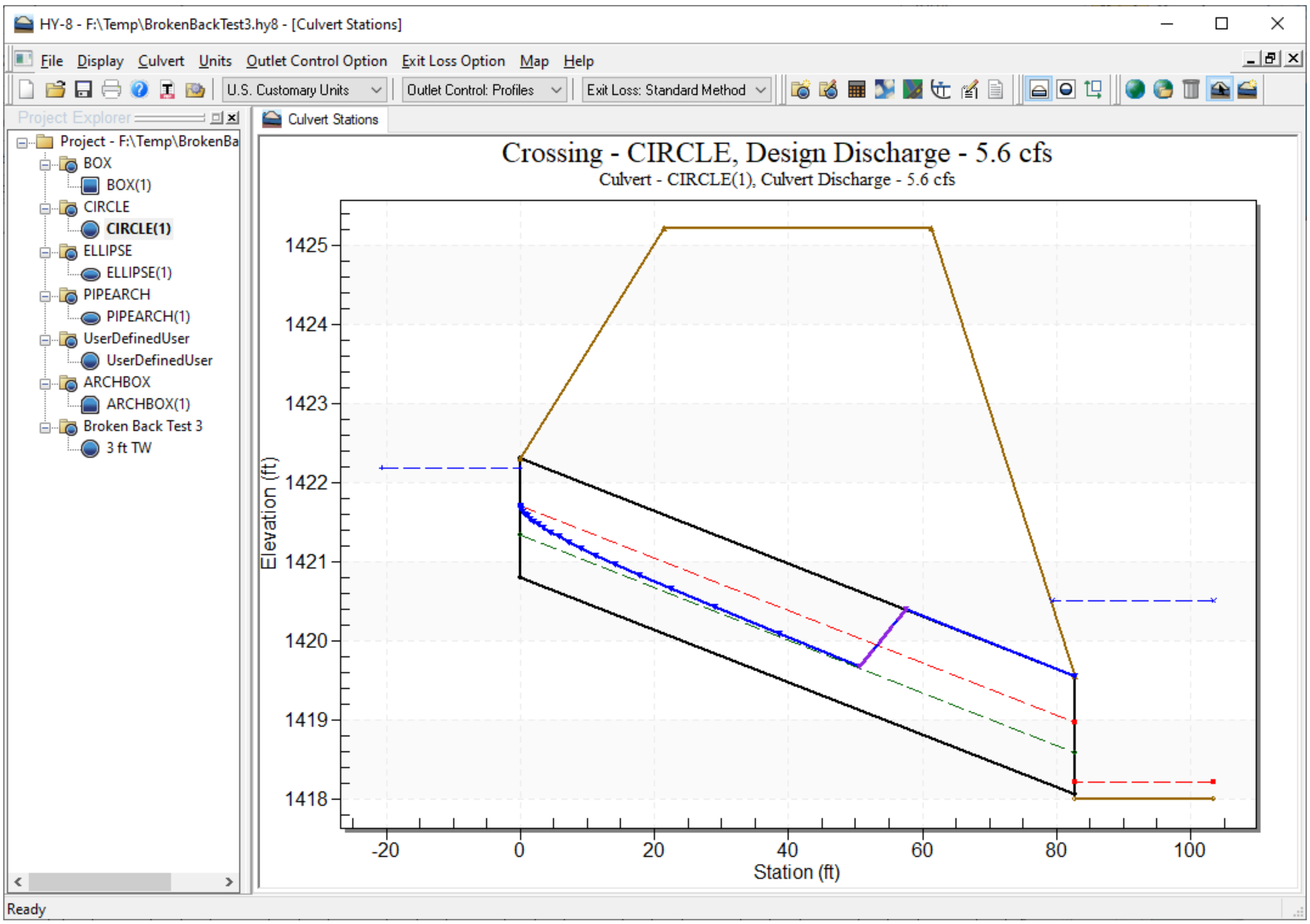
v. 8.0

FHWA HY-8 Culvert Analysis Program

User's Manual



U.S. Department of Transportation
Federal Highway Administration

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1 Introduction

1.1.1 Introduction

HY-8 automates the design methods described in HDS No. 5, "Hydraulic Design of Highway Culverts", FHWA-NHI-12-029 and in HEC No.14, FHWA-NHI-06-086. Hydrologic calculations are available in the Watershed Modeling System (WMS) and in the FHWA Hydraulic Toolbox.

The software has been structured to be self-contained and this help file functions as the program's user's manual. This facilitates its use by roadway design squads. However, the knowledgeable hydraulic engineer will also find the software package useful because it contains advanced features. This help file provides necessary instructions and clarifications.

1.2 History of HY-8

The Pennsylvania State University produced HY-8 versions 1.1, 2.1, and 3.0 in cooperation with FHWA. The Rural Technical Assistance Program (RTAP) of the National Highway Institute sponsored the HY-8 versions 3.0 and earlier versions under Project 18B administered by the Pennsylvania Department of Transportation. Philip L. Thompson developed HY-8 versions 3.1, 4.1, and 6.1 and provided them to the Federal Highway Administration (FHWA) for distribution. GKY and Associates produced version 6.1 (Energy, HYD and Route) under contract with FHWA. Version 6.1 is the last version of the MS-DOS program that was distributed.

Christopher Smemoe developed HY-8 7.0 at the Environmental Modeling Research Lab at Brigham Young University (BYU) under the direction of Jim Nelson of BYU and with the assistance of Rollin Hotchkiss (BYU) and Philip L. Thompson (Retired from FHWA). Version 7.0 provides Windows- based graphical user interface (GUI) for the same hydraulic calculations performed in version 6.1 of HY-8. In the course of the development all program culvert modeling functions were translated from Basic to the C++ programming language. Several minor bugs in version 6.1 were corrected in HY-8 version 7.0. Versions 7.1, 7.2, 7.3, and 7.4 of HY-8 were incremental updates in which several new features were included and several bugs were fixed. Besides bug fixes, the following new features were added to HY-8 7.1 and 7.2:

1. Energy dissipation calculators
2. A new culvert shape/coefficient database
3. The ability to model embedded (ie “buried”) culverts
4. The Utah State University exit loss equation
5. Modeling of plastic pipes
6. Improvements to the HY-8 report generation tools.
7. Section property matrix of 10 points for interpolation was replaced with direct computation of section properties for each discharge.

Christopher Smemoe and Eric Jones at Aquaveo (LLC) developed HY-8 7.3 with help from Rollin Hotchkiss (BYU) and Philip L. Thompson (Retired from FHWA). The following new features were added to HY-8 7.3:

1. The profile computation code was rewritten to increase program stability and efficiency
2. Sequent depth computations for hydraulic jump computations
3. Capability was added to model hydraulic jumps and their lengths in culverts
4. Capability was added to model broken back culverts and hydraulic jump locations/lengths in broken back culverts
5. Ability to model horizontal and adverse slopes was added
6. Two new culvert types were added to the culvert shape/coefficient database: Concrete open-bottom arch (CON/SPAN) and South Dakota prefabricated reinforced concrete box culverts

Several graduate students contributed to both the theory and programming efforts of HY-8. Brian Rowley assisted in the development of version 7.0 and 7.1 while a graduate student at BYU. Elizabeth Thiele compared several culvert hydraulic computer models in her research **HY-8 in Culvert Hydraulics: Comparison of Current Computer Models by Elizabeth Anne Thiele (2007)** and determined several improvements, some of which were implemented in later versions. Nathan Lowe studied hydraulic jumps in various closed conduit configurations to make possible comprehensive hydraulic jump calculations in **Theoretical Determination of Subcritical Sequent Depths for Complete and Incomplete Hydraulic Jumps in Closed Conduits of Any Shape by Nathan John Lowe (2008)**. Nathan's equations were used to determine locations and lengths of hydraulic jumps in HY-8 7.3.

The following features were added to versions 7.4 and above (by Christopher Smemoe and Eric Jones at Aquaveo (LLC)):

1. Stream simulation aquatic organism passage (AOP) as described in Hydraulic Engineering Circular No. 26 (HEC-26), was added to 7.4
2. Low Flow Hydraulics, as described in Fish Passage in Large Culverts with Low Flows, was added to 7.5
3. HY-8 7.6 was updated with bug fixes, embedment issues corrections, improved stability, and interface updates.

Appendix C explains the differences between the Windows and DOS versions of HY-8.

1.3 Conceptual Model of HY-8

HY-8 computes the headwater elevation and the water surface profiles through a culvert crossing. To perform these calculations, HY-8 computes hydraulic information for each component of the culvert crossing.

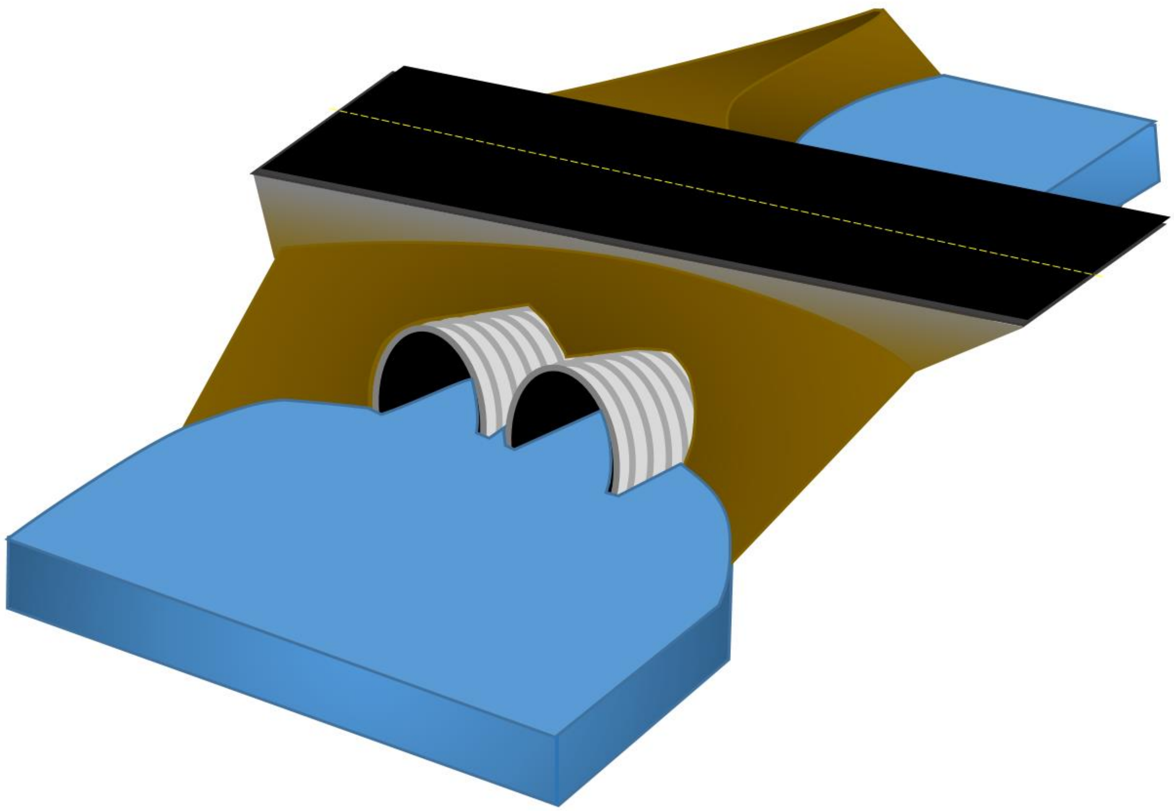


Figure 1.1: Culvert crossing with multiple barrels

A culvert crossing comprises of the following components from upstream to downstream:

- A single, upstream channel
- Culvert barrels with inlets that connect the upstream channel to the culvert barrel.
- A roadway that travels over the culvert barrels
- A single, tailwater channel

1.3.1 Upstream Channel

HY-8 assumes that the channel upstream is ponded and has zero velocity, not because this is likely but because this is a simplifying assumption and the governing condition. A flowing stream would result in a lower headwater.

The assumption of an upstream pond with no velocity means the only hydraulic characteristic that will affect the culvert crossing is the headwater elevation. This is the main variable that HY-8 will compute and therefore, the user does not need to add input for the upstream channel.

1.3.2 Culvert Barrels with Inlet Connections

Culvert barrels are analyzed with inlet and outlet control computations. Inlet control computations determine how much water can flow into the culvert barrels from a ponded condition. This manual provides more detail later in the section describing Inlet Condition Calculations. The outlet control computations use Manning's n equation and the tailwater elevation. The headwater depth is the greater of the inlet and outlet control depths. A water surface profile in the culvert barrel is determined based on the results of these computations.

If there are multiple culvert barrels, the flow is balanced across the barrels that results in the same headwater across all culvert barrels and overtopping the roadway, if applicable.

1.3.3 Roadway

HY-8 will model the roadway as a weir. It can be sharp-crested or broad-crested depending on the geometry. If the headwater exceeds the roadway elevation, the water will flow over the top of the roadway and then into the tailwater channel.

1.3.4 Tailwater Channel

The tailwater channel determines the effect of the tailwater on the flow through the culvert barrels and over the roadway weir. The tailwater elevation can change the flow profile regimes and the resulting headwater elevation. If the tailwater is high enough, it will surcharge the culvert barrel and submerge the roadway weir.

1.4 Getting Started

HY-8 automates culvert hydraulic computations and enables users to analyze:

- The performance of culverts
- Multiple culvert barrels at a single crossing as well as multiple crossings
- Roadway overtopping at the crossing and
- Report documentation in the form of performance tables, graphs, and key information regarding the input variables

New to HY-8 is the ability to define multiple crossings within a single project. A crossing is defined by 1 to 6 culverts, where each culvert may consist of multiple barrels along with discharge, tailwater, and roadway data. In HY-8 allows defining any number of crossings within the same project. The diagram below illustrates the hierarchy of a HY-8 project.

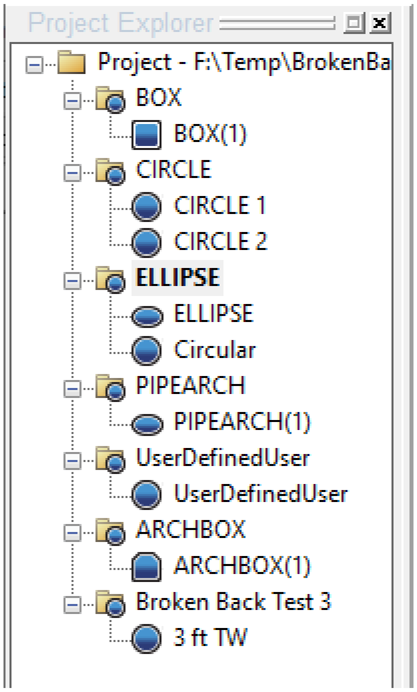


Figure 1.2: Project explorer with culvert crossings

Within a project, the user can create new crossings. For each crossing can define up to six culverts.

After defining the culvert properties, the analysis (including overtopping of the roadway) is completed and the performance output can be evaluated, graphed, and summarized in reports. A sample of the first output screen is shown below.

1.4.1 HY-8 Workflow

An HY-8 project involves the design and analysis of single or multiple culverts at one or more crossings. The process of building a culvert project involves the following steps:

- Locate Project & Crossing
- Input Crossing and Culvert Barrel Data
- Run Analysis
- Report Generation

The user may add crossings to the project as needed.

1.4.1.1 Locate Project & Crossing

The first step in building a project is to identify the location of the crossing. The project contains all of the crossings while the crossings are the locations at which the culverts are placed. If desired (not required), the map viewer tool may be used to locate the crossing by entering (latitude, longitude) coordinates or the address of the crossing as shown in the figure below.

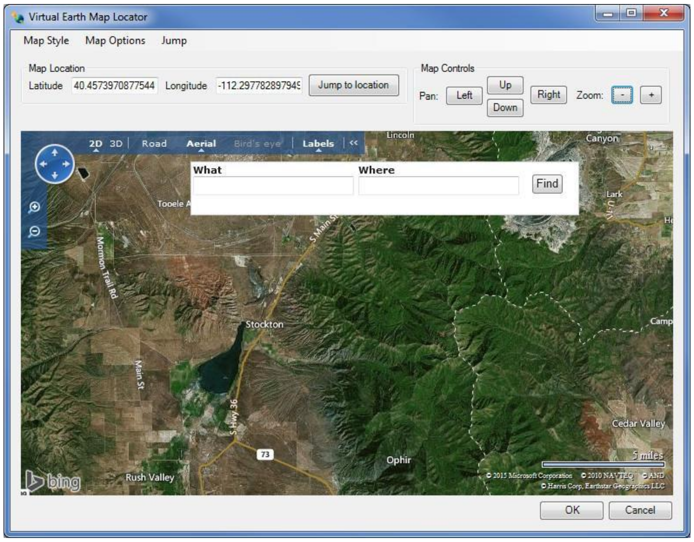


Figure 1.3: Virtual Earth Map Locator

The user may add the culvert crossing by using the ‘Add Crossing’ tool in the plan view image, by clicking the ‘Add New Crossing’ menu or toolbar, or right-clicking in the project explorer.

1.4.1.2 Input Crossing and Culvert Barrel Data

The user may choose up to 99 barrels for each culvert which is defined by the same site conditions, shape configuration, culvert type, and "n", and/or up to 6 independent culverts. In both cases the culverts share the same headwater pool, tailwater pool or channel, and roadway characteristics. The input properties define the crossing and culvert. The user enters the data defining each culvert in the input parameters widow. The input parameters window is accessed from the *File* menu, or from Project Explorer window by right-clicking on the culvert or crossing and selecting **Culvert Crossing Data** from the list. The user may also select the culvert properties icon from the tool bar. From the *Culvert Crossing Data* window, the site, culvert, tailwater, discharge, and roadway data are all entered.

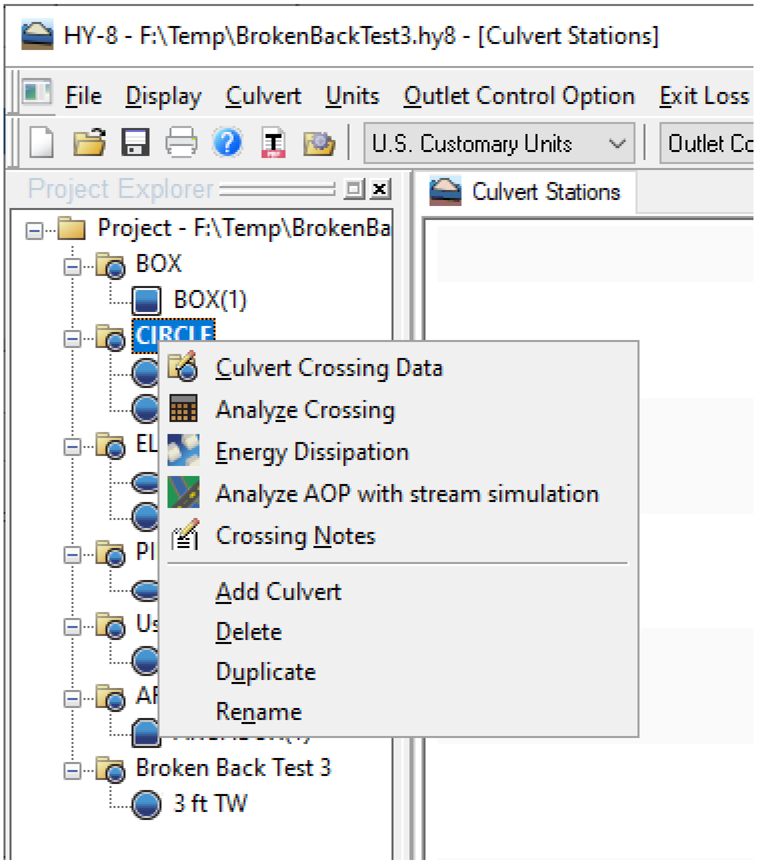


Figure 1.4: Right-click menu for a culvert crossing in the project explorer

The user can define all of the parameters necessary to define crossing and culvert information from the *Culvert/Crossing Data* window as shown below.

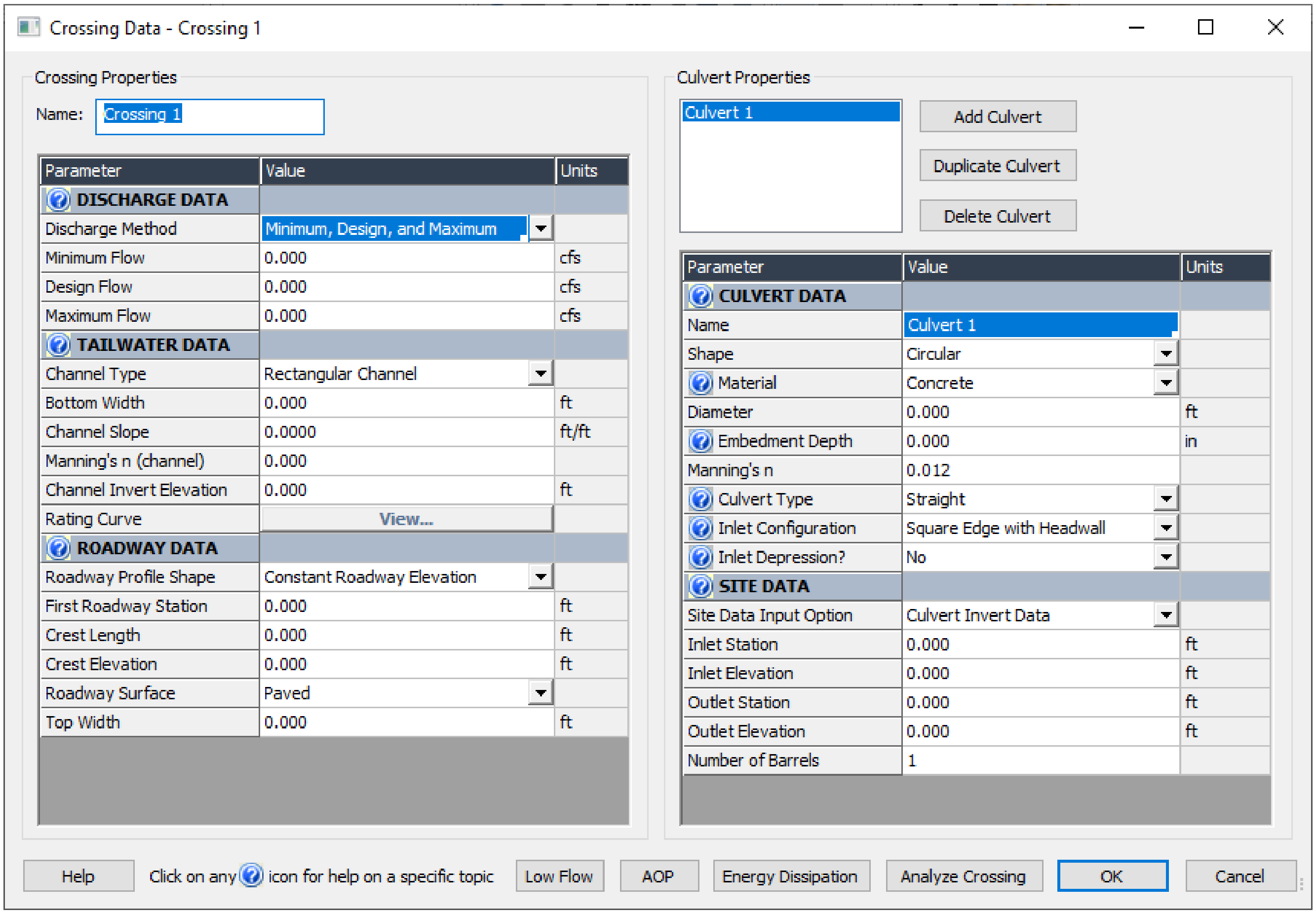


Figure 1.5: Example of the culvert/crossing data window

1.4.1.3 Run Analysis

After defining the culvert and crossing data, HY-8 will analyze the culvert hydraulics, including balancing flow through multiple culverts and over the roadway. Viewing the analysis of a crossing can be done by right-clicking on the desired crossing in the *Project Explorer* window and selecting **Analyze Crossing** as seen in the figure below. The *Analyze Crossing* feature can also be accessed for the currently selected crossing from the *Culvert Crossing Data Window*, the *Culvert* menu, or from the culvert toolbar.

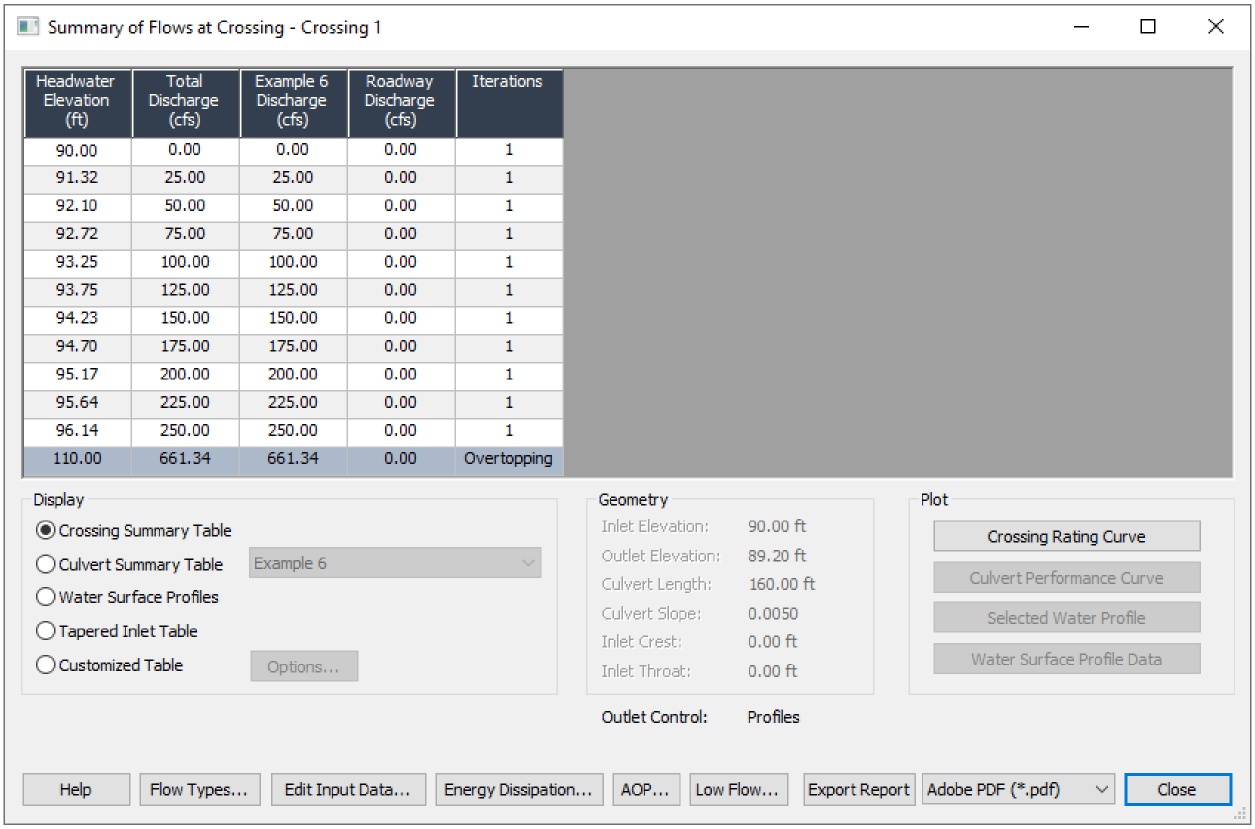


Figure 1.6: Results dialog for a sample culvert crossing

During the analysis, the program completes the necessary hydraulic computations after which the crossing performance table will be displayed. HY-8 will display a summary of flows at the crossing, including any overtopping flows if they occur. While viewing the analysis the user can also view individual Culvert Summary table, Water Surface Profiles, the Tapered Inlet, as well as a Customized table made up of any of the parameters computed during the analysis.

1.4.1.4 Report Generation

Once a culvert project is completed and analyzed, the option exists for creating a report. A report can be created for just one or multiple crossings. The user can also select from the available fields which data to include in the report and in which order to report them. The report file type is a rich text file (*.rtf) which can be opened in Microsoft Word for editing. The report generation window is divided into the following sections:

1.4.1.5 Choose Crossing(s) to Include

All crossings in the project appear here. The user may select a single, multiple, or all of the crossings to include in the report.

1.4.1.6 Format

Three report types are available. The user may select the default standard report, which includes the results in the figure below. The second report type is Summary, which includes the crossing and culvert summary tables along with the site, tailwater, roadway, and culvert data. Custom is the final report type in which the user designates which topics to include in the report.

'DOCX' is the only available file format available for report generation in HY-8 version 7.70.

The user needs to specify a filename where the generated report will be saved.

1.4.1.7 *Report* Content

This section contains available fields and included fields. The available fields section comprises a list of all possible report topics the user can include in the report. Topics found in the included fields section are what will be displayed in the final report. These fields will appear in the report in the same order they appear here, but they may be moved up or down in the list by selecting the desired topic and clicking on the button describing the direction the user wants the topic to move. To add or remove topics, the user selects the appropriate topic and clicks the right or left arrow button, depending on the desired result.

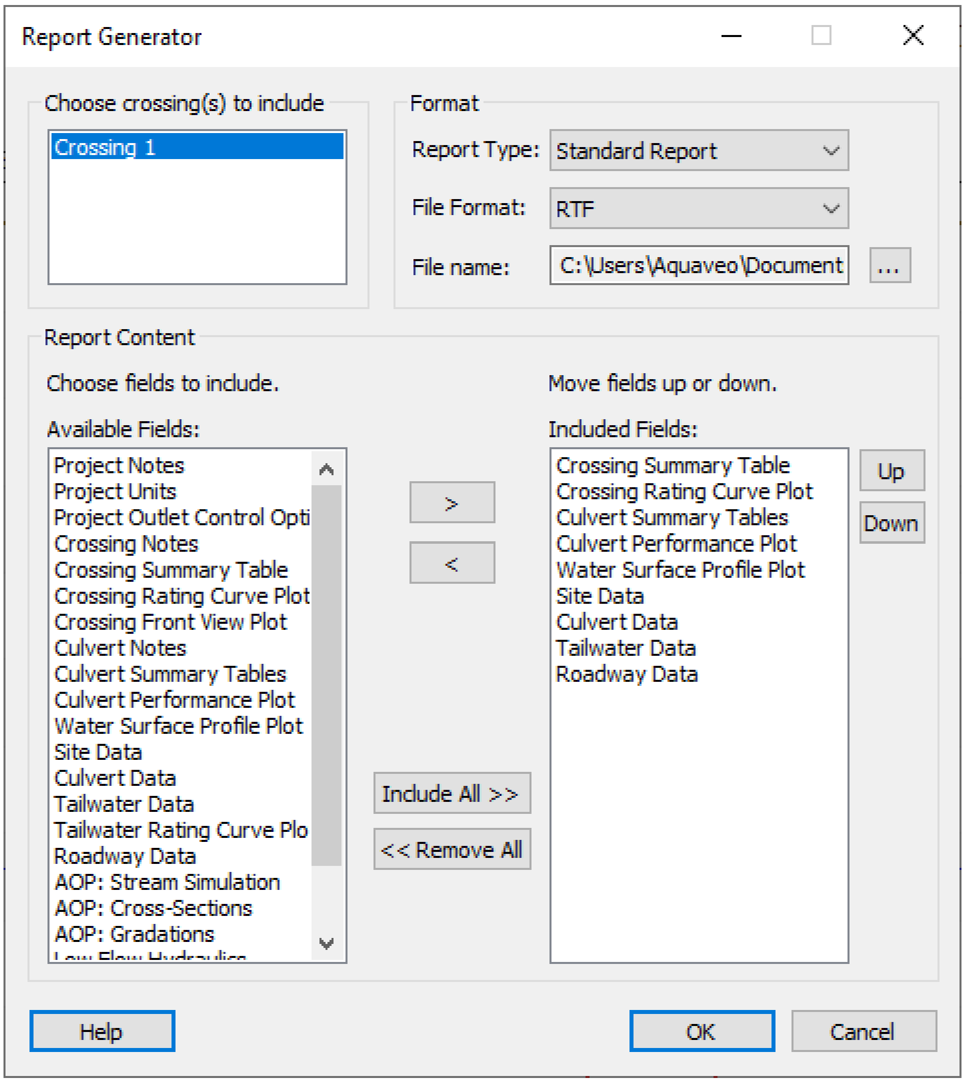


Figure 1.7: Example of the report generator dialog

This is the general work flow of a HY-8 project. The rest of this help file document provides more detailed information about the interface, data input, analysis, and reporting.

1.4.2 Quick Tutorial

HY-8 comes with a document titled HY-8 Quick Start Tutorial. This document is accessible by accessing the help | HY-8 Quick Start Tutorial. The document guides the user to creating a culvert crossing, navigating through the results and creating a report file.

1.5 Limitations

1.5.1 Inlet and Profile Limitations

1.5.1.1 Entrance Limitations

Since HY-8 is not primarily a water surface profile computation program but is a culvert analysis tool, it assumes a pooled condition at the entrance to the culvert.

1.5.2 Vena Contracta Assumptions

In some cases, a *vena contracta* drawdown of the water surface profile could occur in a culvert barrel since the culvert has the potential to act as a sluice gate at the entrance. This drawdown at the entrance is sometimes called a *vena contracta*. The vena contracta is not yet computed for S2 curves, but is computed for horizontal if certain conditions exist on horizontal or adversely sloped culverts. A coefficient that is generalized for circular and box culverts is used to compute the location and depth of the vena contracta for all culvert shapes. For more information on Vena Contracta computations, see below.

1.5.2.1 What is a Vena Contracta

When water is forced through an orifice opening, like a sluice gate, the water continues to decrease in depth as the streamline curves turn to follow the direction of travel. This contraction of depth is called the Vena Contracta.

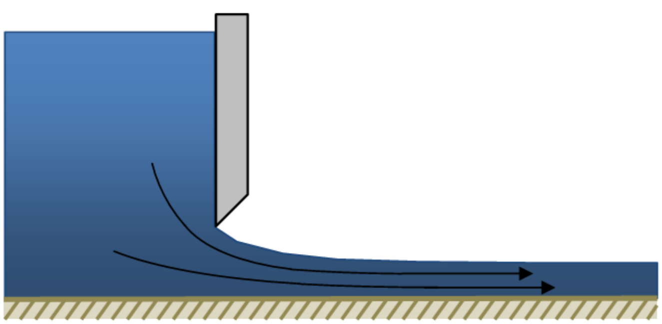


Figure 1.8: Water surface profile diagram flowing through a sluice gate.

1.5.2.2 When and where does it occur in culvert hydraulics?

The Vena Contracta occurs at the inlet of a culvert whenever the inlet control depth is greater than the outlet control depth. These conditions are created when the tailwater is low and the culvert is short.

1.5.2.3 How does HY-8 handle those computations?

HY-8 neglects the Vena Contracta except when the culvert slope is horizontal or adverse under inlet control. HY-8 will use the following equation to determine the length of the Vena Contracta:

$L = 0.5 \times D$ Where:

- L = Vena Contracta Length
- D = Rise of Culvert

HY-8 uses the following equation to determine the final depth of the Vena Contracta: $d_{vc} = c \times y_{inlet}$ Where:

- d_{vc} = Vena Contracta Final Depth
- c = Vena Contracta Coefficient
- y_{inlet} = Headwater Depth or Rise of the Culvert, whichever is smaller

1.5.3 Brink Depth

For culverts with tailwater elevations below the outlet invert of the culvert, water flowing out of the culvert would theoretically pass through a brink depth instead of through critical depth. In this case, HY-8 uses critical depth to determine the final culvert depth and velocity rather than the brink depth.

1.5.4 Culvert Cross Section

HY-8 assumes the culvert cross section shape, size, and material does not change in the barrel except in the case of broken back runout sections, where the user can change the material and Manning's roughness in the runout (lower) culvert section.

1.5.5 Hydraulic Jump Computations

Hydraulic jump computations are supported in HY-8 7.3 and later versions.

1.5.6 Computed Outlet Velocity and Tailwater Elevation

If the tailwater is above the crown at the outlet, the barrel will indeed be full immediately at the outlet. However, that doesn’t mean that the barrel will be in a full flow condition along its entire length. HY-8 determines a water profile using the direct step method in each direction and the sequent depth associated with each of the steps. If the sequent depth associated with the forward profile matches the depth along the backward profile through the culvert, a hydraulic jump occurs and the length of the jump is calculated from that location. Since the lengths of jumps have not been tested for all culvert sizes and slopes, only a limited set of equations are available for computing the lengths of jumps in HY-8. More information on the jump length computations is available in the section of this manual that describes hydraulic jump computations. A water surface profile for this case is shown below.

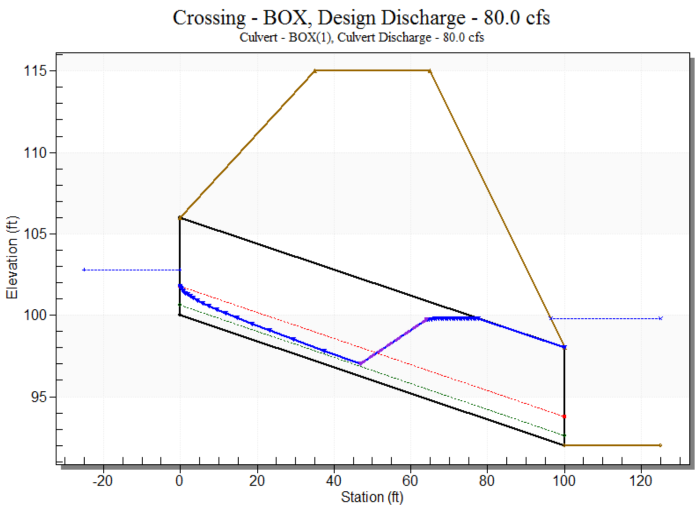


Figure 1.9: Culvert Barrel Side-View Plot with Hydraulic Jump

In this case, the hydraulic jump length computed by HY-8 may or may not be correct since the equation used to compute hydraulic jump length is for box culverts only, but is applied to all the other possible HY-8 culvert shapes. If a hydraulic jump occurs inside the culvert and the end of the hydraulic jump is located outside the culvert, HY-8 assumes the hydraulic jump occurs outside the culvert and a hydraulic jump is not shown in the profile. If both the beginning and end of the hydraulic jump occur inside the culvert barrel, the hydraulic jump is shown in the profile and is reflected in the profile computations, as shown in the image above.

1.5.7 Culvert Types

1.5.7.1 Newly supported culvert types

Previous versions of HY-8 did not fully support CON/SPAN culverts, HDPE culverts, or culverts installed with a natural stream bed as the bottom.

CON/SPAN (Concrete Open-bottom Arch) culvert types are supported in HY-8 7.3 and later; HDPE plastic culvert types are supported in HY-8 version 7.1 and later.

Embedded culverts (i.e. culverts with inverts lowered below the stream channel to retain stream bed soil) are supported in HY-8 version 7.1 and later versions.

1.5.7.2 Inlet control computation limitations for selected shapes

User Defined, Open Bottom Arch, Low-Profile Arch, High-Profile Arch, and Metal Box do not use, and may not have, original research that describes coefficients that can be used for their inlet control equations. Instead, these shapes use an HW/D interpolation table, defined by a chart in HDS-5, that can be used to determine headwater values at various values of Q/AD^0.5.

1.5.7.3 Broken Back Culverts

1.5.7.3.1 Broken back culvert support

Culverts with multiple slopes (broken back) and horizontal/adverse slopes are supported in HY-8 7.3 and later versions.

1.5.7.3.2 Side and slope-tapered inlets

Broken back culverts with side and slope-tapered inlets are not currently supported.

1.5.7.3.3 High-slope sections

The equations for broken back culverts used in HY-8 should not be applied to culvert sections with slopes greater than 55 degrees. These equations are not valid for very steep slopes and will give unrealistic results.

2 Main Interface of HY-8

The main interface consists of 4 components.

- Menus
- Toolbars
- Project Explorer
- Plot Window

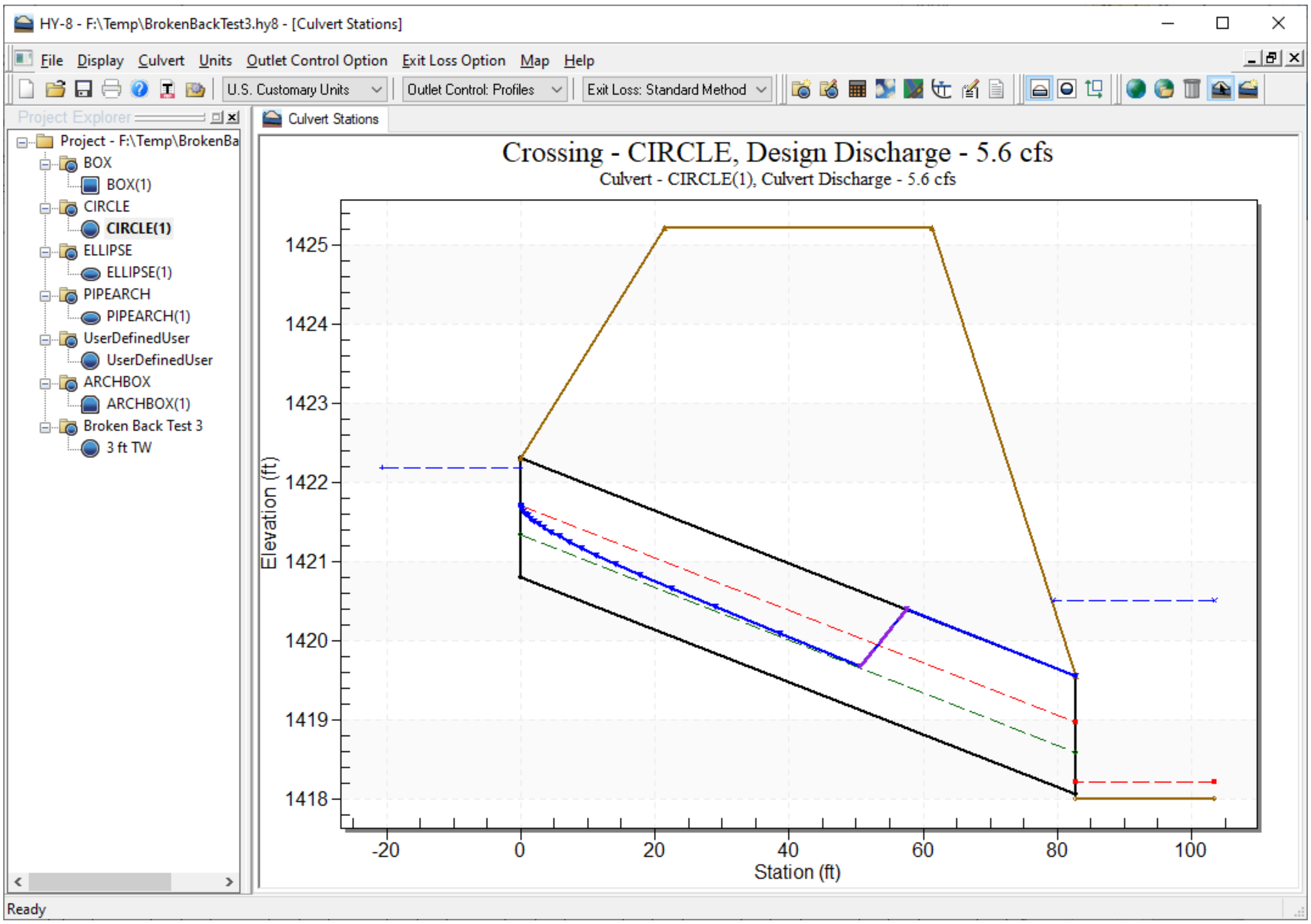


Figure 2.1: HY-8 Main Interface

All of the commands are available on the toolbars are also available in the menus. Many of these commands are also available as right-click menus within the project explorer.

2.1 Menus and Toolbars

The user may navigate to the menus by pressing the ‘alt’ key and then navigate along it through using the arrow keys.

2.1.1 File Menu

The file menu provides the user with commands to manage the culvert crossing data in the project explorer and close the program. The File menu is shown below.

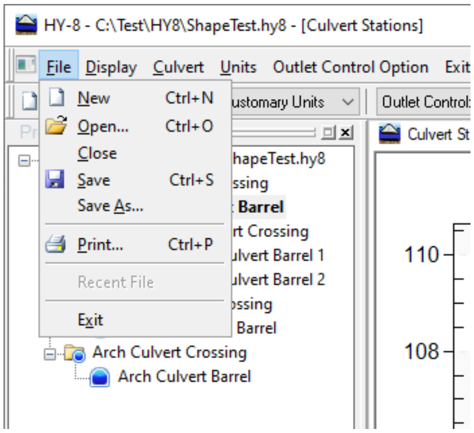


Figure 2.2: File Menu

The File toolbar is shown below.

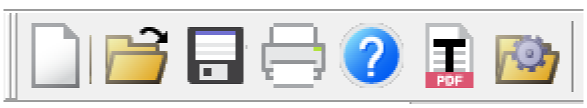


Figure 2.3: File Toolbar. The commands left to right are as follows: New, Open, Save, Print, Quick start Tutorial, and Help.

2.1.1.1 File | New

The 'File | New' command clears all culvert crossings from the project explorer.

2.1.1.2 File | Open

The 'File | Open' command reads culvert crossings from an hy8 file. HY-8 does NOT clear the current culvert crossings from the project explorer as part of this step. This allows the user to combine culvert crossings into one hy8 file.

2.1.1.3 File | Close

The 'File | Close' command closes the HY-8 program.

2.1.1.4 File | Save

The 'File | Save' command will update the current hy8 file, if one has been defined. If there is not an hy8 file defined, than it will call the 'File | Save As' command.

2.1.1.5 File | Save As

The 'File | Save As' command will prompt the user to specify a filename. HY-8 will save the culvert crossings in the project explorer to the specified filename.

2.1.1.6 File | Print…

The 'File | Print…' command will prompt the user to specify print settings for plot showing in the plot window.

2.1.1.7 File | Exit

The ‘File | Exit’ command closes the HY-8 program

2.1.2 Display Menu

The display menu provides the user to control the interface and the views shown in the plot window. The Display menu is shown below.

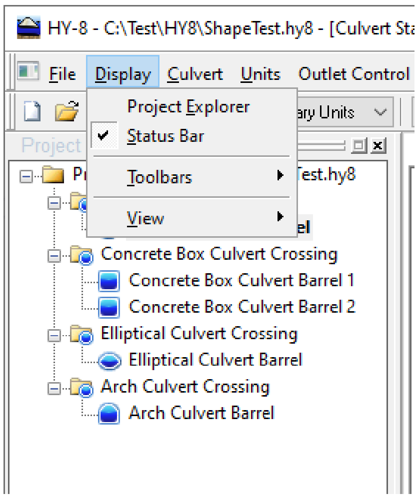


Figure 2.4: Display Menu

The Views Toolbar is shown below.

Figure 2.5: Views Toolbar. The commands left to right are as follows: Side View, Front View, and Plan View.

2.1.2.1 Display | Project Explorer

The ‘Display | Project Explorer’ command will shift the selection to the project explorer.

2.1.2.2 Display | Status Bar

The ‘Display | Status Bar’ command will hide or show the status bar.

2.1.2.3 Display | Toolbars

The ‘Display | Status Bar’ command will provide commands that hide or show the toolbars.

2.1.2.4 Display | View

The ‘Display | View’ command will provide commands that will select the plot view of either side, front, or plan view.

2.1.3 Culvert Menu

The culvert menu provides commands to create, edit, or use the culvert crossing objects and view resulting computations. The Culvert Menu is shown below.

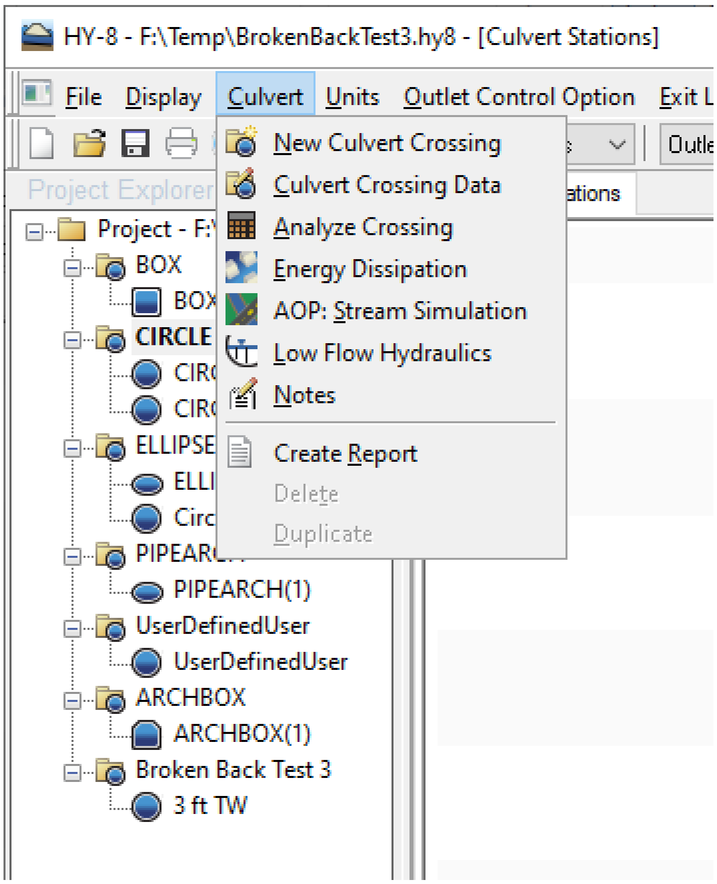


Figure 2.6: The Culvert Menu

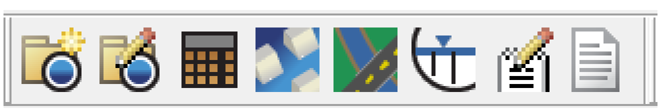


Figure 2.7: Culvert Toolbar. The commands left to right are as follows: New Culvert Crossing, Culvert Crossing Data, Analyze Crossing, Energy Dissipation, AOP: Stream Simulation, Low Flow Hydraulics, Notes, and Create Report.

