

Application of HEC-RAS to Culvert Hydraulics

I. Introduction

Objectives:

- To Know the required data for the HEC-RAS Culvert routines.
- To become familiar with how to enter the culvert data through the use of the HEC-RAS user interface.
- To become familiar with the available output that is specific to culverts.

References:

FHWA, 1985. *Hydraulics Design of Highway Culverts*, HDS No. 5, U.S. Department of Transportation, September 1985, Washington, D.C.

HEC, 1995. *HEC-RAS User's Manual*, Chapter 6, Hydrologic Engineering Center, July 1995.

HEC-RAS computes energy losses caused by structures such as culverts in three parts (Figure 1):

1. The losses that occur in the reach immediately downstream from the structure (cross sections 1-2), where an expansion of flow takes place.
2. The losses through the structure itself (cross sections 2-3).
3. The losses that occur in the reach immediately upstream of the structure (cross sections 3-4), where the flow is contracting towards the opening.

The culvert hydraulic computations in HEC-RAS are similar to the bridge hydraulic computations, except the Federal Highway Administration's (FHWA, 1985) standard equations for culvert hydraulics under inlet control are used to compute the losses through the structure. Because of the similarities between culverts and other types of bridges, the cross section layout, the use of ineffective areas, the selection of contraction and expansion coefficients, and many other aspects of bridge analysis apply to culverts as well.

The culvert routines in HEC-RAS have the ability to model nine different types of culvert shapes. These shapes include box (rectangular), circular, elliptical, arch, pipe arch, semi circular, low arch, high arch, and Conspan culverts.

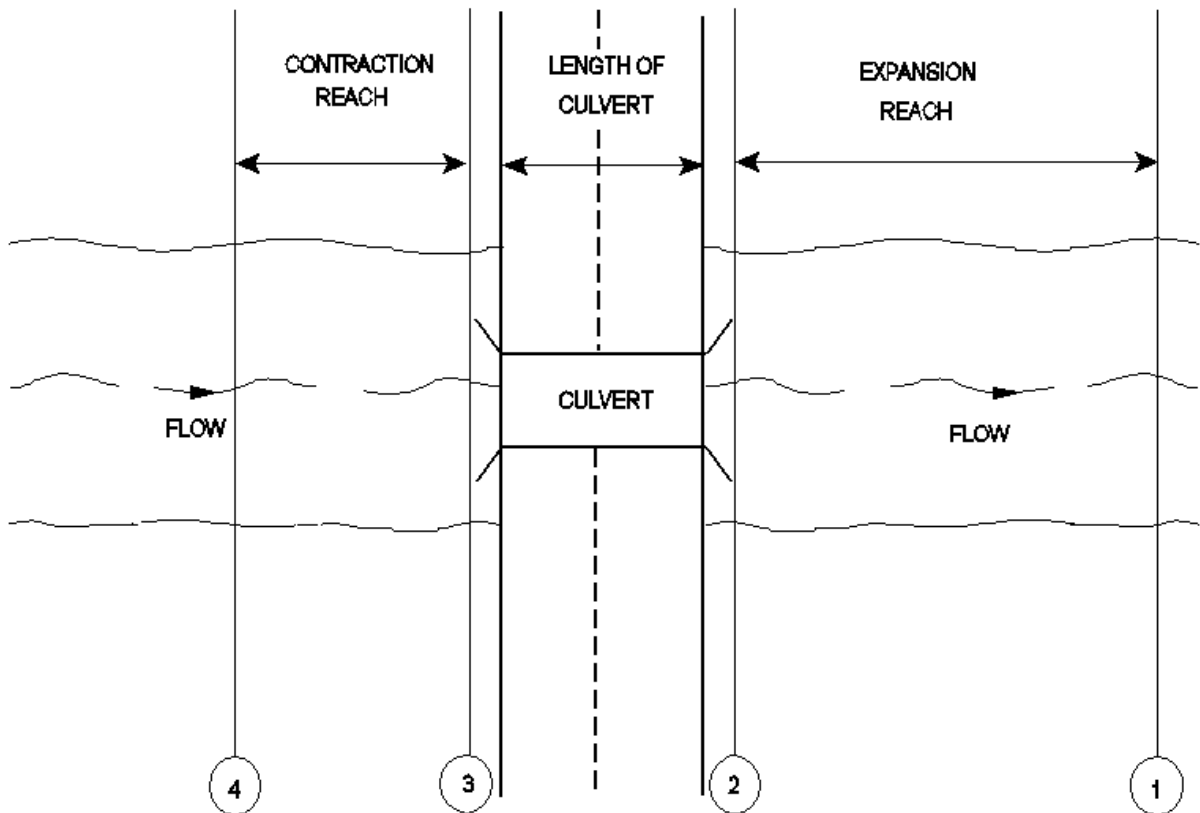


Figure 1. Cross Section Layout for Culvert Modeling

II. Entering and Editing Culvert Data

Culvert data are entered in the same manner as bridge data. To enter culvert data the user presses the **Bridge/Culvert** button on the Geometric Data window. Once this button is pressed, the Bridge/Culvert Data Editor will appear (Figure 2).

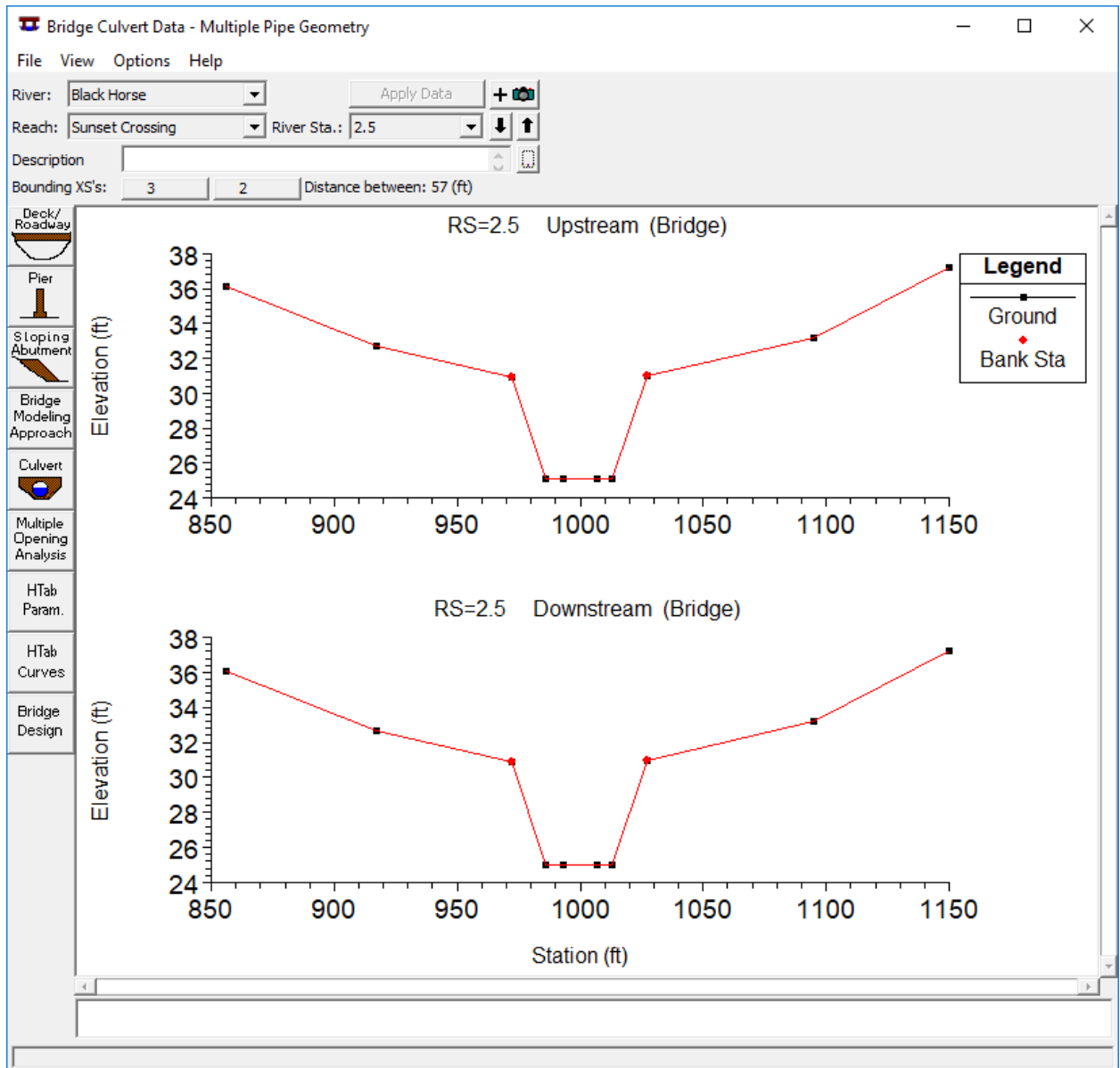


Figure 2. Bridge/Culvert Data Editor

To add a culvert group to the model the user must then do the following:

1. Select the river and reach that you would like to place the culvert in. This is accomplished by pressing the down arrow on the reach box, and then selecting the reach of choice.
2. Go to the **Options** menu of the Bridge/Culvert editor and select **Add a Bridge and/or Culvert** from the list. An input box will appear prompting you to enter a river station identifier for the new culvert group. After entering the river station, press the **OK** button and the cross sections that bound the new culvert group will appear in the editor.

