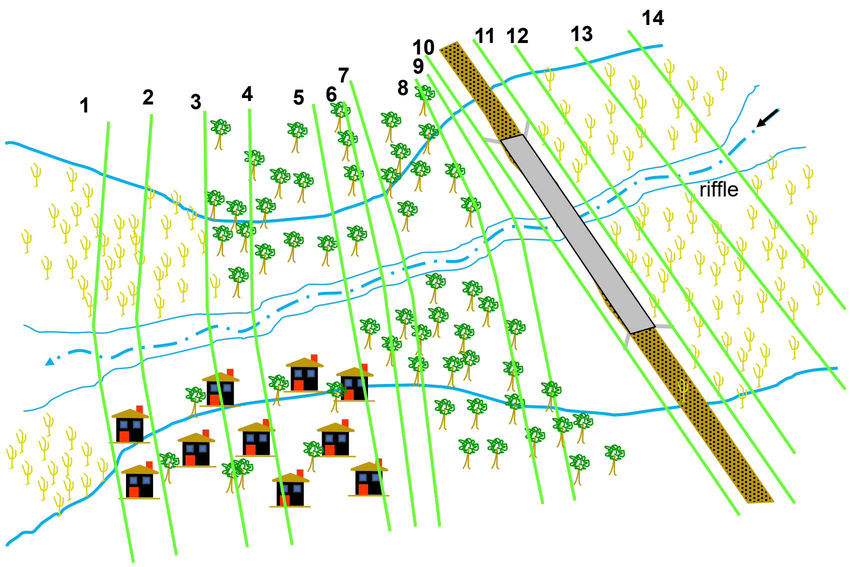
The most important thing to consider is laying out cross sections to properly account for conveyance. Above is a picture of a cross section that properly captures the floodplain (dog-legged section in green) and a cross section that does not (straight section in magenta). The doglegged section is perpendicular to flow in the overbanks AND in the main channel and results in properly capturing the flow area. In the figure of the cross sections, you can see that the wide section would over-estimate the area available to convey water downstream – in the end this would lead to an incorrect water surface.

Cross Section Layout



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Boundary geometry for the analysis of flow in natural streams is specified in terms of ground surface profiles (cross sections) and the measured distances between them (reach lengths). Cross sections are located at intervals along a stream to characterize the flow carrying capability of the stream and its adjacent floodplain.

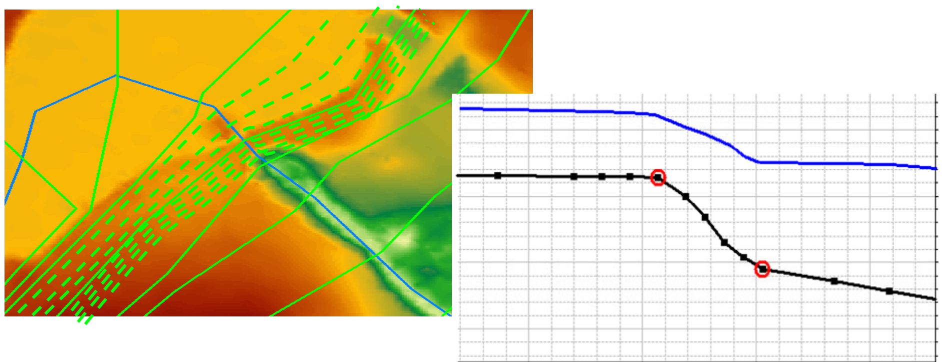
They should extend across the entire floodplain and should be perpendicular to the anticipated flow lines (approximately perpendicular to the ground contour lines). Occasionally it is necessary to lay out cross sections in a curved or dog-leg alignment to meet this requirement. There are many rules to consider when laying out your cross sections. But the key is to remember that you need a new cross section anytime there is a change in the cross-sectional properties.

General cross section rules: cross section should be drawn perpendicular to flow and be representative of the section of river it is modeling. Cross sections should be placed at the following locations:

1. Change of width (expansion, contraction)
2. Change of roughness (land use, Manning's *n* value)
3. Change of channel slope
4. Change in discharge (flow)
5. Control points – such as critical depth
6. Bridges and other hydraulic structures
7. Distance for hydraulic computations

Significant Hydraulic Drops

- More frequent placement of cross sections for a rapid change in slope.