2.1.3.1 Culvert | New Culvert Crossing

The 'Culvert | New Culvert Crossing' command launches the 'Edit Crossing' dialog with default values. When the user exits the dialog, HY-8 adds the new crossing to the project explorer.

2.1.3.2 Culvert | Culvert Crossing Data

The 'Culvert | Culvert Crossing Data' command launches the 'Edit Crossing' dialog with the values from the selected culvert crossing.

2.1.3.3 Culvert | Analyze Crossing

The ‘Culvert | Analyze Crossing’ command launches the ‘Analyze Crossing’ dialog with the results from the selected culvert crossing.

2.1.3.4 Culvert | Energy Dissipation

The ‘Culvert | Energy Dissipation’ command launches the ‘Energy Dissipation’ dialog with the selected culvert crossing.

2.1.3.5 Culvert | AOP: Stream Simulation

The ‘Culvert | AOP: Stream Simulation’ command launches the ‘AOP Stream Simulation’ dialog with the selected culvert crossing.

2.1.3.6 Culvert | AOP: Low Flow Hydraulics

The ‘Culvert | AOP: Low Flow Hydraulics’ command launches the ‘Low Flow Hydraulics’ dialog with the selected culvert crossing.

2.1.3.7 Culvert | Notes

The ‘Culvert | Notes’ command launches a dialog that allows the user to edit the notes associated with the project (including the project title, designer, date, and notes), the culvert crossing, or culvert barrel, depending on the current selection.

2.1.4 Units Menu

The Units Menu specifies the unit system used to display input and results in HY-8. The menu displays the currently selected units with a checkmark. HY-8 performs all computations in the U.S. Customary Unit System, but displays all units in the selected unit system.

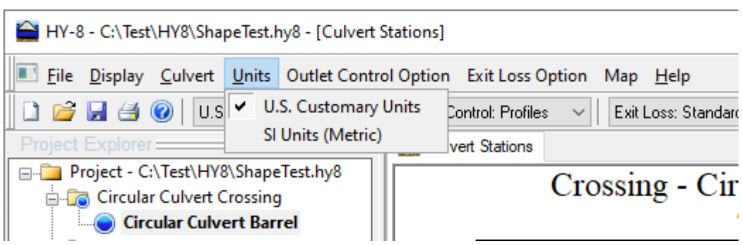


Figure 2.8: The Units Menu

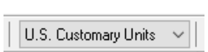


Figure 2.9: The Units Toolbar

2.1.4.1 Units | U.S. Customary Units

The ‘Units | U.S. Customary Units’ command sets HY-8 to use U.S. Customary Units.

2.1.4.2 Units | SI Units (Metric)

The ‘Units | SI Units (Metric)’ command sets HY-8 to use SI Units or the Metric System.

2.1.5 Outlet Control Option Menu

The Outlet Control Option Menu specifies the outlet control option used within HY-8. The menu displays the currently selected option with a checkmark. More detail about the outlet control option is given in the analysis section at Water Surface Profile Option.

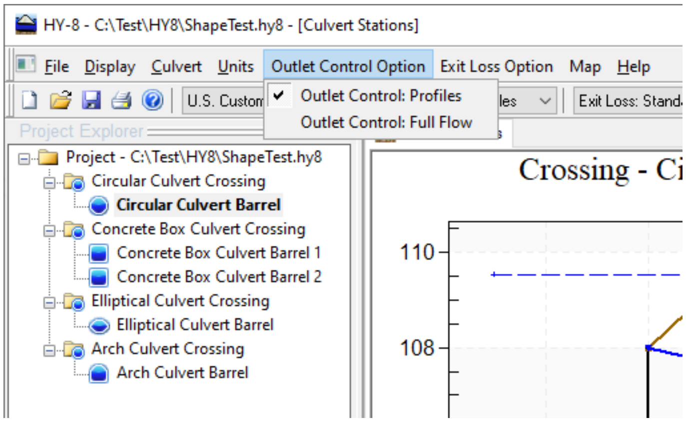


Figure 2.10: The Outlet Control Option Menu

Figure 2.11: The Outlet Control Option Toolbar

2.1.5.1 Outlet Control Option | Outlet Control: Profiles

The 'Outlet Control Option | Outlet Control: Profiles' command sets HY-8 to use the profiles as the outlet control option.

2.1.5.2 Outlet Control Option | Outlet Control: Full Flow

The 'Outlet Control Option | Outlet Control: Full Flow' command sets HY-8 to use full flow as the outlet control option.

2.1.6 Exit Loss Option Menu

The Exit Loss Option Menu specifies the exit loss used within HY-8. The menu displays the currently selected option with a checkmark. More detail about the exit loss option is given in the analysis section at Exit Loss Options.

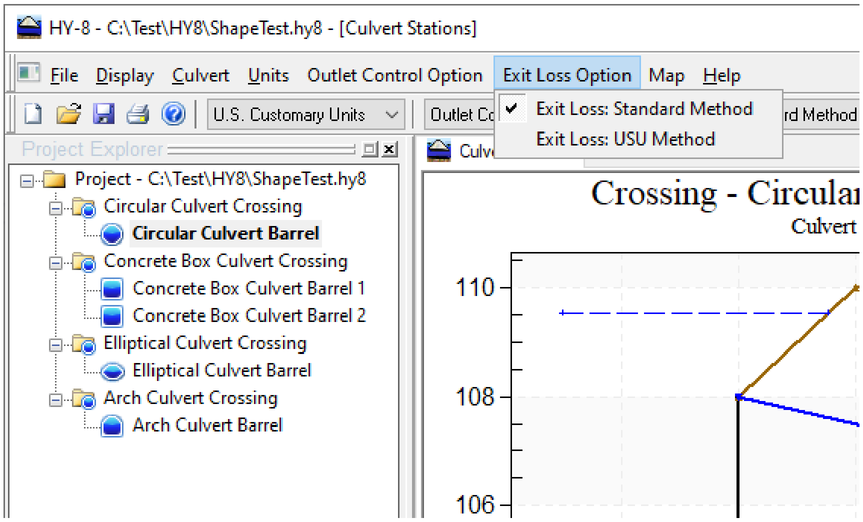


Figure 2.12: The Exit Loss Option Menu

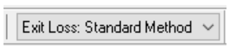


Figure 2.13: The Exit Loss Option Toolbar

2.1.6.1 Exit Loss Option | Exit Loss Option: Standard

The 'Exit Loss Option | Outlet Control: Profiles' command sets HY-8 to use the profiles as the outlet control option.

2.1.6.2 Exit Loss Option | Exit Loss Option: USU

The 'Exit Loss Option | Outlet Control: Full Flow' command sets HY-8 to use full flow as the outlet control option.

2.1.7 Map Menu

The Map Menu loads maps for project display and organization in HY-8. More information is in 2.3 Plot and Map View

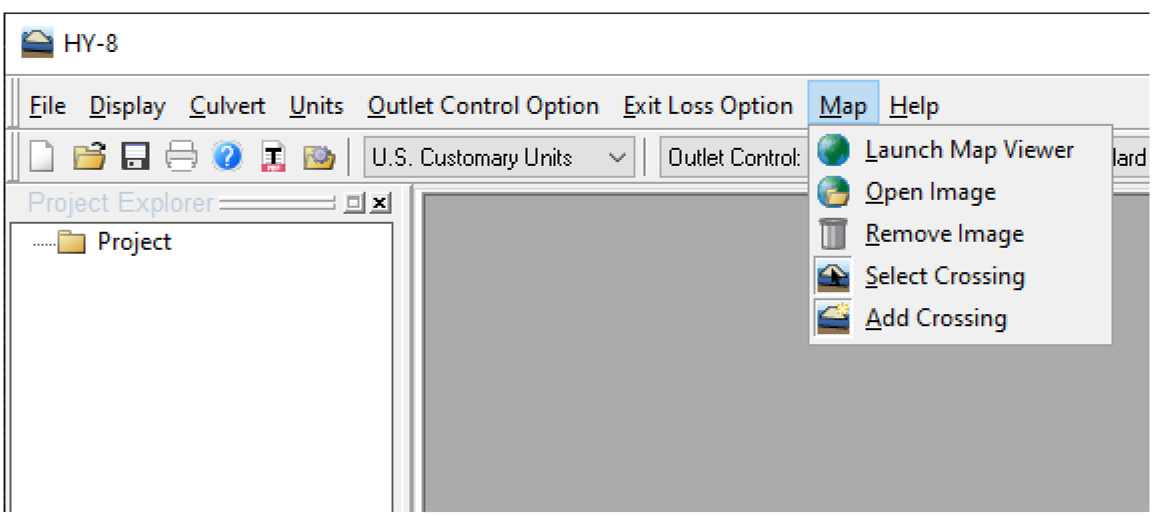


Figure 2.14: The Map Tools Menu

Figure 2.15: The Map Tools Toolbar

2.1.7.1 Map | Launch Map Viewer

The 'Map | Launch Map Viewer' command launches Virtual Earth Map Locator which allows the user to pan and zoom on a virtual map. You should orient the map viewer to show the project area. Note that the size of the virtual Earth map viewer will affect the size of the image in the HY-8. When you click OK, the image will then load in the graphics window.

2.1.7.2 Map | Open Image

The 'Map | Open Image' command launches a window to specify an image file to be used as a project map.

2.1.7.3 Map | Remove Image

The 'Map | Remove Image' command removes the current image from the graphics window.

2.1.7.4 Map | Select Crossing

The 'Map | Select Crossing' command allows you to select and move crossings in the graphics window. The right-click menu will allow the user to edit or delete the crossing.

2.1.7.5 Map | Add Crossing

The 'Map | Add Crossing' command will launch the 'Edit Crossing' dialog when you click in the graphics window. When the crossing has been defined and you click OK, HY-8 will place a mark on the location clicked with the crossing name.

2.1.8 Help Menu

The Help Menu provides commands for assistance in using HY-8 or provide reference for the computations used. The Help menu is shown below.

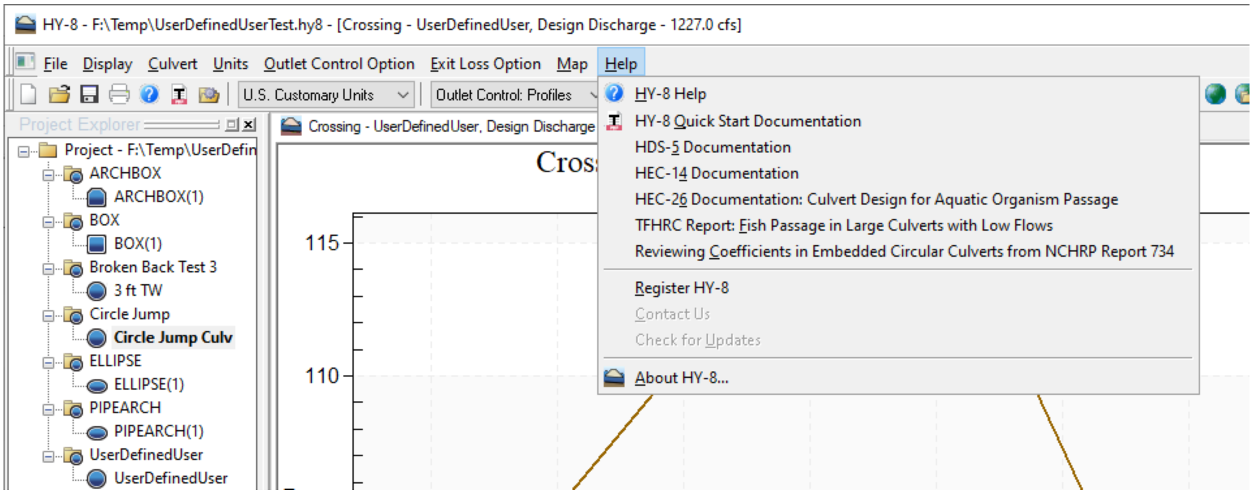


Figure 2.16: The Culvert Menu

2.1.8.1 Help | HY-8 Help

The ‘Help | HY-8 Help’ command launches the ‘HY-8 User’s Manual’.

2.1.8.2 Help | HDS-5 Documentation

The ‘Help | HDS-5 Documentation’ command launches the ‘Hydraulic Design Series: 5, Hydraulic Design of Highway Culverts, Third Edition’ publication. This document describes the procedure to design and analyze a culvert crossing. The computational methods described in this document describe the methods used by HY-8 to compute basic hydraulic results of a culvert crossing. The publication is also available from the following link:
https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=7&id=13

2.1.8.3 Help | HY-8 Quick Start Documentation

The ‘Help | HY-8 Quick Start Documentation’ command launches the ‘HY-8 Quick Tutorial’ Document. This tutorial guides the user through creating a culvert crossing, viewing the results, and creating a report.

2.1.8.4 Help | HEC-14

The ‘Help | HDS-5 Documentation’ command launches the ‘Hydraulic Engineering Circular: 14, Hydraulic Design of Energy Dissipators for Culverts and Channels’ publication. This document describes the procedure to design and analyze energy dissipators. The energy dissipator design module of HY-8 uses these methods. The publication is also available from the following link:

https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=13&id=129

2.1.8.5 Help | HEC-26 Culvert Design for Aquatic Organism Passage

The ‘Help | HEC-26 Culvert Design for Aquatic Organism Passage’ command launches the ‘Hydraulic Engineering Circular: 26, Culvert Design for Aquatic Organism Passage’ publication. This document describes the procedures to design and analyze culverts for Aquatic Organism Passage. The AOP : Stream Simulation module in HY-8 uses these methods. The publication is also available from the following link:
https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=204&id=145

2.1.8.6 Help | TFHRC Report – Fish Passage in Large Culverts with Low Flows

The ‘Help | TFHRC Report – Fish Passage in Large Culverts with Low Flows’ command launches the ‘Turner-Fairbank Highway Research Center Report on Fish Passage in Large Culverts with Low Flows’ publication. This document describes the procedures to determine hydraulic qualities, particularly velocity and depth, of lows flows in a large culvert. The Low Flow module in HY-8 uses these methods. The publication is also available from the following link:
https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/14064/14064.pdf

2.1.8.7 Help | Register HY-8

The ‘Help | Register HY-8’ command will bring up a website hosted by Aquaveo to record your registration information. It includes options to receive updates about HY-8 and another to receive updates about products related to HY-8.

2.1.8.8 Help | Register HY-8

The ‘Help | Register HY-8’ command will bring up a website hosted by Aquaveo to record your registration information. There are options included to receive updates about HY-8 and another to receive updates about products related to HY-8.

2.1.8.9 Help | About HY-8

The ‘Help | About HY-8’ command launches the About dialog. This dialog provides information about HY-8, including the version of the HY-8 that is running and when it was built.

2.2 Project Explorer

The project explorer displays the culvert crossings within HY-8 under a project folder. Each folder item can be collapsed or expanded.

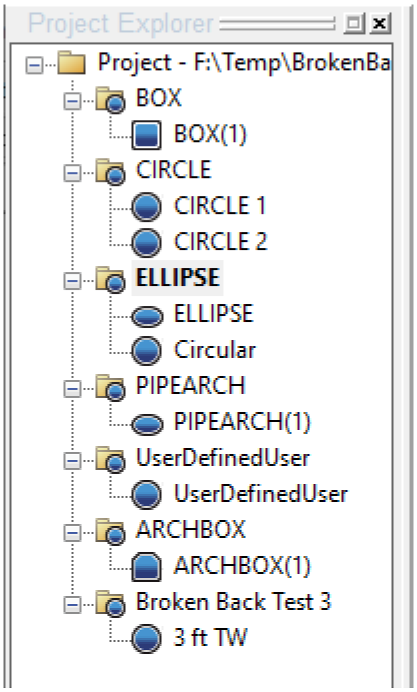


Figure 2.17: Project Explorer

2.2.1 Project Folder

Everything is contained in the project folder. Selecting the project folder and editing the notes allows the user to set the Project Notes, including the project title, designer, date, and notes.

2.2.2 Culvert Crossing

Crossings are shown as a folder with a culvert icon. The crossing can have up to 6 culvert barrels assigned to the crossing. The culvert barrel icons vary according to the selected shape. Culvert crossings and culvert barrels can be interacted with directly in the project explorer by renaming, duplicating, or deleting them. Additionally, you can edit the notes associated with a culvert crossing or culvert barrel.

2.3 Plot and Map View

There are three views available for the plot and map view.

- Side View
- Front View
- Map View

2.3.1 Side View

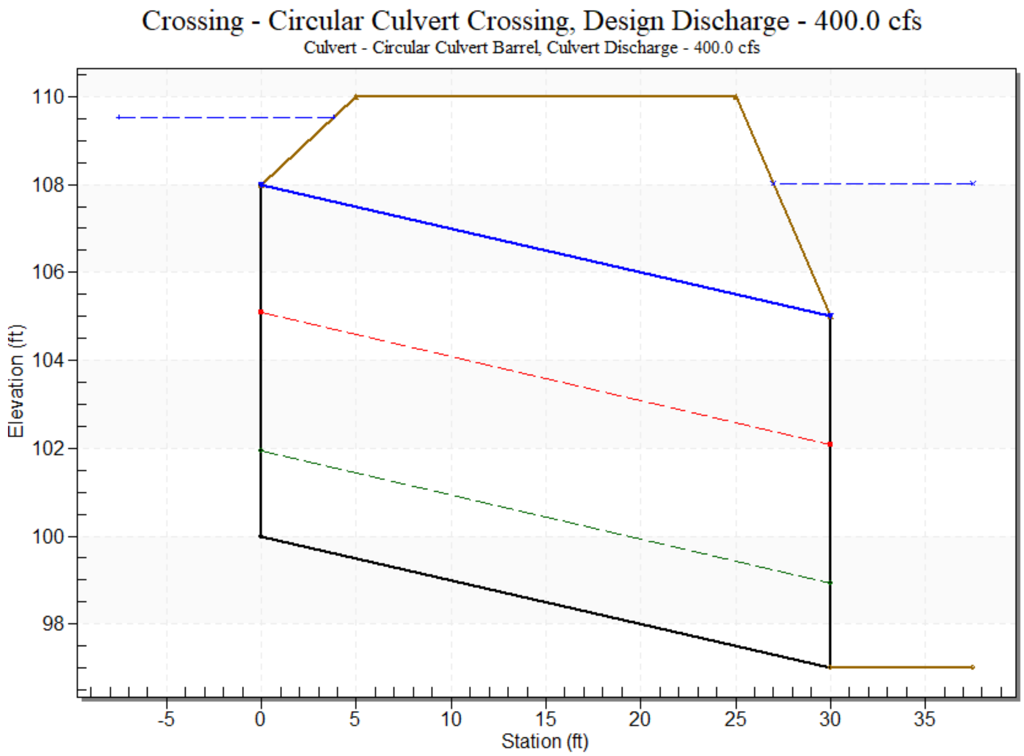


Figure 2.18: Culvert barrel plotted in side-view

The side view displays a single culvert barrel sliced lengthwise. The discharge that applies to the plot is given in the title of the plot. The plot will show the embankment and tailwater invert elevation in brown, the culvert barrel in black, the critical depth in a dashed red line, the normal depth in a dashed green line, the water surface profile in solid blue, the headwater surface elevation in dashed blue and the tailwater surface elevation in dashed blue.

It is important to note that HY-8 plots only one elevation for the roadway elevation. If an irregular roadway is plotted, the culvert may overtop before the headwater line is above the roadway line.

2.3.2 Front View

The front view will display the culvert crossing with the culvert shapes plotted, the roadway, and the headwater elevation. The culvert barrels are plotted in black, the roadway embankment is plotted brown, and the headwater elevation is plotted in a dashed, blue line. If a culvert is selected, that culvert will be plotted in red.

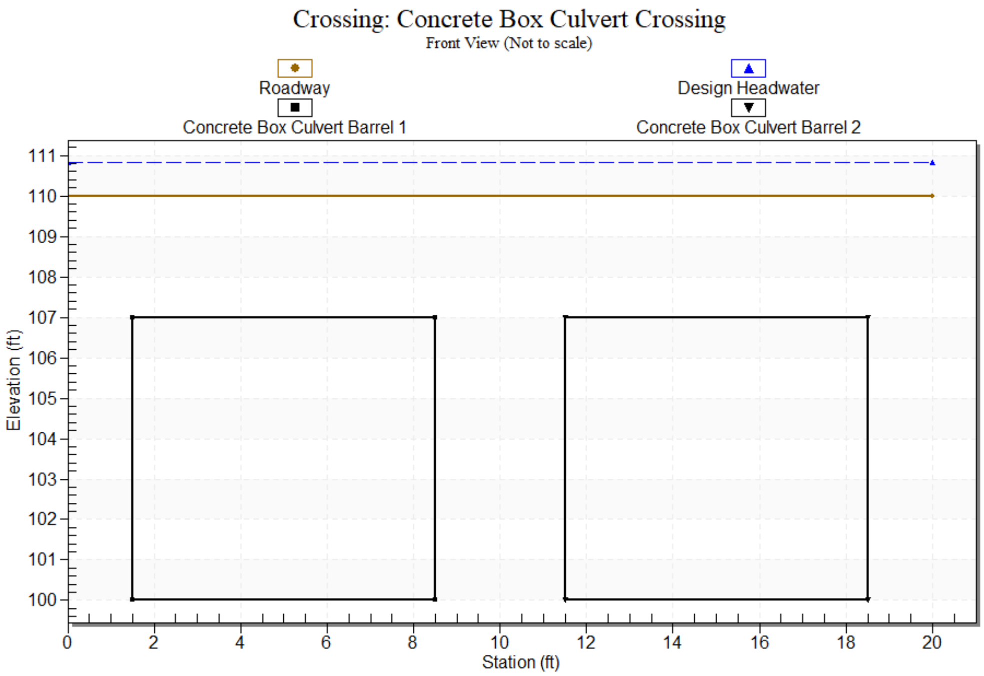


Figure 2.19: Front View of a Culvert Crossing plotted by HY-8

For the culvert crossing to be plotted, the lateral culvert stations need to be defined. Before these stations are defined, HY-8 displays the following message:

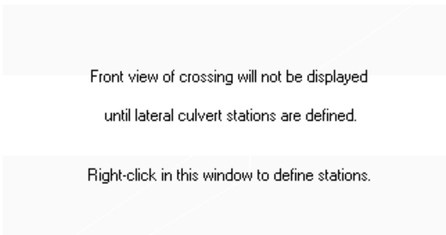


Figure 2.20: Error message for plotting culvert crossing in front view without lateral culvert stations

The lateral culvert stations are not part of the hydraulic calculations. The front view of the culvert crossing is generated to verify user input, not as a hydraulic input or result.

2.3.3 Plan View

The Plan view gives geographic context to the culvert crossing. It can be generated using the map viewer tool. The user can locate the culvert crossing on a map with an X mark as shown in the figure below. More information is available in the 2.1.7 Map Menu section.

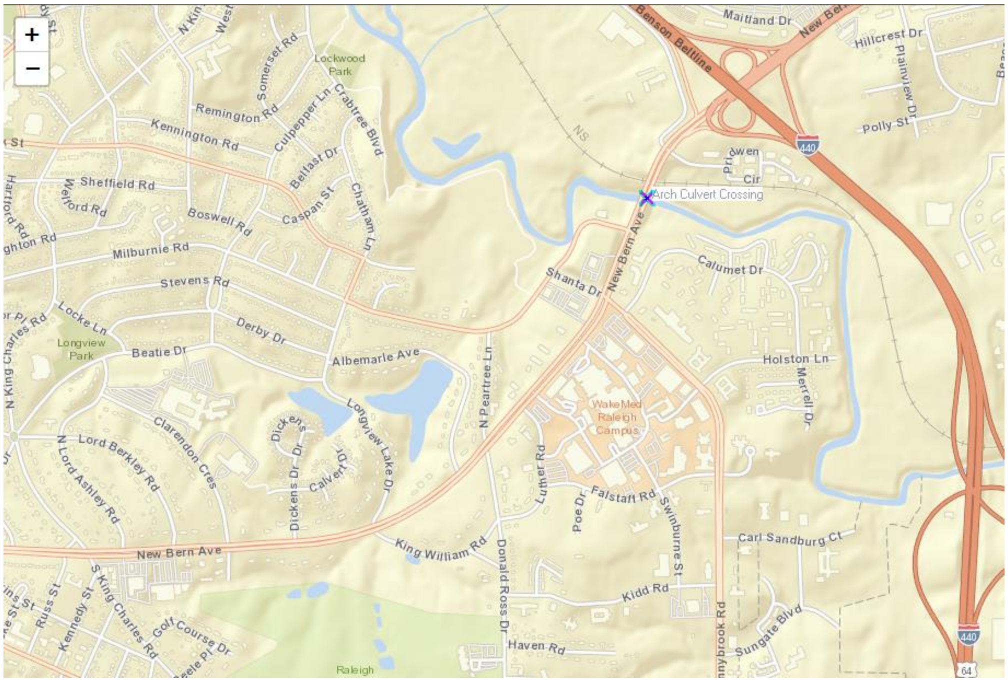


Figure 2.21: Plan view, or map view with a culvert crossing mark added

3 Crossing Data

The culvert crossing contains a collection of culverts. A crossing may consist of single or multiple culverts, and each culvert can be defined with multiple barrels. A project may contain multiple crossings, as seen in Figure 1, and each crossing may contain one or multiple culverts (Figure 2).

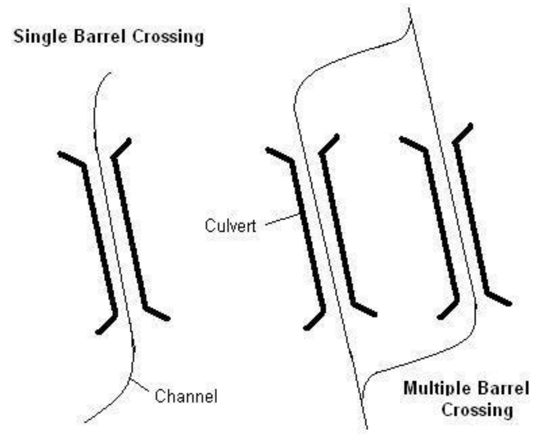


Figure 3.1: Plan view of a single culvert barrel crossing and multiple culvert barrel crossing

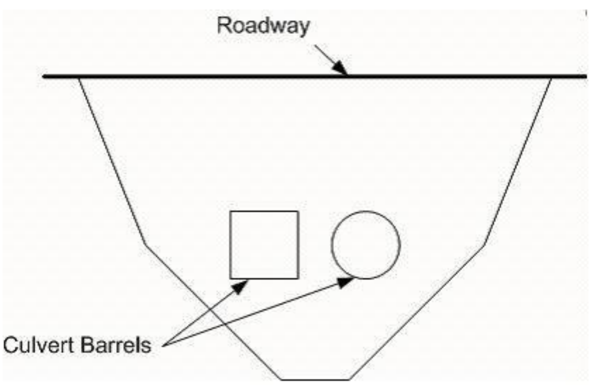


Figure 3.2: Front view of multiple culvert barrels in a culvert crossing

3.1 Discharge Data

HY-8 provides three options to enter discharge data: "Minimum, Design, and Maximum", "User-Defined", and "Recurrence". The "Minimum, Design, and Maximum" is the default option and historically was the only option available.

3.1.1.1 Minimum, Design, and Maximum

HY-8 will perform culvert crossing hydraulic calculations based on the input minimum, design, and maximum discharge values. Calculations comprising the performance curve are made for ten equal discharge intervals between the minimum and maximum values. A user may input a narrower range of discharges in order to examine crossing performance for a discharge interval of special interest.

3.1.1.1.1 Minimum Discharge

Lower limit used for the crossing performance curve. Can be edited to a number greater than '0'.

3.1.1.1.2 Design Discharge

This option designs discharge for the crossing. It is always included as one of the points on the performance curve.

3.1.1.1.3 Maximum Discharge

Upper limit used for the crossing performance curve.

3.1.1.2 User-Defined

The user first specifies the number of flows they wish to enter. The user then enters the flows in ascending order (smallest flows at the top, highest at the bottom). The user can assign a name to a flow if desired. If no name is given the name column will not be shown in the results or report.

3.1.1.3 Recurrence

The user specifies the flow next to the recurrence year. The user does not need to enter all the years in the table and any flows that are left at zero will not show up in the results or report.

3.2 Tailwater Data

3.2.1 Tailwater Data

HY-8 provides the following options for calculating the tailwater rating curve downstream from a culvert crossing:

- Channel Shape
- Rating Curve
- Constant Tailwater Elevation
- Irregular Channel

HY-8 uses normal depth to represent tailwater elevations for both a defined channel shape and an irregular channel. The cross section representing these two options should be located downstream from the culvert where normal flow is assumed to occur (downstream from channel transitions, for example). The calculated water surface elevations are assumed to apply at the culvert outlet.

3.2.2 Channel Shape

There are three available channel shapes to define the downstream tailwater channel: rectangular, trapezoidal, and triangular. When selecting a channel shape the input window adjusts to display only those parameters required for the defined shape. When defining a channel shape, the analysis requires the following channel properties:

- Bottom Width — Width of channel at downstream section, shown in drawing below.
- Side Slope (H:V) (_:1) — This item applies only for trapezoidal and triangular channels. The user defines the ratio of Horizontal/Vertical by entering the number of horizontal units for one unit of vertical change.
- Channel Slope — Slope of channel in m/m or ft/ft. If a zero slope is entered, an error message appears upon exiting the input data window. The user must enter a slope greater than zero before the crossing may be analyzed.
- Manning's *n* — User defined MANNING'S roughness coefficient for the channel.
- Channel Invert Elevation — User must enter elevation. Program will show actual barrel #1 outlet invert elevation.

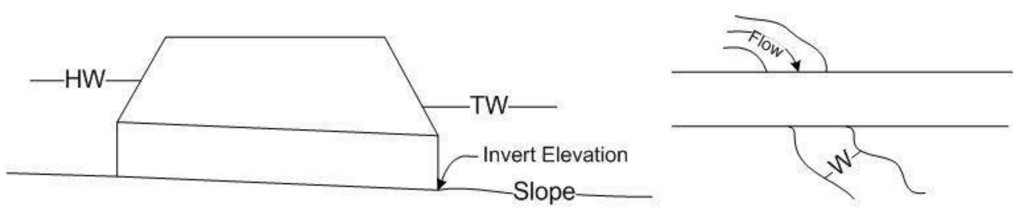


Figure 3.3: Definition sketch for tailwater input to HY-8.

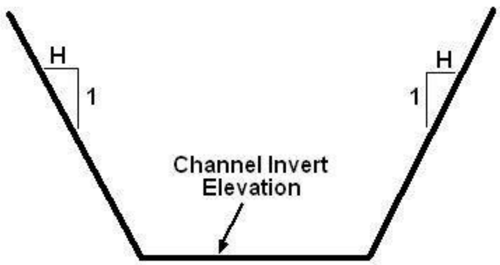
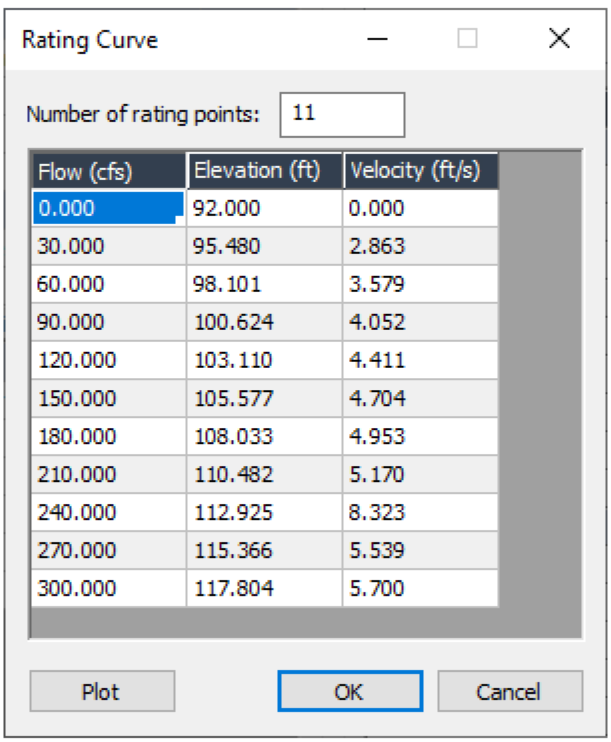


Figure 3.4: Definition sketch for tailwater input in cross section for HY-8

3.2.3 Rating Curve

The rating curve option represents flow rate versus tailwater elevation for the downstream channel. When the *Enter Rating Curve* option is selected, the user will receive a prompt to define 11 increasing flow and elevation values, as shown below. This option requires a channel invert elevation (generally the same as the downstream invert of the culvert) so that a tailwater depth can be computed from the rating curve.



Flow (cfs)	Elevation (ft)	Velocity (ft/s)
0.000	92.000	0.000
30.000	95.480	2.863
60.000	98.101	3.579
90.000	100.624	4.052
120.000	103.110	4.411
150.000	105.577	4.704
180.000	108.033	4.953
210.000	110.482	5.170
240.000	112.925	8.323
270.000	115.366	5.539
300.000	117.804	5.700

Figure 3.5: Rating Curve Dialog

3.2.4 Constant Tailwater Elevation

A constant tailwater elevation means that the tailwater elevation entered remains constant for all flows. This option requires a channel invert elevation (generally the same as the downstream invert of the culvert) so that a tailwater depth can be computed. A constant tailwater elevation may represent, for example, the design elevation of a lake, bay, or estuary into which the culvert(s) discharge.

3.2.5 Irregular Channel

An irregular channel cross section option defines a channel using the channel slope and the station, elevation, and Manning's *n* at each input coordinate point. The number of coordinates allowed is unlimited, but using more coordinates will take longer to compute the results. All coordinates and n values may be copied from Microsoft Excel and pasted into the table. After all data have been entered, the user can plot and view the channel cross section looking downstream.

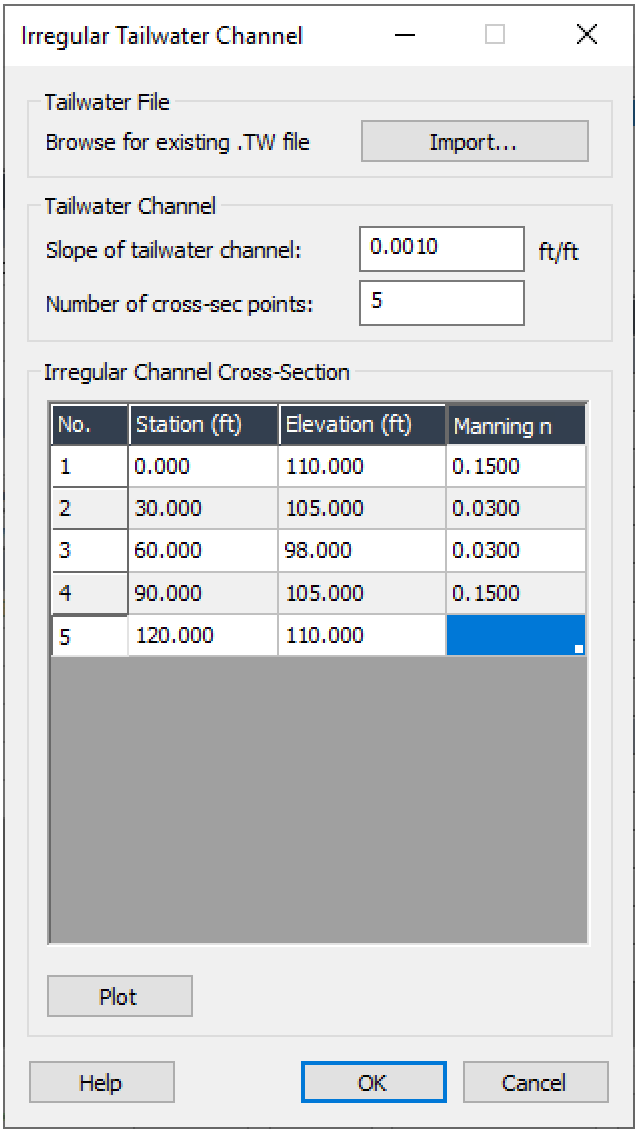


Figure 3.6: Irregular Channel Tailwater Editor

Manning's *n* is defined as shown in the figure below. An *n* value is assigned for each segment of the cross section beginning at the left (looking downstream) coordinate (below). If the *n* value is the same throughout the cross section, the user may copy the *n* value be dragging the value from the first cell.

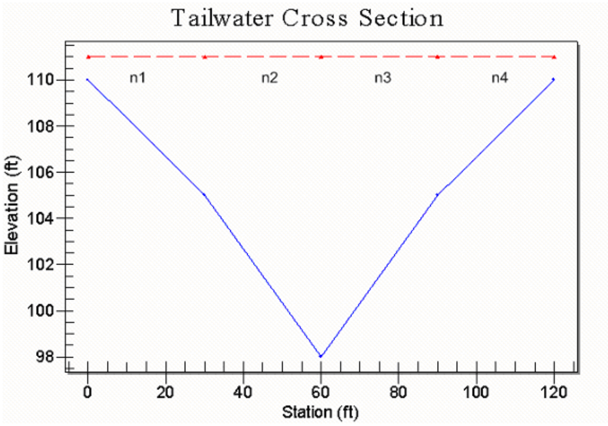


Figure 3.7: Tailwater cross section plot

3.2.6 Irregular Channel Error

When the capacity of an irregular channel is not sufficient to convey the range of discharges, version 6.1 of HY-8 "spilled" excess water into an infinitely wide floodplain (see drawing below). The rating curve shows a constant-tailwater elevation, cross-section velocity and computed shear stress for all discharges exceeding the channel capacity.

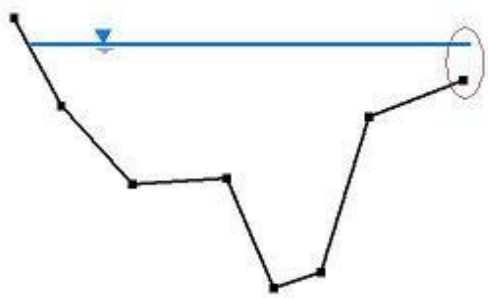


Figure 3.8: Irregular channel in cross section with flow greater than channel can convey

HY-8 does not use the "spill" concept. If the irregular cross section cannot convey the range of discharges entered by the user, the application displays the following error message: "Irregular tailwater channel is not big enough to convey flow."

The user has two options to correct this error. The first option is to enter additional data points for the purpose of extending the cross section horizontally and vertically based on field surveys or best judgment. This option could be used to simulate the "spill" concept of HY-8 by simulating a very wide floodplain with extended channel points. A second option is to create vertical walls to trap the flow so the depth of flow increases.

3.3 Roadway Data

3.3.1 Roadway Data

When defining the roadway data for the crossing, HY-8 requires the following parameters:

- Roadway Profile
- Roadway Station
- Crest Length
- Crest Elevation
- Roadway Surface
- Top Width

The roadway elevation can be either a constant or vary with station. The user may define an initial roadway station or use the default of 0.0. The stationing is used to position culverts along the length of the roadway profile when choosing the *Front View* option.

The roadway surface may be paved or gravel, or an overtopping discharge coefficient in the weir equation may be entered. The user may select a paved roadway surface or a gravel roadway surface from which the program uses a default weir coefficient value. If input discharge coefficient is selected, the user will enter a discharge coefficient between 2.5 and 3.095.

The values entered for the crest length and top width of the roadway have no effect on the hydraulic computations unless overtopping occurs.

3.3.2 Roadway Profile

There are two options available when defining the roadway profile: constant elevation and irregular. With the constant roadway elevation option selected, the user receives a prompt to enter values for the crest length and elevation of the roadway, shown in the figure below. While not necessary for culvert hydraulic calculations, the beginning station of the roadway is also entered (the default is 0.0 and does not need to be changed if the user does not know the station or does not wish to enter it). By defining the beginning station, culverts can be located laterally and displayed in proper relationship to the roadway in the front view. When the irregular profile shape is selected, the user receives a prompt to enter between 3 and 15 points defining the station and elevation of each point along the roadway profile. The user receives a prompt to enter a beginning station for the roadway when viewing the culvert from the front using the *Views* toolbar.

Figure 3.9: Definition sketch for the roadway data in HY-8

The length for a horizontal roadway is somewhat arbitrary but should reflect the top width of the water surface in the channel upstream from the culvert at the roadway elevation. Roadway width includes the shoulders, traffic lanes, and median.

4 Culvert Data

Culvert data are entered by selecting the **Input Properties** option from the *Culvert* menu, or by right-clicking on the culvert in the *Project Explorer* window and selecting **Input Properties**. The following culvert data are required:

- Shapes
- Material (Manning's n)
- Size
- Culvert Profile and Taper Type
- Inlet Configurations
- Inlet Depression

The use can enter the site data for each culvert in the culvert data portion of the *culvert properties* window. The user has the option of entering culvert invert data or embankment toe data.

4.1 Shapes

HY-8 will perform hydraulic computations for the following culvert shapes (see Figure 4.1):

- Circular Pipe
- Box
- Elliptical long axis horizontal
- Pipe-Arch
- Arch
- Low-Profile Arch
- High-Profile Arch
- Metal Box
- Concrete Open Bottom Arch
- South Dakota Concrete Box
- User Defined

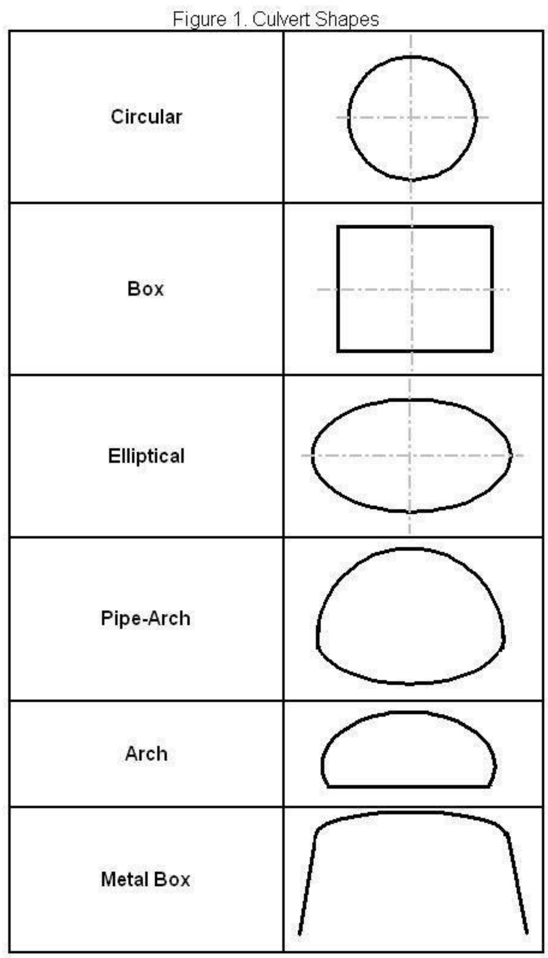


Figure 4.1: Culvert barrel shapes available in HY-8

4.1.1 Concrete Open Bottom Arch

HY-8 Version 7.3 and later has coefficients for computing inlet control depths for concrete open-bottom arch (commonly called Con/Span) culverts.

4.1.1.1 Geometric Characteristics

Con/Span culverts have unique geometric configurations, sizes, and shapes. The exact coordinates used in HY-8 to compute areas and other geometric cross section parameters are available in this document. Since the culverts can be made to accommodate any required rise for a given span. HY-8 contains culvert geometry in 3 inch increments of rise.

4.1.2 Inlet Control Polynomial Coefficients

The selection of the culvert shape and inlet edge type determines the polynomial coefficients that will be used in computations.

For information on the exact coefficients used and to view diagrams showing the different culvert wingwall configurations, see the see Appendix A. To see more information on how the polynomial coefficients are used, see Fifth Degree Polynomial Equation.

4.1.3 South Dakota Concrete Box

HY-8 Version 7.3 and later has coefficients for computing inlet control depths using research contained in FHWA Publication No. FHWA-HRT-06-138, October 2006: **Effects of Inlet Geometry on Hydraulic Performance of Box Culverts**.

4.1.3.1 Overview and implementation

The document "Effects of Inlet Geometry on Hydraulic Performance of Box Culverts" (FHWA Publication No. FHWA-HRT-06-138, October 2006) describes a series of tests that were performed to obtain design coefficients for various inlet configurations on reinforced concrete box culverts. The tests covered the following variations in inlet configurations: wingwall and top edge bevels and corner fillets, multiple barrels, different culvert span-to-rise ratios, and skewed headwalls. The results of the tests were K, M, c, and Y inlet control design coefficients and 5th degree polynomial coefficients (required by HY-8) that were given in the FHWA document. The 5th degree polynomial coefficients given in the FHWA document cannot be used directly in HY-8 because the coefficients were only developed for a HW/D range between 0.5 and 2.0. HY-8 requires the polynomial coefficients to be valid between HW/D values of 0.5 and 3.0. Therefore, the polynomial coefficients had to be re-computed using the K, M, c, and Y coefficients from the FHWA report.

The end of the FHWA document makes several recommendations. Since the recommendations were a consolidation of the FHWA research, HY-8 uses these recommendations. The recommendations consolidated the results of the South Dakota box culvert testing into 13 different sets of coefficients, called "Sketches", which represent different inlet conditions. The HY-8 developers further consolidated the results into 10 sets of inlet configurations that were added as a "South Dakota Concrete Box Culvert" type in HY-8.

For information on the exact coefficients used and to view diagrams showing the different culvert configurations that were implemented in HY-8, see the help describing the South Dakota Concrete Box.

4.2 Material

The following culvert materials are available:

- Corrugated Steel
- Steel Structural Plate
- Corrugated Aluminum
- Aluminum Structural Plate
- Reinforced Concrete
- PVC
- Smooth HDPE
- Corrugated PE

Each culvert type has only certain culvert materials available. HY-8 assigns a default Manning's 'n' value for the selected material, but this value can be changed if desired. For more information on the plastic pipes (PVC, HDPE, and PE) please see Plastic Pipe Materials.

4.2.1 Plastic Pipe Materials

HY-8 7.1 has been updated to incorporate different types of plastic pipes. The following types of plastic pipes and their associated inlet configurations have been added to HY-8 7.1:

1. PVC
    a. Manning's n (From HDS-5): 0.009-0.011 (use 0.011)
    b. Inlet Configurations:
        i. Square Edge with Headwall
            1. Notes:
                a. Use HY8 Equation Number 9
                b. HDS5 Chart Number 1-1
                c. Equation for Concrete Pipe Square Edge with Headwall
        ii. Beveled Edge (1:1)
            1. Notes:
                a. Use HY8 Equation Number 6
                b. HDS5 Chart Number 3-A
                c. Equation for Circular pipe culvert with beveled edge (1:1)
        iii. Beveled Edge (1.5:1)
            1. Notes:
                a. Use HY8 Equation Number 7
                b. HDS5 Chart Number 3-B
                c. Equation for Circular pipe culvert with beveled edge (1.5:1)
        iv. Mitered to Conform to Slope
            1. Notes:
                a. Use HY8 Equation Number 2
                b. HDS5 Chart Number 2-2
                c. Equation for Corrugated Metal pipe culvert, Mitered to conform to slope
2. Smooth HDPE
    a. Manning's n (From HDS-5): 0.009-0.015 (use 0.012)
    b. Inlet Configurations:
        i. Square Edge with Headwall
            1. Notes:
                a. Use HY8 Equation Number 9
                b. HDS5 Chart Number 1-1
                c. Equation for Concrete Pipe Square Edge with Headwall
        ii. Beveled Edge (1:1)
            1. Notes:
                a. Use HY8 Equation Number 6
                b. HDS5 Chart Number 3-A
                c. Equation for Circular pipe culvert with beveled edge (1:1)
        iii. Beveled Edge (1.5:1)

1. Notes:
    a. Use HY8 Equation Number 7
    b. HDS5 Chart Number 3-B
    c. Equation for Circular pipe culvert with beveled edge (1.5:1)

iv. Thin Edge Projecting
1. Notes:
    a. Use HY8 Equation Number 1
    b. HDS5 Chart Number 2-3
    c. Equation for Corrugated Metal pipe culvert, Thin edge projecting

v. Mitered to Conform to Slope
1. Notes:
    a. Use HY8 Equation Number 2
    b. HDS5 Chart Number 2-2
    c. Equation for Corrugated Metal pipe culvert, Mitered to conform to slope

3. Corrugated PE
    a. Manning's n (From HDS-5): 0.009-0.015 (use 0.024)
    b. Inlet Configurations:
        i. Square Edge with Headwall
            1. Notes:
                a. Use HY8 Equation Number 3
                b. HDS5 Chart Number 2-1
                c. Equation for Corrugated Metal pipe culvert with Headwall
        ii. Beveled Edge (1:1)
            1. Notes:
                a. Use HY8 Equation Number 6
                b. HDS5 Chart Number 3-A
                c. Equation for Circular pipe culvert with beveled edge (1:1)
        iii. Beveled Edge (1.5:1)
            1. Notes:
                a. Use HY8 Equation Number 7
                b. HDS5 Chart Number 3-B
                c. Equation for Circular pipe culvert with beveled edge (1.5:1)
        iv. Thin Edge Projecting
            1. Notes:
                a. Use HY8 Equation Number 1
                b. HDS5 Chart Number 2-3
                c. Equation for Corrugated Metal pipe culvert, Thin edge projecting
        v. Mitered to Conform to Slope
            1. Notes:
                a. Use HY8 Equation Number 2
                b. HDS5 Chart Number 2-2
                c. Equation for Corrugated Metal pipe culvert, Mitered to conform to slope

4.3 Culvert Profile and Taper Type

Five culvert types are supported in HY-8:

- Straight
- Side Tapered
- Slope Tapered
- Single Broken Back Culverts
- Double Broken Back Culverts

4.3.1 Straight

Straight inlets contain no special or additional modification made by the manufacturer or when constructed in the field. Straight inlets for corrugated metal pipes (CMP) include thin edge projecting, pipes mitered to conform to the fill slope, or pipes with a headwall. Straight inlets for concrete pipes and boxes include the standard groove-end section (pipe only), and inlets with a headwall and/or wingwall. Flared end sections fit to either CMP or concrete are also considered straight inlets. Since beveling the entrance is so common, a beveled entrance appears on the straight inlet menu for HY-8.

