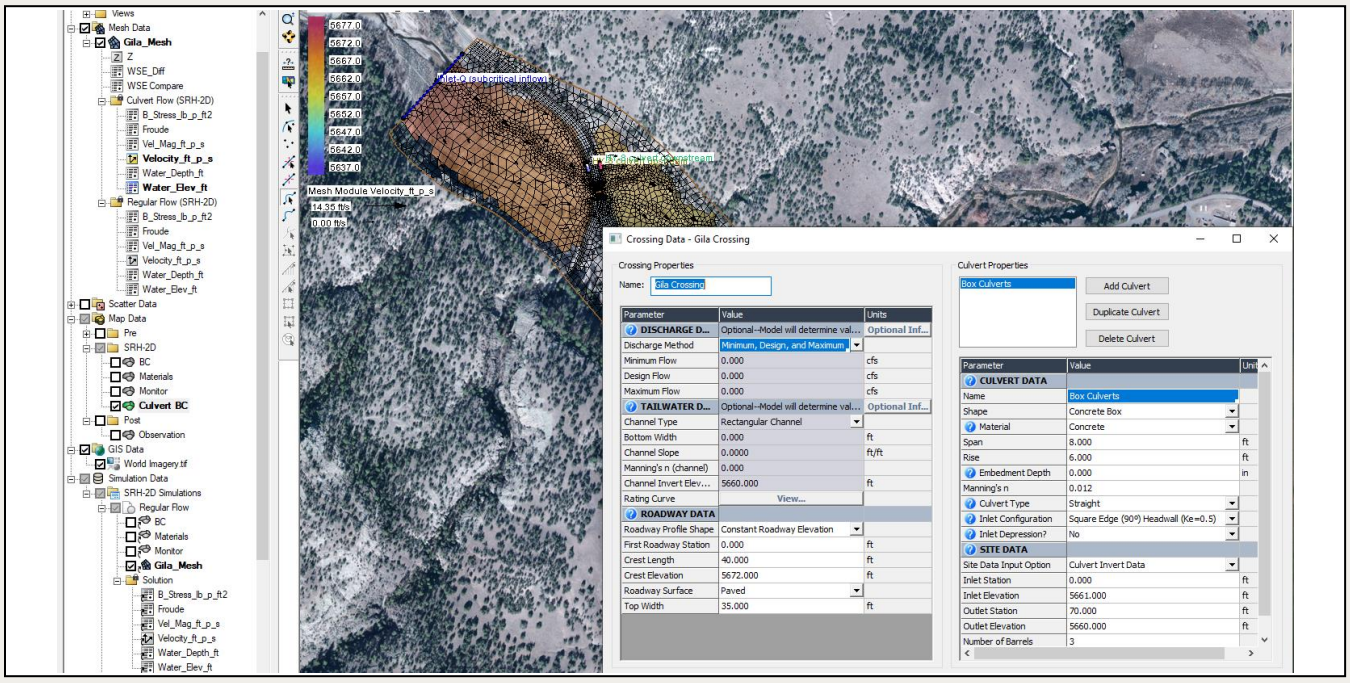
SRH-2D Tutorial

Culvert Structures with HY-8

Add culvert structures to SRH-2D simulations



Objectives

This tutorial demonstrates the process of modeling culverts in SRH-2D coupled with the Federal Highway Administrations HY-8 culvert analysis application. The “SRH-2D Simulations” tutorial should have been completed before attempting this one. All files for this tutorial are found in the “Data Files” folder within the “SMS_SRH-2D_HY8_Culvert” tutorial folder.

Prerequisite Tutorials

- SRH-2D
- SRH-2D – Simulations

Required Components

- SMS Core
- SRH-2D Model & Interface

Time

- 15–20 minutes

1 Introduction

An existing SRH-2D model will be used to facilitate the setup for this tutorial. SRH-2D provides two different ways to define a culvert. For circular barrels or anything more complex, the recommended method to simulate a culvert in SRH-2D is to couple the FHWA HY-8 culvert model with SRH-2D. This tutorial will demonstrate how HY-8 is used with SRH-2D. The second approach for simulation of a culvert involves incorporating the lower half of the culvert barrel into the mesh/grid. This approach, which could be referred to as a 2D culvert, is not described in this tutorial.

The area being modeled in this tutorial is located at the confluence of the west and middle forks of the Gila River, located in New Mexico.

The purpose of this tutorial is to simulate a culvert relief structure near the bridge to mitigate the flooding over the road.

It should be noted that the HY-8 culvert model was developed as a still pool calculation. Therefore, it does not simulate the change in flow due to momentum. SRH-2D includes momentum. There is an option to use total head rather than simple water level to partially account for this limitation.

2 Getting Started

To begin, do the following:

1. Open a new instance of SMS.
2. Select *File* | **Open** to bring up the *Open* dialog.
3. Navigate to and select the “Gila_Structure.sms” project found in the */SMS_SRH-2D_HY8_Culvert/Data Files* folder for this tutorial.
4. Click **Open** to import the data.

