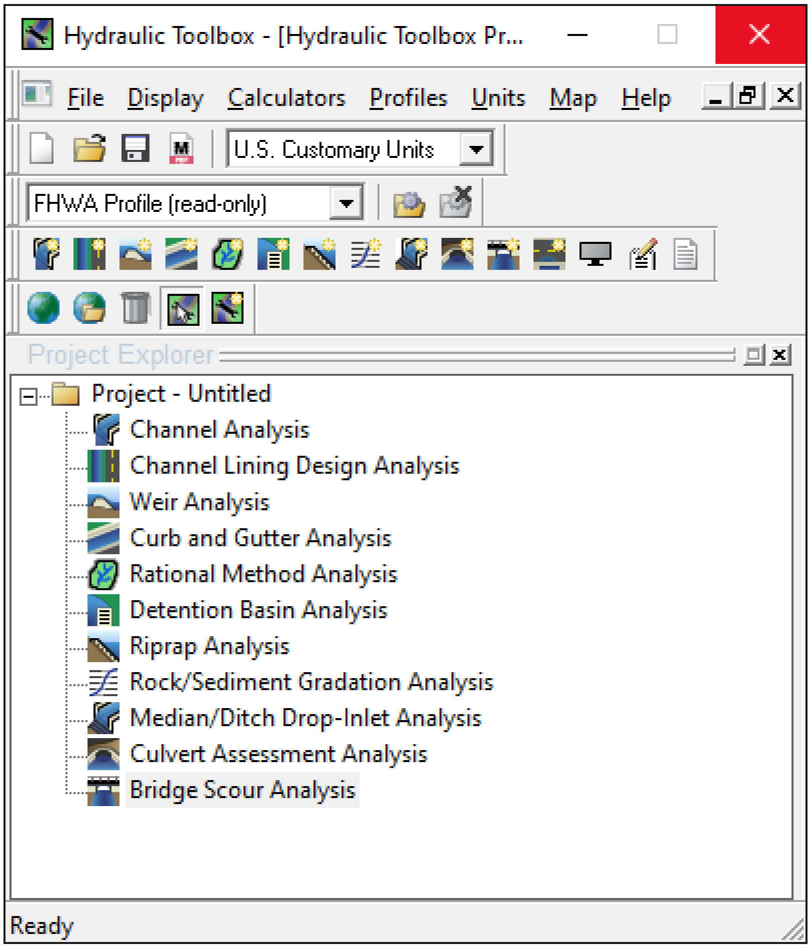
v. 5.1

# *FHWA Hydraulic Toolbox*

*User's Manual*




U.S. Department of Transportation
Federal Highway Administration

# 1 Acknowledgement

Development of the FHWA Hydraulic Toolbox and Desktop Reference Guide was a collaboration between the Federal Highway Administration's (FHWA) Resource Center (RC) and Federal Lands Highway (FLH) offices. The methods and techniques included in the software draws heavily from materials and documents published by the FHWA.

Aquaveo, LLC. developed the FHWA Hydraulic Toolbox software for the FHWA. Aquaveo continues to develop improved versions and furnish program updates. The authors of the manual were Bart S. Bergendahl, P.E., FHWA, Central Federal Lands Highway Division, Lakewood, Colorado and Larry A. Arneson, Ph.D.,P.E., FHWA, Resource Center, Lakewood, Colorado and updated in 2021 by Veronica M. Ghelardi, PE, FHWA, Resource Center, Lakewood, Colorado.

# 2 Introduction

The FHWA Hydraulic Toolbox Program provides a stand-alone suite of calculators that performs routine hydrologic and hydraulic computations. The Hydraulic Toolbox significantly extends the basic functionality of the historic version of the FHWA DOS Hydraulic Toolbox and Visual Urban Programs. The Toolbox allows a user to perform and save hydraulic calculations in one project file, analyze multiple scenarios, and create plots and reports of these analyses. The Toolbox allows computations in either CU or SI units.

1. Channel Analysis
2. Channel Lining Design Analysis
3. Weir Analysis
4. Curb and Gutter Analysis
5. Rational Method Hydrologic Analysis
6. Detention Basin Analysis
7. Riprap Analysis
8. Rock / Sediment Gradation Analysis
9. Median / Ditch Drop-Inlet Analysis
10. Culvert Assessment Analysis
11. Horizontal Grade Inlet

The Toolbox contains modules that represent a project graphically and save notes and reports with the analysis results. Printing of these results is at the user's discretion.

## 2.1 Installation and Registration

You can install the FHWA Hydraulic Toolbox Program on Windows based computers by executing the installation program. Running the installation again or running an updated installation for the same version of the hydraulic toolbox will allow you to modify, repair, or re-move the software on your computer. The Toolbox has an optional registration component that allows users to sign up for notification of future program releases and updates.

## 2.2 Hydraulic Toolbox Interface

The FHWA Hydraulic Toolbox main program window contains five main features.

- Use of Menu Options to select the type of calculation, open, save, save as, and rename files.
- Use of File Operations, Help, & Units to create a new file, open, save, and access help documentation
- Use of Calculator Macros, Edit, Notes, & Create Report icons to quickly select options similar to the Menu Pull Down options
- The Project Explorer Window shows the number and types of associated with a project. The type of icon next to the calculation identifies the type of calculation in the Project Explorer Window. The Toolbox gives the calculation a default name when created but also allows the user to rename it to provide something more meaningful as the project develops.

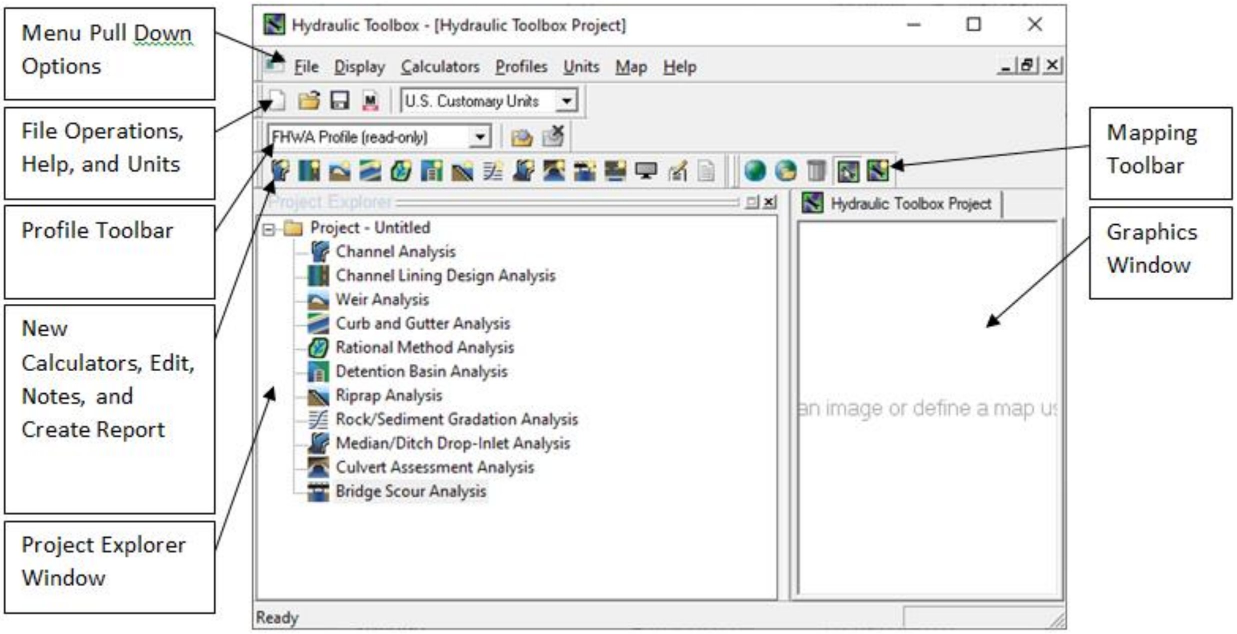



*Figure 2.1: Hydraulic Toolbox window*

### 2.2.1 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.

#### 2.2.1.1 File Menu

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

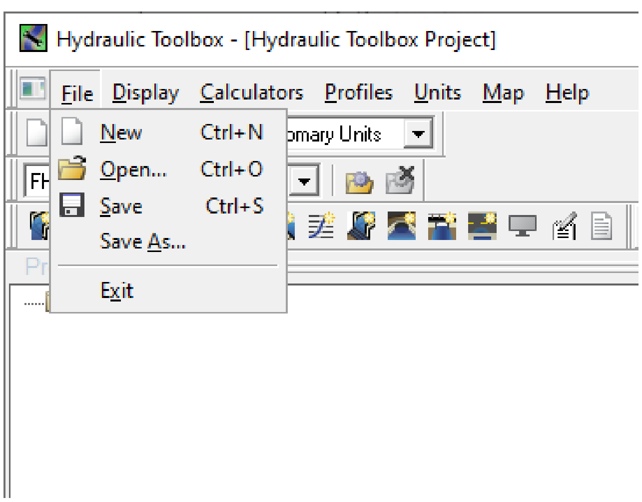



*Figure 2.2: File Menu*

The File toolbar is shown below. The Units selection tool will be discussed with the Units Menu.

*Figure 2.3: File Toolbar. The commands left to right are as follows: New, Open, Save, Print, and Help. Note the Help command launches the User's Manual and is detailed in the Help Menu.*

##### 2.2.1.1.1 File | New

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

##### 2.2.1.1.2 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.

##### 2.2.1.1.3 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.

##### 2.2.1.1.4 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.

##### 2.2.1.1.5 File | Exit

The 'File | Exit' command closes the HY-8 program

#### 2.2.1.2 Display Menu

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

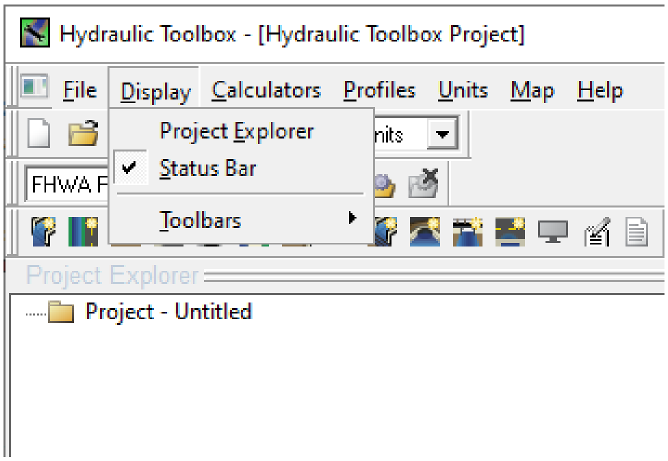



*Figure 2.4: Display Menu*

##### 2.2.1.2.1 Display | Project Explorer

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

##### 2.2.1.2.2 Display | Status Bar

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

##### 2.2.1.2.3 Display | Toolbars

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

#### 2.2.1.3 Calculators Menu

The calculator menu provides commands to create, edit, or use the hydraulic toolbox calculator objects and view resulting computations. The Calculators Menu is shown below.

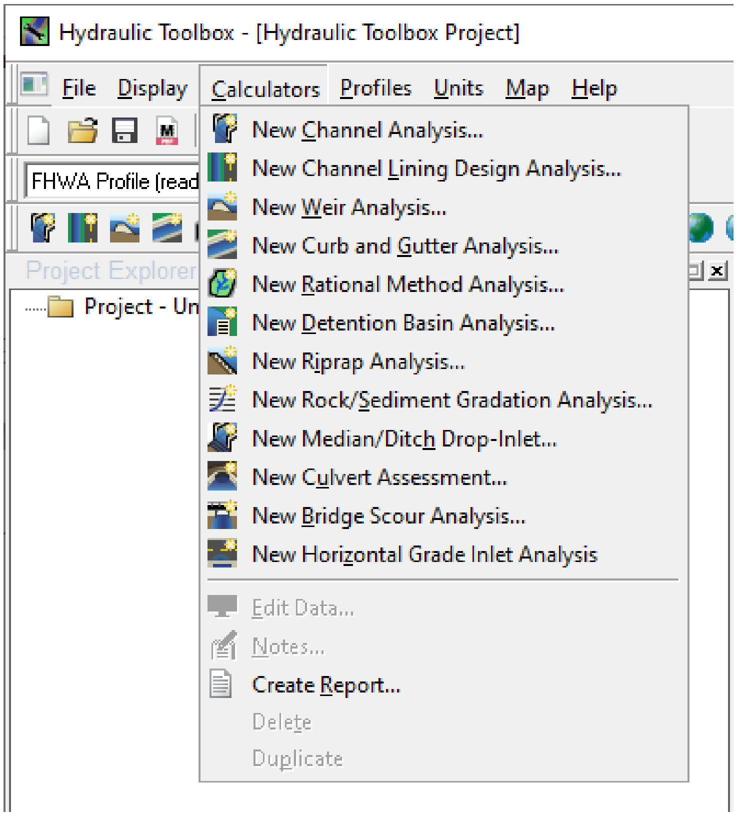



*Figure 2.5: The Calculators Menu*

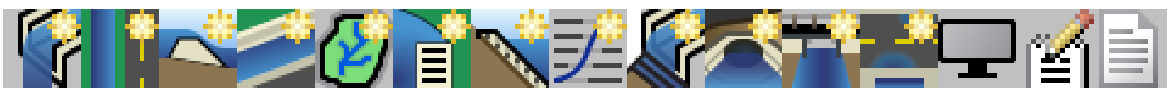


*Figure 2.6: Calculators Toolbar. The tools are left to right: New Channel Analysis, New Channel Lining Analysis, New Weir Analysis, New Curb and Gutter Analysis, New Rational Analysis, New Detention Basin Analaysis, New Riprap Analysis, New Rock/Sediment Gradation Analysis, New Median/Ditch Drop-Inlet Analysis, New Culvert Assessment, New Bridge Scour Analysis, New Horizontal Grade Inlet Analysis*

##### *2.2.1.3.1 Calculators | New ____*

The 'Calculator | New ____' where the ____ represents the name of the specified calculator, command adds a calculator to the project explorer.

##### *2.2.1.3.2 Calculators | Edit Data*

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

##### *2.2.1.3.3 Calculators | Notes*

The 'Calculators | 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), or calculator, depending on the current selection.

##### *2.2.1.3.4 Calculators | Create Report*

The 'Calculators | 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), or calculator, depending on the current selection.

##### *2.2.1.3.5 Calculators | Delete*

The 'Calculators | Delete' command deletes the currently selected calculator.

##### *2.2.1.3.6 Calculators | Duplicate*

The 'Calculators | Duplicate' command will copy the currently selected calculator with the current input values.

#### 2.2.1.4 Profile Menu

The Profile Menu specifies the system settings, culvert assessment profile, and the standard riprap gradations that should be used for Hydraulic Toolbox. More information about the Profiles is in 3 Profile Setup Tool.

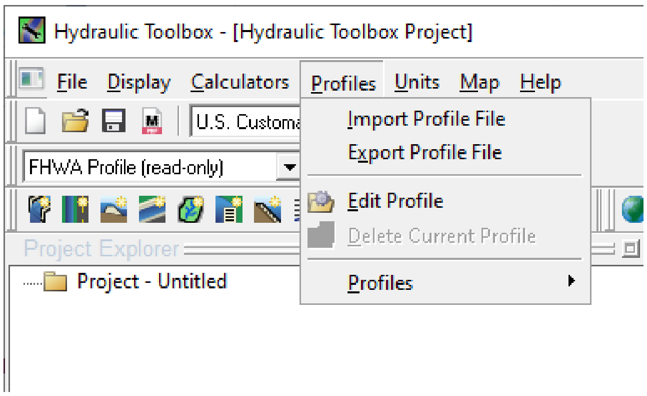



*Figure 2.7: The Profiles Menu*


*Figure 2.8: The Profiles Toolbar*

#### 2.2.1.5 Units Menu

The purpose of the Units Menu is to specify the unit system used to display input and results in HY-8. The Toolbox 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.

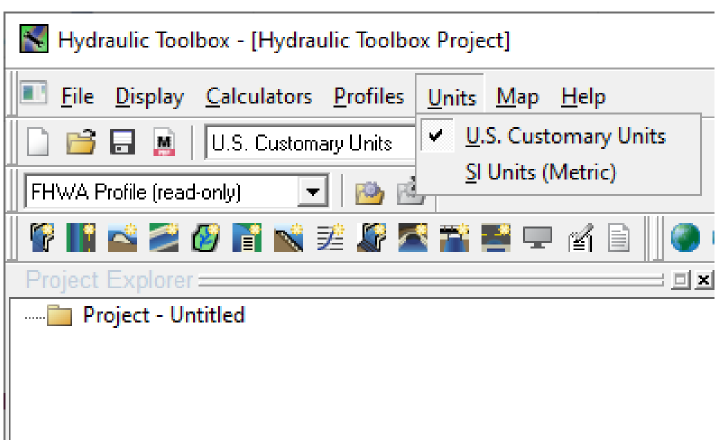



*Figure 2.9: The Units Menu*


*Figure 2.10: The Units Tool part of the File Toolbar*

##### *2.2.1.5.1 Units | U.S. Customary Units*

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

##### *2.2.1.5.2 Units | SI Units (Metric)*

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

#### 2.2.1.6 Map Menu

The Map Menu loads maps for project display and organization in Hydraulic Toolbox.

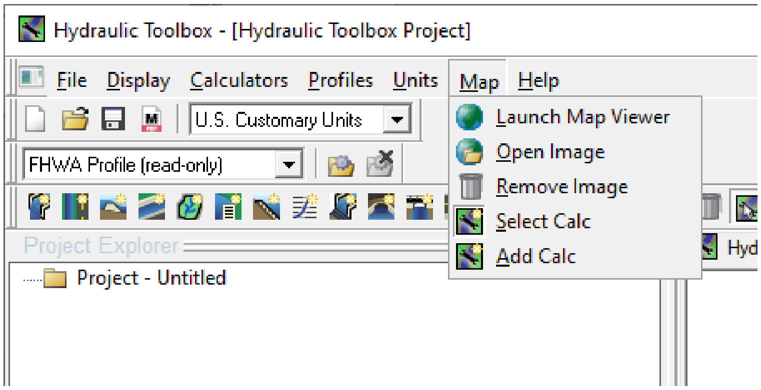



*Figure 2.11: The Map Menu*

*Figure 2.12: The Map Toolbar*

##### *2.2.1.6.1 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 Hydraulic Toolbox. When you click OK, the image will then be loaded in the graphics window.

##### *2.2.1.6.2 Map | Open Image*

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

##### *2.2.1.6.3 Map | Remove Image*

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

##### *2.2.1.6.4 Map | Select Calc*

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

##### *2.2.1.6.5 Map | Add Calc*

The 'Map | Add Calc' command will launch the node properties when you click in the graphics window. After completing the node properties and you click OK, Hydraulic Toolbox will place a mark on the location clicked with the calculator name.

#### 2.2.1.7 Help Menu

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

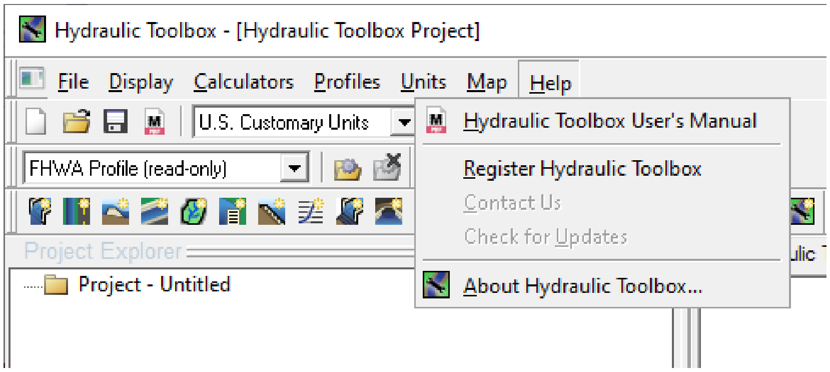



Figure 2.13: The Culvert Menu

#### 2.2.1.7.1 Help | HY-8 Help

The 'Help | Hydraulic Toolbox User's Manual' command launches the 'Hydraulic Toolbox User's Manual'.

#### 2.2.1.7.2 Help | Register Hydraulic Toolbox

The 'Help | Register Hydraulic Toolbox' command will bring up a website hosted by Aquaveo to record your registration information. The website includes options to receive updates about Hydraulic Toolbox and another to receive updates about products related to Hydraulic Toolbox.

#### 2.2.1.7.3 Help | About Hydraulic Toolbox

The 'Help | About Hydraulic Toolbox' command launches the About dialog. This dialog provides information about Hydraulic Toolbox, including the current version of the Hydraulic Toolbox and build date.

### 2.2.2 Project Explorer

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

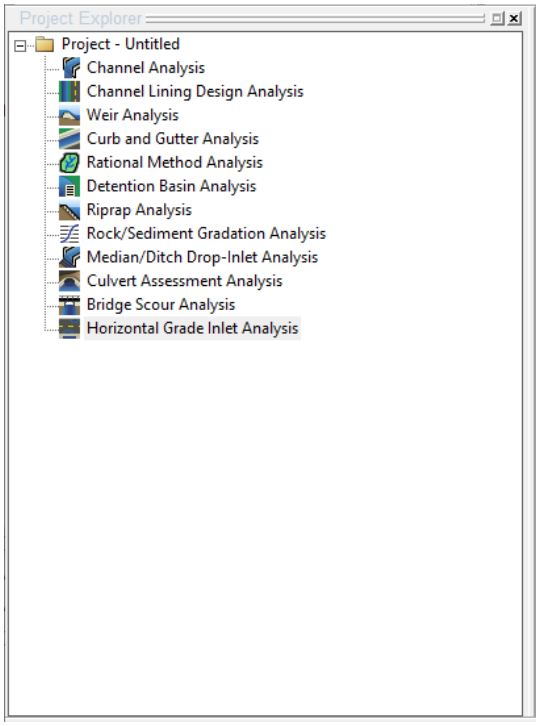



*Figure 2.14: Project Explorer*

#### 2.2.2.1 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.

#### 2.2.2.2 Culvert Crossing

A folder with a culvert icon depicts a crossing. The crossing can have up to 6 culvert barrels assigned to the crossing. The culvert barrel icons vary according to the selected shape. You can interact with culvert crossings and culvert barrels directly in the project explorer which allows you to rename, duplicate, or delete the crossing or culvert barrel. Additionally, you can edit the notes associated with a culvert crossing or culvert barrel.

# 3 Profile Setup Tool

The FHWA Hydraulic Toolbox contains a **Profile Setup Tool** that allows the user to set a few personal preferences, input culvert assessment criteria for the Culvert Assessment Calculator, and use custom riprap gradation standards for use in the Riprap Analysis and Rock/Sediment Analysis. Additionally, you can import and export your profile with those you work with. Find this tool in the profile toolbar and the profile menu options.

## 3.1 User Settings

The user settings allow the user to set a default profile that will be the profile when Hydraulic Toolbox starts up. If the user loads a file that uses a different profile, the current profile will change to the profile specified by the file. When Hydraulic Toolbox is closed and started again, it will return to the default profile.

The default units operate in a similar manner. This will change what unit system Hydraulic Toolbox will launch in, but that may change based on loading a file that selected a different unit system. After closing and restarting the toolbox, the default unit system will be active again.

The final option in the user preferences allows the user to set what unit all of the gradations are displayed and reported in. The user can choose feet, inches, or millimeters.

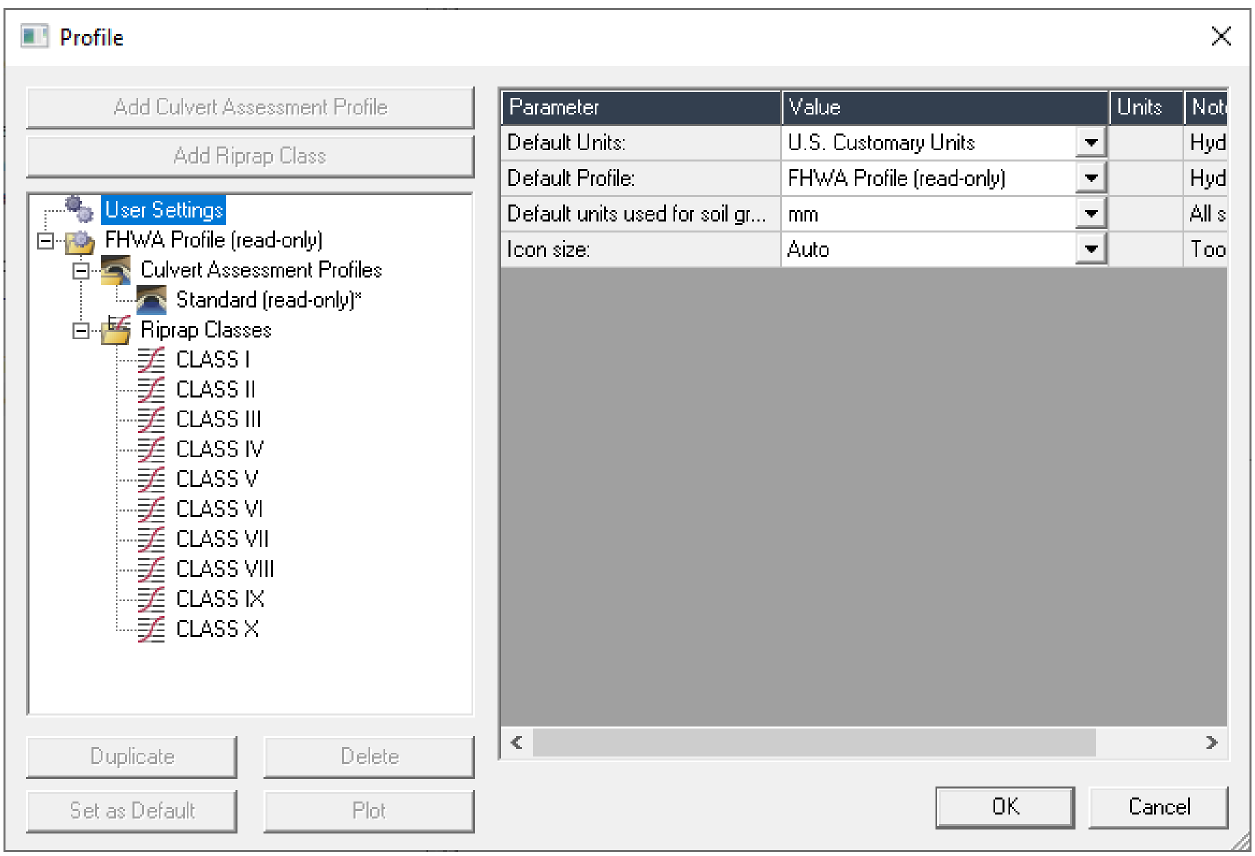



*Figure 3.1: Profile window*

Upon opening the Toolbox, the 'active' profile is the last profile used; therefore, the user should always check this toolbar before using the Riprap Analysis or Culvert Assessment Calculators to ensure the desired profile is active.

The Toolbox comes pre-loaded with the riprap standards and culvert assessment criteria advocated by FHWA. The user cannot edit these pre-loaded riprap standards; however, they can view them by selecting the 'FHWA Profile (read only)' option from the dropdown window located in the toolbar at the top of the Toolbox opening screen and clicking the "Edit Profile" icon adjacent to the dropdown window. This will bring up the 'profile window.' View the individual properties of the culvert assessment profile or the riprap classes on the right side of the pro-file window by clicking on the profile or class name listed on the left side of the window.

To change or customize these profiles, the user selects the '<new>' option in the profile dropdown window and clicks the "Edit Profile" icon. This will bring up the 'profile window' which contains option buttons for adding a culvert assessment profile or a riprap class to the existing profiles, and tools for duplicating, deleting, and editing the profiles. To delete an entire profile option, the user selects the profile in the dropdown window then clicks the "Delete Profile" icon adjacent to the Edit Profile icon.

After selecting a specific culvert assessment profile from the list on the left side of the 'profile window' (other than the FHWA 'Standard (read only)'), the window on the right allows the user to edit all the control parameters by placing the cursor in the desired field. The 'default' typically represents the most frequently used culvert assessment profile. After creating a culvert assessment file or when the user cannot find a previously selected profile in the local Toolbox data base, the default is always the active profile. However, the user can select any profile to evaluate culverts. The Toolbox places an asterisk (*) behind the default profile name to help the user identify it.

As with the culvert assessment profiles, after selecting a specific riprap class on the left side of the 'profile window' (other than those under 'FHWA Profile (read only)'), the window on the right allows the user to edit the class name, order, and size characteristics. **It is important to order riprap classes according to size, with number '1' assigned to the smallest class.** This requirement ensures the Toolbox choses the correct class by the riprap sizing calculators within the Toolbox. So, if an added riprap class size range falls between two existing classes, a sequential list is not necessary but assigning the 'Class Order' numbers accordingly is necessary. After selecting the class, the user can view a plot of a specific riprap class as a check on input accuracy by clicking 'Plot'. Select the folder and click 'Plot to view the entire set of riprap classes.

# 4 Hydraulic Toolbox Calculators

Each calculator performs a specific type of analysis and only one calculator can be active at any given time. As the user opens the calculator windows, data inputs displayed are unique to the opened calculator.

A description of the calculators continues in the following chapters.