3. Enter all of the required data for the culvert group. This includes the culvert deck information and the culvert specific data. The culvert deck and roadway information is entered in the same manner as a bridge (using the deck/roadway editor). To enter culvert specific data, press the **Culvert** button on the Bridge/Culvert Data editor.
4. Once all of the culvert data are entered, press the **OK** button in order for the interface to accept the information.

River, Reach and River Station. The River box is used to select the river for the culvert from the available rivers setup in the schematic diagram. The Reach box allows the user to select a reach within the selected river. The river and reach label defines which reach the culvert will be located in. The River Station tag defines where the culvert will be located within the specified reach. The River Station tag does not have to be the actual river station of the culvert, but it must be a numeric value. The River Station tag for the culvert should be numerically between the two cross sections that bound the culvert. Once the user selects **Add a Bridge and/or Culvert** from the options menu, an input box will appear prompting you to enter a River Station tag for the new culvert. After the River Station tag is entered, the two cross sections that bound the culvert will be displayed on the editor.

Description. The description box is used to describe the culvert location in more detail than just the reach and river station. This box has a limit of 256 characters. Only the first line of information is displayed, unless the button to the right of the box is pressed. Also, the first 40 characters of the description are used as a label for culvert plots and tables.

Culvert Deck. The culvert deck is virtually the same as the bridge deck/roadway information. The deck is used to describe the area blocking the stream and the roadway profile. The only difference in the deck information for culverts is that the low chord elevations should be left blank or set to elevations below the ground data. This will cause the deck to completely fill the channel up to the roadway elevations (high chord data). Therefore, the only opening below the roadway will be what ever culvert openings are entered. To enter the culvert deck information, press the **Deck/Roadway** button on the Bridge/Culvert Data Editor window.

Culvert Data. To enter culvert specific information, press the **Culvert** button on the Bridge/Culvert Data Editor window. When this button is pressed, the Culvert Data Editor will appear as shown in Figure 3.

The information entered in the Culvert Data Editor consists of the following:

Culvert ID# - The culvert identifier (ID#) is automatically assigned to "Culvert #1" the first time you open the editor. The user can enter more than one culvert type if they are working on a multiple culvert opening problem. If all of the culvert barrels are exactly the same, then only one culvert type (Culvert ID#) should be entered. The number of barrels is an input parameter in the culvert data. If the user has culverts that are different in shape, size, elevation, or loss coefficients, then additional culverts types (Culvert ID#'s) must be added for each culvert type.

Culvert Data Editor

Add ... Copy Delete ... Culvert Group: Culvert #1

Solution Criteria: Computed Flow Co

Shape: Circular Span: Diameter: 6

Chart #: 1 - Concrete Pipe Culvert

Scale #: 1 - Square edge entrance with headwall

Distance to Upstrm XS: 5

Culvert Length: 50

Entrance Loss Coeff: 0.5

Exit Loss Coeff: 1

Manning's n for Top: 0.013

Manning's n for Bottom: 0.013

Depth to use Bottom n: 0

Depth Blocked: 0

Upstream Invert Elev: 25.1

Downstream Invert Elev: 25

Culvert Barrel Data

Barrel Name	US Sta	DS Sta
1 Barrel #1	996	996
2 Barrel #2	1004	1004
3		
4		
5		

Barrel GIS Data: Barrel #1

Length: 0

X	Y
1	
2	
3	
4	
5	

Individual Barrel Centerlines ... Show on Map OK Cancel Help

Select culvert to edit

Figure 3. Culvert Data Editor

To add an additional culvert type you can either use the **Add** or **Copy** buttons. The Add button increments the culvert ID# and clears the culvert editor. The Copy button increments the culvert ID# and makes a copy of the original culvert data. Once a copy is made of a culvert, the user can change any of the existing culvert information. Culverts can be deleted by pressing the **Delete** button.

Solution Criteria - This field allows the user to have control over which solution criteria (Inlet or outlet control) is used as the final answer. The default is to let the program use the answer that produces the greater upstream energy. In general, the program should be left in this mode. The option to force the program to use either the Inlet control answer or the Outlet control answer is available for added flexibility. This option should only be used when the user thinks that either the inlet control or outlet control answer is incorrect or not appropriate for the problem that it is being applied to.

Rename - This button allows the user to put in their own identifier for each of the culvert types. By default the culvert types will be labeled "Culvert #1," "Culvert #2," and so on. The user can enter up to twelve characters for each culvert type.

Shape - The shape selection box allows the user to select from one of the nine available shapes. This selection is accomplished by pressing the down arrow on the side of the box, then selecting one of the nine available shapes.

Span - The span field is used to define the maximum width inside of the culvert. The span is left blank for circular culverts.

Rise - The rise field describes the maximum height inside of the culvert.

Chart # - This field is used to select the Federal Highway Administration Chart number that corresponds to the type and shape of culvert being modeled. Once the user has selected a culvert shape, the corresponding FHWA chart numbers will show up in the chart # selection box. More information on FHWA chart numbers can be found in the Hydraulics Reference manual.

Scale# - This field is used to select the Federal Highway Administration Scale number that corresponds to the type of culvert entrance. Once the user has selected a culvert shape and chart #, the corresponding FHWA scale numbers will show up in the scale selection box. More information on FHWA scale numbers can be found in the Hydraulics Reference manual.

Distance to Upstream XS - This field is used to locate the culvert in space, relative to the two cross sections that bound the culvert crossing. The user should enter the distance between the upstream cross section and the upstream end of the culvert barrel.

Culvert Length - The culvert length field describes the length of the culvert along the centerline of the barrel.

Entrance Loss Coefficient - The coefficient entered in this field will be multiplied by the velocity head inside of the culvert at the upstream end. This value represents the amount of energy loss that occurs as flow transitions from the

upstream cross section to inside the culvert barrel. This coefficient is used in the outlet control computations.

Exit Loss Coefficient - The coefficient entered in this field will be multiplied by the change in velocity head from inside the culvert to outside the culvert at the downstream end. This value represents the energy loss that occurs as water exits the culvert. This coefficient is used in the outlet control computations.

Manning's n for Top - The n-value fields are used for entering the Manning's n values of the culvert barrel. This version of HEC-RAS allows the user to enter a separate n value for the top (which includes top and sides) of the culvert, as well as for the bottom. If the culvert has the same roughness for the top and bottom, the user can enter the value for the top. The Manning's n value for the bottom will automatically be copied from the top field.

Manning's n for Bottom – This field is used to enter a Manning's n value for the bottom of the culvert. This n value will be used up to a user specified depth inside of the culvert. When the water surface gets higher than that depth, a composite Manning's n value is computed based on the bottom and top n values and their corresponding wetted perimeters.

Depth to use Bottom n – This field is used to specify the depth that the “Bottom n value” is applied inside of the culvert. The surface of the culvert below this depth is given the n value for the bottom of the culvert, while the surface of the culvert above this depth is given the n value for the top of the culvert.

Depth Blocked – This field is used to block off a portion of the bottom of the culvert. When a value is entered into this field, the culvert is completely blocked up to the depth specified. This blocked out area persists the whole way through the culvert.

Upstream Invert Elevation - This field is used to describe the elevation of the culvert invert at the upstream end.

Downstream Invert Elevation - This field is used to describe the elevation of the culvert invert at the downstream end.

Identical Barrels - This field is used to display the number of identical barrels. The number of identical barrels is limited to 25. To enter more than one identical barrel, the user must provide different centerline stationing information for each barrel. As the centerline stationing information is added, the number of identical barrels will automatically change to reflect the number of centerline stations. The user does not enter anything into this field, it is just used to display the number of identical barrels

Centerline Stations - This table is used to enter the stationing of each culvert barrel. Centerline stations must be provided for both the upstream and downstream side of each culvert barrel.

Once all of the culvert information is entered, the user should press the **OK** button at the bottom of the window. Pressing the **OK** button tells the interface to accept the data and close the window. Once the culvert editor is closed, the graphic of the culvert will appear on the Bridge/Culvert Data editor window. An example culvert is shown in Figure 4. **Note! The data are not saved to the hard disk at this point.** Geometric data can only be saved from the **File** menu on the Geometric Data window.