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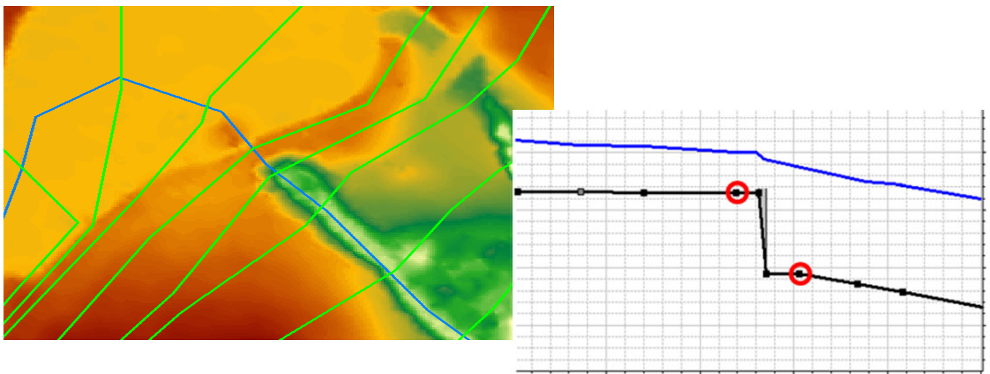
What is one of the main guiding principles when laying out cross sections? Making sure that the geometry represented by the cross sections gradually/smoothly transitions from one cross section to the next. In the case where the slope of the river profile changes rapidly, cross section spacing will need to be reduced to smoothly capture the rapidly varying terrain. Further, if you want to know the water surface profile along the steep slope, you will need additional computation points (more cross sections) in RAS.
For a proper cross section layout for steep terrain will have a cross section at the top of the drop, a the toe of the drop, and then an increase density of cross section leading up to and through the drop to model the rapidly varied flow scenario that will occur.

Significant Hydraulic Drops

- Extreme drops such as a natural waterfall require cross sections located at the top and toe to model with an inline structure.



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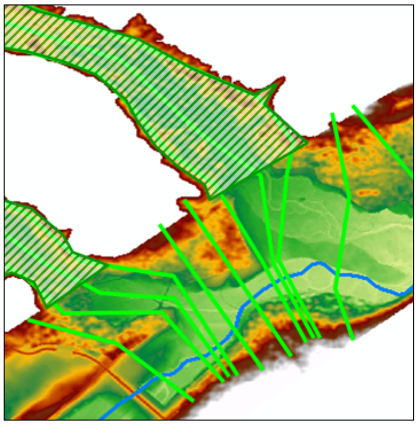
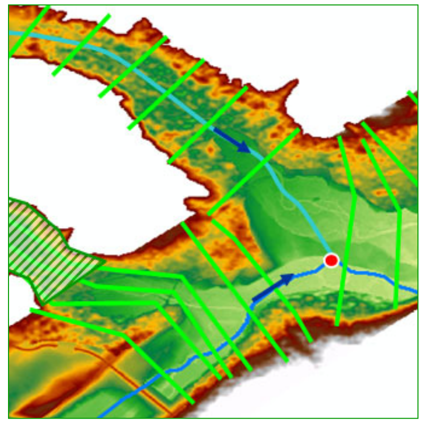
An alternative method for modeling a steep hydraulic drop in HEC-RAS is use the Inline Structure option. The inline structure requires cross sections be located at the top and toe of the drop. The inline structure will then use the geometry of the upstream cross section (top cross section) to compute hydraulics across the structure.
The inline structure option is appropriate when the change in terrain is extremely steep and the water surface profile elevation around the structure is not the primary goal of the hydraulics model. The computed water surface will valid upstream and downstream on the bounding sections of the inline structure, but will not compute the water surface profile through the structure.
I the figure above, the circled cross sections are the bounding cross section for the inline structure. For drawing the profile plot, RAS copies the bounding sections and places them based on the downstream distance and width of the inline structure from the upstream cross section. (In this case, the downstream reach length is 135ft, the downstream distance is 50ft an the weir width is 20ft. Therefore, there is 65ft from the d/s copied section to the downstream cross section – the inline structure is almost “centered”.)