4.3.2 Side Tapered

The available side tapered option allows for circular or box culverts and is shown below. A side-tapered inlet provides a more efficient inlet control section to increase culvert performance. A side-tapered, circular inlet has an enlarged elliptical face section with a transition (taper) to the circular culvert barrel. The side-tapered dimensions are entered as follows:

- **Face Width** – width of enlarged face section, denoted Wf in the drawing below.
- **Side Taper** – (4:1 to 6:1) (_:1) Flare of walls of circular transition. The input value should be the number of units of wall length for every 1 unit of flare.
- **Face Height** – shown as Hf in the drawing below, can be no smaller than the barrel height and no larger than 1.1 times the barrel height.
- A side-tapered, rectangular inlet has an enlarged rectangular face section with transition (taper) to the culvert barrel. The side-tapered dimensions are entered as follows:
- **Face Width –** width of enlarged face section.
- **Side Taper** – (4:1 to 6:1) (_:1) flare of walls of rectangular transition. The input value should be the number of units of wall length for every 1 unit of flare.

If the selected face width is not wide enough, the face section will produce a higher headwater elevation than the culvert throat as shown in the “Improved Inlet Table.” The user must continue to increase the face width and run the analysis until the headwater depth ceases to change with increasing face width. Once this occurs the face section no longer controls and may be used in analysis and construction. Detailed information pertaining to side- tapered inlets can be found in FHWA Publication HDS 5, bundled with the HY-8 program and accessed from the Help menu.

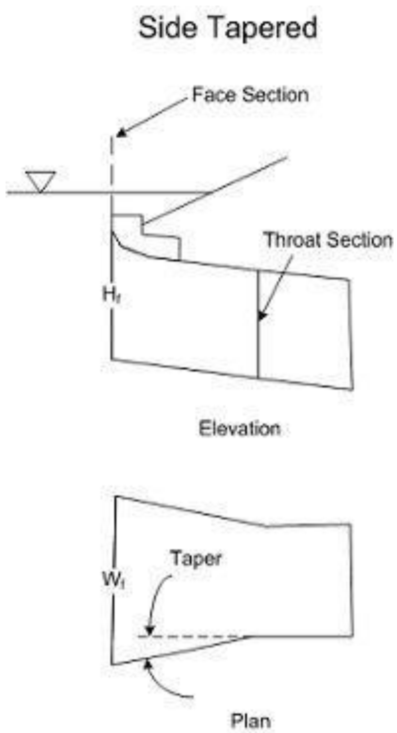


Figure 4.2: Definition sketch for a side tapered culvert inlet.

4.3.3 Slope Tapered

A slope tapered inlet increases the culvert performance by providing a depression and a more efficient control section at the throat, designated to represent the location of the culvert where a constant size begins (see drawing below). Slope tapered dimensions are entered as follows:

- **Face Width** – width of enlarged face section, denoted Wf in the drawing below.
- **Side Taper** – (4:1 to 6:1) (_:1) Slope of walls of tapered transition. Value that is input should be the number of units of wall length for every 1 unit of flare.
- **Depression Slope** – (2:1 to 3:1) (_:1) Slope between the entrance and throat invert, shown as St in the drawing below.
- **Throat Depression** – depression of inlet control section below stream bed. Measured from stream bed to throat invert.
- **Mitered Face** (Y/N) – Face of culvert cut to conform to embankment slope.
- **Crest Length** – length of the upstream paved crest at the stream bed. This length is only used when the culvert face is mitered.

If the selected face width (and crest width in the case of a mitered face) is not wide enough the face (or crest) section will produce a higher headwater elevation than the culvert throat. The user must continue to increase the face width (and/or the crest width in the case of a mitered face) and run the analysis until the headwater depth ceases to change with increasing face width (and crest width in the case of a mitered face). Once this occurs the face section (and/or the crest section) no longer controls and may be used in analysis and construction. Detailed information pertaining to slope tapered inlets can be found in FHWA

Publication HDS 5 and accessed from the Help menu.

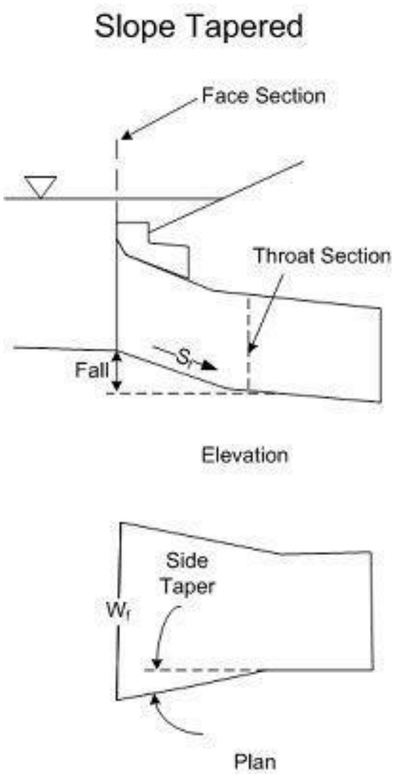


Figure 4.3: Definition sketch for a slope tapered culvert inlet.

4.3.4 Broken Back Culverts

4.3.4.1 Overview

Broken-back culverts have one or more changes in slope along the length of the culvert. HY-8 supports single and double broken-back culverts, meaning one or two changes in slope. In this manual, the sections for a single broken-back culvert are referred to as ‘Upper’ and ‘Runout’ sections. The sections for a double broken-back culvert are referred to as ‘Upper’, ‘Steep’, and ‘Runout’ sections. Broken-back culverts are used to save on excavation costs or to force a hydraulic jump for energy dissipation and prevent scour in the channel downstream from the culvert.

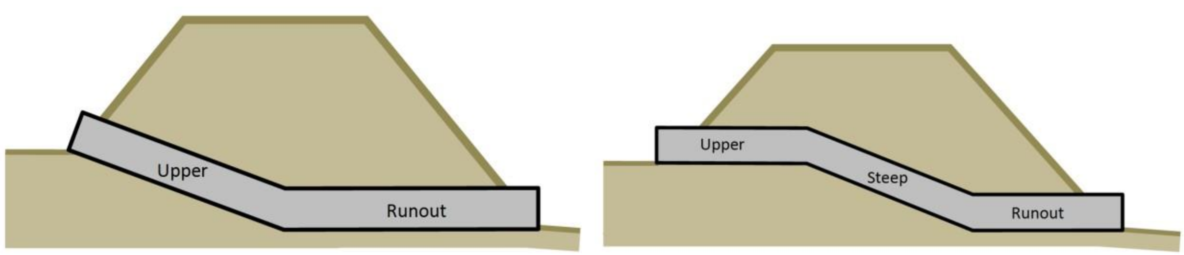


Figure 4.4: Definition sketch for culvert barrels in a broken back culvert crossing

4.3.4.2 Broken Back Culvert Computation Approach

To analyze a broken-back culvert, HY-8 computes each section as a single culvert. HY-8 determines the order that each section is calculated based on the slopes of each section. A culvert is steep if the normal depth of flow is less than critical depth and it is mild if normal depth is greater than critical depth.

The following table shows the computational order for single broken-back culverts. Please note that the order is only the initial computation. If necessary, some sections are recomputed with updated boundary conditions. The computation order is shown with the following abbreviations: U = Upper and R = Runout.

Table 4.1: Computation order for single broken-back culvert crossings

Slope (Steep or Mild)		**Check for Hydraulic Jumps**		
Upper	**Lower**	**Upper**	**Lower**	**Order**
Steep	Steep	X	X	UR
Steep	Mild	X	X	UR
Mild	Steep		X	RU
Mild	Mild			RU

The following table shows the computational order for double broken-back culverts. Please note that the order is only the initial computation. If necessary, some sections are recomputed with updated boundary conditions. The computation order is shown with the following abbreviations: U = Upper, S = Steep, and R = Runout.

Table 4.2: Computation order for double broken-back culvert crossings

Slope (Steep or Mild)			**Check for Hydraulic Jumps**			
Upper	**Middle**	**Lower**	**Upper**	**Middle**	**Lower**	**Order**
Steep	Steep	Steep	X	X	X	USR
Steep	Steep	Mild	X	X	X	USR
Steep	Mild	Steep	X	X	X	RSU
Steep	Mild	Mild	X	X	X	URS
Mild	Steep	Steep		X	X	SRU
Mild	Steep	Mild		X	X	SRU
Mild	Mild	Steep			X	RSU
Mild	Mild	Mild				RSU

To determine the water surface profile of each section, HY-8 determines starting conditions for each section of a broken back culvert so the direct step method can be computed. The starting conditions HY-8 determines include the water depth at the beginning and end of each section, the computation direction for each section, and whether the water surface increases or decreases in depth in the downstream direction for each section. The starting conditions for steep broken-back culvert sections are initialized based on the flowchart below.

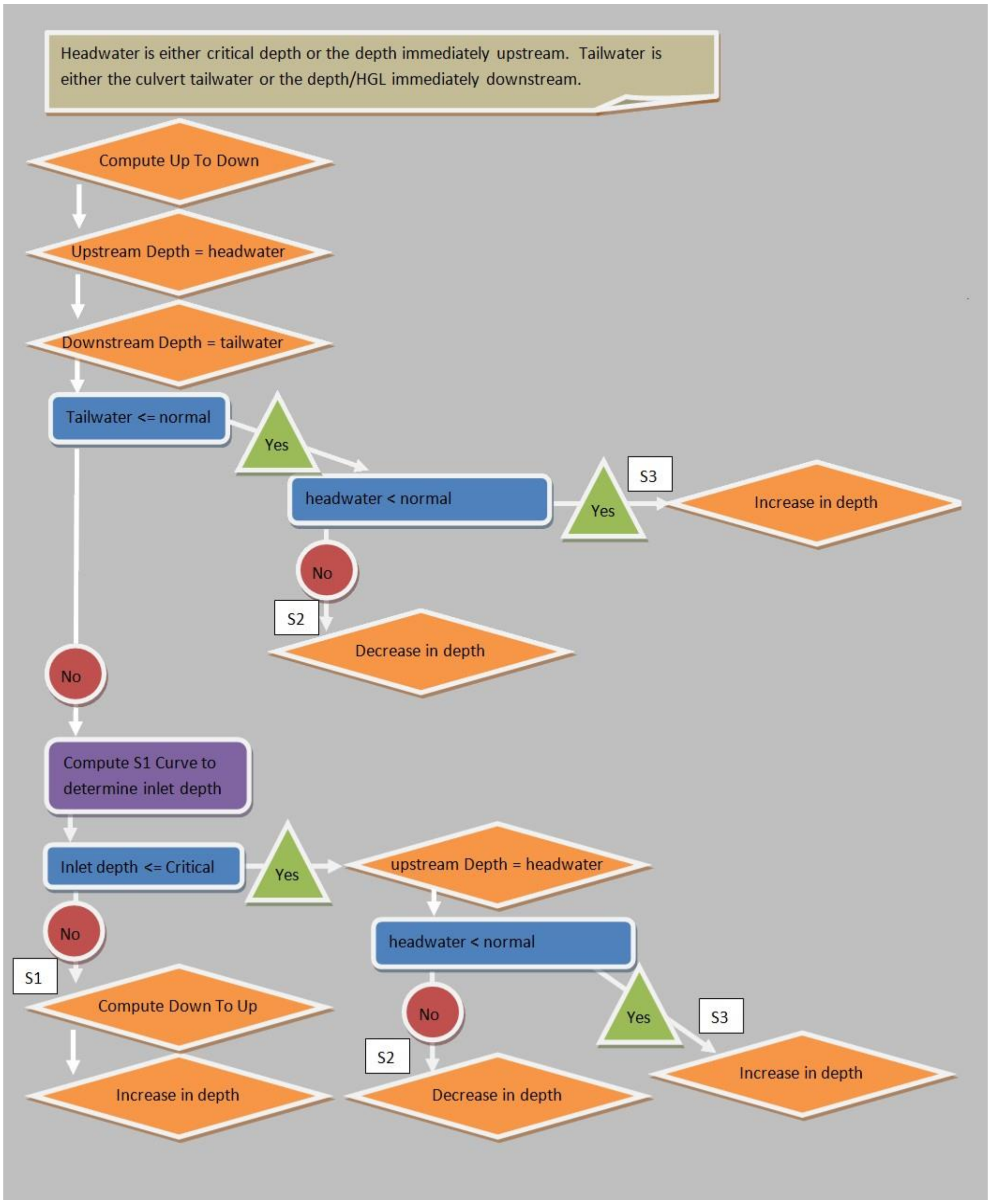


Figure 4.5: Starting conditions for steep broken-back culvert section

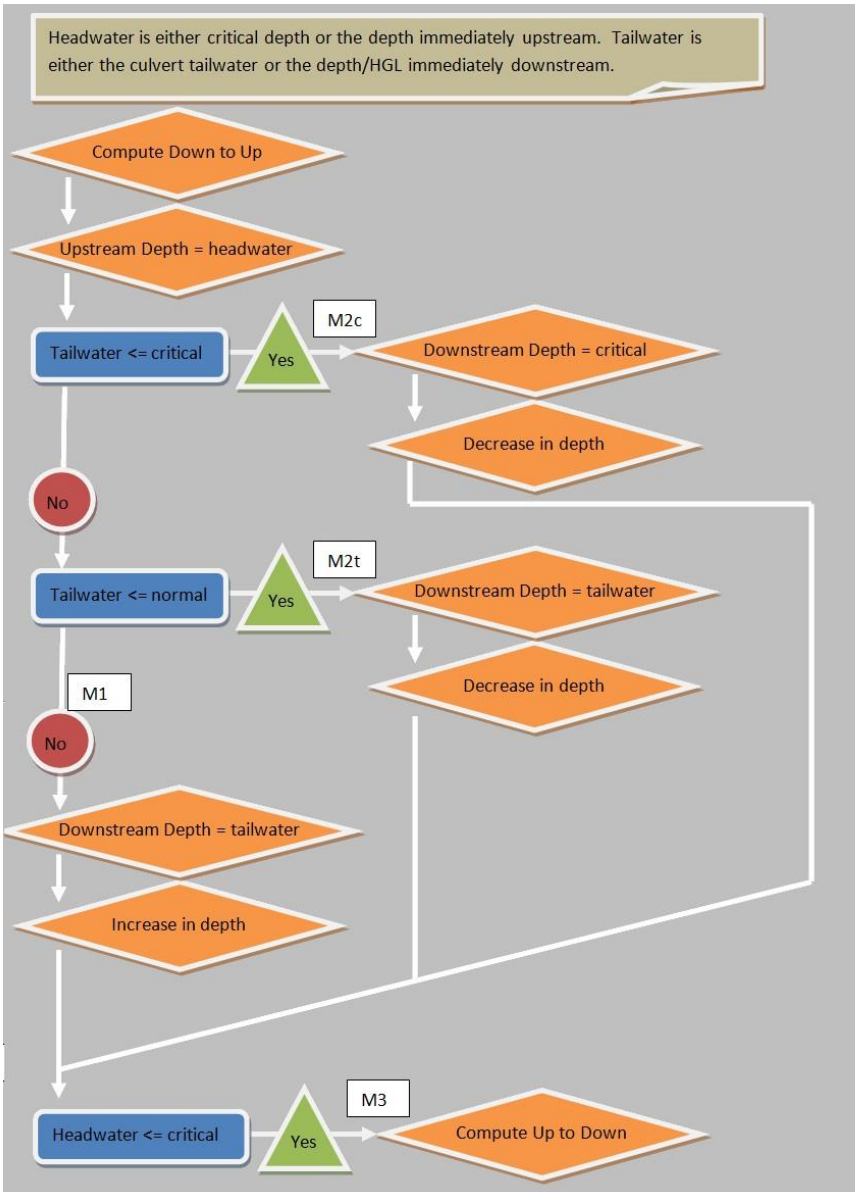


Figure 4.6: Outlet Control Procedures that produce an Outlet Control Profile

Once HY-8 computes a profile for one section, it updates the water surface profile depth for the section(s) that it is next to. HY-8 pieces the profiles for each section together to create a seamless water surface profile through the broken-back culvert.

4.3.4.3 Broken Back Culvert Results

When analyzing broken back culverts in HY-8, the normal and critical depth in the Culvert Summary Table is not shown because it can vary in each section. The flow type reported is the flow type of the upper section.

The option to display the Tapered inlet table is not available and instead there is a **Broken-Back Section** option. After selecting this option, select **Upper** or **Runout** if it is a single broken-back culvert or select **Upper**, **Steep**, or **Runout**. This option displays a table that is similar to the Culvert Summary Table, displaying the flow type, normal depth, and critical depth of the selected culvert section.

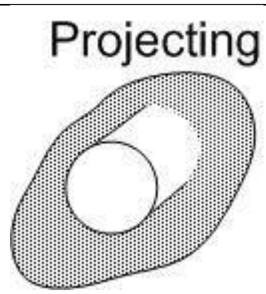
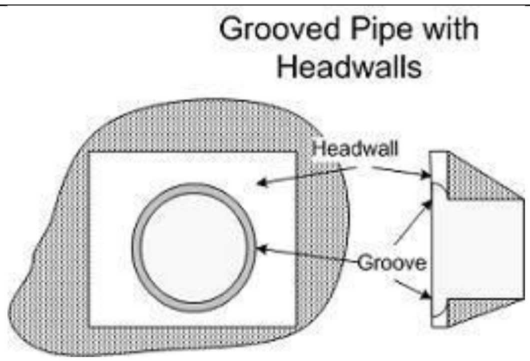
4.4 Inlet Configurations

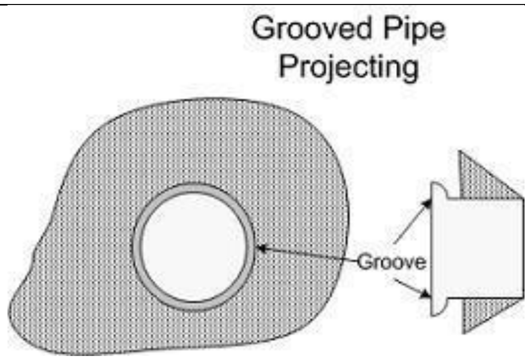
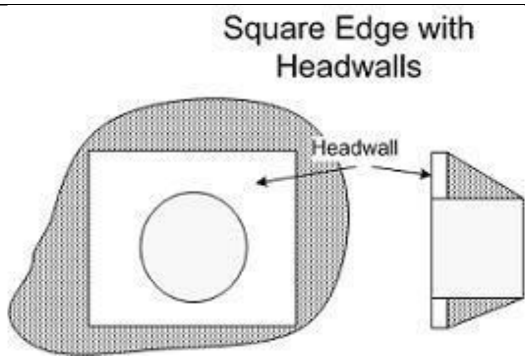
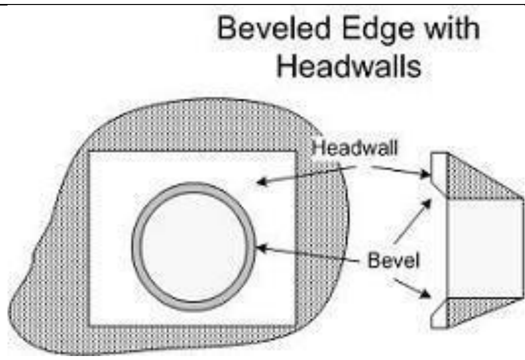
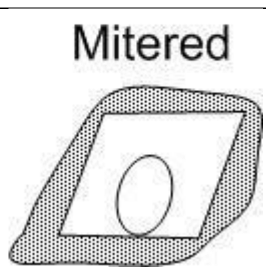
Select from the following inlet configurations which are available according to the selected culvert shape. The following inlet conditions are available (see drawing), but may not apply to all shapes or materials:

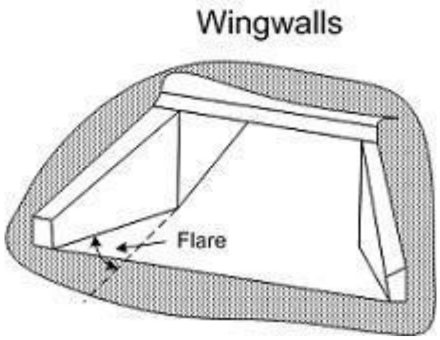
- Projecting
- Grooved end with headwall (0.05 X 0.07D)
- Grooved end projecting (0.05 X 0.07D)
- Square edge with headwall
- Beveled
- Mitered to conform with fill slope
- Headwall

The user can select only one inlet condition for each culvert. Detailed explanations of these inlet conditions can be found in FHWA Publication HDS No. 5 (2001) bundled with the program.

Table 4.3: Culvert barrel inlet edge types in HY-8

	This configuration results in the end of the culvert barrel projecting out of the embankment.
	The grooved pipe is for concrete culverts and decreases the loss through the culvert entrance.

	This option is for concrete pipe culverts.
	Square edge with headwall is an entrance condition where the culvert entrance is flush with the headwall.
	'Beveled edges' is a tapered inlet edge that decreases head loss as flow enters the culvert barrel.
	A mitered entrance is when the culvert barrel is cut so it is flush with the embankment slope.

	Wingwalls are used when the culvert is shorter than the embankment and prevents embankment material from falling into the culvert.

- NOTE: HDS-5 notes that "Flared end sections made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet"

4.5 Inlet Depression

The depression of a culvert is the vertical drop of the inlet control section below the stream bed. Define an inlet depression by entering a value for each of the following items (see drawing below):

- Depression (T)
- Depression Slope
- Crest Width (minimum value is B+4*T)

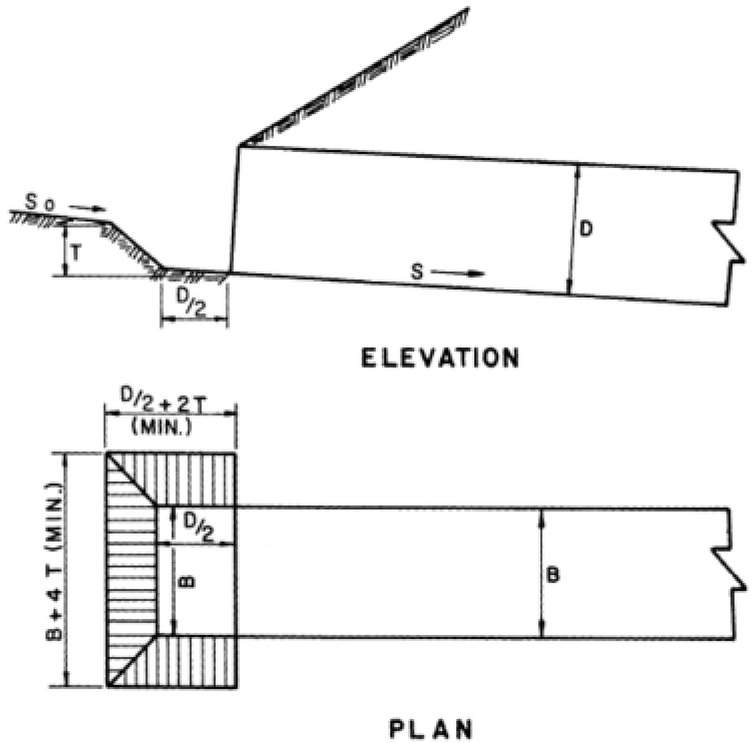


Figure 4.7: Definition Sketch of variables for inlet depression

4.5.1 Depression

The depression is the vertical drop of inlet control section below the stream bed, shown as T in Figure 4.7: Definition Sketch of variables for inlet depression.

4.5.2 Depression Slope

The depression slope is the slope between the stream bed and the face invert. The depression slope must be set between 2:1 and 3:1. The streambed slope is shown as S_0 in Figure 4.7: Definition Sketch of variables for inlet depression.

4.5.3 Crest Width

Crest width is the length of the weir crest at the top of the depression slope. It is a minimum of B+4*T. Designing the crest width becomes an iterative process in HY-8 as the user must select a crest width wide enough so that it does not control the headwater calculations. If the selected crest width is not wide enough the crest section will produce a higher headwater elevation than the culvert throat. The user must continue to increase the crest width and run the analysis until the headwater depth ceases to change with increasing crest width. Once this occurs the crest section no longer controls and may be used in analysis and construction.

4.6 Embedment Depth

“Embedment Depth” is the depth the culvert is embedded from the invert of the culvert barrel to the top of the embedding material.

There are two ways the user can simulate embedment in HY-8. The first method is to enter an embedment depth and HY-8 will compute the geometry necessary and use polynomial coefficients, if available. If they are not available, HY-8 will use interpolation coefficients. The second method is to select the user-defined shape and manually enter the geometry of the culvert. User-defined shapes use interpolation coefficients to determine the inlet control depth. A useful shortcut to determine the geometry is to select the desired shape (for example circular), enter the rise, span, and embedment depth. Click 'Analyze Crossing', then click 'Edit Crossing' to return. Change the shape to 'User-Defined' and note that the geometry used for the previous culvert is maintained in the user-defined shape geometry.

For more discussion on polynomial coefficients vs interpolation coefficients, see the Inlet Control Computations.

For more detail, when an embedment depth greater than zero is entered, HY-8 will simulate an embedded culvert. If the culvert barrel shape is circular, in HY-8 versions 7.3 and later, HY-8 will use a 5th degree polynomial equation with coefficients derived from a research study to determine the headwater elevation. If the shape is Concrete Box or South Dakota Concrete Box Culvert, the unembedded 5th degree polynomial equation and coefficients will be used with a modified shape. Other shapes and earlier versions with embedment will use the interpolation method with coefficients derived from Chart 52B in HDS-5. The interpolation method does not use data derived from that specific shape and is more generalized.

If HY-8 uses the interpolation method, it will determine the coordinates and treat the shape as a ‘User Defined’ shape internally. Because of this, only the ‘User Defined’ inlet types and inlet configurations will be available. This is a significant difference from the computations for non-embedded culverts for the Concrete Box, Elliptical, and Pipe Arch shapes.

HY-8 version 7.3 added polynomial coefficients for circular culverts to determine the inlet control depth. HY-8 derives the coefficients used from the NCHRP 15-24 project resulting with the NCHRP 734 report. This report gives coefficients for a circular culvert that is embedded 20%, 40%, and 50%. HY-8 will linearly interpolate between the coefficients for the level of embedment specified; however, if the embedment is outside the range of data, the closest set of coefficients is used.

The coefficients determined for use in HY-8 7.3 with circular culverts were based on data with a mathematical error as published in NCHRP report 734. Further, the data reported for the 50% beveled embedded circular case were incorrect. These issues lead to incorrect results when computing headwater depths in embedded circular culverts.

The incorrect data in the 50% beveled embedded circular case were replaced with the original data that was recovered. This data still contained the mathematical error found in the other tables and also required further correction as described below.

A review of the embedment data determined that the AD^0.5 values were incorrect. These values were corrected and new 5th degree polynomial coefficients were determined to fit the curve with the corrected data.

Reviewing the results determined that the original range of the data did not extend across a sufficient range to provide a stable result at higher headwater depths. The data was extended following the trend of the unembedded curve to provide a better result at these higher depths. Each curve was extended to be stable to HW/D = 10.0. Doing this provided stability to the curve above the range backed by data while maintaining the same accuracy in the curve backed by experimental data.

After applying the coefficients to the HY-8 program, the HY-8 developers created an HY-8 model of the test setup and checked the results of HY-8 with the original and correct test data.

For a more detailed discussion on the process and results of updating these coefficients, see "Reviewing Coefficients in Embedded Circular Culverts from NCHRP Report 734" that is included with HY-8 and found in the help menu.

When a culvert is embedded, the user will need to define a top and bottom Manning's n values to handle the culvert and embedding material properties which HY-8 uses to run the culvert analysis.

Finally, if the user enters an embedment depth, all the materials for the selected shape will still be available for selection. However, the material selected will be converted internally to one of the two user-defined materials using the following chart:

Table 4.4: Material conversion for embedded shapes to be used internally in HY-8 for embedded culvert barrels

Shape	Material	Equivalent User-Defined Material (for embedded culverts)
Circular	Concrete	Concrete
	Any other material	
	Corrugated Steel	Corrugated Metal Riveted or welded
	Corrugated Aluminum	
Concrete Box	Concrete	Concrete
Elliptical	Steel or Aluminum	Corrugated Metal Riveted or Welded
	Concrete	Concrete
	Any other material	
Pipe Arch	Steel or Aluminum	Corrugated Metal Riveted or Welded
	Steel Structural Plate	
	Aluminum Structural Plate	
	Concrete	Concrete
	Any other material	
User Defined	Corrugated Metal Riveted or Welded	Corrugated Metal Riveted or Welded
	Concrete	Concrete
Arch, Open Bottom	Corrugated Steel	Corrugated Metal Riveted or Welded
	Corrugated Aluminum	
Low-Profile Arch	Corrugated Steel	Corrugated Metal Riveted or Welded
	Corrugated Aluminum	
High-Profile Arch	Corrugated Steel	Corrugated Metal Riveted or Welded
	Corrugated Aluminum	
Metal Box	Corrugated Steel	Corrugated Metal Riveted or Welded
Arch-Box, Concrete	Concrete	Concrete
Any other Shape	Any other material	Corrugated Metal Riveted or Welded

4.7 Site Data

4.7.1 Site Data Input Option

Site data describe the positioning and length of the culvert within an embankment. The program adjusts culvert length according to site data, culvert type, culvert height, and depression. The following options are available for entering site data:

- Culvert Invert Data
- Embankment Toe Data

4.7.2 Culvert Invert Data

The culvert invert data option is used to enter known coordinates of culvert inverts. This option is generally used to analyze known, existing culverts. Coordinates are defined by the following input as seen in the figure below:

- **Inlet Station** – station of culvert inlet invert
- **Inlet Elevation** – elevation at culvert inlet invert
- **Outlet Station** – station of culvert outlet invert, must be greater than the inlet station
- **Outlet Elevation** – elevation at culvert outlet invert
- **Number of Barrels** – the program default is 1, although this may be changed by the user.

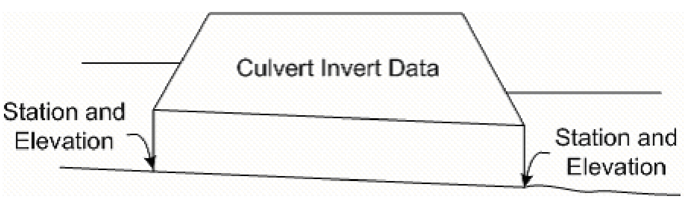


Figure 4.8: Definition Sketch for culvert invert site data

Once the user defines the culvert invert data, the program computes the culvert barrel length along the culvert barrel, rather than horizontally between the inlet and outlet stations. Horizontal and adverse slopes may be entered. Stations may be entered in ascending or descending order.

4.7.3 Embankment Toe Data

Embankment toe data are used to describe the fill into which a culvert will be placed. No culvert dimensions are provided at this point, and the goal of the designer is to fit the culvert in the designed roadway cross section when geometry is provided from design drawings. Once the culvert height has been entered, the program will calculate the culvert invert station and elevation data (see the diagram below). The following parameters are defined by the user and are shown in the figure below:

- **Upstream Station** – station (m or ft) of the upstream intersection of the stream bed or drainage channel and embankment slope. Stationing may increase or decrease from upstream to downstream.
- **Upstream Elevation** – stream bed elevation (m or ft) at upstream station
- **Upstream Embankment Slope** – embankment slope on the upstream side of the roadway (m/m

or ft/ft)

- **Downstream Station** – station (m or ft) of downstream intersection of the stream bed or drainage channel and embankment slope. Stationing may increase or decrease from upstream to downstream.
- **Downstream Elevation** – stream bed elevation (m or ft) at downstream station
- **Downstream Embankment Slope** – embankment slope on the downstream side of the roadway (m/m or ft/ft)
- **Number of Barrels** – program default is 1 barrel, although the user may place multiple barrels with the same characteristics

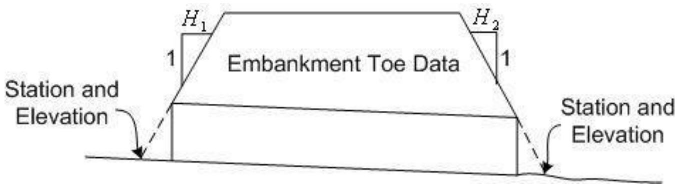


Figure 4.9: Definition sketch for embankment toe data

Horizontal and adverse slopes may be entered. Stations may be entered in ascending or descending order.

4.8 Alternative Designs

In HY-8 Version 8, the Alternative Designs module can be found alongside the culvert properties buttons. This module will determine a list of culverts that meet specific design criteria based on selected shapes, materials, and inlet configurations. The design criteria is based on minimum or maximum HW/D, freeboard below low roadway or maximum headwater elevation.

The primary function of the Alternative Designs module is to calculate the optimum culvert size while ensuring it complies with the designated design criteria. The computational process is as follows:

1. Begin with the smallest possible culvert size.
2. Check if this size meets the specified design requirements.
3. If the current size does not meet the design criteria, increase the size.
4. Continue increasing the size iteratively until a size is found that satisfies the design requirements.

To utilize this module, you must first define a crossing and input the site data including an initial culvert size for your project. Please note that this module is not compatible with multiple culverts, depressed inlets, tapered culverts, or broken-back culverts.

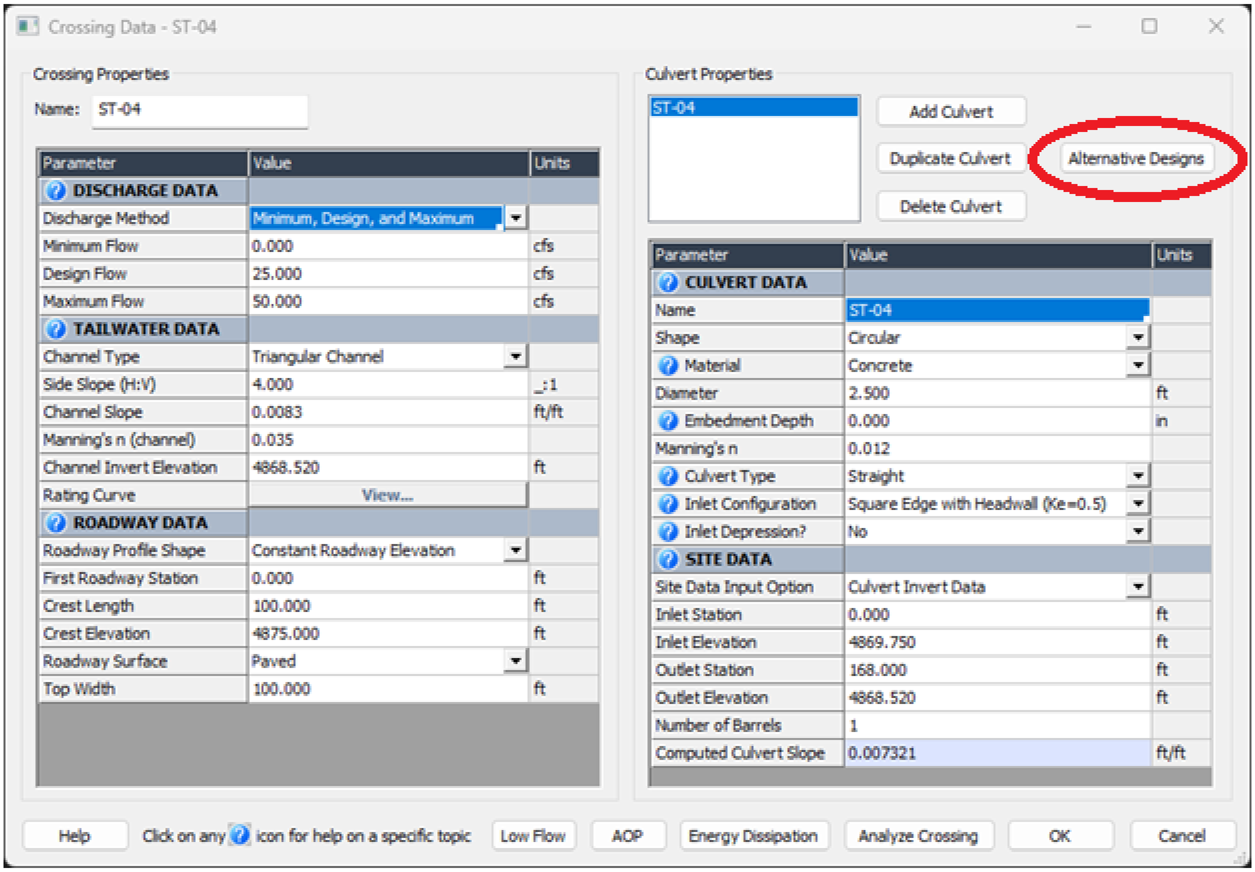


Figure 10: Alternative Designs Button Location

4.8.1 Alternative Designs Input

To initiate the Alternative Designs module, the initial step involves configuring the culvert's characteristics, including shape, material, inlet configurations, design preferences, and requirements.

4.8.1.1 Configuring Culvert Attributes

Within the Input dialog on the left side, a hierarchical representation is presented, displaying the entire array of culvert shapes available in HY-8. These shapes can be expanded to reveal the materials applicable to each shape. Furthermore, materials can be expanded to expose the available inlet configurations for each material.

- To enable or disable a particular shape, you can toggle the checkbox associated with that shape. This action will likewise affect the materials and inlet configurations related to that specific shape.
- If you choose to enable or disable a specific material, it will impact the inlet configurations associated with that material.
- Upon initialization, the tree structure is set to the currently selected shape, material, and inlet configuration.

4.8.1.2 Culvert Design Preferences

Within the configuration, the Culvert Design Options offer the ability to define parameters and preferences that will provide guidance throughout the design process.

- **Span to rise ratio** – applies to shapes that have two dimensions and do not have a pre-defined geometry, for example a concrete box and a South Dakota Concrete box.
- **Rise increment –** defines the growth of culvert rise for single dimension culverts that do not have a pre-defined geometry, for example circular culverts.
- **Max number of barrels –** specifies how many identical barrels to consider in the design alternatives. Specifying the Max number of barrels as 1 means that only a single barrel will be considered. Specifying the Max number of barrels as 2 means that a single barrel and two identical barrels will be considered.
- **Minimum Cover –** specifies the cover that is required for an accepted culvert design from the crown of the culvert to the roadway elevation.

The design requirements specify criteria used to determine an acceptable design.

- **Selected Discharge** – allows selecting one single discharge value from the defined discharge values to check for an acceptable design.
- **Design criteria** – will be used to specify the maximum acceptable headwater elevation. You may select **Lower than given freeboard of the roadway** and specify a **freeboard** value, for the maximum acceptable headwater elevation to be the overtopping roadway elevation minus the specified freeboard value. Alternatively, you may choose the **Lower than given HW elevation** option and directly specify the **maximum acceptable headwater elevation**.
- **Maximum HW/D** – will limit designs to those that keep the headwater to culvert rise ratio below the set value. It is recommended that you do not use a value greater than 3.0.
- **Minimum HW/D** – will limit designs to those that keep the headwater to culvert rise ratio above the set value. It is recommended that you do not use a value less than 0.5.
- **Outlet cannot be submerged** – will limit designs that have a culvert rise large enough that the culvert outlet is not submerged by the tailwater depth.

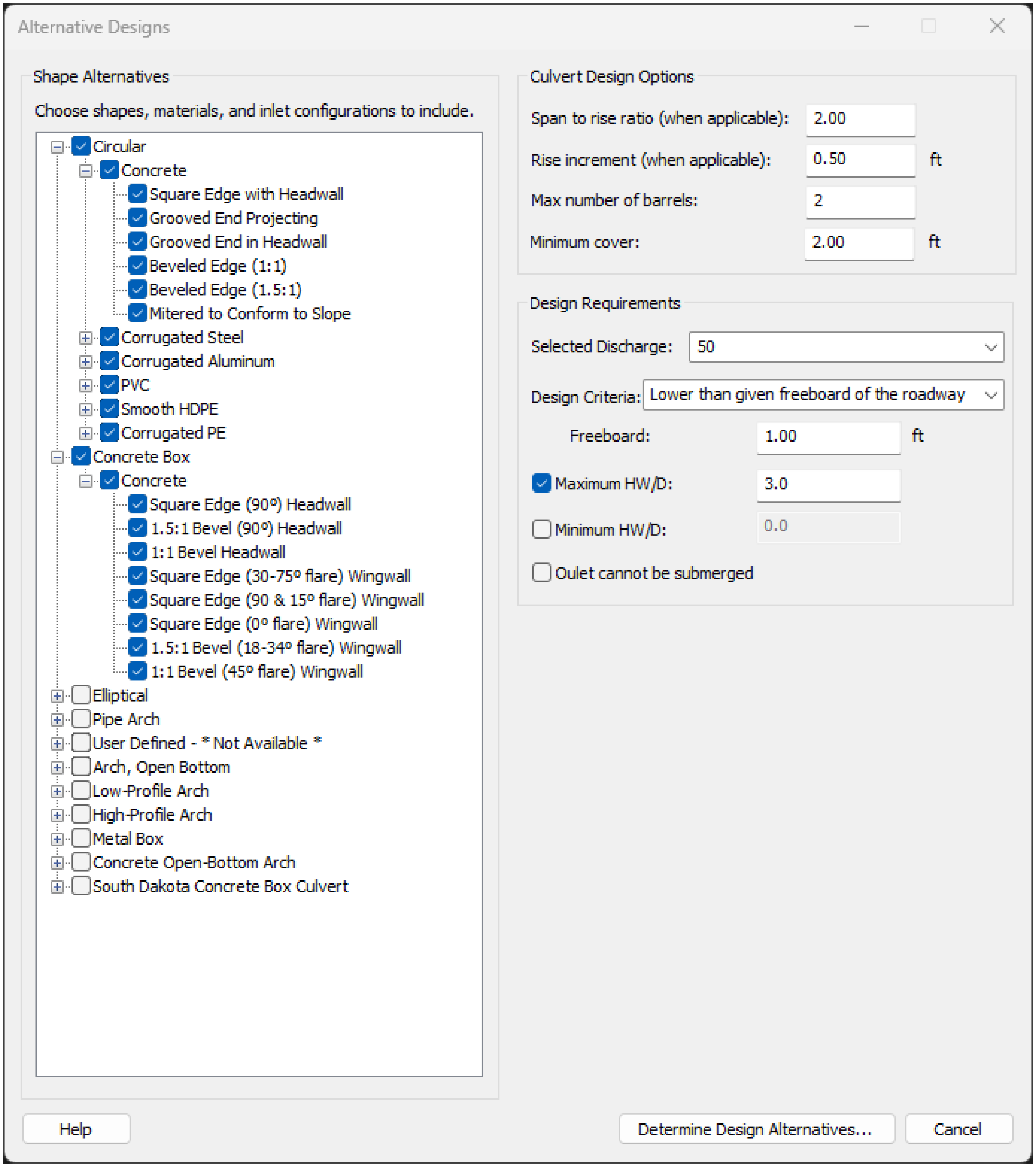


Figure 11: Alternative Designs Input Window

4.8.2 Alternative Designs Optimization

The optimizing step in the Alternative Designs module is where the computations take place. HY-8 will report the calculations that are being performed and whether it was successful in finding a culvert that fulfills the design requirements or not.

You may cancel the computations. Once the Cancel button is clicked, the current culvert calculation will be completed and you will be able to close the window.

When the computations are complete, HY-8 will report the time taken and change the Cancel button to be a Close button.

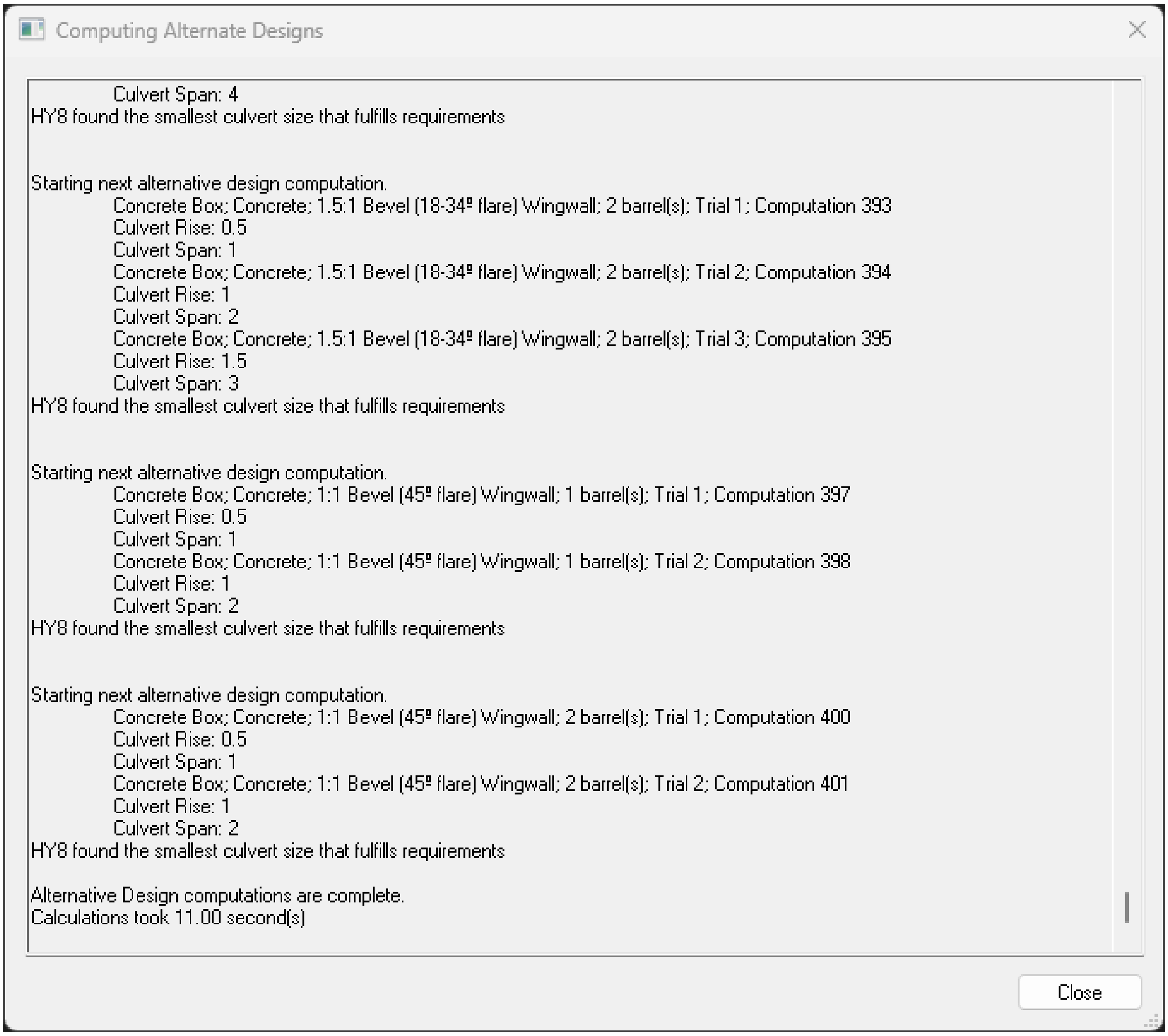


Figure 12: Alternative Designs Optimization Window

4.8.3 Alternative Designs Results

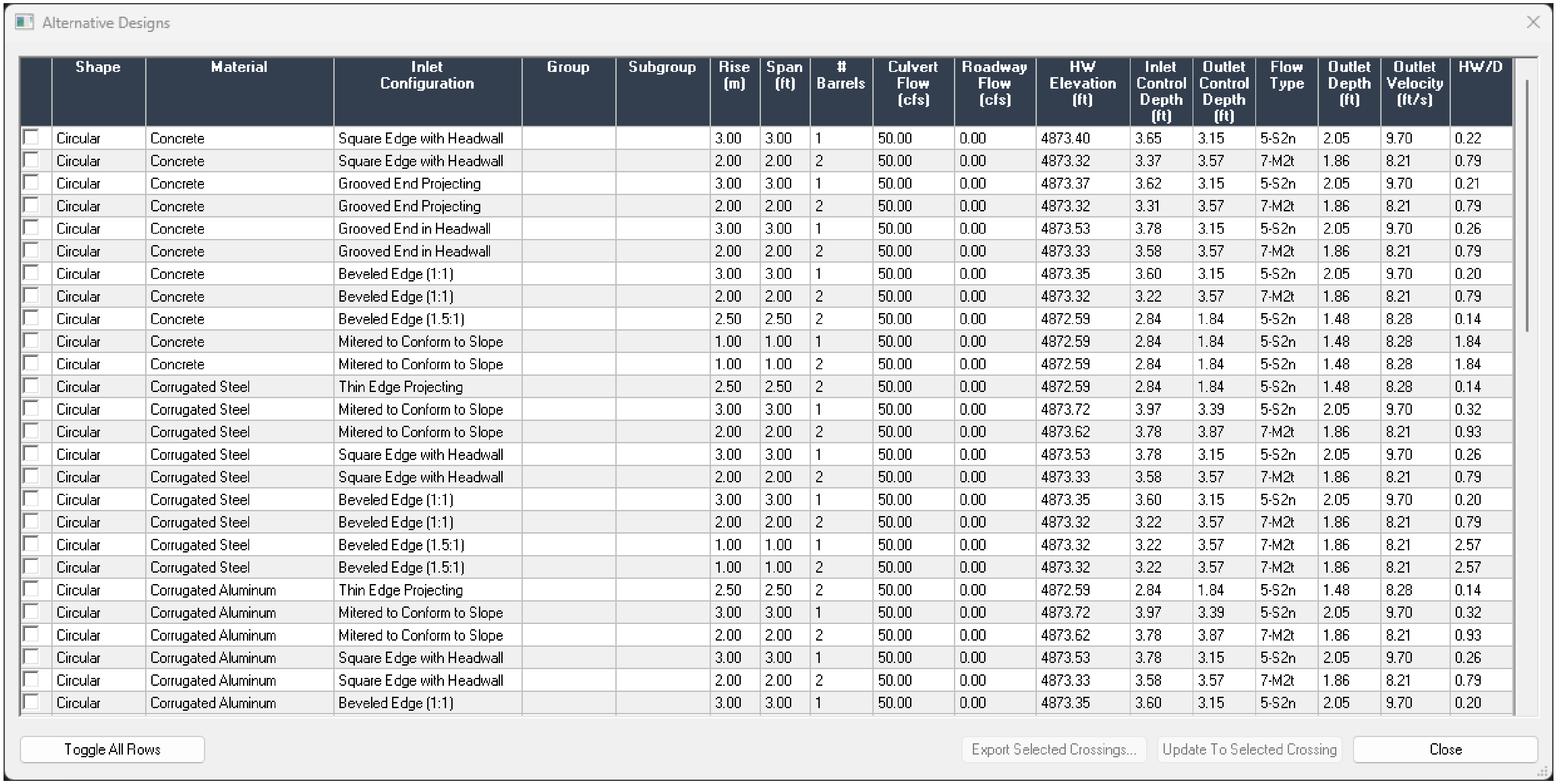
The final step of the Alternative Designs module is to review the results. The results table is populated only with culvert designs that meet the design requirements. HY-8 ignores culvert designs that were skipped or failed to have any size meet the design requirements.

