

EXAMPLE 2

Beaver Creek - Single Bridge

Purpose

This example demonstrates the use of HEC-RAS to analyze a river reach that contains a single bridge crossing. For this example, the bridge is composed of typical geometry and was located perpendicular to the direction of flow in the main channel.

The stream for this example is a section of Beaver Creek located near Kentwood, Louisiana. The bridge crossing is located along State Highway 1049, near the middle of the river reach. The field data for this example were obtained from the United States Geological Survey (USGS) Hydrologic Atlas No. HA-601. This atlas is one part of a series developed to provide data to support hydraulic modeling of flow at highway crossings in complex hydrologic and geographic settings. The bridge, cross section geometry, and high water flow data were used to evaluate the flood flow of 14000 cfs that occurred on May 22, 1974, along with analysis of two additional flow values of 10000 cfs and 5000 cfs. It should be noted that modelers typically do not have access to high water marks and actual field flow measurements at bridges during the peak events. However, for this example, the flood stage water depth values were compared to the output from the model.

For this analysis, the water surface profiles were determined by first using the pressure/weir flow method and then the energy method. Next, an evaluation of the bridge contraction and expansion reach lengths was performed and resulted in the necessity to reposition the location of certain cross sections. After these adjustments were made, the model was then calibrated with the observed water surface elevation data. Finally, a comparison of the pressure/weir flow method to the energy method was made.

Pressure/Weir Flow Analysis

From the main program window, select **File** and then **Open Project**. Select the project labeled "Single Bridge - Example 2." This will open the project and activate the following files:

Plan :	"Pressure/Weir Method"
Geometry :	"Beaver Cr. + Bridge - P/W"
Flow :	"Beaver Cr. - 3 Flows"

To perform the pressure/weir flow analysis, the following data were entered:

- River System Schematic
- Cross Section Geometric Data
- Bridge Geometry Data
- Ineffective Flow Areas
- Bridge Modeling Approach
- Steady Flow Data

After the input of this data, the pressure/weir flow method was used to determine the resulting water surface elevations for the selected flow values.

River System Schematic

From the main program window, select **Edit** and then **Geometric Data**. This will activate the **Geometric Data Editor** and the screen will display the river system schematic for the Beaver Creek reach, as shown in Figure 2.1. The river name was entered as "Beaver Creek" and the reach name was "Kentwood."

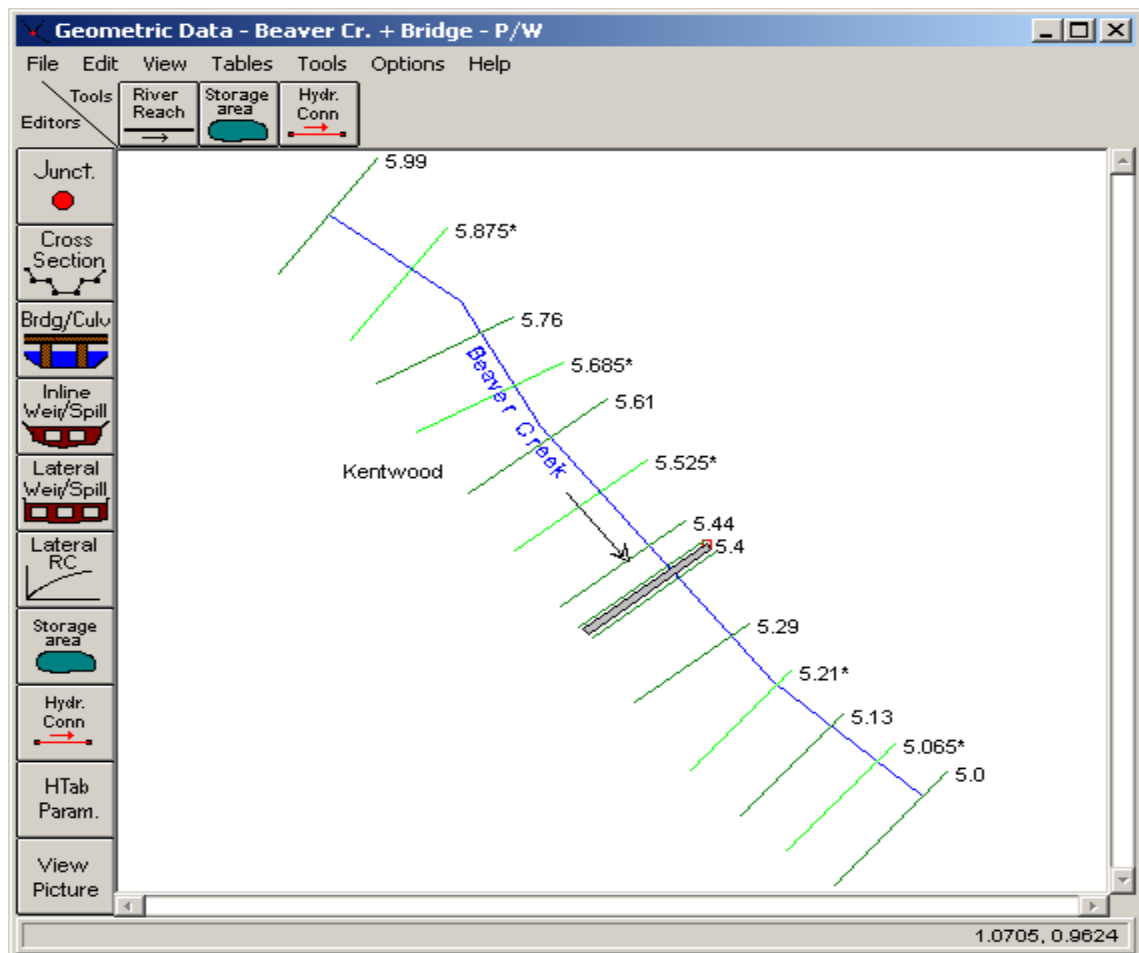


Figure 2.1 River System Schematic for Beaver Creek

The reach was initially defined with 14 cross sections beginning at river mile 5.00 as the downstream river station and river mile 5.99 as the upstream river station. The cross sections with an asterisk (*) were added by interpolation for the purposes of this example. When the bridge was added, it was placed at river mile 5.40 to place it at the appropriate location. On the river schematic, some of the cross section labels may not appear due to overlapping of the labels. If this occurs, the labels can be seen by zooming in on the location of the closely spaced cross sections.

Cross Section Geometric Data

The cross section geometric data consists of the: X-Y coordinates, reach lengths, Manning's n values, location of levees, and contraction and expansion coefficients. Each of these river station geometric data components are described in the following sections.

X-Y Coordinates. To view the cross section geometry data, from the **Geometric Data Editor** select the **Cross Section** icon. This will activate the **Cross Section Data Editor** as shown in Figure 2.2 for river mile 5.99. As shown in Figure 2.2, the X-Y coordinates were entered in the table on the left side of the editor. The additional components of the cross section geometry are described in the following sections.

Cross Section Data - Beaver Cr. + Bridge - P/W

Exit Edit Options Plot Help

River: Apply Data

Reach: River Sta.:

Description: ...

Cross Section X-Y Coordinates			
	Station	Elevation	n Val
1	0	221	0.1
2	7	220.3	
3	36	216.6	
4	131	216.6	
5	233	216.8	
6	282	216.6	
7	351	216.4	
8	518	216.1	0.14
9	591	213.3	
10	627	213.2	

Downstream Reach Lengths		
LOB	Channel	ROB
440	600	400

Manning's n Values		
LOB	Channel	ROB
N/A	N/A	N/A

Main Channel Bank Stations	
Left Bank	Right Bank
866	948

Cont\Exp Coefficients	
Contraction	Expansion
0.1	0.3

Levee on left side

Figure 2.2 Cross Section Data Editor For River Station 5.99

Reach Lengths. The distances between the cross sections are entered as the downstream reach lengths in the **Cross Section Data Editor**. To view the summary of the reach lengths, the table as shown in Figure 2.3 can be activated by selecting **Tables** and then **Reach Lengths** from the **Geometric Data Editor**. The reach lengths were obtained by measuring the distances on the USGS atlas. To determine the main channel distances, it was initially assumed that during the peak event, the major active portion of the flow will follow the course of the main channel. If, after the analysis, it is determined that the major portion of the active flow is not following the main channel course, then the main channel flow distances will need to be adjusted. In other words, if the major portion of the active flow is "cutting across" the meanders of the main channel, then these reach lengths will need to be reevaluated.

	River Sta	LOB	Channel	ROB
1	5.99	440	600	400
2	5.875*	440	600	400
3	5.76	225	400	275
4	5.685*	225	400	275
5	5.61	240	460	190
6	5.525*	240	460	190
7	5.44	270	170	500
8	5.41	100	100	100
9	5.4	Bridge		
10	5.39	320	500	580
11	5.29	410	416.5	410

Figure 2.3 Reach Lengths Summary Table

The reach lengths determine the placement of the cross sections. The placement of the cross sections relative to the location of the bridge is crucial for accurate prediction of expansion and contraction losses. The bridge routine utilizes four cross sections to determine the energy losses through the bridge. (Additionally the program will interpret two cross sections inside of the bridge by superimposing the bridge data onto both the immediate downstream and upstream cross sections from the bridge.) The following is a brief summary for the initial estimation of the placement of the four cross sections. The modeler should review the discussion in Chapter 6 of the **User's Manual** and Chapter 5 of the **Hydraulic Reference Manual** for further detail.

First Cross Section. Ideally, the first cross section should be located sufficiently downstream from the bridge so that the flow is not affected by the structure (ie, the flow has fully expanded). This distance should generally be determined by field investigation during high flows and will vary depending on the degree of constriction, the shape of the constriction, the magnitude of the flow, and the velocity of the flow. In order to provide better guidance to determine the location of the fully expanded cross section, a study was performed by the Hydrologic Engineering Center [HEC-1995]. This study focused on determining the expansion reach length, the contraction reach length, and the expansion and contraction energy loss coefficients.

For this example, cross section number 5.29 was initially considered as the cross section of fully expanded flow. This cross section was determined by field investigations as the approximate location of fully expanded flow during the high flow event. After the pressure/weir flow analysis was performed, the location of this cross section was evaluated using the procedures as outlined in the recent HEC study [HEC-1995]. The procedures required flow parameters at the initially chosen location to evaluate the location of the cross section. These procedures will be described after the pressure/weir flow analysis is performed near the end of this example.