In the Project Explorer, duplicates of the “ Regular Flow” simulation and “ BC” coverage have been made to expedite the model setup process. The duplicates have been renamed as “ Culvert Flow” and “ Culvert BC” respectively. In addition, the “ Culvert BC” has been added to the “ Culvert Flow” simulation in place of the original “ BC” coverage. The culvert structure will be created within the “ Culvert BC” coverage and simulated in the “ Culvert Flow” simulation.

The process of duplicating these items and swapping out the boundary condition coverage was demonstrated in the “SRH-2D Simulations” tutorial.

The project should appear similar to Figure 1.

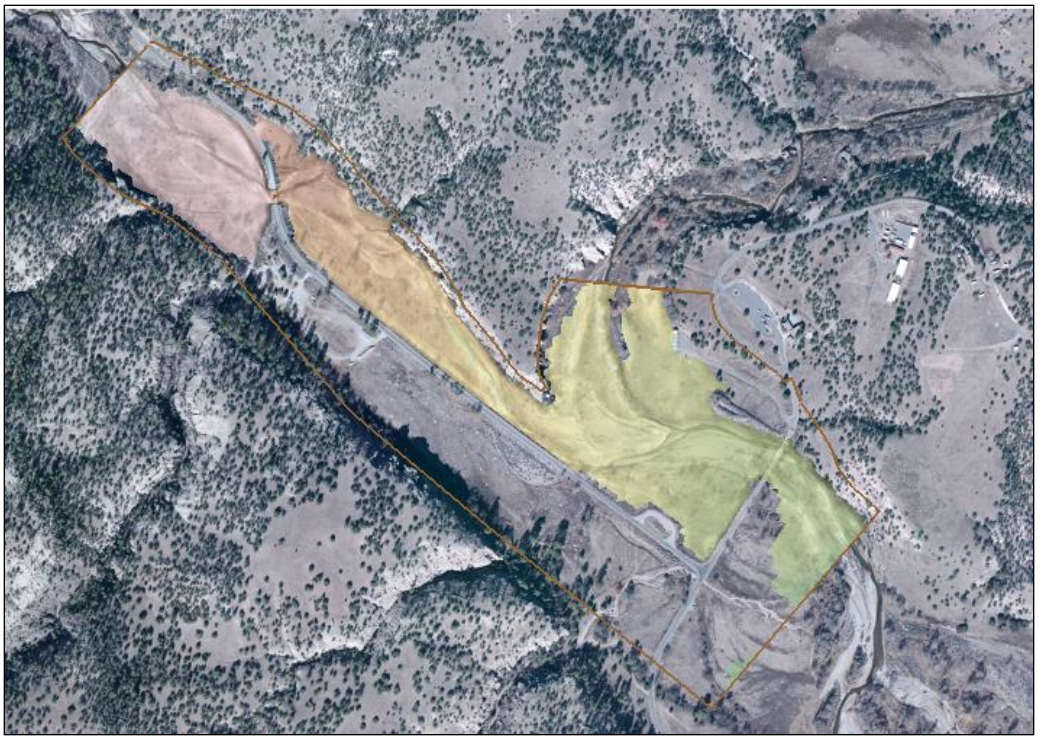


Figure 1 Gila_Structure.sms project

The mesh datasets located under the "Regular Flow (SRH-2D)" folder in the Project Explorer are from an SRH-2D solution of the existing flow conditions, without the culvert relief structure. The datasets can be used to make comparisons and visualize the effects the culvert structure boundary condition will have on the model.

3 Creating the Culvert Structure

The culvert structure will be created near the bridge location (as shown in Figure 2). Culvert structures are defined by creating two boundary condition arcs, one on the upstream face and one on the downstream face of the structure. The boundary condition arcs are then defined as a culvert structure and the attributes of the culvert are defined in the HY-8 culvert definition dialog.

3.1 Creating the Culvert Arcs

The first step for creating a culvert structure for SRH-2D is to create arcs representing the structure within the SRH-2D boundary condition coverage.

1. Select *Display* | **Display Options…** to open the *Display Options* dialog.
2. Select "2D Mesh" from the list on the left.
3. On the *2D Mesh* tab, check the box next to the *Elements* option to turn on the display of mesh elements.
4. Check the box next to the *Vectors* option to turn on the display of vector arrows.
5. Select **OK** to exit the *Display Options* dialog.