The table has columns to report the geometry of the culvert: Shape, material, inlet configuration, group, subgroup, rise, span, and number of identical barrels.

The table also includes columns to report hydraulic results of the culverts to provide guidance on which culvert design to select: Culvert Flow, Roadway Flow, HW elevation, Inlet Control Depth, Outlet Control Depth, Flow Type, Outlet Depth, Outlet Velocity, and HW/D.

Multiple culvert designs can be exported to an HY-8 file for a more complete comparison. You can select the culverts by checking the toggle box in the first column or by using the **Toggle All Rows** button. After selecting all of the culvert crossings, click the **Export Selected Crossings** button. You will be prompted for a filename. Once entered and accepted, HY-8 will save the culvert crossings to a file and HY-8 will return to the Alternative Designs Results window.

You can update the current the culvert, by selecting only one culvert crossing by checking the toggle box in the first column and clicking the **Update to Selected Crossing**. If you do not want any changes to the current culvert crossing click the Close button to close the Alternative Designs module.



	Shape	Material	Inlet Configuration	Group	Subgroup	Rise (m)	Span (ft)	# Barrels	Culvert Flow (cfs)	Roadway Flow (cfs)	HW Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Outlet Depth (ft)	Outlet Velocity (ft/s)	HW/D
☐	Circular	Concrete	Square Edge with Headwall			3.00	3.00	1	50.00	0.00	4873.40	3.65	3.15	5-S2n	2.05	9.70	0.22
☐	Circular	Concrete	Square Edge with Headwall			2.00	2.00	2	50.00	0.00	4873.32	3.37	3.57	7-M2t	1.86	8.21	0.79
☐	Circular	Concrete	Grooved End Projecting			3.00	3.00	1	50.00	0.00	4873.37	3.62	3.15	5-S2n	2.05	9.70	0.21
☐	Circular	Concrete	Grooved End Projecting			2.00	2.00	2	50.00	0.00	4873.32	3.31	3.57	7-M2t	1.86	8.21	0.79
☐	Circular	Concrete	Grooved End in Headwall			3.00	3.00	1	50.00	0.00	4873.53	3.78	3.15	5-S2n	2.05	9.70	0.26
☐	Circular	Concrete	Grooved End in Headwall			2.00	2.00	2	50.00	0.00	4873.33	3.58	3.57	7-M2t	1.86	8.21	0.79
☐	Circular	Concrete	Beveled Edge (1:1)			3.00	3.00	1	50.00	0.00	4873.35	3.60	3.15	5-S2n	2.05	9.70	0.20
☐	Circular	Concrete	Beveled Edge (1:1)			2.00	2.00	2	50.00	0.00	4873.32	3.22	3.57	7-M2t	1.86	8.21	0.79
☐	Circular	Concrete	Beveled Edge (1.5:1)			2.50	2.50	2	50.00	0.00	4872.59	2.84	1.84	5-S2n	1.48	8.28	0.14
☐	Circular	Concrete	Mitered to Conform to Slope			1.00	1.00	1	50.00	0.00	4872.59	2.84	1.84	5-S2n	1.48	8.28	1.84
☐	Circular	Concrete	Mitered to Conform to Slope			1.00	1.00	2	50.00	0.00	4872.59	2.84	1.84	5-S2n	1.48	8.28	1.84
☐	Circular	Corrugated Steel	Thin Edge Projecting			2.50	2.50	2	50.00	0.00	4872.59	2.84	1.84	5-S2n	1.48	8.28	0.14
☐	Circular	Corrugated Steel	Mitered to Conform to Slope			3.00	3.00	1	50.00	0.00	4873.72	3.97	3.39	5-S2n	2.05	9.70	0.32
☐	Circular	Corrugated Steel	Mitered to Conform to Slope			2.00	2.00	2	50.00	0.00	4873.62	3.78	3.87	7-M2t	1.86	8.21	0.93
☐	Circular	Corrugated Steel	Square Edge with Headwall			3.00	3.00	1	50.00	0.00	4873.53	3.78	3.15	5-S2n	2.05	9.70	0.26
☐	Circular	Corrugated Steel	Square Edge with Headwall			2.00	2.00	2	50.00	0.00	4873.33	3.58	3.57	7-M2t	1.86	8.21	0.79
☐	Circular	Corrugated Steel	Beveled Edge (1:1)			3.00	3.00	1	50.00	0.00	4873.35	3.60	3.15	5-S2n	2.05	9.70	0.20
☐	Circular	Corrugated Steel	Beveled Edge (1:1)			2.00	2.00	2	50.00	0.00	4873.32	3.22	3.57	7-M2t	1.86	8.21	0.79
☐	Circular	Corrugated Steel	Beveled Edge (1.5:1)			1.00	1.00	1	50.00	0.00	4873.32	3.22	3.57	7-M2t	1.86	8.21	2.57
☐	Circular	Corrugated Steel	Beveled Edge (1.5:1)			1.00	1.00	2	50.00	0.00	4873.32	3.22	3.57	7-M2t	1.86	8.21	2.57
☐	Circular	Corrugated Aluminum	Thin Edge Projecting			2.50	2.50	2	50.00	0.00	4872.59	2.84	1.84	5-S2n	1.48	8.28	0.14
☐	Circular	Corrugated Aluminum	Mitered to Conform to Slope			3.00	3.00	1	50.00	0.00	4873.72	3.97	3.39	5-S2n	2.05	9.70	0.32
☐	Circular	Corrugated Aluminum	Mitered to Conform to Slope			2.00	2.00	2	50.00	0.00	4873.62	3.78	3.87	7-M2t	1.86	8.21	0.93
☐	Circular	Corrugated Aluminum	Square Edge with Headwall			3.00	3.00	1	50.00	0.00	4873.53	3.78	3.15	5-S2n	2.05	9.70	0.26
☐	Circular	Corrugated Aluminum	Square Edge with Headwall			2.00	2.00	2	50.00	0.00	4873.33	3.58	3.57	7-M2t	1.86	8.21	0.79
☐	Circular	Corrugated Aluminum	Beveled Edge (1:1)			3.00	3.00	1	50.00	0.00	4873.35	3.60	3.15	5-S2n	2.05	9.70	0.20

Figure 13: Alternative Designs Results Window

5 Analysis

5.1 Roadway Overtopping

When the headwater elevation exceeds the elevation of the roadway, overtopping will occur as shown below. When overtopping is simulated, the program computes the discharge for each culvert and for the roadway that will result in the same headwater elevation. HY-8 will complete an overtopping analysis for every crossing, and, if overtopping occurs, will display the corresponding flow values.

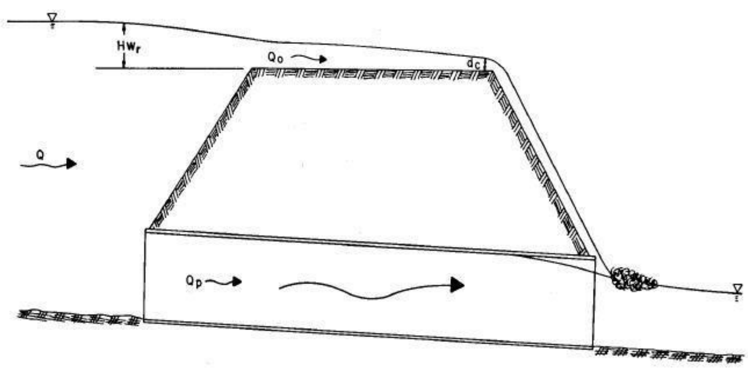


Figure 5.1: Definition sketch for roadway overtopping

5.2 Head Water Computations

The headwater computation depends on the results of inlet control depth and outlet control depth computations. The larger depth of the two will govern and be used to compute the headwater elevation.

5.2.1 Inlet Control Computations

Inlet control means that the amount of water the culvert barrel can carry is limited by the culvert entrance. Flow passes through critical depth at the culvert entrance and is supercritical in the barrel. There are several flow profiles possible, HY-8 simulates so-called Type A, B, C, and D conditions as shown below and as described in HDS-5. These profiles are known as Type 1 (A, C) and Type 5 (B, D) within HY-8. You can find the various flow type properties in HY-8 by selecting the **Flow Types** button from the Culvert Summary Table and are shown below. Because the flow in the barrel is supercritical, outlet losses and friction losses are not reflected in the headwater elevation. The headwater elevation is a function of the entrance size, shape, and culvert type. The computed inlet control headwater elevation is found by accessing the results of scaled physical model tests.

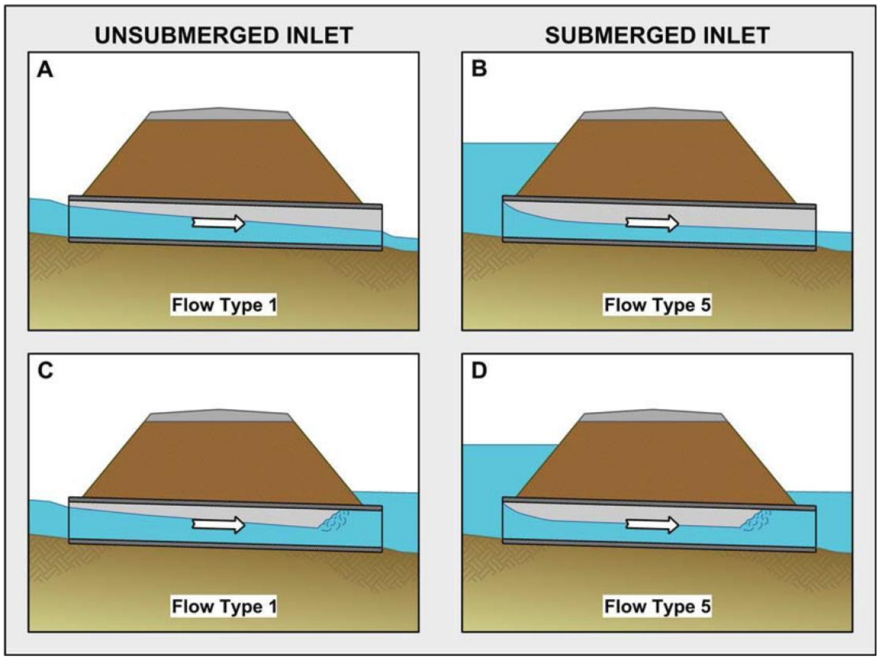


Figure 5.2: Inlet Control Flow Profiles Types.

HY-8 utilizes two methods to determine the inlet control depth.

- Fifth Degree Polynomial Equation
- Interpolation Coefficient

The fifth degree polynomial equation uses coefficients determined through physical model testing for the specific culvert shape and inlet configuration. Polynomial coefficients are available for the following shapes: 'Circular', embedded 'Circular', 'Concrete Box', 'Elliptical', 'Pipe Arch', and 'South Dakota Concrete Box Culvert'. These are considered more accurate because you have empirical data for the specific culvert shape and inlet edge type that you have selected.

5.2.1.1 Fifth Degree Polynomial Equation

Inlet control means that flow within the culvert barrel is supercritical and not capable of transmitting losses upstream. The determination of the headwater depth, therefore, is not found using the energy equation, but is the result of many scaled model tests. In HDS-5 (Appendix A), submerged and unsubmerged equations developed by the National Bureau of Standards from the scaled model tests were originally used to determine headwater depths. These equations required four coefficients, K, M, c, and Y. Unfortunately, once plotted, the transition zone between unsubmerged and submerged flow was not well defined. For the purposes of the HY-8 program, a fifth degree polynomial curve was fitted through the three regions of flow: unsubmerged, transition, and submerged (see equation below). Fifth degree polynomial coefficients were obtained for all combinations of culvert shape and inlet configurations.

$$\frac{HW}{D} = a + b\left[\frac{Q}{BD^{1.5}}\right] + c\left[\frac{Q}{BD^{1.5}}\right]^2 + d\left[\frac{Q}{BD^{1.5}}\right]^3 + e\left[\frac{Q}{BD^{1.5}}\right]^4 + f\left[\frac{Q}{BD^{1.5}}\right]^5$$

5.2.1.2 Polynomial Coefficients

5.2.1.2.1 Overview

HY-8 use the polynomial coefficients derived from a study and document prepared by Don Chase at the University of Dayton, Ohio (1999). Dr. Chase determined a different set of coefficients for culverts with different span-to-rise ratios. Con/Span culverts with a 4:1 span-to-rise ratio performed better (resulted in a lower headwater) than culverts with a 2:1 span-to-rise ratio. Because of this, separate polynomial coefficients were determined for culverts with each of these span-to-rise ratios.

Dr. Chase's study determined the K, c, M, and Y NBS coefficients described in HDS-5, and these coefficients were fitted to a 5th degree polynomial equation so they can be used in HY-8.

In HY-8, the 2:1 coefficients are used if the span:rise ratio is less than or equal to 3:1 and the 4:1 coefficients are used if the span:rise ratio is greater than 3:1. If the culvert being modeled has less than a 2:1 or greater than a 4:1 span-to-rise ratio, the user will see a note in HY-8 saying that the culvert is outside of the tested span-to-rise ratios. Further testing may be required to account for these large or smaller span-to-rise ratios, but it is likely that the computed headwater will be higher than the observed headwater if the span:rise ratio is greater than 4:1 and the computed headwater will be less than that observed if the span:rise ratio is less than 2:1.

For circular, box, elliptical, pipe arch, concrete open-bottom arch (commonly called CON/SPAN), and South Dakota Concrete Box culverts, polynomial coefficients, found in Appendix A, are utilized in the inlet control headwater computations. Other culvert shapes use Appendix A Table 11.8: Reference for User-defined interpolation coefficients: FHWA HDS-5, Appendix D, Chart 52B, which shows the HW/D points A(1) through A(10) for interpolation. Each row of coefficients represents different inlet configurations for different culvert shapes.

5.2.1.2.2 Note about Coefficient Changes in HY-8 7.3 and Higher

In HY-8 7.3 and later versions of HY-8, several significant changes were made to the coefficients used in HY-8. A summary of the changes to the HY-8 coefficients in this version follows:

5.2.1.2.3 Changes to Shapes Using Polynomial Coefficients

Changed the slope correction coefficient, SR, used for all the mitered inlet configurations to the recommended -0.7.

5.2.1.2.4 Changes to Box Culverts

HY-8 changed the 1.5:1 Bevel Wingwall inlet configuration from HY-8 Equation 6 to equation 2. For HY-8 Equations 2, 3, and 6, added 0.01 to the "A" Coefficient in the shape database to account for the fact that the equations were derived using a 2% slope (a 2% slope was used to derive the polynomial equations, meaning 0.5(0.02) was subtracted from each of the polynomial curves and needed to be added back into the equations before correcting for slopes).

5.2.1.2.5 Changes to Shapes using A(1) to A(10) Interpolation Coefficients

Added the slope correction term SR*Slope to the interpolation equations in the code and added 0.01 to the interpolation coefficients for thin, square, and bevel inlets. Subtracted 0.01 for the mitered inlet. Added the SR coefficients (All = 0.5 except for mitered which = -0.7) to the coefficient database and the documentation on this page.

5.2.1.3 Interpolation Coefficients

HY-8 uses interpolation coefficients to determine headwater for culvert shapes that do not have polynomial coefficients available. These shapes include:

- User defined
- Arch, open bottom
- Low-profile arch
- High-profile arch
- Metal box
- Concrete open-bottom arch

These shapes are assumed to have an arch or embedded shape. The interpolation coefficients use figure 3.32 in the FHWA HDS-5 manual, also known as Chart 52B. For more information about how these interpolation coefficients are used, refer to section 3.6.1 of HDS-5.

5.2.1.4 Outlet Control Procedures That Produce an Inlet Control Profile

Sometimes, inlet control is determined when running the outlet control procedures. The flowchart for this condition is described below and in Table 5.1:

1. Compute critical depth (dco)
2. Compute normal depth (dno)
3. Compute fullflow if nomograph solution assumed "6-FFt or FFc".
4. If dno > .95(rise), assume fullflow "6-FFn".
5. If dno > dco, assume mild slope (SEE OUTLET.DAT).
6. If dno <= dco, assume steep slope.
    A. If twh is >= So(L) + rise, assume fullflow "4-FFt".\
    B. If twh is >= rise, outlet submerged, assume inlet unsubmerged.
    C. If twh is < rise, outlet is unsubmerged, assume inlet unsubmerged.
        i. Assume headwater (oh) = inlet control headwater (ih)
        Calculate S2 curve "1-S2n" for outlet depth.
        If oh >= rise, inlet submerged "5-S2n"
        ii. If twh > headwater, tailwater drowns out jump.
        Calculate M1 curve "3-M1t".
        If culvert flows part full, "7-Mit".

Table 5.1: Inlet Control Flow Type Chart

Step	Flow Type	Flow Control	Submerged Inlet	Submerged Outlet	Length Full	Loss Calc	Outlet Depth
6C1	1	Inlet	No	No	None	S2n	Normal
6B3b	1	Inlet	No	Yes	Part	S1f	Full
6C1	5	Inlet	Yes	No	None	S2n	Normal
6B3b	5	Inlet	Yes	Yes	Part	S1f	Full

5.2.2 Outlet Control Computations

5.2.2.1 Outlet Control Flow Types

Outlet control means that the amount of water the culvert barrel can carry is limited by the barrel and/or tailwater conditions downstream. As a result, the flow in the barrel is subcritical, and the energy equation may be used to find the upstream headwater depth. Several flow profiles are possible as are shown below and as described in HDS-5. HY-8 flow types 2, 3, 4, 6, and 7 are all outlet control flow types and are shown in the figure below. The various flow type properties may be found in HY-8 by selecting the Flow Types button from the Culvert Summary Table and are shown below.

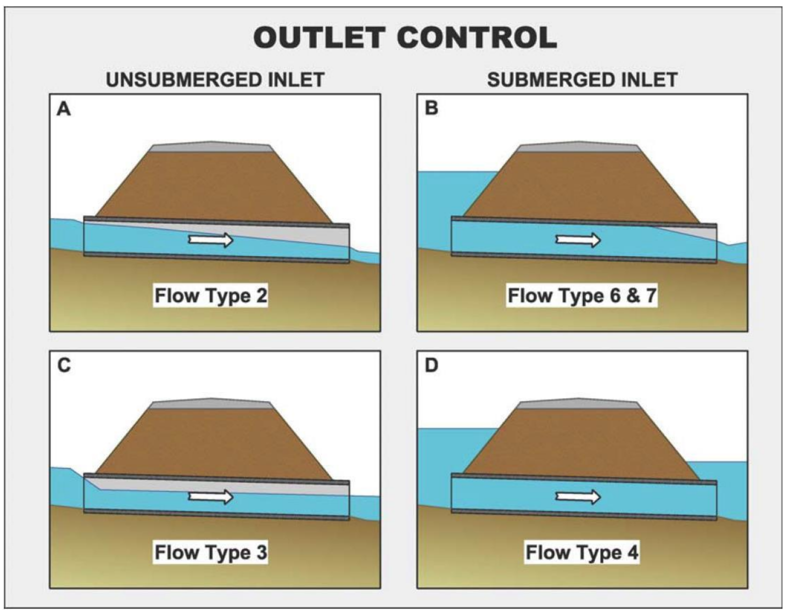


Figure 5.3: Outlet Control Flow Profiles Types.

5.2.2.2 Outlet Control Computations

The initial step of the outlet control computations is to computing the critical and normal depths of the culvert. The outlet control head is initialized to tailwater elevation minus the inlet invert elevation. It will be updated based on the water surface profile.

If the user has selected full flow as the water surface profile option, HY-8 will compute the hydraulic parameters as the culvert barrel is flowing full, and update the Outlet Control Depth based on flowing full.

If the user has selected profiles as the water surface option, the next step is to determine the flow type based on the inlet control depth, the outlet control depth, critical depth, and normal depth. The final step is to perform a direct step computation based on the flow type and hydraulic parameters of the culvert barrel.

The logic for determining flow type due to outlet control in a steeply sloped culvert barrel is shown in the figure below. Please note that function to compute full flow has its own logic to assign flow types and detected hydraulic jumps may change the determined flow type. In the flow chart, where the flow type is assigned, the water surface profile is computed using the direct step method.

This flowchart uses the following terms:

- **Compute Full flow** = Perform full flow computations and determine full flow type.
- **TWH** = Depth of the tailwater from the invert of the tailwater channel at the culvert outlet
- **TW depth** = Depth of the tailwater from the invert of the culvert at the culvert outlet. If the culvert is buried, this value is taken from the top of the embedment material.
- **S** = Slope of the culvert barrel.
- **L** = Length of the culvert barrel.
- **IH** = Inlet control headwater depth measured at the inlet invert of the culvert
- **OH** = Outlet control headwater depth measured at the inlet invert of the culvert
- **RISE** = Height of the culvert. If the culvert is buried, this value is taken from the top of the embedment material.
- **Exit depth** =
- **Critical depth** = The critical depth in the culvert
- **Normal depth** = The normal depth in the culvert
- **Last depth** = the final depth determined in the direct step calculations.

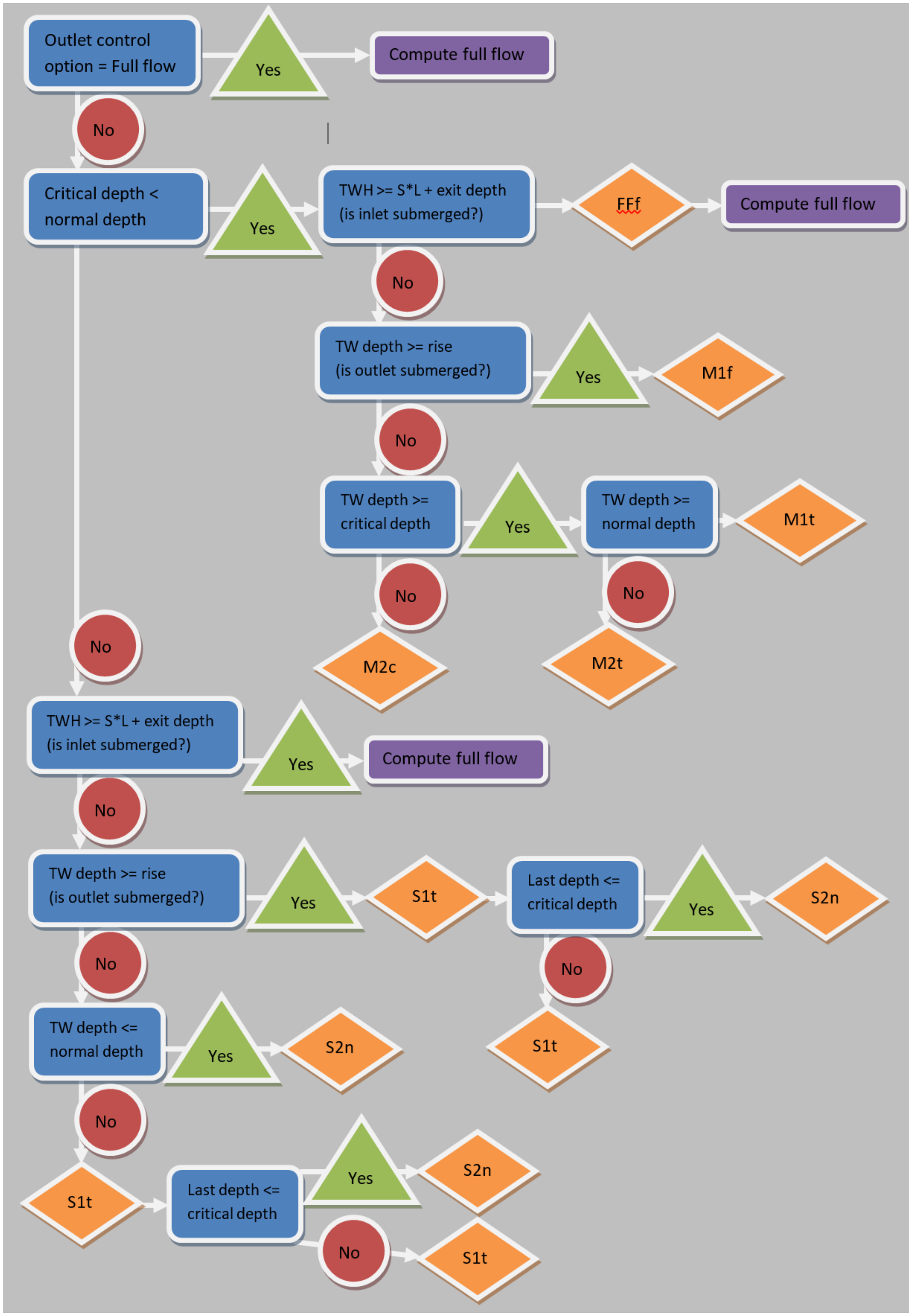


Figure 5.4: Outlet Control Computational Flow Chart.

5.2.3 Composite Manning's n values

5.2.3.1 Composite Manning's n values within Culvert computations

Culverts frequently have two materials. In the case of an open bottom culvert or an embedded culvert, the walls and crown of the culvert have the material of the culvert material while the floor of the culvert is made of the substrate of the streambed material or artificially placed embedment. These materials will vary on the manning's n value. The method used to determine the composite Manning's n value is consistent with equation 3.8 in HDS 5 Third Edition (December 2012) shown on page 3.14 and given below.

$$n_c = \left[\frac{\sum_{i=1}^{G}(p_i {n_i}^{1.5})}{p}\right]^{0.67}$$

n_c	=	Composite or weighted Manning's n value
G	=	Number of different roughness materials in the perimeter
p_1	=	Wetted perimeter in feet influenced by the material 1
p_2	=	Manning's n value for material 1, n_2 is for material 2, etc.
p	=	Total wetted perimeter, ft

5.2.4 Water Surface Profile Option

The user may select the "Outlet Control: Profiles" option to compute water surface profiles or assume the "Outlet Control: Full Flow" option. Most users will not need to change this option from the profile option. Changing this option specifies what is to be used in all computation cases!

Outlet Control: Profiles. The profile outlet control option will compute the flow type and the water surface profile flowing through culvert barrel.

Outlet Control: Full Flow. The full flow outlet control option will compute culvert barrels as flowing full. In the early days of HY-8, users were concerned that they could not duplicate the nomograph results. The full flow option permits the user to compute the same outlet control result that they would have computed by hand using the full flow outlet control nomograph to determine the barrel losses.

The default option of **Outlet Control: Profiles** is the option that should be used in most cases. This profile option will use full flow as appropriate. Using the full flow option will give conservative results.

5.2.5 USGS Flow Type Table

USGS Flow Types

Flow Control	Length Full	Flow Type		Flow Profiles	Outlet		Outlet Depth
		HW>D	HW<D		TW>D	TW<D	
Inlet	none	5	1	S2		n	Normal
Inlet	none	5	1	S1		t	Tailwater (TW)
Inlet	none	5	1	JS1		t	Jump, S1, TW
Inlet	none	5	1	M3, S3, H3, A3		t	Tailwater
Inlet	none	5	1	H3J, A3J		t	H3, Jump, TW
Inlet	part	5	1	S1	f		Full
Inlet	part	5	1	S1	f		Full
Inlet	part	5	1	JS1	f		Jump, S1, Full
Inlet	part	5	1	H3J, A3J	f		H3, Jump, Full
Outlet	none		2	M2, H2, A2		c	Critical
Outlet	none		3	M2, H2, A2		t	Tailwater
Outlet	none		3	M1		t	Tailwater
Outlet	part		3	M1	f		Full
Outlet	all	4		FF	f		Full
Outlet	most	6		FF		t	Tailwater
Outlet	most	6		FF		c	Critical
Outlet	part	7		M1		t	Tailwater
Outlet	part	7		M2, H2, A2		t	Tailwater
Outlet	part	7		M2, H2, A2		c	Critical

Close

Figure 5.5: Outlet Control Computational Flow Chart.

The USGS Flow Type table shows the different options used to categorize the flow profile. A single flow type will be created from the data on a single row.

The first column displays whether the flow type is flowing under inlet or outlet flow control.

The second column displays the length of the culvert that is flowing full from ‘none’, ‘part’, ‘most’, ‘all’.

The third column is divided between whether the inlet is submerged (HW>D) and unsubmerged (HW<D). Numbers are assigned to different flow types primarily by inlet submersion and then by full flow and outlet depth.

The fourth column is the flow profile. The flow profile describes the slope of the culvert and the flow regime that the water surface is located. The culvert can be adversely sloped, horizontally sloped, mildly sloped, or steeply sloped. The flow regimes are separated vertically by the critical and normal depths, as applicable. The flow regimes are shown in the following chart:

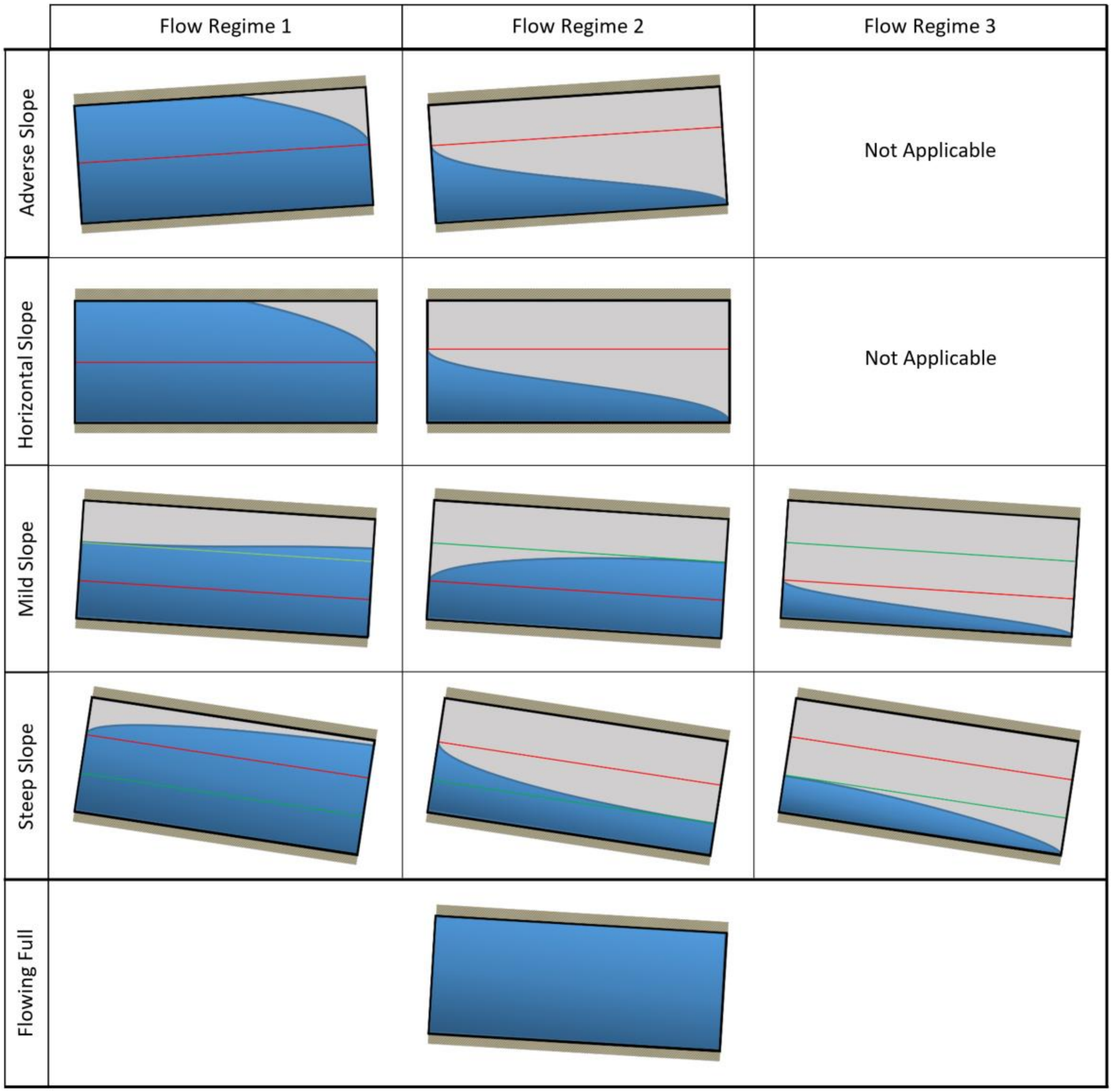


Figure 5.6: Flow Regime Chart. Note that the figures depict the shape that flow will follow across the regime and not actual flow across a culvert.

The fifth column is divided between whether the outlet is submerged (HW>D) and unsubmerged (HW<D). The column is assigned a letter according to the outlet depth: f for full flow depth, t for tailwater depth, n for normal depth, c for critical depth.

The final column is the outlet depth. If there is a possible hydraulic jump, there will be 'jump' included on the row in this column.

An example of a flow type is '1-S2n'. The 1 indicates that this is inlet-controlled with an unsubmerged inlet. The flow profile follows an S2 drawdown curve with a steeply sloped culvert at the flow regime 2 which is between the critical and normal depths. The depth at the outlet is the normal depth which leaves the outlet unsubmerged.

5.2.6 Exit Loss Options

5.2.6.1 Introduction

HY-8 version 7.1 incorporates an alternative modified equation for defining culvert exit loss. The method described in HDS-5 uses the energy equation and several assumptions to compute the exit loss for a culvert. The equation given in HDS-5 ignores the velocity head downstream from a culvert barrel and is given as the following:

$$H_0 = k_0 \frac{V^2}{2g}$$

Where $k_0 = 1.0$

Where H_o is the exit loss, V is the velocity inside the culvert barrel, and g is gravity. However, exit losses obtained from this expression do not match exit losses obtained from experimental studies by the researchers at Utah State University. USU has formulated an alternative expression for determining exit losses that uses the “Borda-Carnot equation”. This equation was originally developed for sudden expansions in pressurized pipes, but was found to give an accurate representation of culvert exit losses by USU’s experimental studies. Two useful forms of this expression are:

$$H_0 = 1.0 \frac{(V_p - V_c)^2}{2g}$$

and

$$H_0 = k_0 \frac{V_p^2}{2g}$$

where

$$k_0 = \left(1 - \frac{A_p}{A_c}\right)^2$$

Where H_o is the exit loss, V_p is the velocity inside the culvert barrel, V_c is the velocity in the downstream channel, and g is gravity. In HY-8, we need to use the first form of the equation ($H_0 = 1.0 \frac{V^2}{2g}$) to compute the exit loss and the corresponding outlet control depth. The only additional value required between this equation and the previous equation is the velocity in the downstream channel. We already compute the downstream channel velocity in HY-8, so we can just use this computed velocity with the Borda-Carnot equation to compute the modified exit loss.

5.2.6.2 Modified Exit Loss Option

To access this equation in HY-8 use *Exit Loss* combo box in the *Macros* toolbar in HY-8. This combo box will have two options: *1) Exit Loss: Standard Method* and *2) Exit Loss: USU Method*.

If the *Standard Method* is selected, HY-8 will use the current method for computing exit losses. If the *USU Method* is selected, HY-8 will use the USU (Borda-Carnot) equation to compute exit losses.

5.2.7 Hydraulic Jump Calculations

5.2.7.1 Determining if a Hydraulic Jump Exists and its Location

A hydraulic jump is created in a rapidly varied flow situation where supercritical flow rapidly becomes subcritical flow. As the flow changes, energy is lost to turbulence. However, momentum is conserved across the jump. The two depths of flow just prior to and after a hydraulic jump are called sequent depths.

To determine if a hydraulic jump exists, HY-8 determines the supercritical and subcritical water surface profiles that form within the culvert using a direct step profile computation. At each location along the two profiles, HY-8 computes the sequent depths of the supercritical profile and compares these sequent depths to the subcritical profile's computed depth.

While HY-8 computes the supercritical profile, a hydraulic jump forms if either of the following two conditions occurs: (1) the sequent depth profile intersects the subcritical profile, or (2) the Froude number is reduced to approximately 1.7 in a decelerating flow environment (M3, S3, H3, or A3 flow) (See the section in FHWA's HEC-14 on broken back culverts, 7.4).

If the outlet is submerged, HY-8 uses the energy equation to determine the hydraulic grade line. Once the hydraulic grade line falls below the crown of the culvert, HY-8 uses the direct step method to determine the remainder of the profile.

The equations used to determine the sequent depth vary by shape and are detailed in Nathan Lowe's thesis (Lowe, 2008). Sequent Depths are not adjusted for slope or hydraulic jump type (see Hydraulic Jump Types).

An example of a profile set and sequent depth calculations from a box culvert is given in Table 1 and plotted in Figure 1. The subcritical depth is shown extending above the crown of the culvert to show the hydraulic grade line for comparison purposes. Once HY-8 concludes the hydraulic jump calculations, the flow profile is modified to be contained within the culvert barrel.

Table 5.2: Parameters of the culvert used for an example

Parameter	Value	Units
Culvert Shape	Box	
Rise:	6.0	ft
Span:	6.0	ft
Length:	100.0	ft
Flow:	80.0	cfs

Table 5.3: HY-8 Water surface profile and sequent depth calculations

Computation Direction: Upstream to Downstream		
Location (ft)	**S2 Water Depth (ft)**	**Sequent Depth (ft)**
0	1.767423128	1.767423128
0.029316423	1.717423128	1.818384336
0.121221217	1.667423128	1.871344458
0.284143628	1.617423128	1.926427128
0.528025114	1.567423128	1.983769228
0.86466911	1.517423128	2.043522893
1.308192917	1.467423128	2.105857905
1.87561876	1.417423128	2.17096453
2.587657601	1.367423128	2.239056945
3.469764745	1.317423128	2.310377355
4.553586554	1.267423128	2.385201009
5.878983069	1.217423128	2.463842333
7.496921363	1.167423128	2.546662495
9.473726216	1.117423128	2.634078814
11.89752361	1.067423128	2.726576563
14.88838	1.017423128	2.824723925
18.61499626	0.967423128	2.929191151
23.32377651	0.917423128	3.040775386
29.3931714	0.867423128	3.160433253
37.44519272	0.817423128	3.289324251
48.60550709	0.767423128	3.42886946
65.23610698	0.717423128	3.580832395
93.76009585	0.667423128	3.747432593
100	0.663122364	3.762533062

Computation Direction: Downstream to Upstream	
Location (ft)	**S1 Water Depth (ft)**
100	7.78884205
76.62538619	6
76.01536408	5.95
75.40596369	5.9
74.79697048	5.85
74.18839865	5.8
73.58026305	5.75
72.97257915	5.7

72.36536314	5.65
71.75863195	5.6
71.15240324	5.55
70.54669552	5.5
69.94152813	5.45
69.33692135	5.4
68.73289638	5.35
68.12947544	5.3
67.52668185	5.25
66.92454003	5.2
66.3230756	5.15
65.72231547	5.1
65.12228788	5.05
64.5230225	5
63.92455054	4.95
63.32690478	4.9
62.73011975	4.85
62.13423177	4.8
61.5392791	4.75
60.94530208	4.7
60.35234323	4.65
59.76044741	4.6
59.16966197	4.55
58.58003695	4.5
57.9916252	4.45
57.40448266	4.4
56.81866848	4.35
56.23424533	4.3
55.6512796	4.25
55.06984171	4.2
54.49000634	4.15
53.91185285	4.1
53.33546552	4.05
52.76093401	4
52.18835372	3.95
51.61782627	3.9
51.04946001	3.85

50.48337049	3.8
49.91968113	3.75
49.35852381	3.7
48.80003962	3.65
48.24437962	3.6
47.69170569	3.55
47.1421915	3.5
46.59602356	3.45
46.05340235	3.4
45.51454362	3.35
44.97967983	3.3
44.44906168	3.25
43.92295991	3.2
43.40166723	3.15
42.88550053	3.1
42.37480328	3.05
41.86994835	3
41.37134098	2.95
40.87942233	2.9
40.39467334	2.85
39.91761912	2.8
39.44883402	2.75
38.98894719	2.7
38.53864914	2.65
38.09869903	2.6
37.66993312	2.55
37.25327445	2.5
36.84974393	2.45
36.46047324	2.4
36.08671965	2.35
35.72988334	2.3
35.39152756	2.25
35.07340226	2.2
34.77747182	2.15
34.50594783	2.1
34.26132798	2.05
34.04644235	2

33.86450893	1.95
33.71920038	1.9
33.61472501	1.85
33.55592549	1.80

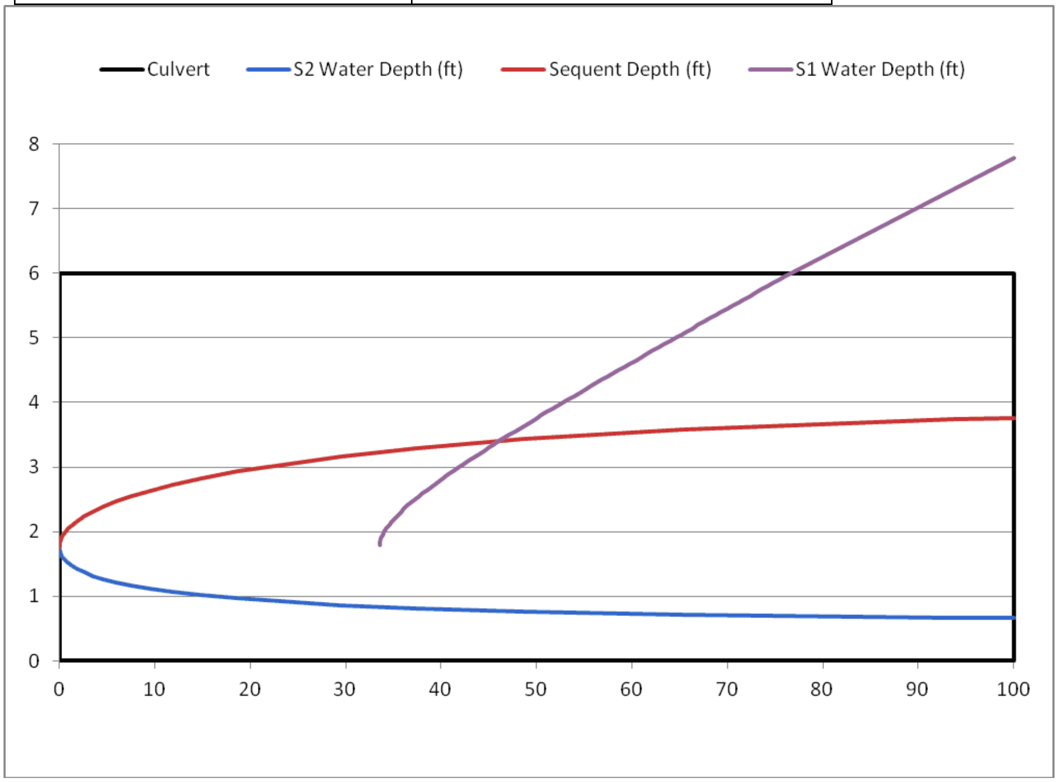


Figure 5.7: Computed water surface profiles and sequent depth plotted in culvert barrel

Figure 1: HY-8 Water Surface Profile and Sequent Depth Calculations

In Figure 1, the sequent depth shown by the red line crosses the S1 water depth shown by the purple line. The point of intersection is where a hydraulic jump occurs and is located at approximately 46' downstream of the inlet of the culvert. HY-8 creates a combined water surface profile from the two profiles. If you assume that the length of the hydraulic jump is zero, the jump would be a vertical line. An example of a water surface profile for a hydraulic jump assuming zero jump length is shown in the figure below.

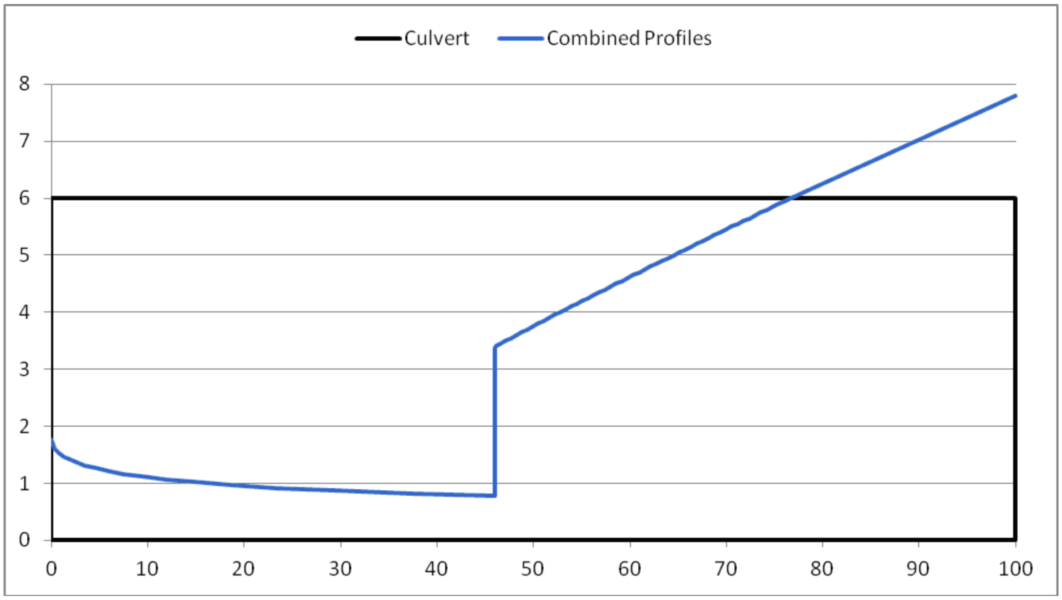


Figure 5.8: Computed water surface profiles with a vertical hydraulic jump where the sequent depth crosses the S1 profile

Once HY-8 determines that a jump occurs and the jump's location, HY-8 determines the length of the jump and applies that length to the profile. Before determining the length, however, HY-8 must first determine the type of hydraulic jump so the appropriate equation can be used for computing the length.

5.2.7.2 Hydraulic Jump Types

HY-8 divides hydraulic jumps into 3 different types: A, B, and C (See Figure 3). Type A jumps occur on a flat slope, and this condition often occurs at the downstream section of a Broken Back Culverts if a hydraulic jump did not occur in the steep section of the culvert. Type B jumps only occur in Broken Back Culverts where the jump starts in the steep section of the culvert but finishes in the downstream section of the culvert. Type C jumps could occur in any sloped culverts.

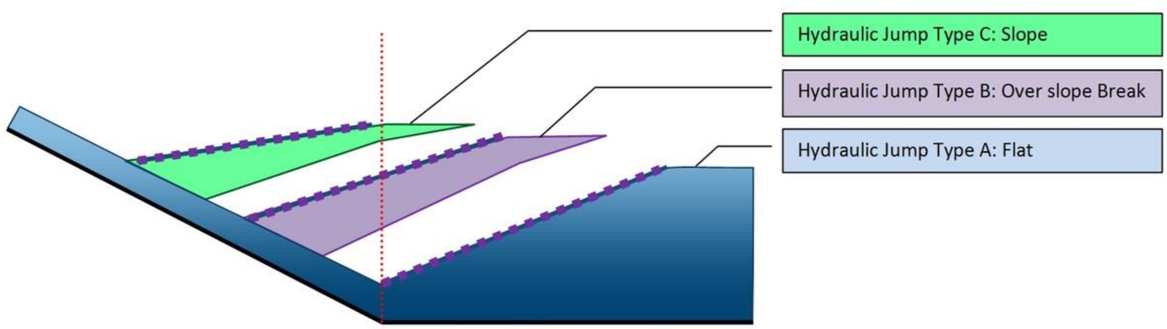


Figure 5.9: Hydraulic Jump types used in HY-8

5.2.7.3 Determining the Length of a Hydraulic Jump

HY-8 uses equations determined by Bradley and Peterka (1957) and Hager (1992) as shown in the following table. Complete information about the lengths of hydraulic jumps does not exist in the literature. These portions of the table, where equations representing the hydraulic jump length are not available, are denoted with a "-". In instances where an equation has not been determined, an explanation of how HY-8 computes the length is shown.