Second Cross Section. The second cross section used by the program to determine the energy losses through the bridge is located a short distance downstream of the structure. This section should be very close to the bridge, and reflect the effective flow area on the downstream side of the bridge. For this example, a roadway embankment sloped gradually from the roadway decking on both sides of the roadway. Cross section 5.39 was located at the toe of the roadway embankment and was used to represent the effective flow area on the downstream side of the bridge opening. The program will superimpose the bridge geometry onto this cross section to develop a cross section inside the bridge at the downstream end.

Third Cross Section. The third cross section is located a short distance upstream from the bridge and should reflect the length required for the abrupt acceleration and contraction of the flow that occurs in the immediate area of the opening. As for the previous cross section, this cross section should also exhibit the effective flow areas on the upstream side of the bridge. For this example, cross section 5.41 was located at the toe of the roadway embankment on the upstream side of the bridge. Similar to the previous cross section, the program will superimpose the bridge geometry onto this cross section to develop a cross section inside the bridge at the upstream end.

Fourth Cross Section. The fourth cross section is located upstream from the bridge where the flow lines are parallel and the cross section exhibits fully effective flow. For this example, cross section 5.44 was initially used as this section where the flow lines were parallel. After the pressure/weir flow analysis, the location of this cross section was evaluated using the procedures as outlined in the HEC study [HEC-1995]. This evaluation will be presented in the discussion near the end of this example.

Manning's n Values. The Manning's n values were obtained from the field data displayed on the USGS atlas. For some of the cross sections, the Manning's n values changed along the width of the overbank areas and the horizontal variation in n values option was selected, such as for cross section 5.99. This option was performed from the **Cross Section Data Editor** by selecting **Options** and **Horizontal Variation in n Values**. This caused a new column to appear under the *Cross Section X-Y Coordinates* heading (as shown in Figure 2.2). For cross section 5.99, the n values changed at the X-coordinates of 518 (in the left overbank), 866 (the main channel left bank station), and 948 (the main channel right bank station). This can be seen by scrolling down in the coordinates window of the cross section editor. The overbank areas have densely wooded areas, which created the necessity for the variation in n values. The final data are shown in the cross section plot in Figure 2.4.

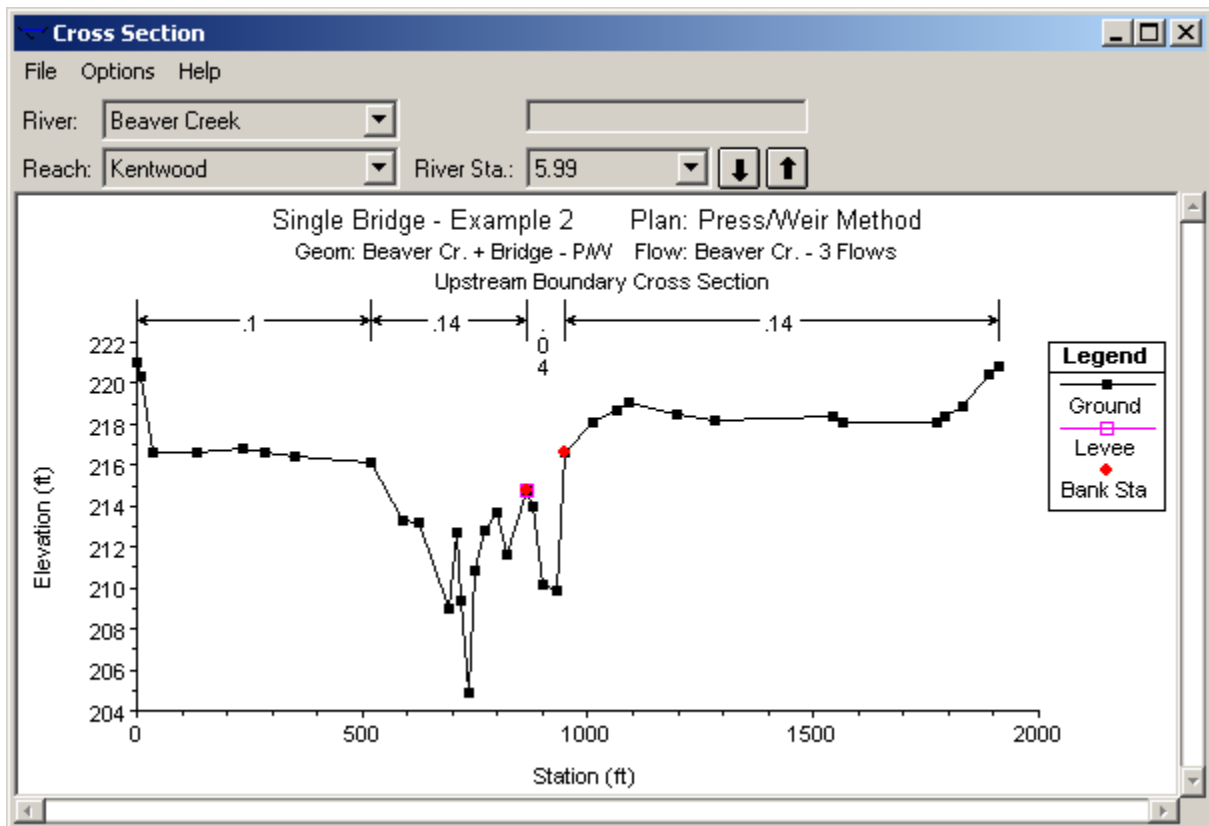


Figure 2.4 Cross Section 5.99: Horizontal n Variation and Levee Options

Levees. As can be seen in the plot of cross section 5.99 in Figure 2.4, there exists a large area to the left of the main channel that is lower in elevation than the invert of the main channel. During the analysis, the program will consider the water to be able to go anywhere in the cross section. The modeler must determine whether or not the lower area to the left of the main channel can initially convey flow. If the area cannot convey flow until the main channel fills up and then overtops, then the levee option should be used. For this example, a left levee was established at the left main channel bank

station for river station 5.99. This prevents water from being placed to the left of the levee until the elevation of the levee is reached. The elevation selected for this levee was the elevation of the left side of the main channel.

To insert the levee, **Options** and then **Levees** were selected from the **Cross Section Data Editor**. This resulted in the display shown in Figure 2.5. The values for this example were station 866 and elevation 214.8 for a left levee. As can be seen in Figure 2.4, the levee is displayed as a small square located at the LOB station. Additionally, a note appears identifying the selection of a levee for the specific cross section at the bottom of the **Cross Section Data Editor**. This note can be seen in the box at the bottom of Figure 2.2. Levee options were selected for other cross sections in addition to cross section 5.99. In each case, the modeler needs to view each cross-section and determine whether the levee option needs to be utilized.

The image shows a dialog box titled "XS Levee Data". Inside, there is a green instruction bar that says "Enter station and elevation points to mark levee on cross section". Below this, there are two columns of input fields labeled "Left" and "Right". Under the "Left" column, the "Station" field contains the value "866" and the "Elevation" field contains the value "214.8". The "Right" column has empty input fields for both "Station" and "Elevation". At the bottom of the dialog box, there are four buttons: "OK", "Cancel", "Defaults", and "Clear".

Figure 2.5 Levee Option for Cross Section 5.99

Contraction/Expansion Coefficients. The contraction and expansion coefficients are used by the program to determine the transition energy losses between two adjacent cross sections. From the data provided by the recent HEC study [HEC-1995], gradual transition contraction and expansion coefficients are 0.1 and 0.3, and typical bridge contraction and expansion coefficients are 0.3 and 0.5, respectively. For situations near bridges where abrupt changes are occurring, the coefficients may take larger values of 0.5 and 0.8 for contractions and expansions, respectively. A listing of the selected values for this river reach can be viewed by selecting **Tables** and then **Coefficients** from the **Geometric Data Editor**. This table is shown in Figure 2.6 and displays the values selected for the river cross sections. Typical gradual transition values were selected for stations away from the bridge. However, near the bridge section, the coefficients were increased to 0.3 and 0.5 to represent greater energy losses. For additional discussion concerning contraction and expansion coefficients at bridges, refer to Chapter 5 of the **Hydraulic Reference Manual**.

	River Sta	Contraction	Expansion
1	5.99	.1	.3
2	5.875*	.1	.3
3	5.76	.1	.3
4	5.685*	.1	.3
5	5.61	.1	.3
6	5.525*	.1	.3
7	5.44	.3	.5
8	5.41	.3	.5
9	5.4	Bridge	
10	5.39	.3	.5
11	5.29	.1	.3

Figure 2.6 Coefficients For Beaver Creek

This completed the input for the cross section geometric data. Next, the bridge geometry data was entered as outlined in the proceeding section.

Bridge Geometry Data

To enter the bridge geometry data, the **Bridge/Culvert** icon was selected from the **Geometric Data Editor**. This activated the **Bridge/Culvert Data Editor**. The river and reach were selected as "Beaver Creek" and "Kentwood" (the only reach for this example). Then, **Options**, and **Add a Bridge or Culvert** were selected and river station 5.4 was entered as the location for the bridge. The **Bridge/Culvert Data Editor** then displayed the upstream (river station 5.41) and downstream (river station 5.39) cross sections. A description was then entered as "Bridge #1." The following section provides a brief summary of the input for the bridge geometry including the bridge deck/roadway and then the bridge piers.

Bridge Deck and Roadway Geometry. From the **Bridge/Culvert Data Editor**, the **Deck/Roadway** icon was selected and this activated the **Deck/Roadway Data Editor**, as shown in Figure 2.7.

Deck/Roadway Data Editor

Del Row	Distance	Width	Weir Coef
Ins Row	30	40	2.6

Upstream				Downstream		
	Station	high chord	low chord	Station	high chord	low chord
1	0	216.93	200	0	216.93	200
2	450	216.93	200	450	216.93	200
3	450	216.93	215.7	450	216.93	215.7
4	647	216.93	215.7	647	216.93	215.7
5	647	216.93	200	647	216.93	200
6	2000	216.93	200	2000	216.93	200
7						
8						

U.S Embankment SS: 2 D.S Embankment SS: 2

Weir Data
 Max Submergence: 0.95 Min Weir Flow El:
 Weir Crest Shape
☒ Broad Crested
☐ Ogee

OK Cancel Clear Copy Up to Down

Enter distance between upstream cross section and deck/roadway. (ft)

Figure 2.7 Bridge/Deck and Roadway Data Editor

The first input at the top of the editor is the distance from the upstream side of the bridge deck to the cross section immediately upstream from the bridge (cross section 5.41). This distance was determined to be 30 feet from the USGS atlas. In the next field, the bridge deck width of 40 feet was entered. Finally, a weir flow coefficient of 2.6 was selected for the analysis. (Additional discussion of the weir flow coefficient will be presented in the calibration section.)