6. Select the "Z" dataset to make it active.

7. Use the **Zoom** tool to zoom into the culvert location near the bridge (Figure 2).

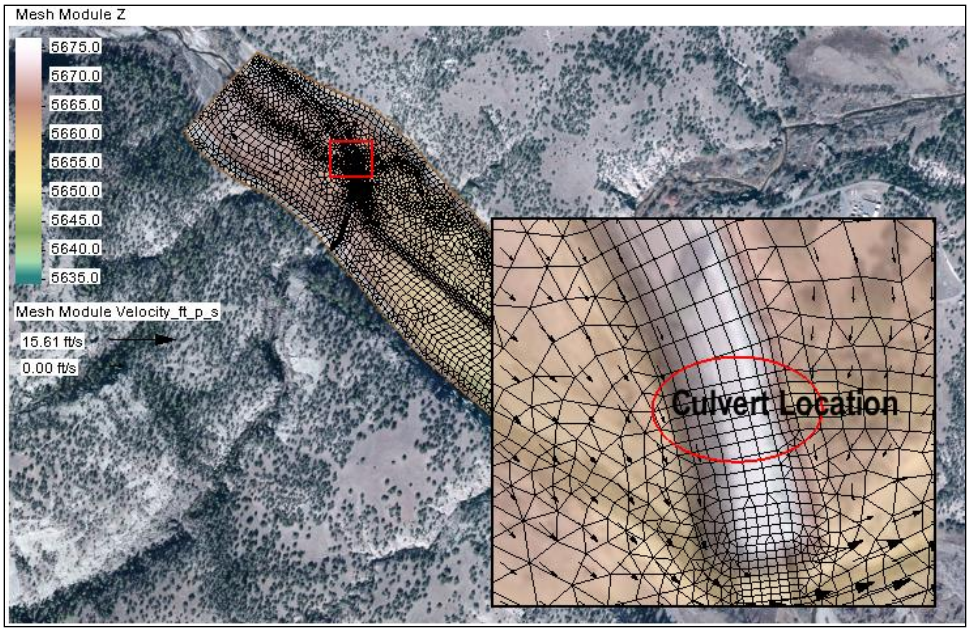


Figure 2 Culvert location

8. In the Project Explorer, check the box next to the "Culvert BC" coverage under the "SRH-2D" folder and select it to make it the active coverage.

9. Using the **Create Feature Arc** tool, create two arcs,one on each side of the road. The created arcs should be placed in the locations shown in Figure 3.

These arcs will define the upstream and downstream faces of the culvert structure.

Remember that the arcs should be created in the same direction. For this tutorial create both arcs from south to north.

Notes: The following should be kept in mind when creating arcs for culverts:

- The downstream arc (on the right side of the embankment) should be positioned at the toe of the embankment. If the toe is not clearly defined, err on the side of being further downstream or lower the elevation in the mesh to clearly define the toe. The element edges aligned with the downstream location should be at or below the culvert invert elevation.
- Experience has shown that the culvert calculations are more stable if they are aligned to quadrilateral elements and the culvert includes more than a single element. The mesh may need to be modified to represent the area.
- These arcs should be created in the same direction (north to south or south to north). After the first arc has been drawn, ensure that the second arc is drawn in the same direction. Drawing them in opposing directions may cause an error when running SRH-2D.
- It is recommended that the mesh be created to contain quadrilateral elements around the downstream arc to improve the transition of flow from 1D HY-8 model into the 2D SRH-2D model.

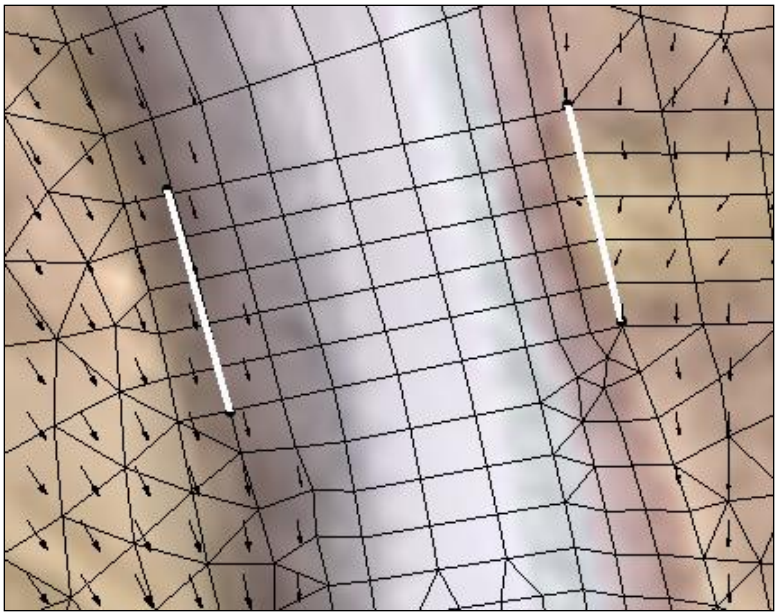


Figure 3 Upstream and Downstream BC Culvert Arcs

3.2 Examining the Mesh around the Culvert

Care should be taken to ensure that the mesh and the culvert are compatible. In other words, they should fit together in space.