Table 5.4: HY-8 hydraulic jump length equations

Culvert Shape	Flat Slope (Type A)	Sloped Culvert (Type C)	Jump Over Slope Break (Type B)
Circular	$L_j^* = 6y_2$	- (Use box equation)	- (Use box equation)
Box	$L_j^* = 220(y_1)\left(\tanh\left(\frac{Fr_1 - 1}{22}\right)\right)$		First, solve for Fr_{1t} $Fr_{1t} = 11.3\left(1 - \frac{2}{3}[(h_2 - z_1)/h_2]\right)$ Then, if $Fr_1 > Fr_{1t}$ $L_j = L_j^*$ Otherwise, if $Fr_1 \leq Fr_{1t}$ $L_j = h_2\left[\frac{7}{3}(2 + [6E * exp(1 - 6E)]) - \frac{1}{20}(1 + 5[6E * exp(1 - 6E)](Fr_1 - 2))\right]$ Where: $E = (h_2 - z_1)/h_2$
Ellipse	Use longer of circular and box equations	- (Use box equation)	- (Use box equation)
Pipe Arch	Use longer of circular and box equations	- (Use box equation)	- (Use box equation)
User Defined/ Other	Use longer of circular and box equations	- (Use box equation)	- (Use box equation)

In the above table, you can see that the literature is incomplete for the jump lengths of several of the shapes supported in HY-8. Further research is required for a more accurate analysis. The following variables are used in the above table and are shown in Figure 4:

- **L j *** = Length of the hydraulic jump on a flat slope (ft or m)
- **y** 1 = Sequent depth at the upstream end of the hydraulic jump (ft or m)
- **y** 2 = Sequent depth at the downstream end of the hydraulic jump (ft or m)
- **Fr** 1 = Froude number at the upstream end of the hydraulic jump
- **θ** = Channel angle of repose (in radians, = Arctan(channel slope))
- **L j** = Length of the hydraulic jump on a sloping channel (ft or m)
- **z** 1 = Distance from the invert of the flat part of the channel to the channel invert at the beginning of the jump (ft or m)
- **h** 2 = Depth of water on a flat slope after the jump (ft or m)

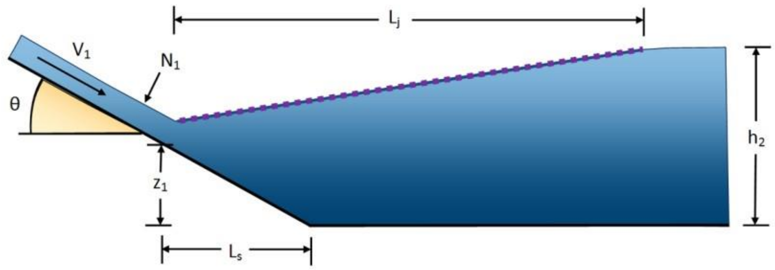


Figure 5.10: Definition sketch for the variables used in hydraulic jump length computations

HY-8 determines the length of the jump and modifies the profile to an angled transition to the subcritical flow rather than a vertical transition. The beginning of the jump is assumed to be the location previously determined as the jump location. The end of the jump is the beginning of the jump plus the jump length. If the end of the jump is outside of the culvert, the jump is assumed to be swept out. This may or may not happen, but is considered to be conservative. This assumption means HY-8 reports less hydraulic jumps than may actually occur. Example hydraulic jump length calculations are shown in Table 4. The profile showing the hydraulic jump with the jump length applied is shown in Figure 5.

Table 5.5: Sample hydraulic jump length calculations

Parameter	Value	Units
Culvert Shape	Box	
Froude Number 1:	3.4229	
Depth 1:	0.7778	ft
Length of Jump:	18.77	Ft
Station 1:	46.0	ft
Station 2:	64.8	ft

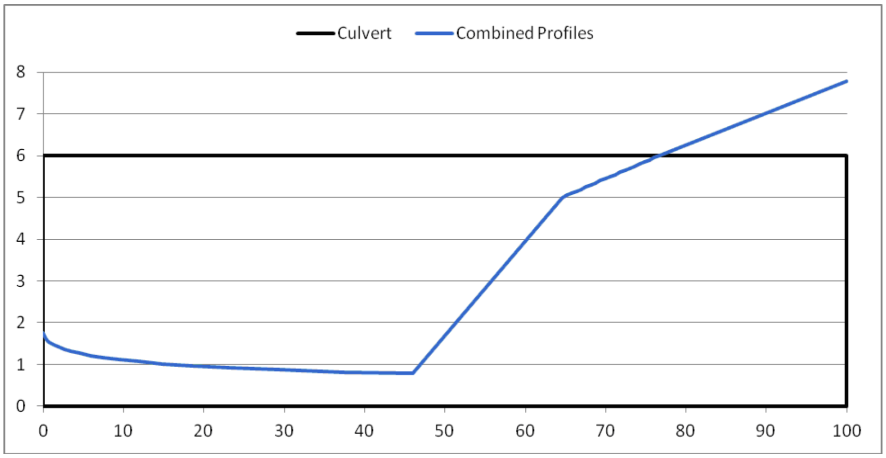


Figure 5.11: Water profle with hydraulic jump with calculated jump length

When HY-8 finishes computing the hydraulic jump length, and has applied it to the profile, HY-8 trims the profile to stay within the culvert barrel. The completed profile is shown in Figure 6.

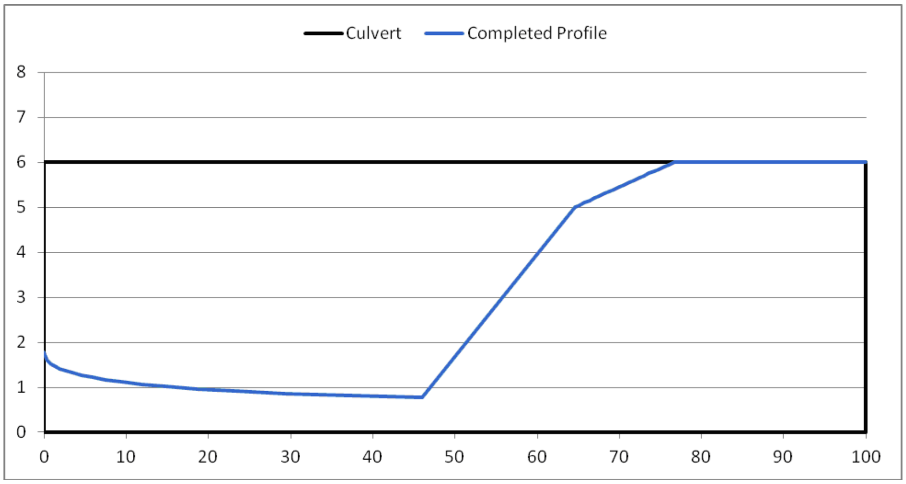


Figure 5.12: Completed water surface profile

5.2.7.4 References

- Lowe, N. J. (2008). THEORETICAL DETERMINATION OF SUBCRITICAL SEQUENT DEPTHS FOR COMPLETE AND INCOMPLETE HYDRAULIC JUMPS IN CLOSED CONDUITS OF ANY SHAPE. Provo, Utah: Brigham Young University.
- Bradley, J.N. and Peterka, A.J., The hydraulic design of stilling basins: hydraulic jumps on a horizontal apron (Basin I), Journal of the Hydraulics Division, ASCE, 83 (HY5), pp. 1401 (1-24), 1957.
- Hager, W.H. Energy Dissipators and Hydraulic Jump. Kluwer Academic Publishers, Dordrecht, Netherlands, 1992.

5.3 Tables and Plots

5.3.1 Tables and Plots

After analyzing the culvert crossing, the user can view the following tables and plots:

- Crossing Summary Table
- Culvert Summary Table
- Water Surface Profiles
- Tapered Inlet Table
- Customized Table

The user can control the appearance of plots within HY-8 using the Plot Display Options

5.3.2 Crossing Summary

The crossing summary table shows the balance of discharge moving through the culvert(s) at the crossing and over the roadway. The table displays the following variables:

- **Headwater Elevation**: the elevation of the headwater when the flow is balanced between the culvert(s) and roadway.
- **Total Discharge**: the sum of the discharge through the culvert barrel(s) and over the roadway.
- **Culvert Discharge**: the balance discharge through all the barrels in the first culvert.*
- **Roadway Discharge**: total discharge overtopping the roadway.
- **Iteration**: displays the number of iterations required to reach the convergence limit. Note: there will be a column for the discharge through each culvert in the crossing.

When the crossing summary table option is selected, the user may also view the total rating curve for all culverts in the crossing. A sample rating curve is shown in the figure below.

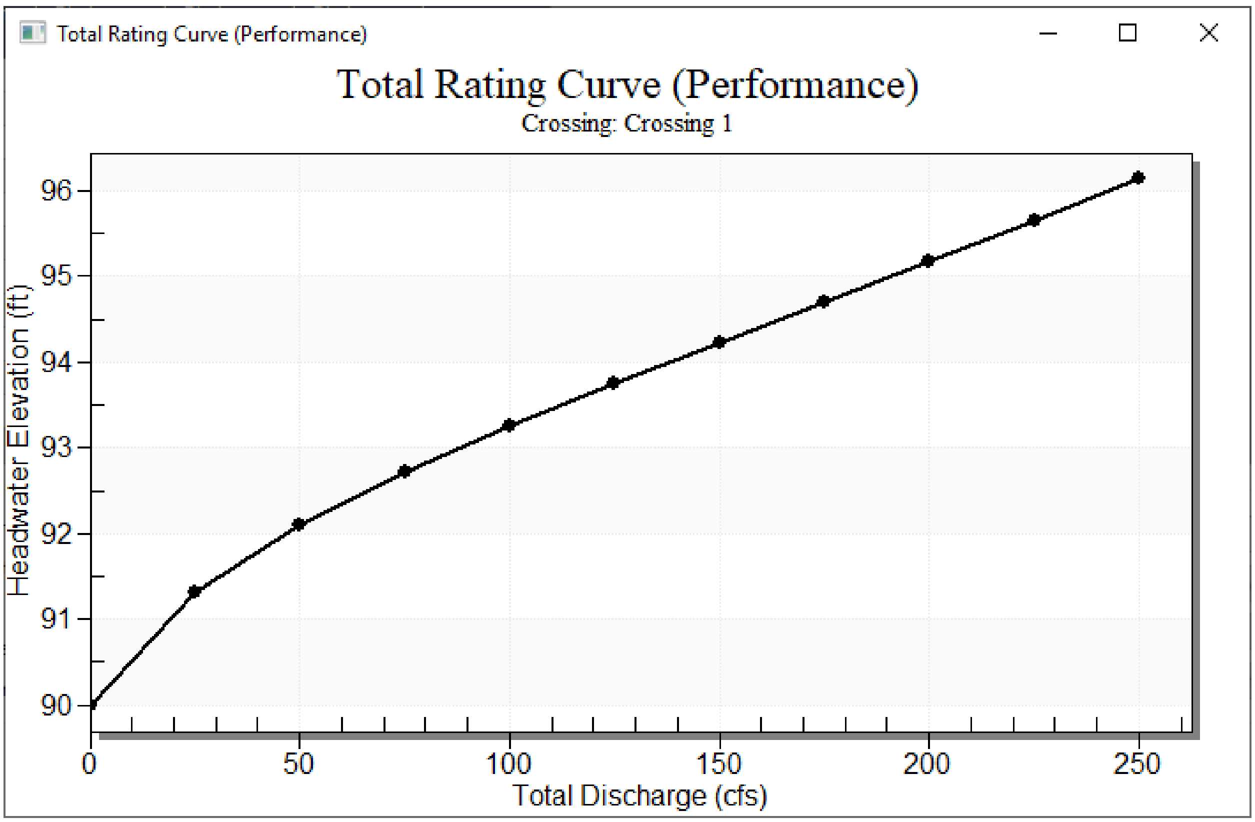


Figure 5.13: Total rating curve plot

5.3.3 Culvert Summary

The culvert summary table shows the performance table for each culvert in the crossing. Each culvert's properties can be viewed by selecting the desired culvert from the drop-down list. The following properties are represented in the table:

- **Total Discharge**: Total discharge at the culvert crossing
- **Culvert Discharge**: Amount of discharge that passes through the selected culvert barrel(s)
- **Headwater Elevation**: Computed headwater elevation at the inlet of the culvert(s)

- **Inlet Control Depth**: Inlet control headwater depth above inlet invert
- **Outlet Control Depth**: Outlet control headwater depth above inlet invert
- **Flow Type**: USGS flow type 1 through 7 is indicated and the associated profile shape and boundary condition. Press the *Flow Types* button for a summary of Flow Types.
- **Normal Depth:** Normal depth in the culvert. If the culvert capacity is insufficient to convey flow at normal depth, normal depth is set equal to the barrel height.
- **Critical Depth**: Critical depth in culvert. If the culvert capacity is insufficient to convey flow at critical depth, critical depth is set equal to the barrel height.
- **Outlet Depth**: Depth at culvert outlet
- **Tailwater Depth**: Depth in downstream channel
- **Outlet Velocity**: Velocity at the culvert outlet
- **Tailwater Velocity**: Velocity in downstream channel

In the table, bold values indicate inlet or outlet controlling depths. Within the culvert summary option, the user may plot the performance curve for each culvert in the crossing. A sample performance curve is displayed in the figure below.

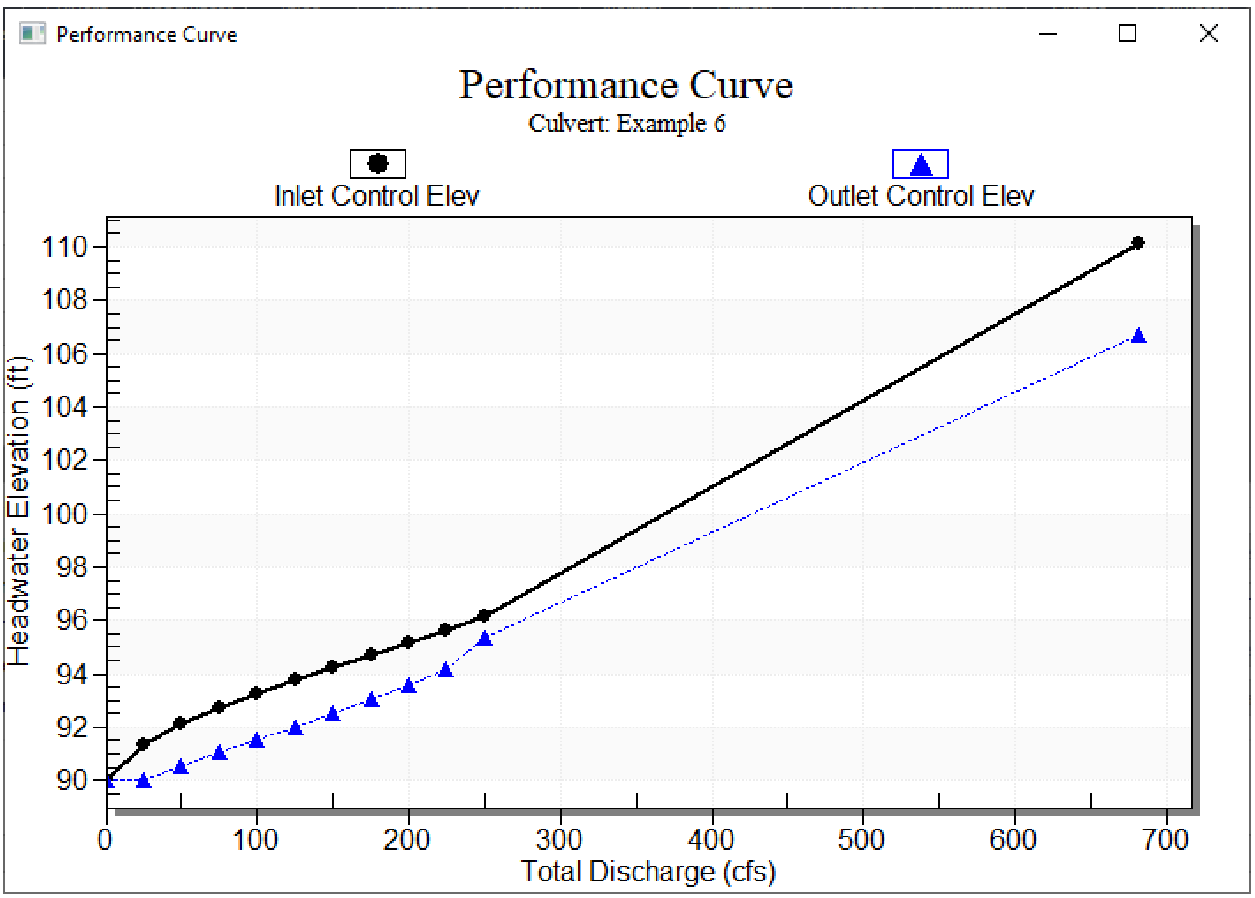


Figure 5.14: Performance curve plot

5.3.4 Water Surface Profiles

Water surface profile information is displayed in a table format for each of the discharge values. Once a profile is selected, the user may then plot and view the profile. The following parameters are displayed in the water surface profiles table:

- **Total Discharge**: Total discharge at the culvert crossing
- **Culvert Discharge**: Amount of discharge that passes through the culvert barrel(s)
- **Headwater Elevation**: Computed headwater elevation at the inlet of the culvert
- **Inlet Control Depth**: Headwater depth above inlet invert assuming inlet control
- **Outlet Control Depth**: Headwater depth above inlet invert assuming outlet control
- **Flow Type**: USGS flow type 1 through 7 is indicated and the associated profile shape and boundary condition. Press the *Flow Types* button for a summary of Flow Types
- **Length Full**: Length of culvert that is flowing full.
- **Length Free**: Length of culvert that has free surface flow.
- **Last Step**: Last length increment calculated in profile.
- **Mean Slope**: Last mean water surface slope calculated.
- **First Depth**: Starting depth for water surface profile.
- **Last Depth**: Ending depth for the water surface profile.

While viewing the water surface profiles table, the user may plot any of the profiles by selecting the desired profile in the table and clicking the water profile button in the window. Below is a sample water surface profile for a circular culvert.

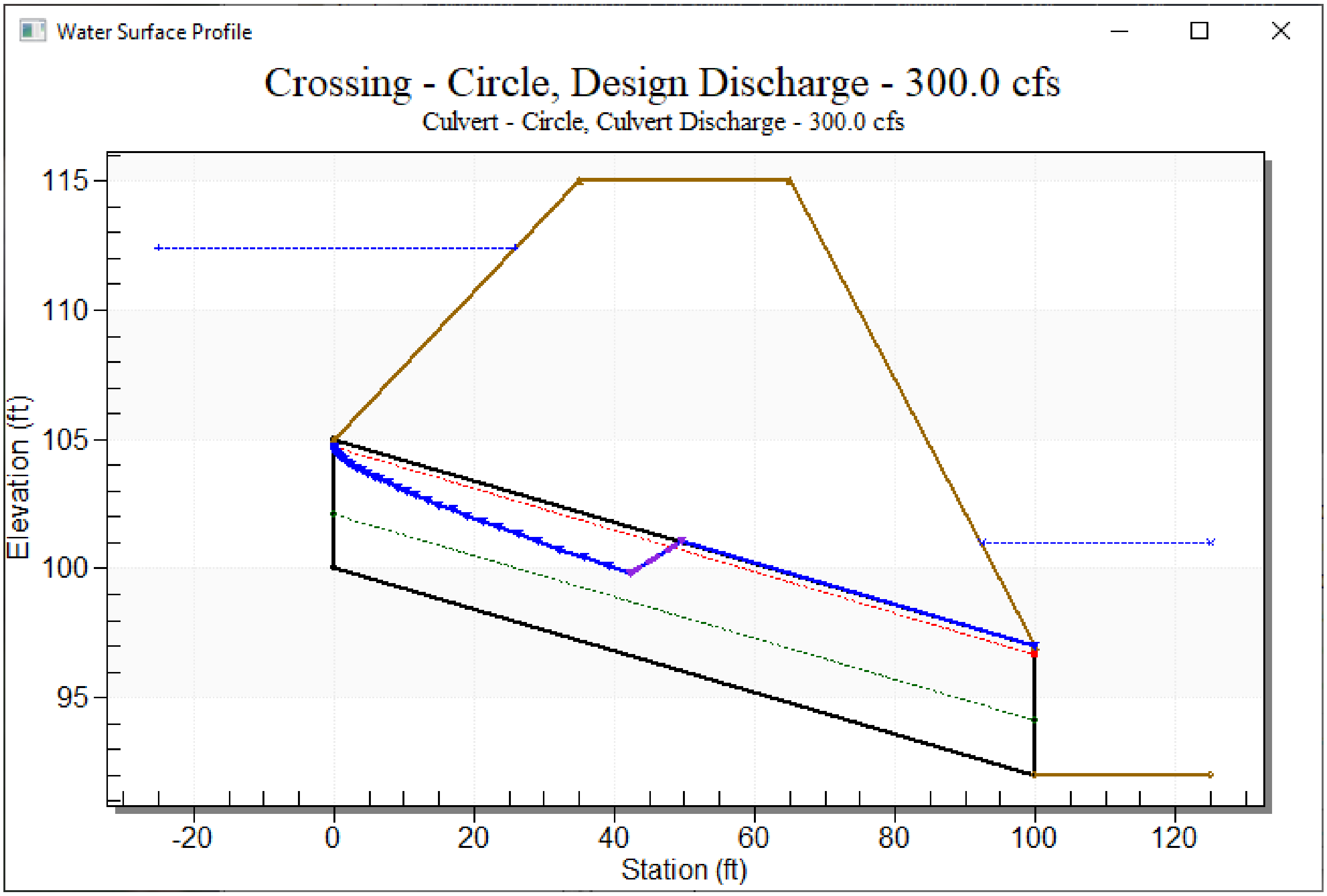


Figure 5.15: Water surface profile plot

5.3.5 Tapered Inlet

The tapered inlet table is designed to be used with tapered inlets and shows the headwater elevation at the culvert inlet based on different controls such as the crest, face, and throat. The following parameters are computed and displayed:

- **Total Discharge**: Total discharge at the culvert crossing
- **Culvert Discharge**: Amount of discharge that passes through the culvert barrel(s)
- **Headwater Elevation**: Computed headwater elevation at the inlet(s) of the culvert(s)
- **Inlet Control Depth**: Inlet control headwater depth above inlet invert
- **Outlet Control Depth**: Outlet control headwater depth above inlet invert
- **Flow Type**: USGS flow type "Full Flow HDS-5" is shown if full flow outlet control option is selected
- **Crest Control Elevation**: Headwater elevation calculated assuming crest control.
- **Face Control Elevation**: Headwater elevation calculated assuming face control.
- **Throat Control Elevation**: Headwater elevation calculated assuming throat control.
- **Tailwater Elevation**: Tailwater elevation at culvert outlet from downstream channel.

The tapered inlet table also provides the option of plotting and viewing the culvert performance curve.

5.3.6 Customized

The user sets up the customized table by clicking on the options button when the customized table feature is selected. The figure below shows the different variables that can be displayed in the culvert summary, profile, and tapered inlet tables.

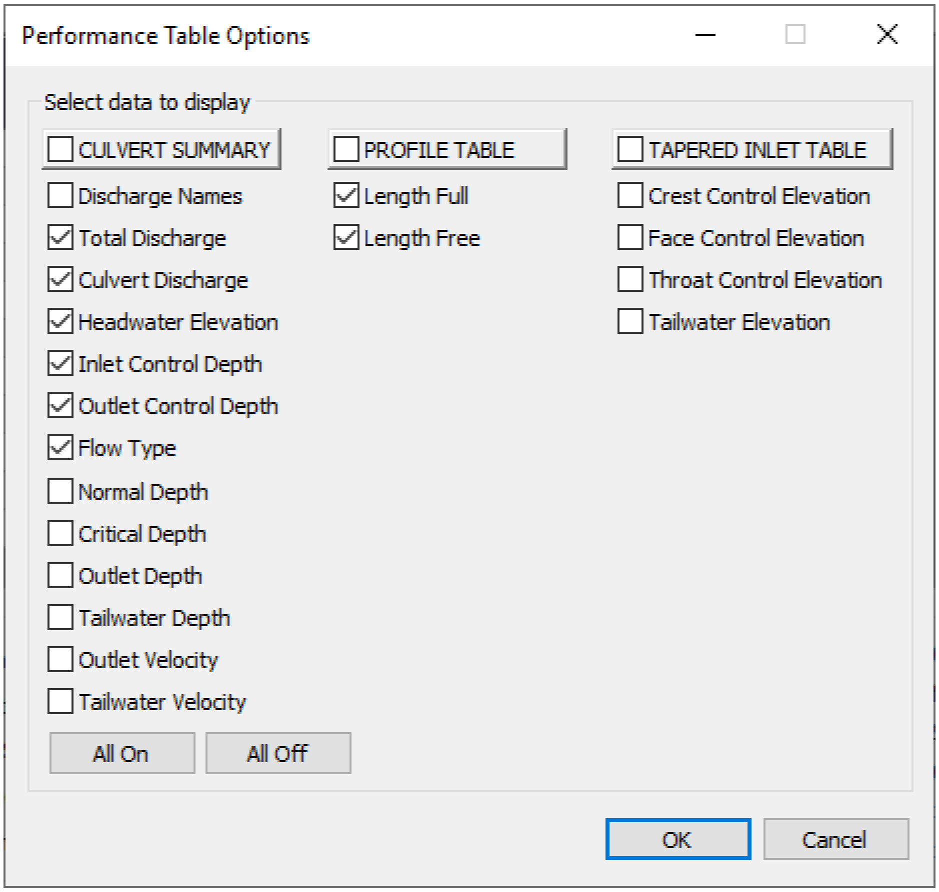


Figure 5.16: Example of the Customized Table Options dialog

5.3.7 Controlling Plot Display Options

The user can manage the available plots in HY-8 through right-clicking in the plot window. Because the same plot library is used for all plots (culvert profiles, front views, performance curves, etc.) they can all be controlled in the same fashion, but the menus are slightly different depending on the plot. For example the right-click menu for the front and side views of the main HY-8 window include menus for editing the culvert crossing data, analyzing the culvert crossing, and defining culvert notes. The right-click menu for a performance curve would not include these menus.

However, it should be emphasized that changing the display options of a plot window DOES NOT alter the hydraulic computations, it only modifies the display of currently computed values.

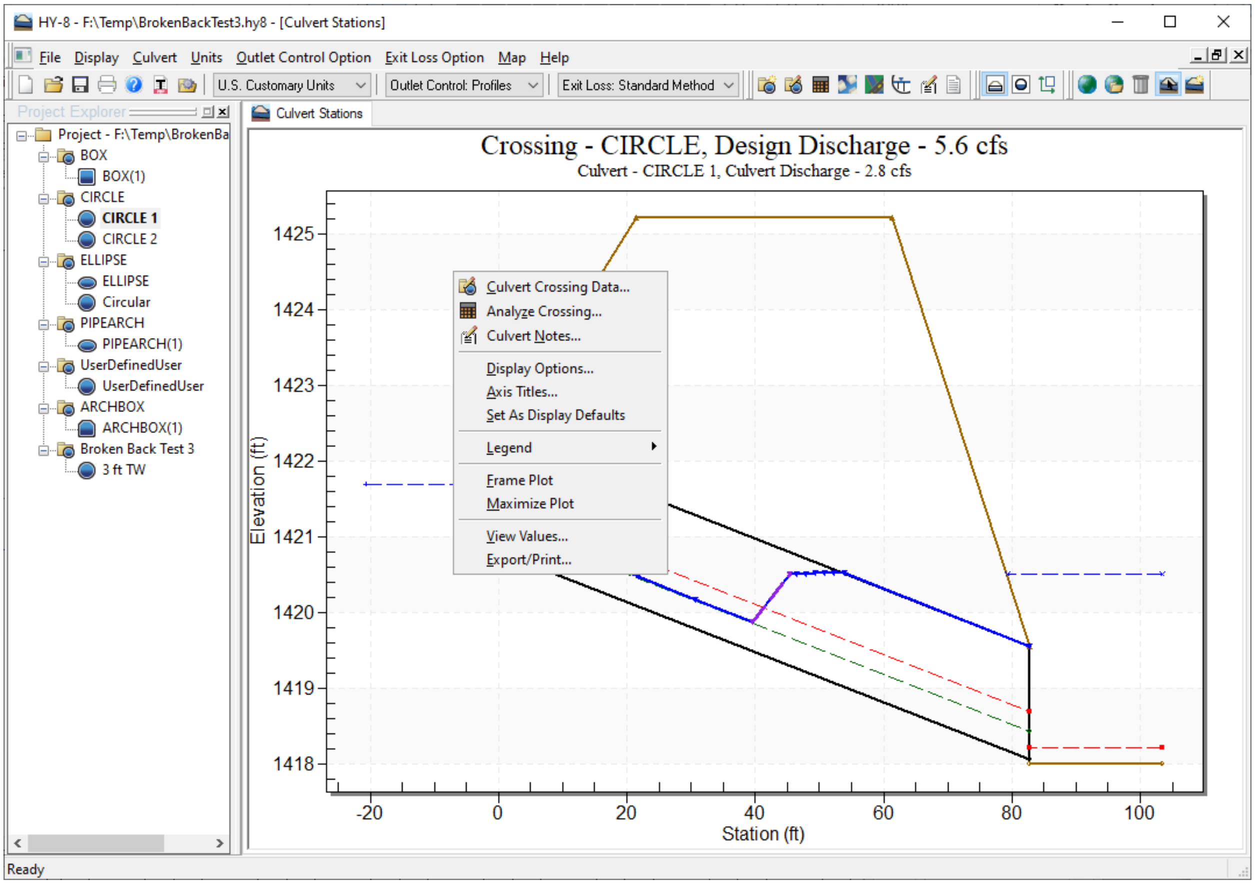


Figure 5.17: Example of the plot window right-click

The right-click menu provides options for the user to control the *Display Options* of the plot. These options include the ability to modify fonts, symbols, colors, axis ranges and titles, legends, exporting, and more as shown in the *Display Options* dialog below.

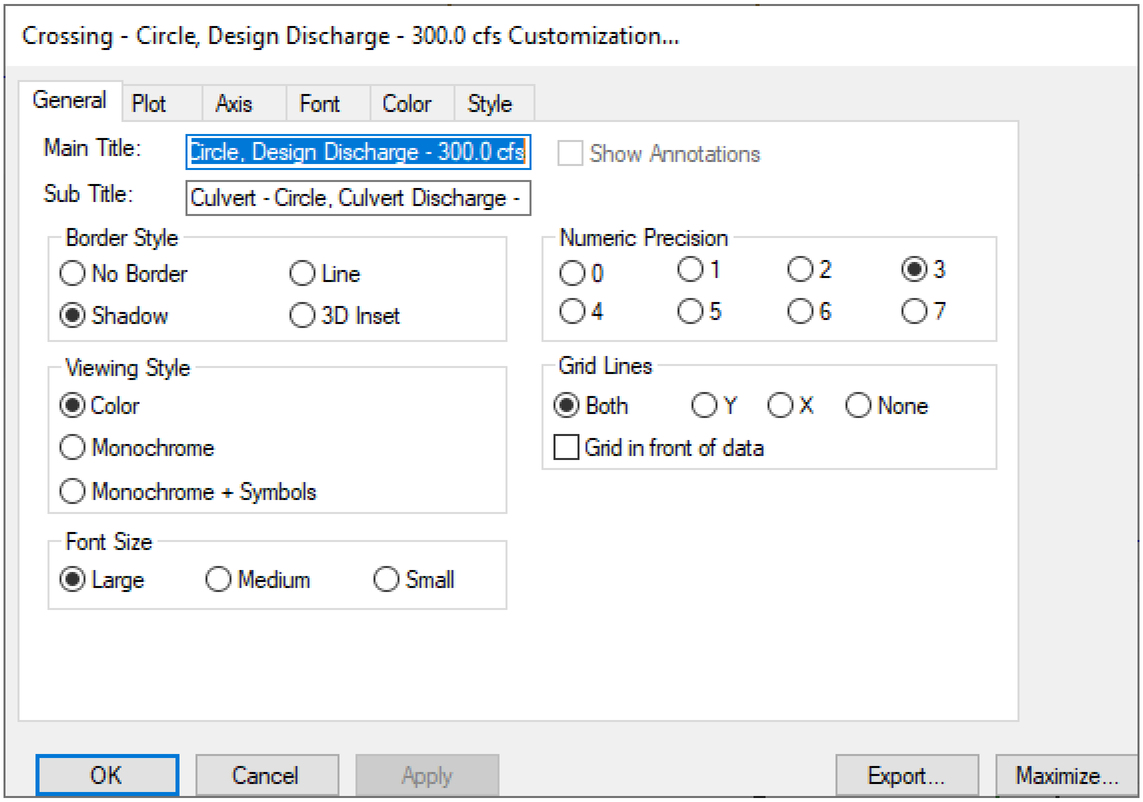


Figure 5.18: Example of the Display Options dialog.

Some of the more commonly used options like axis titles, legends, and exporting are available directly from the right-click menu.

5.3.7.1 Exporting and Printing

The user may export the plot to three different locations: the system clipboard, a file, or printer. You can also export to the following formats: MetaFile, BMP, JPG, PNG, and Text. The text format contains a table of the values that are plotted. These can be viewed by right-clicking on the plot, and selecting View Values. If you are exporting a MetaFile, BMP, JPG, or PNG, you can select the size of the image you wish to export.

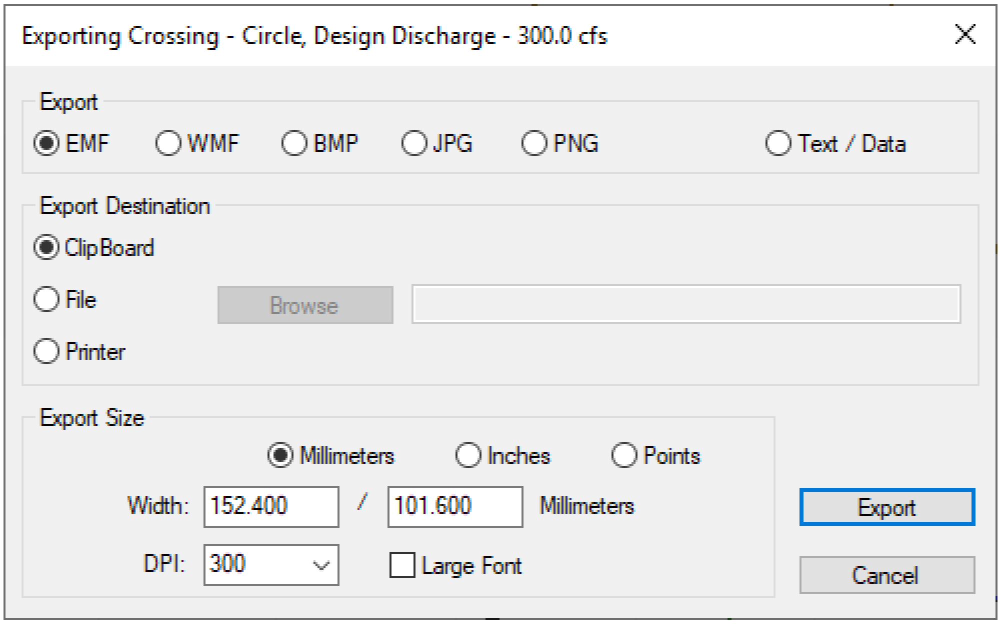


Figure 5.19: Example of the Export Crossing dialog

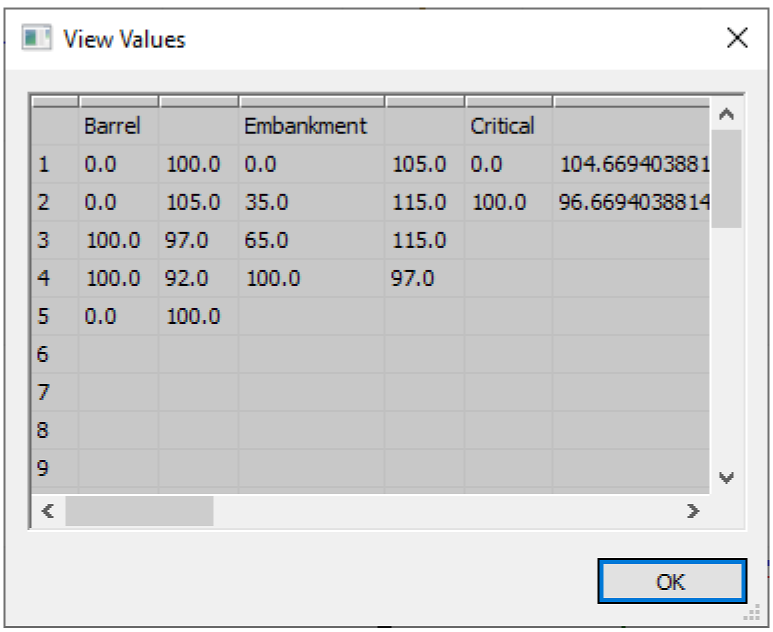


Figure 5.20: Example of the View Values Dialog

5.3.7.2 Zooming and Panning

To zoom in on a part of a plot, drag a box over the area you wish to see. There is no zoom out tool. To view the entire image, right-click on the plot and select *Frame Plot*. You can also view the plot in Full-Screen mode by right-clicking on the plot and selecting *Maximize Plot*. To exit Full-Screen mode, press escape.

6 Energy Dissipation

Hydraulic Engineering Circular No. 14 (HEC-14) describes several energy dissipating structures that can be used with culverts. HEC-14 describes procedures that can be used to compute scour hole sizes and design internal and external dissipators. It outlines the following steps that can be used when designing a culvert:

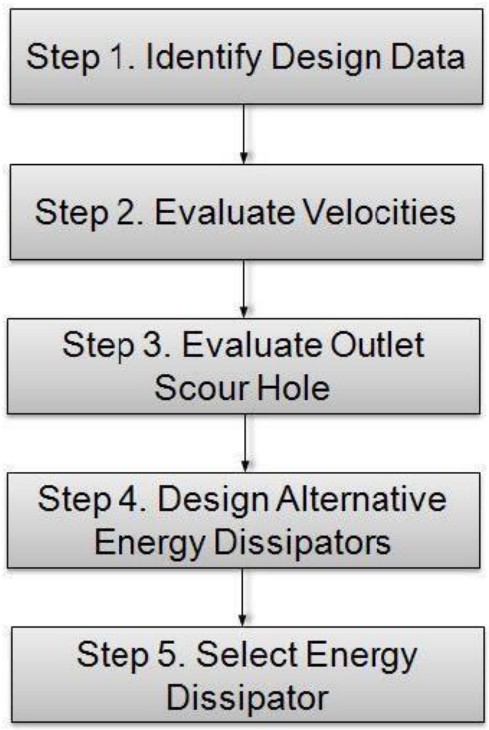


Figure 6.1: Energy dissipation workflow diagram

HEC-14 also describes the energy dissipators and their limitations as follows:

Table 6.1: Energy dissipators available in HY-8

Chapter	**Dissipator Type**	**Froude Number [1] (Fr)**	**Allowable Debris [2]**			**Tailwater (TW)**
Silt/Sand	**Boulders**	**Floating**				
4	Flow transitions	na	H	H	H	Desirable
5	Scour hole	na	H	H	H	Desirable
6	Hydraulic jump	> 1	H	H	H	Required
7	Tumbling flow [3]	> 1	M	L	L	Not needed
7	Increased resistance [4]	na	M	L	L	Not needed

7	USSBR Type IX baffled apron	< 1	M	L	L	Not needed
7	Broken-back culvert	> 1	M	L	L	Desirable
7	Outlet weir	2 to 7	M	L	M	Not needed
7	Outlet drop/weir	3.5 to 6	M	L	M	Not needed
8	USBR Type II stilling basin	4.5 to 17	M	L	M	Required
8	USBR Type IV stilling basin	2.5 to 4.5	M	L	M	Required
8	SAF stilling basin	1.7 to 17	M	L	M	Required
9	CSU rigid boundary basin	< 3	M	L	M	Not needed
9	Contra Costa basin	< 3	H	M	M	< 0.5D
9	Hook basin	1.8 to 3	H	M	M	Not needed
9	USBR Type VI impact basin [5]	na	M	L	L	Desirable
10	Riprap basin	< 3	H	H	H	Not needed
10	Riprap apron [6]	na	M	L	L	Desirable
11	Straight drop structure [7]	< 1	H	L	M	Required
11	Box inlet drop structure [8]	< 1	H	L	M	Required
12	USACE stilling well	na	M	L	N	Desirable

na = not applicable.

1 At release point from culvert or channel
2 Debris notes: N = none, L = low, M = moderate, H = heavy
3 Bed slope must be in the range 4% < S_o < 25%
4 Check headwater for outlet control
5 Discharge, Q < 11 m^3/s (400 ft^3/s) and Velocity, V < 15 m/s (50 ft/s)
6 Culvert rise less than or equal to 1500 mm (60 in)
7 Drop < 4.6 m (15 ft)
8 Drop < 3.7 m (12 ft)

6.1 Scour Hole Geometry

The scour hole geometry presented in this screen represents the local scour at the outlet of structures based on soil and flow data and culvert geometry. Chapter 5 of FHWA publication HEC 14, Hydraulic Design of Energy Dissipators for Culverts and Channels, dated July 2006, presents the general concept and equations used by the program to compute the scour hole geometry for cohesive and cohesionless materials.

NOTE – a soil analysis should be performed prior to running this option of the program. For Cohesive soils, the program requires the following parameters:

- Time to Peak—enter the value obtained in the 'HYDROLOGY' option of HY-8 (If unknown enter 30 minutes).
- Saturated Shear Strength—obtained by performing test no. ASTM D211-66-76.

- Plasticity Index—obtained by performing test no. ASTM D423-36. For cohesionless soils, the program requires the following parameters:
- Time to Peak—enter the value obtained in the 'HYDROLOGY' option of HY-8 (If unknown enter 30 minutes).
- D16, D84—soil particle diameters which represent percent of particles finer.

6.1.1 Note on Time to Peak

The user should estimate the time of scour based upon knowledge of peak flow duration. Lacking this knowledge, it is recommended that a time of 30 minutes be used in Equation 5.1. The tests indicate that approximately 2/3 to 3/4 of the maximum scour depth occurs in the first 30 minutes of the flow duration. The exponents for the time parameter in Table 5.1 reflect the relatively flat part of the scour-time relationship (t > 30 minutes) and are not applicable for the first 30 minutes of the scour process.

6.2 Internal Energy Dissipators

6.2.1 Increased Resistance in Box Culverts

The input variables required for this calculation are the following:

- h/r_i —Ratio of roughness element height divided by hydraulic radius taken about the top of the roughness element.
- Height of the roughened section (h)

The following figure shows the flow regimes and variables for an increased resistance energy dissipator implemented in a circular culvert.

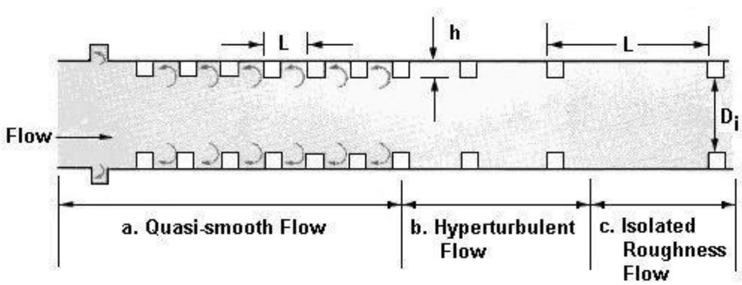


Figure 6.2: Definition sketch for increased resistance in box culverts

Variables from the figure

- L—Length from beginning of one roughness element to the beginning of the next roughness element.
- h—height of roughness element
- D_i —diameter of roughened section (opening)

6.2.2 Increased Resistance in Circular Culverts

The input variables required for this calculation are the following:

- L/D_i — Ratio of roughness element spacing divided by the diameter of the culvert opening at the roughness element. (Range = .05 to 1.5)
- h/D_i — Ratio of roughness element height divided by the diameter of the culvert opening at the roughness element. (Range = .005 to .1).
- L_r/P_i — Ratio of the roughness length to inside perimeter (Range = 0.0 to 1.0)
- Diameter of roughened section (Opening, D_i)

The following figure shows the flow regimes and variables for an increased resistance energy dissipator implemented in a circular culvert.

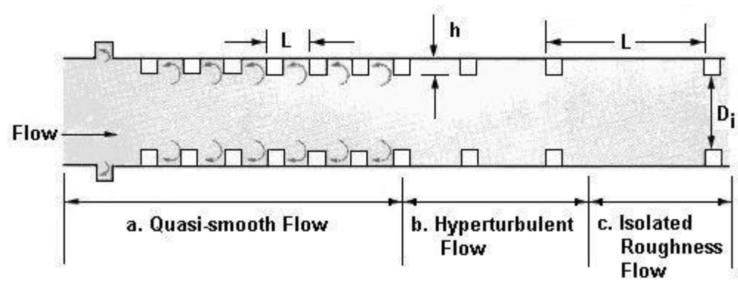


Figure 6.3: Definition sketch for increased resistance in circular culverts

Variables from the figure

- L — Length from beginning of one roughness element to the beginning of the next roughness element.
- h — height of roughness element
- D_i — diameter of roughened section (opening)

6.2.3 Tumbling Flow in Box Culverts

The input variables required for this calculation is the following:

Roughness Spacing to Height Ratio — the user must select a value of either 8.5 or 10 for the ratio of roughness element spacing divided by roughness element height. If after calculations the flow through the roughened section of the culvert impacts on the culvert roof, then the minimum enlarged section height needed to correct this problem will be given and the user will be prompted to enter a value equal to or larger than this minimum value.

Height must be equal to or greater than the height of the culvert.

The following figures show two configurations of tumbling flow dissipators.

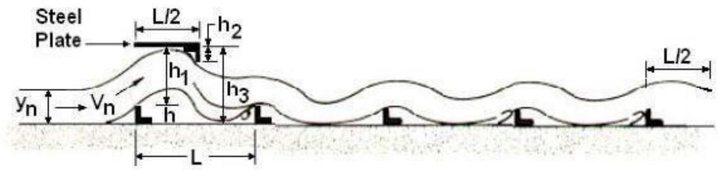


Figure 6.4: Tumbling flow in a box culvert or open chute: recommended configuration, Figure 7.2a in HEC-14.

Variables from the figure

- L — Length from beginning of one roughness element to the beginning of the next roughness element.
- h — Height of roughness element
- h_1 — Distance from top of dissipator to ceiling of culvert
- h_2 — Height of splash shield on ceiling of culvert
- h_3 — Culvert rise
- y_n — Tailwater depth

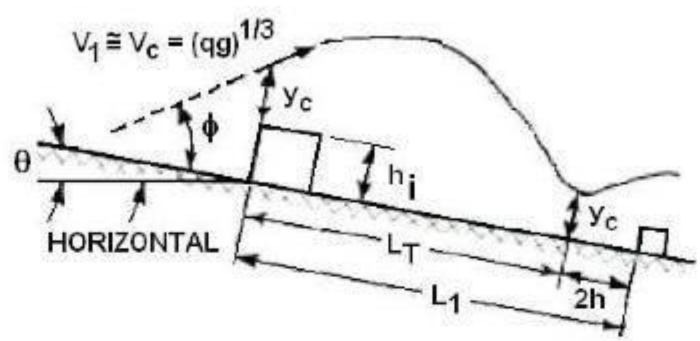


Figure 6.5: Tumbling flow in a box culvert or open chute: alternative configuration, Figure 7.2b in HEC-14

Variables from the figure

- L_1 — Length from beginning of one roughness element to the beginning of the next roughness element.
- L_T — Transition Length
- h_i — Height of roughness element
- y_c — Critical depth
- θ — slope of the culvert bottom expressed in degrees
- φ — jet angle, taken as 45 degrees

6.2.4 Tumbling Flow in Circular Culverts

The only input variable required for this calculation is the following:

- Diameter of enlarged culvert

The following figures show implementations of tumbling flow within circular culverts along with the variables used to design the energy dissipator.

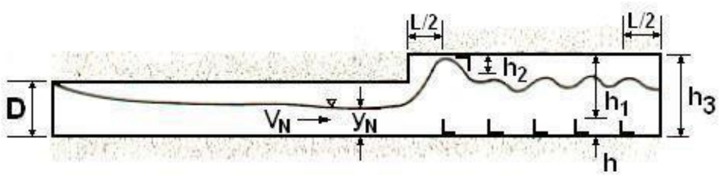


Figure 6.6: Definition sketch for tumbling flow in a culvert, Figure 7.1 in HEC-14

Variables from the figure

- D — Diameter of original culvert
- V_n — Tailwater velocity
- y_n — Tailwater depth
- L — Length from beginning of one roughness element to the beginning of the next roughness element.
- h — Height of roughness element
- h_1 — length from top of roughness element to enlarged culvert ceiling
- h_2 — height of splash shield on enlarged culvert ceiling.
- h_3 — rise of enlarged culvert.