# 5 Channel Calculator

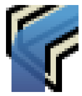


*Figure 5.1: Channel Calculator icon*

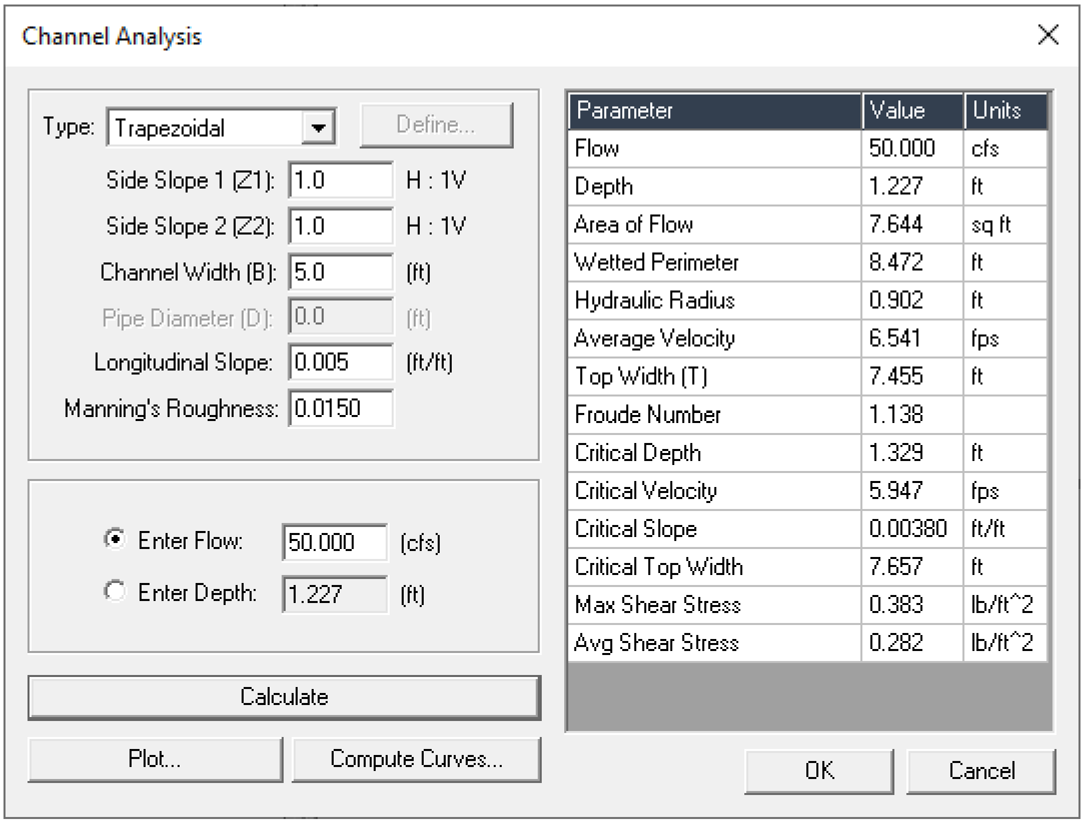



*Figure 5.2: Channel calculator*

The Channel Calculator can compute the full range of hydraulic parameters at a single, steady-state cross section in a uniform flow condition for trapezoidal, rectangular, triangular, circular, or user-defined (irregular) channel shapes for a given depth or discharge. For the selected channel geometry, the Toolbox prompts the user for the necessary input including cross section definition, channel side slopes, bottom width, diameter, channel slope, Manning's n value, and flow or depth.

Further details about the equations used in the channel calculator are located in the following reference:

**Schall, J.D., Richardson, E.V., Morris, J.L., June 2008, Introduction to Highway Hydraulics, Hydraulic Design Series No. 4, Fourth Edition, FHWA-NHI-08-090, HDS 4.**

https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=47&id=138

## 5.1 Channel Equation

The Manning's Equation computes the discharge or depth, depending on the selection.

The Manning's Equation is given below.

$$Q = \frac{K_u}{n} A R^{2/3} S^{1/2} \text{ (HDS-4, Eqn. 4.5)}$$

Where:

Q = Discharge, $m^3/s$ ($ft^3/s$)

n = Manning's Roughness Coefficient

A = Area $m^2$ ($ft^2$)

P = Wetted Perimeter m (ft)

R = Hydraulic Radius, m (ft), (=A/P)

If the user has selected a cross section geometry, the Lotter Method determines the composite Manning's n value. This method assumes that the total channel discharge equals the sum of subarea discharges. Normally use this method for irregularly shaped open channels, including natural floodplains.

The Lotter Method Equation is given below.

$$n = \sqrt{\frac{\sum_1^N (P_N {n_N}^2)}{P}} = \sqrt{\frac{P_1 {n_1}^2 + P_2 {n_2}^2 + \cdots + P_N {n_N}^2}{P}}$$

Where:

$n_c$ = Composite Manning's Roughness Coefficient

n = Manning's Roughness Coefficient

P = Wetted Perimeter

N = Subscripts denoting individual subareas of the cross section

## 5.2 Channel Types

The Channel Calculator offers five channel types to choose from:

- Trapezoidal
- Rectangular
- Triangular
- Circular
- User Defined Cross section

Each type of channel requires slightly different variables. When you select a channel type, an input window will appear.

## 5.3 Channel Plot Options

Select the "Plot" button to bring up a plot of the channel geometry and water surface elevation. The "Compute Curves" button will plot depth or discharge against a user defined variable selected from nine available options. Double-clicking on the plot graph brings up a new window that will allow the user to change the look of the graph. There are tabs for General, Plot, Axis, Font, Color and Style. All channel types contain the same "Plot" and "Compute Curves" options.

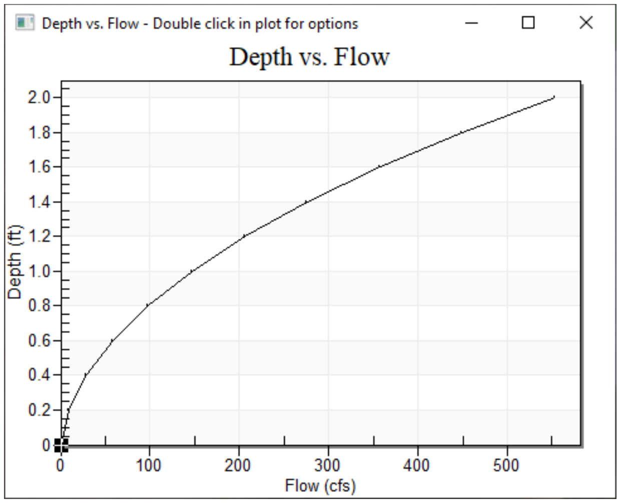



*Figure 5.3: Channel plot showing depth versus flow*

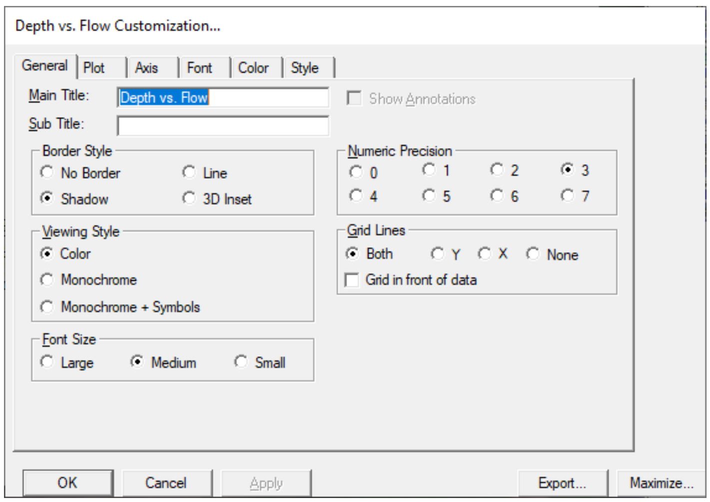
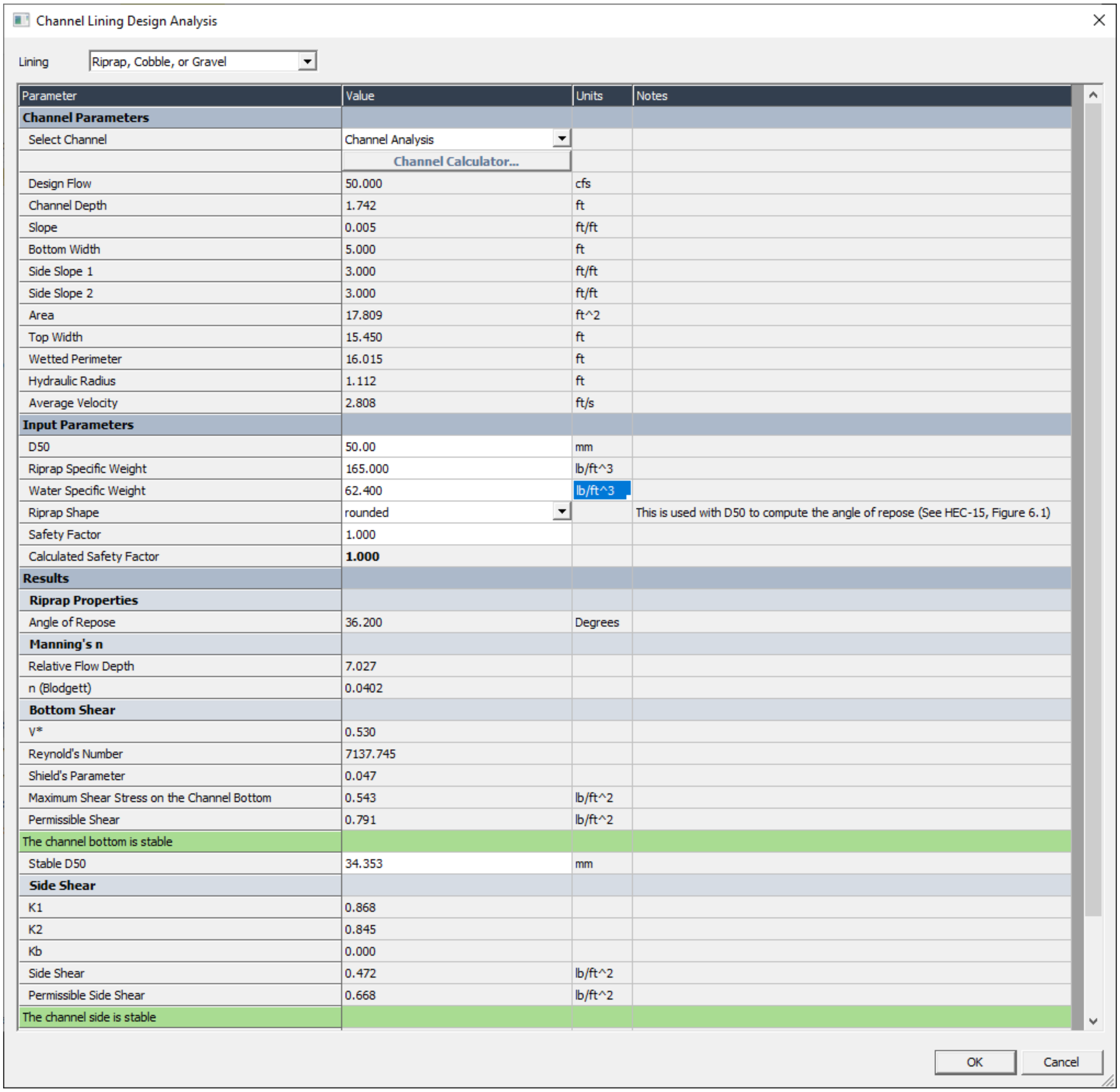



*Figure 5.4: Plot display options*

# 6 Channel Lining Design Calculator

*Figure 6.1: Channel Lining Design Calculator icon*



Channel Lining Design Analysis

Lining: Riprap, Cobble, or Gravel

| Parameter | Value | Units | Notes |
|---|---|---|---|
| **Channel Parameters** | | | |
| Select Channel | Channel Analysis | | |
| | Channel Calculator... | | |
| Design Flow | 50.000 | cfs | |
| Channel Depth | 1.742 | ft | |
| Slope | 0.005 | ft/ft | |
| Bottom Width | 5.000 | ft | |
| Side Slope 1 | 3.000 | ft/ft | |
| Side Slope 2 | 3.000 | ft/ft | |
| Area | 17.809 | ft^2 | |
| Top Width | 15.450 | ft | |
| Wetted Perimeter | 16.015 | ft | |
| Hydraulic Radius | 1.112 | ft | |
| Average Velocity | 2.808 | ft/s | |
| **Input Parameters** | | | |
| D50 | 50.00 | mm | |
| Riprap Specific Weight | 165.000 | lb/ft^3 | |
| Water Specific Weight | 62.400 | lb/ft^3 | |
| Riprap Shape | rounded | | This is used with D50 to compute the angle of repose (See HEC-15, Figure 6.1) |
| Safety Factor | 1.000 | | |
| Calculated Safety Factor | **1.000** | | |
| **Results** | | | |
| **Riprap Properties** | | | |
| Angle of Repose | 36.200 | Degrees | |
| **Manning's n** | | | |
| Relative Flow Depth | 7.027 | | |
| n (Blodgett) | 0.0402 | | |
| **Bottom Shear** | | | |
| V* | 0.530 | | |
| Reynold's Number | 7137.745 | | |
| Shield's Parameter | 0.047 | | |
| Maximum Shear Stress on the Channel Bottom | 0.543 | lb/ft^2 | |
| Permissible Shear | 0.791 | lb/ft^2 | |
| The channel bottom is stable | | | |
| Stable D50 | 34.353 | mm | |
| **Side Shear** | | | |
| K1 | 0.868 | | |
| K2 | 0.845 | | |
| Kb | 0.000 | | |
| Side Shear | 0.472 | lb/ft^2 | |
| Permissible Side Shear | 0.668 | lb/ft^2 | |
| The channel side is stable | | | |

OK Cancel

*Figure 6.2: Channel lining design calculator*

The **Channel Lining Design Calculator** offers four channel lining types to choose from for designing stable roadside channels:

- Rock (Small Riprap, Cobble, Gravel)
- Vegetation
- Rolled Erosion Control Product (RECP)

- Gabion (Mattress)

Typically, by comparing the maximum applied shear stress imparted by the flow, to the permissible shear stress of the lining determines the acceptability of a given lining type. If the permissible shear stress is greater than or equal to the computed shear stress, including consideration of a safety factor, the lining is acceptable. If a lining is unacceptable, a lining with a higher permissible shear stress is selected, the discharge is reduced, or the channel geometry is modified. The general equation for maximum applied shear stress in open-channel flow is:

$$\tau_d = \gamma d S_0 \qquad \textit{(HEC 15, Eqn. 3.1)}$$

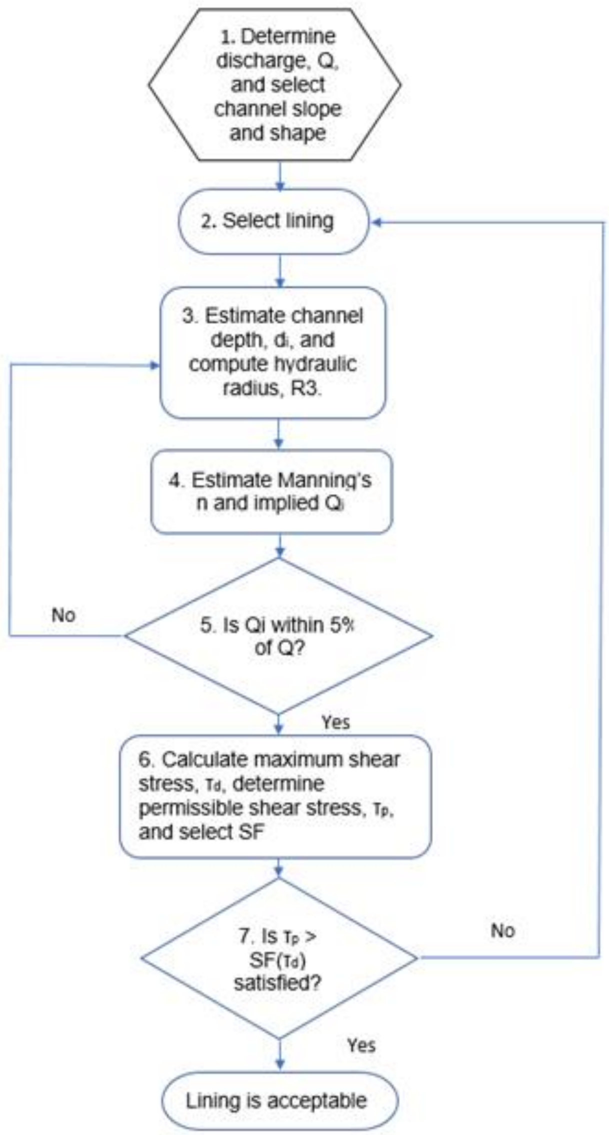
Where:

$\tau_d$ = Shear stress in channel at maximum depth, N/m$^2$ (lb/ft$^2$)

$\gamma$ = unit weight of water, N/m$^3$ (lb/ft$^3$)

d = depth of flow in channel, m (ft)

$S_o$ = channel bottom slope, m/m (ft/ft)




**Flexible Channel Lining Design Flow Chart**

*Figure 6.3: Flexible Channel Lining Design Flow Chart, from FHWA HEC 15, Figure 3-1*

The equation for permissible shear stress is different for each lining material. The following descriptions of the lining types include the appropriate equation.

Each lining type requires different Input Parameters. When you select a lining type, the associated data input screen will open. After selecting the desired lining type, the user provides the initial, normal-depth hydraulic parameters required for lining design. The user provides these parameters by either selecting a previously defined Channel Calculator file that appears in the 'Select Channel' window or inputting new hydrologic and channel characteristic data locally using the Channel Calculator. (Refer to the use of the Channel Calculator described earlier in this document.) Note that the user must provide an initial Manning's n-value. Since the Toolbox determines the final n- value through an iterative computational routine, the only requirement is an initial guess of this value. The Toolbox will transfer the results of the selected Channel Calculator to the input screen.

After providing the hydraulic parameters for the channel, the user must provide the Input Parameters unique to the selected lining type. Upon entering all input data, the Toolbox immediately determines the adequacy of the selected lining type for the given channel hydraulics. If the lining type proves satisfactory for the given channel characteristics, a green highlighted message stating such will appear. If the lining is not satisfactory, a red message will appear.

The above operations and requirements are common to all four lining types. A description of the unique Input Parameters and Results are below for each lining type.

Further details about the equations used in the channel lining design calculator are located in the following reference:

**Kilgore, R.T., and Cotton, G.K., September 2005, Design of Roadside Channels with Flexible Linings, Hydraulic Engineering Circular No. 15, Third Edition, FHWA-NHI-05-114, HEC 15.**

**https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=15&id=32**

## 6.1 Channel Lining Design Calculator – Rock Lining

The equation for permissible shear stress of a loose rock lining is:

$$\tau_p = F_*(\gamma_s - \gamma)D_{50} \qquad \textit{(FHWA HEC 15, Eqn. 6.7)}$$

The following required unique Input Parameters for Rock-lined channels are:

- $D_{50}$ size-fraction for the proposed rock, ft
- Rock specific weight, lb/ft$^3$ (typically 150 – 170)
- Water specific weight, lb/ft$^3$ (fresh water: 62.4; salt water: 64.4)
- Shape of the rock (Crushed, Angular, Round)
- Safety Factor desired

Typically, the practice is to use a specific stone weight of 165lb/ft$^3$ but if the available stone is different from this value, use the site-specific value.

*Table 6.1: Selection of Shields' Parameter and Safety Factor (HEC 15, section 6.2)*

| Reynolds number | F* (Shields' parameter) | SF |
|---|---|---|
| $\leq 4x10^4$ | 0.047 | 1.0 |
| $4x10^4<R_e<2x10^5$ | Linear interpolation | Linear Interpolation |
| $\geq 2x10^5$ | 0.15 | 1.5 |

The following unique generated Results for Rock-lined channels are:

- Angle of Repose
- Manning's n-value
- Permissible and Applied Shears for channel bottom, side slopes, and any bend
- Length of Protection required beyond any bend
- Additional Freeboard due to super-elevation at any bend

Typically, the designer incrementally adjusts the rock size ($D_{50}$) according to the computed results until identifying a satisfactory size.

## 6.2 Channel Lining Design Calculator—Vegetative Lining

The combined effects of the soil permissible shear stress and the effective shear stress transferred through the vegetative lining results in a permissible shear stress for the vegetative lining. The equation for permissible shear stress of a vegetative lining is:

$$\tau_p = \frac{\tau_{p,soil}}{(1-C_f)}\left(\frac{n}{n_s}\right)^2 \quad \text{(HEC 15, Eqn. 4.7)}$$

The following unique required input parameters for vegetation-lined channels are:

- Water Specific Weight, $lb/ft^3$ (fresh water: 62.4; salt water 64.4)
- Height of Vegetation
- Condition of Vegetation
- Form of Vegetation
- Soil Type (Non-Cohesive or Cohesive)
- Soil Class characteristics (Non-Cohesive: D75; Cohesive: PI, Porosity, etc.)
- Safety Factor desired
- The following unique Results for Vegetation-lined channels are:
- Permissible and applied shears for channel bottom and any bend
- Length of protection required beyond any bend
- Additional freeboard due to super-elevation at any bend

Typically, the designer adjusts the vegetation characteristics until identifying a satisfactory combination. If the designer cannot identify a satisfactory combination of vegetative characteristics, the designer must select and test a more robust lining type.

## 6.3 Channel Lining Design Calculator—RECP Lining

The combined effects of the soil permissible shear stress and the effective shear stress transferred through the RECP lining results in a permissible shear stress for the RECP lining.

The equation for permissible shear stress of RECP lining is:

$$\tau_p = \frac{\tau_1}{\alpha}\left(\tau_{p,soil} + \frac{\alpha}{4.3}\right) \qquad \textit{(HEC 15, Eqn. 5.5)}$$

The following required unique Input Parameters for RECP-lined channels are:

- RECP Type (Open-weave textile, Erosion control blanket, Turf reinforcing mat)
- Shear Stress that causes 0.5 inches of erosion for selected REC
- Manning's n-value for selected REC
- Water specific weight, lb/ft$^3$ (fresh water: 62.4; salt water 64.4)
- Soil Type (Non-Cohesive or Cohesive)
- Soil Class characteristics (Non-Cohesive: D75; Cohesive: PI, Porosity)
- Safety Factor desired
- The following unique Results for RECP-lined channels are:
- Permissible and Applied Shears for channel bottom and any bend
- Length of Protection required beyond any bend
- Additional Freeboard due to super-elevation at any bend

Typically, the designer selects different RECPs until identifying a satisfactory type. If the designer cannot identify a satisfactory lining type, the designer must select and test a more robust lining.

## 6.4 Channel Lining Design Calculator—Gabion Lining

Estimate the permissible shear stress for gabions based on the size of the rock fill or based on the gabion mattress thickness. The Toolbox calculates the permissible shear stress for both estimates and uses the largest value. The mattress thickness provides the basis for the equation for permissible shear stress of gabion mattress. The equation is:

$$\tau_p = 0.0091(\gamma_s - \gamma)(MT + MT_c) \qquad \textit{(FHWA HEC 15, Eqn. 7.2)}$$

The laboratory data used to derive this equation provide the limits of its use. Rock sizes within the mattress typically range from 0.25 to 1.5 ft depending on the mattress thickness. See HEC 15, page 7-2 for more information.

The following required unique Input Parameters for Gabion-lined channels are:

- $D_{50}$ size-fraction for the proposed rock, ft
- Gabion mattress thickness, ft (limited to between 0.5 and 1.5 ft maximum)
- Rock specific weight, lb/ft$^3$ (typically 150 – 170)
- Safety Factor desired
- The following unique Results for Gabion-lined channels are:
- Manning's n-value
- Permissible and Applied Shears for channel bottom and any bend
- Length of Protection required beyond any bend
- Additional Freeboard due to super-elevation at any ben

- Minimum Extensions upstream and downstream from protected area
- Minimum Freeboard for flow type

Typically, the designer incrementally adjusts the rock size and/or mattress thickness according to the computed results until identifying a satisfactory combination.

# 7 Weir Calculator

*Figure 7.1: Channel Calculator icon*

## 7.1 Weir Computations

A weir is typically a notch of regular shape (rectangular, square, or triangular), with a free surface. The edge or surface over which the water flows is called the crest.

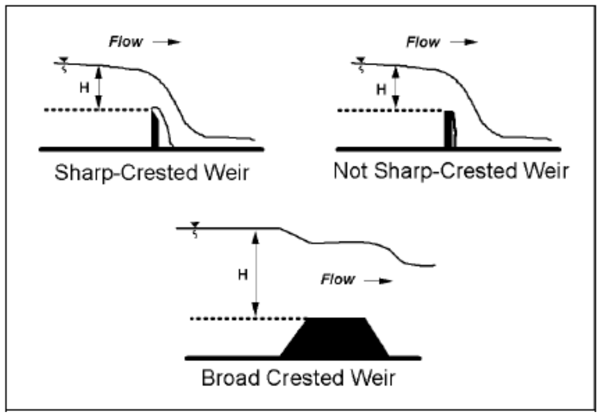



*Figure 7.2: Weir crest types, from FHWA HDS 4, figure 3.6.*

Weir Equation

$$Q = C_D L H^{3/2}$$

Where:

Q = Discharge, m3/s ($ft^3/s$)

$C_D$ = Coefficient of discharge for weirs, sharp edge or broad crested

L = Flow length across the weir (channel width), m (ft)

H = Head on the weir, m (ft). The depth of flow above the weir crest upstream of the weir (typically measured a distance of about 2.5H upstream of the weir).

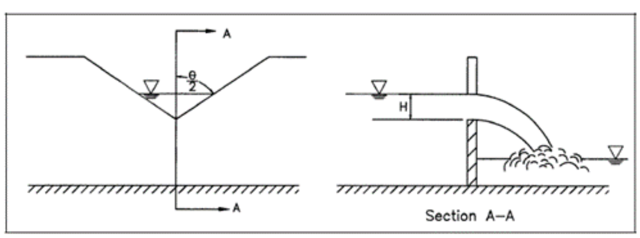



*Figure 7.3: Weir input parameter diagram*

Note that the flow length across the weir in the equation above is actually the channel width. Coefficients of discharge are given in most handbooks for the different types of weirs or flow conditions. If entering weir information in Metric units, note that since $C_D$ has units of $\sqrt{g}$, $C_D$ values tabulated in English units must be converted to metric units by multiplying by the value $\sqrt{9.81}/\sqrt{32.2}$ or 0.552. When switching between English and metric units, the Hydraulic Toolbox automatically handles the conversion of the weir coefficient.

Further details about the equations used in the weir calculator are located in the following reference:

**Schall, J.D., Richardson, E.V., Morris, J.L., June 2008, Introduction to Highway Hydraulics, Hydraulic Design Series No. 4, Fourth Edition, FHWA-NHI-08-090, HDS 4.**

https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=47&id=138

## 7.2 Weir Calculator Interface

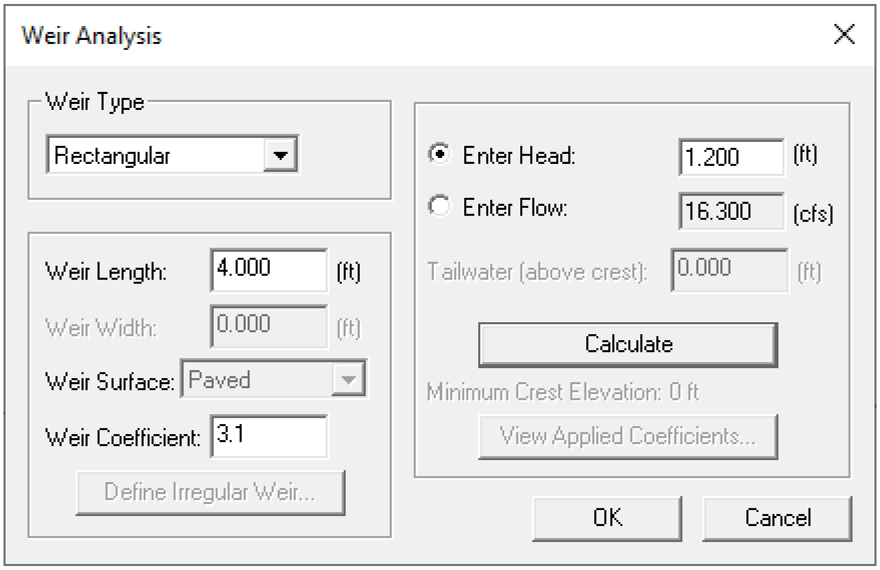



*Figure 7.4: Weir calculator*

The **Weir Calculator** offers 8 weir cross sectional shapes for analysis:

- Rectangular
- Cipolletti (trapezoidal with 4:1 (V:H) side slopes)
- V-notch (90 degrees)
- V-notch (60 degrees)
- V-notch (45 degrees)
- V-notch (22.5 degrees)
- User-defined v-notch
- Irregular weir

For V-notch weirs (including the user-defined v-notch), the weir analysis window requires the user to select the weir cross section (v-notch and the degree of angle) and either the head or the amount of flow. If the user has selected the user-defined v-notch, the user may select the weir coefficient.

The Cipolleti weir requires the user to specify the weir length (the length of the low, horizontal crest of the trapezoidal weir shape), and either the head or the amount of flow.

The Rectangular weir shape requires the user to specify the weir length, either the head or the amount of flow, and specify a weir coefficient that is defaulted to 1.711.

Check your agency guidance to select a weir coefficient other than the default value. This statement applies to the Rectangular and user-defined v-notch weirs.