Tributaries

- Backwater areas modeled using extended cross sections



- Slope water surface modeled with separate river reach



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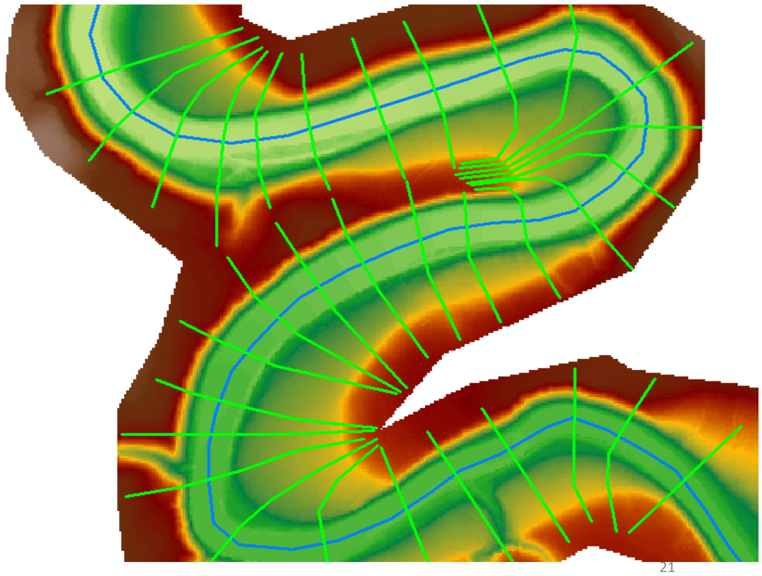
As long as your cross sections extend out to high ground covering the extent of the floodplain and are spaced a reasonable distance, the cross section placement should generally lead to a successful floodplain delineation. However, the fringe areas of the floodplain are of the biggest interest in the delineation process and often need the most consideration. For backwater areas such as a small tributary, extending the cross sections up the tributary is a reasonable approach to providing a water surface for floodplain delineation. For the backwater situation, the water surface used will be based on the extended cross section – it will control what water surface elevation is used so care should be taken in selecting the cross section. Of course, the non-conveying area should be blocked out with ineffective areas. If the you expect to have a sloped water surface on the tributary, then the tributary should be modeled using a separate river reach with cross sections.

River Bends

- Cross sections should tie into high ground.
- Cross section must not cross.



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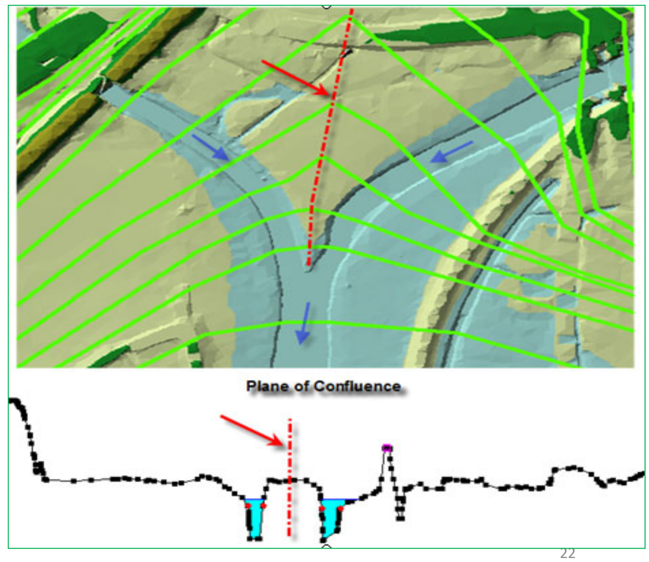
In river systems that significantly meander to produce bends, cross sections should remain perpendicular to flow. This produces the challenge of how to orient cross sections on the inside of bends, where many cross sections will "come together". The thing to remember is that you need to tie the cross sections into the high ground on the inside of the bends and not allow the cross sections to cross. This can be accomplished by choose the "highest" ground and using it as your tie-in location. From there, keep the cross sections dog-legged so that they are perpendicular to flow at all locations. Don't be to concerned that the end of the cross section are very close together, while your reach lengths may be far greater – flow will never be up that high using that portion of the cross section for conveyance.
On the outside of bends, make sure the cross sections extend far enough to capture the entire floodplain for mapping.