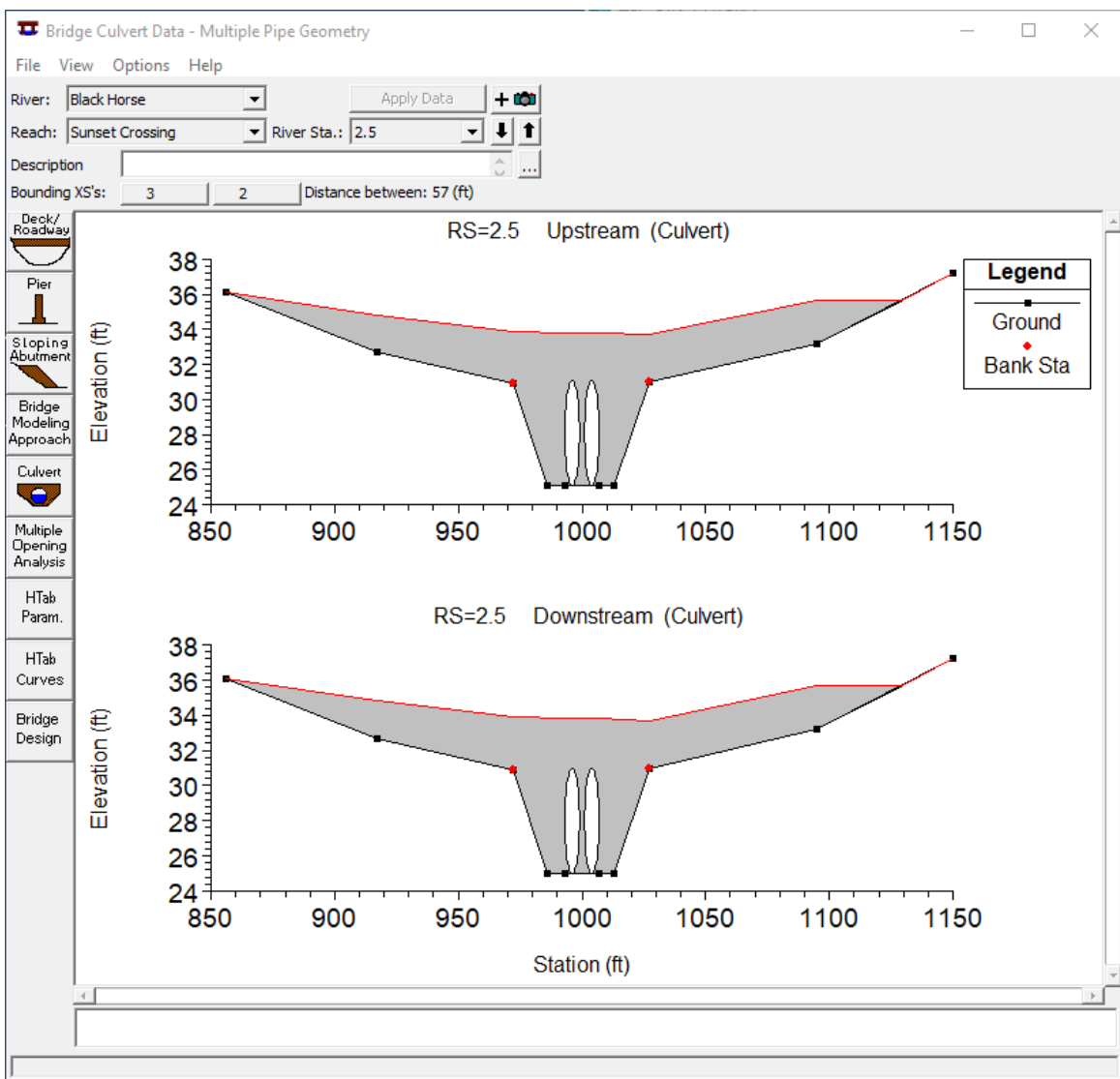


Figure 4. Bridge/Culvert Data Editor With Example Culvert

III. Culvert Example

In order to gain a better understanding of how to enter culvert data, an example culvert problem will be demonstrated in class. The following notes parallel what will be demonstrated in class.

For this example, the Multiple Pipe data set will be used to demonstrate the entry of culvert data. This data set has five cross sections. The schematic diagram for this data set is shown in Figure 5.

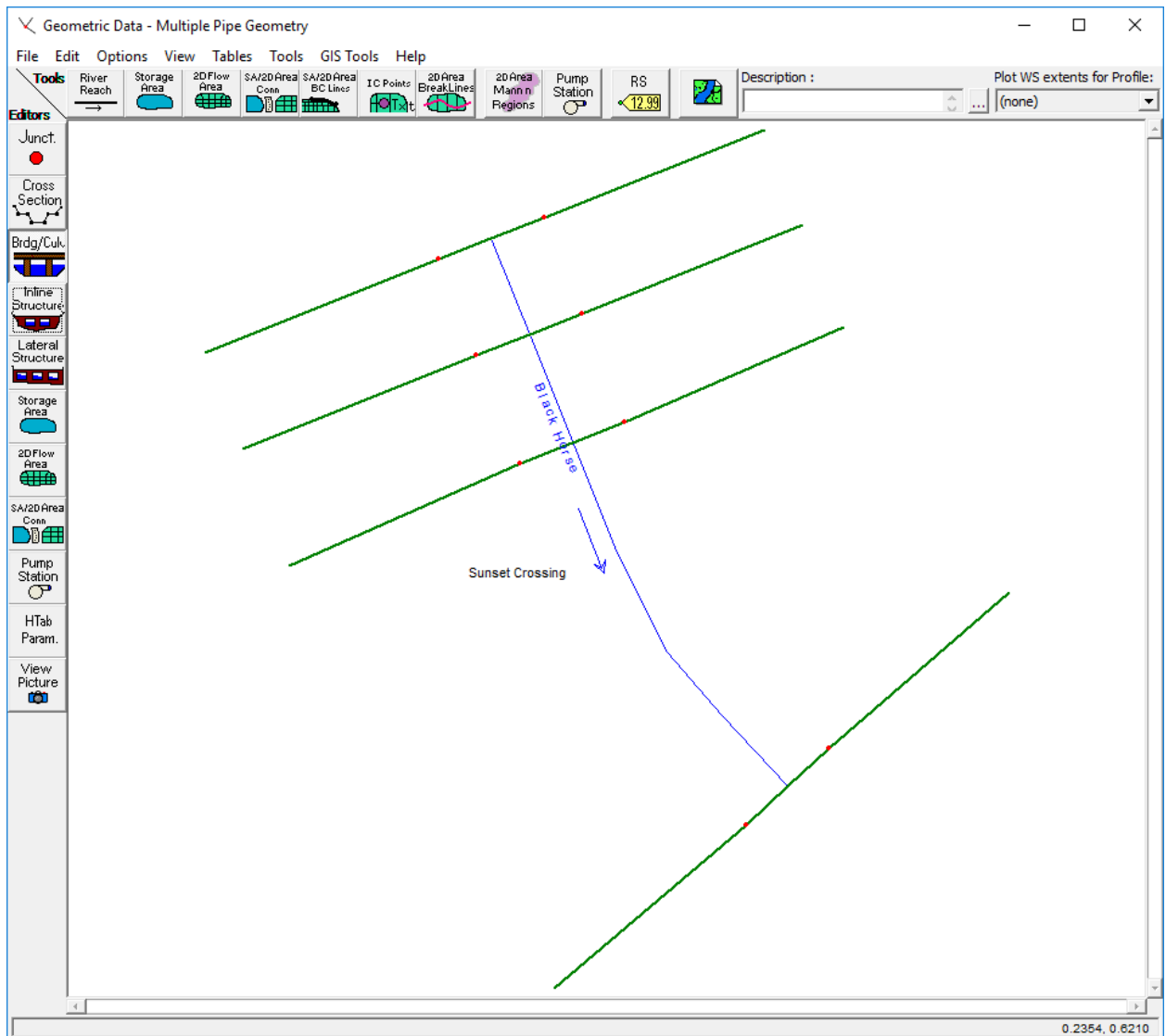


Figure 5. Schematic of Multiple Pipe Data Set

The steps in entering the culvert data are as follows:

- A. **Press the Bridge/Culvert Data Editor Button.** Pressing this button will bring up the bridge and culvert data editor as shown in Figure 6 (except it will be blank at first).
- B. **Select Add a Bridge and/or Culvert from the Options menu.** When this is selected, the program will ask for the river station of the culvert crossing; enter a value of 2.5. This will place the bridge between cross sections 2 and 3. Figure 6 shows the cross sections when they first come up in the editor.
- C. **Next enter the road embankment information by pressing the Deck/Roadway button on the editor.** Figure 7 shows the editor along with the data to be entered for this problem.