### 7.2.1 Irregular Weir

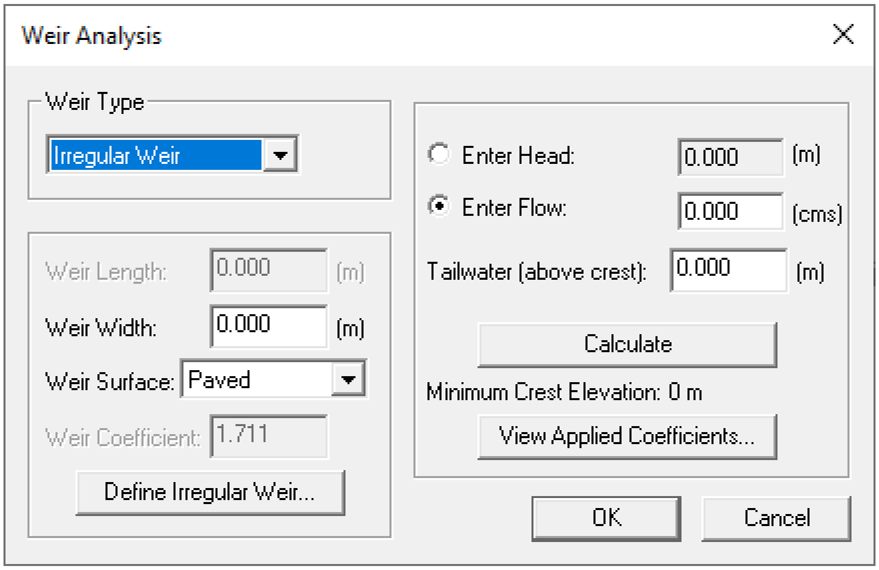



*Figure 7.5: Weir Calculator set to Irregular Weir*

The irregular weir allows the user to specify the shape of an irregular weir. The user specifies a series of points by station and elevation to define the weir. After entering these points, Hydraulic Toolbox will determine the lowest point of the weir crest and display it as the minimum crest elevation. The head or flow is computed by summing the weir flow across each individual segment of the irregular weir using the weir equation and a computed or specified and adjusted discharge coefficient.

The weir calculator requires the geometry, weir width (the distance the water will flow across the weir crest), weir surface (paved, gravel, or user-defined), either the head (height above the minimum crest elevation, not the headwater elevation or the amount of flow, and the tailwater head (height above the minimum crest elevation, not the tailwater elevation).

Note that the Weir Width only applies to the Irregular Weir. The Weir Width is the distance across the top of the weir and used to determine whether it is a sharp-crested or broad-crested weir.

The discharge coefficients are determined for a paved or gravel roadway or specified by the user. The computed paved or gravel roadway coefficient will be determined for each line segment of the irregular weir geometry based on the width of the weir (which determines if it is sharp-crested or not). All discharge coefficients for the irregular weir will adjust for submergence. Once the weir computations finished, the user can view the coefficients applied to each line segment of the weir.

The figure below shows the source for the discharge coefficients used for paved and gravel coefficients and the submergence factors used in Hydraulic Toolbox. The figure comes from HDS-5 and is also used in HY-8.

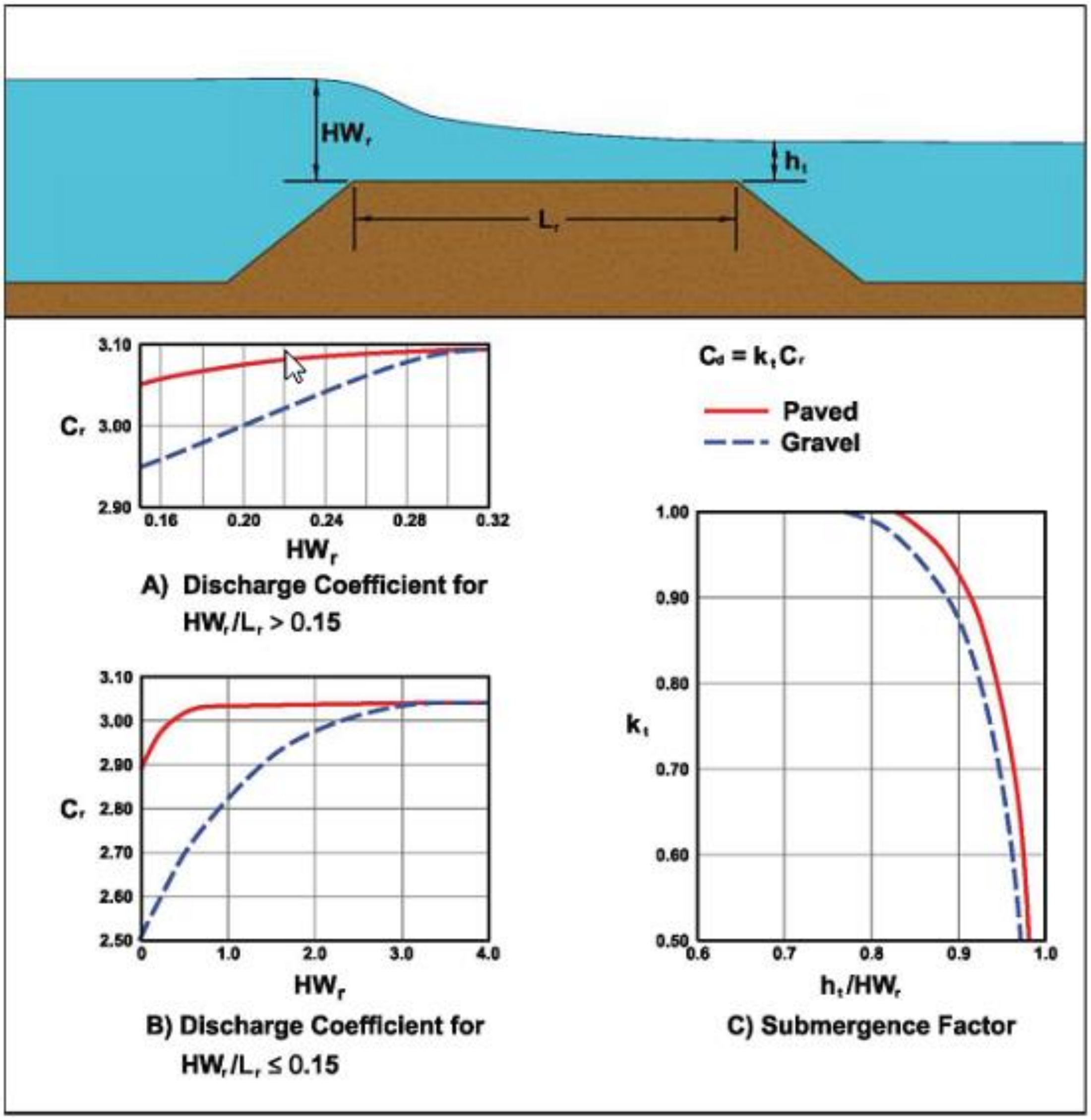



*Figure 7.6: Discharge coefficients for roadway overtopping from HDS-5, Figure 3.11.*

# 8 Curb and Gutter Calculator

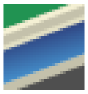


*Figure 8.1: Curb and Gutter Calculator icon*

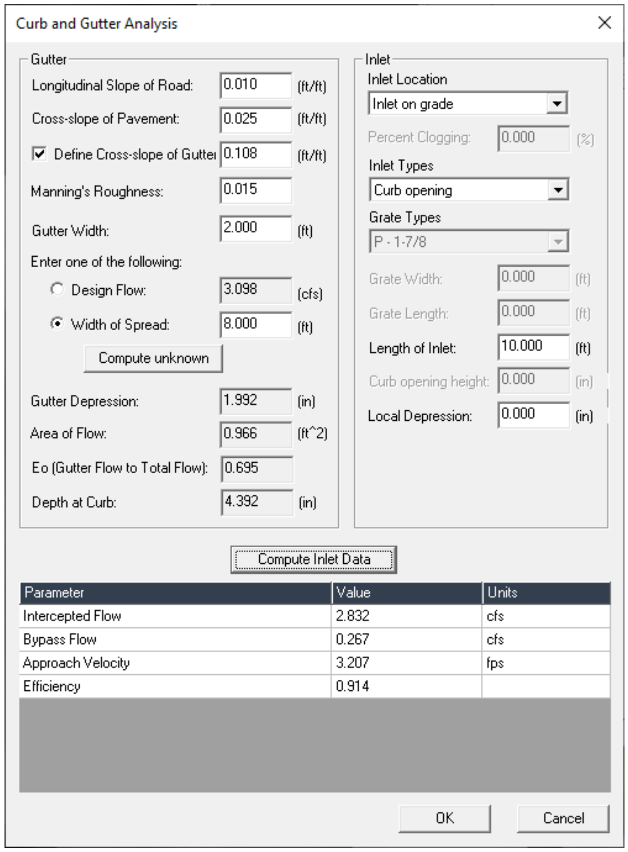



*Figure 8.2: Curb and gutter calculator*

The **Curb and Gutter Calculator** can handle uniform or compound gutters. The curb and gutter analysis allows the user to calculate the design flow or the width of spread. If the gutter cross slope, $S_W$, is different than that of the pavement cross slope, $S_X$, the user defines the gutter cross section slope, $S_W$, by selecting the "Define cross-slope of gutter" box and entering the slope. After entering the governing discharge or width of spread and selecting the compute unknown button, the Toolbox will automatically calculate and display the gutter depression value ("a" for compound gutter) along with the area of flow, ratio of frontal flow to total gutter flow, $E_o$, and depth of flow at the curb face.

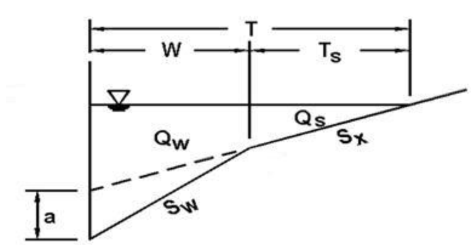



*Figure 8.3: Compound Gutter Cross Slope, from FHWA HEC 22, "Urban Drainage Design Manual"*

The **Curb and Gutter Calculator** also has a separate inlet capacity calculator on the right-hand side of the screen. It allows the user to define the inlet location, type, size, and whether there is an added local depression at the inlet. In sag locations, the user can also specify percent clogging, which will reduce the inlet perimeter and open area accordingly. After entering the variables, select the "Calculate" button to show the results in a table in the bottom window.

The inlet capacity calculator contains five inlet types:

- Grate Only (P-1-7/8, P-1- 7/8-4, P-1-1/8, Curved Vane, 45 Degree Tilt Bar 2-1/4", 45 Degree Tilt Bar 3-1/4", 30 Degree Tilt bar, Reticuline)
- Curb Opening
- Slotted Drain
- Sweeper Combination
- Equal Length Combination

Typical computed results for on-grade inlets include:

- Area of Flow
- Intercepted Flow
- Bypass Flow
- Velocity
- Splash-over Velocity<br>(limited to grate lengths of 5 ft or less)
- Efficiency
- Typical computed results for inlets in sags include:
- Flow Type
- Effective Perimeter (accounting for clogging)
- Effective Area (accounting for clogging)
- Depth at Curb Face
- Width of Spread

Further details about the equations used in the curb and gutter calculator are located in the following reference:

**Brown, S.A., Schall, J.D., Morris, J.L., Doherty, C.L., Stein, S.M., Warner, J.C., September 2009, Urban Drainage Design Manual, Hydraulic Engineering Circular 22, Third Edition, FHWA-NHI-10-009, HEC 22.**

**https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=22&id=140**

**https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=22&id=140**

# 9 Rational Method Calculator

*Figure 9.1: Rational Method Calculator icon*

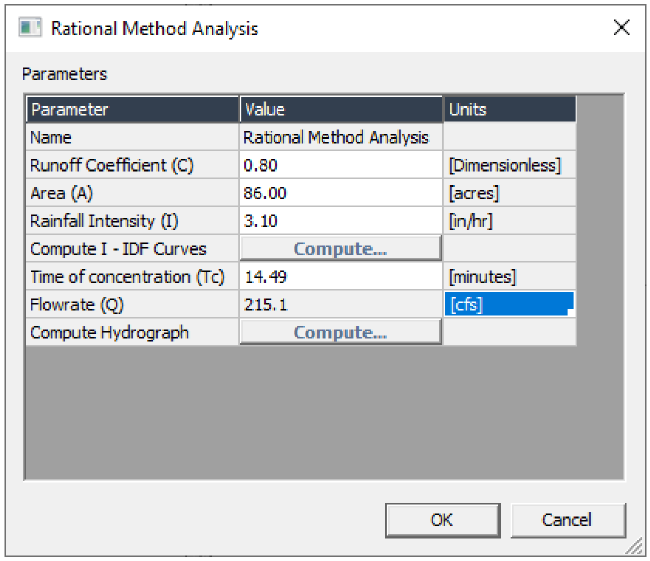



*Figure 9.2: Rational method calculator*

Use the **Rational Method Calculator** to enter the variables required to compute discharge rate using the Rational Method. The calculator can also compute the total time of concentration, $t_{c,}$ and plot the intensity-duration- frequency (IDF) curves. After determining the discharge, the Toolbox uses various methods to compute and display a hydrograph. Use the Rational Method for watersheds typically no larger than 200 acres.

Rational Method Equation

$$Q = CIA$$

Where:

Q = Discharge, $ft^3/s$

C = Rational Method Runoff Coefficient

I = Rainfall Intensity, in/hr

A = Area, acres

Further details about the equations used in the rational method calculator are located in the following reference:

**McCuen, R.H., Johnson, P.A., Ragan, R.M., October 2002, Highway Hydrology, Hydraulic Design Series Number 2, Second Edition, FHWA-NHI-02-001, HDS 2.**

**https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=2&id=6**

## 9.1 Rational Method Calculator – IDF Curve Computation

To compute the Intensity-Duration-Frequency (IDF) curves the user must select the precipitation data source to compute the curves. The source is dependent on where the project is located and what type of precipitation data is available. Depending on the source selected, a new window will open that will require the user to input applicable variables or in the case of user defined storm data, precipitation information for the 2- through 100-year storms and the 5-min to 60-min durations.

Upon entering the precipitation data and selecting the "Compute Intensity" button, the Toolbox calculates and displays the IDF curves. The user can export and save the curves for future use.

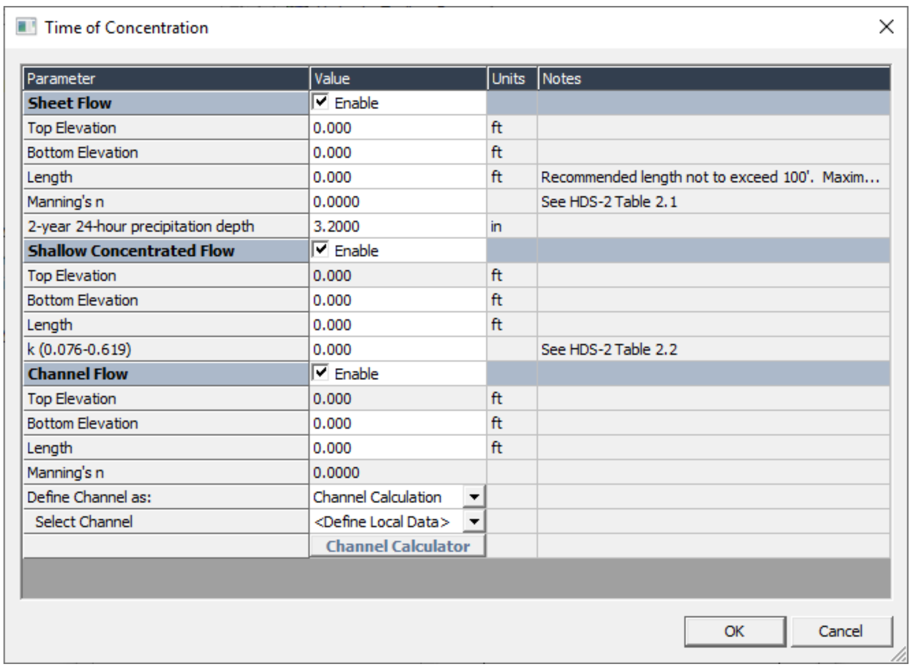
The **Rational Method Calculator** allows the input of precipitation information from NOAA Atlas 14 and NOAA Atlas 2 (since Atlas 14 is not yet available for some northwest states) as well as user defined precipitation values.

After entering the precipitation values, the **Rational Method Calculator** generates IDF Curves for 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year recurrence intervals. To determine the time of concentration, $t_c$, and peak discharge the user selects the recurrence interval as shown in the image on the right.

Further details about NOAA Atlas 2 and NOAA Atlas 14 are located on the Precipitation Frequency Data Server (PFDS) site:

https://hdsc.nws.noaa.gov/hdsc/pfds/

## 9.2 Time of Concentration—Overview




| Parameter | Value | Units | Notes |
|---|---|---|---|
| **Sheet Flow** | ☑ Enable | | |
| Top Elevation | 0.000 | ft | |
| Bottom Elevation | 0.000 | ft | |
| Length | 0.000 | ft | Recommended length not to exceed 100'. Maxim... |
| Manning's n | 0.0000 | | See HDS-2 Table 2.1 |
| 2-year 24-hour precipitation depth | 3.2000 | in | |
| **Shallow Concentrated Flow** | ☑ Enable | | |
| Top Elevation | 0.000 | ft | |
| Bottom Elevation | 0.000 | ft | |
| Length | 0.000 | ft | |
| k (0.076-0.619) | 0.000 | | See HDS-2 Table 2.2 |
| **Channel Flow** | ☑ Enable | | |
| Top Elevation | 0.000 | ft | |
| Bottom Elevation | 0.000 | ft | |
| Length | 0.000 | ft | |
| Manning's n | 0.0000 | | |
| Define Channel as: | Channel Calculation | | |
| Select Channel | <Define Local Data> | | |
| | Channel Calculator | | |

*Figure 9.3: Time of concentration calculator*

The total time of concentration, $t_c$, is a function of three potential flow types; sheet flow, shallow concentrated flow, and channel flow along a single flow path to a point of interest. The overland/sheet flow and shallow concentrated flow components are straight forward. The Toolbox solves the channel flow component through an iterative process using the Manning Equation.

One of the inputs to the Manning Equation is the hydraulic radius, R, which is a function of discharge, Q. Since the determination of Q creates the desired outcome, providing an initial estimate of Q allows the Toolbox to make an initial determination of R and the channel travel time. The **Rational Method Calculator** will then make a second estimate of the discharge using this travel time. Selecting the "optimize" button in the opening screen automatically starts this iterative process until the resulting discharge matches the previous estimate within an acceptable tolerance.

## 9.3 Time of Concentration—Overland/Sheet Flow

| Parameter | Value | Units | Notes |
|---|---|---|---|
| **Sheet Flow** | ☑ Enable | | |
| Top Elevation | 2600.000 | ft | |
| Bottom Elevation | 2595.000 | ft | |
| Length | 275.000 | ft | Recommended length not to exceed 100'. Ma... |
| Manning's n | 0.0420 | | See HDS-2 Table 2.1 |
| 2-year 24-hour precipitation depth | 3.2000 | in | |
| Slope | 0.0182 | ft/ft | |
| Time of Concentration | 8.2582 | min | HDS-2 Equation 2.6 |

*Figure 9.4: Calculating sheet flow travel time*

$$t_c = \frac{\alpha}{P_2^{0.5}}\left(\frac{nL}{\sqrt{S}}\right)^{0.8}$$

Where:

$P_2$ = 2-year, 24-hour rainfall depth, in (mm)

α = unit conversion constant equal to 5.5 in SI units and 0.42 in CU units.

n = roughness coefficient (see Table 2.1) L = flow length, ft (m)

S = slope of the surface, ft/ft (m/m)

The basin characteristics input for the sheet flow component of time of concentration include the top elevation, the bottom elevation, length, Manning "n", and 2-year 24-hour precipitation depth. The top elevation, bottom elevation, and length determines the slope.

## 9.4 Time of Concentration—Shallow Concentrated Flow

| | | | |
|---|---|---|---|
| **Shallow Concentrated Flow** | ☑ Enable | | |
| Top Elevation | 2595.000 | ft | |
| Bottom Elevation | 2592.000 | ft | |
| Length | 250.000 | ft | |
| k (0.076-0.619) | 0.500 | | See HDS-2 Table 2.2 |
| Slope | 0.012 | ft/ft | |
| Velocity | 1.807 | ft/s | HDS-2 equation 2.7 |
| Time of Concentration | 2.305 | min | |

*Figure 9.5: Calculating shallow concentrated flow travel time*

The basin characteristics needed for the shallow concentrated flow component of time of concentration include the top elevation, bottom elevation, length, and a value for k (the k value is based on the type of land cover).

Computing the slope requires the top elevation, bottom elevation, and length.

$$V = \alpha k S^{\frac{1}{2}}$$

Where:

V = velocity, m/s (ft/s)

S = slope, m/m (ft/ft)

k = dimensionless function of land cover

(see HDS-2, Table 2.2 below)

α = unit conversion constant equal to 10 in SI and 33 in CU units

*Table 9.1: Shallow concentrated flow "k" values, from FHWA HDS 2, Table 2.2*

| k | Land Cover/Flow Regime |
|---|---|
| 0.076 | Forest with heavy ground litter; hay meadow (overland flow) |
| 0.152 | Trash fallow or minimum tillage cultivation; contour or strip cropped; woodland (overland flow) |
| 0.213 | Short grass pasture (overland flow) |
| 0.274 | Cultivated straight row (overland flow) |
| 0.305 | Nearly bare and untilled (overland flow); alluvial fans in western mountain regions |
| 0.457 | Grassed waterway (shallow concentrated flow) |
| 0.491 | Unpaved (shallow concentrated flow) |
| 0.619 | Paved area (shallow concentrated flow); small upland gullies |

## 9.5 Time of Concentration—Channel Flow

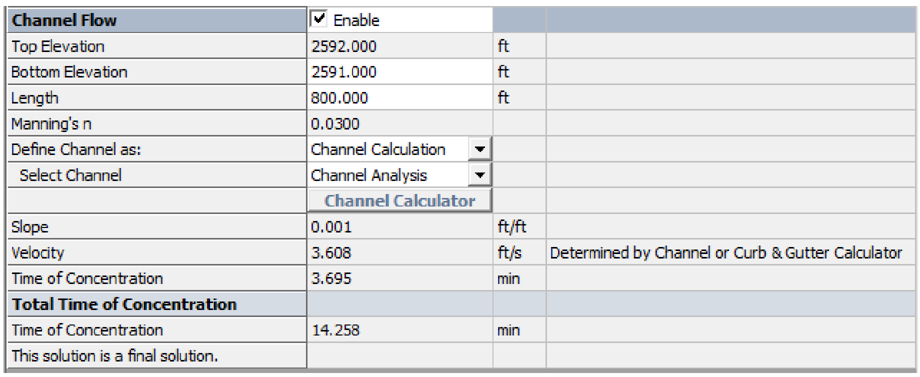



*Figure 9.6: Calculating channel flow travel time*

The basin characteristics for the Channel Flow component of time of concentration, $t_c$, inlcude the Top Elevation, Bottom Elevation, Length, and Manning's "n." The Toolbox uses either the Channel Calculator or Curb and Gutter Calculator to calculate the velocity which the designer selects in this window. You can also select an already defined channel or curb and gutter analysis from the Project Explorer Window.

$$V = \frac{\alpha}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where:

V = velocity, ft/s (m/s)

n = Manning's roughness coefficient

R = hydraulic radius, ft (m)

α = unit conversion constant equal (1.0 SI units, 1.49 CU units)

S = slope, ft/ft (m/m)

# 10 Detention Basin Calculator

*Figure 10.1: Detention Basin Calculator icon*

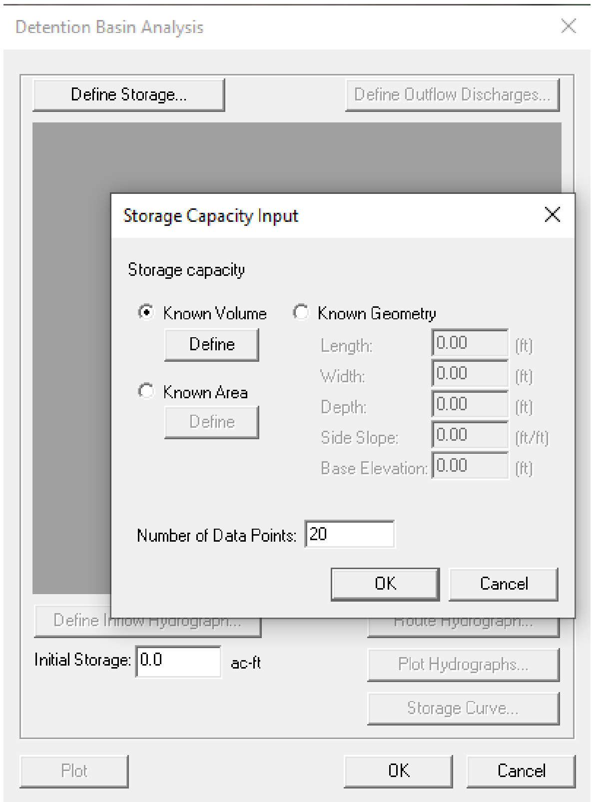



*Figure 10.2: Detention basin calculator-storage capacity input*

One of the fundamental objectives of storm water management is to maintain the peak runoff rate in a developed area at or below the predevelopment rate. The **Detention Basin Calculator** uses the basin storage, the inflow hydrograph and the outflow discharge to achieve this goal. To reduce the peak discharge, the calculator makes an estimate of the volume of storage. The calculator uses the Modified Puls Method of applying the storage-indication and storage routing to calculate the needed storage based on the inflow hydrograph's volume of water entering the basin and the water discharged through the user defined structure.

The detention basin analysis begins by selecting the "Define Storage" button and entering the volume, geometry, or area of the basin. By selecting the "Define" button for the known volume, a new window opens and the user enters the acre-ft of storage below its corresponding elevation. The "Known area" option allows the user to enter up to 200 pairs of elevation and corresponding area of the surface in acres. If the geometry is known, the user enters the dimensions of the basin bottom.

The next step is to specify how outflow leaves the basin by selecting the "Define Outflow Discharges" button and either entering a known discharge or adding a structure such as a weir, riser, or standpipe.

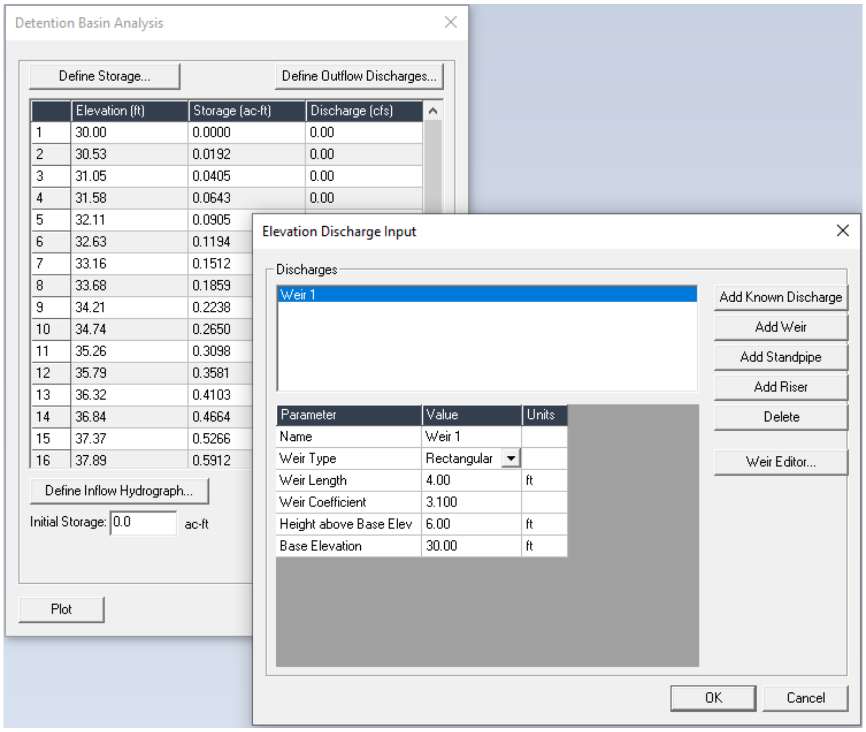



*Figure 10.3: Detention basin calculator-elevation discharge input*

The final step in the detention basin analysis defines the inflow hydrograph. There several methods exist to determine the hydrograph such as the Triangular Hydrograph Method and the SCS Procedure. For more information on these Methods refer to the FHWA Publication **HDS 2, Highway Hydrology**. Enter the hydrograph by clicking on the "Define Inflow hydrograph", selecting the number of "Time", "Inflow" points and entering the data.

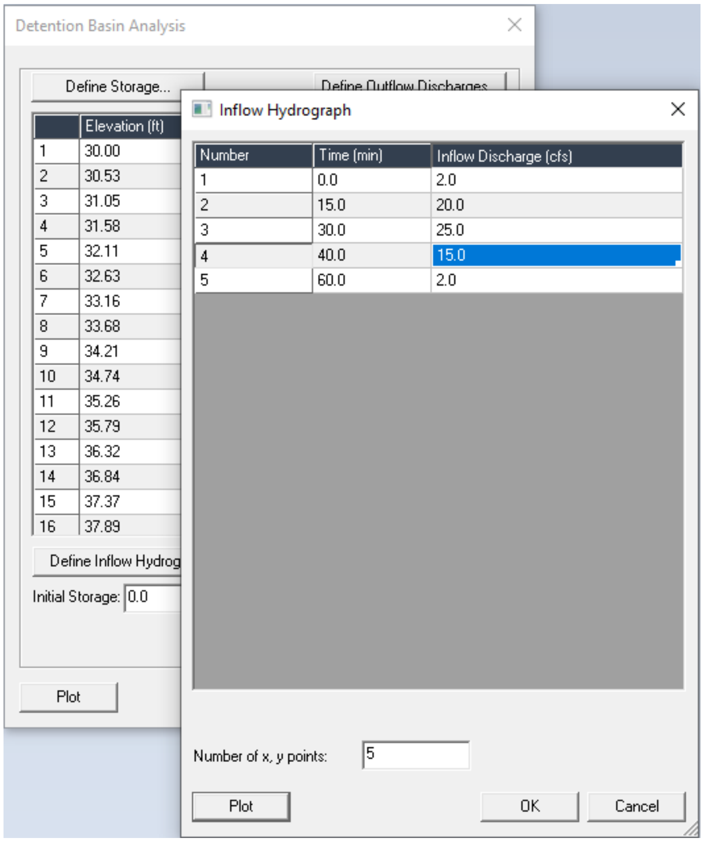



*Figure 10.4: Detention basin calculator-defining inflow hydrograph*

After providing all the input data, select the "Route Hydrograph" button to perform the computations. The calculator can report the routed outflow hydrograph and required storage results in tabular format along with plots of storage curves, inflow hydrographs, and routed outflow hydrographs.