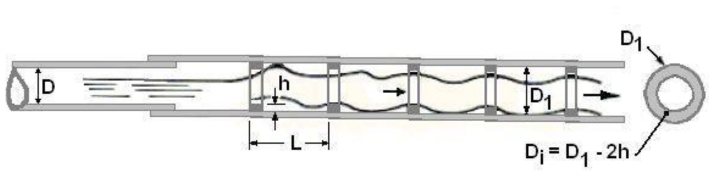


Figure 6.7: Definition sketch for tumbling flow in circular culvert, Figure 7.4 in HEC-14

Variables from the figure

- D — Diameter of original culvert
- D_1 — Diameter of enlarged culvert
- D_i — Diameter of roughened section
- h — Height of roughness element
- L — Length from beginning of one roughness element to the beginning of the next roughness element.

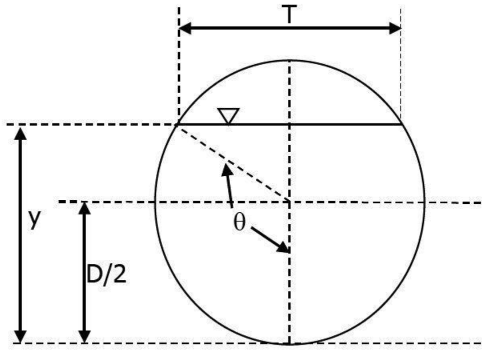


Figure 6.8: Definition sketch for flow in circular pipes, Figure 7.5 in HEC-14

Variables from the figure

- D — Diameter of original culvert
- T — Water surface width at critical flow condition
- y — Depth of flow

6.2.5 USBR Type IX Baffled Apron

The input variables required for this calculation are the following:

- Approach Channel Slope
- Vertical Drop Height
- Baffled Apron Slope
- Baffled Apron Width

The following figure shows a USBR Type IX Baffled Apron.

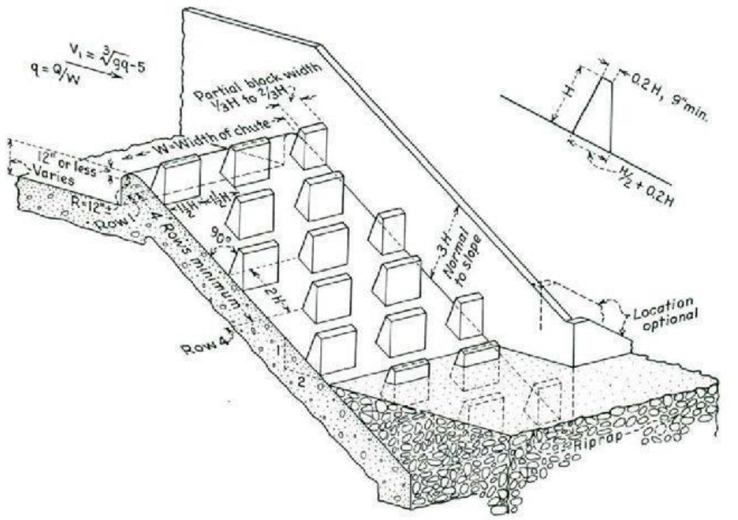


Figure 6.9: USBR Type IX Baffled Apron (Peterka, 1978), Figure 7.9 in HEC-14

Variables from the figure

- H — height of the dissipator
- W — Width of Chute

6.3 External Dissipators

6.3.1 Drop Structures

Drop structures are commonly used for flow control and energy dissipation. They mainly change the slope from steep to mild by placing drop structures at intervals along the channel reach. Two types of Drop Structure External Dissipators are available:

- Box Inlet Drop Structure
- Straight Drop Structure

6.3.2 Box Inlet Drop Structure

The input variables required for this calculation is the following:

- H_D — Desired drop height. Must be between 2 and 12 ft or between 0.6 and 3.7 m.
- New Slope — the slope that will exist on the channel once the drop structures are in place (The new slope must be subcritical).
- Box Length — Length of box inlet. (USER'S CHOICE)
- W_2 — Width of box inlet. Must fit criteria ($.25 < H_D / W_2 < 1$)
- W_3 — Width of the Downstream End of Stilling Basin. This must be equal to or larger than the

culvert width.

- Flare of Stilling Basin (1 Lateral: Z long) — This value must be greater than or equal to 2, which is to say 1 lateral: 2 Long)
- Length from Toe of Dike to Box Inlet — if a dike is used, the distance from the toe of the dike to the box inlet must be entered. If no dike is used, enter a value of 100 ft or 30.48 m for this distance.

The following figure shows a plan and side view of a box inlet drop structure.

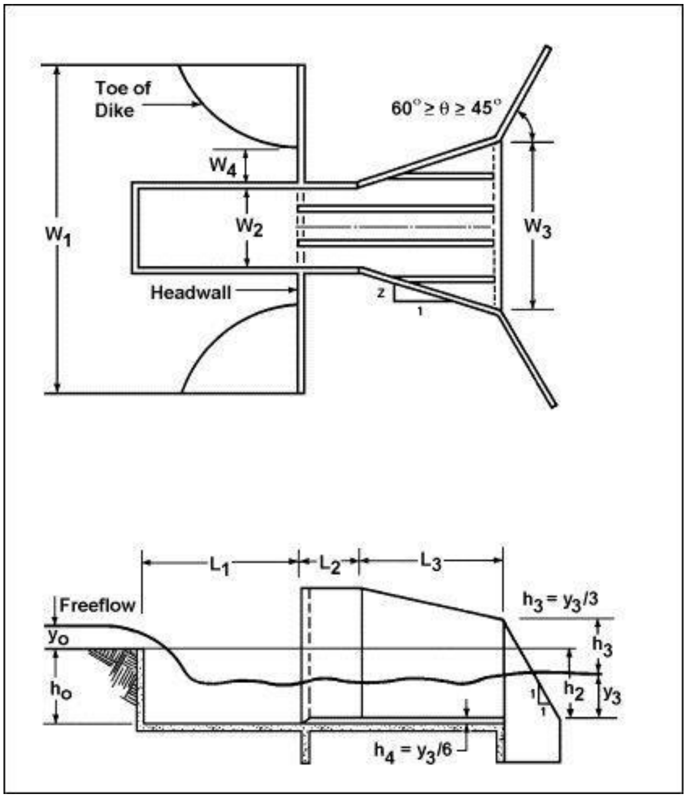


Figure 6.10: Box inlet drop structure, Figure 11.4 in HEC-14

Variables from the figure

- W_1 — Width of the upstream end of the basin
- W_2 — Width of box inlet crest
- W_3 — Width of the downstream end of the basin
- W_4 — Distance from the toe of dike to the box inlet
- L_1 — Length of box inlet
- L_2 — Minimum length for the straight section
- L_3 — Minimum length for final section (potentially flared)
- H_0 — Drop from crest to stilling basin floor
- h_2 — Vertical distance of the tailwater below the crest
- h_3 — Height of the end sill

- y_0 — Required head on the weir crest to pass the design flow
- y_3 — Tailwater depth above the floor of the stilling basin
- h_4 — Sill height

6.3.3 Straight Drop Structure

The input variables required for this calculation is the following:

- Drop Height — the vertical drop height from structure crest to channel bottom. In the final design, the drop height to the basin bottom is given. The difference between the two is the amount the basin is suppressed below the channel bottom.
- New Slope — the slope that will exist on the channel once the drop structures are in place (the new slope must be subcritical).

The following figures show straight drop structures.

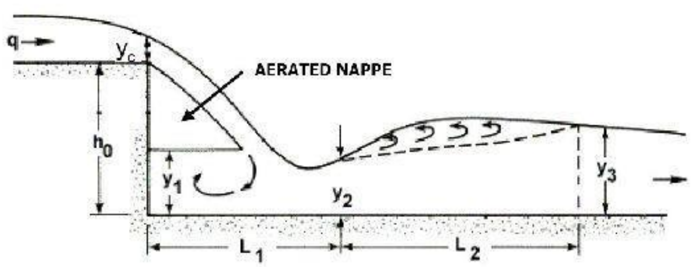


Figure 6.11: Flow geometry of a straight drop spillway, Figure 11.1 in HEC-14

Variables from the figure

- q — Design Discharge
- y_c — Critical depth
- h_0 — Drop from crest to stilling basin floor
- y_1 — Pool depth under the nappe
- y_2 — Depth of flow at the tow of the nappe or the beginning of the hydraulic jump
- y_3 — Tailwater depth sequent to y2
- L_1 — Distance from the headwall to the point where the surface of the upper nappe strikes the stilling basin floor
- L_2 — Distance from the upstream face of the floor blocks to the end of the stilling basin

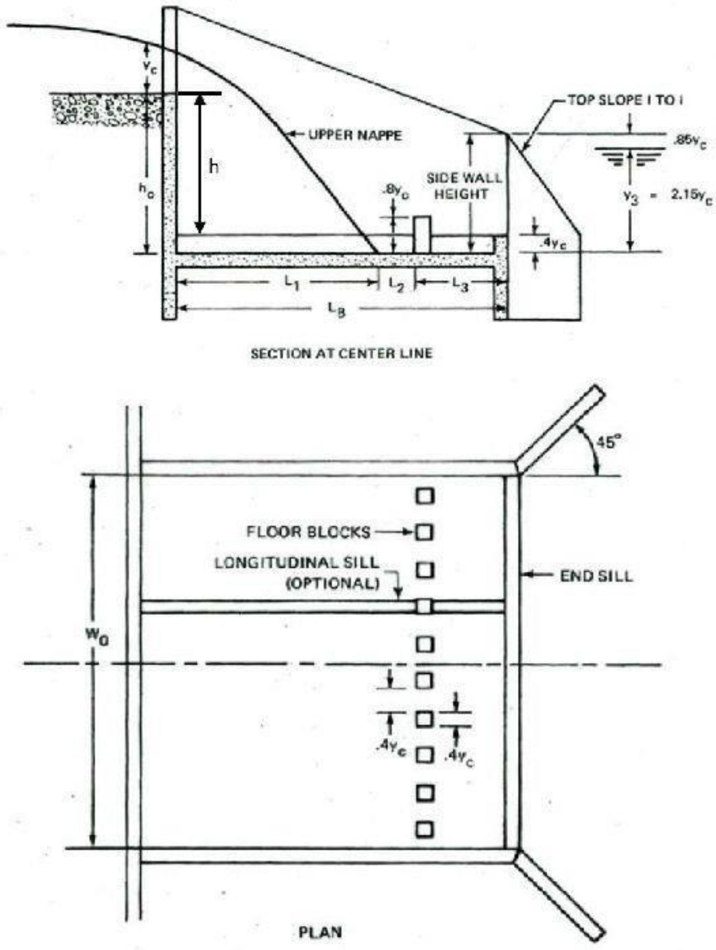


Figure 6.12: Straight drop structure (Rand, 1955), Figure 11.3 in HEC-14

Variables from the figure

- y_c — Critical depth
- h_0 — Drop from crest to stilling basin floor
- h — Vertical drop between the approach and tailwater channels
- y_1 — Pool depth under the nappe
- y_2 — Depth of flow at the tow of the nappe or the beginning of the hydraulic jump
- y_3 — Tailwater depth sequent to y2
- L_1 — Distance from the headwall to the point where the surface of the upper nappe strikes the stilling basin floor
- L_2 — Distance from the upstream face of the floor blocks to the end of the stilling basin
- L_3 — distance from the upstream face of the floor blocks to the end of the stilling basin
- L_B — Stilling basin length

6.4 Stilling Basin

The types of Stilling Basins External Energy Dissipators available in the program are as follows:

- USBR Type III Stilling Basin
- USBR Type IV Stilling Basin
- SAF Stilling Basin

HY-8 limits the maximum width of an efficient 'USBR' type stilling basin by the width that a jet of water would flare naturally on the basin foreslope. The user is given the maximum flare value and is prompted to enter a basin width smaller than this value. If a 'SAF' basin is used, the basin width is set equal to the culvert width and the user is prompted to choose either a rectangular or flared basin depending on site conditions. Stilling Basins resemble the following illustration.

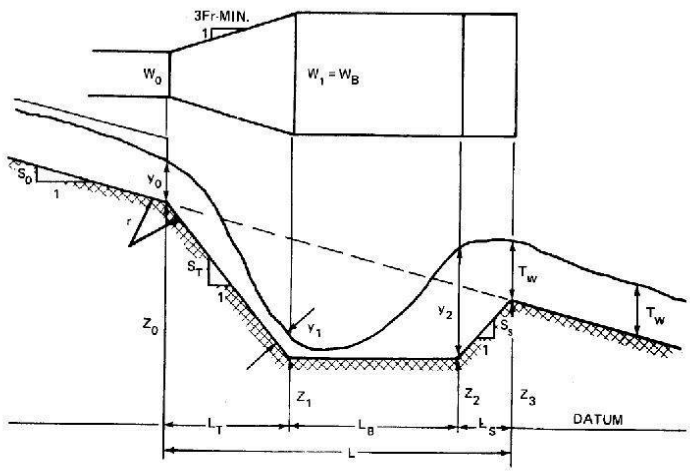


Figure 6.13: Definition sketch for stilling basin, Figure 8.1 in HEC-14

Variables from the figure

- W_0 — width of the channel
- W_B — Width of the basin
- y_0 — Culvert outlet depth
- y_1 — Depth entering the basin
- y_2 — Conjugate depth
- S_0 — Slope of the channel
- S_T — Slope of the transition
- S_S — Slope leaving the basin
- Z_0 — ground elevation at the culvert outlet
- Z_1 — ground elevation at the basin entrance
- Z_2 — ground elevation at the basin exit
- Z_3 — Elevation of basin at basin exit (sill)
- L_T — Length of transition from culvert outlet to basin
- L — Total basin length

- L_B — Length of the bottom of the basin
- L_S — Length of the basin from the bottom of the basin to the basin exit (sill)
- T_w — Tailwater depth leaving the basin

6.4.1.1 Warning for Stilling Basin Width

Since the maximum basin width is a function of basin depth, the maximum width may decrease as the program increases the basin depth while converging on a solution. Therefore the maximum basin width may fall below the user's first choice for basin width. In this case, the user will be prompted for a new basin width.

6.4.2 USBR Type III Stilling Basin

The only input variable required for this calculation is the following:

- Basin Width

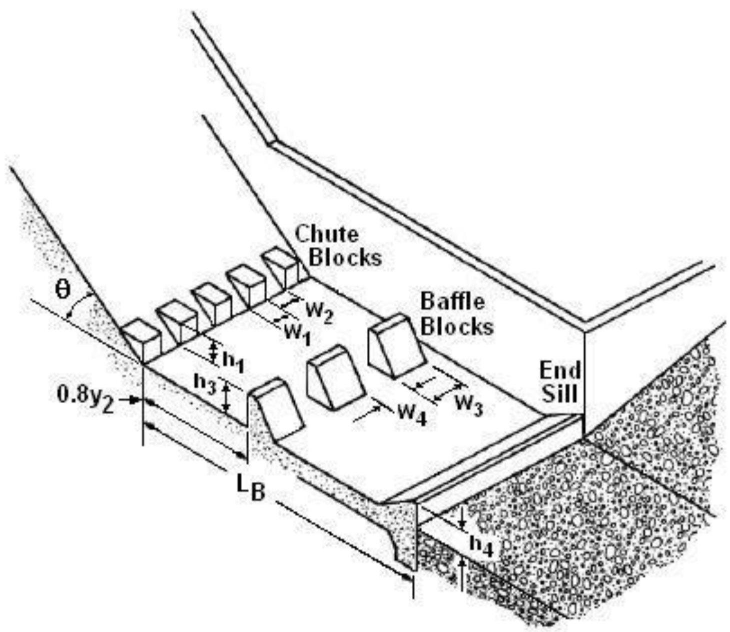


Figure 6.14: USBR Type III Stilling Basin, Figure 8.3 in HEC-14

Variables from the figure

- W_1 — width of the chute blocks
- W_2 — space between chute blocks
- h_1 — height of the chute blocks
- W_3 — width of the chute blocks
- W_4 — space between chute blocks

- h_3 — height of the baffle blocks
- h_4 — height of the end sill
- L_B — Length of the bottom of the basin
- y_2 — Conjugate depth

6.4.3 USBR Type IV Stilling Basin

The only input variable required for this calculation is the following:

- Basin Width

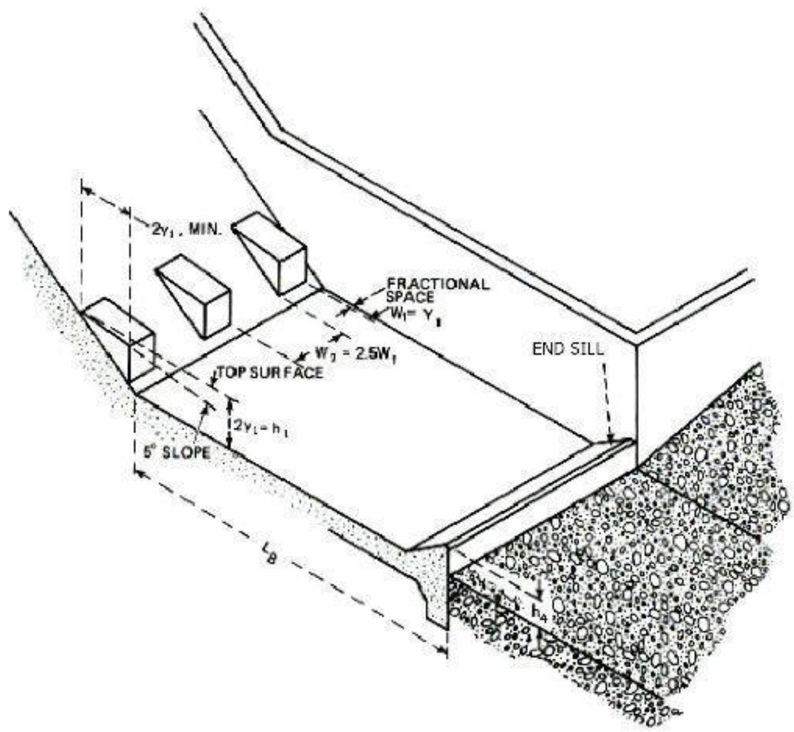


Figure 6.15: USBR type IV stilling basin, Figure 8.4 in HEC-14

Variables from the figure

- y_1 — height of the chute blocks
- h_1 — width of the chute blocks
- h_4 — Height of the end sill
- W_1 — space between chute blocks
- W_2 — height of the end sill
- L_B — Length of the bottom of the basin

6.4.4 Saint Anthony Falls (SAF Stilling Basin)

The input variables required for this calculation is the following:

- Shape (Flared or Rectangular)
- Sidewall Flare — This will only apply if the basin has a flared shape

The following figure shows a Saint Anthony Falls stilling basin.

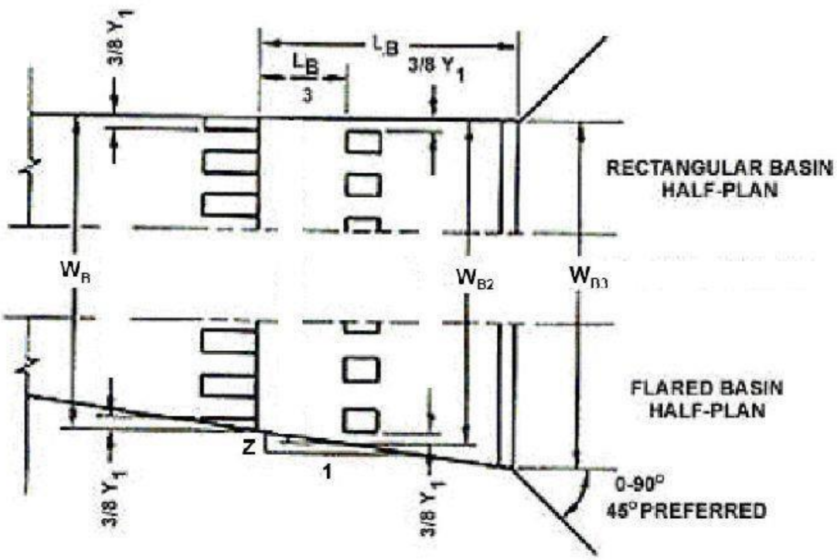


Figure 6.16: SAF stilling basin (Blaisdell, 1959), figure 8.5 in HEC-14

Variables from the figure

- W_B — Basin width
- W_{B2} — Basin width at the baffle row
- W_{B3} — Basin width at the sill
- Y_1 — height of the chute blocks
- L_B — Length of the basin
- Z *— basin flare

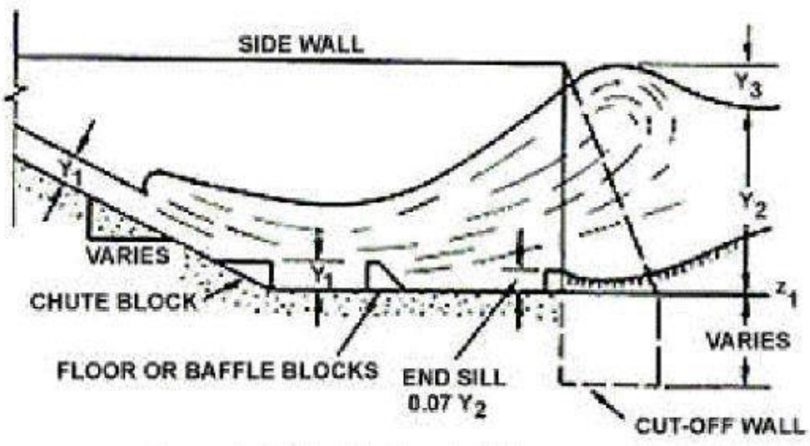


Figure 6.17: SAF stilling basin (Blaisdell, 1959), figure 8.5 in HEC-14

Variables from the figure

- Y_1 — height of the chute blocks
- Y_2 — Conjugate height
- Y_3 — height of the chute blocks
- z_1 — elevation of basin floor

6.5 Streambed level Structures

The five types of At-Stream-Bed Structure External Energy Dissipators are available in the program:

- Colorado State University (CSU) Rigid Boundary Basin
- Riprap Basin and Apron
- Contra Costa Basin
- Hook Basin
- USBR Type VI Impact Basin

6.5.1 Colorado State University (CSU) Rigid Boundary Basin

No input variables are required for this calculation; however, the user selects one design.

HY-8 calculates all possible designs for CSU Rigid Boundary Basins for the given culvert and flow. It discards designs which do not dissipate sufficient energy. The criteria of the remaining designs are numbered and displayed one at a time.

HY-8 calculates and displays designs in order of increasing width, increasing number of element rows, and increasing element height. As a result, smaller, less expensive designs are presented first.

The following figures show a Colorado State University (CSU) Rigid Boundary Basin

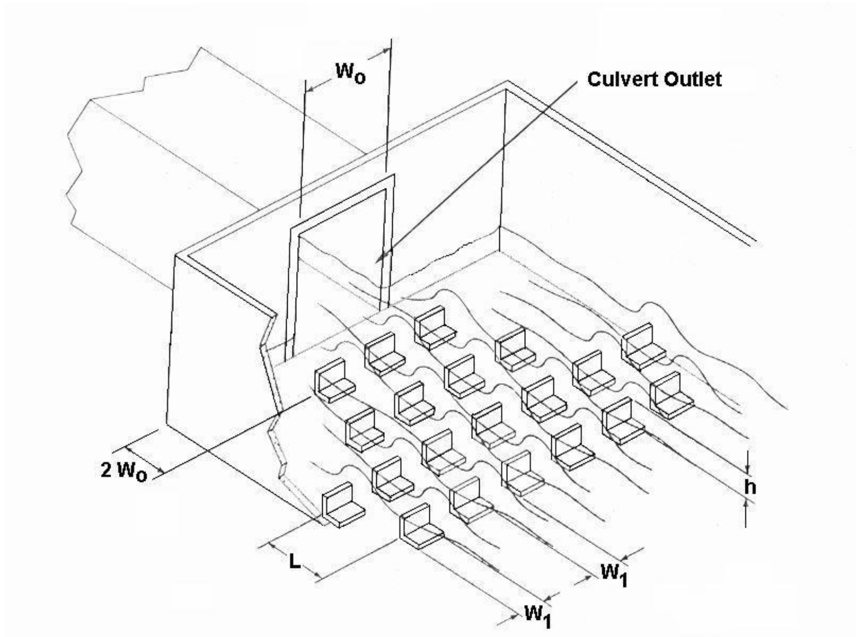


Figure 6.18: CSU Rigid Boundary Basin

Variables from the figure

- W_0 — Culvert width at culvert outlet
- W_1 — Element width which is equal to element spacing
- h — Roughness element height

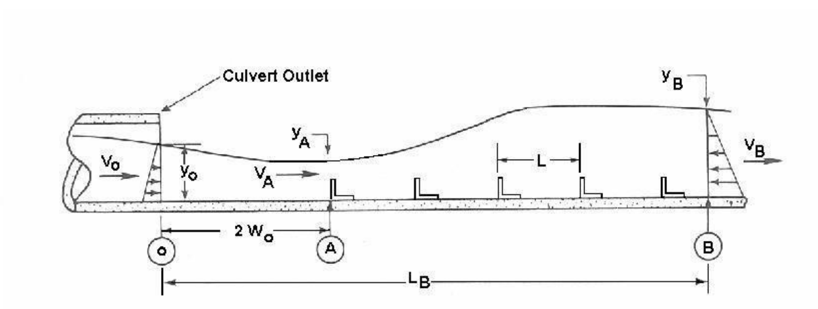


Figure 6.19: Definition sketch for the momentum equation, Figure 9.2 in HEC-14

Variables from the figure

- V_0 — Velocity at the culvert outlet
- V_A — Approach velocity at two culvert widths downstream of the culvert outlet
- V_B — Exit velocity, just downstream of the last row of roughness elements
- y_0 — Depth at the culvert outlet
- y_A — Approach depth at two culvert widths downstream of the culvert outlet
- y_B — Depth at exit

- W_0 — Culvert width at the culvert outlet
- L_B — Total basin length
- L — Longitudinal spacing between rows of elements

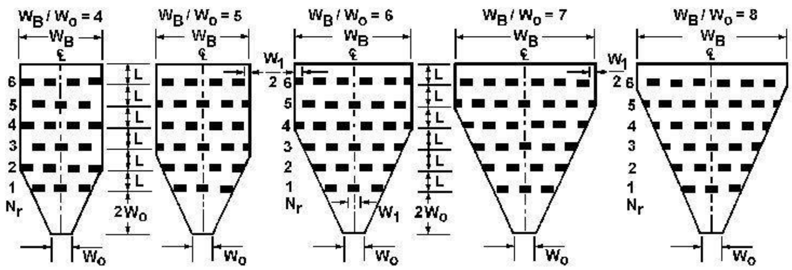


Figure 6.20: Roughness configurations tested, Figure 9.3 in HEC-14

Variables from the figure

- W_B — Width of basin
- W_0 — Culvert width at the culvert outlet
- L — Longitudinal spacing between rows of elements
- N_r — Row number

Table 6.2: Design values for roughness elements, Table 9.1 in HEC-14

W_B/W_0			2 to 4			5			6			7		8
W_1/W_0			0.57			0.63			0.6			0.58		.62
Rows (N_r)			4	5	6	4	5	6	4	5	6	5	6	6
Elements (N)			14	17	21	15	19	23	17	22	27	24	30	30
	h/y_A	**L/h**	**Basin Drag Coefficient, C_B**											
Rectangular	.91	6	0.32	0.28	0.24	0.32	0.28	0.24	0.31	0.27	0.23	0.26	0.22	0.22
	.71	6	0.44	0.40	0.37	0.42	0.38	0.35	0.40	0.36	0.33	0.34	0.31	0.29
	0.48	12	0.60	0.55	0.51	0.56	0.51	0.47	0.53	0.48	0.43	0.46	0.39	0.35
	0.37	12	0.68	0.66	0.65	0.65	0.62	0.60	0.62	0.58	0.55	0.54	0.50	0.45
Circular	0.91	6	0.21	0.20	0.48	0.21	0.19	0.17	0.21	0.19	0.17	0.18	0.16	
	0.71	6	0.29	0.27	0.40	0.27	0.25	0.23	0.25	0.23	0.22	0.22	0.20	
	0.31	6	0.38	0.36	0.34	0.36	0.34	0.32	0.34	0.32	0.30	0.30	0.28	
	0.48	12	0.45	0.42	0.25	0.40	0.38	0.36	0.36	0.34	0.32	0.30	0.28	
	0.37	12	0.52	0.50	0.18	0.48	0.46	0.44	0.44	0.42	0.40	0.38	0.36	

6.5.2 Riprap Basin and Apron

The input variables required for this calculation is the following:

- Condition to compute Basin Outlet Velocity — The user can select *Best Fit Curve* or *Envelope Curve*.

The user should choose *Best Fit Curve* if the flow downstream of the basin is believed to be supercritical. If the flow downstream is believed to be subcritical, the user should choose *Envelope Curve*.

- D50 of the Riprap Mixture — Mean diameter (by weight) of the riprap to be used.
- DMax of the Riprap Mixture — Maximum diameter (by weight) of the riprap to be used.

The design criteria for this basin were based on model runs in which D50/YE ranged from 0.1 to 0.7; values outside this range are rejected by the program.

The following figures show riprap basins and aprons.

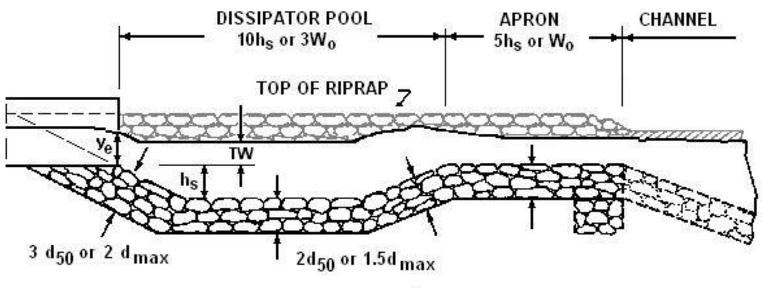


Figure 6.21: Profile of riprap basin, Figure 10.1 in HEC-14

Variables from the figure

- h_S — Dissipator pool depth
- W_0 — Culvert width
- TW — Tailwater depth
- y_e — Equivalent brink (outlet) depth
- d_{50} — Median rock size by weight
- d_{max} — Max rock size by weight

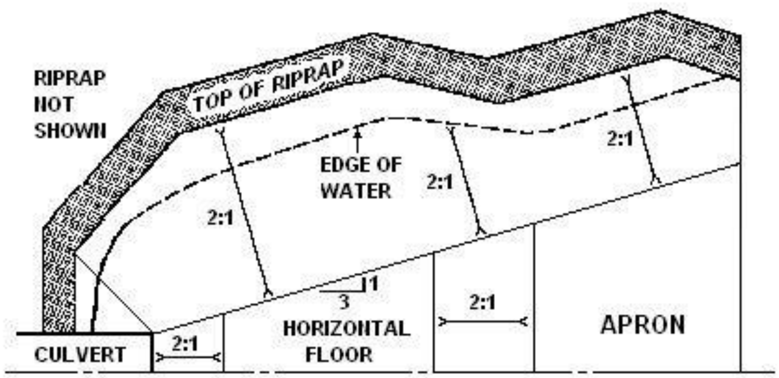


Figure 6.22: Half plan of riprap basin, Figure 10.2 in HEC-14

6.5.3 Contra Costa Basin

The input variables required for this calculation is the following:

- Baffle Block Height Ratio — the ratio of the baffle block height to baffle block distance from the culvert.
- End Sill Height to Maximum Depth Ratio — ratio to determine the end sill height from the maximum depth.
- Basin Width — the channel width is recommended for the basin width.

The following figures show the design of a Contra Costa basin.

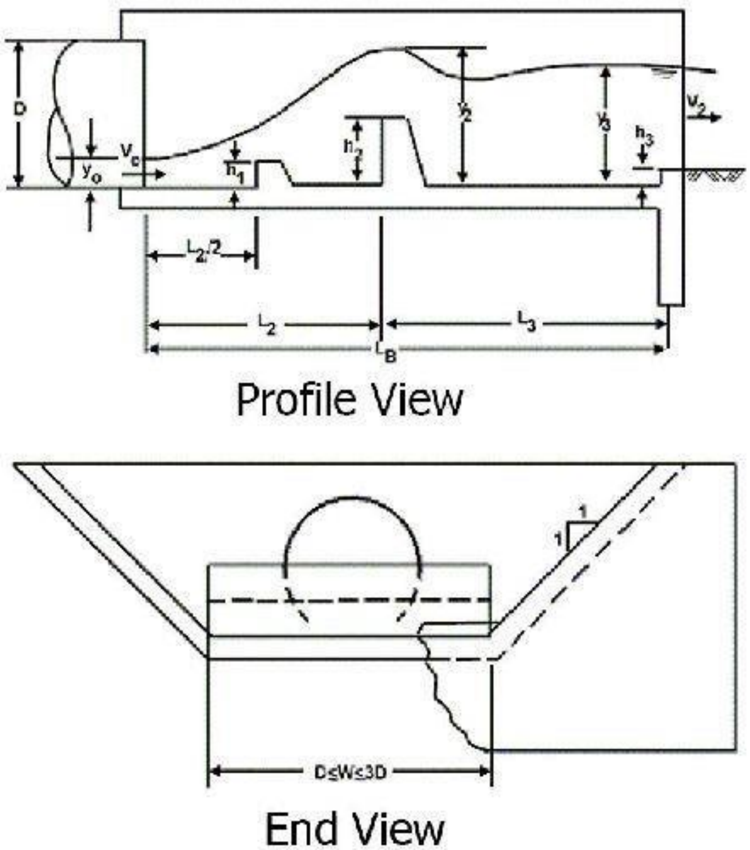


Figure 6.23: Contra costa basin

Variables from the figure

- D — Diameter of culvert
- y_0 — Outlet depth
- y_2 — Approximate maximum water surface depth
- y_3 — Basin exit velocity
- V_0 — Outlet velocity
- V_2 — Exit velocity
- h_1 — Height of small baffle
- h_2 — Height of large baffle
- h_3 — Height of end sill
- L_2 — Length from culvert exit to large baffle
- L_3 — Length from large baffle to end sill
- L_B — Basin length

6.5.4 Hook Basin

The input variables required for this calculation is the following:

- Shape of Dissipator — the user can select 'Warped Wingwalls' or 'Trapezoidal'. See illustrations below for examples.
- Flare Angle (Warped Wingwalls only) — Flare angle per side of the basin.
- Ratio of Length to A-hooks over Total Basin Length (Warped Wingwalls only) — Distance from culvert exit to first row of hooks (A-HOOKS) divided by the total length of the basin.
- Ratio of Width to A-hooks over Total Basin Length (Warped Wingwalls only) — Distance between hooks in the first row divided by the basin width at the first row.
- Ratio of Length to B-Hooks over Total Basin Length (Warped Wingwalls only) — Distance from culvert exit to second row of hooks (B-HOOKS) divided by the total length of the basin.
- Width for the Downstream End of the Basin (Warped Wingwalls only)
- Basin Side Slope (Trapezoidal shape only) — The user can select either '1.5 : 1' or '2 : 1'.
- Basin Bottom Width (Trapezoidal shape only)

The next two figures show a hook basin with warped wingwalls:

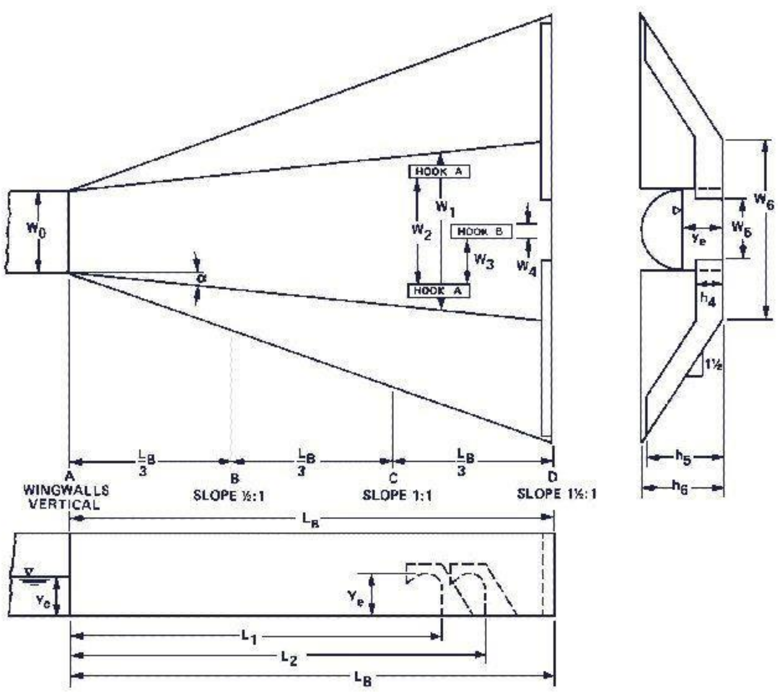


Figure 6.24: Hook basin with warped wingwall, Figure 9.7 in HEC-14

Variables from the figure

- W_0 — Outlet width
- W_1 — Width at first hooks
- W_2 — Distance between first hooks (row A)
- W_3 — lateral spacing between A and B hook
- W_4 — Width of hooks
- W_5 — Width of slot in end sill

- W_6 — approximately channel width
- h_4 — Height of end sill
- h_5 — Height to top of end sill
- h_6 — Height to top of warped wingwall
- y_e — Equivalent depth
- L_1 — Distance to first hooks
- L_2 — Distance to second hooks (row B)
- L_B — Basin length

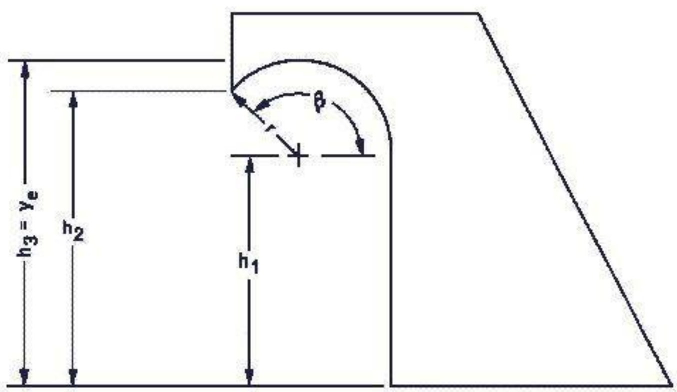


Figure 6.25: Hook for warped wingwall basin, Figure 9.8 in HEC-14

Variables from the figure

- ß — Angle of radius
- r — radius
- h_1 — height to center of radius
- h_2 — Height to point
- h_3 — Height to top of radius
- y_e — Equivalent depth

The next two figures show a hook basin with a uniform trapezoidal channel:

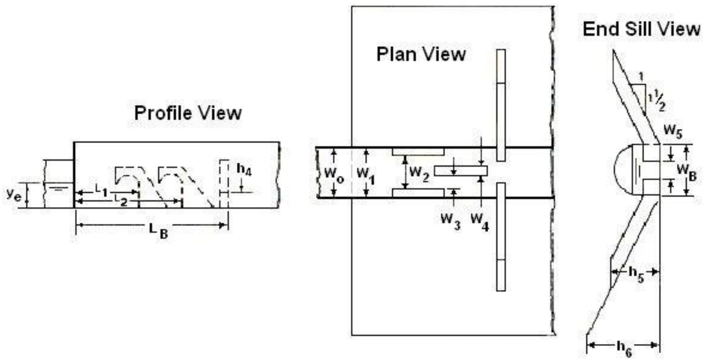


Figure 6.26: Hook basin with uniform trapezoidal channel, Figure 9.10 in HEC-14

Variables from the figure

- W_0 — Outlet width
- W_1 — Width at first hooks
- W_2 — Distance between first hooks (row A)
- W_3 — lateral spacing between A and B hook
- W_4 — Width of hooks
- W_5 — Width of slot in end sill
- W_B — approximately channel width
- h_4 — Height of end sill
- h_5 — Height to top of end sill
- h_6 — Height to top of warped wingwall
- y_e — Equivalent depth
- L_1 — Distance to first hooks
- L_2 — Distance to second hooks (row B)
- L_B — Basin length

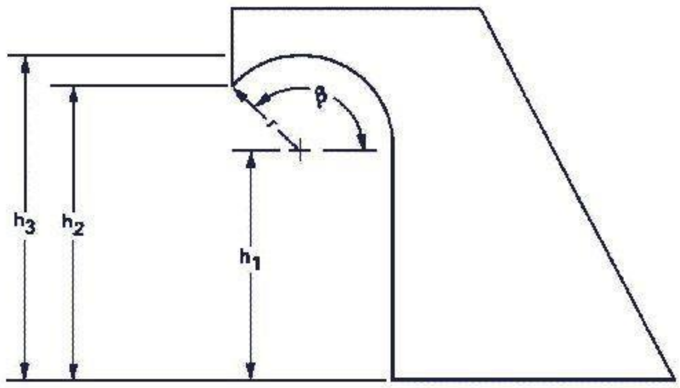


Figure 6.27: Hook for uniform trapezoidal channel basin, Figure 9.11 in HEC-14

Variables from the figure

- ß — Angle of radius
- r — radius
- h_1 — height to center of radius
- h_2 — Height to point
- h_3 — Height to top of radius

6.5.5 USBR Type VI Impact Basin

No input variables are required for this calculation.

The following figures show a USBR Type VI impact basin.

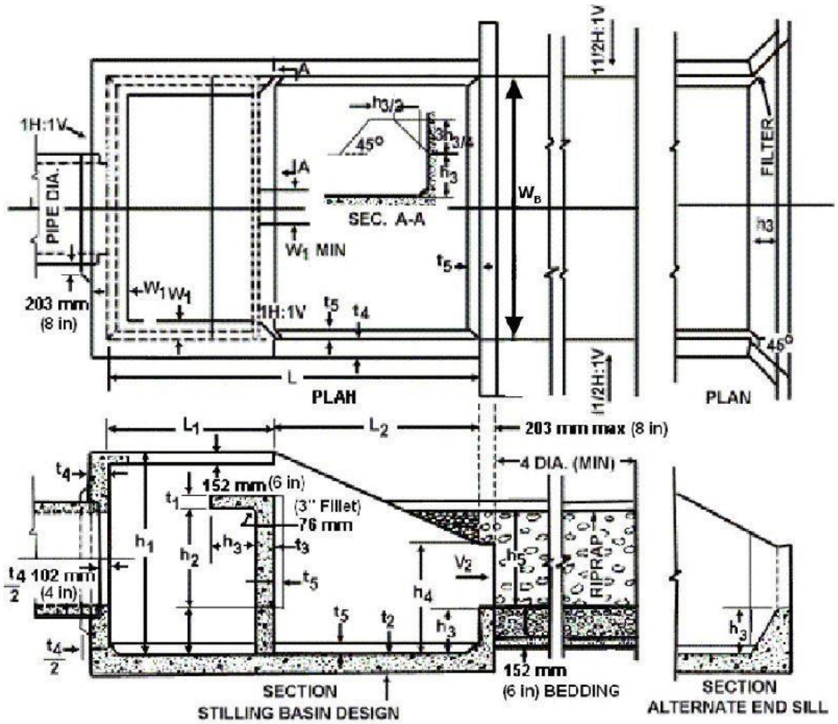


Figure 6.28: USBR Type VI Impact Basin, Figure 9.13 in HEC-14

Variables from the figure

- W_B — Required basin width
- W_1 — Geometry design variable
- h_1 through h_5 — Geometry design variable
- t_1 through t_5 — Geometry design variable
- L_1 and L_2 — Geometry design variable
- L — Length of the Basin

7 Aquatic Organism Passage

7.1.1 Aquatic Organism Passage (AOP)

Aquatic Organism Passage defines whether aquatic organisms, such as fish and amphibians, are able to pass through a culvert from the outlet to the inlet. There are several approaches to determine aquatic organism passage, and some procedures are specific to a type of organism or a specific species.

A few of the common barriers to fish passage are excessive velocity, culvert length, depth that is too shallow, a culvert that is perched (requiring a fish to jump) or perched too high, and excessive turbulence.

7.1.2 Stream Simulation

HY-8 incorporates stream simulation aquatic organism passage, as described in Hydraulic Engineering Circular No. 26 (HEC-26) . The principle behind this approach is to simulate the stream throughout the culvert and make the culvert less of a barrier to passage than the stream immediately upstream and downstream.

To begin the AOP Stream Simulation Analysis, the user first must create a crossing (or load an existing crossing from a file) that does not have any errors. The user can then select it from the menu: Culvert | AOP: Stream Simulation, or the user can click the AOP: Stream Simulation Tool from the toolbar 

7.2 Stream Simulation

7.2.1 Overview

HY-8 will determine if the culvert is more of a barrier than the immediate upstream and downstream channels. The user will need to determine the lowest flow to allow fish passage, the highest flow to allow fish passage, the peak flow for culvert embedment stability, the cross-section geometry upstream and downstream of the culvert, know the stability of the streambed, and enter the gradations of the streambed upstream and downstream of the culvert crossing.

HY-8 will only perform this analysis on crossings with one culvert.

The HY-8 AOP process is defined in HEC 26. A flowchart outlining the method is given in the following illustration.

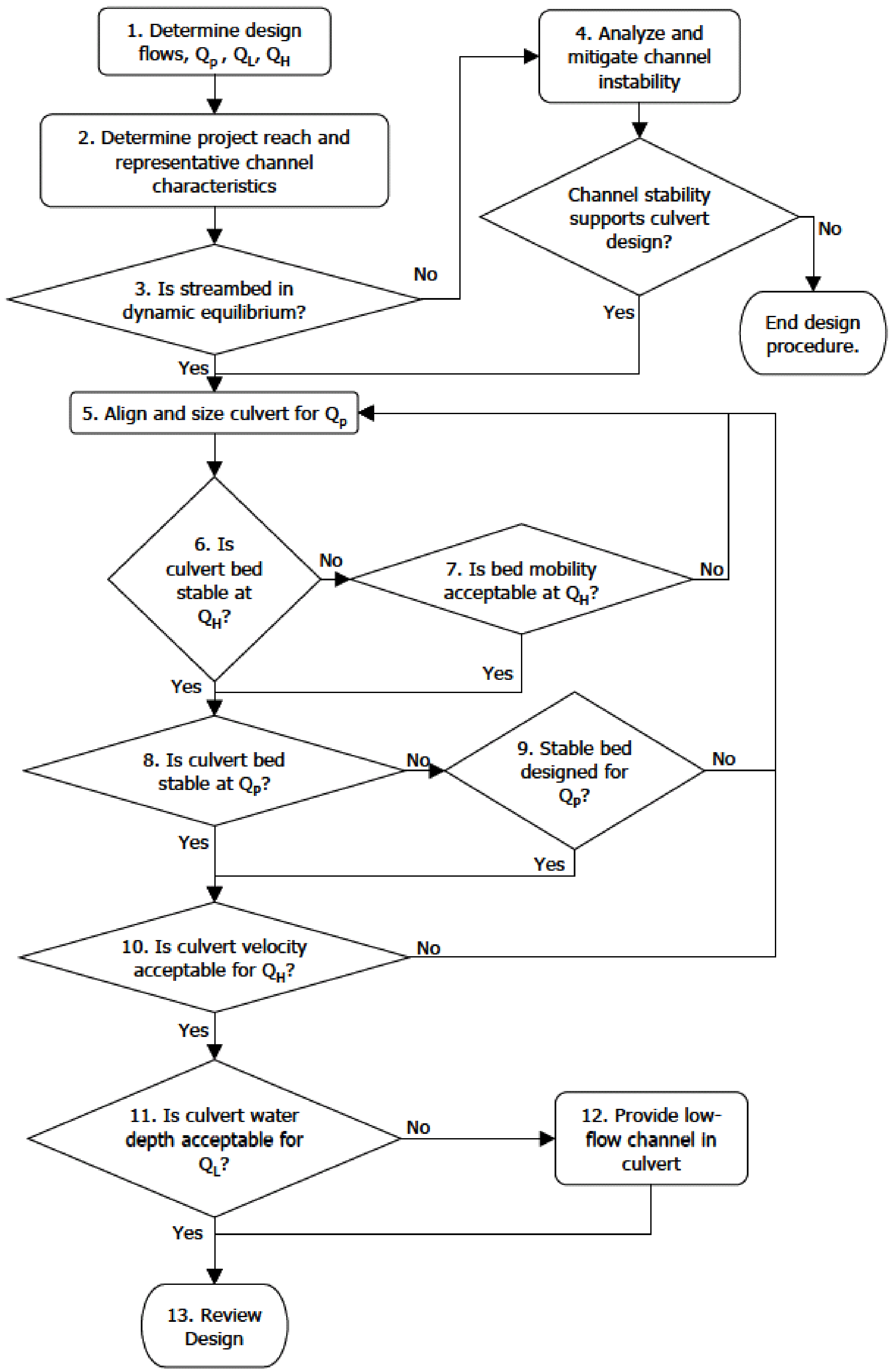


Figure 7.1: Aquatic Organism Passage design procedure in culvert crossings. From HEC-26, Figure 7.1

The *AOP Stream Simulation* dialog has 4 steps in a wizard format:

1. Input Reach Data where you enter the flows, channel geometry, and streambed stability
2. Gradation Data where you enter the gradations in the streambed and within the culvert
3. Align and Size Culvert where you can change the culvert barrel properties
4. Results Table Where you can see most of the variables used to perform these calculations. Use this page to verify that the results are reasonable.

The main AOP Stream Simulation dialog has the steps listed on the left, the selected step data on the right, and navigation buttons along the bottom. You can navigate the steps by clicking on the list or the Next, Back buttons. You can also shift to the Crossing Input Dialog, the Crossing Result Dialog, or the Energy Dissipation Dialog by clicking on the buttons along the bottom.

7.2.2 Limitations

HY-8 will compare the velocity and depth from the culvert that were computed using direct step against the velocity and depth in the cross-sections that were computed using manning's equation.