The central section of the **Deck/Roadway Editor** is comprised of columns for input of the station, high cord elevation, and low cord elevation for both the upstream and downstream sides of the bridge deck. The data are entered from left to right in cross section stationing and the area between the high and low cord is the bridge structure. The stationing of the upstream side of the deck was based on the stationing of the cross section located immediately upstream. Likewise, the stationing of the downstream side of the deck was based on the stationing of the cross section placed immediately downstream.

If both the upstream and downstream data are identical, the user needs only to input the upstream data and then select **Copy Up to Down** to enter the downstream data.

As a final note, the low cord elevations that are concurrent with the ground elevation were entered as a value lower than the ground elevation. The

program will automatically clip off and remove the deck/roadway area below the ground. For example, at station 0, a low cord elevation of 200 feet was entered. However, the actual ground elevation at this point is approximately 216 feet. Therefore, the program will automatically remove the area of the roadway below the ground. Additionally, the last station was entered as a value of 2000 feet. This stationing ensured that the roadway and decking extended into the limits of the cross section geometry. As described previously, the program will clip off the area beyond the limits of the cross section geometry.

The **US** and **DS Embankment SS** (upstream and downstream embankment side slope) values were entered as 2 (horizontal to 1 vertical). These values are used for graphical representation on the profile plot and for the WSPRO low flow method. The user is referred to Example 13 - Bogue Chitto Single Bridge (WSPRO) for a discussion on the use of this parameter with the WSPRO method. The WSPRO method is not employed for this example.

At the bottom of the **Deck/Roadway Data Editor**, there are three additional fields for data entry. The first is the **Max Allowable Submergence**. This input is a ratio of downstream water depth to upstream energy, as measured above the minimum weir elevation. When the ratio is exceeded, the program will no longer consider the bridge deck to act as a weir and will switch the computation mode to the energy (standard step) method. For this example, the default value of 0.95 (95 %) was selected, however this value may be changed by the user.

The second field at the bottom of the editor is the **Min Weir Flow Elevation**. This is the elevation that determines when weir flow will start to occur over the bridge. If this field is left blank (as for this example), the program will default to use the lowest high cord value on the upstream side of the bridge. Finally, the last field at the bottom of the editor is the selection of the **Weir Crest Shape**. This selection will determine the reduction of the weir flow coefficient due to submergence. For this example, a broad crested weir shape was selected. Upon entering all of the above data, the **OK** button was selected to exit the **Deck/Roadway Data Editor**.

Bridge Pier Geometry. From the **Bridge/Culvert Data Editor**, select the **Pier** icon. This will result in the display shown in Figure 2.8. The modeler should not include the piers as part of the ground or bridge deck/roadway because pier-loss equations use the separate bridge pier data during the computations.

Pier Data Editor

Add Copy Delete Pier # 1 [Down Arrow] [Up Arrow]

Del Row Centerline Station Upstream 470

Ins Row Centerline Station Downstream 470

☐ Floating Debris

Upstream		Downstream		
	Pier Width	Elevation	Pier Width	Elevation
1	1.25	200	1.25	200
2	1.25	216	1.25	216
3				
4				
5				

OK Cancel Help Copy Up to Down

Edit pier widths and elevations (ft)

Figure 2.8 Bridge Pier Data Editor

The program will establish the first pier as pier number 1. As shown in Figure 2.8, the upstream and downstream stations were entered for the centerline of the first pier. The upstream and downstream stations were based on the geometry of the cross sections located immediately upstream (cross section 5.41) and immediately downstream (cross section 5.39) of the bridge. The user needs to be cautious placing the pier centerline stations because the X-coordinates for the upstream and downstream cross section stationing may be different. This is to ensure that the piers "line up" to form the correct geometry. For this example, the pier centerline stations are 470, 490, 510, 530, 550, 570, 590, 610, and 630 for the nine piers. Each pier was set to start at an elevation of 200 feet (this elevation is below the ground level and the excess will be removed by the program) and end at an elevation of 216 feet (this elevation is inside the bridge decking and the excess was removed by the program). Additionally, each pier had a continuous width of 1.25 feet. After entering the data, the **OK** button was selected and the schematic of the bridge with the piers was displayed on the **Bridge/Culvert Data Editor** as shown on Figure 2.9. (Note: The figure in the text displays the ineffective flow areas that will be added in the next section.)

The cross sections shown in Figure 2.9 are developed by superimposing the bridge data on the cross sections immediately upstream (5.41) and immediately downstream (5.39) of the bridge. The top cross section in Figure 2.9 reflects the geometry immediately inside the bridge on the upstream side and the bottom cross section reflects the geometry immediately inside the bridge on the downstream side.

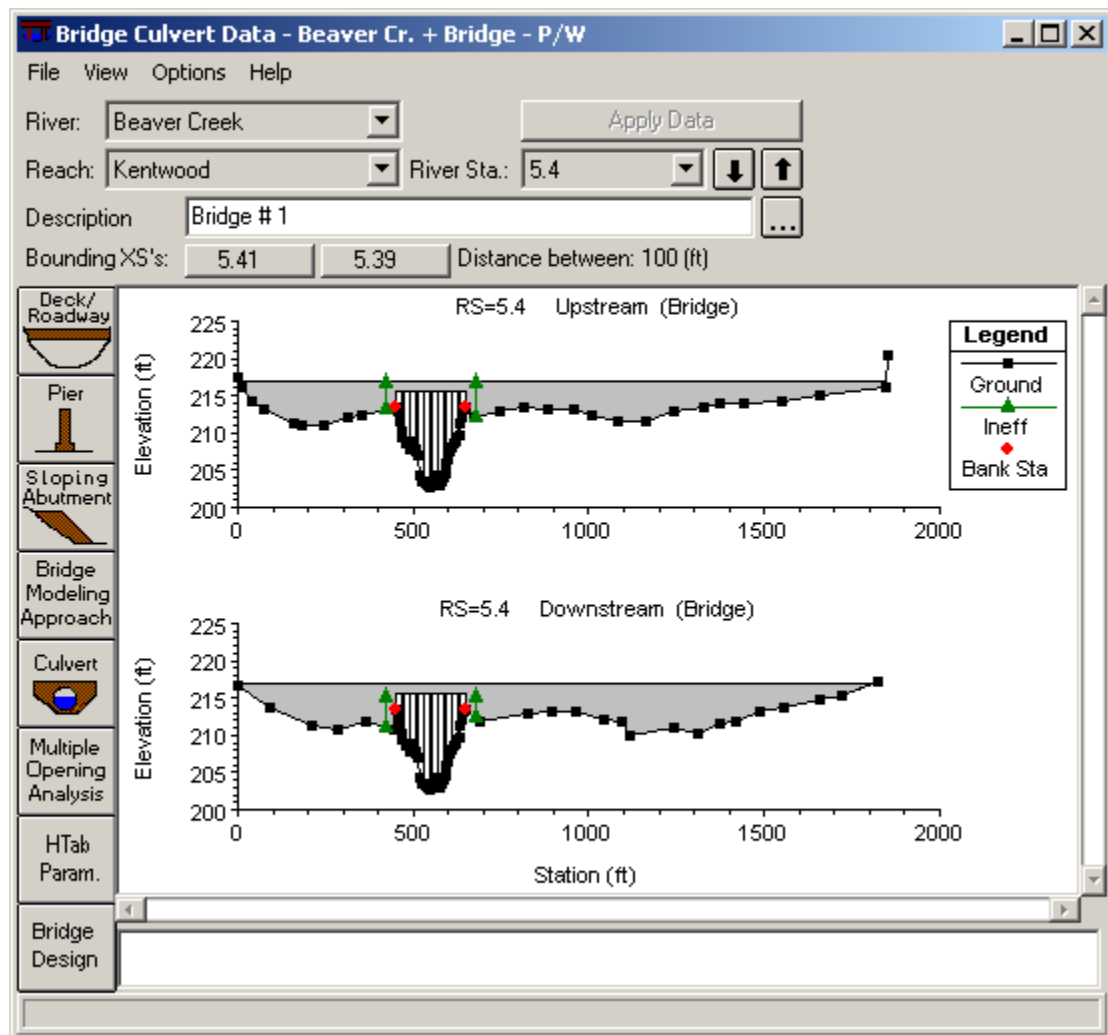


Figure 2.9 Bridge/Culvert Data Editor

While viewing the bridge, the modeler can select to view just the upstream, just the downstream, or both of the cross section views. This is performed by selecting **View** and then the required option. Additionally, from the **View** menu, the user should select **Highlight Weir, Opening Lid and Ground** as well as **Highlight Piers**. These options enable the modeler to view what the program will consider as the weir length, bridge opening, and pier locations. Any errors in the data may appear as inconsistent images with these options. Also, the zoom-in option will allow the user to examine data details.

As a final note for the bridge geometry, a bitmap image of the bridge was added to the geometry file (denoted by a red square on the river system schematic, Figure 2.1). The user can view this image by selecting the **View Picture** icon on the **Geometric Data Editor**.

Ineffective Flow Areas

As a final step for the bridge geometry, any ineffective flow areas that existed due to the bridge (or any other obstruction) were entered. Ineffective flow is used to define an area of the cross section in which the water will accumulate but is not being actively conveyed. At a bridge, ineffective flow areas normally occur just upstream and downstream of the road embankment, away from the bridge opening.

For this example, ineffective flow areas were included on both the upstream cross section (5.41) and the downstream cross section (5.39). To determine an initial estimate for the stationing of the ineffective flow areas, a 1:1 ratio of the distance from the bridge to the cross section was used. For this example, section 5.41 is located 30 feet upstream of the bridge. Therefore, the left and right ineffective flow areas were set to start at 30 feet to the left and right of the bridge opening. Similarly, cross section 5.39 is located 30 feet downstream from the bridge and the ineffective flow areas at this cross section were set at 30 feet to the left and right of the bridge opening.