The Detention Basin Calculator can plot the inflow and outflow hydrographs and the storage-discharge curves. The storage-discharge curves define the relationship between the storage volume in the basin, and the discharge for a given water elevation. The red line defines the storage curve and the blue line defines the discharge. The discharge will remain at 0 cubic feet per second until reaching the elevation of the outflow structure. Then the discharge curve will climb.

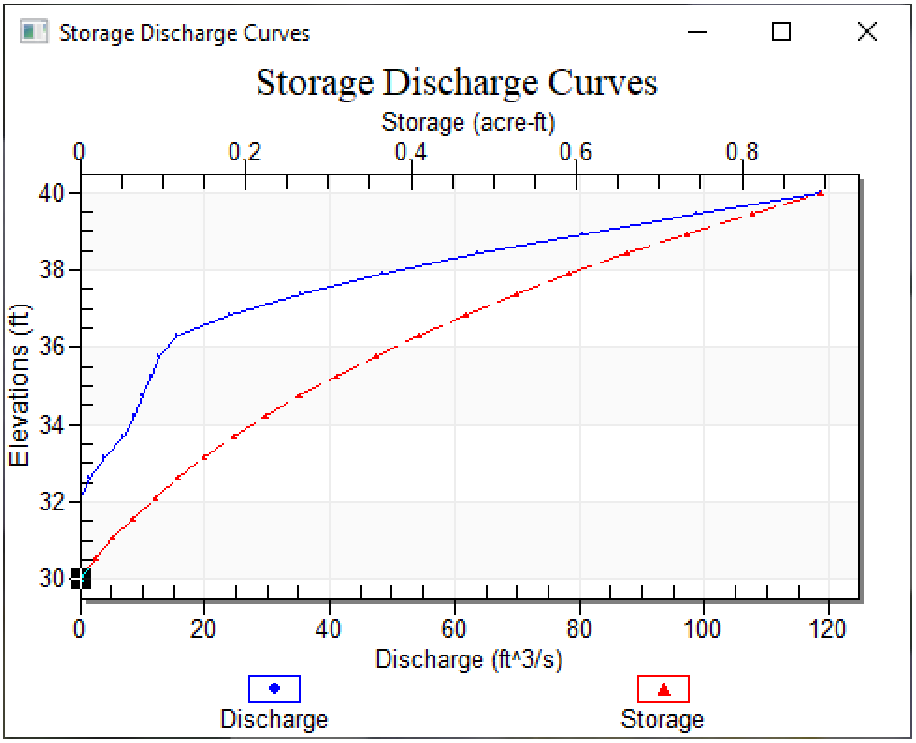



*Figure 10.5: Detention basin calculator plots-storage discharge curves*

The **Detention Basin Calculator** can produce a number of useful plots. The Inflow and Outflow Hydrographs figure shows an inflow and routed outflow hydrograph while the Storage Curve figure shows the detention basin storage curve.

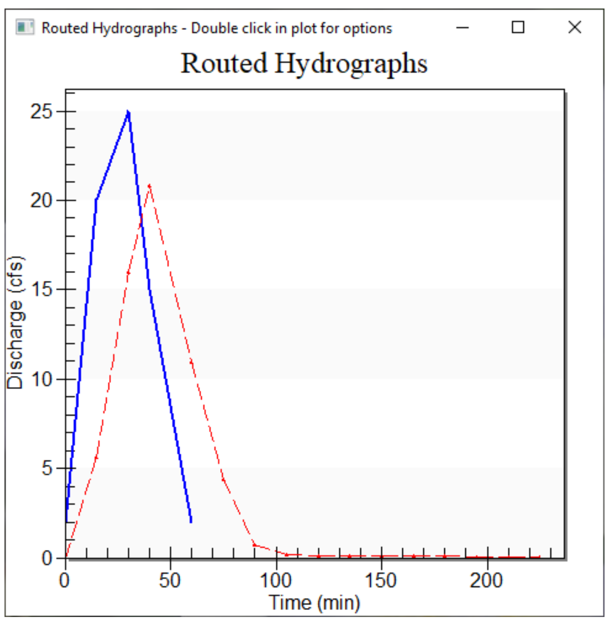



*Figure 10.6: Detention basin calculator plots-inflow vs outflow hydrographs*

The blue line in the Inflow and Outflow Hydrographs figure shows the inflow hydrograph to have a peak discharge of 25 $ft^3$/sec and the red line shows the routed hydrograph to have a discharge of 21 $ft^3$/sec for a reduction of 4 $ft^3$/sec.

The Storage Curve figure shows the needed storage while routing the inflow hydrograph. The maximum storage volume used to route the hydrograph through the detention basin to be approximately 0.48 ac-ft

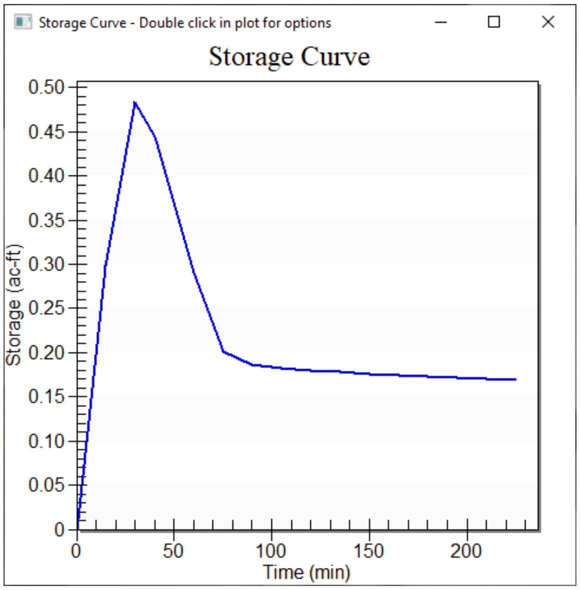



*Figure 10.7: Detention basin calculator plots-storage curve*

Further details about the methods used in the detention basin calculator are located in the HDS 2, chapter 8:

**McCuen, R.H., Johnson, P.A., Ragan, R.M., October 2002, Highway Hydrology, Hydraulic Design Series Number 2, Second Edition, FHWA-NHI-02-001, HDS 2.**

**https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=2&id=6**

# 11 Riprap Calculator

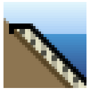


*Figure 11.1: Riprap Calculator icon*

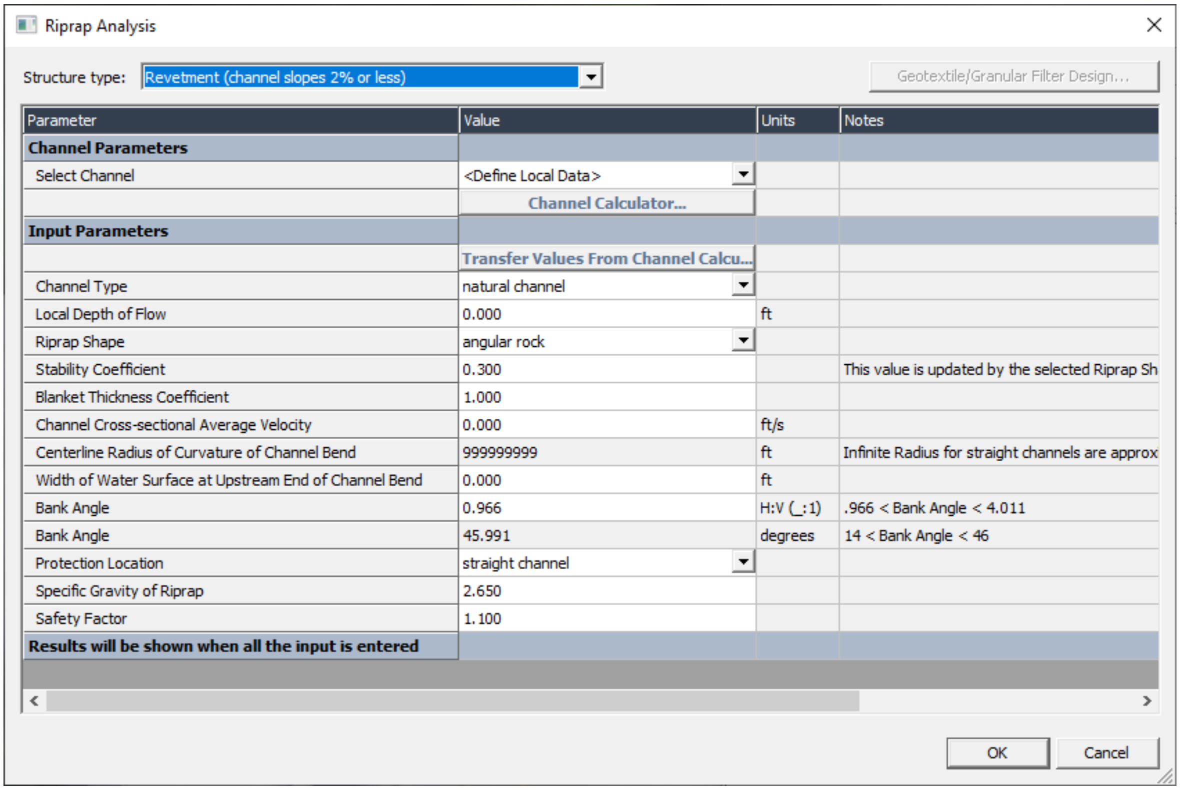



*Figure 11.2: Riprap calculator*

The **Riprap Calculator** offers eight applications for designing rock riprap armor protection/scour countermeasures:

- Channel Revetment (slopes < 2%)
- Bridge Piers
- Bridge Abutments / Guide Banks
- Channel Spurs
- Embankment Overtopping/channel slopes > 2%
- Culvert Outlet Protection
- Open-bottom Culvert Protection
- Wave Attack

In addition, a Riprap Filter Design Calculator is available for each of the above riprap applications. The Filter Calculator will design both granular or geotextile filters; with multiple layers available for the granular filter design if needed. A detailed description of the Filter Design Calculator is below. FHWA's HEC 23, Volume 2 contains detailed descriptions of all the above methods.

Each of the above riprap applications requires different Input Parameters. When you select an application, the associated data input screen will open.

After selecting the desired application, the user provides the hydraulic parameters required for the specific riprap design. The user inputs these parameters directly, or computes them by either selecting a previously defined Channel Calculator file that appears in the 'Select Channel' window or inputting new hydrologic and channel characteristic data locally using the Channel Calculator. (See the description of the use of the Channel Calculator earlier in this document.) To transfer the Channel Calculator output to the appropriate Input Parameter fields, select the "Transfer Values From Channel Calculator" button under the Input Parameters heading.

Upon entering the hydraulic parameters, the Input Parameters unique to the selected riprap application must be pro-vided. The Toolbox will immediately output the necessary riprap rock size for the given channel hydraulics.

With a couple of variations, the above operations and requirements are common to all eight riprap applications. The variations occur in the Embankment Overtopping and Wave Attack applications. The Embankment Overtopping application includes the Weir Calculator, in addition to the Channel Calculator, and the option to transfer the results of the Weir Calculator to the appropriate Input Parameter fields, if desired. (For more information of the Weir Calculator see the description earlier in this document.) The Wave Attack application is for shoreline protection and includes a Design Wave Calculator rather than a Channel Calculator. The Toolbox will transfer the computed or edited results in the Design Wave Calculator to the Wave Attack riprap calculator.

The description of the unique Input Parameters, governing equation, and Results for each riprap application, as well as the Filter Design and Design Wave Calculators, are below.

Further details about the equations used in the rational method calculator are located in the following reference:

**Lagasse, P.F., et. al., September 2009, Bridge Scour and Stream Instability Countermeasures—Experience, Selection, and Design Guidance, Hydraulic Engineering Circular No. 23, Third Edition, FHWA-NHI-09-111 & 112, HEC 23.**

https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=23&id=142

## 11.1 Channel Revetment

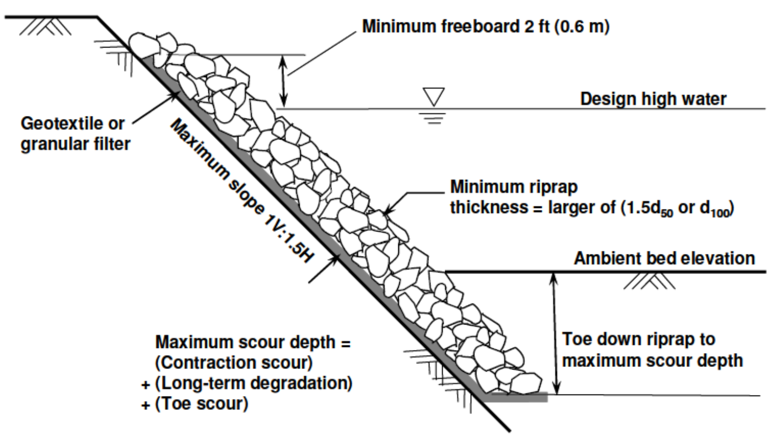



*Figure 11.3: Riprap revetment diagram with buried toe, from FHWA HEC 23, Volume 2, Figure 4.2*

The governing equation for computing riprap size for **Channel Revetment** is:

$$d_{30} = y(S_f C_S C_V C_T)\left[\frac{(V_{des})}{\sqrt{K_1(S_g-1)gy}}\right]^{2.5} \quad \textit{(See FHWA HEC 23, Volume 2, Eqn. 4.1)}$$

The list below shows the required unique input parameters for Channel Revetment riprap design:

- Channel Type (Natural or Trapezoidal)

- Local Flow Depth, ft (typically taken at toe of slope for bank revetments)
- Riprap Shape (Angular or Rounded)
- Channel Cross-sectional Average Velocity
- Centerline Radius of any Channel Bend
- Width of Water Surface Upstream end of channel bend
- Bank Angle
- Protection Location (straight channel, outside bend, inside bend, downstream of concrete channel, end of dike)
- Specific Gravity of Rock (typically 2.65)
- Safety Factor desired

The following unique Results for Channel Revetment riprap are:

- Side Slope Correction Factor
- Velocity Distribution Coefficient
- Design Velocity, ft/sec.
- $D_{30}$ and $D_{50}$ Rock Size-Fractions, in
- Riprap Gradation
- Minimum Riprap Thickness, in

## 11.2 Bridge Pier

The governing equation for computing riprap size for **Bridge Pier** protection is:

$$d = \frac{0.692(V_{des})^2}{(S_g - 1)2g}$$ *(See FHWA HEC 23, Volume 2, Eqn. 11.1)*

The following required input parameters for Bridge Pier riprap design are:

- Velocity Input Type (Average Channel Velocity at the Bridge or Local Velocity at Pier)
- Average Channel Velocity at Bridge or Local Velocity at Pier, ft/sec.
- Pier Shape (Round-nose or Square-faced)
- Pier Width (normal to flow), ft
- Contraction Scour Depth, if applicable, ft
- Bed Form Depth, if applicable, ft
- Specific Gravity of Rock (typically 2.65)

The following results for Bridge Pier riprap design are:

- Design Velocity, ft/sec.
- $D_{50}$ Rock Size-Fractions, in
- Riprap Gradation
- Depth of Riprap Below Streambed, ft
- Minimum Riprap Extent, ft
- Filter Placement Extent, ft

## 11.3 Bridge Abutments or Guide Banks

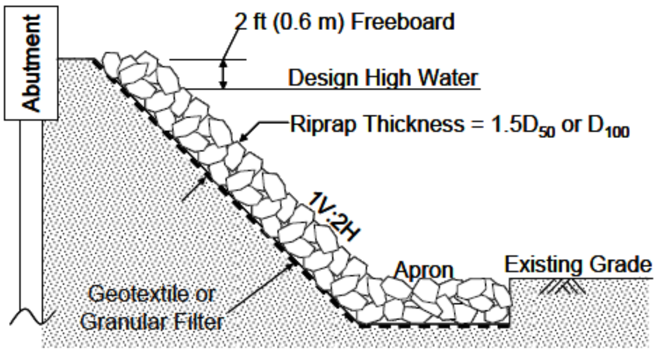



*Figure 11.4: Typical cross section for abutment riprap, from FHWA HEC 23, Volume 2, Figure 14.8*

The general equation for computing riprap size for **Bridge Abutment or Guide Bank** protection is:

$$\frac{D_{50}}{y} = \frac{K}{(S_s-1)}\left[\frac{V^2}{gy}\right] \quad \textit{(FHWA HEC 23, Volume 2, Eqn. 14.1)}$$

The following required input parameters for Bridge Abutment or Guide Bank riprap design are:

- Structure Type (Abutment or Guide Bank)
- Abutment Type (Spill-thru or Vertical-wall)
- Setback Length from main channel, ft (distance from near edge of main channel to toe of abutment)
- Main Channel Average Flow Depth, ft
- Flow Depth at Toe, ft
- Total Discharge, $ft^3$/sec
- Overbank Discharge, $ft^3$/sec
- Total Bridge Flow Area, $ft^2$
- Setback Flow Area, $ft^2$
- Maximum Channel Velocity, ft/sec.
- Specific Gravity of Rock (typically 2.65)

The following results for Bridge Abutment or Guide Bank riprap are:

- Setback Ratio (ratio of set-back length to channel flow depth)
- Characteristic Velocity, ft/sec
- Froude Number at Toe
- Abutment Coefficient
- $D_{50}$ Rock Size-Fractions, in
- Riprap Gradation
- Riprap Thickness, in
- Minimum Horizontal Extent from Toe, ft
- Minimum Extent of Wrap-Around, ft

## 11.4 Channel Spur

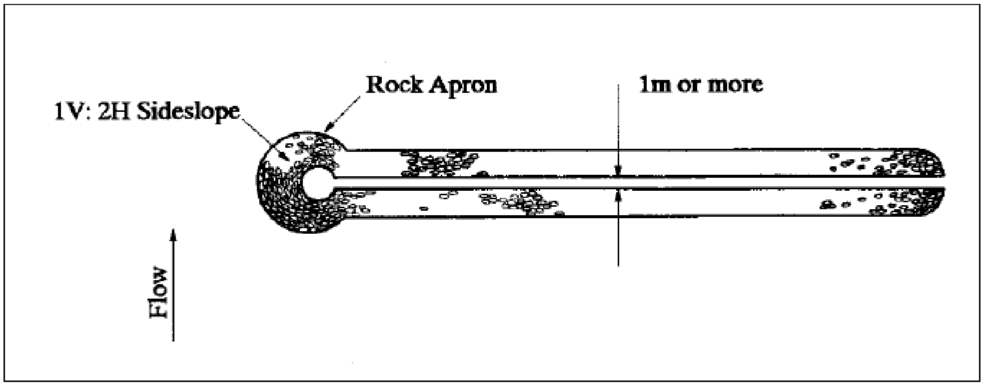



*Figure 11.5: Typical straight, round nose spur, from FHWA HEC 23, Volume 2, Figure 2.12*

The governing equation for computing riprap size for **Channel Spurs** is:

$$d_{30} = y(S_f C_S C_V C_T)\left[\frac{(V_{des})}{\sqrt{K_1(S_g-1)gy}}\right]^{2.5} \quad \textit{(FHWA HEC 23, volume 2, Eqn. 4.1)}$$

The following required Input Parameters for Channel Spur riprap design are:

- Channel Type (Natural or Trapezoidal)
- Local Flow Depth at end of Spur, ft
- Riprap Shape (Angular or Rounded)
- Channel Cross-sectional Average Velocity
- Centerline Radius of any Channel Bend
- Width of Water Surface Upstream
- Bank Angle
- Specific Gravity of Rock (typically 2.65)
- Safety Factor desired

The following results for Channel Spur riprap are:

- Side Slope Correction Factor
- Local Velocity at Spur Nose, ft/sec
- $D_{30}$ and $D_{50}$ Rock Size-Fractions, in
- Riprap Gradation
- Minimum Riprap Thickness, in

## 11.5 Embankment Overtopping

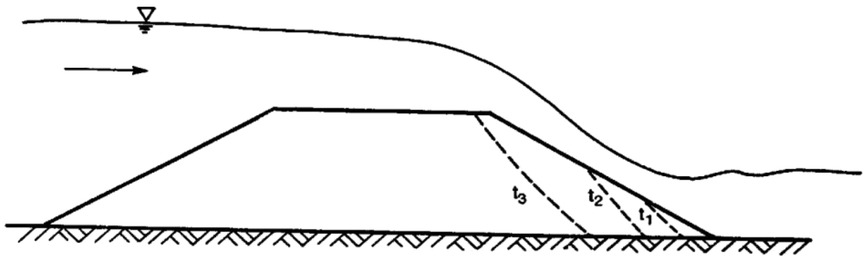



*Figure 11.6: Typical embankment erosion pattern with free flow, from FHWA HEC 23, Vol. 2, Figure 5.2*

The general equation for computing riprap size for **Embankment Overtopping** protection is:

$$d_{50} = \frac{K_u q_f^{0.52}}{C_u^{0.25} S^{0.75}} \left( \frac{\sin\alpha}{(S_g \cos\alpha - 1)(\cos\alpha \tan\phi - \sin\alpha)} \right)^{1.11} \quad \textit{(FHWA HEC 23, Volume 2, Eqn. 5.2)}$$

The following required Input Parameters for Embankment Overtopping riprap design are:

- Embankment Side Slope
- Total Discharge, $ft^3$/sec
- Overtopping Length, ft
- Weir Coefficient
- Coefficient of Uniformity for riprap, $D_{60}/D_{10}$
- Porosity of riprap

The following results for **Embankment Overtopping** riprap are:

- Overtopping Depth, ft
- Unit Discharge, $ft^3$/sec /ft
- Median Rock Size, $D_{50}$, in
- Riprap Gradation
- Interstitial Velocity, ft/sec
- Average Velocity, ft/sec
- Manning's n-value
- Minimum Riprap Thickness, in
- Unit Discharge over riprap, $ft^3$/sec /ft
- Unit Discharge through riprap, $ft^3$/sec /ft

## 11.6 Culvert Outlet Protection

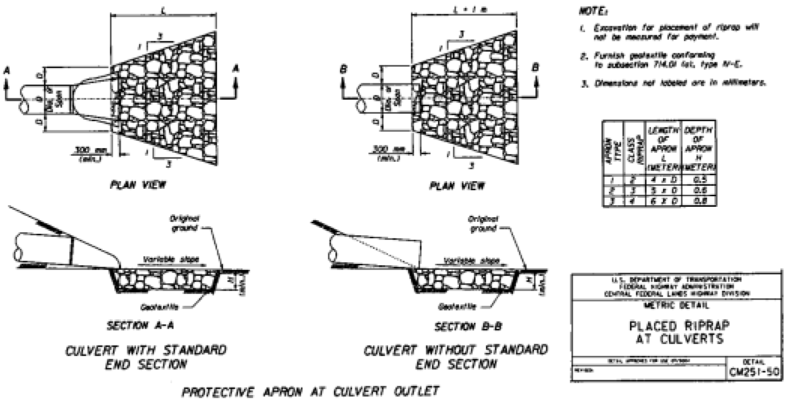



*Figure 11.7: Placed riprap at culverts, from FHWA HEC 14, Figure 10.4*

For culverts 60 in or smaller the most commonly used device for outlet protection is a riprap apron. The governing equation for computing riprap size for **Culvert Outlet** protection is:

$$D_{50} = 0.2D\left(\frac{Q}{\sqrt{g}D^{2.5}}\right)^{4/3}\left(\frac{D}{TW}\right) \qquad \textit{(HEC 14, Eqn. 10.4)}$$

The following required Input Parameters for Culvert Outlet Protection riprap apron design are:

- Flow, $ft^3$/sec
- Culvert Diameter, ft
- Normal Depth in Culvert, ft
- Tailwater Depth, ft
- Flow Type (Subcritical or Supercritical)

The following unique results for Culvert Outlet Protection riprap are:

- Median Rock Size, $D_{50}$, in
- Riprap Gradation
- Apron Length, ft
- Apron Width, ft
- Apron Thickness, ft
- Tailwater Depth used in calculations, ft
- Culvert Diameter used in calculations, ft

Further details about the culvert outlet protection computations are located in chapter 10 of the FHWA HEC 14 document:

**Thompson, P.L., Kilgore, R.T., July, 2006, Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14, Third Edition, FHWA-NHI-06-086, HEC 14.**

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

## 11.7 Open-Bottom Culvert Protection

The governing equation for computing riprap size for open-bottom culverts is:

$$d_{50} = \frac{K_r y_0}{(S_g - 1)}\left(\frac{V_{AC}^2}{gy}\right)^{0.33}$$ *(FHWA HEC 23, Volume 2, Eqn. 18.1)*

The following required Input Parameters for Open-Bottom Culvert Protection riprap design are:

- Design Curve (Envelope or Best-Fit)
- Average Velocity at entrance, ft/sec.
- Average Flow Depth at entrance, ft
- Invert Elevation, ft
- Contraction Scour + Long-Term Degradation, ft

The following results for Open-Bottom Culvert riprap are:

- Median Rock Size, $D_{50}$, in
- Riprap Gradation
- Top of Footing Elevation, ft
- Riprap Thickness, ft
- Riprap Layout Dimensions, ft

## 11.8 Wave Attack

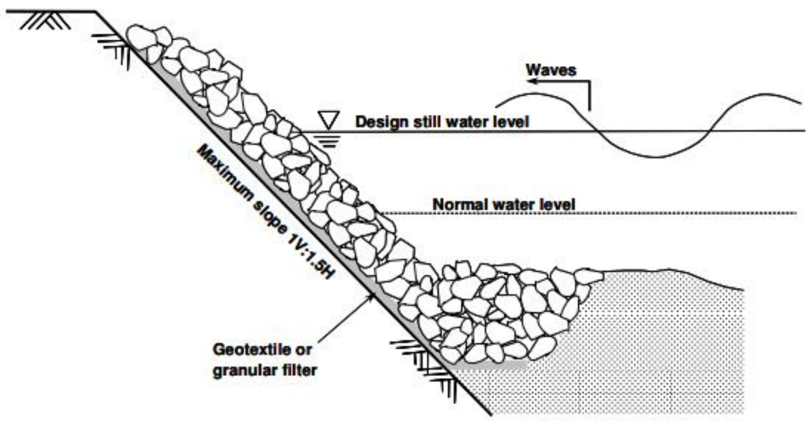



*Figure 11.8: Riprap shore protection-typical design configuration, from FHWA HEC 23, Volume 2, Figure 17.2*

Two equations exist for computing riprap size for **Wave Attack** protection: the Hudson and Pilarczyk Methods. The Hudson Method considers wave height, riprap density, and slope of the embankment to compute a median-size riprap particle. The Pilarczyk Method considers additional variables associated with particle stability in different wave environments and should more thoroughly characterize the rock stability threshold.

Hudson Method Equation

$$W_{50} = \frac{\gamma_r H^3 (\tan\theta)}{K_d (S_r - S_w)^3}$$ *(FHWA HEC 23, Volume 2, Eqn. 17.8)*

Pilarczyk Method Equation

$$\frac{H_s}{\Delta D} \leq \psi_u \phi \frac{\cos\theta}{\xi^b}$$ *(FHWA HEC 23, Volume 2, Eqn. 17.11)*

The following Input Parameters for Wave Attack Protection riprap design are:

- Angle of Slope Inclination

- Freeboard, ft
- Sizing Method (Hudson or Pilarczyk)
- Specific Gravity of Rock (2.4 – 2.7)
- Specific Gravity of Water (Fresh=1.0; Salt=1.03)
- Significant Wave Height, ft (via Design Wave Calculator)
- Hudson Method
- Design Wave Height, ft
- Pilarczyk Method
- Stability Factor

The following unique results for **Wave Attack** riprap are:

- Median Rock Size, $D_{50}$, in
- Riprap Gradation
- Riprap Thickness, ft
- Dimensionless Breaker Parameter
- Wave Runup, ft
- Height of Riprap above Toe, ft
- Hudson Method
- Weight of $D_{50}$ Rock Size, lbs

## 11.9 Design Wave Calculator

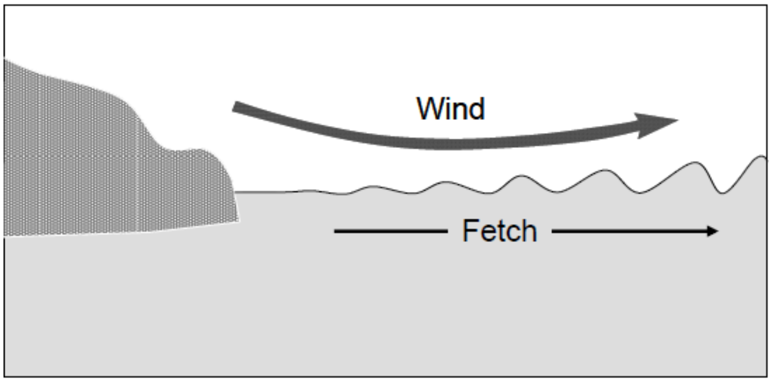



*Figure 11.9: Definition Sketch for Wave Calculations at channels and floodplains, from FHWA HEC 23, Volume 2, Figure 17.4*

As mentioned earlier, use the **Design Wave Calculator** to compute the basic input wave parameters (i.e. Significant Wave Height and Wave Period) required for designing riprap Wave Attack Protection when those basic parameters are not known. The Toolbox transfers the results from the Design Wave Calculator to the Wave Attack Protection Calculator upon closing the Design Wave window. The user can manually change the values of these basic parameters if necessary.