To check this, elevations and distances can be measured in the area where the culvert will be inserted into the mesh.

Culvert dimensions

1. Using the **Measure Tool**, measure the distance between the two culvert arcs (just created) and the length of the two arcs.

The distance between the arcs is the station length of the culvert. This will be entered as the "Outlet Station" of the culvert in HY-8. This should be around 70–80 ft.

The average length of the two arcs is referred to as the "Crest Length" of the road in HY-8. This should be around 40 ft.

Culvert elevations

The "culvert crest elevation" is the elevation at which water will start overtopping the road. The "invert elevations" are the bottom elevations of the culvert barrels (up and down stream ends).

To evaluate the culvert elevations:

1. Expand the "Post" folder in the "Map Data" section of the Project Explorer.

2. Check the box next to the "Observation" coverage inside the "Post" folder.

This coverage contains 5 arcs that have been created to help review the elevation of the geometry in the area of the culvert.

3. Using the **Select Feature Arc** tool, select the bottom arc.

4. Right-click and select **Show Observation Plot** to bring up the *Plot 1* dialog.

A plot of the transect along that arc appears in the plot window.

5. Right-click on the plot window and select **Plot Data** to open the *Data Options* dialog.
6. In the *Coverage* section, turn on the toggle boxes for all 6 culvert profiles in the *Show* column of the table.
7. Click **OK** to exit the *Data Options* dialog.

This plot (Figure 4) shows:

- A crest elevation of around 5672.6 ft.
- A toe elevation for the embankment on the upstream side that varies between 5660 and 5661 ft.
- A toe elevation for the embankment on the downstream side that is not flat. For the middle section of the channel leading away from the culvert, the bed elevation is between 5659 and 5660. However, the edges jump up to 5663 on one side and about 5664 of the other side.

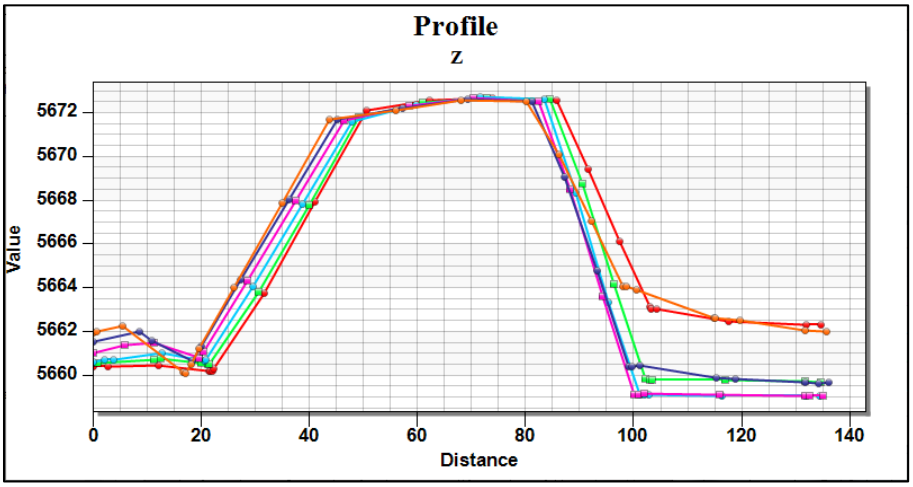


Figure 4 The elevation plot

8. Close the plot window by clicking on the  in the upper right corner.

If this culvert is to be constructed (design mode), the mesh elevations could be modified to match the anticipated construction. If this simulation represents existing conditions, care should be taken to make sure the mesh represents the conditions being simulated.

3.3 Assigning Culvert Structure Attributes in HY-8

SMS set each of the arcs created earlier in the tutorial to “Wall (no-slip boundary)”. This is the default boundary condition type. Therefore, the next step in creating the culvert structure is to specify the boundary condition type and define the culvert attributes.

1. Turn off the “ Observation” coverage and select the “ Culvert BC” coverage to make it active.
2. Using the **Select Feature Arc** tool, select the upstream (leftmost) culvert arc and take note of the ID for this arc which is displayed in the *Status Bar* at the bottom of the SMS application.

3. Hold the *Shift* key and select the downstream (right) culvert arc so that both of the arcs are selected.
4. Right-click on either arc then select the **Assign BC...** command to open the *SRH-2D Linear BC* dialog.
5. In the *BC Type* combo box, select “Culvert HY-8”. Be sure to select “Culvert HY-8” and not “Culvert”.

Note the assignment of “Upstream” and “Downstream” to the two arcs, associated with their ID values under *Arc id* in the *Structure boundaries* section. If the ID displayed for the ”Upstream” arc is not the same as noted above in step 2, switch the associations using the combo box *Structure boundaries* section.

6. Leave *Units for HY-8 display* as “English”.

The *Use total head* option will add the velocity head to the water surface elevations for the 1D culvert calculations. Since this culvert is not in the main channel, it will not be used for this application.