Junctions

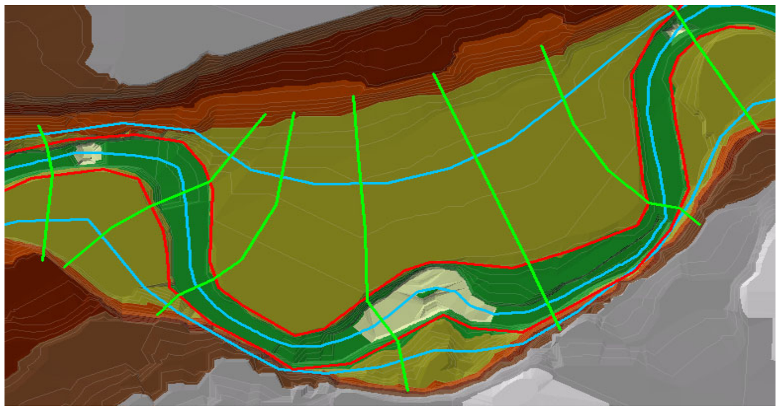
- Do not double account conveyance.
- High water plane-of-confluence to terminate cross sections.



The placement of cross sections at junctions for low-flow scenarios is relatively straightforward – cross sections can be laid out independently from one another. If, during high flows, however, water "mixes" from the two combining reaches cross sections should be laid out such that conveyance is not doubly accounted for. This requires identifying a "plane-of-confluence" where the water on one side of the plane is conveying down one reach and water on the other side is conveying down the other reach. The cross section layout for this situation requires that the cross sections from each reach terminate along the plane. If there is very high ground, this separation zone for conveyance will be easy to identify; however, at some junctions you will need to make a decision based on engineering judgment based on the size of the river reaches and the angle of approach.

Conveyance

- Perpendicular to flow in the overbanks. Flow paths help visualize the floodplain.



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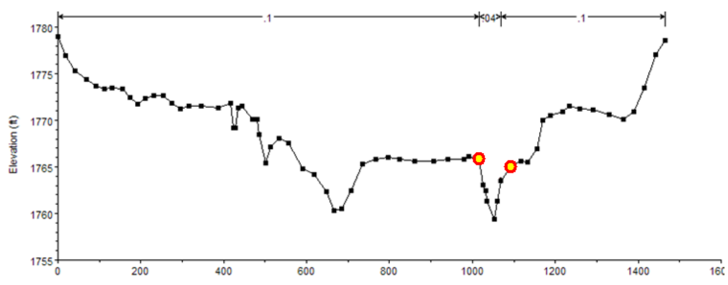
One way to gain perspective on how cross sections should be laid out is to identify where the main channel is from the overbanks and draw in flow paths in the main channel and overbank areas. Cross sections can then “easily” be drawn in perpendicular to flow in for all parts of the floodplain.

Bank Stations

- Bank stations define that main channel conveyance from the left and right overbank areas
- Allows for better representation of the overall flow distribution and computation of average cross section velocity and water surface



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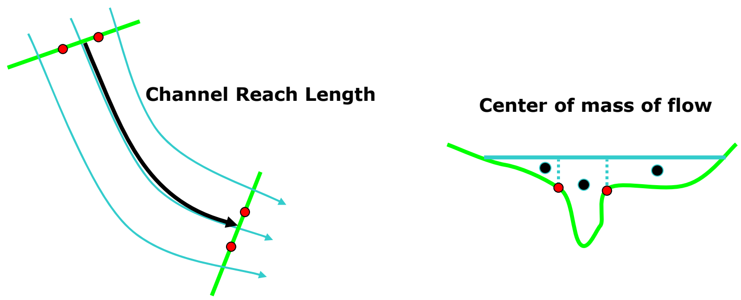
Bank stations must be defined for each cross section to indicate the main flow channel. Conveyance for the main flow channel and overbank areas is computed separately in order to satisfy Manning’s equations where uniform flow is the base assumption. (Further conveyance subdivision are used when horizontal n values are defined. This is discussed in the Flow Roughness Lecture.) Total cross-section conveyance is computed by summing the conveyance subdivisions.