The required input parameters for the Design Wave Calculator include:

- Wind Speed, ft/sec
- Fetch Length, ft
- Still Water Depth, ft

Computed results include:

- Coefficient of Drag
- Friction Velocity, ft/sec.
- Dimensionless Fetch Length
- Dimensionless Wave Height
- 10% Wave Height, ft
- 5% Wave Height, ft
- 1% Wave Height, ft
- Dimensionless Wave Period
- Significant Wave Height, ft
- Wave Period, sec

## 11.10 Riprap Filter Design

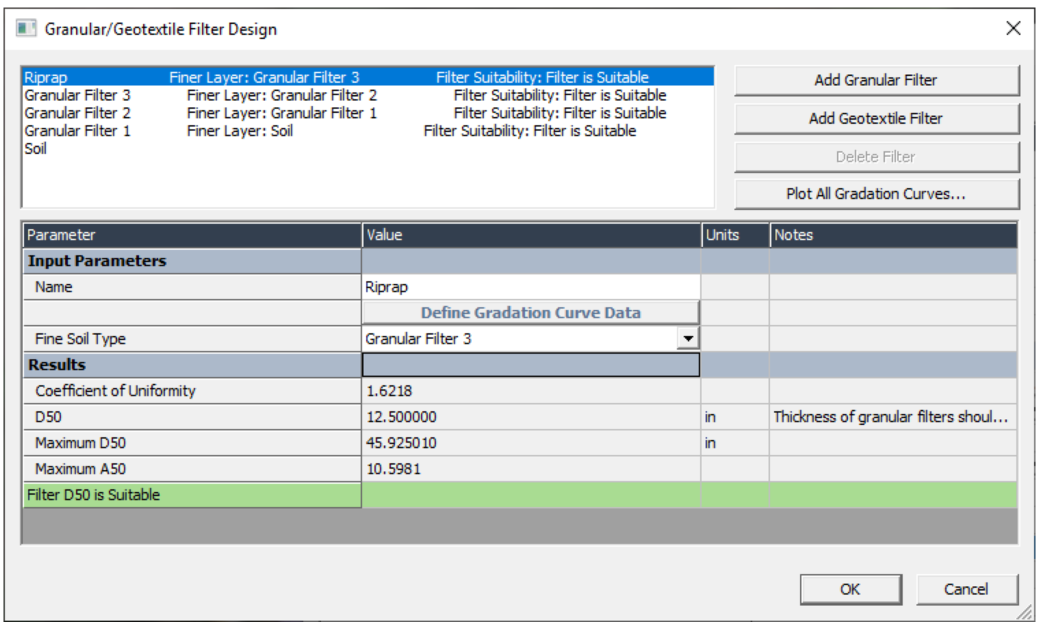



*Figure 11.10: Granuar/geotextile filter design calculator*

The **Riprap Filter Design** procedure is available as an optional routine within each of the riprap design calculators described above. (Note the button at the top right corner of the riprap calculator opening window.) The filter design procedure, explained further in HEC 23, Volume 2, DG 16, determines the need for and compatibility of proposed filters by successively comparing coarser materials to underlying finer materials using the Cisten-Ziems criteria for granular filters and the fabric characteristics for geotextile filters. If the materials are compatible, a highlighted green message will appear stating that the proposed filter is suitable. If not compatible, a highlighted red message will appear stating the filter is not suitable. If the filter is not suitable, select another suitable filter or design an additional granular filter(s) as a transition layer(s) to attain suitability. As in the riprap calculators, the user must input all data before the Filter Design calculator will provide results.

Since the procedure begins by comparing the proposed riprap gradation with the base soil characteristics, the required base soil characteristics and proposed riprap gradation must be known and input as a first step. The required input parameters for the soil include:

- Gradation (Include $D_{10}$ and $D_{60}$ for best results)

- Hydraulic Conductivity, in/sec
- Plasticity Index (for soils with more than 20% clay content)
- Undrained Shear Strength (for geotextiles only), lbs./$ft^2$
- Computed results for the soil are:
- Coefficient of Uniformity, $D_{60}/D_{10}$
- Median Particle Size, $D_{50}$, in

The input parameters required for the riprap are:

- Gradation
- Fine Soil Type (select soil or proposed filter from drop-down window)

The Toolbox automatically transfers the gradation from the results of an associated riprap design to the filter design routine but the user can manually change to any desired gradation. Consequently, the user can use the filter design routine within any riprap calculator to accomplish an 'off-line' filter design for any soil/riprap combination.

Computed results for the Riprap include:

- Coefficient of Uniformity, $D_{60}/D_{10}$
- Median Particle Size, $D_{50}$, in
- Maximum $D_{50}$ of the underlying finer material (soil or filter), in
- Maximum Cisten-Ziems ratio, $A_{50}$

If the proposed riprap is compatible with the base soil (green message), there is no filter needed and the procedure is complete. If not, select either a granular or geotextile filter.

The required input parameters for a Granular Filter include:

- Gradation
- Fine Soil Type (select soil or another filter from drop-down window)
- Hydraulic Conductivity, in/sec

Computed results for a Granular Filter are:

- Coefficient of Uniformity, $D_{60}/D_{10}$
- Median Particle Size, $D_{50}$, in
- Maximum $D_{50}$ of the underlying finer material, in
- Maximum Cisten-Ziems ratio, $A_{50}$
- Conductivity Ratio

The required input parameters for a Geotextile Filter include:

- Fine Soil Type (select soil from drop-down window)
- Hydraulic Conductivity, in/sec
- Geotextile Apparent Opening Size (AOS), $O_{95}$
- Flow Type (select open channel or wave attack from drop-down window)

Computed results for a Geotextile Filter are:

- Maximum $O_{95}$ of the Geotextile, in
- Minimum $O_{95}$ of the Geotextile, in
- Conductivity Ratio

If the proposed filter is compatible with the underlying base soil or other granular filter (the Toolbox provides a green message), the procedure ends here. If the filter is not suitable, select another suitable filter design or an additional granular filter(s) as a transition layer(s) and repeat the procedure until attaining suitability.

Note that the Filter Design calculator includes a 'Plot Gradations' button that will display all input gradations on one plot. This is very useful for identifying the appropriate gradation needed for intermediate filters when using multiple granular filters. Also, when evaluating the suitability of a selected layer (i.e. the user sees the riprap or a filter highlighted in the top window) with the underlying material (filter or soil) of a multiple layer granular system, make sure to select the correct underlying material in the drop-down window of the Finer Soil Type input parameter

# 12 Rock/Sediment Gradation Calculator

*Figure 12.1: Rock/Sediment Calculator icon*

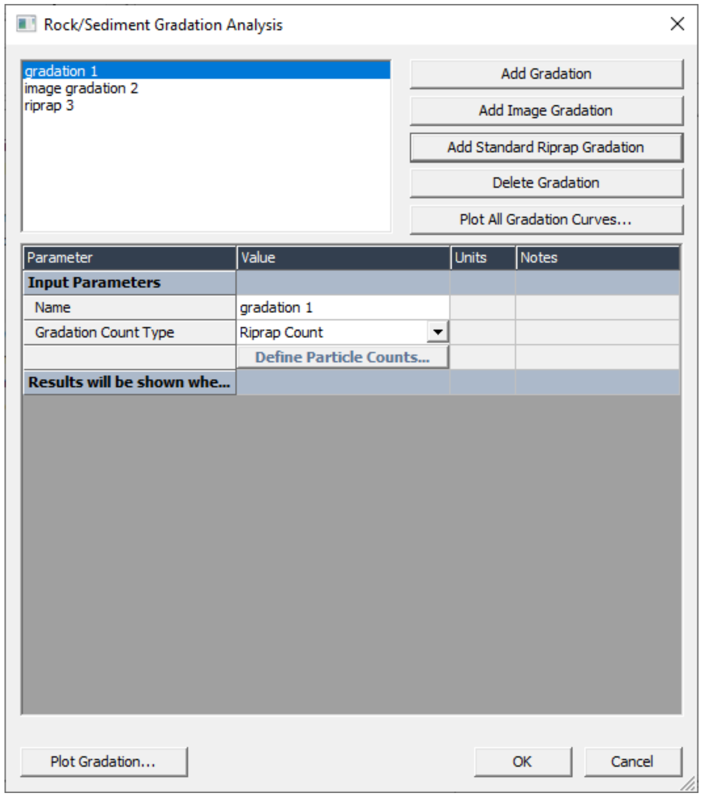



*Figure 12.2: Rock/sediment gradation calculator*

The **Rock/Sediment Gradation Calculator** tool will compute gradation information from pebbles counts conducted in the field (in accordance with the Wolman Count procedure) or from high resolution digital images (photographs) of any surface composed of discrete particles. The tool will compare those field gradations to control gradations by viewing them together on standard, semi-log gradation plots. The intent of the calculator is primarily to produce gradation plots for riprap and stream bed sediments. The methods for adding gradations are as follows:

- Gradation
- Image Gradation
- Standard Riprap Gradation

The gradation tool uses the Wolman count procedure to determine a gradation. The gradation count type specifies the intervals used to group the gradations.

The image gradation will take an image of a gradation with an object for scale an estimate the gradation. Consider the results as approximate.

The standard riprap tool adds a predefined riprap from the Hydraulic Toolbox's profiles.

Further details about the methods used in the rock/sediment gradation calculator are located in the following references:

**Strom, K.B.; Kuhns, R.D.; Lucas, H.J., Comparison of Automated Image-Based Grain Sizing to Standard Pebble-Count Methods, ASCE Journal of Hydraulic Engineering, August 2010, pp. 461-473.**

**Wolman, M.G., A Method of Sampling Coarse Bed Material, American Geophysical Union, Transactions, 1954, vol. 35, pp. 951-956.**

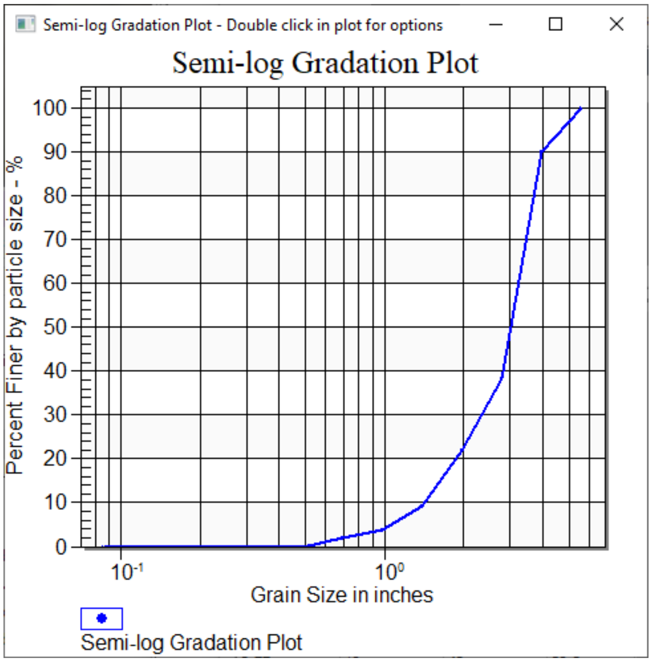



*Figure 12.3: Percent finer semi-log gradation plot*

Upon opening the calculator, the designer chooses whether to enter field count information (Add Gradation), a digital image (Add Image Gradation) or a control gradation (Add Standard Riprap Gradation).

## 12.1 Gradation

Upon selecting the "Add Gradation" button and highlighting "Gradation #" in the top window, the user enters the following data:

- Gradation Name
- Gradation Type (Riprap or Stream Bed from drop-down window)
- Particle Count ('Define Particle Count' button)

The Riprap gradation type uses 'all particles less than 3 inches' as the smallest size interval; while the Stream Bed gradation uses the smallest particle measured as the smallest size interval. The following interval sizes for riprap gradations are: 4.25", 6.0", 8.5", 12.0", 17.0", 24.0", 34.0", 48.0", 68.0", and 96.0", and larger. Note these numbers may convert to a different unit of length. The stream bed gradation interval sizes increase by $\sqrt{2}$ from the smallest particle size measured.

After selecting the 'Define Particle Count' button, the designer sees another window prompting them to "Add Transect" data. This is the actual field count data, or portion thereof. (Enter the field count data via one or several named 'transects.') Upon selecting the 'Add Transect' button and highlighting "Transect #" in the top window, the user sees the summary table associated with the selected transect. At this point, the user selects the "Edit Transect" button, which brings up the count input screen where the user inputs (or edits) the measured intermediate axis dimensions of the individual particles. Note enter the number of particles measured in the transect at the bottom of the screen to get a complete input table to appear.

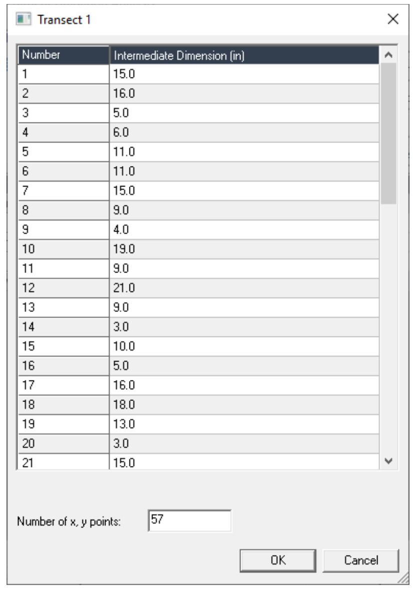



*Figure 12.4: Transect editor*

The user can now view the individual transect plot by selecting the "Plot Gradation" button or press 'OK'. To view the results gradation results ($D_5$, $D_{15}$, $D_{50}$, $D_{85}$, $D_{100}$) for the associated transects in tabular form, back out to the previous screen. To view all available gradation information (previously input counts and/or controls) on a single plot, select the "Plot All Gradation Curves" button.

## 12.2 Image Gradation

The digital imaging tool is quick and can be very accurate. However, because of the potential impacts of shadows and rock color variations, consider the resulting gradations as approximate. Therefore, do not use the current technology to reject manufactured rock. If gradation results seem questionable, perform a manual pebble count (e.g. Wolman procedure) for final rock acceptance testing.

### 12.2.1 Gradation Photography

Note a few things to keep in mind when photographing riprap, cobbles, or gravel that will lead to better results with the image gradation tool:

- Include an object or marks for scale
- Position the camera and shot to be square and straight to the subject material
- Prepare for the shot by removing anything that is not the subject material
- Higher resolution pictures and multiple images will yield better results
- If possible, time or locate the shot to be in soft lighting

#### 12.2.1.1 Include an Object or Marks for Scale

To be able to 'measure' the surrounding rock, cobble, and gravel, Hydraulic Toolbox needs an object to use as a scale. This object can be a surveying rod, a ruler, a tool with known length, or painted marks a known distance apart. The object needs to only provide a scale in one direction. It does NOT need to be vertical and horizontal.

This object will be counted as a rock, cobble, or gravel unless it is cropped out. As a result, it is best to keep the scaling object small relative to image. We expect that the tool will not have a precise count, but assume that the large amount of correct pebble counts to leave the inaccurate counts to be statistically insignificant.

### 12.2.1.2 Position the Camera and Shot to be square and straight to the Subject Material

The camera needs to be lined up square and straight to the subject material. If the subject material at the top of the image is further away from the camera than the subject material at the bottom of the image, Hydraulic Toolbox will not be able to scale the gradation correctly, because the scale in the image will change vertically. The scale needs to remain the same throughout the image. The subject material in each corner of the photograph should be a similar distance away. The example below shows a camera properly positioned to take an image in a vertical plane relative to the camera.

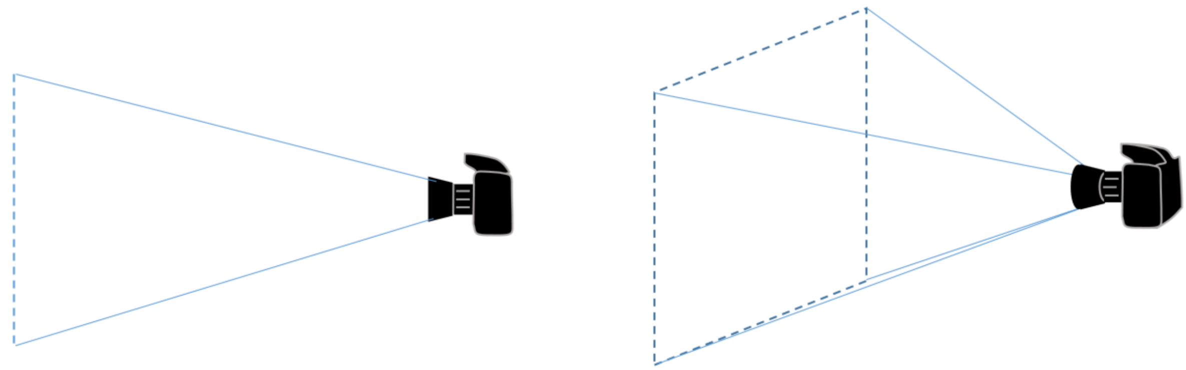


*Figure 12.5: Side view and oblique view of a camera setup properly positioned for photographing a subject material with all 4 corners at the same distance from the camera.*

It may be easier to take a picture of the subject material that is sloping away from the camera and to take the level to the ground instead of straight towards the subject material. This will lead to an image that is 'keyed' and the objects at the top of the image will appear smaller than the objects at the bottom of the image. This will skew the results of the image gradation. The example below shows NOT properly positioning the camera for an image gradation photograph.

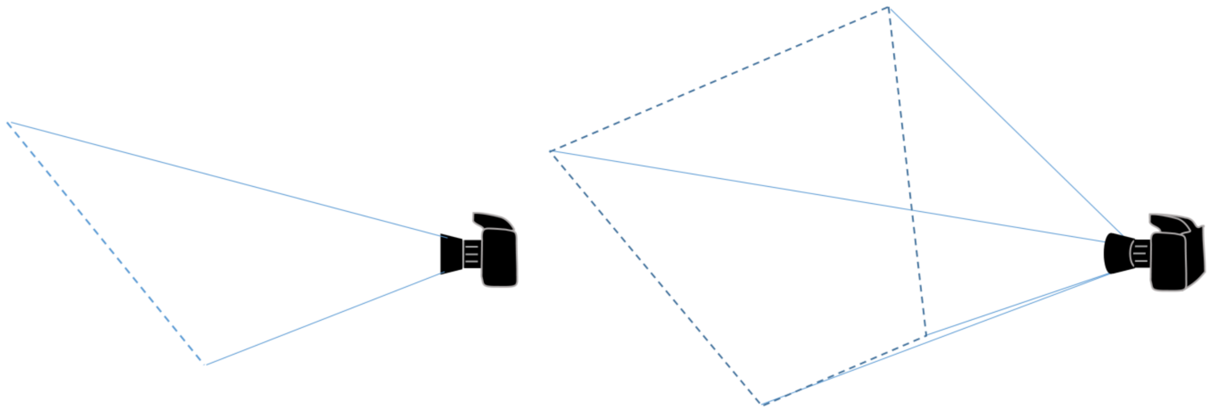


*Figure 12.6: Side view and oblique view of a camera IMPROPERLY positioned for photographing a subject material which has the bottom of the image much closer than the top of the image.*

### 12.2.1.3 Prepare for the Shot by Removing Anything that is not the Subject Material

The subject material should be cleared of tools, weeds, excessive sediment, or anything else that can be relocated but would be counted as part of the gradation by the image tool. Image Gradations yield the most accurate results when the photos are of 'clean, easily distinguishable rock,' (i.e. no vegetative growth or debris is present)

### 12.2.1.4 Higher Resolution Pictures and Multiple Images will Yield Better Results

This process will count all of the individual rocks, cobbles, and gravel that can be determined on the image. Higher resolution cameras will include smaller rocks, cobbles, and gravels and provide a finer definition of the scale. This will yield better results.

Including multiple images will include more objects which means a higher number of counts. Increasing the pebble counts will diminish the effects of inaccurate pebble counts that will be found in each image. It will also reduce any errors from one image, if there were any errors made or poor lighting conditions.

### 12.2.1.5 If Possible, Time or Locate the Shot to be in Soft Lighting

Harsh lighting comes from having a strong light source that is distant, for example daylight sun on a sunny day. This creates strong, sharp shadows. These shadows may be counted separately as a different rock. The example below shows a photograph taken under the harsh lighting of direct sunlight.

*Figure 12.7: An example of a photograph under harsh, direct sunlight*

Soft lighting comes from having a moderate light source that is close or diffused, for example daylight on a partly cloudy or cloudy day. This creates weak, soft shadows. In the case of photographing rocks, cobbles, and gravel, it leaves more of the rock visible to the image. Below is an example of a photograph taken one minute later under the soft lighting of diffused cloudy daylight.

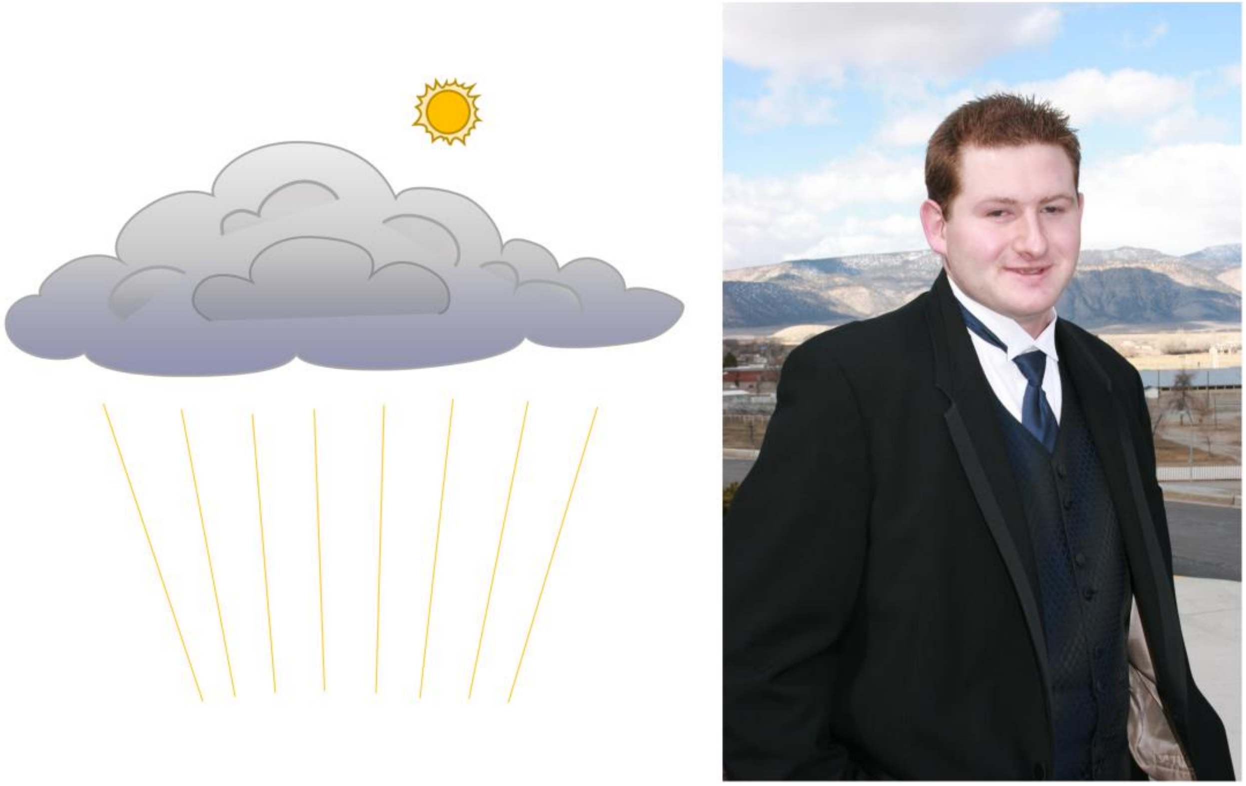
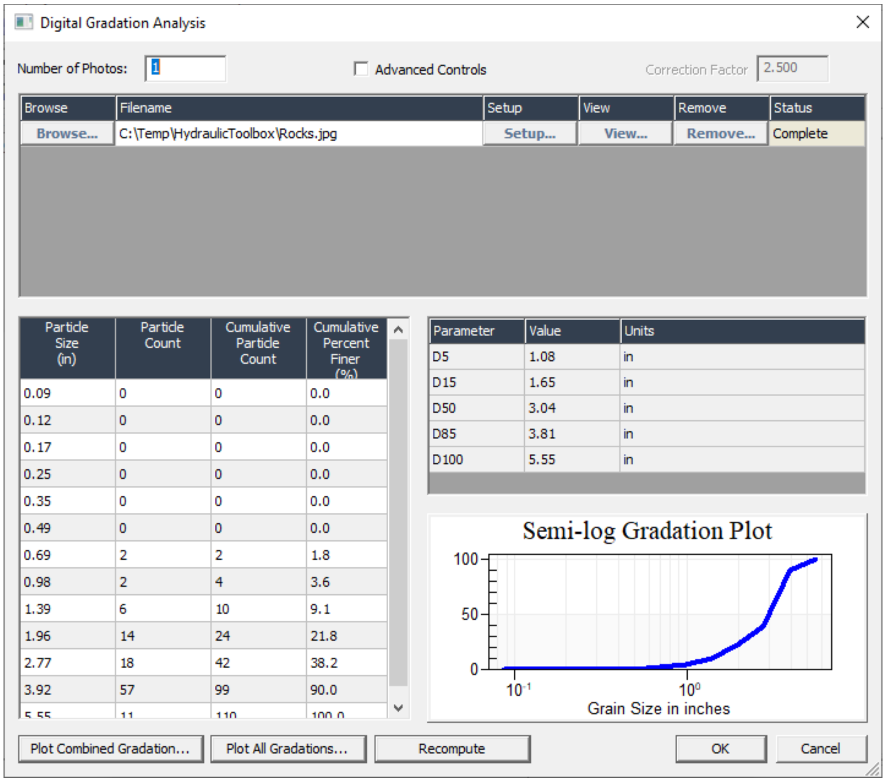


*Figure 12.8: An example of a photograph under soft, diffused cloudy daylight*

### 12.2.2 Image Gradation Interface

Upon selecting the "Add Image Gradation'" button and highlighting "Image Gradation #" in the top window, the user enters an "Image Gradation Name" and proceeds to the 'Define Image Gradations' button. Upon selecting the 'Define Image Gradations' button, in the next window the user specifies the number of digital images to use, as well as browsing and importing those images.




| Particle Size (in) | Particle Count | Cumulative Particle Count | Cumulative Percent Finer (%) |
|---|---|---|---|
| 0.09 | 0 | 0 | 0.0 |
| 0.12 | 0 | 0 | 0.0 |
| 0.17 | 0 | 0 | 0.0 |
| 0.25 | 0 | 0 | 0.0 |
| 0.35 | 0 | 0 | 0.0 |
| 0.49 | 0 | 0 | 0.0 |
| 0.69 | 2 | 2 | 1.8 |
| 0.98 | 2 | 4 | 3.6 |
| 1.39 | 6 | 10 | 9.1 |
| 1.96 | 14 | 24 | 21.8 |
| 2.77 | 18 | 42 | 38.2 |
| 3.92 | 57 | 99 | 90.0 |
| 5.55 | 11 | 110 | 100.0 |

*Figure 12.9: Digital gradation analysis window*

After importing the image(s), the user must select the 'Setup' button for each image. The Setup button will open the image with a superimposed scaling tool. Simply click the ends of this tool, one at a time, and drop them (click again) on reference points within the image that define a known dimension. For best results, the known dimension within the image should be a long line that spans the image diagonally. The designated input field in the lower left corner of the window allows the user to enter the length of this diagonal.

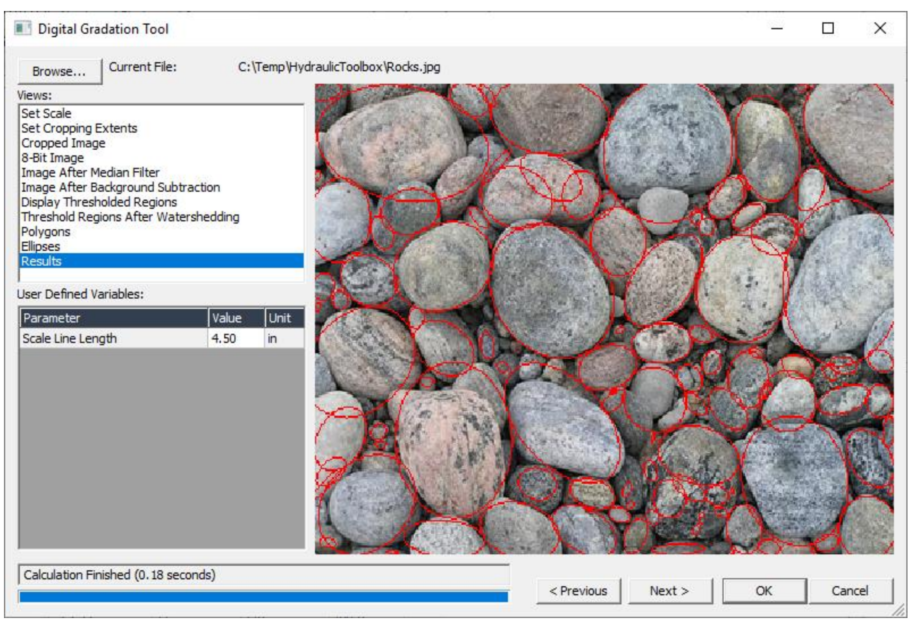



*Figure 12.10: Digital gradation tool window*

After identifying the scaling distance, the user should select 'Set Cropping Extents' from the list of 'views' located at the top left corner of the window (second view on list). This view allows the user to crop the image to exclude portions that do not represent the particles to be graded. Crop the image by clicking and holding any of the 8 tabs around the perimeter of the image. Move them as required to eliminate unwanted portions of the image, and release. After cropping the image, the user can 'click' on "Results" at the bottom of the listed views located at the top left of the window. Alternately, if the user would like to walk through each of the filtering mechanisms employed to get the final gradation results, they can click on the individual view labels and observe the resulting changes to the image.