Due to the way that the HY-8 engine is setup, it can be difficult for HY-8 to accurately compute low flows. While we are working to improve HY-8 to handle this condition better, a work around is to set the discharge in the Culvert Crossing Input Data Dialog to User Defined, and setting the number of discharges to a number higher than 10. It doesn't matter what the discharges are, just the total number of discharges.

7.2.3 Input Reach Data

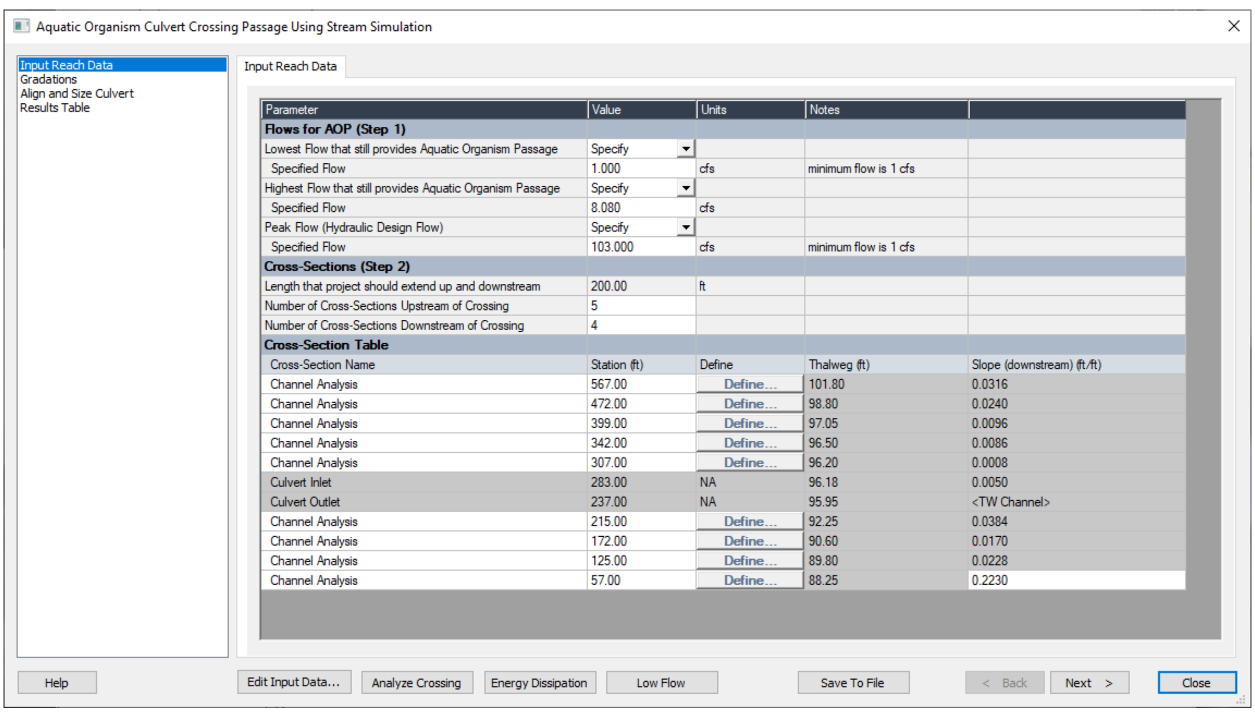


Figure 7.2: AOP Stream Simulation, Input Reach Data

7.2.3.1 Flows

The user needs to determine the lowest and highest flow that will still require aquatic organism passage. The lowest flow the user is allowed to enter is 1 cfs. The user can specify the flow directly, or if the flow has already been entered in the Culvert Input Data Dialog, you can select the flow in the drop down menu. If multiple flows are below 1 cfs, then the list will have "1 cfs" multiple times, but will not cause any computational issues. HEC 26 provides guidance on determining these flows in Chapter 5.

The user will then need to determine the hydraulic design flow, which is the design flow used to design the culvert crossing. It is used to determine that the embedment will be stable.

7.2.3.2 Cross-Sections

HY-8 will use the culvert length to determine the length upstream and downstream that the cross-sections need to cover. The user will then need to enter 3 cross sections upstream and 3 cross sections downstream. More cross sections will give HY-8 more information to compare.

7.2.3.3 Cross-Section Table

The user can then enter the name of each cross-section (or leave it with the default name), must enter the station, then define the geometry of the cross-section. Note that HY-8 has now been updated to allow the user to enter the 'site data' in the Culvert Crossing Input Data Dialog in ascending or descending order, and this table will need to follow the same order that was entered in the Culvert Crossing Input Data Dialog.

7.2.3.4 Save To File

The 'Save To File' button is available on all pages of the AOP dialog. If the user has not already saved or loaded from a file, HY-8 will prompt the user to specify a filename. Otherwise, HY-8 will update the filename already in use. It is recommended to save often.

7.2.3.5 Data Validation

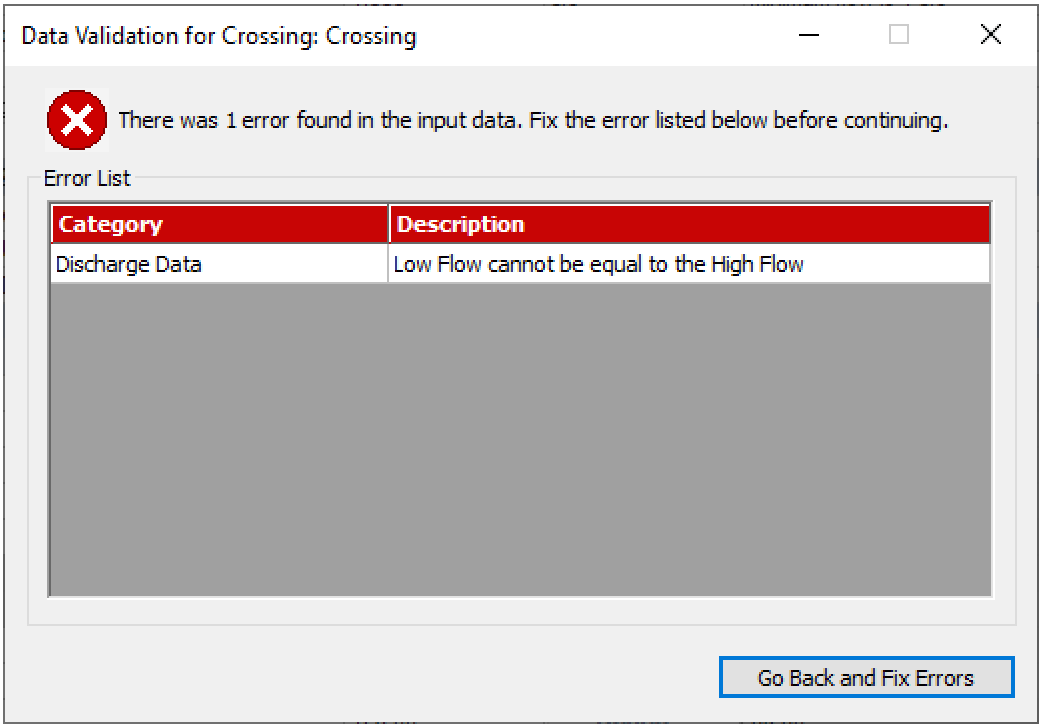


Figure 7.3: Data Validation Dialog

When the user moves to another step of the AOP Stream Simulation, HY-8 will check the input for any errors. If they are detected, a dialog will pop up with a list of errors and the category they belong to. These errors must be corrected before you can continue to a new step.

7.2.4 Gradation Data

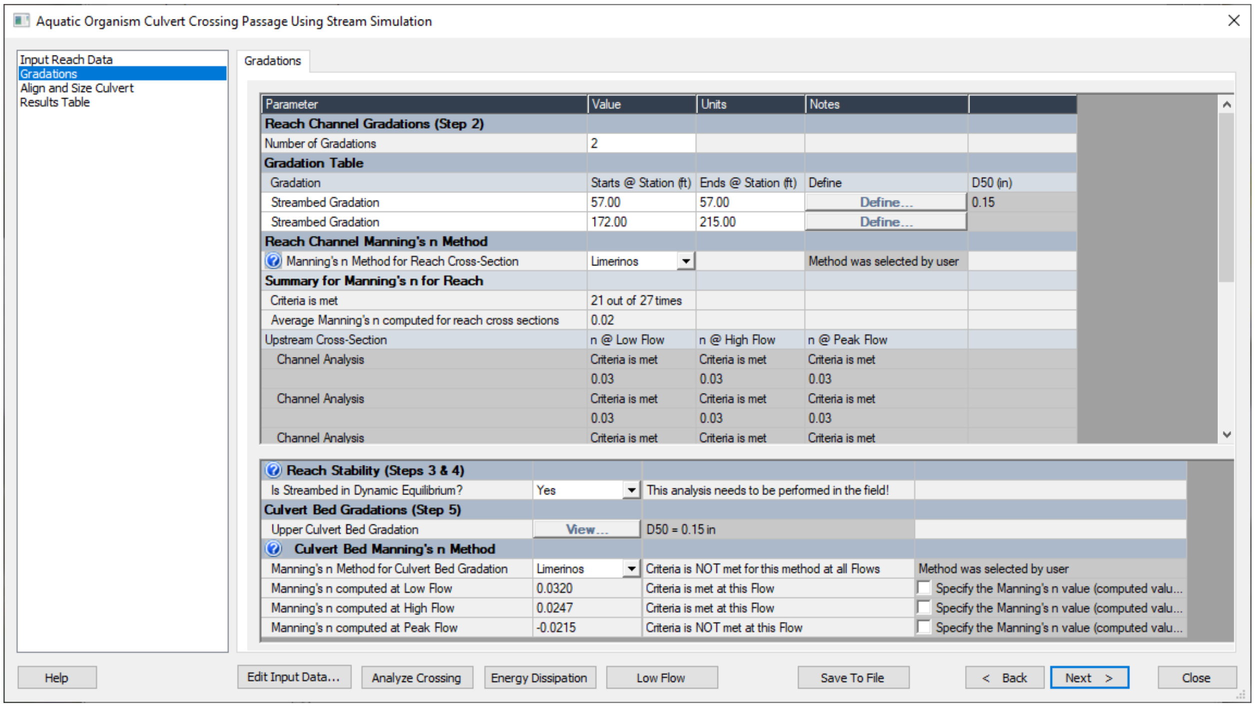


Figure 7.4: AOP Stream Simulation, Gradation Data

The gradations determine the Manning's n value for the channel and culvert as well as the stability of the embedment within the culvert.

7.2.4.1 Reach Channel Gradations

You can enter several gradations across your stream. The first value you will need to define is how many gradations you wish to enter. Then in the first column of the table, you can change the name or leave the default name. You then define where stations between which the gradation was gathered and determined from. The cross section will use the gradation that is closest to it.

You then define the gradation by supplying the D5, D16, D50, D84, and D95 of the streambed. If you need some tools to determine the gradation, use the 'Rock/Sediment Calculator' from Hydraulic Toolbox, developed for FHWA by Aquaveo. This calculator allows you to enter a gradation by entering a Wolman Count, an image gradation (you enter a picture of riprap with a scale, and it will calculate a gradation), or a standard riprap. The standard riprap can be personalized by installing Hydraulic Toolbox and modifying the profiles.

HY-8 only allows one gradation to be defined at any location. When the gradation is properly defined, the calculated D50 of the gradation will show in the final column.

Finally you can select method to compute the Manning's n value. HY-8 will automatically select a method when you make a change in the definition of one of the gradation or its station. It is recommended that the user update the selected method to match the culvert gradations. If there is a tie, HY-8 will select the method that provides an average value that is closest to 0.03. It is recommended that you review the selected method. To learn more about the methods and the required criteria of each method, see HEC-26 Appendix C.

Once the data is entered, HY-8 will provide the number of calculations performed that met the criteria of the method selected and the average value of all the calculations given. These values are not used for any computations, but they are reported to the user to facilitate selecting a Manning's n computation method. The result of the calculation at each cross section with each flow is then reported in the final table of the spreadsheet. It is important to note that the average value of a method may be reasonable, but many of the individual calculations could still be very unreasonable.

7.2.4.2 Manning's n Methods

From HEC-26, Appendix C:

An appropriate equation selection must consider the basis on which the equation was developed and how it might apply within a closed conduit. The Bathurst, Jarrett, and Mussetter equations tend to better represent n values on steeper channels or channels with larger roughness elements. Limerinos and Blodgett attempt to encompass a wider range of conditions. The Bathurst equation depends on channel top width for calculation of Manning’s n (See Kilgore and Cotton (2005) for details). However, in a closed conduit, top width does not monotonically increase with depth as it does in a natural channel. Therefore, the Bathurst equation would be problematic to apply within a culvert.

7.2.4.3 Reach Stability

Finally, the user must make a stream stability assessment and then answer the Reach stability questions. Is the streambed in Dynamic Equilibrium? If not, does the channel stability support culvert design? If the answer to both questions is no, the stream needs to be stabilized before the aquatic organism passage can be determined.

The engineer must perform this analysis during a site visit. You find more information in HEC-26 on page 7-4, under the heading 'Step 3. Check for Dynamic Equilibrium' and continued through the heading 'Step 4. Analyze and Mitigate Channel Instability' on page 7-6.

7.2.4.4 Culvert Bed Gradations

The culvert may have two gradations: an upper layer and a lower layer. If only one layer is needed, HY-8 will use the upper layer. The upper Layer is computed by averaging all of the streambed gradations. When the streambed gradations are properly defined, the calculated D50 of the gradation will show in the final column of the upper culvert bed gradation. HY-8 will determine if the lower layer is needed and determine the size later.

Then, you can select method to compute the Manning's n value. When you make a change in the definition of one of the gradation, HY-8 will choose the method that has the most criteria that is met. If there is a tie, HY-8 will select the method that provides an average value that is closest to 0.03. It is recommended that you review the selected method. To learn more about the methods and the required criteria of each method, see HEC-26 Appendix C.

The final three rows show the results of the computations on the culvert bed.

7.2.5 Align and Size Culvert

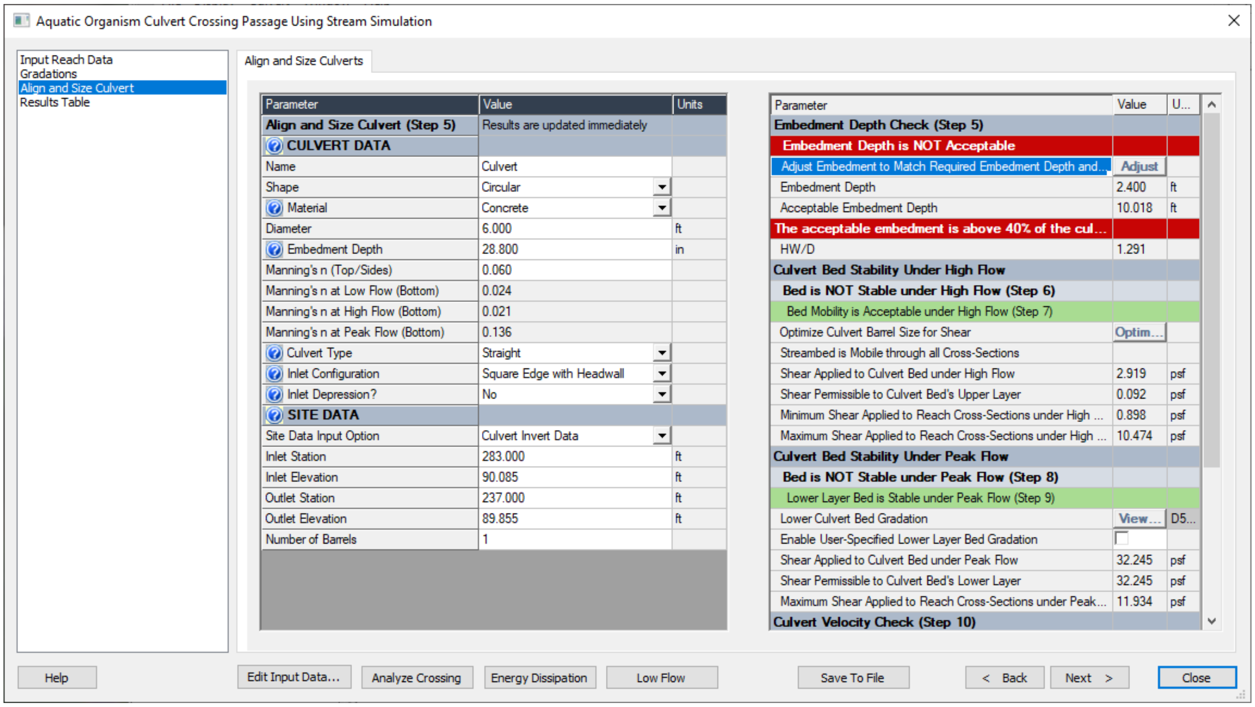


Figure 7.5: AOP Stream Simulation Alignment and Sizing dialog

This dialog will allow you to make changes to the layout and size of your culvert and immediately see the results in the Aquatic Organism Passage. It will also allow you to hit a button and have HY-8 change the size of the culvert until it is the smallest culvert barrel size that still allows passage for shear and then for shear and velocity. Before you optimize the culvert, you need to verify that the site data of the culvert is correct. Also recognize that there is no undo or cancel on optimize or any changes made to the culvert alignment and size.

7.2.5.1 Align and Size Culverts

The left side of the dialog contains the same spreadsheet that is available on the right side of the *Crossing Input Data* dialog. Any changes made on this page will change the data that is shown in that dialog. There is no undo or cancel on this page. More information is available at the Culvert Data section.

7.2.6 Aquatic Organism Passage Results

7.2.6.1 Embedment Depth Check

The Right side of the dialog reports the Aquatic Organism Passage results. It starts with the embedment level. The level of embedment depends on the layers that are required, the gradations of those layers, and the shape of the culvert. The dialog has a button that will adjust the embedment to match the required amount of embedment. This may change the invert elevations of your culvert as well as the embedment depth. The headwater depth over culvert rise, HW/D, is also reported in this section so the user can verify that the culvert still meets hydraulic design criteria. This calculation does not include the section of culvert that is embedded when calculating the rise and the headwater depth.

7.2.6.2 Culvert Bed Stability under High Flows

Next is the stability of the culvert bed under High Flow. First, HY-8 checks if the culvert bed's upper layer is stable under high flow. It does this by comparing the shear applied to the shear permissible to the culvert bed's upper layer. If the permissible shear is greater, then it is stable. If that fails, the bed mobility may still be acceptable. First HY-8 determines if the streambed is mobile. If the applied shear on all cross-section are above the permissible shear, then all cross-section will be eroding and the streambed will be mobile. If the bed is mobile and as long as the shear applied to the culvert bed, is less than the maximum shear applied to the cross-sections immediately upstream or downstream of the culvert crossing, then the mobility is acceptable. If the bed is NOT mobile or if the culvert's shear is higher than the maximum shear in the cross sections, it is not acceptable.

For more information on the optimize button, see Optimize Culvert Barrel Size below.

7.2.6.3 Culvert Bed Stability under Peak Flows

In the next section, HY-8 checks the stability of the culvert bed under Peak flow. First it checks if the culvert bed's upper layer is stable under peak flow. It does this by comparing the shear applied to the shear permissible to the culvert bed's upper layer. If the permissible shear is greater, then it is stable. If it is unstable, HY-8 will determine the gradation that will be stable. The user can then specify their own gradation to be used in the calculations. For the user's ability to compare, the maximum shear applied to the reach cross-section under peak flow is reported, although it is not used in these calculations.

7.2.6.4 Culvert Velocity Check

The third check is the velocity under high flow. HY-8 determines the maximum average velocity within the barrel when it determines the water surface elevations through direct step. It then compares this velocity with the maximum average velocity computed using the Manning's Equation at the cross-sections. As long as the culvert's velocity is less than the velocity in the cross-sections, the velocity is acceptable.

The optimize routine increases the barrel size to decrease the culvert barrel velocity. As this is not the most effective way of decreasing the velocity, this routine is often unstable. Each time you click the optimization routine, it will not increase the barrel size more than 2'. The designer should keep in mind the allowable tolerances of the velocities and whether a velocity that is still higher than the maximum cross-section channel velocity, may still be acceptable. For example, a velocity slightly higher than those in the natural channel, but over a much shorter flow length within the culvert, compared to the flow lengths in the natural channel. Also, the velocities are determined through different methods: the culvert velocity is computed through the direct step method while the reach cross-sections are determined through normal depth. Finally, if the velocity is significantly higher than the reach cross-sections, the engineer should consider a change in the slope of the culvert.

For more information on the optimize button, see below

7.2.6.5 Culvert Depths

The final check is the depth in the culvert under low flow. HY-8 determines the minimum depth within the barrel when it determines the water surface elevations through direct step. It then compares the minimum depth in the culvert, with the minimum depth in the cross section that is computed by the Manning's Equation.

If the depth is too shallow, the user can create a low flow channel in the embedment. The side slope of the low flow channel is 1:8 (V:H), but the the user can adjust the depth. The shape of the embedded culvert will be modified in the computations and in the front view of the culvert. This change will affect the computations in the Culvert Crossing Output Dialog as well.

It is difficult to meet the minimum depth requirements, even with a well-designed culvert crossing. The user should remember that the two depths are computed differently: the minimum depth in the culvert is determined through the direct step method while the minimum depth in the reach cross-sections is determined by normal depth. The user should make their best effort to maintain the minimum depth, including specifying a low flow channel, but once these options have been exhausted, there is little more that can be done to improve the design and aquatic organism passage. At this point, the user should accept the best possible design.

7.2.6.6 Optimize Culvert Barrel Size

Near the bottom of this dialog is the 'Optimize Culvert Barrel Size'. This will change the size of the culvert barrel to 4' and turn off the low flow channel. HY-8 will then increase the barrel size until the culvert bed is stable (or acceptable). If the optimize button in the velocities section is clicked, then HY-8 will continue to increase the size of barrel until the velocity is acceptable.

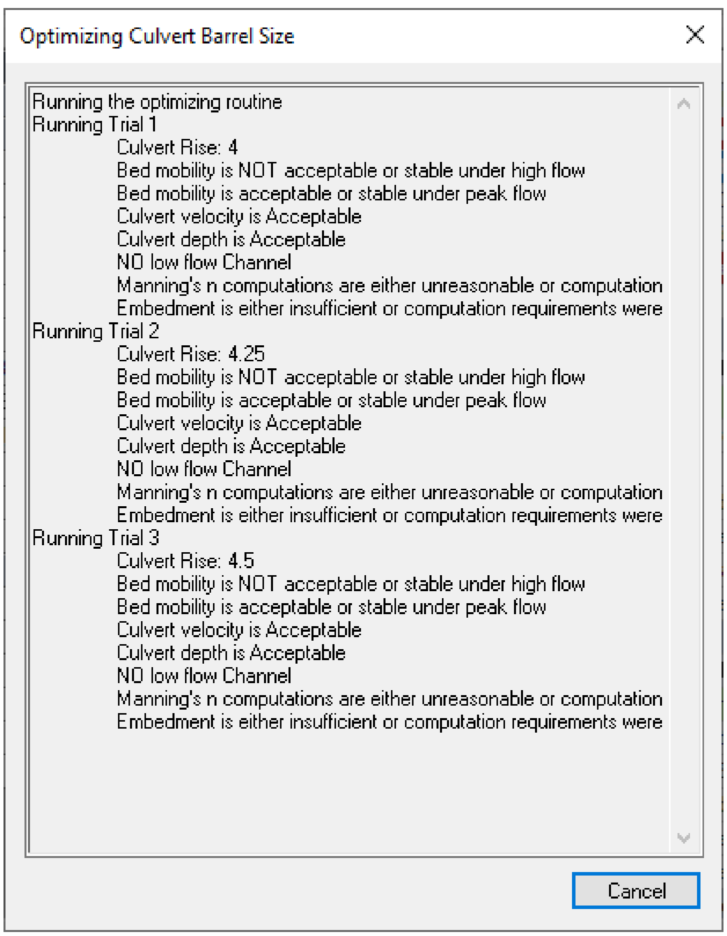


Figure 7.6: Optimizing culvert barrel size dialog

HY-8 will launch the Optimize dialog that will show each calculation being performed and the result of that run. It will also allow you to cancel if HY-8 is taking too long to optimize. Eventually, HY-8 will give up on finding an optimized culvert.

The Optimization routine will modify the values of the culvert barrel size that will change the results in the AOP dialog and the Culvert Crossing Input Data and the View Culvert Crossing Results Dialog. There is no undo or cancel for this option. It is recommended that if you wish to be able to return to the state before optimizing the culvert size, that you save the crossing to a file.

7.2.7 Results Table

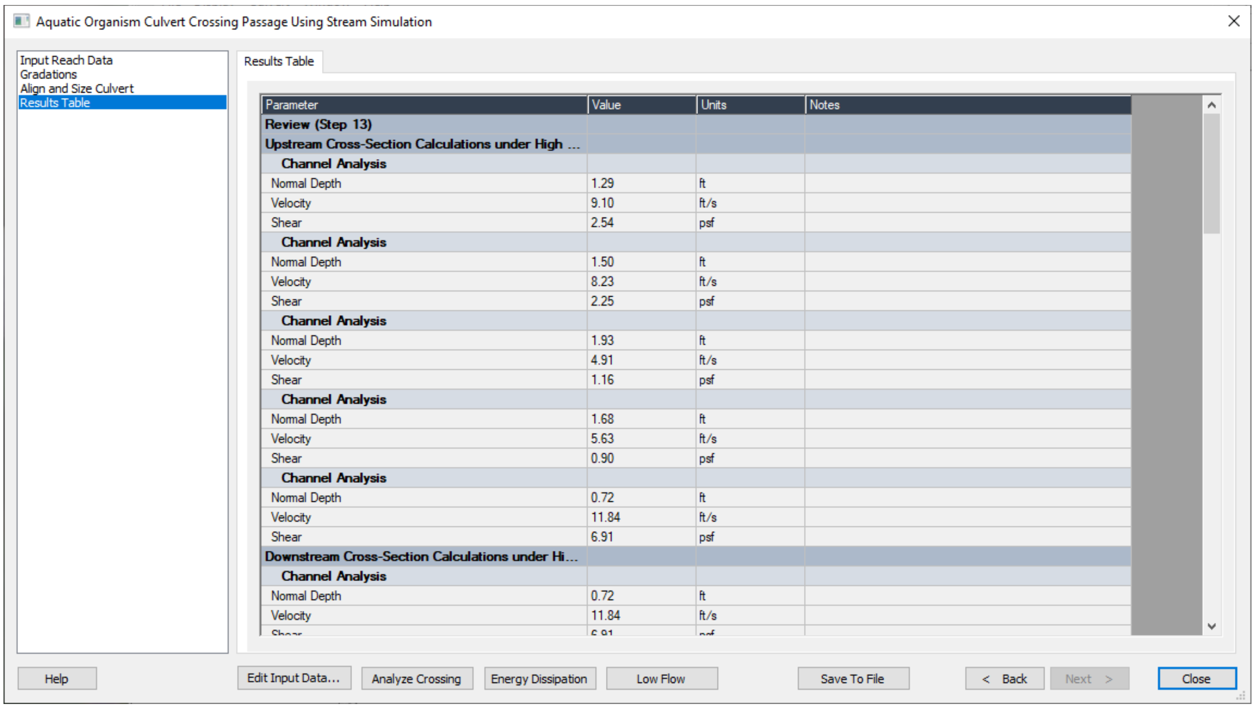


Figure 7.7: AOP Stream Simulation, Results Table

This dialog reports to the user most of variables used in the computations to the user who can then verify that the results are reasonable.

7.2.7.1 Cross Section Calculations

The normal depth, velocity and shear from each cross-section that was calculated using Manning's Equation.

7.2.7.2 Shear Calculations

The equations used to perform these calculations are available in HEC-26 Chapter 7. It reports the energy slope used, the D50 of the gradation used, the v*, Reynold's value, and Shield's value for the shear calculations and the resulting shear computations.

7.2.7.3 Depth & Velocity Calculations

These results are the same as given in the Align and Size Culvert step, and are included on this page for completeness and to make comparison easier.

8 Low Flow Hydraulics

8.1 Low Flow Hydraulics Method

The HY-8 Low Flow Hydraulics method is based on the TFHRC report: Fish Passage in Large Culverts With Low Flow. The method divides half of the culvert span into slices. The velocity and depth of that slice are computed then compared to a threshold. If the slice has a velocity lower than the threshold and a depth greater than the threshold, the slice is determined to pass the requirements. For more information on this method, please see the TFHRC report listed above.

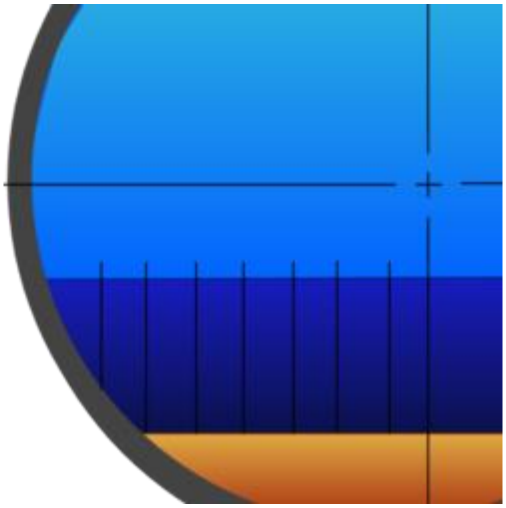


Figure 8.1: Low flow hydraulics diagram in an embedded, circular culvert barrel

The *Low Flow Hydraulics* calculator may be used any time that there is a requirement on depth or velocity through a culvert. This method is commonly used to determine fish passage where the threshold depth and velocity relate to the swimming ability of a targeted fish.

8.2 Low Flow Hydraulics Interface

8.2.1 Input Data

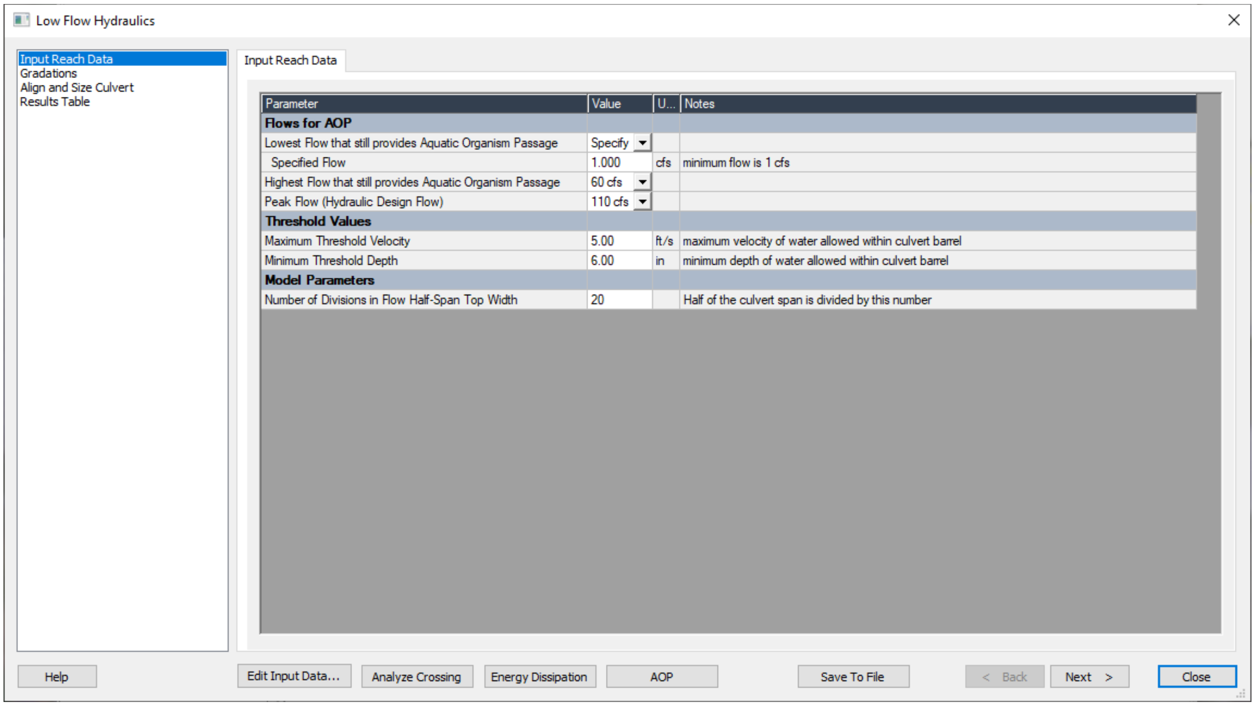


Figure 8.2: Low Flow Hydraulics, Input Reach Data

8.2.1.1 Flows

The user needs to determine the lowest and highest flow that are of interest to the user. If the user is performing a fish passage or aquatic organism passage study, the flows should still provide passage throughout the remainder of the stream. The lowest flow the user is allowed to enter is 1 cfs. The user can specify the flow directly, or if the flow has already been entered in the *Culvert Input Data* dialog, the user can select the flow in the drop down menu. If multiple flows are below 1 cfs, then the list will have "1 cfs" multiple times, but will not cause any computational issues. HEC 26 provides guidance on determining AOP/Fish Passage flows in Chapter 5.

The user will then need to determine the hydraulic design flow, which is the design flow used to design the culvert crossing. It is used to determine that the embedment will be stable.

8.2.1.2 Save To File

The **Save To File** button is available on all pages of the *Low Flow Hydraulics* dialog. If the user has not already saved or loaded from a file, HY-8 will prompt the user to specify a filename. Otherwise, HY-8 will update the filename already in use. It is recommended to save often.

8.2.1.3 Data Validation.

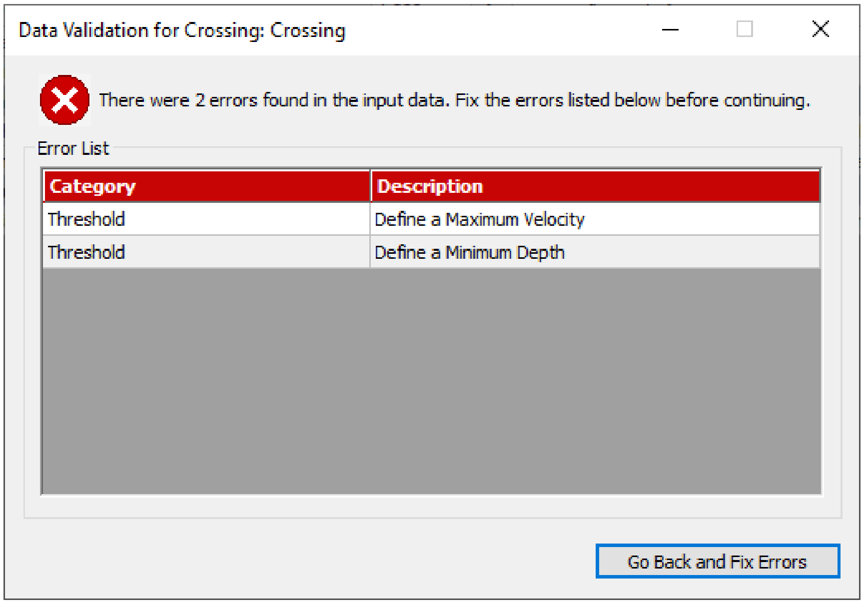


Figure 8.3: Example of the Data Validation dialog

When the user moves to another step of the Low Flow Hydraulics, HY-8 will check the input for any errors. If HY-8 detects errors, a dialog will pop up with a list of errors and the category they belong to. These errors must be corrected before continuing to a new step.

8.2.1.4 Gradation Data

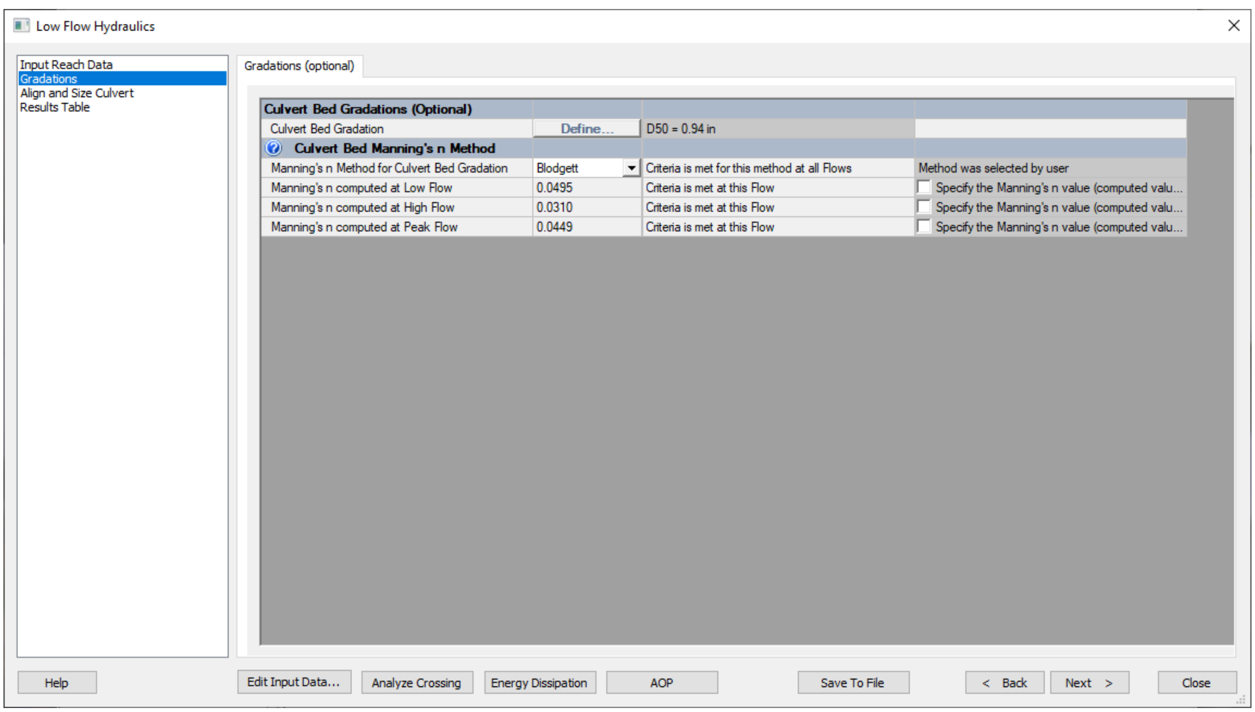


Figure 8.4: Low Flow Hydraulics dialog show the Gradations options

The gradations are used to determine the Manning's n value for the channel and culvert as well as the stability of the embedment within the culvert. This step is NOT required for the Low Flow Hydraulics method. The step allows the user to use a computed Manning's n value and to provide embedment check computations. If the culvert has a metal, plastic, or concrete floor, the user should not enter gradation data. If there is gradation data already entered, the user should clear it out. The gradations should only be used on embedded culverts or open-bottom culverts.

8.2.1.4.1 Manning's n Methods

From HEC-26, Appendix C:

> An appropriate equation selection must consider the basis on which the equation was developed and how it might apply within a closed conduit. The Bathurst, Jarrett, and Mussetter equations tend to better represent n values on steeper channels or channels with larger roughness elements. Limerinos and Blodgett attempt to encompass a wider range of conditions. The Bathurst equation depends on channel top width for calculation of Manning’s n (See Kilgore and Cotton (2005) for details). However, in a closed conduit, top width does not monotonically increase with depth as it does in a natural channel. Therefore, the Bathurst equation would be problematic to apply within a culvert.

8.2.2 Align and Size Culvert

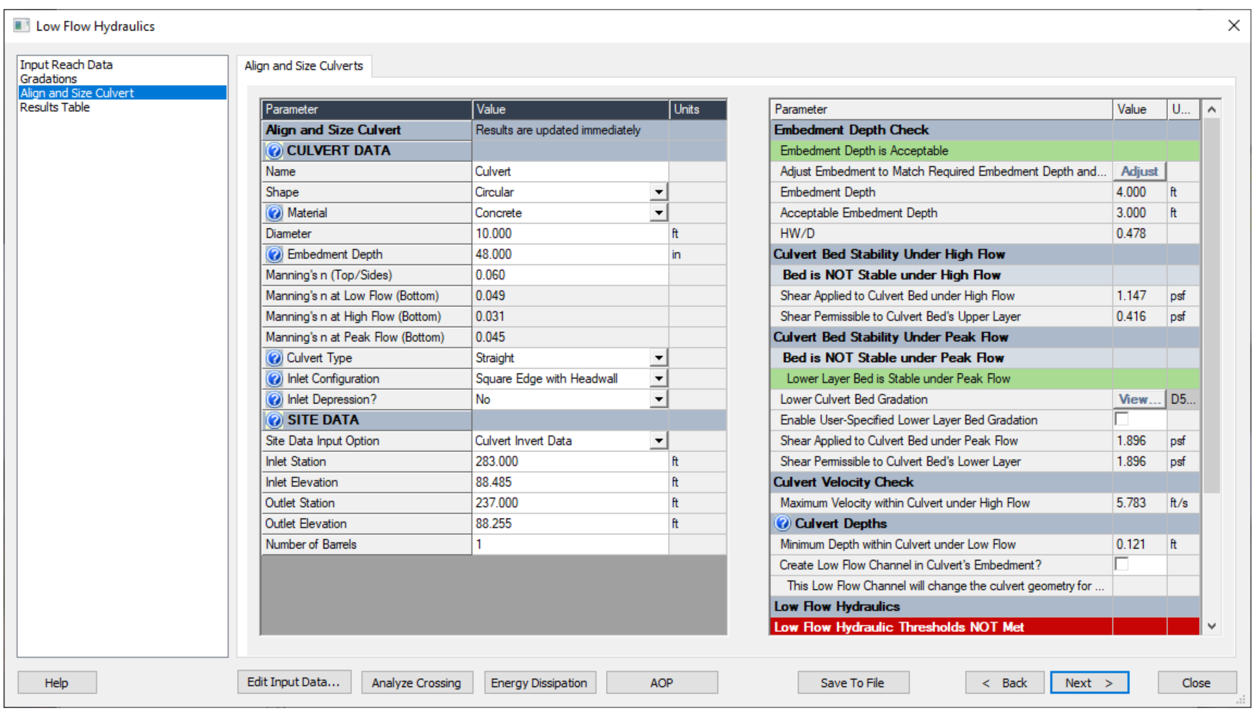


Figure 8.5: Low Flow Hydraulics dialog show the Align and Size Culvert options

This dialog will allow the user to make changes to the layout and size of the culvert and immediately see the results in the *Low Flow Hydraulics Results Table*.

8.2.2.1 Align and Size Culverts

The left side of the dialog contains the same spreadsheet that is available on the right side of the *Crossing Input Data* dialog. Any changes made on this page, will change the data that is shown in that dialog. There is no undo or cancel on this page. More information is available in section 4: Culvert Data.

8.2.2.2 Results if Gradation is Included

8.2.2.2.1 Embedment Depth Check

The right side of the dialog reports the Aquatic Organism Passage results. It starts with the embedment level. The level of embedment depends on the layers that are required, the gradations of those layers, and the shape of the culvert. The dialog has a button that will adjust the embedment to match the required amount of embedment. This may change the invert elevations of your culvert as well as the embedment depth. The headwater depth over culvert rise, HW/D, is also reported in this section so the user can verify that the culvert still meets hydraulic design criteria. This calculation does not include the section of culvert that is embedded when calculating the rise and the headwater depth.

8.2.2.2.2 Culvert Bed Stability under High Flows

Next is the stability of the culvert bed under high flow. First, it checks if the culvert bed's upper layer is stable under high flow. To do this, the check compares the shear applied to the shear permissible to the culvert bed's upper layer. If the permissible shear is greater, then it is stable. If that fails, the bed mobility may still be acceptable. First HY-8 determines if the streambed is mobile. If the applied shear on all cross section are above the permissible shear, then all cross section will be eroding and the streambed will be mobile. If the bed is mobile and as long as the shear applied to the culvert bed, is less than the maximum shear applied to the cross sections immediately upstream or downstream of the culvert crossing, then the mobility is acceptable. If the bed is NOT mobile or if the culvert's shear is higher than the maximum shear in the cross sections, it is not acceptable.

8.2.2.2.3 Culvert Bed Stability under Peak Flows

In next section, HY-8 checks the stability of the culvert bed under peak flow. First it checks if the culvert bed's upper layer is stable under peak flow. To do this, the check compares the shear applied to the shear permissible to the culvert bed's upper layer. If the permissible shear is greater, then it is stable. If it is unstable, HY-8 will determine the gradation that will be stable. The user can then specify their own gradation to be used in the calculations. For the user's ability to compare, the maximum shear applied to the reach cross section under peak flow is reported, although it is not used in these calculations.

8.2.2.2.4 Culvert Velocity Check

The third check is the velocity under high flow. HY-8 determines the maximum average velocity within the barrel when it determines the water surface elevations through direct step. It then compares this velocity with the maximum average velocity computed using the Manning's Equation at the cross sections. As long as the culvert's velocity is less than the velocity in the cross sections, the velocity is acceptable.

8.2.2.3 Low Flow Hydraulics Results

8.2.2.3.1 Culvert Depths

The final check is the depth in the culvert under low flow. HY-8 determines the minimum depth within the barrel when it determines the water surface elevations through direct step. It then compares the minimum depth in the culvert, with the minimum depth in the cross section that is computed by the Manning's Equation.

If the depth is too shallow, the user can create a low flow channel in the embedment. The side slope of the low flow channel is 1:8 (V:H), but the user can adjust the depth. The shape of the embedded culvert will be modified in the computations and in the front view of the culvert. This change will affect the computations in the *Culvert Crossing Output* dialog as well.

8.2.2.3.2 Low Flow Hydraulic Thresholds

There are three results given for both flows: The combined width of the slices that meet threshold depth, the highest average velocity (along the water surface profile for the given flow), and the lowest depth in the culvert (along the water surface profile for the given flow).

8.2.3 Results Table

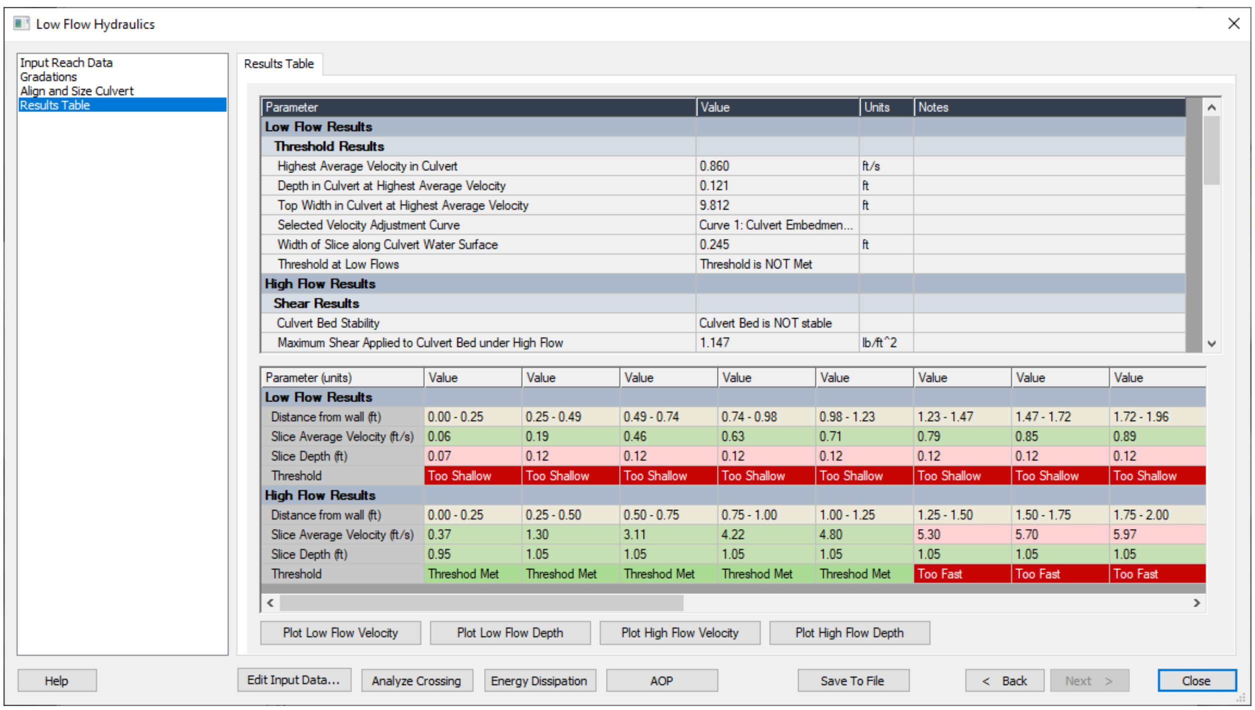


Figure 8.6: Low Flow Hydraulics dialog showing the Results Table options.

The purpose of this dialog is to report to the user most of variables used in the computations to the user who can then verify that the results are reasonable.

8.2.3.1 Results Table

8.2.3.1.1 Culvert Results (First Spreadsheet)

The user can plot the velocity and depth across half of the span of the culvert (from the wall to the center) for the low and high flows by clicking the buttons below the respective flow heading. Then HY-8 gives the threshold results, displaying the highest average velocity, the depth at that location, the top width, the velocity adjustment curve that was selected, the width of the slices, and whether the threshold is ever satisfied.

If a gradation is included, the table also includes shear results. The equations used to perform these calculations are available in HEC-26 Chapter 7. It reports the energy slope used, the D50 of the gradation used, the v*, Reynold's value, and Shield's value for the shear calculations and the resulting shear computations.

The threshold inputs are also included at the bottom of the table.