Downstream Reach Lengths

- Used in computing the friction loss between adjacent cross sections

$$h_e = L\overline{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$



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Reach lengths represent the distance between adjacent cross sections. They represent the flow path length for the center of mass of the fluid in each subsection. The flow-weighted reach length (L) is used from cross section to cross section to compute the friction loss component in the energy loss equation. Because the computed reach length is flow-weighted, the length will vary based on the amount of flow in the cross section (once flow is out of the main channel).

There are 3 reach lenghts: Left Overbank, Main Channel, and Right Overbank.

Manning's Roughness Coefficients

- Used in computing the friction loss between adjacent cross sections

$$h_e = L\overline{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$

- Friction slope is computed from Manning's Equation

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The friction loss component of the energy loss from cross section to cross section is based on the Manning's n values of the cross section (and the downstream reach lengths). Manning's equation is used to compute conveyance and therefore to estimate the friction slope from cross section to cross section.

Manning's Roughness Coefficients

- An estimation of resistance to flow in the channel cross section
- Factors affecting *n* values:
  - Surface roughness
  - Vegetation
  - Channel irregularity and alignment
  - Flow obstructions
  - Scour and deposition

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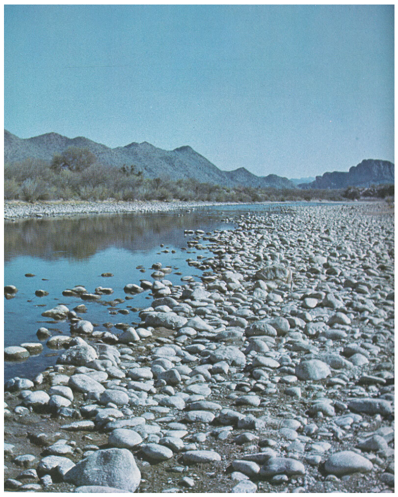
Manning's n-values are a measure of resistance to flow in the channel.
Several factors affect *n* values. A description of the many are provide below.

1. Surface roughness – this refers to the size of the material in the bed of the cross section. The *n* value for fines such as silt and clay will be less than that for coarse material such as gravels or boulders. When the bed material is fine the *n* value is relatively unaffected by change in flow stage. When the material is large, the *n* value can be quite high, particularly during low and high stage. At low stage boulders produce obstructions, at high stage energy goes into moving the bed.
2. Vegetation – vegetation can greatly affect *n* values. This may lead to seasonal *n* values, where *n* value are small during winter when the branches are barren, to very high during spring leaf-out. Values may vary by depth based on branching patterns and plant flexibility.
3. Channel irregularity and alignment – channels that are highly irregular in cross section will increase surface roughness compared with those that do not have sand bars, ridges, depressions, and holes and humps. Moreover, a meandering channel that has sharps bends will give higher *n* values than those having smooth curvature.
4. Obstructions – the presence of debris, ice, bridge piers,and other obstructions will increase *n* values.
5. Scour and deposition – silting may take a rough, irregular channel and make it smooth, while scour may create a more irregular channel, thereby affecting surface roughness. Further, energy will be lost during scour, increasing an *n* value.

Manning's n values



$n = 0.032$

$n = 0.055$

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Contraction/Expansion Coefficients

- Used to compute energy loss due to transitions between cross sections

$$h_e = L\overline{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$

	Contraction	Expansion
No transition loss computed	0.0	0.0
Gradual transitions	0.1	0.3
Highly contracted bridge sections	0.3	0.5
Abrupt transitions	0.6	0.8