Repeat the above procedure for each image used to define the gradation. The final gradation includes the combined gradation results for each image and the user can view it in a tabular format in the 'Define Image Gradation' window or in a graphical form by selecting the "Plot Combined Gradation" button at the bottom of the window. To view the gradation plots for the individual images, select the "Plot All Gradation" button

At the top of the 'Define Image Gradation' window (Correction Factor) and the lower left corner of the 'Setup' window are the primary analysis parameters needed to process digital images and their default values. To change the default values, check the 'Advanced Controls' box located at the top of the 'Digital Image Gradation' window. This will allow the user to change the Correction Factor, as well as other advanced controls in the lower left corner of the 'Setup' window. In addition, checking the 'Advanced Controls' box will allow the user to access and edit other 'Advanced Settings' in the 'Setup' window. Upon changing a parameter value, the Toolbox automatically repeats all the computations for all images by clicking the "Recompute" button at the bottom of the 'Define Image Gradation' window.

Caution: Unless calibrating to a known gradation or the user is familiar with the computational algorithms used in this tool and the effects of each parameter we recommend that the user not change parameter default values.

## 12.3 Standard Gradation

Upon selecting the "Add Standard Gradation" button and highlighting "Riprap #" in the top window, the Toolbox prompts the user to do the following

- Enter a Standard Gradation name
- Select a default Riprap Class or the User-Defined Class from drop-down window

To view the standard gradation information for a class in the results, select a Riprap Class from the drop-down window. Results include the upper and lower limits of $D_{15}$, $D_{50}$, $D_{85}$, and $D_{100}$ associated with the selected class. Note the calculator comes pre-loaded with the 10 FHWA standard riprap classes.

To change these standards, use the Profile Setup tool on the Toolbox main menu bar. The user can create custom control gradations by selecting the User-Defined option which will allow entry of gradation data and necessary editing. The user can now view the individual standard class plot by selecting the "Plot Gradation" button, or view all available gradation information (previously input counts and/or controls) on a single plot by selecting the "Plot All Gradation Curves" button.

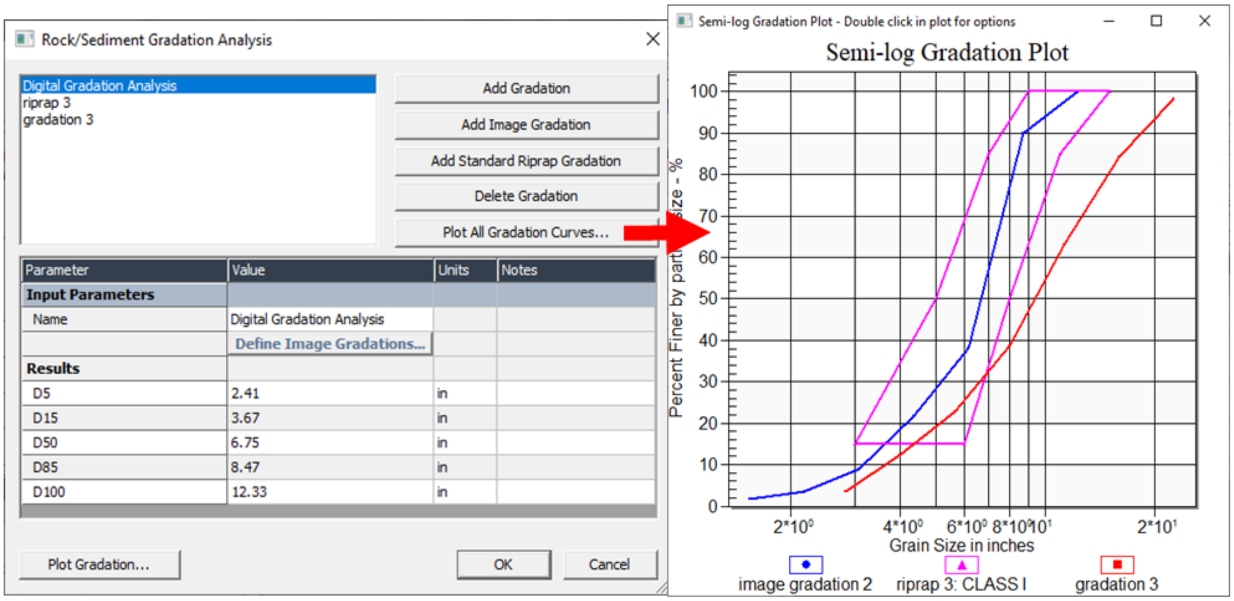



*Figure 12.11: Completed rock/sediment gradation analysis with gradation curve comparison plots*

# 13 Median/Ditch Drop-Inlet Calculator

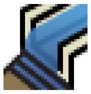


*Figure 13.1: Median/Ditch Drop-Inlet Calculator icon*

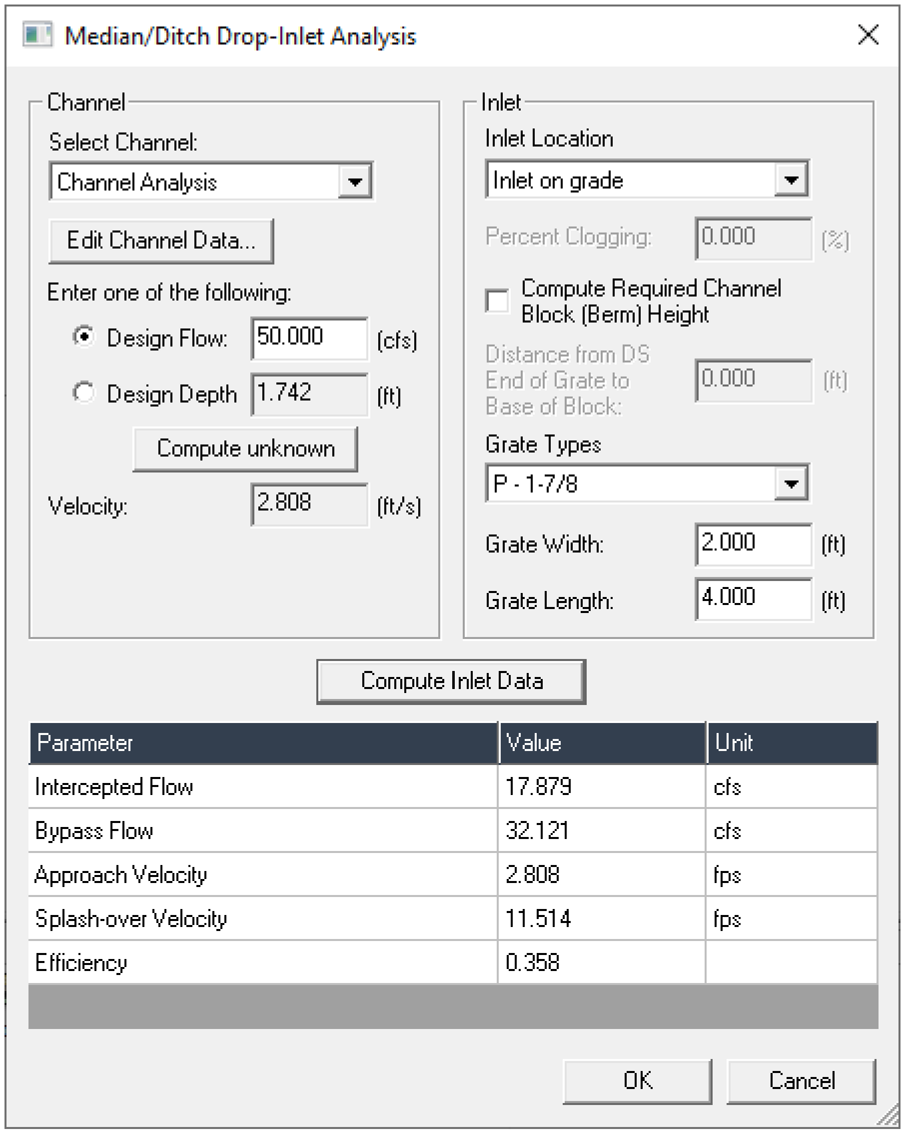



*Figure 13.2: Median/ditch drop-inlet calculator*

The **Median/Ditch Drop-Inlet Calculator** computes the amount of flow captured and by-passed by a typical drop-inlet placed in the bottom of median, roadside, or similar ditch. Upon opening the calculator, the Toolbox asks the user to select a channel in the upper left window. After making a channel selection, select the "Edit Channel Data" button to open the Channel Calculator and enter new data or review previous input data. Upon closing the **Channel Calculator**, the Toolbox reports the design discharge, depth, and velocity for the channel in the upper left channel window. If the configuration of the chosen channel is satisfactory, the user can edit the input discharge or depth directly from the channel window without re-opening the **Channel Calculator**.

Using the options presented in the upper right window, the designer selects the specific inlet configuration. Similar to the **Curb and Gutter Calculator**, the user must first specify whether the inlet is located on-grade, or in a sag. If on-grade, the user can further specify a 'channel block' if desired down-stream of the inlet. If the designer specifies an on-grade block or a sag location, there is an option to enter a "percent clogged" for the grate. Entering a percentage reduces both the open area and the perimeter of the selected grate accordingly.

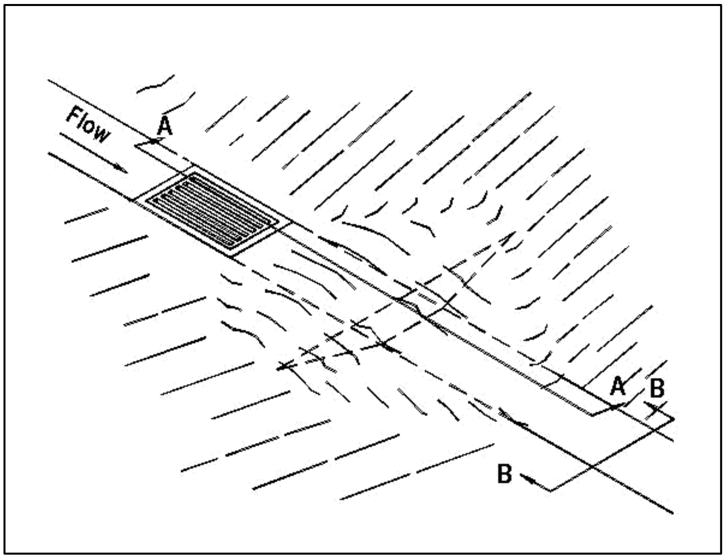



*Figure 13.3: Median drop inlet, from FHWA HEC 22, "Urban Drainage Design Manual"*

For on-grade applications, if the designer checks the 'Compute required channel block height' box for an on-grade application, the Toolbox asks the user to specify the distance from the downstream end of the grate to the block "base." (The default value of '0' indicates that the base of the block is located immediately at the downstream end of the grate.) This is an important input since the height of the channel block required to capture 100% of the flow increases with distance downstream, when the grate is operating under either weir or orifice control. Furthermore, the computed "Minimum Block Height" is the greater of weir or orifice flow depth at the block and the specific energy of the approach flow. Specific energy is an important check when the grate is narrower than the channel bottom and the channel slope is steep.

The user is next asked to specify the grate type and dimensions. Once specified, the user selects the "Compute Inlet Data" button located above the bottom window and the calculator will report the analysis results. For on-grade applications without a channel block, the calculator reports the following results:

- Intercepted Flow
- Bypass Flow
- Approach Velocity
- Splash-over Velocity
- Efficiency
- For in-sag applications, the Toolbox reports the following
- Results:
- Effective Perimeter (accounts for clogging)
- Effective Area (accounts for clogging)
- Depth at center of grate
- Top width at center of grate
- Flow Type (Weir or Orifice)
- Efficiency

Refer to HEC 22, Chapter 4.4.7 for more information on Median Inlets:

**Brown, S.A., Schall, J.D., Morris, J.L., Doherty, C.L., Stein, S.M., Warner, J.C., September 2009, Urban Drainage Design Manual, Hydraulic Engineering Circular 22, Third Edition, FHWA-NHI-10-009, HEC 22.**

# 14 Culvert Assessment Calculator

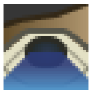


*Figure 14.1: Culvert Assessment Calculator icon*

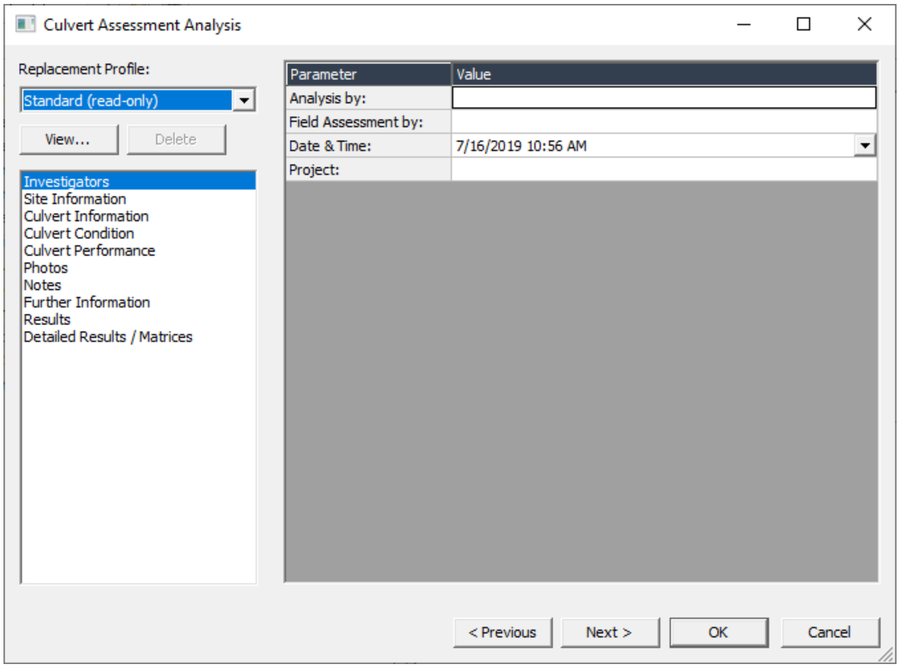



*Figure 14.2: Culvert assessment calculator*

The **Culvert Assessment Calculator** is a project-level tool that identifies suggested culvert rehabilitation, repair, and replacement methods based on the findings of field assessments conducted in accordance with FHWA's Culvert Assessment and Decision-Making Procedures. The methods included range from various types of linings to various replacement techniques. The **FHWA-CFL/TD-10-005 publication dated September 2010**, defines the assessment parameters and rating criteria, as well as the criteria governing rehabilitation, repair, or replacement.

The reference for this manual is as follows. It is not readily available in FHWA's hydraulic document repository, but may be available by doing an internet search:

**Hunt, J.H., Zerges, S.M., Roberts, B.C., Bergendahl, B., Culvert Assessment Decision Making Procedures, FHWA-CFL/TD-10-005, September 2010.**

Upon opening the calculator, a wizard along the left side of the window contains a list of 10 data types for the user to complete. After completing the list, the Toolbox generates the final recommendation(s) for a culvert rehabilitation, repair, or replacement. Upon selecting (clicking) an item in the list, a window containing a number of input fields will open. Typically, to generate final results, fill in all fields.

Above this list, a drop-down window contains the **Replacement Profiles** that are available for use in determining whether a culvert replacement is the most appropriate choice. To view the specific criteria for each profile, select the profile name in the drop-down window and click the view button. Use the 'Profile Setup' tool on the Toolbox main menu bar to change the number of profiles and their specific criteria.

The label **Investigators** is first data type in the wizard list. The associated input window allows the user to record their name as the person performing the analysis, as well as enter the name of the person who conducted the culvert field assessment. In addition, enter the analysis date and project identification in their respective fields.

The second data type is culvert **Site Information**. To analyze a specific culvert, the associated window asks for location metadata. Enter all requested information to provide a complete record.

The third data type is specific **Culvert Information** for the culvert analysis. The input window consists of two parts. The first part contains the 'Culvert Parameters' or the physical characteristics of the culvert such as number of barrels, shape, size, material, etc. The second part contains information on 'Appurtenances Parameters' such as end treatments present, aquatic organism passage features, historic features, utilities, etc. All parameters with limited choices have associated drop-down windows.

The fourth data type covers the field assessment results on **Culvert Condition** of the barrel and appurtenant structures such as headwalls and end sections. Example barrel parameters include condition of the invert and pipe joints. All parameters have limited rating choices consistent with those described in the FHWA procedures manual, i.e. Good, Fair, Poor, Critical, Unknown, or Not Applicable. The available choices are in drop-down windows for each parameter.

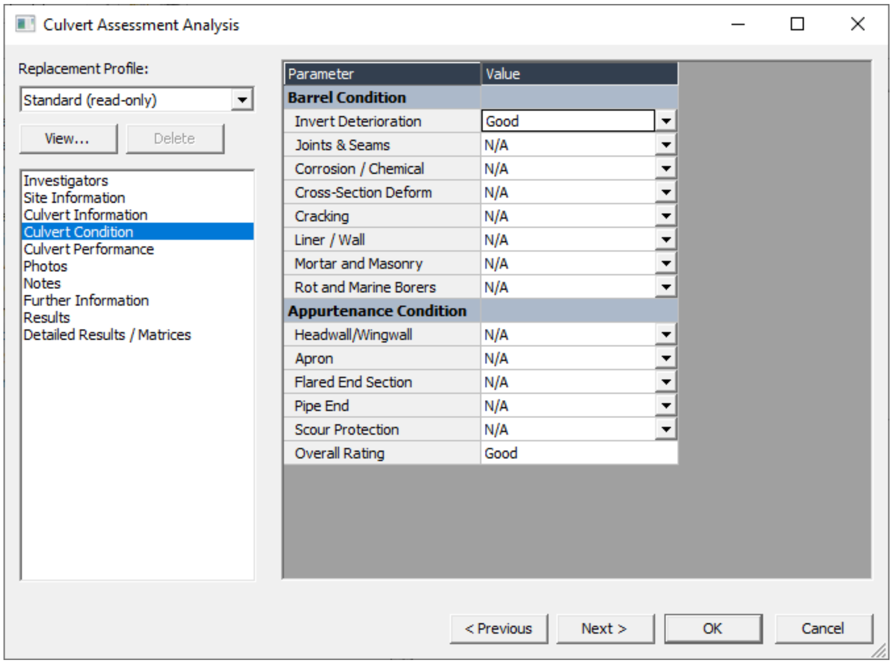



*Figure 14.3: Culvert assessment calculator-defining the culvert condition*

The fifth data type requires entry of the field assessment results of the **Culvert Performance.** The two main performance categories covered are: those requiring a Level 1 action, and those requiring a Level 2 action. (A Level 1 action is routine, while a Level 2 action requires some sort of special assistance.) Each category identifies the specific performance problems that would trigger an associated action. Check each performance problem if it is present at the site, or leave unchecked if it is not present. The FHWA procedures manual provides a description of the listed performance categories and problems.

Data Types 6 and 7 allow importing applicable **Photos** and appropriate **Notes** into the Toolbox file, respectively. The final recommendations do not require these two data types, but the user should complete them, as needed, to provide a complete record.

**Data Type 8 is Further Information**. Further information gathers additional questions and answers that generate final recommendations. The number and specific nature of the questions depend upon all previous input. All questions have limited responses provided via drop-down windows. If the Calculator requires no further information, a 'Results Complete' message will appear.

Data Type 9 is **Results.** When applicable, the Toolbox lists important notes related to the recommended rehab or repair. To read these notes, click the associated 'View' button.

Data Type 10 is **Detailed Results / Matrices**. When selected, a window appears that reveals a summary of previous input questions along with the responses provided and any applicable notes. In addition, the name(s) of matrices containing the specific recommended rehabilitation, repair, or replacement method(s) appear as a 'sub-list' below the data type label on the left side of the window.

Upon clicking on a specific matrix name in the sub-list, that matrix will appear and highlight the recommended method(s) in bold font along with applicable facts, limitations, and cautions that will assist the user in making a final decision regarding the rehabilitation, repair, or replacement.

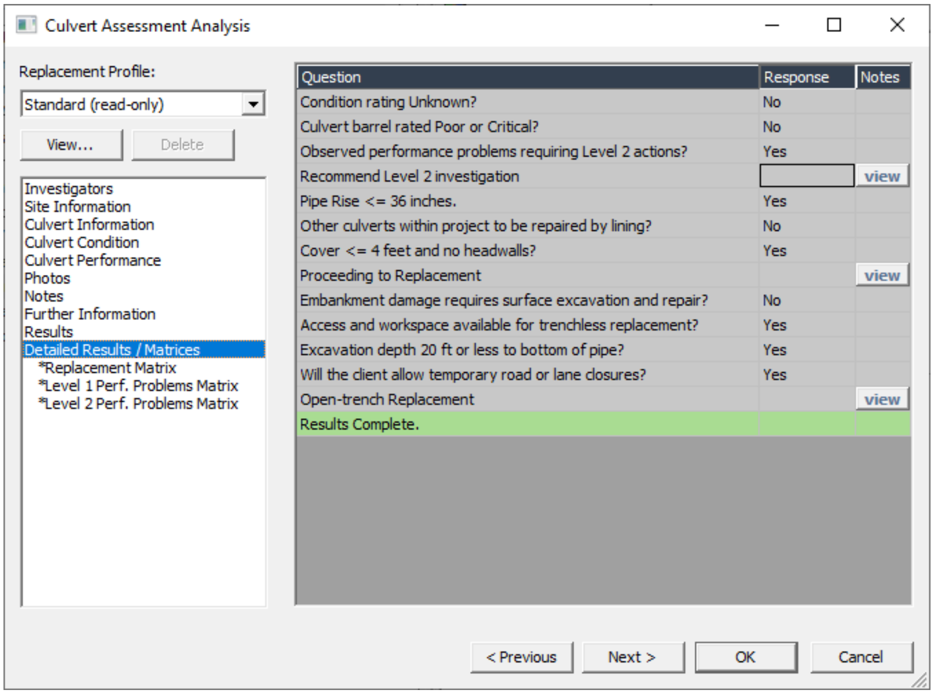



*Figure 14.4: Culvert assessment calculator-detailed results*

# 15 Bridge Scour Calculator

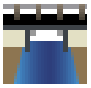


*Figure 15.1: Bridge Scour Calculator icon*

## 15.1 Bridge Scour

A bridge crossing will generally consist of the following elements: a bridge deck, left and right abutments, and optionally piers.

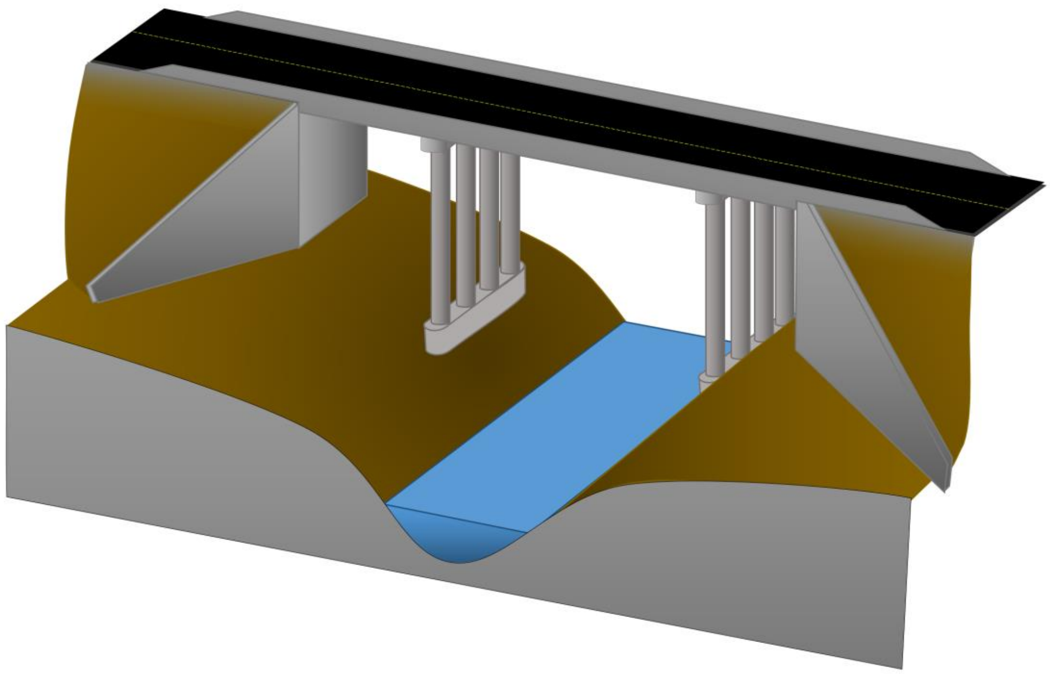


*Figure 15.2: Conceptual drawing of a bridge crossing*

Hydraulic Toolbox will not compute hydraulic parameters of the bridge, but will predict the scour that will take place from hydraulic parameters determined from another model, like HEC-RAS or SRH2D.

### 15.1.1 Main Channel Definition

Some parameters will be able to be calculated from this model, while some parameters will rely on engineering judgement.

First the engineer will need to determine the banks of the main channel of the stream approaching and passing through the bridge crossing. A generalized cross section of a stream at a bridge crossing will show a main channel lowest point of the cross section, with banks on either side where there is an inflection point in the curvature of the cross section. Floodplains will rise from both sides of the banks to meet the terrain surrounding the stream. The floodplains are also commonly referred to as the overbank area. An example of a symmetrical, straight flowing stream is given below. It is not intended as an example of how or where to define the banks of a channel, nor to represent natural streamflow.

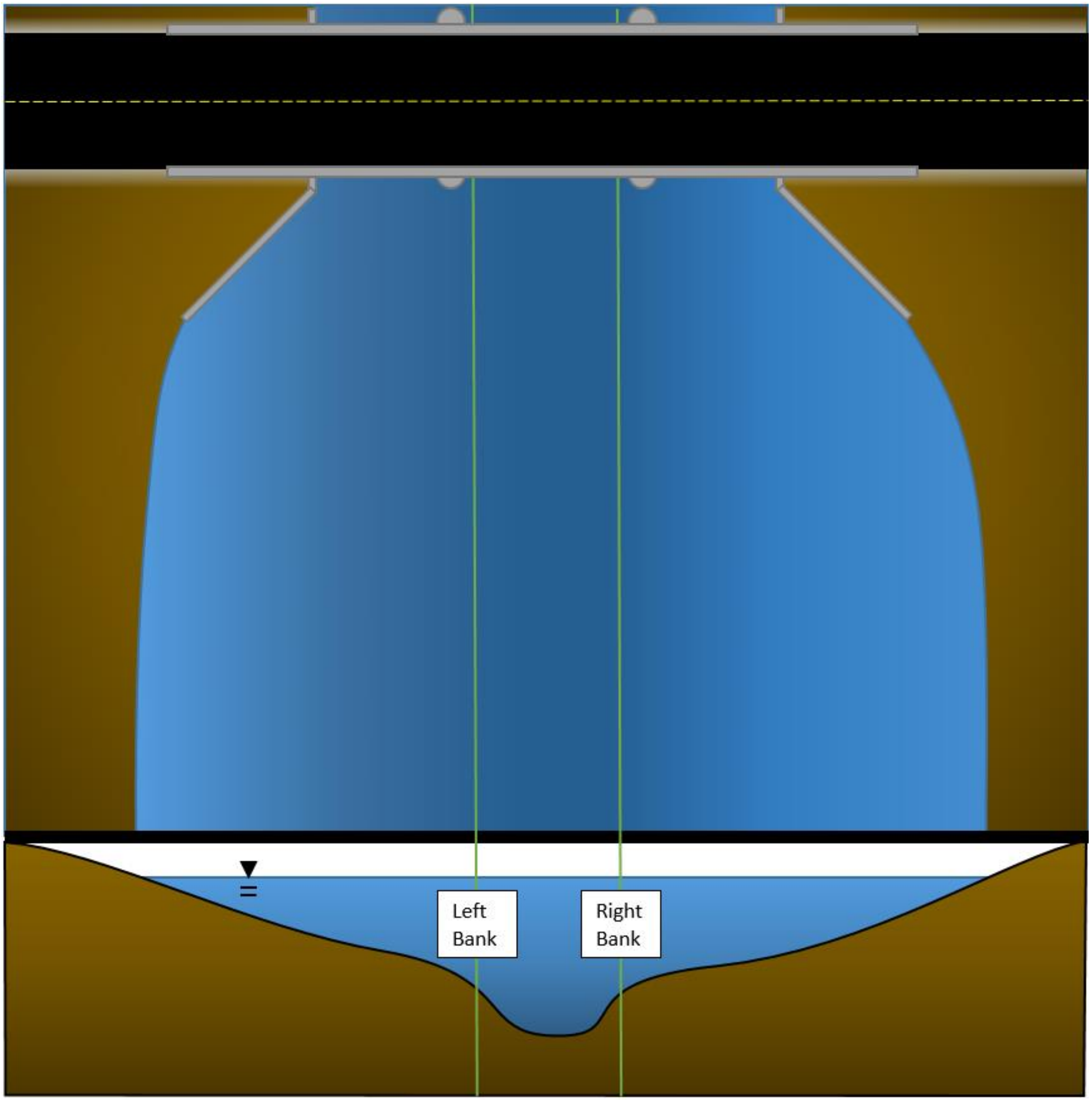



*Figure 15.3: An example of defining a main channel in a symmetrical, straight flowing stream flowing into a bridge crossing. This is not intended as an example of where or how to define the main channel banks*

The engineer will need to determine if the main channel is able to migrate across the floodplain. Over time, the main channel may shift its location as shown in the figures below. If the channel migrates to a pier that was once on the floodplain, the pier will be eroded down to the level of the thalweg of the channel. For this reason, the engineer needs to determine if the channel is confined to its current location or how far it is likely able to migrate during the design life of the bridge.