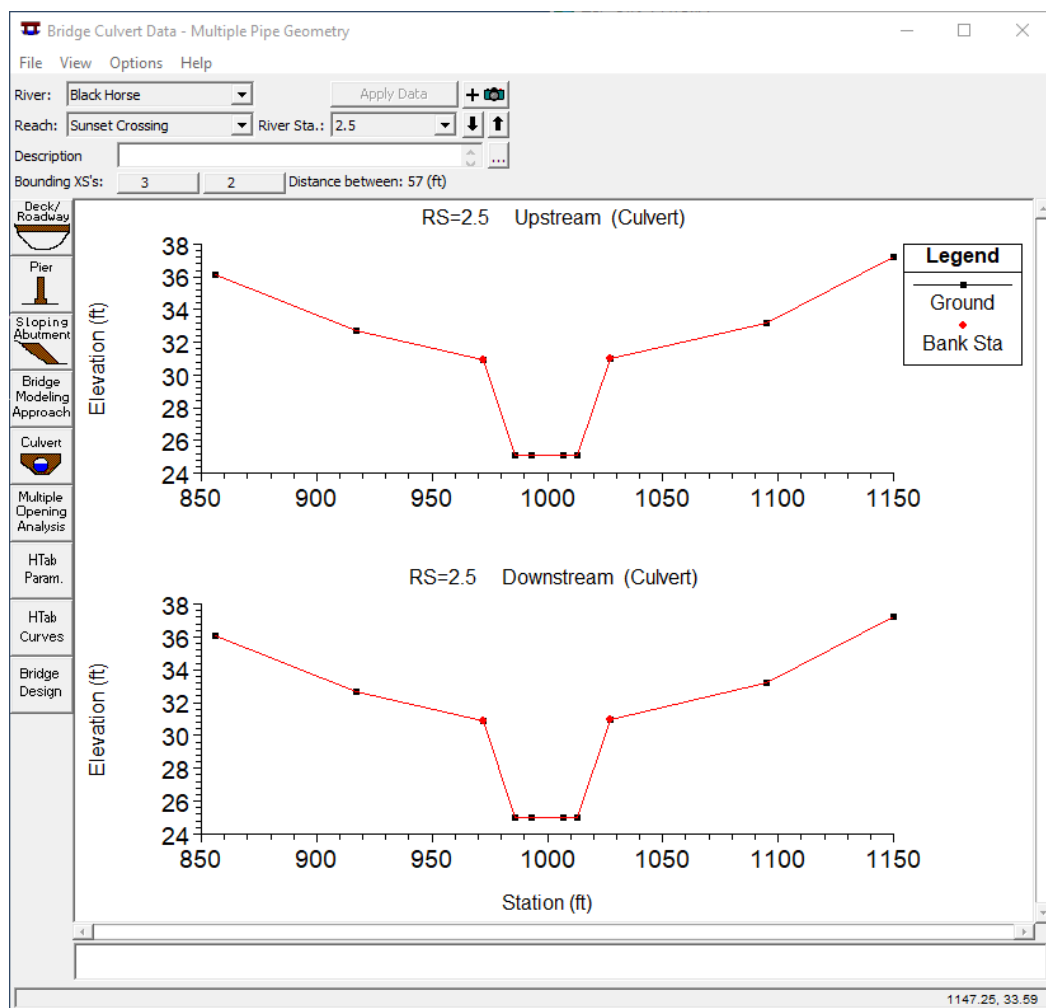


Figure 6. Bridge and Culvert Data Editor

Deck/Roadway Data Editor

Distance	Width	Weir Coef
5	50	3

Clear Del Row Ins Row Copy US to DS

Upstream			Downstream			
	Station	high chord	low chord	Station	high chord	low chord
1	856	36.1		856	36.1	
2	917	34.8		917	34.8	
3	972	33.9		972	33.9	
4	993	33.8		993	33.8	
5	1007	33.8		1007	33.8	
6	1027	33.7		1027	33.7	
7	1095	35.7		1095	35.7	
8	1150	35.7		1150	35.7	

U.S Embankment SS 0 D.S Embankment SS 0

Weir Data

Max Submergence: 0.98 Min Weir Flow El:

Weir Crest Shape

Broad Crested

Ogee

OK Cancel

Figure 7. Deck/Roadway editor With Example Data.

Once the data are entered, press the **OK** button. The editor will close and the deck/roadway information will be added to the cross sections plotted on the bridge/culvert data editor. Figure 8 shows the editor with the road embankment data added.

D. The next step is to enter the culvert data. This is accomplished by pressing the **Culvert** button on the bridge/culvert editor. Figure 9 shows the culvert data editor with the data for this example.

Culvert Data Editor

Add ... Copy Delete ... Culvert Group: Culvert #1

Solution Criteria: Computed Flow Co Rename ...

Shape: Circular Span: Diameter: 6

Chart #: 1 - Concrete Pipe Culvert

Scale #: 1 - Square edge entrance with headwall

Distance to Upstrm XS: 5

Culvert Length: 50

Entrance Loss Coeff: 0.5

Exit Loss Coeff: 1

Manning's n for Top: 0.013

Manning's n for Bottom: 0.013

Depth to use Bottom n: 0

Depth Blocked: 0

Upstream Invert Elev: 25.1

Downstream Invert Elev: 25

Culvert Barrel Data

Barrel Centerline Stations # Barrels : 2

	Barrel Name	US Sta	DS Sta
1	Barrel #1	996	996
2	Barrel #2	1004	1004
3			
4			
5			

Barrel GIS Data: Barrel #1

Length: 0

	X	Y
1		
2		
3		
4		
5		

Individual Barrel Centerlines ... Show on Map OK Cancel Help

Select culvert to edit

Figure 9. Culvert Data Editor With Example Data

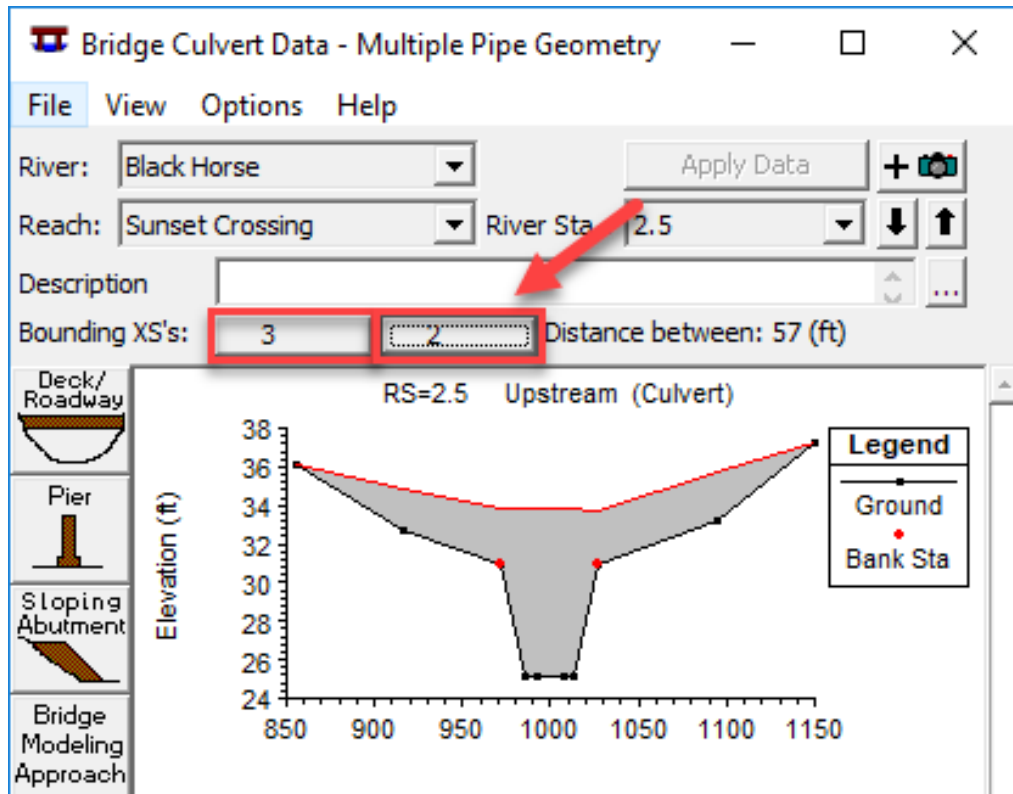
As shown in Figure 9, the data for this example consists of a circular culvert with twin barrels. Each barrel is 6.0 feet in diameter. The culverts are concrete with square edge head walls at the entrance (chart #1 and scale #1). The length of the culvert is 50 feet, the selected Manning's n value is 0.013, and the entrance and exit loss coefficients are 0.5 and 1.0 respectively.