To determine the initial elevation of the ineffective flow areas for the upstream cross section, a value slightly lower than the lowest high cord elevation was used. This ineffective flow elevation was chosen so that when the water surface becomes greater than this ineffective elevation, the flow would most likely be weir flow and would be considered as effective flow. At the downstream cross section, the elevation of the ineffective flow area was set to be slightly lower than the low cord elevation. This elevation was chosen so that when weir flow occurs over the bridge, the water level downstream may be lower than the high cord, but yet it will contribute to the active flow area. (Additional discussion of the selection of these elevations is described in the calibration section of this example.)

To enter the ineffective flow areas, from the **Geometric Data Editor** select the **Cross Section** icon. Toggle to cross section 5.41 and select **Options** and then **Ineffective Flow Areas**. This will result in the display shown in Figure 2.10. The default option (normal) is to enter the areas as a left station and elevation and/or a right station and elevation. For this example, both the left and right ineffective flow areas were used.

Select Ineffective Mode	
<input checked="" type="radio"/> Normal	<input type="radio"/> Multiple Blocks
Left	Right
Station: 420	Station: 677
Elevation: 216.7	Elevation: 216.7
<input type="checkbox"/> Permanent	<input type="checkbox"/> Permanent
OK	Cancel
Defaults	Clear

Figure 2.10 Normal Ineffective Flow Areas For Cross Section 5.41

The left and right ineffective flow stations were entered as 420 and 677 feet, respectively. These values are 30 feet to the left and right of the bridge opening, as discussed previously. The elevation was then entered as 216.7 feet, a value slightly lower than the high cord elevation. These entries imply that all the water to the left of the left station and to the right of the right station will be considered as ineffective flow until the water level exceeds the elevation of 216.7 feet.

Similarly, ineffective flow areas were set at river station 5.39 with a left station at 420 and a right station at 677, both at an elevation of 215.0 feet. The **OK** button was selected and the ineffective flow areas appeared as green triangles, as shown previously on Figure 2.9. Additionally, the ineffective flow areas will appear on the plots of the cross sections. Finally, a note will appear in the box at the bottom of the **Cross Section Data Editor** that states an ineffective flow exists for each cross section for which this option was selected.

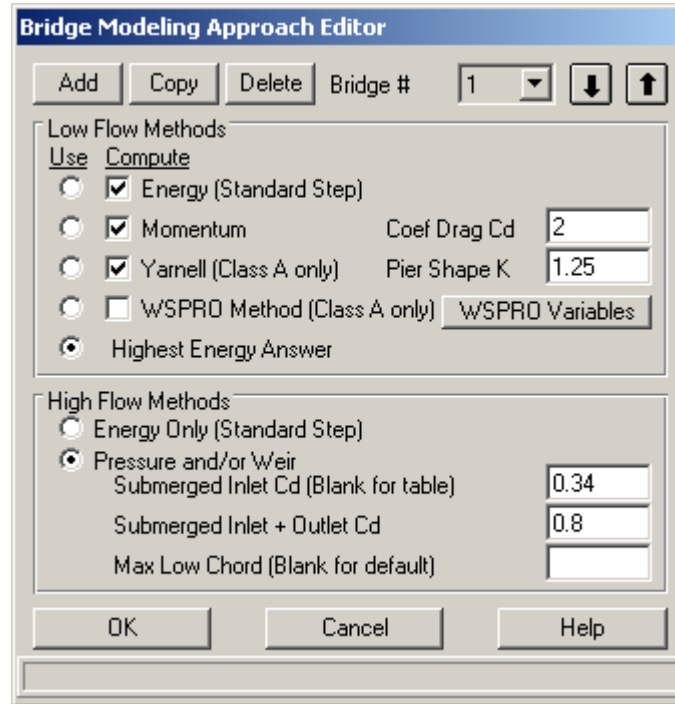
Bridge Modeling Approach

The bridge routines allow the modeler to analyze the bridge flows by using different methods with the same geometry. The different methods are: low flow, high flow, and combination flow. Low flow occurs when the water only flows through the bridge opening and is considered as open channel flow (i.e., the water surface does not exceed the highest point of the low cord on the upstream side of the bridge). High flow occurs when the water surface encounters the highest point of the low cord on the upstream side of the bridge. Finally, combination flow occurs when both low flow or pressure flow occur simultaneously with flow over the bridge. The modeler needs to select appropriate methods for both the low flow and for the high flow methods. For the combination flow, the program will use the methods selected for both of the flows.

From the **Geometric Data Editor**, select the **Bridge/Culvert** icon and then the **Bridge Modeling Approach** button. This will activate the **Bridge Modeling Approach Editor** as shown in Figure 2.11. For this example, there is only 1 bridge opening located at this river station and therefore the bridge number was 1. The following sections describe the additional parameters of the bridge modeling editor. The modeler is referred to Chapter 6 of the **User's Manual** and Chapter 5 of the **Hydraulic Reference Manual** for additional discussion on the bridge modeling approach editor.

Low Flow Methods. Low flow exists when the flow through the bridge is open channel flow. As can be seen in Figure 2.11, the program has the capability of analyzing low flow with four methods:

- Energy Equation (Standard Step)
- Momentum Balance
- Yarnell Equation (Class A only)
- WSPRO Method (Class A only)



The image shows a software dialog box titled "Bridge Modeling Approach Editor". At the top, there are buttons for "Add", "Copy", and "Delete", followed by a "Bridge #" dropdown menu set to "1" and two arrow buttons (down and up). The dialog is divided into two main sections: "Low Flow Methods" and "High Flow Methods".

Low Flow Methods: This section has two sub-sections, "Use" and "Compute". Under "Use", there are radio buttons for "Energy (Standard Step)", "Momentum", "Yarnell (Class A only)", "WSPRO Method (Class A only)", and "Highest Energy Answer". Under "Compute", there are checkboxes for "Energy (Standard Step)", "Momentum", "Yarnell (Class A only)", and "WSPRO Method (Class A only)". To the right of these checkboxes are input fields for "Coef Drag Cd" (value: 2) and "Pier Shape K" (value: 1.25). There is also a button labeled "WSPRO Variables".

High Flow Methods: This section has a radio button for "Energy Only (Standard Step)" and a checked radio button for "Pressure and/or Weir". Below these are input fields for "Submerged Inlet Cd (Blank for table)" (value: 0.34), "Submerged Inlet + Outlet Cd" (value: 0.8), and "Max Low Chord (Blank for default)".

At the bottom of the dialog are three buttons: "OK", "Cancel", and "Help".

Figure 2.11 Bridge Modeling Approach Editor

The *Energy Equation (Standard Step)* method considers the bridge as just being part of the natural channel and requires Manning's n values for the friction losses through the bridge and coefficients of contraction and expansion. The *Momentum Balance* method performs a momentum balance through the bridge area and requires the selection of a drag coefficient, C_d . This coefficient is used to estimate the force due to the water moving around the piers, the separation of flow, and the resulting downstream wake. The *Yarnell Equation* is an empirical equation based on lab experiments. Finally, the *WSPRO* method is an energy based method developed by the USGS for the Federal Highway Administration.

At this time, the modeler needs to select which methods the program should compute and which method the program should use. The modeler can select to have the program compute particular methods or all of the methods. Then, the modeler needs to select which method the program will use as a final solution. Alternatively, the modeler can select the computation of several or all of the methods, and then have the program use the method with the greatest energy loss for the final solution. This will allow the modeler to view the results of all the methods and compare the results of the different techniques.

For this example, the Energy, Momentum, and Yarnell methods were selected to be computed. For the momentum method, a drag coefficient $C_d = 2.00$ was entered for the square nose piers and for the Yarnell method, a value of $K = 1.25$ was entered. Finally, the method that resulted in the greatest energy loss was selected to be used for the solution. (The user is referred to Example 13 for an application of the WSPRO method.)

High Flow Methods. High flows occur when the water surface elevation upstream of the bridge is greater than the highest point on the low cord of the upstream side of the bridge. Referring to Figure 2.11, the two alternatives for the program to compute the water surface elevations during the high flows are: *Energy Only (Standard Step)* or *Pressure and/or Weir Flow*. The *Energy Only (Standard Step)* method regards the flow as open channel flow and considers the bridge as an obstruction to the flow. Typically, most bridges during high flows may act primarily as just an obstruction to the flow and the energy method may be most applicable.

As a second method for the analysis of high flows, the program can consider the flow to be causing *Pressure Flow and/or Weir Flow*. For pressure flow, there are two possible scenarios. The first is when only the upstream side of the bridge deck is in contact with the water. For this scenario, the submerged inlet coefficient, C_d , was set to be 0.34. (This value was arrived at during the calibration, which is described later in this example.) The second scenario for pressure flow is when the bridge constriction is flowing completely full. For this situation, the submerged inlet and outlet coefficient was set to 0.80.

The program will begin to calculate either type of pressure flow when the computed low flow energy grade line is greater than the highest point of the upstream low cord. Alternatively, the user can set the elevation at which pressure flow will begin to be checked, instead of the highest low cord value. This value can be entered as the last input to the **Bridge Modeling Approach Editor** (Figure 2.11). For this example, this field was left blank which implies that the program used the highest value of the low cord (the default). As an additional option, the user can select to have the program begin to calculate the pressure flow by using the value of the water surface instead of the value of the energy grade line. This is accomplished from within the **Bridge/Culvert Data Editor** by selecting **Options** and then **Pressure flow criteria**. This will result in the display shown in Figure 2.12. For this example, the option to use the upstream energy grade line was chosen.

Finally, for the high flow analysis, *Weir Flow* occurs when the upstream energy grade line elevation (as a default setting) exceeds the lowest point of the upstream high cord. The weir flow data was entered previously in the **Deck/Roadway Data Editor**. At this point, all of the bridge data have been entered. The user should exit the geometry data editors and save the geometry data. For this example, the geometry data was saved as the file "Beaver Cr. + Bridge - P/W."

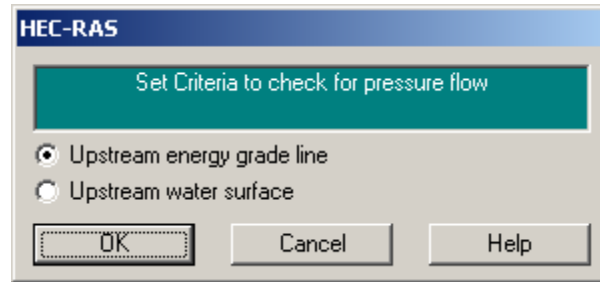


Figure 2.12 Pressure Flow Check Criteria

Steady Flow Data

To enter the steady flow data, from the main program window **Edit** and then **Steady Flow Data** were selected. This activated the **Steady Flow Data Editor** as shown in Figure 2.13. For this analysis on the reach of Kentwood, three profiles were selected to be computed. The flow data were entered for river station 5.99 (the upstream station) and the flow values were 5000, 10000, and 14000 cfs. These flows will be considered continuous throughout the reach so no flow change locations were used. Additionally, the three profile names were changed from the default values of "PF#1," etc., to "25 yr," "100 yr," and May '74 flood," respectively. These names will be used to represent the flow profiles when viewing the output.