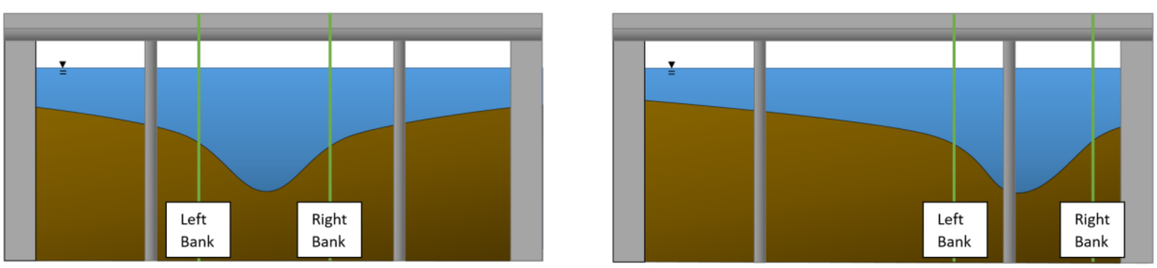



*Figure 15.4: Channel migration shown in bridge cross section*

## 15.1.2 Bridge Scour Components

Bridge Scour is computed in the following components:

- Long-term degradation
- Contraction Scour
- Pier Scour
- Abutment Scour

Hydraulic Toolbox will compute these scour components individually and then combine these components into a complete bridge scour computation. If the user specifies geometric data, Hydraulic Toolbox will also plot them.

### 15.1.2.1 Long-term Degradation

Long-term degradation is the degrading of the stream over long periods of time as opposed to a single event. The engineer needs to determine the change in the stream that may occur during the life of the bridge.

Long-term degradation, as applied in Hydraulic Toolbox, will uniformly lower the streambed elevations within the main channel as shown in the figure below.

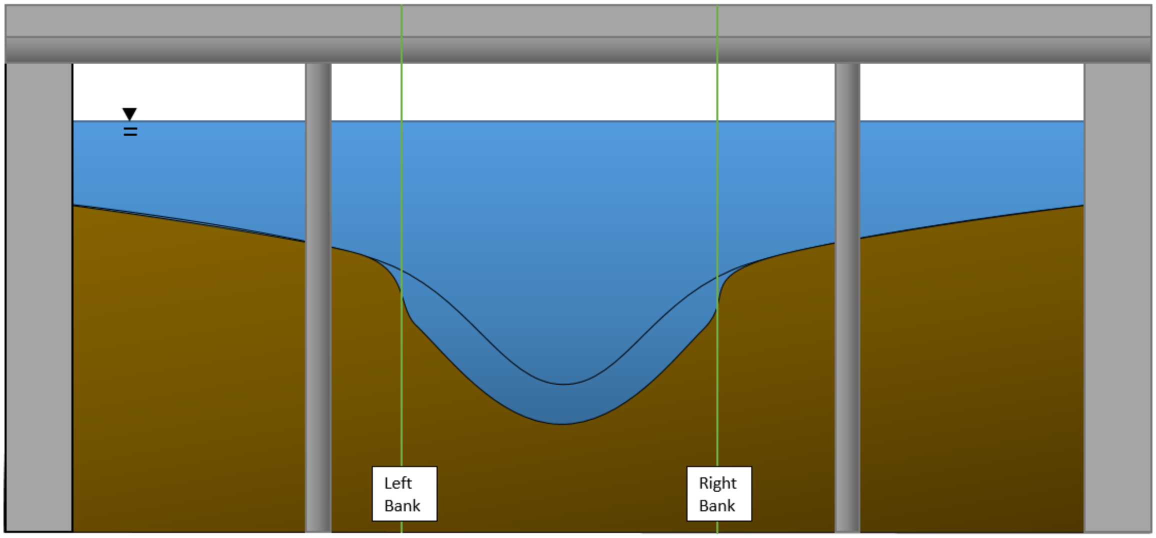



*Figure 15.5: Bridge cross section with long-term degradation*

Hydraulic Toolbox uses the following methods to determine long-term degradation:

- Controlled by armoring
- Controlled by equilibrium slope
- User-specified scour depth

### 15.1.2.2 Contraction Scour

Contraction scour results from the unconfined stream being constricted as it flows through the bridge crossing. The bridge section will constrict the flow horizontally and if the flow reaches the low chords of the bridge, it will pressurize and constrict the flow vertically.

Contraction scour is specified across the entire cross section or in the main channel, left overbank area, and right overbank area. Hydraulic Toolbox will apply the contraction scour uniformly across the specified area, while it may not have a uniform depth as it occurs in the field. An example of contraction scour applied to a bridge cross section with a higher main channel scour depth is shown in the figure below.

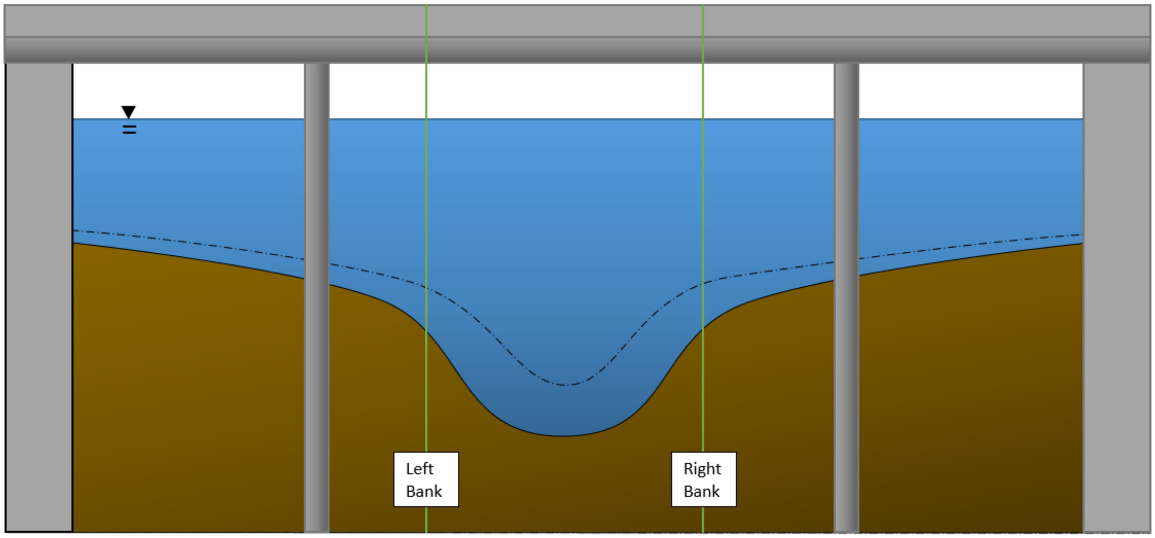



*Figure 15.6: Bridge cross section with an equal contraction scour depth applied to the left and right overbanks and a greater contraction scour depth applied to the main channel*

Hydraulic Toolbox uses the following methods to determine contraction scour:

- Clear-water or live-bed scour
- Clear-water and live-bed scour
- Pressure flow (or vertical contraction)
- Cohesive soils

### 15.1.2.3 Pier Scour

As streamflow passes piers, it causes turbulence in the water. The turbulence increases scour immediately surrounding and following the pier.

Hydraulic Toolbox has an option called the scour reference location which is the elevation that the scour depth is measured from. It can be measured from the streambed local to the pier or to the thalweg of the main channel. This decision should remain consistent with the probability of the main channel to migrate to the pier.

The engineer will need to decide whether to use main channel hydraulics or local hydraulics just upstream of the pier. This decision should be consistent with the probability of the main channel to migrate to the pier.

The angle of attack of flow on the pier could be selected as the flow local to the pier or the channel flow relative to the bridge crossing. Engineering judgement should be used to determine the governing case.

Hydraulic Toolbox applies pier scour as a scour hole with a bottom width equal to the pier width. The top width of the pier scour hole is determined using a specified angle of repose. An example of two pier scour holes is shown in the figure below. The left pier scour hole is generated with a local scour reference location and the right pier scour hole is generated with a thalweg scour reference.

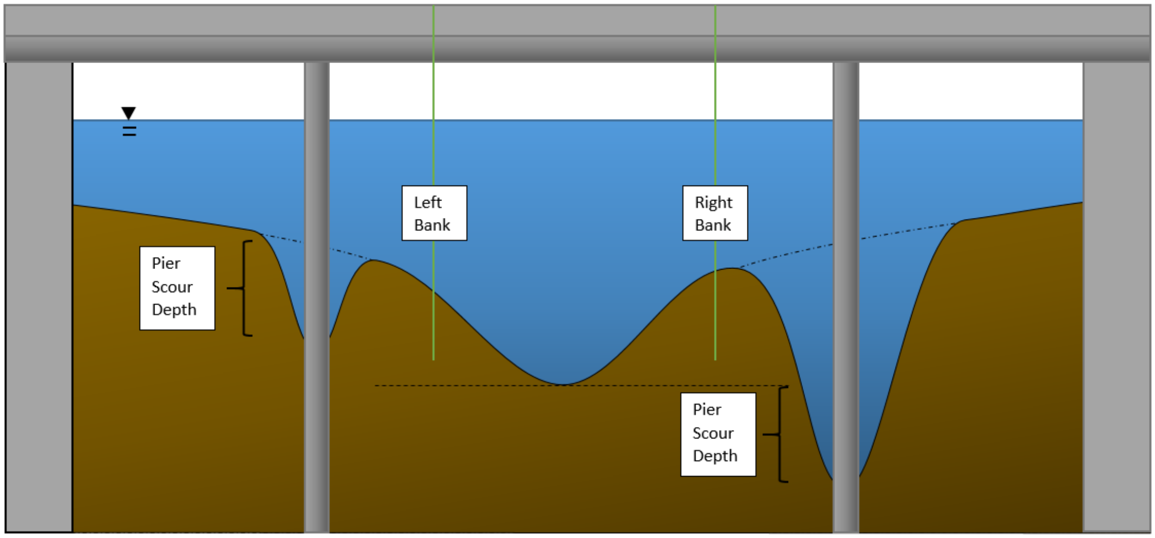



*Figure 15.7: Bridge cross section with two equal depth pier scour holes applied. The left pier scour hole is generated with a local scour reference location and the right pier scour hole is generated with a thalweg scour reference location*

Hydraulic Toolbox uses the following methods to determine contraction scour:

- Complex Piers
- HEC-18
- Florida DOT
- Coarse Bed
- Cohesive Materials

### 15.1.2.4 Abutment Scour

The stream flows from unconstructed channel to the constricted channel between the abutments of the bridge crossings. This intensifies the contraction scour that occurs near the abutments.

If the NCHRP method is selected, the engineer will need to make the engineering judgement of whether the channel can migrate to the abutment and therefore use scour condition A (main channel hydraulics) or use scour condition B (overbank hydraulics). This method will compute the flow depth that will be created by scour, meaning that the scour is measured from the water surface as opposed to a scour hole measured from the existing streambed.

Hydraulic Toolbox applies the abutment scour as a scour hole without width at the bottom. The top width of the pier scour hole is determined using a specified angle of repose. The example below shows an abutment scour being applied to a bridge cross section.

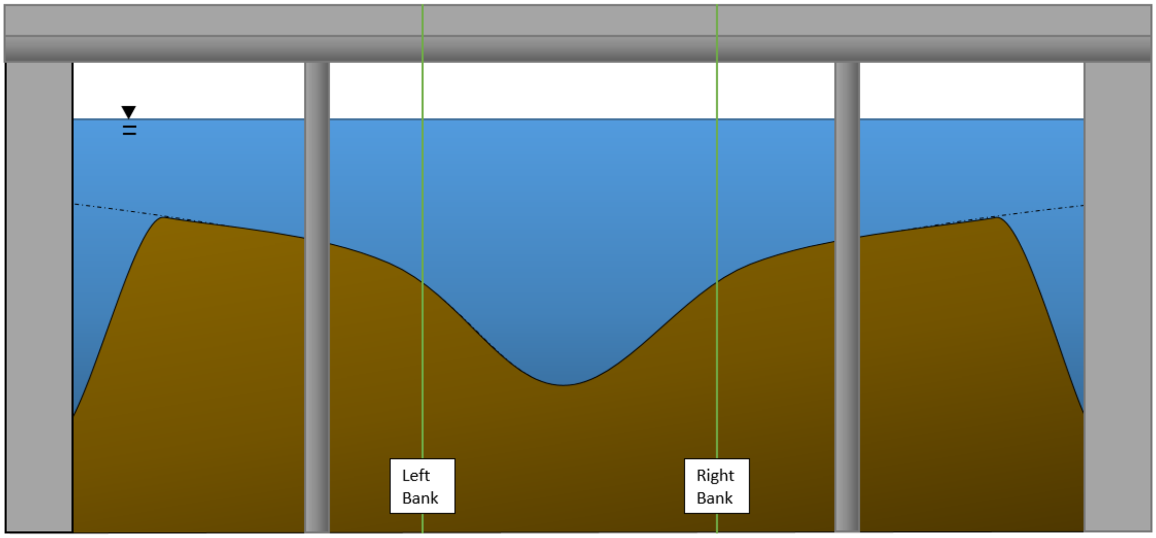



*Figure 15.8: Bridge cross section with abutment scour holes applied*

Hydraulic Toolbox uses the following methods to determine contraction scour:

- Froelich's
- HIRE
- NCHRP

### 15.1.3 Bridge Scour Variable Measurements

Hydraulic toolbox will generally refer to variables that come from upstream of the crossing and variables included in the constricted cross section. The constricted cross section is within the bridge crossing, similar to the centerline of the highway. The upstream cross section is from a cross section that is placed far enough upstream that it is not influenced by the bridge crossing. One method to determine this distance is to look at the flow patterns. As the flow approaches the bridge crossing, the flow will converge. The upstream cross section should be upstream of the point where the flow begins converging together. The figure below shows a bridge crossing with arrows representing flow direction at different locations in the approaching stream with a red line representing where the upstream cross section could be placed.

Note that some variables will be measured across the entire section of a cross-section and other variables will be measured across only the main channel of the cross-section.

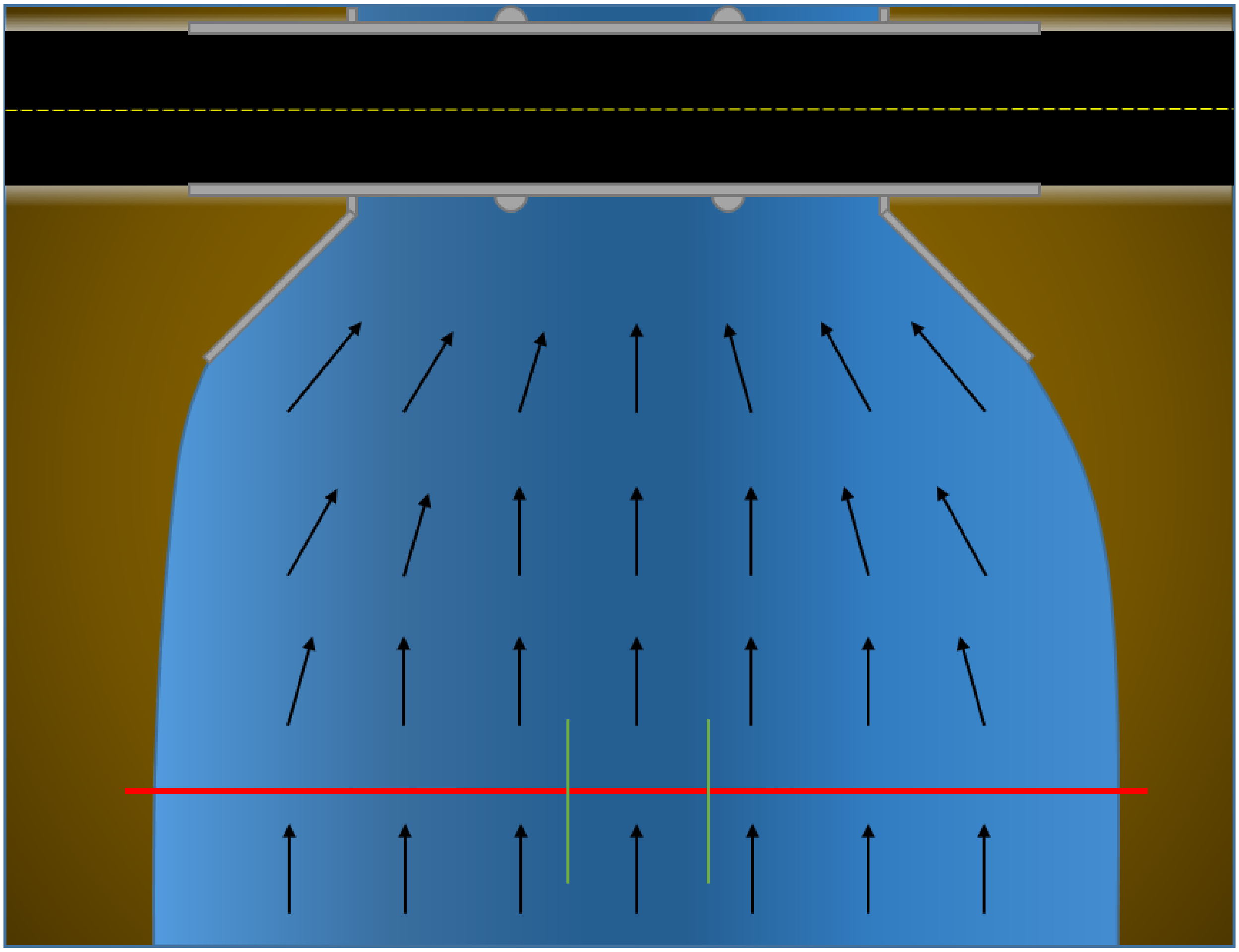


*Figure 15.9: A bridge crossing with arrows representing flow direction at different locations in the approaching stream with a red line representing where the upstream cross section could be placed*

In similar fashion, if the engineer has decided to use local hydraulic parameters for a pier, make these measurements directly upstream of the pier but outside of its influence. The flow will diverge as it approaches the pier. The measurements should be taken upstream of this divergence. The angle of attack on the pier for local hydraulics should be measured as the approach angle of the flow on the pier. The figure below shows the diverging flow and an angle of attack measurement.

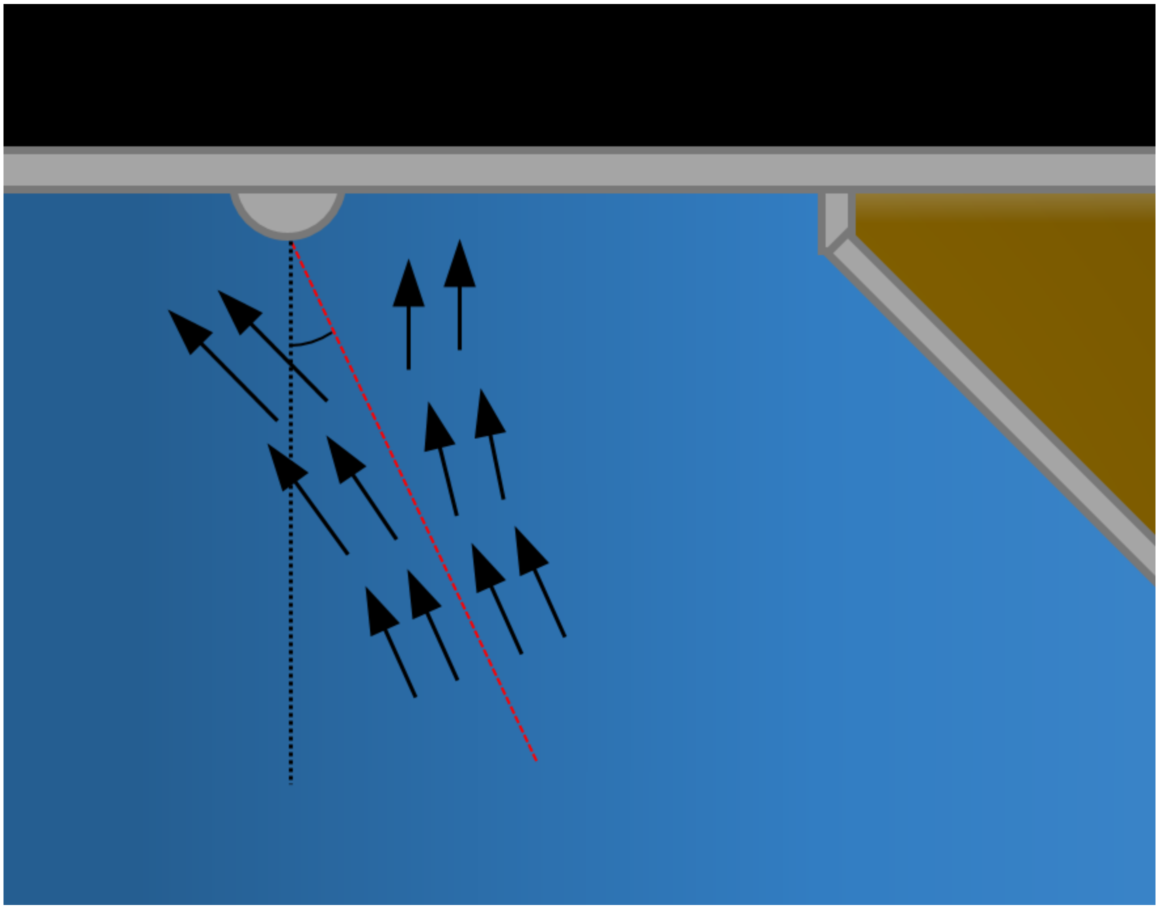


*Figure 15.10: Local flow diverging as it approaches a pier. The angle of attack is measured using the approaching flowline in a red, dotted line*

### 15.1.4 Multiple Scenarios

Hydraulic Toolbox allows the user to use multiple scenarios or multiple flood events. This allows the user to specify geometry once, but different hydraulic parameters and easily compare the results.

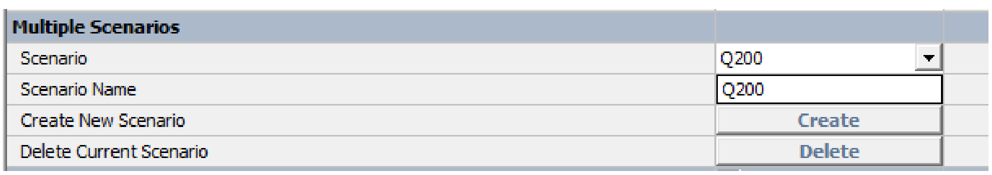
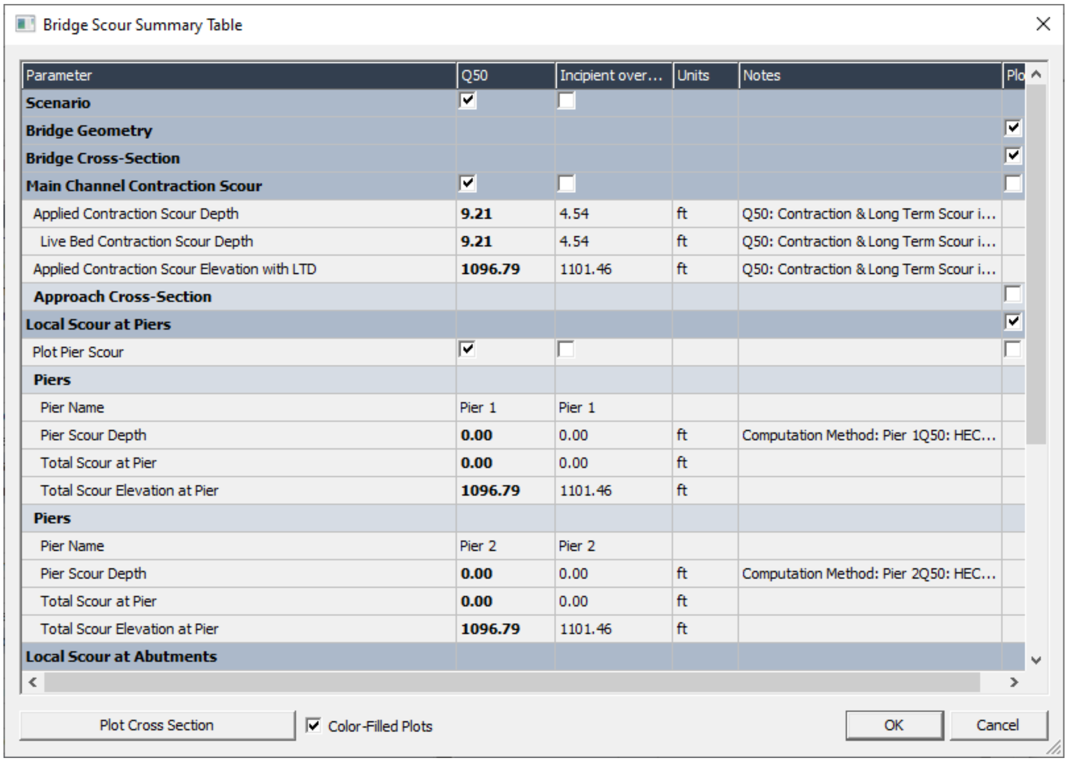



*Figure 15.11: Interface for managing and editing multiple scenarios*

To create a new scenario, click the 'Create' button. To select a scenario, use the combo box. To rename the scenario, edit the name in the 'Scenario Name' row. To delete the scenario that is currently selected, click 'Delete'.

To view the values of the multiple scenarios together, see the Scour Summary Table.

## 15.2 Bridge Scour Calculator




| Parameter | Q50 | Incipient over… | Units | Notes | Plo |
|---|---|---|---|---|---|
| **Scenario** | ☑ | ☐ | | | |
| **Bridge Geometry** | | | | | ☑ |
| **Bridge Cross-Section** | | | | | ☑ |
| **Main Channel Contraction Scour** | ☑ | ☐ | | | ☐ |
| Applied Contraction Scour Depth | **9.21** | 4.54 | ft | Q50: Contraction & Long Term Scour i… | |
| Live Bed Contraction Scour Depth | **9.21** | 4.54 | ft | Q50: Contraction & Long Term Scour i… | |
| Applied Contraction Scour Elevation with LTD | **1096.79** | 1101.46 | ft | Q50: Contraction & Long Term Scour i… | |
| **Approach Cross-Section** | | | | | ☐ |
| **Local Scour at Piers** | | | | | ☑ |
| Plot Pier Scour | ☑ | ☐ | | | ☐ |
| **Piers** | | | | | |
| Pier Name | Pier 1 | Pier 1 | | | |
| Pier Scour Depth | **0.00** | 0.00 | ft | Computation Method: Pier 1Q50: HEC… | |
| Total Scour at Pier | **0.00** | 0.00 | ft | | |
| Total Scour Elevation at Pier | **1096.79** | 1101.46 | ft | | |
| **Piers** | | | | | |
| Pier Name | Pier 2 | Pier 2 | | | |
| Pier Scour Depth | **0.00** | 0.00 | ft | Computation Method: Pier 2Q50: HEC… | |
| Total Scour at Pier | **0.00** | 0.00 | ft | | |
| Total Scour Elevation at Pier | **1096.79** | 1101.46 | ft | | |
| **Local Scour at Abutments** | | | | | |

*Figure 15.12: Bridge scour calculator*

The **Bridge Scour Calculator** tool evaluates, displays, and compares common scour computations at a bridge location. The tool does not perform hydraulic computations, but requires that these computations are performed by an external model, like HEC-RAS or SRH-2D. The tool will import geometry from existing HEC-RAS models or from SMS SRH-2D hydraulic models to use with updated equations in FHWA published documents. It handles multiple flow scenarios at the same bridge crossing to minimize data entry and facilitate comparison. It evaluates scour by determining 4 scour components that are commonly applicable to bridge foundation design. The 4 scour components are:

- Abutment Scour
- Contraction Scour
- Long-Term Degradation
- Pier Scour

Depending on the structure(s) at the location and the components required for the scour evaluation of the structure(s), the user will turn these components on or off with checkboxes in the main Bridge Scour data entry window. The Toolbox combines these components together into one project scour solution for each scenario. The user can then compare scenarios in a table or plot.

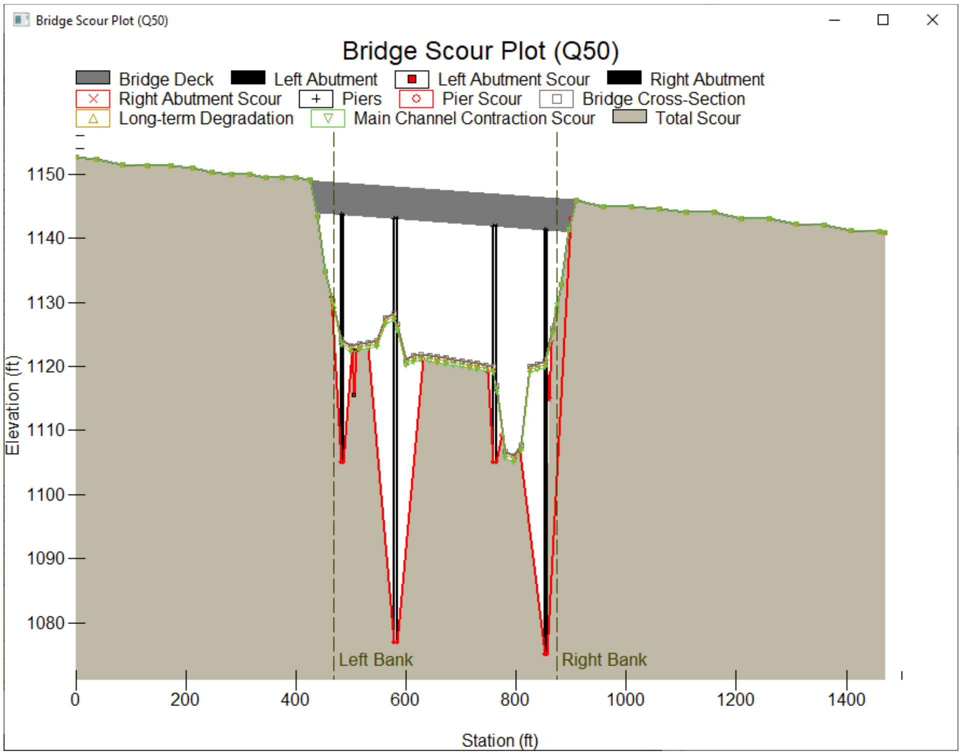



*Figure 15.13: Bridge scour plot*

Described below, multiple methods are available for evaluating each of the above scour components. The user decides which methodology is most appropriate for a given application. FHWA publications HEC 18 and 20 contain detailed descriptions of all the methods used to evaluate the above 5 scour components.