Once all of the culvert data are entered, press the **OK** button. The bridge/culvert data editor will be updated to include the culvert information in the cross section graphics. Figure 10 shows what the bridge/culvert data editor will look like once the culvert data is entered.

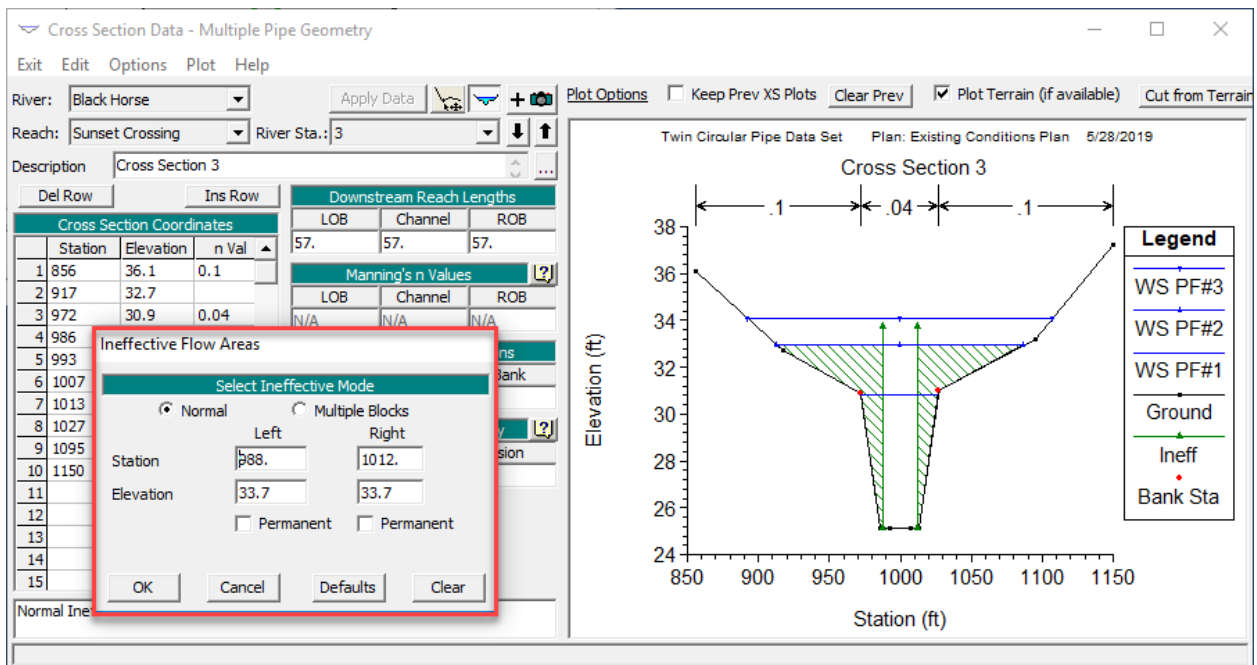
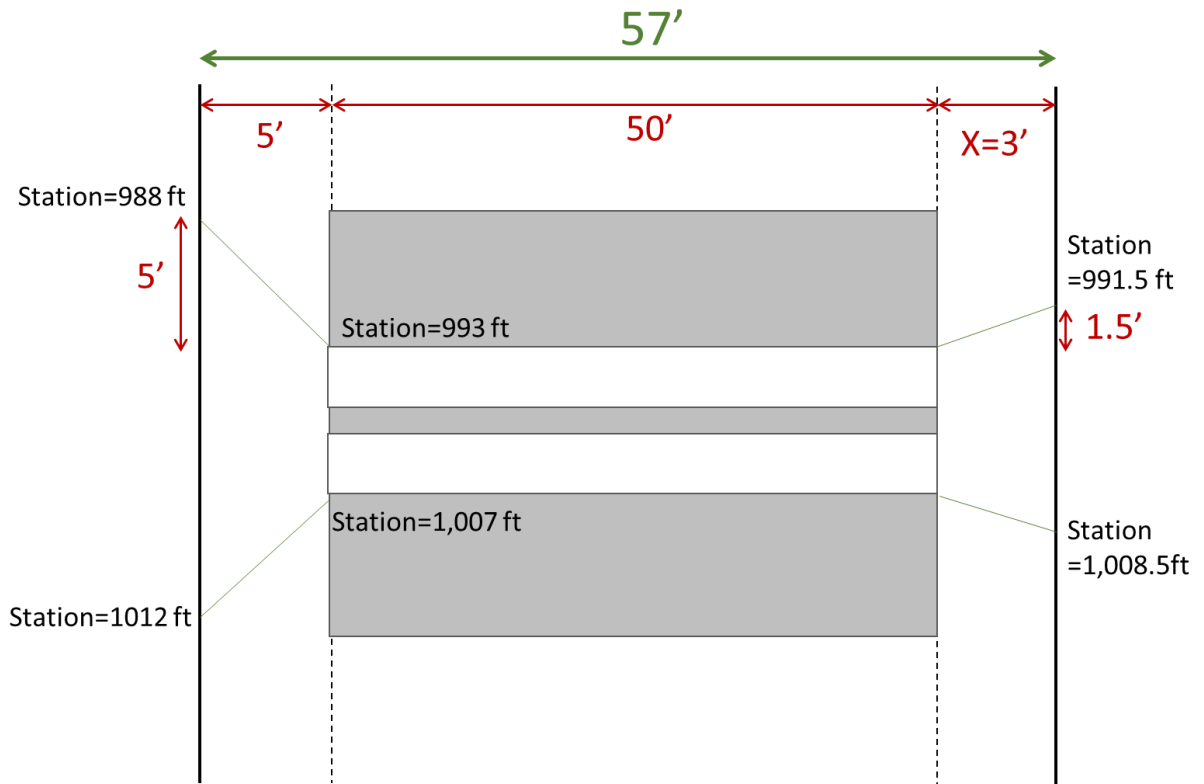
Next we have to add ineffective flow areas.

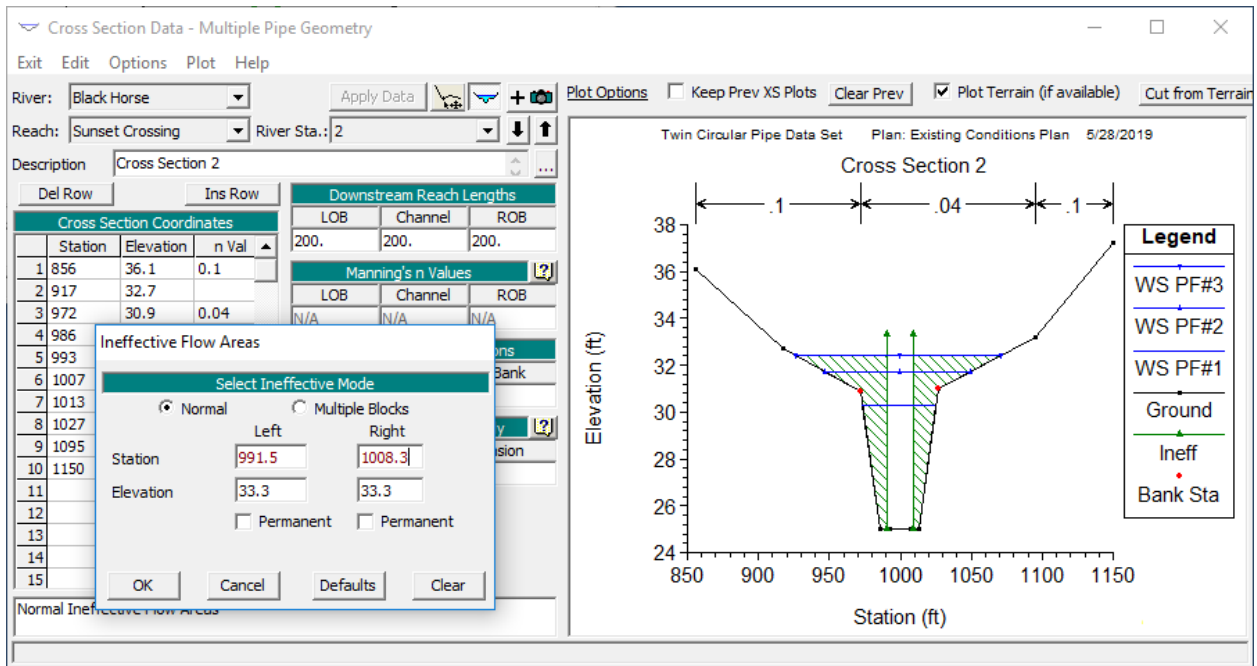
Ineffective flow areas are essential to calculate conveyance and contraction and expansion in a one-dimensional model, particularly surrounding a multi-dimensional structure like a culvert.