Steady Flow Data - Beaver Cr. - 3 Flows

File Options Help

Enter/Edit Number of Profiles (500 max):

Locations of Flow Data Changes

River:

Reach: River Sta.:

Flow Change Location				Profile Names and Flow Rates		
	River	Reach	RS	25 yr	100 yr	May '74 flood
1	Beaver Creek	Kentwood	5.99	5000	10000	14000

Observed Water Surfaces Entered

Edit Steady flow data for the profiles (cfs)

Figure 2.13 Steady Flow Data Editor

To enter the boundary conditions, the **Boundary Conditions** button was selected and this resulted in the display shown in Figure 2.14. For this example, a subcritical analysis was performed. Therefore, a downstream

boundary condition was required for each flow value. The mouse arrow was placed over the downstream field and then the box was selected (highlighted). Then, 1 of the 4 boundary conditions was selected and this caused the type of boundary condition that was chosen to appear in the downstream end of the reach.

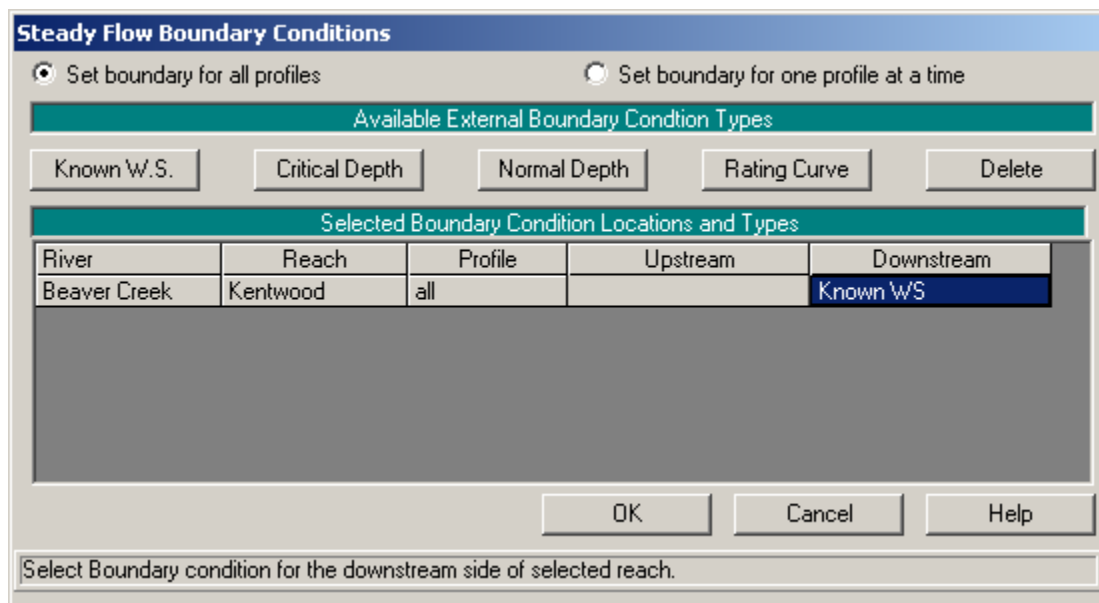


Figure 2.14 Steady Flow Boundary Conditions

For this example, **Known W. S.** was selected. This caused the input editor as shown in Figure 2.15 to appear. For each of the flows, the known downstream water surface elevations of 209.5, 210.5, and 211.8 feet were entered for the flows 1, 2, and 3, respectively. These values were obtained from observed data on the USGS Atlas.

For the purposes of the analysis, if the downstream boundary conditions are not known, then the modeler should use an estimated boundary condition. However, this may introduce errors in the region of this estimated value. Therefore, the modeler needs to have an adequate number of cross sections downstream from the main area of interest so that the boundary conditions do not effect the area of interest. Multiple runs should be performed to observe the effect of changing the boundary conditions on the output of the main area of interest. For a detailed explanation of the types of boundary conditions, refer to Chapter 7 of the **User's Manual** and Chapter 3 of the **Hydraulic Reference Manual**. After entering the boundary condition data, the **OK** button was selected to exit the editor. This completed the necessary input for the flow data and the steady flow data was then saved as "Beaver Cr. - 3 Flows."

	Flow (cfs)	Known WS El (ft)
1	5000	209.5
2	10000	210.5
3	14000	211.8

OK Cancel

Figure 2.15 Known Water Surface Boundary Conditions

Pressure/Weir Flow Simulation

To perform the steady flow analysis, from the main program window **Run** and then **Steady Flow Analysis** were selected. This activated the **Steady Flow Analysis Window** as shown in Figure 2.16. First, it was ensured that the geometry file and steady flow file that were previously developed appeared in the selection boxes on the right side of the window. Then, for this simulation, a subcritical flow analysis was selected. Additionally, from the **Steady Flow Analysis** window, **Options** and then **Critical Depth Output Option** were selected. An "x" was placed beside the option for **Critical Always Calculated**. This may require additional computation time during program execution, but then the user can view the critical depth elevation at all river stations during the review of the output.

Steady Flow Analysis

File Options Help

Plan: Press/Weir Method Short ID: Press/Weir M

Geometry File: Beaver Cr. + Bridge - P/W

Steady Flow File: Beaver Cr. - 3 Flows

Flow Regime:

- ☒ Subcritical
- ☐ Supercritical
- ☐ Mixed

Plan Description:

COMPUTE

Enter to compute water surface profiles

Figure 2.16 Steady Flow Analysis

Select **Options** and then ensure that there is a check mark "T" in front of **Check data before execution**. This will cause the program to check all of the input data to ensure that all pertinent information was entered. Next, the

options were saved as a plan entitled "Press/Weir Method," with a *Short ID* entered as "Press/Weir." Finally, **COMPUTE** was selected at the bottom of the window.

Review of Pressure/Weir Flow Output

After the program has completed the analysis, the last line should read "PROGRAM TERMINATED NORMALLY." This window is closed by double clicking the bar in the upper left corner of the display. From the main program window, **View** and then **Water Surface Profiles** were selected. This displayed the profile plot as shown in Figure 2.17, showing the water surface elevations and critical depth lines for all three profiles. (Note: the variables that are displayed can be changed by selecting **Options** and then **Variables**.)

From Figure 2.17, it can be seen that all three of the flow profiles are occurring in the subcritical flow regime. This ensures that for the low flow analysis, Class A low flow (subcritical flow) was occurring through the bridge. Low flow occurred for the first (5000 cfs) and for the second (10000 cfs) flow profiles. For the high flow, the method of analysis was chosen to be pressure/weir flow. Pressure and weir flow occurred during the third flow profile (14000 cfs). One way to determine the type of flow that occurred is by viewing the bridge only output table. This table is presented in Figure 2.18 and was activated from the main program window by selecting **View**, **Profile Table**, **Std. Tables**, and then **Bridge Only**.

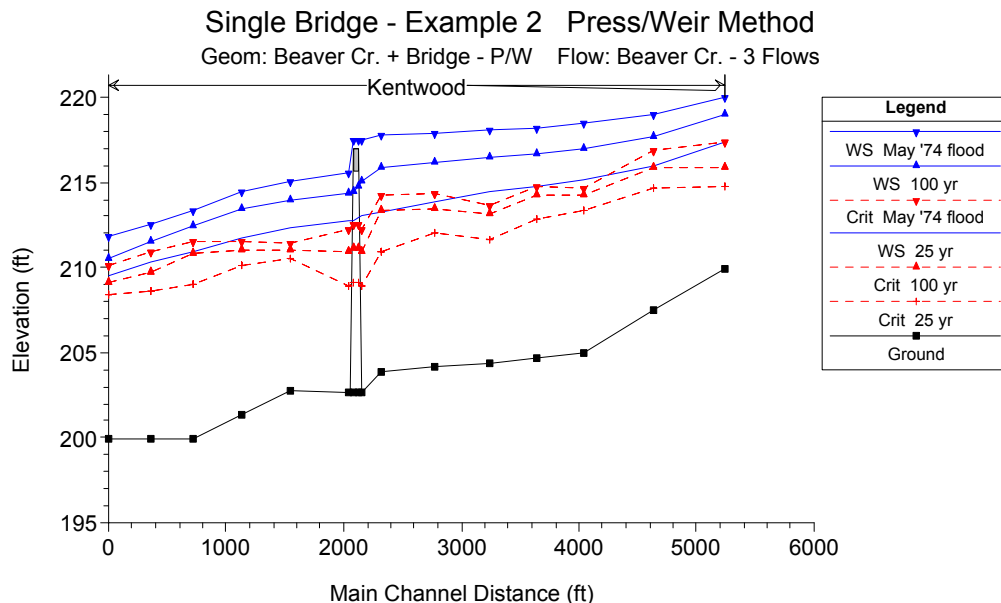


Figure 2.17 Profile Plot for Pressure/Weir Analysis

For this example there is only one bridge located at river station 5.40, as listed in the table. Pressure flow calculations were set to begin when the energy grade line elevation of the upstream section (5.41) was greater than the highest elevation of the upstream low cord (215.7 ft). The first column in

Figure 2.18 shows the energy grade line elevation of the upstream section (EG US) and the second column shows the elevation when pressure flow was set to begin. A comparison of these two columns shows that pressure flow occurred for the third profile. Additionally, it can be seen that weir flow occurred for the third profile, since there is a weir flow value for the third profile. The following sections detail the output for the first two profiles and then for the third flow profile.

Reach	River Sta	E.G. US (ft)	Min El Prs (ft)	BR Open Area (sq ft)	Prs O'WS (ft)	Q Total (cfs)	Min El Weir Flow (ft)	Q Weir (cfs)	Delta EG (ft)
Kentwood	5.4	213.31	215.70	1600.36		5000.00	216.94		0.27
Kentwood	5.4	215.67	215.70	1600.36		10000.00	216.94		0.56
Kentwood	5.4	217.68	215.70	1600.36	221.59	14000.00	216.94	3057.03	1.67

Figure 2.18 Bridge Only Summary Table for Pressure/Weir Flow

First and Second Flow Profiles. The first (5000 cfs) and second (10000 cfs) flow profiles were both computed using the low flow methods of: Energy, Momentum, and Yarnell. From the main program window, select **View**, **Profile Table**, **Standard Tables**, and then **Bridge Comparison**. This will provide a comparison table for the different energy loss methods and is shown in Figure 2.19.