8.2.3.1.2 Slice Results (Second Spreadsheet)

The results from each slice are given, with each column representing one slice. The leftmost column is the slice closest to the wall and the rightmost column is the slice closest to the center. The first result is the distance from the well to the center of the slice. Then the velocity is reported. If it is below the threshold velocity, it is given a light green background while it is light red if it exceeds the threshold velocity. The depth is reported next, and if it is deeper than the threshold velocity, it is given a light green background and a light red one if is shallower than the threshold depth. The final row is the combined threshold result given a green background if both thresholds are met in the slice or a red background if it failed for either reason.

9 HY-8 Testing

HY-8 is continually tested with unit tests to verify culvert crossing computations. The test cases used to verify HY-8 are available at the following website: http://aquaveo.com/hy8-test-cases. If you have a unique culvert crossing that represents a novel test case, that may be submitted for consideration as a test case.

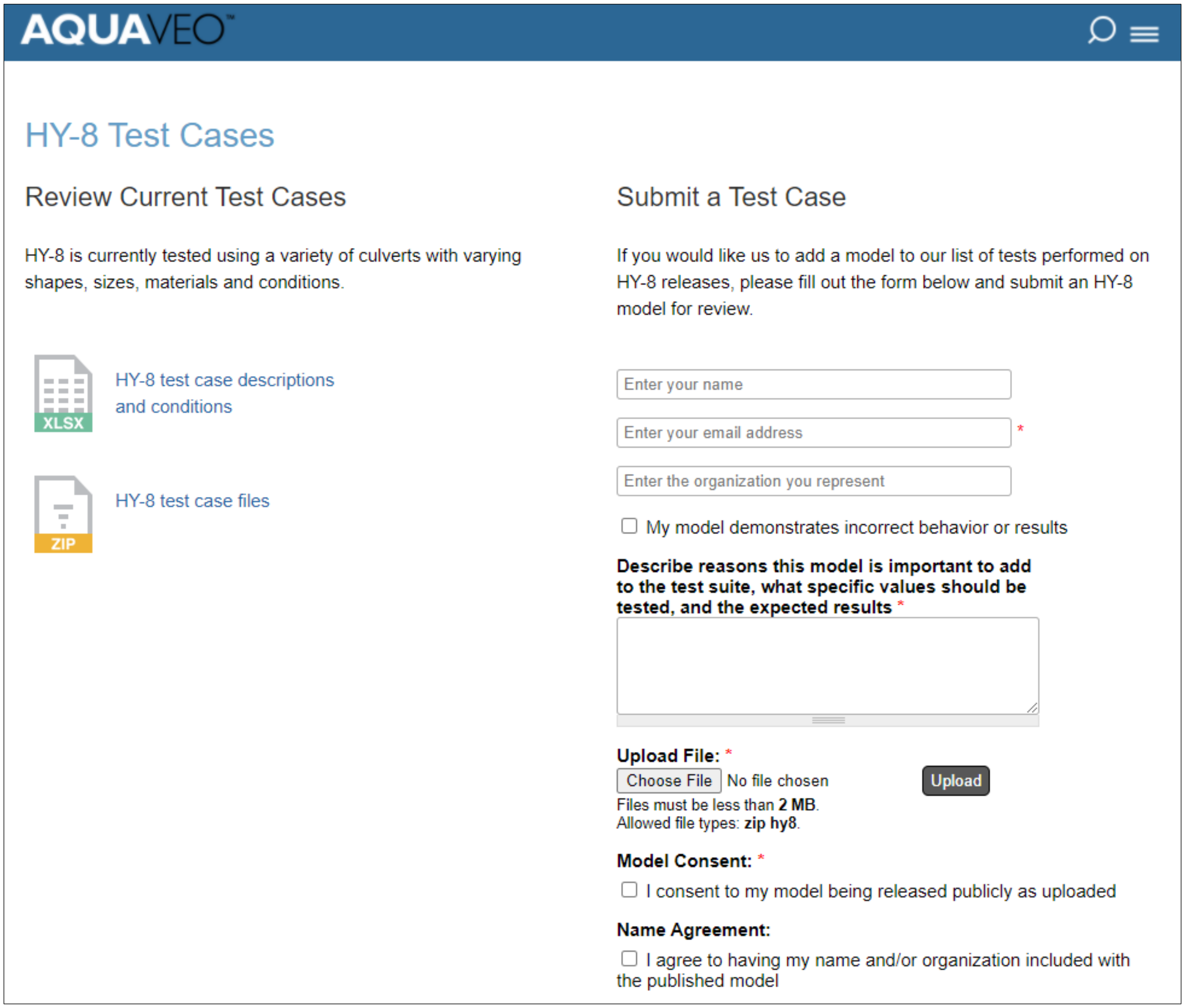


Figure 9.1: HY-8 Test Cases website

10 Troubleshooting

10.1.1 Troubleshooting

If you have problems running HY-8, see if the following sections will help. If you continue to have issues or questions relating to accuracy or specific modeling issues, we encourage you to contact the Federal Highways Administration. As common troubleshooting problems and solutions are discovered, they will be added to this section.

10.1.1.1 Registering Libraries

Previous versions of HY-8 had libraries created by a company named Gnostice for report generation. However, in HY-8 v 7.70 the report options were updated to a new library, called HyReport.

HY-8 relies on the following Libraries:

- vc_redist.x64.exe
- PEGRP64E.DLL
- ShapeDB.dat
- VirtualEarth.html & WinformsEarthV2.exe
- HyReport

If HY-8 crashes when the program launches:

- Install or repair the Microsoft Visual C++ 64-bit Redistributable package (vc_redist.x64.exe).
- Check that the PEGRP64E.dll is located in the HY-8 installation directory.

If HY-8 crashes or has errors in the Edit Crossing dialog

- Check that the shapeDB.dat file is located in the HY-8 installation directory.

If HY-8 crashes or has errors in the Map Viewer

- Check that the VirtualEarth.html & WindormsEarthV2.exe files are located in the HY-8 installation directory.

If HY-8 crashes or has errors when generating a report

- Check that the user has write permissions in the folder of the selected report filename and that the filename is locked for use by another program.
- Check that the HyReport directory is located in the HY-8 installation directory.

10.1.2 Contacting FHWA

If you still have trouble installing or running HY-8, or found a case that seems to provide an inconsistent or incorrect answer or plot, or have suggestions for new features, contact FHWA by sending an e-mail to CommentsonHY8@dot.gov .

Please include the '.hy8' of the project you have created, include what operating system you are using, which version and build date of the HY-8 version you are using, and the steps to needed to recreate the issue you are experiencing. The version and build date of HY-8 is available by going to HY-8's 'Help' menu, then clicking on the 'About' menu item.

11 Appendix A

11.1 Polynomial Coefficients - Circular

Table 11.1: Circular Polynomial Coefficients

HY-8 Equation	Inlet Configuration	KE	SR	A	BS	C	DIP	EE	F
1	Thin Edge Projecting	0.9	0.5	0.187321	0.56771	-0.156544	0.0447052	-0.00343602	8.96610E-05
2	Mitered to Conform to Slope	0.7	-0.7	0.107137	0.757789	-0.361462	0.1233932	-0.01606422	0.00076739
3	Square Edge with Headwall (Steel/Aluminum/ Corrugated PE)	0.5	0.5	0.167433	0.538595	-0.149374	0.0391543	-0.00343974	0.000115882
4	Grooved End Projecting	0.2	0.5	0.108786	0.662381	-0.233801	0.0579585	-0.0055789	0.000205052
5	Grooved End in Headwall	0.2	0.5	0.114099	0.653562	-0.233615	0.0597723	-0.00616338	0.000242832
6	Beveled Edge (1:1)	0.2	0.5	0.063343	0.766512	-0.316097	0.0876701	-0.009836951	0.00041676
7	Beveled Edge (1.5:1)	0.2	0.5	0.08173	0.698353	-0.253683	0.065125	-0.0071975	0.000312451
8	sq. proj.	0.2	0.5	0.167287	0.558766	-0.159813	0.0420069	-0.00369252	0.000125169
9	Square Edge with Headwall	0.5	0.5	0.087483	0.706578	-0.253295	0.0667001	-0.00661651	0.000250619
	(Concrete/PVC/ HDPE)								
10	end sect.	0.4	0.5	0.120659	0.630768	-0.218423	0.0591815	-0.00599169	0.000229287

EQ #'s: REFERENCE

- 1-9: Calculator Design Series (CDS) 3 for TI-59, FHWA, 1980, page 60
- 1-10: Hydraulic Computer Program (HY) 1, FHWA, 1969, page 18

11.2 Polynomial Coefficients - Embedded Circular

Table 11.2: Embedded Circular Polynomial Coefficients

HY-8 Equation	Inlet Configuration	KE	SR	A	BS	C	DIP	EE	F
1	20% Embedded, Projecting End, Pond	1.0	0.5	0.09225658	0.59588355	-0.18033946	0.044397015	-0.0035558622	1.03741644E-4
2	40% Embedded, Projecting End, Pond	1.0	0.5	0.017040825	0.74740434	-0.3109201	0.090210155	-0.010031769	4.1309113E-4
3	50% Embedded, Projecting End, Pond	1.0	0.5	0.026227733	0.6566797	-0.22467102	0.056954376	-0.0052307257	1.8243608E-4
4	20% Embedded, Square Headwall	0.55	0.5	0.08563743	0.55992293	-0.17619072	0.04494229	-0.0047676745	2.0761597E-4
5	40% Embedded, Square Headwall	0.55	0.5	0.07551063	0.54737955	-0.20195223	0.059755154	-0.0066917636	2.8661877E-4
6	50% Embedded, Square Headwall	0.55	0.5	0.08663351	0.43472388	-0.08336235	0.015986685	-8.3243777E-4	1.1144268E-5
7	20% Embedded, 45 degree Beveled End	0.35	0.5	0.036159426	0.66382253	-0.24094956	0.056614485	-0.005639798	2.2724035E-4
8	40% Embedded, 45 degree Beveled End	0.35	0.5	0.1686593	0.3051618	-0.015593394	0.0049916985	-8.836533E-4	7.311242E-5
9	50% Embedded, 45 degree Beveled End	0.35	0.5	-0.061560366	0.5790233	-0.16663338	0.030292464	-0.0023849143	7.206958E-5
10	20% Embedded, Mitered End 1.5H:1V	0.9	0.5	0.072793305	0.6167542	-0.23389544	0.06543605	-0.007126117	2.9917536E-4
11	40% Embedded, Mitered End 1.5H:1V	0.9	0.5	0.08681991	0.36217746	-0.048309285	0.008705983	-3.59507E-4	2.8914428E-6
12	50% Embedded, Mitered End 1.5H:1V	0.9	0.5	-0.048001524	0.7663884	-0.34299952	0.092636675	-0.009846659	3.864864E-4

EQ #'s: REFERENCE

- 1-12: NCHRP 15-24 report

11.3 Polynomial Coefficients - Box

Table 11.3: Concrete Box Polynomial Coefficients

HY-8 Equation	Inlet Configuration	KE	SR	A	BS	C	DIP	EE	F
1	Square Edge (90 degree) Headwall, Square Edge (90 & 15 degree flare) Wingwall	0.5	0.5	0.122117	0.505435	-0.10856	0.0207809	-0.00136757	0.00003456
2	1.5:1 Bevel (90 degree) Headwall, 1.5:1 Bevel (19-34 degree flare) Wingwall	0.2	0.5	0.1067588	0.4551575	-0.08128951	0.01215577	-0.00067794	0.0000148
3	1:1 Bevel Headwall	0.2	0.5	0.1666086	0.3989353	-0.06403921	0.01120135	-0.0006449	0.000014566
4	Square Edge (30-75 degree flare) Wingwall	0.4	0.5	0.0724927	0.507087	-0.117474	0.0221702	-0.00148958	0.000038
5	Square Edge (0 degree flare) Wingwall	0.7	0.5	0.144133	0.461363	-0.0921507	0.0200028	-0.00136449	0.0000358
6	1:1 Bevel (45 degree flare) Wingwall	0.2	0.5	0.0995633	0.4412465	-0.07434981	0.01273183	-0.0007588	0.00001774

EQ #'s: REFERENCE

- 1-6: Hydraulic Computer Program (HY) 6, FHWA, 1969, subroutine BEQUA
- 1,4,5: Hydraulic Computer Program (HY) 3, FHWA, 1969, page 16
- 1,3,4,6: Calculator Design Series (CDS) 3 for TI-59, FHWA, 1980, page 16

11.4 Polynomial Coefficients - Ellipse

Table 11.4: Ellipse Polynomial Coefficients

HY-8 Equation	PIPE	Inlet Configuration	KE	SR	A	BS	C	DIP	EE	F
27	CSPE	headwall	0.5	0.5	0.01267	0.79435	-0.2944	0.07114	-0.00612	0.00015
28	CSPE	mitered	0.7	-0.7	-0.14029	1.437	-0.92636	0.32502	-0.04865	0.0027
29	CSPE	bevel	0.3	0.5	-0.00321	0.92178	-0.43903	0.12551	-0.01553	0.00073
30	CSPE	thin	0.9	0.5	0.0851	0.70623	-0.18025	0.01963	0.00402	-0.00052
31	RCPE	square	0.5	0.5	0.13432	0.55951	-0.1578	0.03967	-0.0034	0.00011
32	RCPE	groove. headwall	0.2	0.5	0.15067	0.50311	-0.12068	0.02566	-0.00189	0.00005
33	RCPE	groove. projecting	0.2	0.5	-0.03817	0.84684	-0.32139	0.0755	-0.00729	0.00027

EQ #'s: REFERENCE

- 27-30: Calculator Design Series (CDS) 4 for TI-59, FHWA, 1982, page 20
- 31-33: Calculator Design Series (CDS) 4 for TI-59, FHWA, 1982, page 22

11.5 Polynomial Coefficients - Pipe Arch

Table 11.5: Pipe Arch polynomial Coefficients

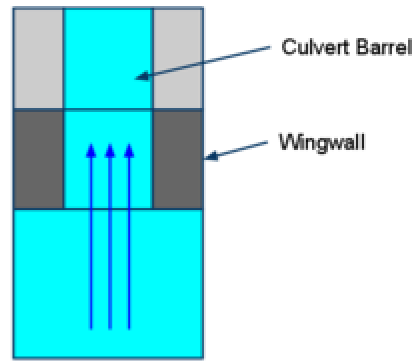
HY-8 Equation	PIPE	Inlet Configuration	KE	SR	A	BS	C	DIP	EE	F
12	CSPA	projecting	0.9	0.5	0.08905	0.71255	-0.27092	0.07925	-0.00798	0.00029
13	CSPA	projecting	0.9	0.5	0.12263	0.4825	-0.00002	-0.04287	0.01454	-0.00117
14	CSPA	Projecting	0.9	0.5	0.14168	0.49323	-0.03235	-0.02098	0.00989	-0.00086
15	CSPA	projecting	0.9	0.5	0.09219	0.65732	-0.19423	0.04476	-0.00176	-0.00012
16	CSPA	mitered	0.7	-0.7	0.0833	0.79514	-0.43408	0.16377	-0.02491	0.00141
17	CSPA	mitered	0.7	-0.7	0.1062	0.7037	-0.3531	0.1374	-0.02076	0.00117
18	CSPA	mitered	0.7	-0.7	0.23645	0.37198	-0.0401	0.03058	-0.00576	0.00045
19	CSPA	mitered	0.7	-0.7	0.10212	0.72503	-0.34558	0.12454	-0.01676	0.00081
20	CSPA	headwall	0.5	0.5	0.11128	0.61058	-0.19494	0.05129	-0.00481	0.00017
21	CSPA	headwall	0.5	0.5	0.12346	0.50432	-0.13261	0.0402	-0.00448	0.00021
22	CSPA	headwall	0.5	0.5	0.09728	0.57515	-0.15977	0.04223	-0.00374	0.00012
23	CSPA	headwall	0.5	0.5	0.09455	0.61669	-0.22431	0.07407	-0.01002	0.00054
24	RCPA	headwall	0.5	0.5	0.16884	0.38783	-0.03679	0.01173	-0.00066	0.00002
25	RCPA	groove. headwall	0.2	0.5	0.1301	0.43477	-0.07911	0.01764	-0.00114	0.00002
26	RCPA	groove. projecting	0.2	0.5	0.09618	0.52593	-0.13504	0.03394	-0.00325	0.00013

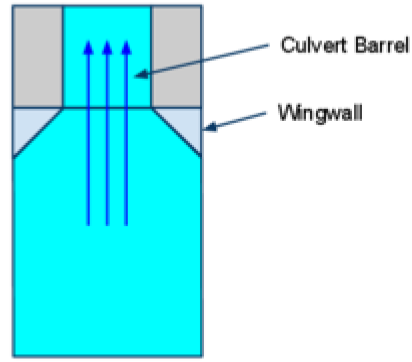
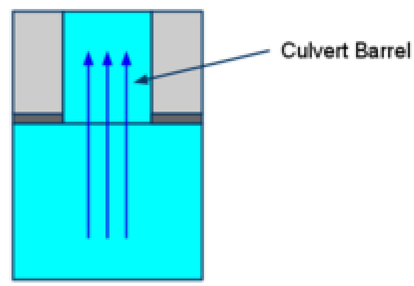
EQ #'s: REFERENCE

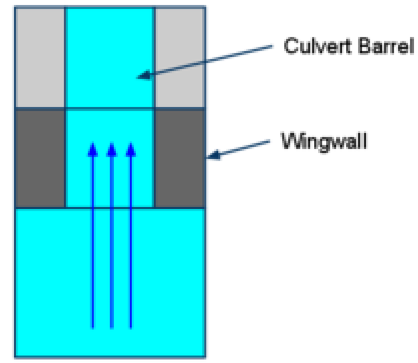
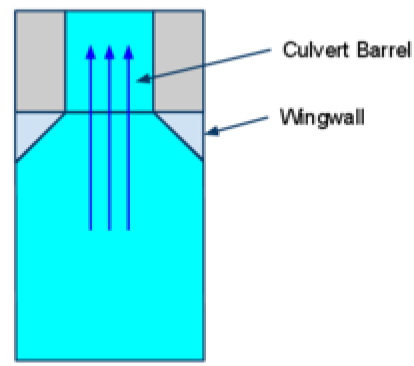
- 12-23: Calculator Design Series (CDS) 4 for TI-59, FHWA, 1982, page 17
- 24-26: Calculator Design Series (CDS) 4 for TI-59, FHWA, 1982, page 24
- 12,16,20: Hydraulic Computer Program (HY) 2, FHWA, 1969, page 17

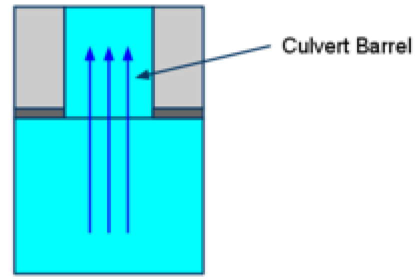
11.6 Polynomial Coefficients - Concrete Open-Bottom Arch

Table 11.6: Concrete Open-Bottom Arch Polynomial Coefficients

Span: Rise Ratio	Wingwall Angle (Inlet Configuration)	KE	SR	A	BS	C	DIP	EE	F	Diagram/Notes
2:1	0 Degrees (Mitered to Conform to Slope)	0.7	0.0	0.0389106557	0.6044131889	-0.1966160961	0.0425827445	-0.0035136880	0.0001097816	2:1 Coefficients are used if the span:rise ratio is less than or equal to 3:1.  0 Degree Wingwall (Mitered to Conform to Slope)

2:1	45 Degrees (45-degree Wingwall)	0.5	0.0	0.0580199163	0.5826504262	-0.1654982156	0.0337114383	-0.0026437555	0.0000796275	2:1 Coefficients are used if the span:rise ratio is less than or equal to 3:1.  45 Degree Wingwall
2:1	90 Degrees (Square Edge with Headwall)	0.5	0.0	0.0747688320	0.5517030198	-0.1403253664	0.0281511418	-0.0021405250	0.0000632552	2:1 Coefficients are used if the span:rise ratio is less than or equal to 3:1.  90 Degree Wingwall (Square Edge with Headwall)

4:1	0 Degrees (Mitered to Conform to Slope)	0.7	0.0	0.0557401882	0.4998819105	-0.1249164198	0.0219465031	-0.0015177347	0.0000404218	4:1 coefficients are used if the span:rise ratio is greater than 3:1  0 Degree Wingwall (Mitered to Conform to Slope)
4:1	45 Degrees (45-degree Wingwall)	0.5	0.0	0.0465032346	0.5446293346	-0.1571341119	0.0312822438	-0.0024007467	0.0000704011	4:1 coefficients are used if the span:rise ratio is greater than 3:1  45 Degree Wingwall

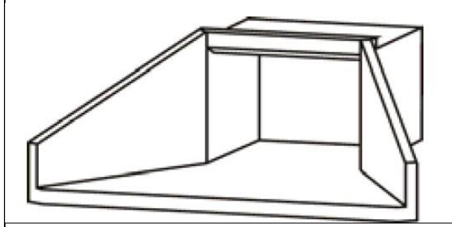
4:1	90 Degrees (Square Edge with Headwall)	0.5	0.0	0.0401619369	0.5774418238	-0.1693724912	0.0328323405	-0.0024131276	0.0000668323	4:1 coefficients are used if the span:rise ratio is greater than 3:1  90 Degree Wingwall (Square Edge with Headwall)

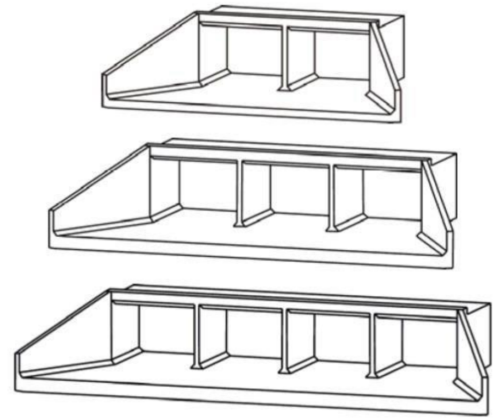
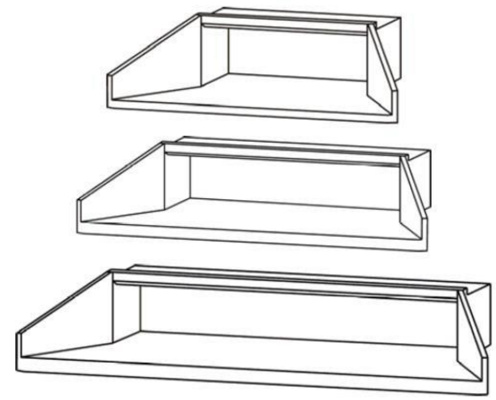
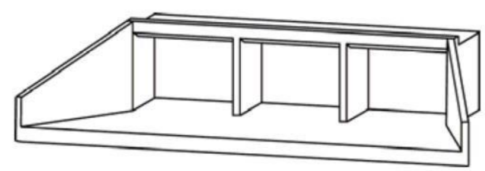
References for Concrete Open-bottom Arch polynomial coefficients:

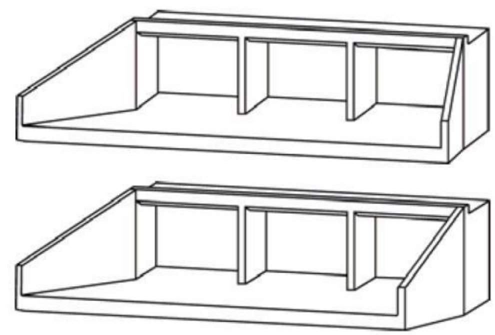
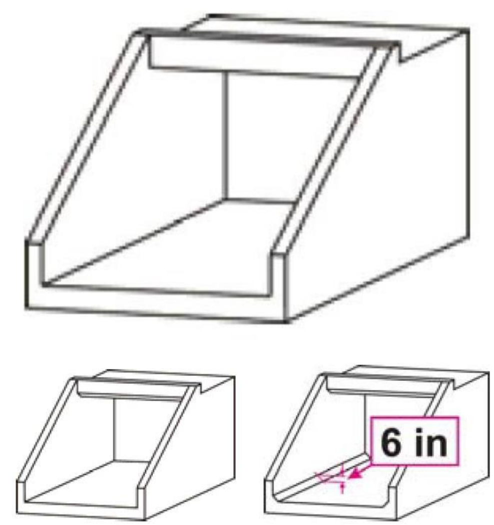
- Thiele, Elizabeth A. Culvert Hydraulics: Comparison of Current Computer Models. (pp. 121-126), Brigham Young University Master's Thesis (2007).
- Chase, Don. Hydraulic Characteristics of CON/SPAN Bridge Systems. Submitted Study and Report (1999)

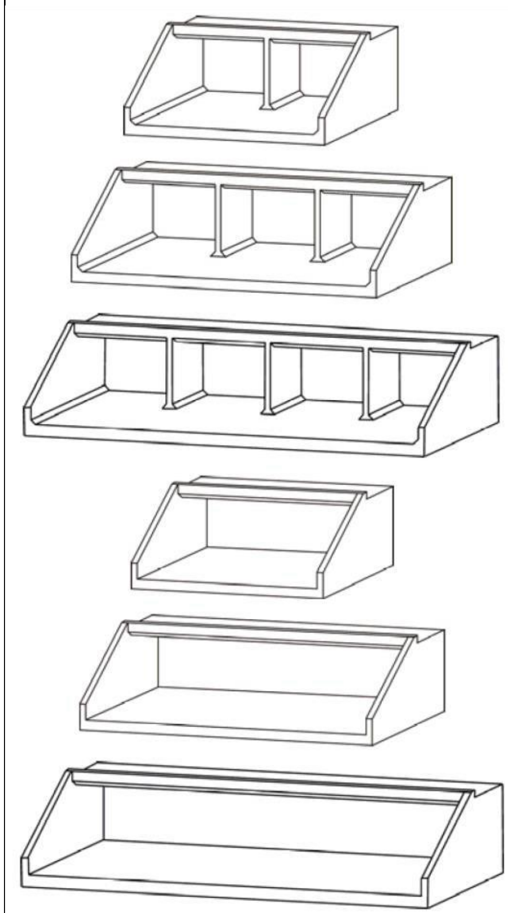
11.7 Polynomial Coefficients - South Dakota Concrete Box

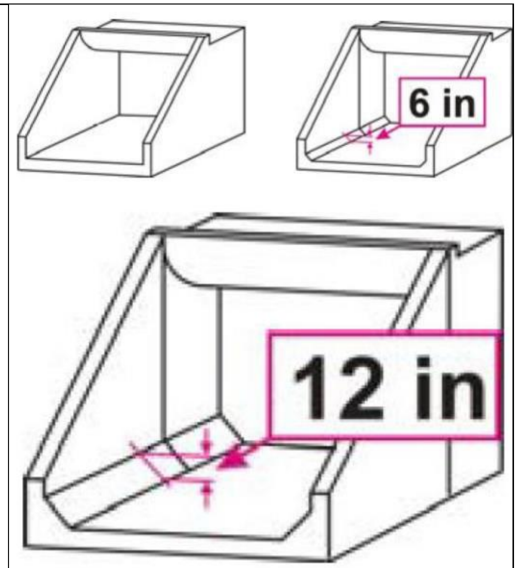
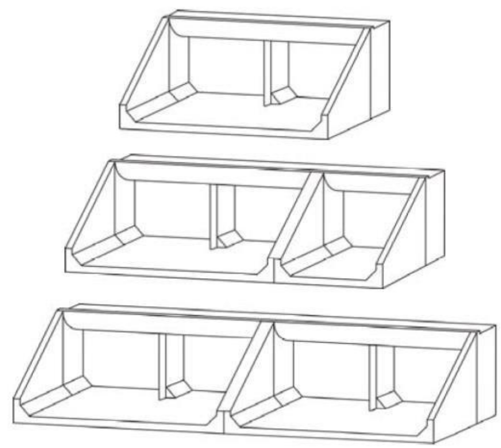
Table 11.7: South Daktoa Concrete Box Polynomial Coefficients

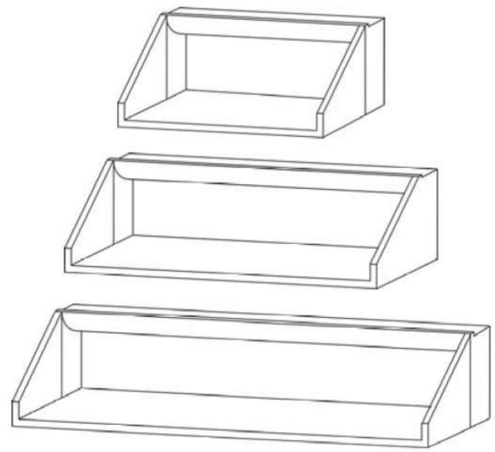
Description	KE	SR	A	BS	C	DIP	EE	F	Diagram/No
Sketch 1: 30 degree-flared wingwalls; top edge beveled at 45 degrees	0.5	0.5	0.0176998563	0.5354484847	-0.1197176702	0.0175902318	-0.0005722076	-0.0000080574	

Sketch 2: 30 degree-flared wingwalls; top edge beveled at 45 degrees; 2, 3, and 4 multiple barrels	0.5	0.5	0.0506647261	0.5535393634	-0.1599374238	0.0339859269	-0.0027470036	0.0000851484	
Sketch 3: 30 degree-flared wingwalls; top edge beveled at 45 degrees; 2:1 to 4:1 span-to-rise ratio	0.5	0.5	0.0518005829	0.5892384653	-0.1901266252	0.0412149379	-0.0034312198	0.0001083949	
Sketch 4: 30 degree-flared wingwalls; top edge beveled at 45 degrees; 15 degrees skewed headwall with multiple barrels	0.5	0.5	0.2212801152	0.6022032341	-0.1672369732	0.0313391792	-0.0024440549	0.0000743575	

Sketch 5: 30 degree-flared wingwalls; top edge beveled at 45 degrees; 30 degrees to 45 degrees skewed headwall with multiple barrels	0.5	0.5	0.2431604850	0.5407556631	-0.1267568901	0.0223638322	-0.0016523399	0.0000490932	
Sketches 6 & 7: 0 degree-flared wingwalls (extended sides); square-edged at crown and 0 degree-flared wingwalls (extended sides); top edge beveled at 45 degrees; 0- and 6-inch corner fillets	0.5	0.5	0.0493946080	0.7138391179	-0.2354755894	0.0473247331	-0.0036154348	0.0001033337	

Sketches 8 & 9: 0 degree-flared wingwalls (extended sides); top edge beveled at 45 degrees; 2, 3, and 4 multiple barrels and 0 degree-flared wingwalls (extended sides); top edge beveled at 45 degrees; 2:1 to 4:1 span-to-rise ratio	0.5	0.5	0.1013668008	0.6600937637	-0.2133066786	0.0437022641	-0.0035224589	0.0001078198	

Sketches 10 & 11: 0 degree-flared wingwalls (extended sides); crown rounded at 8-inch radius; 0- and 6-inch corner fillets and 0 degree-flared wingwalls (extended sides); crown rounded at 8-inch radius; 12-inch corner fillets	0.5	0.5	0.0745605288	0.6533033536	-0.1899798824	0.0350021004	-0.0024571627	0.0000642284	
Sketch 12: 0 degree-flared wingwalls (extended sides); crown rounded at 8-inch radius; 12-inch corner fillets; 2, 3, and 4 multiple barrels	0.5	0.5	0.1321993533	0.5024365440	-0.1073286526	0.0183092064	-0.0013702887	0.0000423592	

South Dakota Concrete Box: Sketch 13: 0 degree-flared wingwalls (extended sides); crown rounded at 8-inch radius; 12-inch corner fillets; 2:1 to 4:1 span-to-rise ratio.	0.5	0.5	0.1212726739	0.6497418331	-0.1859782730	0.0336300433	-0.0024121680	0.0000655665	

References for South Dakota Concrete Box polynomial coefficients:

- Thiele, Elizabeth A. Culvert Hydraulics: Comparison of Current Computer Models. (pp. 121-126), Brigham Young University Master's Thesis (2007).
- **Effects of Inlet Geometry on Hydraulic Performance of Box Culverts** (FHWA Publication No. FHWA-HRT-06-138, October 2006)

11.8 User Defined, Open Bottom Arch, Low-Profile Arch, High-Profile Arch, and Metal Box HW/D Values

Table 11.8: Reference for User-defined interpolation coefficients: FHWA HDS-5, Appendix D, Chart 52B

Q/A*D^.5 =				**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
HY-8 Interpolation Coefficients	**Inlet Configuration**	**KE**	**SR**	**A(1)**	**A(2)**	**A(3)**	**A(4)**	**A(5)**	**A(6)**	**A(7)**	**A(8)**	**A(9)**	**A(10)**
1	Thin Edge Projecting	0.9	0.5	0.31	0.48	0.81	1.11	1.42	1.84	2.39	3.03	3.71	4.26
2	Mitered to Conform to Slope	0.7	-0.7	0.34	0.49	0.77	1.04	1.45	1.91	2.46	3.06	3.69	4.34
3	Square Edge with Headwall	0.5	0.5	0.31	0.46	0.73	0.96	1.26	1.59	2.01	2.51	3.08	3.64
4	Beveled Edge	0.2	0.5	0.31	0.44	0.69	0.89	1.16	1.49	1.81	2.23	2.68	3.18

12 Appendix B

12.1 Concrete Open Bottom Arch (Con/Span) Culvert Geometry Coordinates

Table 12.1: Concrete Open Bottom Arch (Con/Span) Culvert Geometry Coordinates

12' SPAN											
RISE \ X	0	0.01	0.52	1.8	3.88	6	8.12	10.2	11.48	11.99	12
4	0	1	2.55	3.4	3.85	4	3.85	3.4	2.55	1	0
5	0	2	3.55	4.4	4.85	5	4.85	4.4	3.55	2	0
6	0	3	4.55	5.4	5.85	6	5.85	5.4	4.55	3	0
7	0	4	5.55	6.4	6.85	7	6.85	6.4	5.55	4	0
8	0	5	6.55	7.4	7.85	8	7.85	7.4	6.55	5	0
9	0	6	7.55	8.4	8.85	9	8.85	8.4	7.55	6	0
10	0	7	8.55	9.4	9.85	10	9.85	9.4	8.55	7	0

14' SPAN											
RISE \ X	0	0.01	0.5	1.8	6	7	8	12.2	13.5	13.99	14
4	0	1	2.5	3.4	4	4	4	3.4	2.5	1	0
5	0	2	3.5	4.4	5	5	5	4.4	3.5	2	0
6	0	3	4.5	5.4	6	6	6	5.4	4.5	3	0
7	0	4	5.5	6.4	7	7	7	6.4	5.5	4	0
8	0	5	6.5	7.4	8	8	8	7.4	6.5	5	0
9	0	6	7.5	8.4	9	9	9	8.4	7.5	6	0
10	0	7	8.5	9.4	10	10	10	9.4	8.5	7	0

16' SPAN											
RISE \ X	0	0.01	0.48	1.77	4.86	8	11.14	14.23	15.52	15.99	16
4	0	0.47	2.1	3.21	3.8	4	3.8	3.21	2.1	0.47	0
5	0	1.47	3.1	4.21	4.8	5	4.8	4.21	3.1	1.47	0
6	0	2.47	4.1	5.21	5.8	6	5.8	5.21	4.1	2.47	0
7	0	3.47	5.1	6.21	6.8	7	6.8	6.21	5.1	3.47	0
8	0	4.47	6.1	7.21	7.8	8	7.8	7.21	6.1	4.47	0

9	0	5.47	7.1	8.21	8.8	9	8.8	8.21	7.1	5.47	0
10	0	6.47	8.1	9.21	9.8	10	9.8	9.21	8.1	6.47	0

20' SPAN											
RISE \ X	0	0.01	0.48	1.77	5.83	10	14.17	18.23	19.52	19.99	20
5	0	0.87	2.5	3.61	4.65	5	4.65	3.61	2.5	0.87	0
6	0	1.87	3.5	4.61	5.65	6	5.65	4.61	3.5	1.87	0
7	0	2.87	4.5	5.61	6.65	7	6.65	5.61	4.5	2.87	0
8	0	3.87	5.5	6.61	7.65	8	7.65	6.61	5.5	3.87	0
9	0	4.87	6.5	7.61	8.65	9	8.65	7.61	6.5	4.87	0
10	0	5.87	7.5	8.61	9.65	10	9.65	8.61	7.5	5.87	0
11	0	6.87	8.5	9.61	10.65	11	10.65	9.61	8.5	6.87	0

24' SPAN											
RISE \ X	0	0.01	0.48	1.77	6.77	12	17.23	22.23	23.52	23.99	24
5	0	0.07	1.7	2.81	4.45	5	4.45	2.81	1.7	0.07	0
6	0	1.07	2.7	3.81	5.45	6	5.45	3.81	2.7	1.07	0
7	0	2.07	3.7	4.81	6.45	7	6.45	4.81	3.7	2.07	0
8	0	3.07	4.7	5.81	7.45	8	7.45	5.81	4.7	3.07	0
9	0	4.07	5.7	6.81	8.45	9	8.45	6.81	5.7	4.07	0
10	0	5.07	6.7	7.81	9.45	10	9.45	7.81	6.7	5.07	0
11	0	6.07	7.7	8.81	10.45	11	10.45	8.81	7.7	6.07	0

28' SPAN											
RISE \ X	0	0.01	1.17	5.24	9.59	14	18.41	22.76	26.83	27.99	28
6	0	0.25	3.07	5.03	5.76	6	5.76	5.03	3.07	0.25	0
7	0	1.25	4.07	6.03	6.76	7	6.76	6.03	4.07	1.25	0
8	0	2.25	5.07	7.03	7.76	8	7.76	7.03	5.07	2.25	0
9	0	3.25	6.07	8.03	8.76	9	8.76	8.03	6.07	3.25	0
10	0	4.25	7.07	9.03	9.76	10	9.76	9.03	7.07	4.25	0
11	0	5.25	8.07	10.03	10.76	11	10.76	10.03	8.07	5.25	0
12	0	6.25	9.07	11.03	11.76	12	11.76	11.03	9.07	6.25	0

32' SPAN											
RISE \ X	0	0.01	1.17	5.13	10.51	16	21.49	26.87	30.83	31.99	32

7	0	0.49	3.31	5.49	6.62	7	6.62	5.49	3.31	0.49	0
8	0	1.49	4.31	6.49	7.62	8	7.62	6.49	4.31	1.49	0
9	0	2.49	5.31	7.49	8.62	9	8.62	7.49	5.31	2.49	0
10	0	3.49	6.31	8.49	9.62	10	9.62	8.49	6.31	3.49	0
11	0	4.49	7.31	9.49	10.62	11	10.62	9.49	7.31	4.49	0
12	0	5.49	8.31	10.49	11.62	12	11.62	10.49	8.31	5.49	0
13	0	6.49	9.31	11.49	12.62	13	12.62	11.49	9.31	6.49	0

36' SPAN											
RISE \ X	0	0.01	1.17	5	11.41	18	24.59	31	34.83	35.99	36
8	0	0.61	3.43	5.83	7.45	8	7.45	5.83	3.43	0.61	0
9	0	1.61	4.43	6.83	8.45	9	8.45	6.83	4.43	1.61	0
10	0	2.61	5.43	7.83	9.45	10	9.45	7.83	5.43	2.61	0
11	0	3.61	6.43	8.83	10.45	11	10.45	8.83	6.43	3.61	0
12	0	4.61	7.43	9.83	11.45	12	11.45	9.83	7.43	4.61	0
13	0	5.61	8.43	10.83	12.45	13	12.45	10.83	8.43	5.61	0
14	0	6.61	9.43	11.83	13.45	14	13.45	11.83	9.43	6.61	0

42' SPAN EC											
RISE \ X	0	0.01	0.67	5	12.83	21	29.17	37	41.33	41.99	42
10	0	0.81	3.02	6.66	9.16	10	9.16	6.66	3.02	0.81	0
11	0	1.81	4.02	7.66	10.16	11	10.16	7.66	4.02	1.81	0
12	0	2.81	5.02	8.66	11.16	12	11.16	8.66	5.02	2.81	0
13	0	3.81	6.02	9.66	12.16	13	12.16	9.66	6.02	3.81	0
14	0	4.81	7.02	10.66	13.16	14	13.16	10.66	7.02	4.81	0
15	0	5.81	8.02	11.66	14.16	15	14.16	11.66	8.02	5.81	0
16	0	6.81	9.02	12.66	15.16	16	15.16	12.66	9.02	6.81	0

42' SPAN (New)													
RISE \ X	0	0.01	0.67	2.03	5	12.83	21	29.17	37	39.97	41.33	41.99	42
10	0	2.54	4.73	6.25	7.62	9.39	10	9.39	7.62	6.25	4.73	2.54	0
11	0	3.54	5.73	7.25	8.62	10.39	11	10.39	8.62	7.25	5.73	3.54	0
12	0	4.54	6.73	8.25	9.62	11.39	12	11.39	9.62	8.25	6.73	4.54	0
13	0	5.54	7.73	9.25	10.62	12.39	13	12.39	10.62	9.25	7.73	5.54	0
14	0	6.54	8.73	10.25	11.62	13.39	14	13.39	11.62	10.25	8.73	6.54	0

15	0	7.54	9.73	11.25	12.62	14.39	15	14.39	12.62	11.25	9.73	7.54	0
16	0	8.54	10.73	12.25	13.62	15.39	16	15.39	13.62	12.25	10.73	8.54	0

48' SPAN													
RISE \ X	0	0.01	0.67	1.89	5	14.23	24	33.77	43	46.11	47.33	47.99	48
9.5	0	0.77	2.95	4.36	6.02	8.62	9.5	8.62	6.02	4.36	2.95	0.77	0
10	0	1.27	3.45	4.86	6.52	9.12	10	9.12	6.52	4.86	3.45	1.27	0
11	0	2.27	4.45	5.86	7.52	10.12	11	10.12	7.52	5.86	4.45	2.27	0
12	0	3.27	5.45	6.86	8.52	11.12	12	11.12	8.52	6.86	5.45	3.27	0
13	0	4.27	6.45	7.86	9.52	12.12	13	12.12	9.52	7.86	6.45	4.27	0
14	0	5.27	7.45	8.86	10.52	13.12	14	13.12	10.52	8.86	7.45	5.27	0
15	0	6.27	8.45	9.86	11.52	14.12	15	14.12	11.52	9.86	8.45	6.27	0

54' SPAN															
RISE \ X	0	0.01	0.82	3.08	4.76	6.52	16.65	27	37.35	47.48	49.24	50.92	53.18	53.99	54
9.5	0	0	2.28	4.48	5.3	5.94	8.23	9.5	8.23	5.94	5.3	4.48	2.28	0	0
10	0	0.58	3.28	5.48	6.3	6.94	9.23	10	9.23	6.94	6.3	5.48	3.28	0.58	0
11	0	1.58	4.28	6.48	7.3	7.94	10.23	11	10.23	7.94	7.3	6.48	4.28	1.58	0
12	0	2.58	5.28	7.48	8.3	8.94	11.23	12	11.23	8.94	8.3	7.48	5.28	2.58	0
13	0	3.58	6.28	8.48	9.3	9.94	12.23	13	12.23	9.94	9.3	8.48	6.28	3.58	0
14	0	4.58	7.28	9.48	10.3	10.94	13.23	14	13.23	10.94	10.3	9.48	7.28	4.58	0
15	0	5.58	8.28	10.48	11.3	11.94	14.23	15	14.23	11.94	11.3	10.48	8.28	5.58	0

60' SPAN															
RISE \ X	0	0.01	0.83	3.08	6.24	9.53	19.65	30	40.35	50.47	53.76	56.92	59.17	59.99	60
9.5	0	0	1	3.21	4.74	5.94	8.23	9.5	8.23	5.94	4.74	3.21	1	0	0
10	0	0	2	4.21	5.74	6.94	9.23	10	9.23	6.94	5.74	4.21	2	0	0
11	0	0.31	3	5.21	6.74	7.94	10.23	11	10.23	7.94	6.74	5.21	3	0.31	0
12	0	1.31	4	6.21	7.74	8.94	11.23	12	11.23	8.94	7.74	6.21	4	1.31	0
13	0	2.31	5	7.21	8.74	9.94	12.23	13	12.23	9.94	8.74	7.21	5	2.31	0
14	0	3.31	6	8.21	9.74	10.94	13.23	14	13.23	10.94	9.74	8.21	6	3.31	0
15	0	4.31	7	9.21	10.74	11.94	14.23	15	14.23	11.94	10.74	9.21	7	4.31	0

13 Appendix C

13.1.1 Differences from DOS HY-8

13.1.1.1 Differences between DOS HY-8 and HY-8 7.0

An important objective of the conversion of the HY-8 program to a Windows environment was maintaining the basic philosophy and simplicity of model input and operation. While we feel this has been largely achieved, there were obviously some things that we wanted to change and add in order to take advantage of the more modern Windows operating system. This page outlines these changes and new features.

13.1.1.2 Crossings

Previous versions of HY-8 allowed for a single crossing to be designed. Multiple culverts and barrels could be defined, but in a given project only the culvert design information for a single roadway crossway could be defined and analyzed. If in the context of a larger design project multiple crossings needed to be analyzed then each one was defined in a separate input file. In HY-8 version 7.0 any number of crossings can be defined within the same project. While it is just as simple to have a single crossing, mimicking older versions of HY-8, there is also the option of performing an analysis on several crossings and grouping them together. The new mapping feature described below helps create a map identifying each crossing that can be included in the report. The concept of multiple crossings can also be used to represent separate design alternatives of the same crossing within the same project file. In previous versions of HY-8 a user would either have to load them as separate files, or make the incremental changes and reevaluate. In version 7.0 of HY-8 there is the option of “copying” a crossing and then the user can make the changes to evaluate. The project explorer then makes it easy to toggle back and forth between the alternative crossing designs.

13.1.1.3 Order of Input

The MS DOS versions of HY-8 presented the input as a series of linear input screens. The order always began with the discharge, followed by the culvert information followed by the tailwater data and ending with the roadway information. In this new Windows compatible version of HY-8 all of the input necessary to analyze a single crossing is presented in the same input screen. However, the grouping of the information has been organized into the “crossing” information and the “culvert” information. The discharge, tailwater, and roadway data are unique to the crossing while the culvert shape, inlet conditions, and site data define a culvert within the crossing. This grouping, and therefore subsequent tabbing through the main input screen, does not follow the same linear progression of input as previous versions of HY-8.

13.1.1.4 Execution of SINGLE and BALANCE

The MS DOS versions of HY-8 contained separate analysis functions for computing a culvert performance rating curve (SINGLE), and a roadway overtopping analysis (BALANCE) that included the effects of all culverts within a crossing. When running SINGLE, HY-8 assumed that overtopping was not possible even though roadway data were defined. In HY-8 version 7.0 all culvert analysis is done with all culverts in the crossing and roadway overtopping as considerations (BALANCE). This means that when viewing the performance table (or plot) for a given culvert within the crossing, the user sees the performance within the context of any other culverts and overtopping of the roadway for the crossing and not just as an isolated culvert as was the case with SINGLE in older versions of HY-8. If there is only a single culvert and the roadway is high enough that overtopping does not occur, the performance table of HY-8 version 7.0 would match older versions.

13.1.1.5 Front View

HY-8 version 7.0 contains an option for displaying the front view (elevations) of the culvert and roadway at the crossing. Hydraulic computations in version 7.0, like older versions, are not a function of the lateral placement of culverts within a crossing. Only the elevation relationship to the roadway and other culverts is important. However, if viewing this relationship in the front view, HY-8 will prompt to enter the lateral stationing of the culverts. While irregular shaped roadway sections in HY-8 have always prompted for lateral stations and elevations, the constant elevation option only prompted for a length. In order to allow for the possibility of defining actual stationing along a roadway HY-8 now includes a beginning station as well as the length for constant roadway profiles. The default is zero and can be left as zero if actual stationing is not known or important. Lateral stations for culverts are defined from the beginning (left) side of the roadway and elevations taken from the upstream invert elevation parameter. Cross section information is generally provided at the downstream end of the culvert, but the front view represents the upstream view and because there is no cross section defined for the upstream end of the culvert, no cross section is plotted for the front view. A user can change the station of a culvert once entered in the same way by right-clicking in the front view plot window and choosing the menu option to edit the culvert station.

13.1.1.6 Background Map

Because multiple crossings can be defined within a single HY-8 project there is an option to create a background map. This map is only a picture and can be defined from any bitmap (*.bmp) file. When connected to the internet, search for a roadway or aerial view map online and save the result as the background map. A user may also screen capture any image (i.e. a CAD drawing) and save that image as a bitmap (*.bmp) file to import and use for the map as well. The map is only used for reference purposes and it or locations defined for culverts have no bearing on any calculations. Currently the map is sent to the report document, but a user can cut and paste it into the file by capturing it from the screen.

13.1.1.7 Report Generation

With previous versions of HY-8 a comprehensive table could be generated and sent to a text file, however the ability to include graphs and take advantage of formatting in modern word processing programs was lacking. The Report Generation tools in HY-8 7.0 are customizable, include many options for plots and are saved in rich text format (*.rtf). The primary target is an MS-Word document; however the *.rtf format is readable by most Windows-based word processing programs. A few limitations exist with this first version and will likely be improved in future documents. These limitations stem from a problem of placing tables and graphs within document text. In this first version each time a table or graph is saved a new page is started. This is because of a limitation in the library routines being used that do not allow tables and graphs to be “docked” in line with text. After exporting a report, manually dock tables in MS Word by selecting the table frame and then right-clicking on the frame border and choosing the *Format Frame* option. In this screen select the *Lock Anchor* option. For graphs, select the graphic and right-click inside choosing the *Format Picture* option. In this screen choose the *Layout* tab and then the *In Line with Text* option. Once these options are set for tables and graphs new page/sections can be deleted and the tables and graphs placed continuously. It is our intention that this limitation within the library functions used for report generation will be corrected soon.