Ineffective flow areas have to be added to the upstream and downstream cross sections (not the structure itself). So HEC-RAS provides buttons that automatically open the upstream and downstream cross sections.



These buttons open those cross sections with the ineffective flow area editor already open.





- E. The next step is to close the bridge/culvert data editor. This can be done by selecting the **Exit** option from the **File** menu of the editor. Once this option is selected, the editor will close and control will go back to the geometric data window. The schematic of the river system will be updated to include the culvert information. Figure 11 shows the new river system schematic with the culvert data entered.

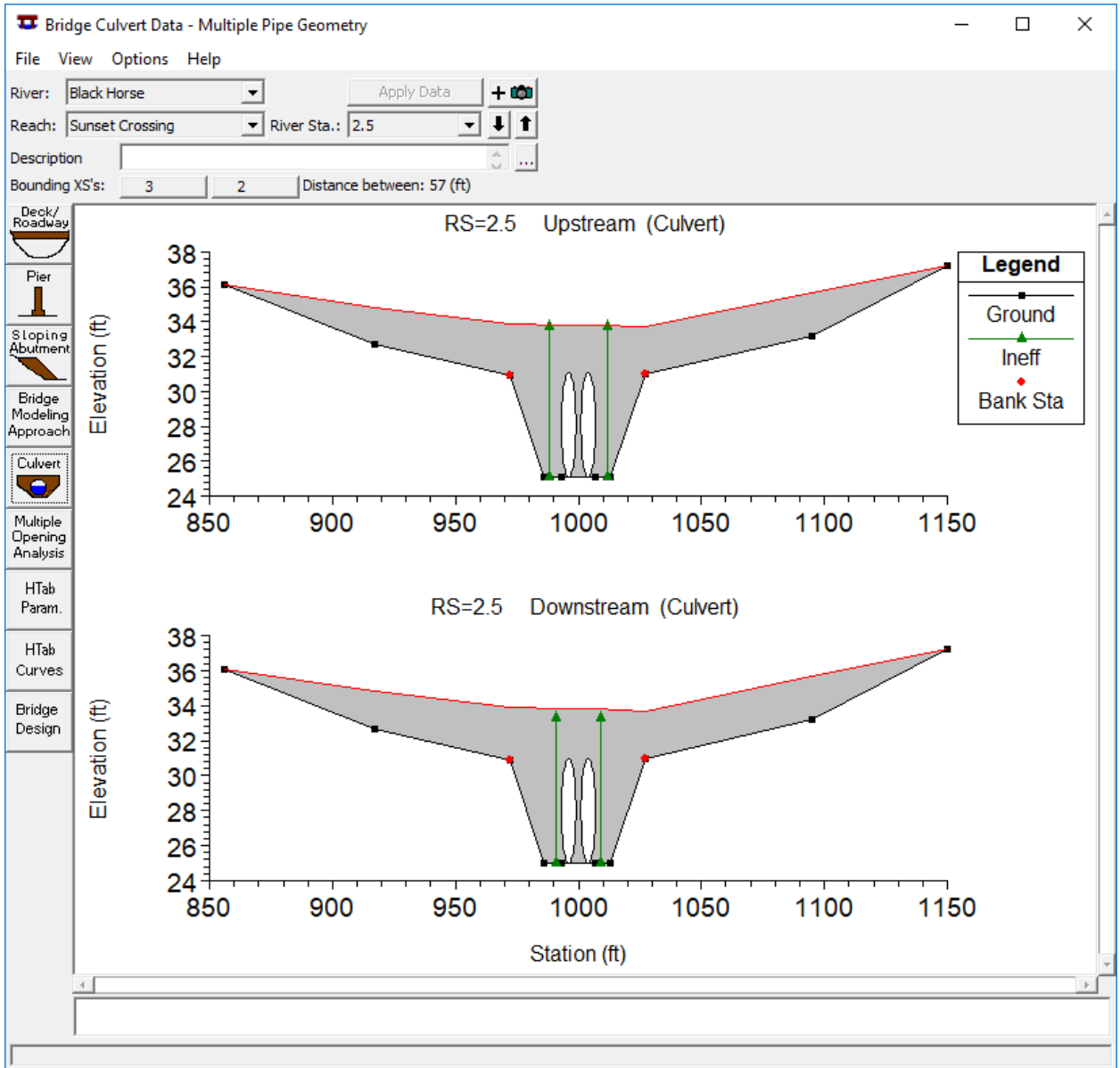


Figure 10. Bridge/Culvert Data Editor With Culvert Data

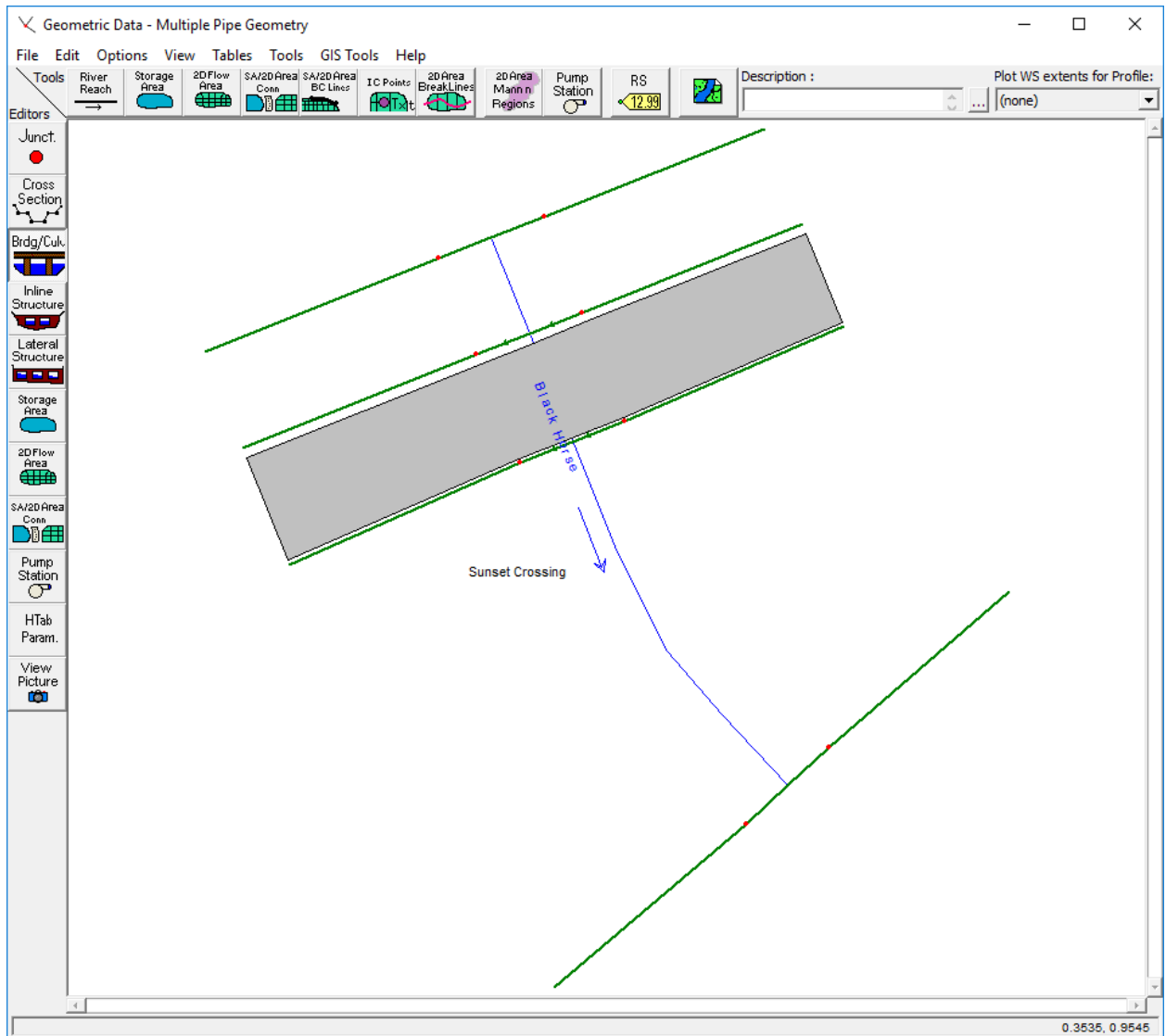


Figure 11. River System Schematic With Culvert Data

- F. The last step is to save the geometric data by selecting **Save Geometric Data** from the **File** menu of the geometric data editor.