In Figure 2.19, the three rows display the results for each of the three flow profiles, in ascending order. The river station is set at 5.4 (the only bridge location for this reach). The fourth column shows the water surface elevation immediately upstream of the bridge. The sixth, seventh and eighth columns show the results of the low flow methods that were chosen to be computed: Energy, Momentum, and Yarnell Methods, respectively. The program compared the results and used the value with the greatest energy loss. For the first and second profiles, the energy method calculated the greatest energy losses and the program used the results of 213.31 and 215.67 feet, respectively.

Reach	River Sta	E.G. US. (ft)	W.S. US. (ft)	Br Sel Method	Energy EG (ft)	Momen. EG (ft)	Yarnell EG (ft)	WSPRO EG (ft)	Prs O EG (ft)	Prs/Wr EG (ft)
Kentwood	5.4	213.31	213.03	Energy only	213.31	213.30	213.10			
Kentwood	5.4	215.67	215.07	Energy only	215.67	215.59	215.27			
Kentwood	5.4	217.68	217.44	Press/Weir	217.26				221.66	217.68

Figure 2.19 Bridge Comparison Table for Pressure/Weir Flow Analysis

Third Flow Profile. The third flow profile was computed for a flow of 14000 cfs. As can be seen in Figure 2.18, approximately 3050 cfs of the total flow was weir flow. The remaining flow, approximately 10950 cfs, was pressure flow through the bridge opening. As can be seen in Figure 2.19, the energy grade line necessary for pressure-only flow was 221.66 feet. Since this value is greater than the upstream high cord, weir flow also developed. Therefore, the program used the pressure/weir energy value as the solution to the high flow method, namely 217.68 feet.

Energy Method Analysis

As a second approach to analyze the three flows, the energy method will be used instead of the pressure/weir flow method for the high flows. From the **Steady Flow Analysis Window**, select **File**, **Open Plan**, and then select "Energy Method." This will activate the plan that employed the energy method for the analysis. The following discussion outlines the procedure used to develop this plan.

Energy Method Data and Simulation

To enter the data for the energy method, from the main program window **Edit**, **Geometric Data**, the **Bridge/Culvert** icon, and then the **Bridge Modeling Approach** icon were selected. This activated the **Bridge Modeling Approach Editor** as was shown in Figure 2.11. The **Energy Only (Standard Step)** option was then selected as the high flow method (instead of the Pressure/Weir method). Then, the editor was closed and the geometry was saved as "Beaver Cr. + Bridge - Energy." Next, **Run** and then **Steady Flow Analysis** were selected from the main program window. This activated the **Steady Flow Analysis Window**. The geometry file was selected as "Beaver Cr. + Bridge - Energy" and the steady flow file was "Beaver Cr. - 3 Flows" (the same steady flow file as used previously). Then, a *Short ID* was entered as "Energy" and the options were saved as the plan "Energy Method." Finally, **COMPUTE** was selected to perform the steady flow analysis.

Review of Energy Method Output

From the main program window, select **View, Profile Table, Standard Tables**, and then **Bridge Comparison**. This bridge comparison table is shown in Figure 2.20. For the first and second profiles, the table shows the same results as for the pressure flow analysis. This is as would be expected since the first and second profiles were calculated using the same low flow procedures. For the third profile, the energy method was used to calculate the energy losses through the bridge for this high flow and resulted in an energy gradeline elevation of 217.38 feet.

Reach	River Sta	E.G. US. (ft)	W.S. US. (ft)	Br Sel Method	Energy EG (ft)	Momen. EG (ft)	Yarnell EG (ft)	W/SPRO EG (ft)	Prs O EG (ft)	Prs/Wtr EG (ft)
Kentwood	5.4	213.31	213.03	Energy only	213.31	213.30	213.10			
Kentwood	5.4	215.67	215.07	Energy only	215.67	215.59	215.27			
Kentwood	5.4	217.38	217.10	Energy only	217.38					

Energy grade elevation at bridge or culvert (final answer).

Figure 2.20 Bridge Comparison Table for Energy Method Analysis

Evaluation of Cross Section Locations

As stated previously, the locations of the cross sections and the values selected for the expansion and contraction coefficients in the vicinity of the bridge are crucial for accurate prediction of the energy losses through the bridge structure. For this example, the locations of the cross sections and the energy loss coefficients were evaluated for the high flow event. The following analysis is based on data that were developed for low flow events occurring through bridges and the modeler should use caution when applying the procedure for other than low flow situations. Each of the reach length and coefficient evaluation procedures are discussed in the following sections.

Expansion Reach Length

The expansion reach length, L_e , is defined as the distance from the cross section placed immediately downstream of the bridge to the cross section where the flow is assumed to have fully expanded. For this example, this distance is from cross section 5.39 to cross-section 5.29. Initially, the expansion reach length is estimated according to observed field data or other appropriate method. For this example, observed data were available so the

initial estimate of the expansion reach length was obtained from the field observations. After the analysis, the modeler can evaluate the initial estimate of the expansion reach length. For the analysis, it is recommended to use the regression results from the US Army Corps of Engineers (USACE) study [HEC-1995]. The results of the study suggest the use of Equation 2-1 to evaluate the expansion reach length. This equation is valid when the modeling situation is similar to the data used in the regression analysis. (In the document, alternative expressions are presented for other situations.) The equation is:

$$L_e = ER(\bar{L}_{obs}) = -298 + 257\left(\frac{F_{5.39}}{F_{5.29}}\right) + 0.918\bar{L}_{obs} + 0.00479Q \quad (2-1)$$

where: L_e = expansion reach length, ft
 ER = expansion ratio
 $F_{5.39}$ = main channel Froude number at the cross section immediately downstream of the bridge (cross section 5.39 for this example)
 $F_{5.29}$ = main channel Froude number at the cross section of fully expanded flow (initially cross section 5.29 for this example)
 \bar{L}_{obs} = average length of obstruction caused by the two bridge approaches, ft
 Q = total discharge, ft³/s

(Note: The subscripts used in Equation 2-1 and all subsequent equations reflect the river station numbering for this example.)

From the field data, the average length of the obstruction is approximately 740 feet and the total discharge, Q , is 14000 cfs for the high flow event. From the initial analysis, the values of the Froude number at cross-section 5.39 was 0.37 and at cross section 5.29 was 0.30. (Both of these values were the same for pressure/weir and energy methods and are displayed on **Standard Table 1**.) Substituting the values into Equation 2-1 yielded that the expansion reach length, L_e , was approximately 778 feet. This equation has a standard error of 96 feet, which yields an expansion reach length range from 682 to 874 feet to define the 68% confidence band. The distance used for the expansion reach length (the distance from cross section 5.39 to cross-section 5.29) was set to be 500 feet in the main channel, which is less than the recommended range from the equation. The modeler now has the option to adjust this length so that it is within the calculated range. Then, after a new analysis, the new Froude numbers should be used to calculate a new expansion reach length. If the geometry is not changing rapidly in this region, then only 1 or 2 iterations should be necessary to obtain a constant expansion reach length value.

For this example, the location of the fully expanded cross section was changed to reflect the new expansion reach length (778 feet) by interpolating a new cross section to be located 778 feet downstream from cross section 5.39. To accomplish this, the following steps were taken. First, the

pressure/weir flow plan ("Pressure/Weir Method") was activated. Then, in the **Geometric Data Editor**, a cross section was interpolated between cross sections 5.29 and 5.21*. This interpolated cross section (5.24*) was set to be at a distance of 278 feet downstream from cross section 5.29. Since cross section 5.29 was already located 500 feet downstream from cross section 5.39, the location of cross section 5.24* was then $500 + 278 = 778$ feet downstream from cross section 5.39. The cross sections 5.29, 5.27*, and 5.21* were then deleted.

Finally, this new geometric data was saved as a file called "Bvr.Cr.+Bridge - P/W: New Le, Lc." On the **Steady Flow Analysis Window**, a *Short ID* was entered as "P/w+NewLeLc" and then the new geometry file and the original steady flow data file were saved as a plan entitled "Press/Weir Method: New Le, Lc." The **Geometric Data Editor** was then reactivated and the **Bridge Modeling Approach Data Editor** was selected. The high flow method was chosen to be the energy method and then the geometry data was saved as "Bvr.Cr.+Bridge - Energy: New Le, Lc." The **Steady Flow Analysis Window** was activated, a *Short ID* was entered as "En.+New LeLc," and the new energy geometry file and the steady flow data file were then saved as a new plan entitled "Energy Method : New Le, Lc." This procedure created two new plans, with each plan containing the necessary interpolated geometry and appropriate high flow calculation methods.

Each of the two new plans were then executed and the resulting flow parameter values were reentered into Equation 2-1. (Note: The Froude number for river station 5.29 was replaced by the Froude number at river station 5.24* in Equation 2-1.) The final mean value of the expansion reach length was then determined to be 750 feet, with a range of ± 96 feet to define the 68% confidence band. The adjusted reach length value of 778 feet is within the confidence band and no additional iterations were computed. Finally, the expansion ratio (ER) as described in Equation 2-1 should not exceed 4:1 and should not be less than 0.5:1. For this example, the final expansion ratio was $ER = (778) / (740) = 1.05$, which is within the acceptable range. In the above procedure, the modeler is directed to Chapter 4 of the **Hydraulic Reference Manual** for additional information on cross section interpolation and to Chapter 5 of the **User's Manual** for further discussion on working with projects.

Upon reviewing the above procedures, the modeler can open either of these new plans and the corresponding geometry and flow data files will be activated. For this example, the results of the water surface profiles for the new plans are approximately equal to the results obtained from the original geometry for both of the pressure/weir flow and energy methods, respectively. However, the modeler should apply the above procedures to evaluate the location of the expansion reach length for each specific application.

Finally, during the procedures as outlined above, if the location of the expansion reach length produces a distance sufficiently far downstream from the bridge, then the modeler may be required to include additional cross

sections within this reach length to accurately predict the energy losses. This may be accomplished by inserting cross sections and providing the appropriate ineffective flow areas at each cross section according to their location with respect to the bridge opening.