***These values are for subcritical flow only. Values should be lower for supercritical flow by a factor of 10.**

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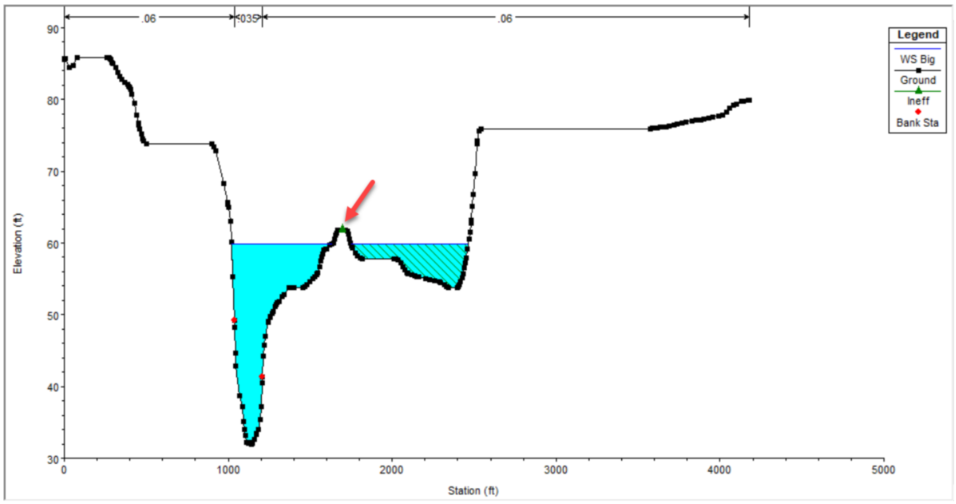
Contraction or expansion of flow due to changes in the cross section is a common cause of energy losses within a reach (between two cross sections). The coefficients, which are applied between cross sections, are specified as part of the data for the upstream cross section. Typical Contraction and expansion coefficients for subcritical flow are shown. As shown in the table, energy losses increase with the abruptness of the transition.

RAS will determine whether the contraction or expansion coefficient should be applied based on the magnitude of velocity in the upstream and downstream cross section.

Note: The maximum value for the contraction and expansion coefficient would be one (1.0).

Ineffective Flow Areas



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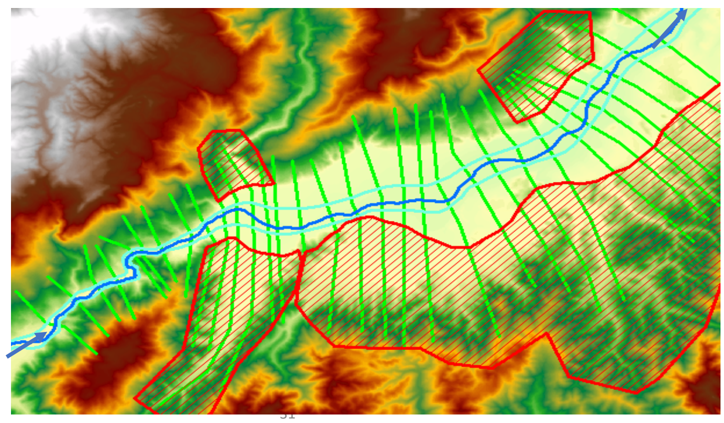
Ineffective Flow Areas - Defines areas of the cross section that will contain water that is not actively being conveyed (ineffective flow).

Used to describe portions of a cross section in which water will pond, but the velocity, in the downstream direction, is close to zero. The area is included in the storage calculations and other wetted cross section parameters, but it is not included as part of the active flow area and no additional wetted perimeter is added to the active flow area.

This example shown above is a Normal Ineffective Area, a second example is the Blocked Ineffective Area.

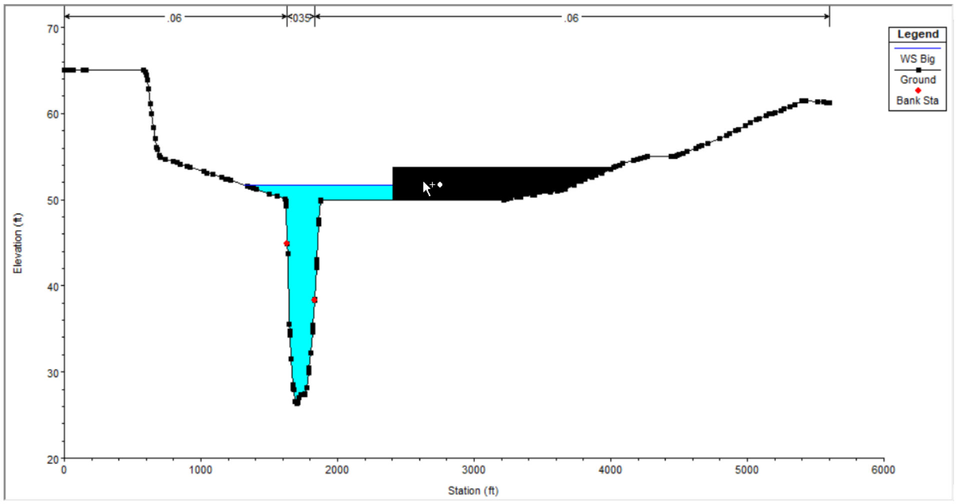
Ineffective Areas

- Ineffective areas are used to eliminate non-conveying (non-active) flow areas.