After the culvert data are saved, you can perform the water surface profile calculations. Once the calculations are finished, you can begin to review the results.

An example cross section plot of the upstream end of the culvert is shown in Figure 12. This plot shows the water surface and energy gradeline for three profiles that were computed. Figure 13 shows the computed water surface profiles for this example, and Figure 14 shows the X-Y-Z perspective plot for the entire reach with the culvert.

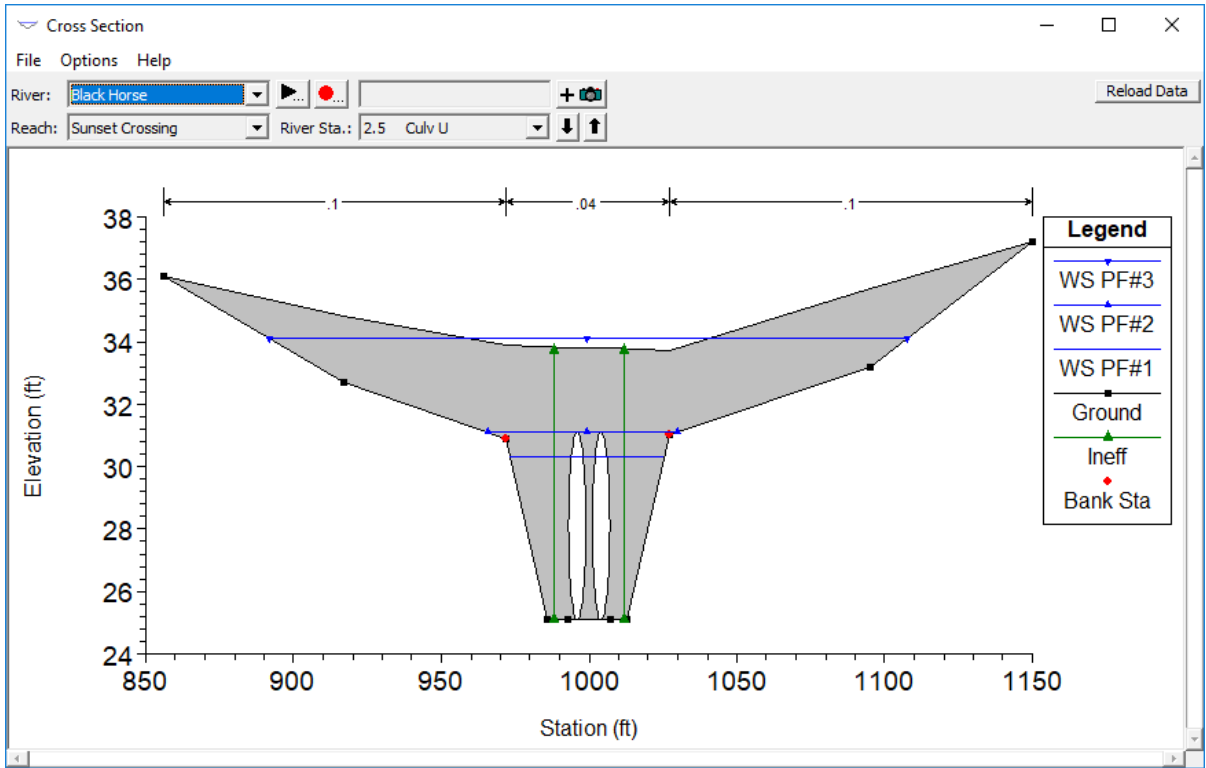


Figure 12. Example Cross Section Plot of Culvert

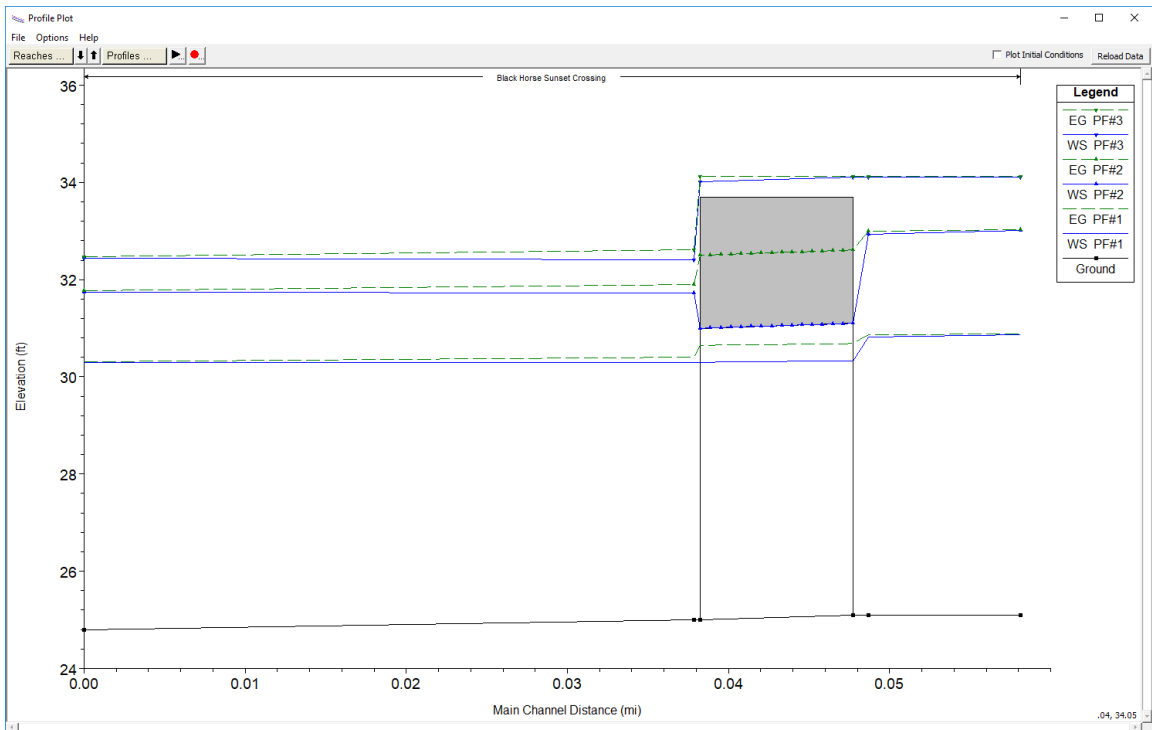


Figure 13. Example Profile Plot With Culvert Data

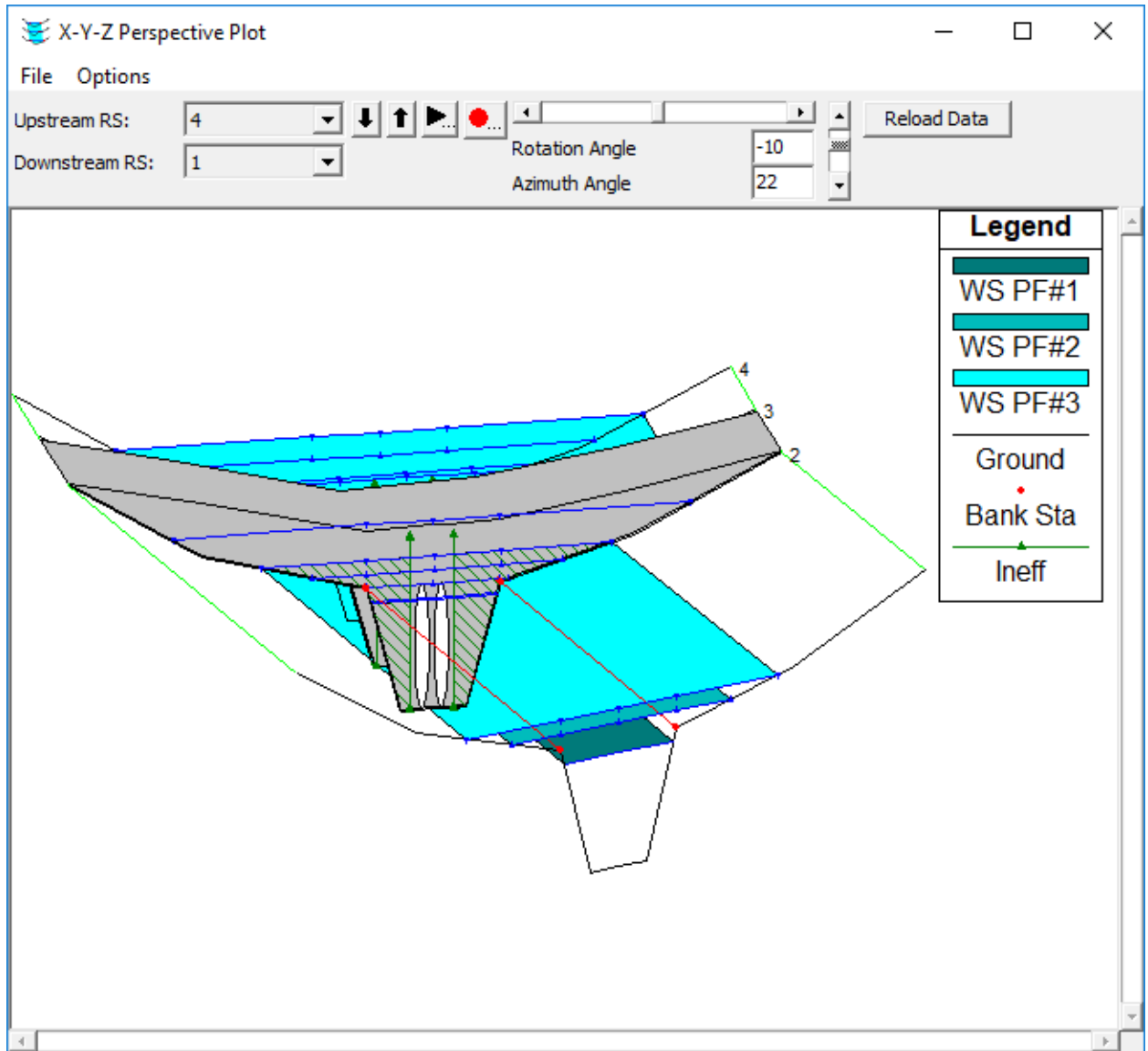


Figure 14. X-Y-Z Perspective Plot With Culvert Data

In addition to the graphical plots, there are several types of tables that contain information about and around the culvert. An example of the **Four Cross Section Culvert** table is shown in Figure 15. Figure 16 shows the **Culvert Only** table, while Figure 17 shows a **Culvert** cross section specific table.

Profile Output Table - Standard Table 1

File Options Std. Tables User Tables Locations Help

HEC-RAS Plan: Plan 01 River: Black Horse Reach: Sunset Crossing Reload Data

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
Sunset Crossing	4	PF#1	0.000000	25.10	0.864150		31	0	1.063145	235	4.591060	0
Sunset Crossing	4	PF#2	0.000000	25.10	3.004890		33	0	1.083300	482	7.439500	0
Sunset Crossing	4	PF#3	0.000000	25.10	4.110570		34	0	1.080684	701	15.827500	0
Sunset Crossing	3	PF#1	0.000000	25.10	0.811460	26.5963	31	0	1.823819	137	4.338870	0