The *General structure options* will not be used in this example. If there is high skew or rapid drawdown at the entry or exit of the structure, then consider using a BC Data line.

For now, leave the option *Checked uses 2D terrain for overtopping* unchecked. This tells SRH-2D that HY-8 will compute overtopping assuming it is in the direction of the culvert.

7. Select **Launch HY-8** under *HY-8 Culvert*. This will open the HY-8 software. If the HY-8 software does not start, check the *Preferences* dialog to make certain the correct file path as been set for the HY-8 exectuable.
8. In the HY-8 Project Explorer, right-click on “ Project – culvert.hy8”, and choose **Add Culvert Crossing** to open the *Crossing Data – Crossing 1* dialog.
9. In the *Crossing Properties* section, change the following:
    a. *Name* to “Gila Crossing”.
    b. *Channel Invert Elevation* in *TAILWATER DATA* to “5660” (from the transect plot above). This value is only used for the plot in HY-8.
    c. *Crest Length* in *ROADWAY DATA* to “40” ft. (measured in SMS).
    d. *Crest Elevation* in *ROADWAY DATA* to “5672” ft (from the transect plot).
    e. *Top Width* in *ROADWAY DATA* to “35” ft (approximated from the top of the road. We are using about half of the length measured in SMS).
10. In the *Culvert Properties section*, change the following:
    a. *Name* in *CULVERT DATA* to “Box Culverts”.
    b. *Shape* in *CULVERT DATA* to “Concrete Box”.
    c. *Span* in *CULVERT DATA* to “8” ft.
    d. *Rise* in *CULVERT DATA* to “6” ft.
    e. *Inlet Elevation* in *SITE DATA* to “5661” ft. (from the transect plot).
    f. *Outlet Station* in *SITE DATA* to “70” ft (measured in SMS).
    g. *Outlet Elevation* in *SITE DATA* to “5660” ft. (from the transect plot.)
    h. *Number of Barrels* in *SITE DATA* to “3”.

The transect plot showed that if there were more than 3 barrels, it would be wider than the outflow channel. Before putting in more barrels, the channel geometry should be modified.