Contraction Reach Length

The contraction reach length, L_c , is defined as the distance from the cross section located immediately upstream of the bridge (5.41) to the cross section that is located where the flow lines are parallel and the cross section exhibits fully effective flow (5.44). To evaluate this reach length, the regression results (shown as Equation 2-2 below) from the US Army Corps of Engineers (USACE) study [HEC-1995] was used. The equation is:

$$L_c = CR(\bar{L}_{obs}) = 263 + 38.8 \left(\frac{F_{5.39}}{F_{5.29}} \right) + 257 \left(\frac{Q_{ob}}{Q} \right)^2 - 58.7 \left(\frac{n_{ob}}{n_c} \right)^{0.5} + 0.161 \bar{L}_{obs} \quad (2-2)$$

where: L_c	=	contraction reach length, ft
CR	=	contraction ratio
$F_{5.39}$	=	main channel Froude number at the cross section immediately downstream of the bridge (cross section 5.39 for this example)
$F_{5.29}$	=	main channel Froude number at the cross section of fully expanded flow (initially cross section 5.29 for this example)
Q_{ob}	=	discharge conveyed in the two overbanks at cross section 5.44, cfs
Q	=	total discharge, ft ³ /s
n_{ob}	=	Manning n value for the overbanks at section 5.44
n_c	=	Manning n value for the main channel at section 5.44

From the field data and the results of the initial analysis, the Froude numbers at sections 5.39 and 5.29 were 0.37 and 0.30, respectively, the total over bank flow at cross section 5.44 was approximately 9780 cfs (an average of 9880 for the pressure/weir flow and 9685 for the energy method), the total flow was 14000 cfs, the weighted n value for both of the overbanks was 0.069, the n value for the main channel was 0.04, and the average length of the obstruction was 740 feet. Substitution of these values into Equation 2-2 yielded the contracted reach length of 478 feet. This equation has a standard error of 31 feet which results in a contraction reach length range from 447 to 509 feet to define the 68% confidence band. For this example, the distance from cross section 5.44 to cross section 5.41 was set at 170 feet along the main channel. Since this value was outside of the confidence range, the reach length was adjusted to reflect the new contraction reach length.

The adjustment of the geometry for the new contraction reach length was performed similarly to the adjustment procedure for the expansion reach length. A cross section (5.49*) was interpolated between river stations

5.525* and 5.44 that was set to be 308 feet upstream of river station 5.44. Then, the reach length from river station 5.49* to river station 5.41 was $308 + 170 = 478$ feet, the required contraction reach length. This new river station can be viewed by opening the plan "Press/Weir Method: New Le, Lc" for the pressure/weir method or the plan "Energy Method: New Le, Lc" for the energy method analysis.

Finally, after the subsequent analysis with the new contraction reach length, the new flow parameters were entered into Equation 2-2 and yielded a contraction reach length of 499 feet, with a range from 468 to 530 feet to define the 68% confidence band. The adjusted contraction reach length of 478 feet is within this range and no additional iterations were necessary. (Note: The Froude number for river station 5.29 was replaced by the Froude number at river station 5.24* in equation 2-2.)

As a final criteria, the contraction ratio (CR) should not exceed 2.5:1 nor should it be less than 0.3:1. For this example, the final contraction ratio was $CR = (499) / (740) = 0.67$, which is within the acceptable range. Table 2-1 shows a relationship of the values computed for the expansion reach lengths and the contraction reach lengths during the iterations as described above. Additionally, the table shows the values as determined by the USGS and the traditional USACE methods.

Table 2.1 Expansion and Contraction Reach Length Determinations

	Expansion or Contraction Reach Length Determination Method				
	USGS	Traditional USACE	Initial Placement from field data	HEC-1995 1st iteration	HEC-1995 2nd iteration
L_e	200	2964	500	770	747
L_c	200	740	170	478	499

As can be seen from the data in Table 2.1, the USGS method will typically provide a minimum criteria and the traditional USACE method will provide a maximum length. The recent study [HEC-1995] was performed to provide better guidance for the evaluation of the reach lengths and these values fall within the range as determined by the previous two methods.

Expansion Coefficient

The expansion coefficient is used to determine the amount of energy loss due to the flow expanding between two particular cross sections. The research document [HEC-1995] suggests the following relationship for the value of the expansion coefficient:

$$C_e = -0.09 + 0.570 \left(\frac{D_{ob}}{D_c} \right) + 0.075 \left(\frac{F_{5.39}}{F_{5.29}} \right) \quad (2-3)$$

where: C_e = expansion coefficient
 D_{ob} = hydraulic depth (flow area / top width) for the overbank at cross section 5.29
 D_c = hydraulic depth in the main channel at cross section 5.29

From the data for the analysis, the hydraulic depth for the overbank at cross section 5.29 was 4.26 feet (an average of 5.31 and 3.20 feet for the LOB and ROB, respectively, with the values being consistent for both the pressure/weir flow and energy method) and the hydraulic depth of the main channel was 7.20 feet. Substitution of the values for the variables yielded an expansion coefficient of 0.34. This is the median value and the range of ± 0.2 defines the 95% confidence band for Equation 2-3. Therefore, the modeler should use the value of 0.34 as an initial value and vary the coefficient by ± 0.2 . For this example, a value of 0.5 was initially used for the expansion coefficient in the vicinity of the bridge. During the iterations for the contraction and expansion reach lengths, this coefficient was reevaluated for each iteration. For the final value, the hydraulic depth in the overbank at cross section 5.24* was 4.11 feet (an average of 5.06 and 3.16 feet for the LOB and ROB, respectively, with the values being consistent for both the pressure/weir flow and energy method) and the hydraulic depth of the main channel was 8.40 feet. This yielded an expansion coefficient of 0.27, ± 0.2 . For the example, a final value of 0.5 was calibrated in order to match the observed data.

Contraction Coefficient

The contraction coefficient is used to determine the amount of energy loss due to the flow contracting between two particular cross sections. The data of the study [HEC-1995] did not lend itself to regression of the contraction coefficient values and an approximate range is recommended by the research. For this example, a range of 0.3 to 0.5 is recommended by the research. A value of 0.3 was used for the contraction coefficient in the vicinity of the bridge.

In summary, the above recommendations for the expansion reach length, the contraction reach length, and the expansion and contraction coefficients represent an improvement in the general methodology behind the prediction of these values. The modeler is recommended to apply these new criteria as a more substantial method for estimating the transition reach lengths. As a final note, after the initial analysis, the expansion and the contraction reach lengths as well as the expansion and contraction coefficients should be evaluated simultaneously. Then, adjustments should be made to the reach length and coefficient values before a subsequent analysis is performed. Finally, the new data should be used to reevaluate all of the reach lengths and coefficients. This procedure will ensure that the modeler is always using the current flow data for the analysis.

Model Calibration

For the high flow event, observed data were available as obtained from the USGS Atlas. Therefore the water surface profiles calculated by the model were calibrated to reflect the observed water surface profiles and weir flow. This calibration occurred after the reach lengths and coefficients had been evaluated.

From the observed data, it was recorded that a flow of approximately 3300 cfs occurred over the highway embankment. Therefore, a target value of weir flow was available for the calibration of the model. From the main menu, select **View** and then **Cross Section Table, Type**, and then **Cross Section**. Select river station 5.41 and profile 3 and this will display the table shown in Figure 2.21. In the right column, the flows in the LOB, main channel, and ROB are shown as 1228.00, 9653.93, and 3118.07 cfs respectively. Since this cross section is placed immediately upstream of the bridge, the majority of the flow in the LOB and ROB will contribute to the weir flow over the bridge. From the top of the table, select **Type** and then select **Bridge**. In the left column, the weir flow is listed as being 3043.90 cfs. This is the total weir flow occurring over the bridge. This value should be approximately equal to the total flow in the LOB and ROB of river station 5.41 of $1228.00 + 3118.07 = 4356.07$. The calculated weir flow is less than this total but all of the flow at cross section 5.41 in the LOB and ROB will not contribute to the weir flow, only a major portion of it. Furthermore, a target value of approximately 3300 cfs of weir flow was observed. The total weir flow was computed as being 3044 cfs, a close approximation to the estimated weir flow.

To obtain this close approximation, the weir flow coefficient was set to a value of 2.6 to account for the inefficiency of the bridge surface structure to act as a true weir and since the depth of water over the bridge was small compared to the height of the weir. Additionally, the Manning's n values were adjusted. Originally, the Manning's n values were the average values obtained from the USGS Atlas. Then, the Manning's n values were raised slightly in the overbank and main channel areas to decrease the amount of conveyance in these areas. This caused the water surface profile and the amount of weir flow to closer approximate the observed data throughout the river reach. It should be noted that the n values were raised on a global scale. Individual specific n values should not be adjusted without taking into account the spatial average of the factor.

For the pressure flow coefficients, the downstream water surface inside the bridge was calculated at a value slightly lower than the low cord. This implies that the program was using the sluice gate (submerged inlet only) pressure flow relationship. Therefore, the submerged inlet coefficient was reduced to decrease the amount of flow through the bridge. This increased the upstream energy and allowed more water to flow over the bridge to concur with what happened during the observed event.