Non-conveying areas must also be determined. In HEC-RAS, zero-velocity areas are termed "ineffective flow areas" and must be identified in the cross section as not available for the conveyance calculations. Ineffective areas are used in many different locations resulting from backwater: behind bridges, up small tributaries, and in small side-channel areas. Ineffective areas can be readily identified using a plan view of the river system.

Normal Blocked Obstructions



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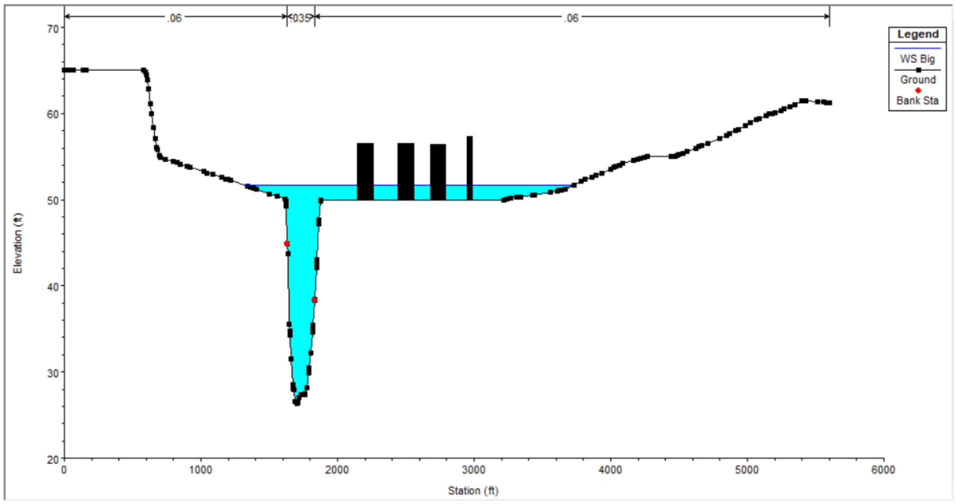
This option defines areas of the cross section that will be permanently blocked out. Blocked obstructions decrease flow area (remove conveyance) and add wetted perimeter when the water comes in contact with the obstruction. A blocked obstruction does not prevent water from going outside of the obstruction.

Two alternatives are available for entering blocked obstructions:

1. **Normal blocked areas**: When this option is used, the area to the left of the left station and to the right of the right station will be completely blocked out.

Multiple Blocked Obstructions



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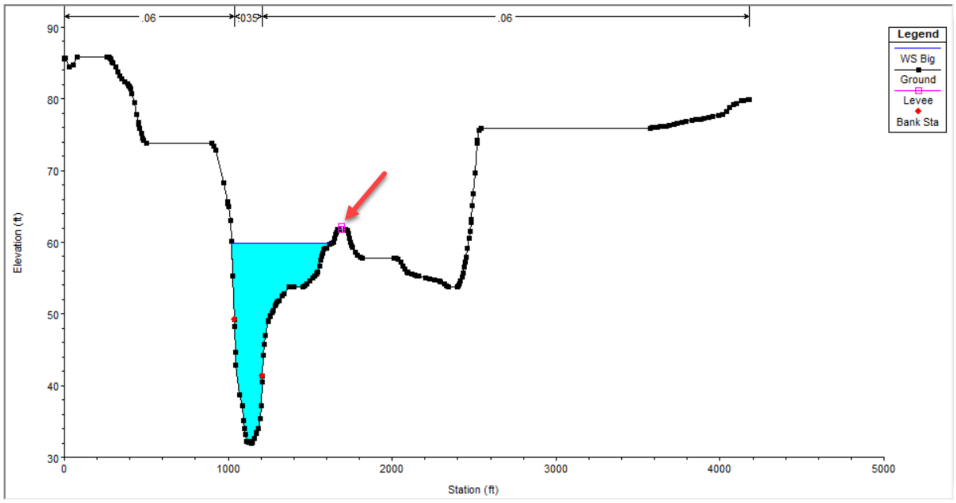
2. **Multiple Blocked Obstructions**: Up to 20 individual blocks can be defined. The left station, right station, and an elevation are entered for each of the blocks.