Sunset Crossing	3	PF#2	0.000000	25.10	2.930120	27.1492	33	0	2.128532	188	3.787000	0
Sunset Crossing	3	PF#3	0.000000	25.10	4.107490	27.4778	34	0	1.081339	700	15.730000	0
Sunset Crossing	2.5		Culvert									
Sunset Crossing	2	PF#1	0.000000	25.00	0.298830	26.8197	30	0	2.621125	95	1.937380	0
Sunset Crossing	2	PF#2	0.000000	25.00	1.722780	27.4847	32	0	3.305511	121	2.481000	0
Sunset Crossing	2	PF#3	0.000000	25.00	2.403060	27.8862	33	0	3.752202	133	4.294100	0
Sunset Crossing	1	PF#1	0.000000	24.80	0.290000	26.1291	30	0	1.152891	217	1.996700	0
Sunset Crossing	1	PF#2	0.000000	24.80	1.740000	26.5932	32	0	1.346808	315	3.539300	0
Sunset Crossing	1	PF#3	0.000000	24.80	2.440000	26.8636	32	0	1.466029	402	6.564500	0

Total flow in cross section.

Figure 15. Example of the Four Cross Section Culvert Table

Profile Output Table - Culvert Only

File Options Std. Tables User Tables Locations Help

HEC-RAS Plan: Plan 01 River: Black Horse Reach: Sunset Crossing Reload Data

Reach	River Sta	Profile	E.G. US. (ft)	W.S. US. (ft)	E.G. IC (ft)	E.G. OC (ft)	Min El Weir Flow (ft)	Q Culv Group (cfs)	Q Weir (cfs)	Delta WS (ft)	Culv Ve (ft/s)	
Sunset Crossing	2.5	Culvert #1	PF#1	30.86	30.81	29.50	30.86	33.71	250.00	0.51	4	
Sunset Crossing	2.5	Culvert #1	PF#2	33.00	32.93	31.13	33.00	33.71	400.00	1.21	7	
Sunset Crossing	2.5	Culvert #1	PF#3	34.12	34.11	32.23	34.12	33.71	464.15	35.85	1.70	8

Upstream energy grade elevation at bridge or culvert (specific to that opening, not necessarily the weighted average).

Figure 16. Example of the Culvert Only Profile Table

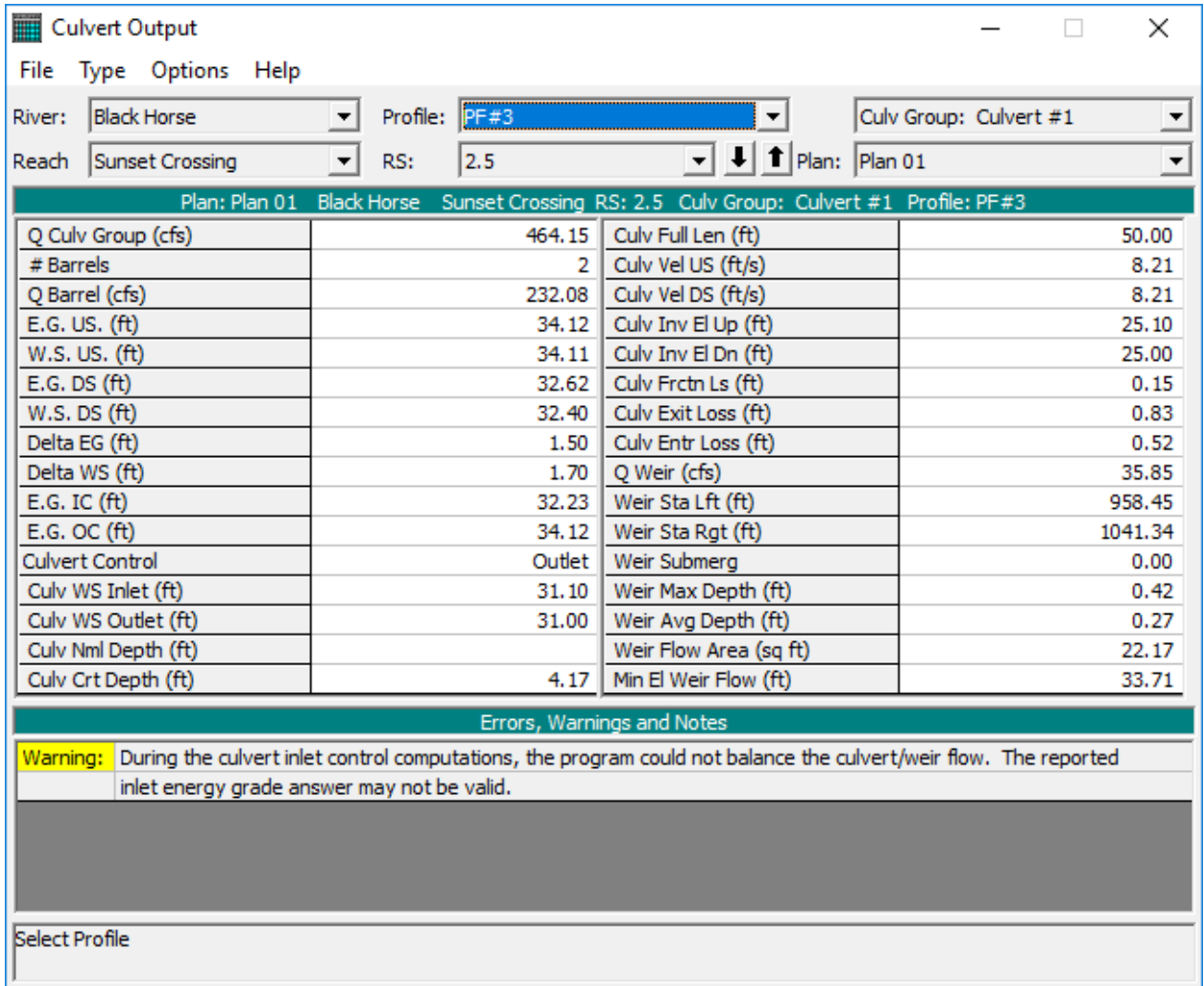


Figure 17. Example of the Culvert Cross Section Specific Table