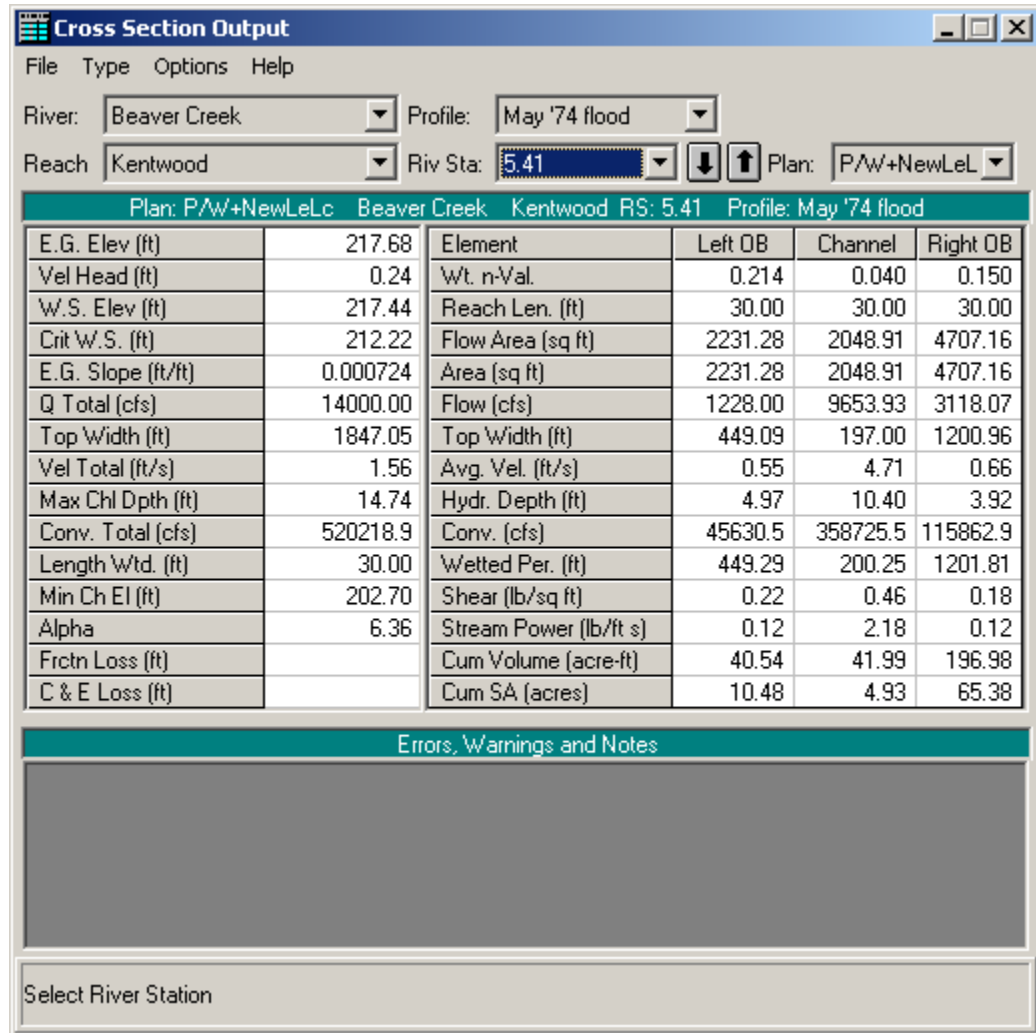


Figure 2.21 Cross Section Table For Plan: P/W New LeLc

Finally, for the calibration, the ineffective flow areas at cross section 5.41 and 5.39 were set to balance the flow going over the weir. Initially, the flow in the LOB and ROB at cross section 5.41 was drastically larger than the flows in the LOB and ROB at the downstream section 5.39. This was due to the fact that the ineffective flow area elevations at cross section 5.39 were previously set to a value in between the low cord and the high cord. When the flow came over the weir, the depth downstream was less than the ineffective flow elevation, so the program initially considered the overbank area as ineffective flow. This is not a realistic answer. When the flow goes over the weir it contributes to the overbank flow at the downstream cross section and then this downstream area should be considered as effective flow. Therefore, the ineffective flow elevations were lowered to allow the weir flow that entered cross section 5.39 to become effective.

These calibrations were performed because the actual flow depths for the event were known. If these actual data were not known, then the adjustment of the Manning's n values, pressure flow coefficients, and weir flow rate

could not be conducted to the refinement in the previous discussion. However, the balancing of the weir flow to the flow in the LOB and ROB at river stations 5.39 and 5.41 could be performed. The calibration to the model accounted for a more accurate determination of the water surface profile to the observed data.

Comparison of Energy and Pressure/Weir Flow Methods to Observed Data

To compare the results of the analyses to the observed data, the observed data was first entered in the **Steady Flow Data Editor** by selecting **Options** and then **Observed WS**. This activated the editor as shown in Figure 2.22 on which the observed data were entered for the flood event. This editor was closed and then the profile plot was activated and is shown in Figure 2.23.

Figure 2.23 displays the three water surfaces for each of the two plans, as well as the observed values. The display options for this figure were selected under the **Options** menu as: 1) **Variables** - select to display the water surface and observed water surface; 2) **Profiles** - select 1,2, and 3; and 3) **Plans** - select both the "Energy Method: New $L_e L_c$ " plan and the "Pressure/Weir Flow: New $L_e L_c$ " plan. As shown in the figure, both methods produced the same water surface profiles for the first two flows (both of the low flows). This is as would be expected because both methods analyzed the two low flows using the same criteria. For the high flow, the water surface profile for the energy method and the pressure/weir flow method varied slightly upstream of the bridge. The **Zoom** feature under the **Options** menu can be used to obtain a closer view of the profiles.

Observed WS Location			Observed Water Surfaces		
River	Reach	RS	25 yr	100 yr	May '74 flood
1 Beaver Creek	Kentwood	5.99			220
2 Beaver Creek	Kentwood	5.875*			219.2
3 Beaver Creek	Kentwood	5.76			218.4
4 Beaver Creek	Kentwood	5.685*			218.3
5 Beaver Creek	Kentwood	5.61			218.1
6 Beaver Creek	Kentwood	5.49*			217.9

Figure 2.22 Observed Water Surface Editor

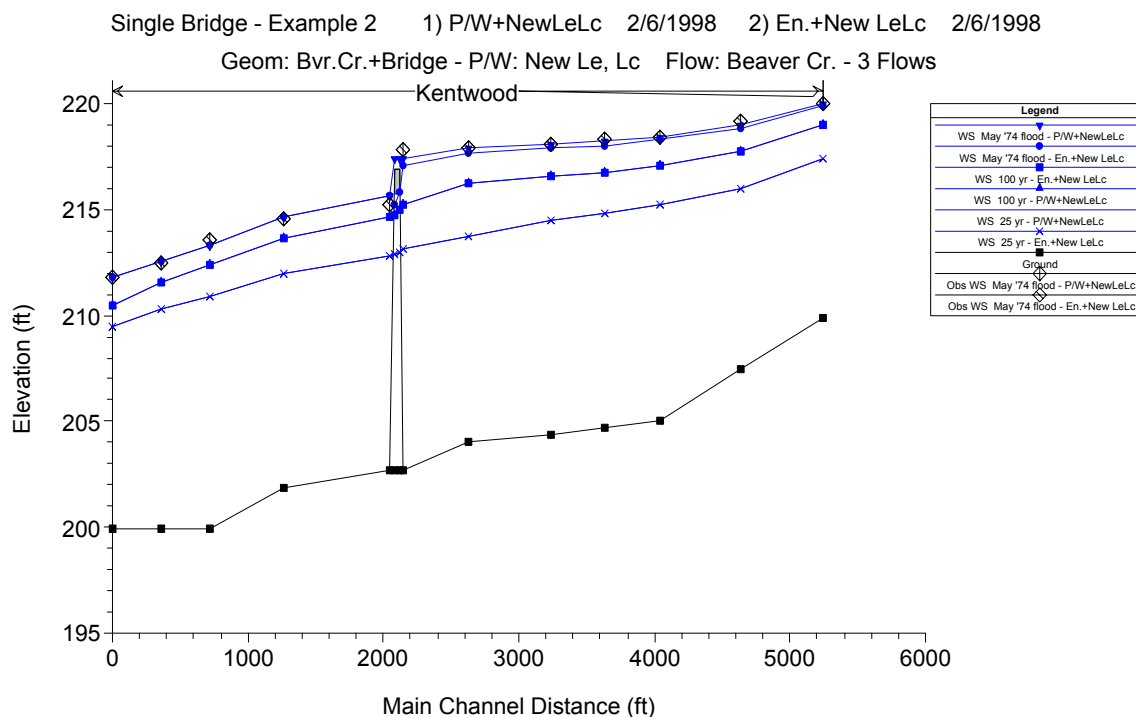


Figure 2.23 All 3 Flow Profiles for Press/Weir and Energy Methods

Table 2.2 shows a tabular comparison of the calculated water surface elevations for both the pressure/weir flow method and the energy method to the observed data. The observed values with a ** denote that the value may be in question due to there being only a few observed values in the vicinity of the location on the atlas or because those that were provided were not in the active flow area.

In comparison of the calculated values to the observed values, both of the modeling approaches were able to predict the actual water surface elevations within a reasonable tolerance. The largest errors occurred where the observed water surface values are in question. Additionally, the observed values in the table are an average water surface elevation over the area of effective flow where the cross sections are located. The one dimensional model can only predict one resulting water surface; therefore, the fluctuations across the cross section will not occur in the model as they did during the actual event.

In comparison of the pressure/weir method to the energy method, the greatest difference occurs at the bridge structure. The water surface elevations for the pressure/weir flow method inside the bridge are estimated using the upstream and downstream flow depths.

Table 2.2 Comparison of Water Surface Elevations for Q = 14000 cfs

Cross Section	Pressure/Weir		Energy		Observed
	Calculated	Absolute Error	Calculated	Absolute Error	
5.99	220.00	0.00	219.95	-0.05	220.0
5.875*	218.99	-0.21	218.87	-0.33	219.2**
5.76	218.46	0.06	218.29	-0.11	218.4
5.685*	218.23	-0.07	218.04	-0.26	218.3
5.61	218.09	-0.01	217.88	-0.22	218.1
5.49*	217.91	0.01	217.66	-0.24	217.9
5.41	217.44	-0.36	217.12	-0.68	217.8**
5.40 - Br Up	217.44		215.86		NA
5.40 - Br Dn	217.44		215.26		NA
5.39	215.62	0.42	215.62	0.42	215.2**
5.24*	214.64	0.04	214.64	0.04	214.6
5.13	213.33	-0.27	213.33	-0.27	213.6
5.065	212.54	0.04	212.54	0.04	212.5
5.00	211.80	0.00	211.80	0.00	211.8

Summary

This example demonstrated the use of HEC-RAS to analyze a river reach that contains a single bridge crossing. The geometric data consisting of the cross sections and bridge geometry were entered for the reach along Beaver Creek, as obtained from the USGS Atlas No. HA-601. Three flow values were used for the analysis, with the largest flow coinciding with the flood event in May 1974. The first plan consisted of the geometry data (with the high flow method selected as press/weir) and the flow data. A second plan was created with the selection of the energy method for the high flow analysis. Review of results for these plans reflected the necessity for adjustments to the expansion and contraction reach lengths.

After the adjustments were made, two new plans were created, one for the pressure/weir and one for the energy method for the high flow analysis. The results of these two new plans were then compared to the observed water surface elevations. From the comparison, the pressure/weir method resulted with the closest values to the observed water surface elevations.