Levee Option



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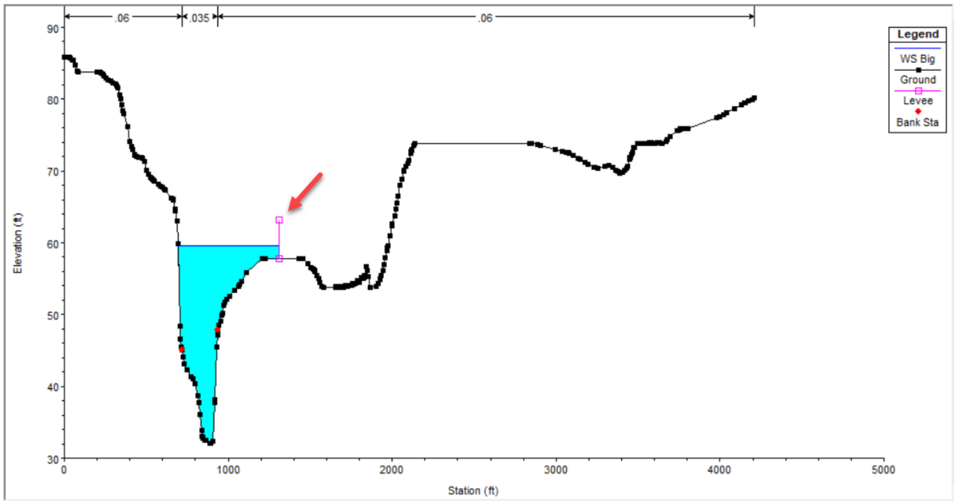
RAS provides the ability to establish a left and/or right levee station and elevation on any cross section. When established, no water can go to the left of the left levee station or to the right of the right levee station until either of the levee elevations are exceeded.

Levee stations must be defined explicitly, or the program assumes that water can go anywhere within the cross section. An example of a cross section with a levee on the left side is shown in the figure.

Levee Added



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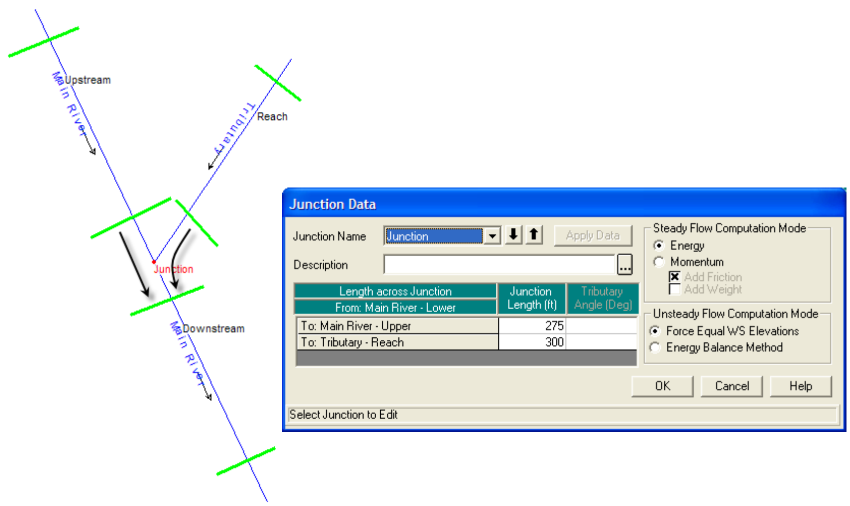
A levee can be added into a data set in order to see what effect a levee will have on the water surface by setting a levee station and elevation that is above the existing ground. A vertical wall is placed at that station up to the established levee height. Additional wetted perimeter is included when water comes into contact with the levee wall.

Junctions



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Stream junctions are defined as locations where two or more streams come together or split apart. Junction data consists of reach lengths across the junction and tributary angles, if the momentum equation is selected. Reach lengths across the junction are entered in the **Junction Data Editor**. This allows for the lengths across very complicated confluences (e.g. flow splits) to be accommodated.

It is necessary to describe lengths across junctions in the **Junction Data Editor**. These lengths should represent the average distance that the water will travel from the last cross section in on reach to the first cross section of the next reaches.

Questions?