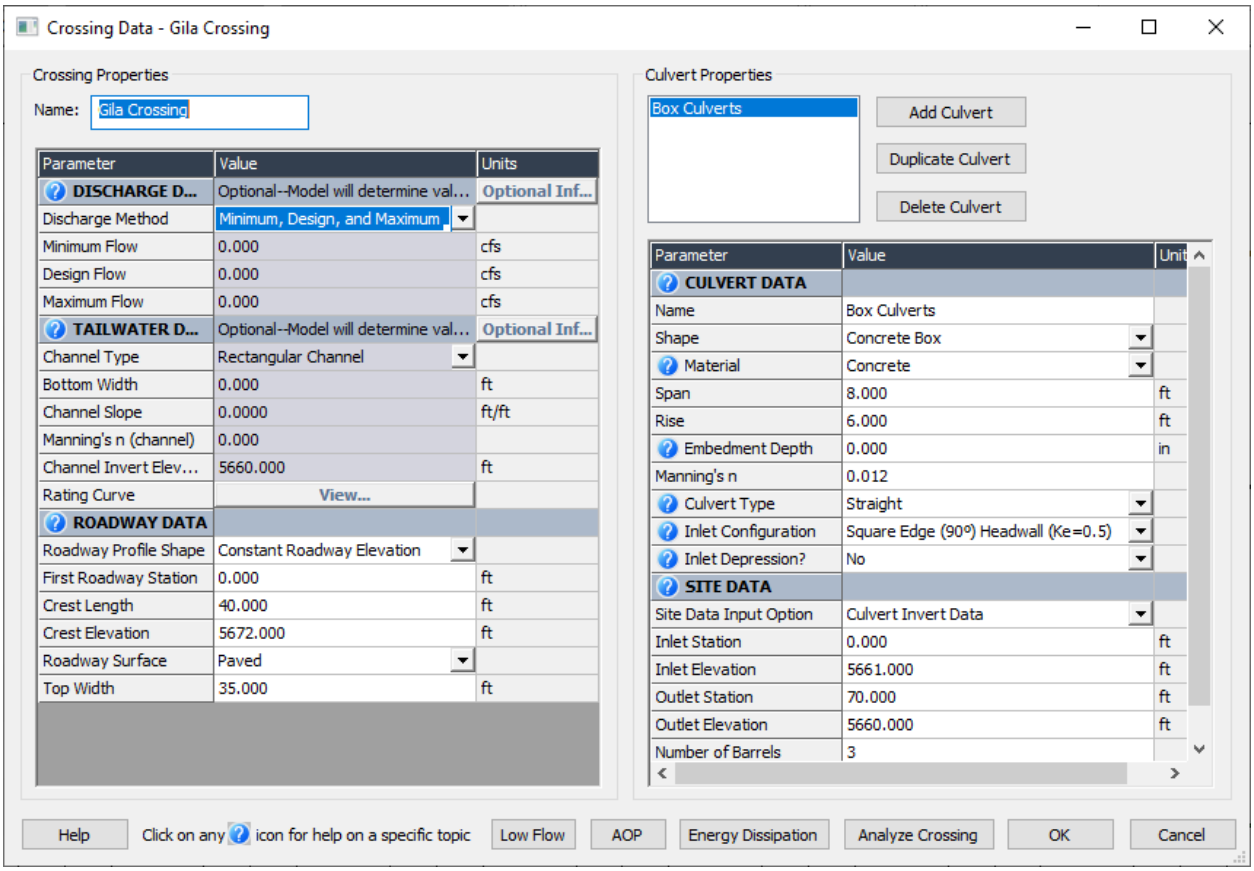


Figure 5 HY-8 Crossing and Culvert Inputs

11. Click **OK** to close the *Crossing Data* dialog.

12. In the main HY-8 window, select "Box Culverts" to view a plot of the culvert transect.

This shows the stationing and the elevations specified above.

13. Exit the main screen of HY-8 by pressing the exit button . All changes will be saved upon exiting.

14. In the *SRH2D Assign BC* dialog select "Gila Crossing" from the *HY-8 crossing* drop-down menu.

All crossings included in a project must be in the same "hy8" file. If the HY-8 crossing is already defined for a location, launch HY-8 from inside of SMS to view the crossings already associated with this project. Then open the HY-8 file with the new crossing definition. This adds the crossings from this file to the crossings defined for the SMS project.

15. For now, leave the BCDATA options unchecked

16. Click **OK** to close the *SRH2D Assign BC* window.

17. Select *File* | **Save …** to the project.

Keeping projects saved is a good idea.

4 Saving, Exporting, and Launching the Simulation

Now that the culvert structure has been created and defined, the model is ready to run.

1. Right-click on the "Culvert Flow" simulation and choose **Save Simulation.**
2. After the project has saved right-click on "Culvert Flow" simulation and select **Run Simulation.**

The execution of SRH-2D includes an HY-8 step because this simulation has a culvert defined.

3. Click the **Load Solution** button in the *Simulation Run Queue* dialog, to import the solution file.
4. Click **Close** to exit the *Simulation Run Queue* dialog.

SMS loads the solution datasets which are now listed in the Project Explorer under "Gila_Mesh" under the "Culvert Flow (SRH-2D)" folder as well as in the solution folder in the simulation.

5 Visualizing the Results

SMS has several ways to visualize results.

One method is to review contour and vector results in the main graphics window.

1. Click on the "Water_Elev_ft" dataset under the "Culvert Flow (SRH-2D)" folder to make the new solution visible.
2. **Zoom** into the area of the culvert.

Note that the water no longer overtops the roadway to the left of the bridge. Also note that the vector arrows denote flow entering and leaving the culvert. Culvert flow is one-dimensional, so the actual culvert is not contoured.

3. Toggle between the "Water_Elev_ft" dataset for "Culvert Flow (SRH-2D)" and "Regular Flow (SRH-2D)" to compare the water level results.
4. Toggle between the "Vel_Mag_ft_p_s" dataset for "Culvert Flow (SRH-2D)" and "Regular Flow (SRH-2D)" to compare the velocity results

Another useful way to compare the effects of the culvert on the channel is to create a new mesh dataset representing the differences in water surface elevations between the culvert solution and the existing condition solution. The dataset for the difference can be created using the *Data Calculator*. To do so, do the following:

1. Select *Data* | **Dataset Toolbox…** to bring up the *Dataset Toolbox* dialog.

An expression will be created in the calculator that takes the difference between both water surface elevation datasets, the existing conditions ("Water_Elev_ft"), and the proposed culvert conditions ("Water_Elev_ft").

2. In the *Tools* section, select "Data Calculator".
3. Under the "Regular Flow" folder, click on the "d6. Water_Elev_ft" dataset to select it and make it active.

4. Select the **Add to Expression** button to add “d6” to the expression.
5. In the *Calculator*, select the subtract [-] button.
6. Select the “d11. Water_Elev_ft” dataset under the “Culvert Flow” folder.
7. Select the **Add to Expression** button. The expression should now be: “d6-d11”.
8. In the *Output dataset name* box, specify the name of the dataset as “WSE_Diff”. The window should look like Figure 6.
9. Select **Compute** to create the new dataset.
10. Select **Done** to close the *Dataset Toolbox*.

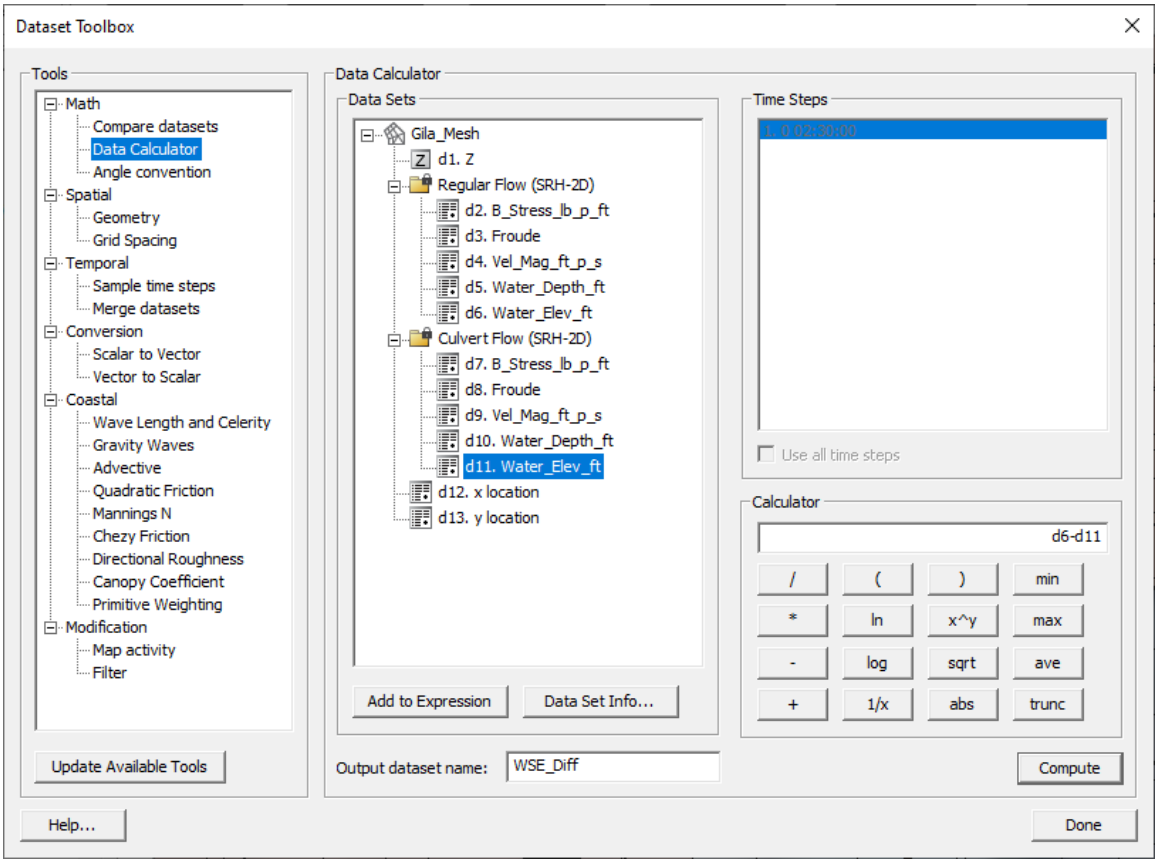


Figure 6 Data Calculator Expression

11. Select the “ WSE_Diff” dataset to view the differences.

The positive values represent water surface elevations that were higher without a culvert, Upstream of the bridge, the reduction in WSE is evident.

The “ WSE_Diff” dataset does not have a predefined dataset template. Therefore, it uses whatever contour options are set. If you switch to this dataset from a water surface dataset, the contour options are not very helpful because that contour option has a specified contour interval that is too large for this dataset. If you switch from a velocity magnitude, the range is more appropriate. Review the contour options and display template options for more information.

5.1 Viewing a Culvert Plot

When SRH-2D was run, an output file was created for the culvert structure that includes diagnostic information for the culvert. This file can be a useful way to understand what is happening within the culvert structure. It can be found in the output directory for the simulation and is called “Culvert_Run_HY1.dat”. It can be opened in a text editor for viewing the flows through the culvert and water surface elevations at the faces of the structure.

Another method for further analysis is to generate a solution plot of the culvert structure. To do this:

1. Select the “ Culvert BC” coverage to make it active.
2. Using the **Select Feature Arc** tool, select just one of the culvert arcs.
3. Right-click and select **Structure Output Plots…** to open the *SRH-2D Solution Plots* dialog.

In the *SRH-2D Solution Plots* dialog, a plot of the discharge through the culvert is shown.

4. In the *Plots* section, turn off the “Discharge (cfs)” plot and turn on both the “WSE_up (ft)” and “WSE_dn(ft)” plots.

The plot updates to display the upstream and downstream water level through the simulation. However, time was not a feature of this simulation. The variation through time only indicates the convergence from initial conditions to steady state. To eliminate the impact of time, do the following:

5. Turn on the *Specify time range* option and enter a *Minimum time* of “2.0”.
6. Click away from the minimum time edit field or press the *TAB* key.

The plot updates again to show the water surface elevation change through the culvert.

7. Select **Close** to close the plot.

Refer to the simulation plots documentation for more information.

6 Culvert Options

SRH-2D supports several options for culverts. This section highlights those changes.

1. Select the “ Culvert BC” coverage to make it active.
2. Use the **Create Feature Arc** tool to create an additional arc upstream (to the left) of the culvert in the location show in Figure 7.

This arc will be used to measure the headwater for the culvert.

3. Using **Select Feature Arc**, double-click on this new arc to open the *SRH2D Assign BC* dialog.
4. Select “Bc Data” from the *BC Type* drop-down.
5. Enter “Upstream of Culvert” as the *Label.*

This implies that this line can be used in conjunction with other boundary conditions.

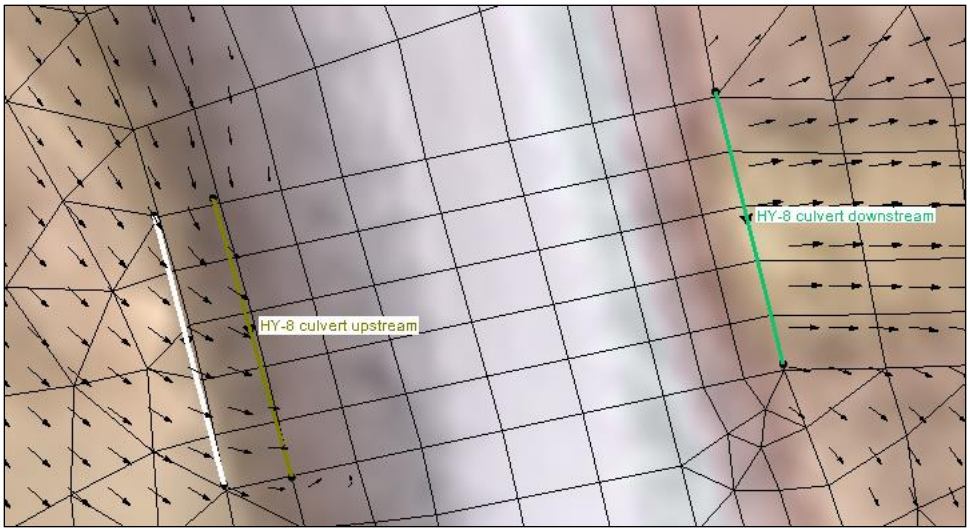


Figure 7 Upstream and Downstream BC Culvert Arcs

6. Using **Select Feature Arc**, double-click on either culvert arc to open the *SRH2D Assign BC* dialog.

7. In the *General structure options* section, toggle on the *Specify upstream BCDATA line* option.

A combo box appears to select the dataline.

8. Select “Upstream of Culvert” to use the new arc to define the upstream water level for the culvert.

BCDATA lines can avoid having structure impacts, such as draw down, influence the computation of flow through the structure of boundary conditions.

9. In the *HY-8 culvert options* section, toggle on the *Checked uses 2d terrain for overtopping* option.

   This culvert does not overtop at this flow, so the option should have no impact. Normally this option is used with long culverts, culverts with complex geometry over the top of the culvert, or culverts where overtopping flow is not expected to follow the culvert direction.

10. Click **OK** to close the *SRH2D Assign BC* window.

11. Right-click on the “ Culvert Flow” simulation and choose **Save project, Simulation and Run**.

12. If the prompt appears to notify you that the old solution will be unloaded, click **OK**.

13. Monitor the run as usual. When it is complete, click the **Load Solution** button in the *Simulation Run Queue* dialog, to import the solution file.

14. Click **Close** to exit the *Simulation Run Queue*.

Review the new solution. For this case, it is almost identical to the previous solution. Note that some of the cells between the culvert arcs are now “wet” or active. This is because SRH-2D did not mark them as inactive. If overtopping is expected, you would want to modify the crossing definition to set the “Crest Length” to a very small number. Otherwise, the model could overestimate the overtopping rate because it would be included in both the 2D and the 1D culvert calculations.

7 Conclusion

This concludes the "SRH-2D Culvert Structures with HY-8"[1] tutorial. Topics covered in this tutorial included:

- Opening an existing SRH-2D project
- Creating a culvert structure
- Saving and running SRH-2D
- Visualizing and comparing solution results
- Using the data calculator
- Reviewing the structure plots for the culvert.
- Using the new BCDATA and 2D overtopping options for a culvert.

If desired, further analysis could be performed on the solution. Possible options include:

- Switching the culvert to use the velocity head in addition to the water level.
- Changing the culvert elevation up or down the embankment. It is strongly recommended that the culvert invert not be below the outflow channel elevation because this can result in high velocities for low leaving the culvert.
- Changing the culvert definition. This could include the number of barrels, the type of barrel, etc.

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[1] This tutorial was developed by Aquaveo, LLC under contract with the Federal Highway Administration.