Upon selecting a specific scour component and methodology from the two drop-down windows at the top of the opening dialogue, the associated data screen will appear below. The user must then fill all required data fields. After entry of all data, the Toolbox will show the scour depth, along with other useful data, for the selected methodology.

For comparison and when appropriate, the Toolbox provides an option to view the results of all methodologies simultaneously for a particular scour component. When available, the Toolbox provides this option in the 'Computation Method' drop-down window.

Description of the governing equation, unique Input Parameters, and results for each scour methodology are below by scour component category.

The **Enable Scour Plot Options** allows the user to turn on the geometry options. This enables import from HEC-RAS or SRH-2D, approach and bridge cross-sections, bridge deck geometry, abutment geometry, pier geometry, and plotting. The options shown are the only available options for the enabled components.

The **Multiple Scenarios** options allow the user to specify different flow conditions and parameters with the same geometry. The user can select the current scenario in the Scenario combo box. Descriptions of all scenarios shown in the Bridge Scour Summary Table are below.

The **Bridge Scour Summary Table** has a column for each scenario and the results of enabled scour components along the rows of the table. The largest scour value of the scenario for each component is bolded. This table also allows the user to customize their plot by selecting or unselecting geometries or scour computations.

The **Bridge Scour Plot** displays the bridge deck, piers, abutments, and the cross-section with the results from scour components. The Toolbox applies the long-term degradation across the main channel and applies the contraction scour to the overbanks and main channel as specified. The Toolbox then applies pier scour and abutment scour as scour holes at the specified locations.

Further details about the methods used in the bridge scour calculator are located in the following references:

**Arneson, L.A., Zevenbergen, L.W., Lagasse, P.F., Clopper, P.E., April 2012, Evaluating Scour At Bridges, Hydraulic Engineering Circular No. 18, Fifth Edition, FHWA-HIF-12-003, HEC 18.**

http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=17&id=151

**Lagasse, P.F., Zevenbergen, L.W., Spitz, W.J.., Arneson, L.A., April 2012, Stream Stability at Highway Structures, Hydraulic Engineering Circular No. 20, Fourth Edition, FHWA-HIF-12-004, HEC 20.**

https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=19&id=152

## 15.3 Bridge Scour Calculator—Long-Term Degradation

The limit of long-term degradation at a given channel location is typically the lesser of depth-to-armoring and depth-to-equilibrium slope for the dominate discharge. If this discharge is unknown, commonly the bank full discharge provides a reasonable estimate.

The computations for long term degradation are Controlled by Armoring, Controlled by Equilibrium Slope, and User-Specified Scour Depth.

### 15.3.1 Armoring

The Toolbox uses the Shield's criterion for incipient motion to identify the sediment size not transported (critical sediment size), and the US Bureau of Reclamation (USBR) armoring equation to estimate the depth-to-armoring for that critical sediment size. The Shield's criterion for incipient motion is:

$$D_c = \frac{\tau_0}{K_s(\gamma_s - \gamma)} \qquad \textit{(HEC 20, Equation 6.13)}$$

The USBR equation for estimating depth-to-armoring is:

$$Y_s = y_a\left(\frac{1}{P_c} - 1\right) \qquad \textit{(HEC 20, Equation 6.16)}$$

These equations represent clear-water conditions, i.e. no sediment supplied from upstream.

The thickness of the armor layer ranges from one to three times the critical size (Dc) determined from the Shields incipient motion relation. A relatively stable armor layer requires a minimum of 2 times the critical size. See HEC 20, page 6-28 for more information.

The following required Input Parameters to compute depth-to-armoring are:

- Shields' parameter
- Flow depth or hydraulic radius
- Average Channel velocity
- Sand bed – Manning's 'n'
- Unit weight of water, lb/ft$^3$
- Unit weight of sediment, lb/ft$^3$
- Coarse bed – $D_{84}$
- Armor Thickness Factor
- Percentage of gradation coarser than the critical size
- The following reported results for depth-to-armoring are:
- Critical sediment size, ft
- Depth to armoring, ft

- Armoring thickness, ft

### 15.3.2 Equilibrium Slope

The Toolbox contains 4 methods for estimating equilibrium slope. Two of them are for no upstream sediment supply (Shields' criterion for incipient motion and Meyer-Peter, Muller equation for the beginning of transport), one is for transport capacity being equal to sediment supply, and one is for a reduction in sediment supply. The latter two methods are based on a power function fitted to Yang's transport equation for sand-bed streams. Provided below is the equation for Shields' criterion and no sediment supply:

$$S_{eq} = \left[K_s D_c \left(\frac{\gamma_s-\gamma}{\gamma}\right)\right]^{(10/7)} \left(\frac{K_u}{qn}\right)^{6/7} \qquad \textit{(HEC 20, Equation 6.17)}$$

The equation assumes that the channel width remains constant for future conditions. The critical size ($D_c$) used in this equation should be $D_{90}$ because the bed will coarsen as degradation occurs. Reference HEC 20 for more detailed information on these methods.

After computing the equilibrium slope, use the following equation to determine the degradation at a given location relative to a downstream control point (i.e. location of erosion resistant material or a reach that is in equilibrium):

As an example, the following required Input Parameters to compute long-term degradation using the Shields' criterion for equilibrium slope are:

- $D_{90}$ sediment particle size, ft
- Shields' parameter
- Manning's n-value
- Unit discharge, $ft^3$/sec /ft
- Current slope, ft/ft
- Distance from base level control to point of interest, ft

The following are example results reported for computing long-term degradation using the Shields' criterion for equilibrium slope:

- Equilibrium slope, ft/ft
- Amount of degradation at point of interest, ft

## 15.4 Bridge Scour Calculator—Contraction Scour

The available methodologies for estimating bridge **Contraction Scour** are **Laursen's live-bed**, **clear-water**, and **Pressure Flow Conditions** approaches. Coarse sediments in the bed material armoring the bed may limit live-bed contraction scour depths. Where coarse sediments are present, recommended practice is to calculate live-bed and clear-water contraction scour and use the smaller calculated scour depth for design. If pressure flow conditions are present, use the greater scour depth (or lower elevation) of pressure flow, live-bed or clear-water contraction scour for design.

Upon inputting the average flow depth and velocity at the approach cross section, and the $D_{50}$ of the bed material, the calculator will indicate whether live-bed or clear-water conditions prevail by comparing Laursen's critical velocity with the average approach velocity. Laursen's equation for critical velocity follows:

$$V_c = K_u y^{1/6} D^{1/3} \qquad \textit{(HEC 18, Equation 6.1)}$$

After this determination, the Toolbox prompts the user for additional input depending upon the transport condition.

Entering the right and left bank stations will enable overbank contraction scours.

Live-bed Method (Horizontal Contraction Scour)

The live-bed contraction scour method assumes transport of bed material from upstream. The equation for computing depth in the contracted section for live-bed scour conditions is:

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{6/7}\left(\frac{W_1}{W_2}\right)^{k_1} \quad \text{(HEC 18, Equation 6.2}$$

The following required additional Input Parameters to compute live-bed contraction scour are:

- Temperature of water, degrees Fahrenheit
- Slope of Energy grade line at approach section, ft/ft
- Flow transporting sediment in contracted section, $ft^3$/sec
- Upstream flow transporting sediment, $ft^3$/sec (typically the discharge in the channel only)
- Bottom width transporting sediment in contracted section (less piers widths), ft
- Upstream bottom width transporting sediment, ft (can substitute the top width)
- Depth prior to scour in contracted section, ft
- Unit weight of water, lb/$ft^3$
- Unit weight of sediment, lb/$ft^3$

The reported results for live-bed contraction scour are:

- k1
- Shear velocity, ft/sec.
- Fall velocity, ft/sec
- Average depth in contracted section after scour, ft
- Scour depth, ft
- Shear applied to bed by live-bed scour, lbs/$ft^2$
- Shear required to move $D_{50}$ particle, lbs/$ft^2$

### 15.4.1.1 Clear-water Method (Horizontal Contraction Scour)

The equation for computing depth in the contracted section after scour for clear-water conditions is:

$$y2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2}\right]^{3/7} \quad \text{(HEC 18, Equation 6.4)}$$

$$y_s = y_2 - y_0 = \text{average contraction scour depth (HEC 18, Equation 6.5)}$$

This equation applies a reasonable lower limit of $D_{50}$ equal to 0.2 mm (0.000656 ft). Using a size smaller than 0.2 mm will over-estimate the clear water contraction scour.

The required additional Input Parameters to compute clear-water contraction scour are:

- Discharge in contracted section, $ft^3$/sec
- Bottom width in contracted section (less pier widths), ft
- Depth Prior to Scour in Contracted Section

The following reported results for clear-water contraction scour are:

- Size of smallest non-transportable sediment, ft
- Average flow depth in contracted section after scour, ft
- Scour depth, ft

### 15.4.1.2 Pressure Flow (Vertical Contraction Scour)

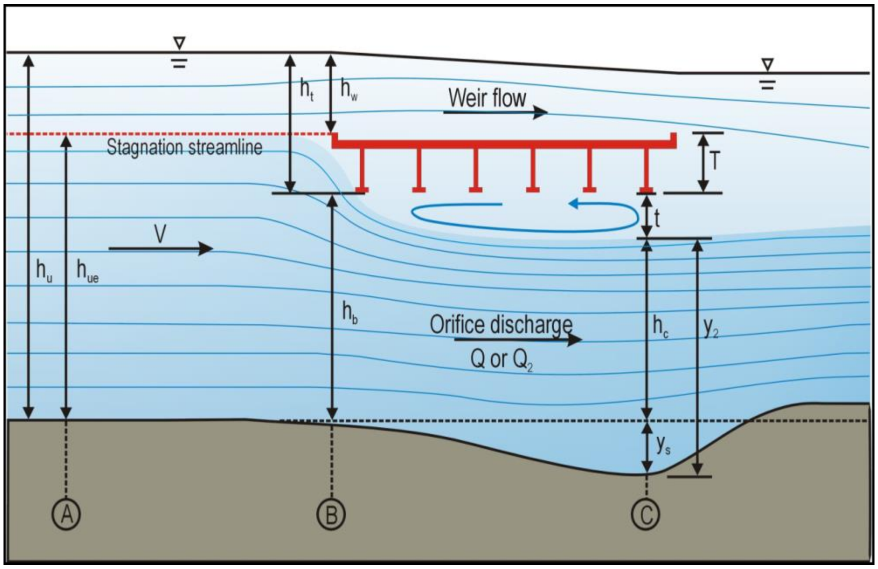



*Figure 15.14: Vertical Contraction & Definition for Geometric Parameters, FHWA HEC 18, Figure 6.18*

As the water-surface contacts the bridge superstructure, pressure flow conditions begin to develop and the bridge opening will begin acting like an orifice. The resulting contraction can dramatically change the potential contraction scour depth, since the contracted flow can be in both the horizontal and vertical directions.

Compute the depth in the contracted section after computing scour for pressure flow conditions using the same live-bed and clear-water contraction scour equations presented above and the actual discharge passing through the bridge. To compute the scour depth requires the thickness of the separation zone beneath the bridge superstructure and computed using the following equation:

$$\frac{t}{h_b} = 0.5\left(\frac{h_b \cdot h_t}{h_u^2}\right)^{0.2}\left(1 - \frac{h_w}{h_t}\right)^{-0.1} \qquad \textit{(HEC 18, Equation 6.16)}$$

Also for live-bed conditions with bridge and/or roadway overtopping, modify the upstream discharge using the following equation:

$$Q_{ue} = Q_1\left(\frac{h_{ue}}{h_u}\right)^{8/7} \textit{(HEC 18, Equation 6.15)}$$

In addition, the Input Parameters required to compute contraction scour without pressure flow conditions, requires the following Input:

- Vertical size of bridge opening before scour, ft
- Thickness of bridge superstructure, ft

In addition to the results reported for contraction scour without pressure flow conditions, the Toolbox provides the flow separation thickness, ft

## 15.5 Bridge Scour Calculator—Pier Scour

The available pier scour methodologies include HEC 18, Florida DOT, Complex Pier, Coarse bed, and Cohesive materials. Give the piers a name to assist in keeping track of them. The computations do not require a name however. The geometry will define its shape in the plot. The centerline station of the pier locates the pier on the bridge cross-section. The pier scour reference point is the elevation of the pier scour hole; either the thalweg of the channel or the local elevation of the streambed at the pier. The duplicate pier is to assist in data entry

### 15.5.1 HEC 18 Method

The HEC 18 method is appropriate for estimating pier scour for simple pier configurations. The equation for computing pier scour via the HEC 18 method is:

$$\frac{y_s}{y_1} = 2.0 K_1 K_2 K_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} \qquad \textit{(HEC 18, Equation 7.1)}$$

The following required Input Parameters for the HEC 18 method are:

- Pier shape
- Channel bed condition (transport type, bed form)
- Flow depth upstream of pier, ft (taken one bridge width (parallel to flow) upstream of the centerline of bridge)
- Velocity upstream of pier, ft/sec. (taken one bridge width (parallel to flow) upstream of the centerline of bridge)
- Pier width and length
- Angle of attack, degrees

The following generated results for the HEC 18 method are:

- Froude Number
- Correction factors K1, K2, and K3
- Pier Length to Pier Width (L/a)
- Scour depth, ft

### 15.5.2 Florida DOT Method

The FDOT method is appropriate to use for the full range of common pier geometries, particularly for wide piers with shallow flow depths with fine, sandy materials. The equations for computing pier scour via the Florida DOT method are:

$$\frac{y_s}{a^*} = 2.5 f_1 f_2 f_3 \qquad \textit{for} \qquad 0.4 \le \frac{V_1}{V_c} < 1.0 \qquad \textit{(HEC 18, Equation 7.5)}$$

$$\frac{y_s}{a^*} = f_1 \left[ 2.2 \left( \frac{\frac{V_1}{V_c} - 1}{\frac{V_{lp}}{V_c} - 1} \right) + 2.5 f_3 \left( \frac{\frac{V_{lp}}{V_c} - \frac{V_1}{V_c}}{\frac{V_{lp}}{V_c} - 1} \right) \right] \qquad \textit{for} \qquad 1.0 \le \frac{V_1}{V_c} \le \frac{V_{lp}}{V_c} \qquad \textit{(HEC 18, Equation 7.6)}$$

$$\frac{y_s}{a^*} = 2.2 f_1 \qquad \textit{for} \qquad \frac{V_1}{V_c} > \frac{V_{lp}}{V_c} \qquad \textit{(HEC 18, Equation 7.7)}$$

The following required Input Parameters for the Florida DOT method are:

- Pier shape
- Flow depth upstream of pier, ft (taken one bridge width (parallel to flow) upstream of the centerline of bridge)
- Flow velocity upstream of pier, ft/sec. (taken one bridge width (parallel to flow) upstream of the centerline of bridge)
- Pier width and length, ft
- Angle of attack, degrees
- $D_{50}$ of bed material, ft

The following generated results for the Florida DOT method are:

- Critical velocity for movement of $D_{50}$
- Velocity at live-bed peak scour, ft/sec.
- Projected pier width, ft
- Effective pier width, ft
- Scour depth, ft

## 15.5.3 Complex Pier Method

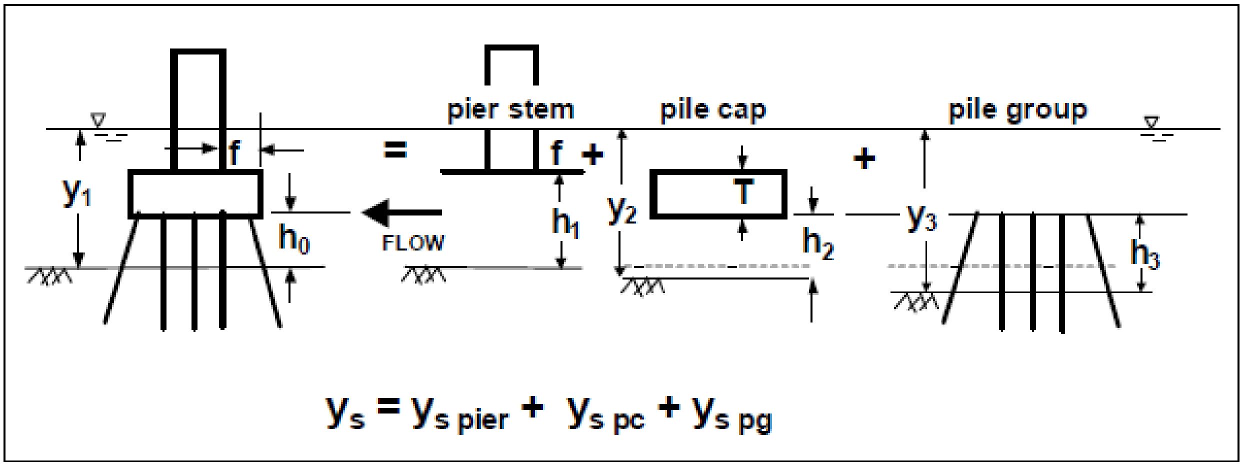



*Figure 15.15: Definition sketch for scour components for a complex pier, FHWA HEC 18, Figure 7.5*

The Complex Pier method is a 'component approach' that estimates scour attributable to the following substructure con-figurations being in the flow field: 1) pile groups (multiple rows of piles), 2) pile groups and a pile cap, 3) pile groups, a pile cap, and a pier stem, and 4) large pile cap or footing and pier stem. The equations for computing pier scour via the Complex Pier method are:

$$\frac{y_{s\,pier}}{y_1} = K_{h\,pier}\left[2.0K_1K_2K_3\left(\frac{a_{pier}}{y_1}\right)^{0.65}\left(\frac{V_1}{\sqrt{gy_1}}\right)^{0.43}\right] \quad \textit{(HEC 18, Equation 7.23 – pier stem scour component)}$$

$$\frac{y_{spc}}{y_2} = 2.0K_1K_2K_3K_w\left(\frac{a_{pg}^*}{y_2}\right)^{0.65}\left(\frac{V_2}{\sqrt{gy_2}}\right)^{0.43} \quad \textit{(HEC 18, Equation 7.24) – case1, pile cap in flow field)}$$

$$\frac{y_{spc}}{y_f} = 2.0K_1K_2K_3K_w\left(\frac{a_{pc}}{y_f}\right)^{0.65}\left(\frac{V_f}{\sqrt{gy_f}}\right)^{0.43} \quad \textit{(HEC 18, Equation 7.26 – case 2, pile cap on or below bed)}$$

$$\frac{Y_{spg}}{y_3} = K_{hpg}\left[2.0K_1K_3\left(\frac{a_{pg}^*}{y_3}\right)^{0.65}\left(\frac{V_3}{\sqrt{gy_3}}\right)^{0.43}\right] \quad \textit{(HEC 18, Equation 7.31 – scour for a pile group)}$$

The following are the minimum Input Parameters required for the Complex Pier method:

- Pier shape
- Channel bed condition (transport type, bed form)
- Bed material (sand, gravel and coarser)
- Angle of attack, degrees
- Flow depth upstream of pier, ft (taken one bridge width (parallel to flow) upstream of the centerline of bridge)
- Flow velocity upstream of pier, ft/sec. (taken one bridge width (parallel to flow) upstream of the centerline of bridge)
- Distance from front of pile cap or footing to pier stem, ft
- Pier width and length, ft

- Height of pile cap or footing above bed before scour, ft
- Thickness of pile cap or footing, ft
- $D_{50}$ and $D_{84}$ of bed material, ft

Additional pier components exposed by the estimated scour requires more detailed input. The additional input fields will appear, as needed. Reference HEC 18 for details.

The following generated results for the Complex Pier method as they apply are:

- Total scour depth, ys, ft
- Scour attributable to pier stem, ys pier, ft
- Scour attributable to pile cap or footing, ys pc, ft
- Scour attributable to pile group, ys pg, ft

### 15.5.4 Pier Scour in Coarse Bed Materials

When flow conditions are clear-water and non-cohesive bed material sediments with a $D_{50}$ greater than or equal to 20 mm and a gradation coefficient greater than or equal to 1.5, the designer can expect armoring to limit pier scour depths. Use the following equation to estimate pier scour if the design meets these conditions:

$$y_s = 1.1 K_1 K_2 a^{0.62} y_1^{0.38} \tanh\left(\frac{H^2}{1.97\sigma^{1.5}}\right) \qquad \textit{(HEC 18, Equation 7.34)}$$

The following required Input Parameters to determine coarse-bed pier scour are:

- Pier shape
- Bed Condition
- Bed Material (sand or gravel and coarser)
- Angle of attack, degrees
- Flow depth upstream of pier, ft
- Flow velocity upstream of pier, ft/sec.
- Pier width and length, ft
- $D_{50}$ and $D_{84}$ of bed material, ft
- Unit weight of sediment and water, lb/ft$^3$

The following generated results for coarse-bed pier scour are:

- Correction factors $K_1$ and $K_2$
- Specific gravity of sediment
- Densimetric particle Froude number = $\left(\frac{V_1}{(\sqrt{g(Sg-1)D_{50}})}\right)$ (HEC 18, page 7.37)
- Scour depth, ft

### 15.5.5 Pier Scour in Cohesive Bed Materials

When bed material is cohesive and the critical velocity required to initiate erosion of the cohesive material is known, preferably through material testing, use the following equation to estimate maximum pier scour (equation assumes flow duration is sufficiently long):

$$y_s = 2.2 K_1 K_2 a^{0.65} \left(\frac{2.6 V_1 - V_c}{\sqrt{g}}\right)^{0.7} \qquad \textit{(HEC 18, Equation 7.35)}$$

The following required Input Parameters for estimating pier scour in cohesive material are:

- Pier shape
- Angle of attack, degrees
- Average Velocity Upstream
- Pier width and length, ft
- Critical velocity of soil for initiation of erosion, ft/sec.
- Flow duration, hrs.
- Initial erosion rate, ft/hr.

The following generated results for pier scour in cohesive material are:

- Maximum scour depth, ft (Eq. 7.35)
- Time dependent scour depth, ft

## 15.6 Bridge Scour Calculator—Abutment Scour

The available **Abutment Scour** methodologies are **NCHRP**, **Froehlich**, and **HIRE** approaches. The user defines the abutment geometry to display the abutments in the plot. The Toolbox requires only one point (abutment toe) to place the abutment scour hole

### 15.6.1 NCHRP

The equations for computing flow depth including maximum abutment scour, $y_{max}$, via the NCHRP method is:

$$y_{max} = \alpha_A y_c \text{ or } y_{max} = \alpha_B y_c \qquad \textit{(HEC 18, Equation 8.3)}$$

The NCHRP equation for computing flow depth including contraction scour for live-bed conditions is:

$$y_c = y_1 \left(\frac{q_{2c}}{q_1}\right)^{6/7} \qquad \textit{(HEC 18, Equation 8.5)}$$

The NCHRP equation for computing flow depth including contraction scour using $D_{50}$ for clear-water conditions is:

$$y_c = \left(\frac{q_{2f}}{K_u D_{50}^{1/3}}\right)^{6/7} \qquad \textit{(HEC 18, Equation 8.6)}$$

In addition to the input required to determine whether live-bed or clear-water transport conditions prevail (see Contraction Scour section below), the NCHRP Method requires the following Input Parameters:

- Abutment type (Spill Through, Vertical Wall, or Vertical Wall with Wing Walls)
- Angle of approach embankment to Flow, degrees
- Centerline length of embankment, ft
- Centerline width of floodplain, ft
- Unit discharge at upstream section, $ft^3$/sec /ft
- Unit discharge in contracted section, $ft^3$/sec /ft
- Flow depth in contracted section prior to scour, ft

The NCHRP method generates the following results:

- Length of embankment normal to flow, ft
- Width of floodplain normal to flow, ft

- Embankment length to floodplain width ratio
- Flow depth including contraction scour, ft
- Unit discharge ratio
- Amplification factor
- Maximum flow depth including abutment scour, ft
- Scour depth, ft

Note that one needs to check the armoring potential for any live-bed condition by comparing the contraction scour estimate for live-bed conditions with the contraction scour estimate for clear-water conditions. To compute the NCHRP abutment scour estimate for live-bed conditions, the standard practice is to use the lesser of these two estimates.

### 15.6.2 Froehlich Method

The equation for computing abutment scour via the Froehlich method is:

$$\frac{y_s}{y_1} = 2.27K_1K_2\left(\frac{L'}{y_a}\right)^{0.43} Fr^{0.61} + 1 \qquad \textit{(HEC 18, Equation 8.1)}$$

The Froehlich method requires the following Input Parameters:

- Abutment type (Spill Thru, Vertical Wall, or Vertical Wall w/wing walls)
- Angle of approach embankment to Flow, degrees
- Centerline length of embankment, ft
- Flow obstructed by embankment, $ft^3$/sec
- Area of obstructed flow, $ft^2$
- 'Active' flow length, ft

The Froehlich method generates the following results:

- Length of embankment normal to flow, ft
- Average flow depth, ft
- Embankment length to flow depth ratio
- Average velocity, ft/sec.
- Froude Number
- Scour depth, ft

### 15.6.3 HIRE Method

The equation for computing abutment scour via the HIRE method is:

$$\frac{y_s}{y_1} = 4Fr^{0.33}\frac{K_1}{0.55}K_2 \qquad \textit{(HEC 18, Equation 8.2)}$$

The HIRE method requires the following Input Parameters:

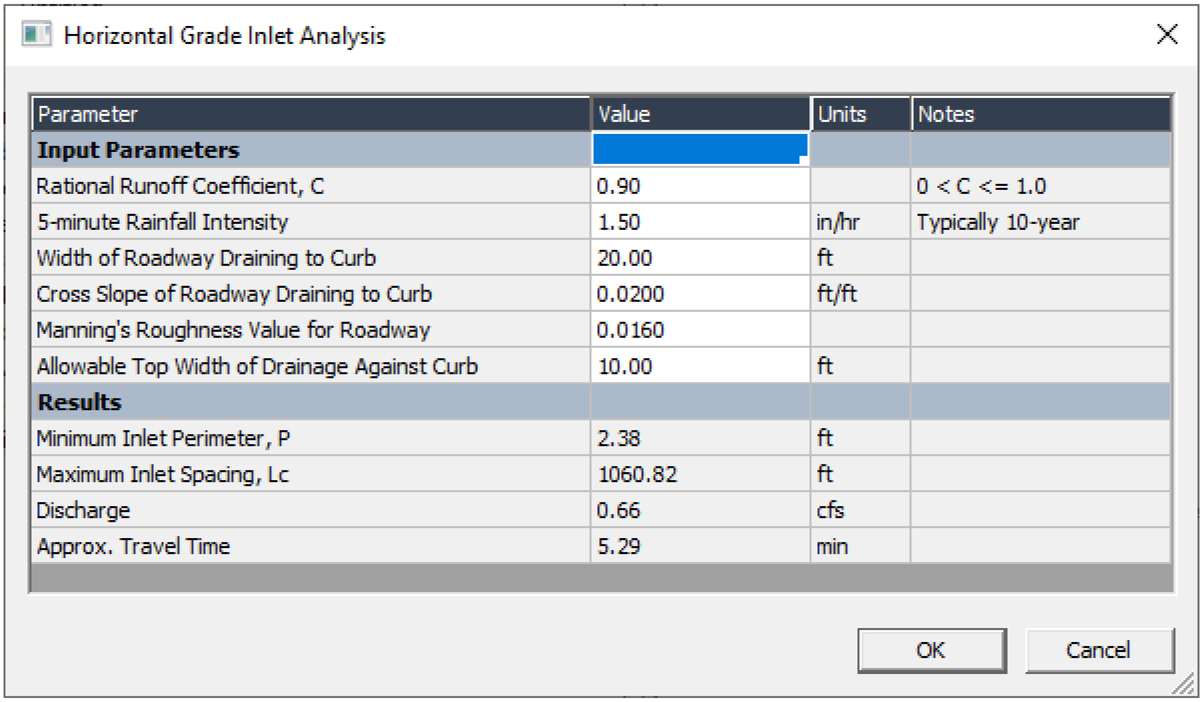
- Abutment type (Spill Thru, Vertical Wall, or Vertical Wall w/wing walls)
- Angle of approach embankment to Flow, degrees
- Centerline length of embankment, ft
- Velocity at toe of abutment, ft/sec.
- Depth at toe of abutment, ft

The HIRE method generates the following results:

- Embankment length to flow depth ratio
- Froude Number
- Scour depth, ft

# 16 Horizontal Grade Inlet Calculator

*Figure 16.1: Horizontal Grade Inlet Calculator icon*




| Parameter | Value | Units | Notes |
|---|---|---|---|
| **Input Parameters** | | | |
| Rational Runoff Coefficient, C | 0.90 | | 0 < C <= 1.0 |
| 5-minute Rainfall Intensity | 1.50 | in/hr | Typically 10-year |
| Width of Roadway Draining to Curb | 20.00 | ft | |
| Cross Slope of Roadway Draining to Curb | 0.0200 | ft/ft | |
| Manning's Roughness Value for Roadway | 0.0160 | | |
| Allowable Top Width of Drainage Against Curb | 10.00 | ft | |
| **Results** | | | |
| Minimum Inlet Perimeter, P | 2.38 | ft | |
| Maximum Inlet Spacing, Lc | 1060.82 | ft | |
| Discharge | 0.66 | cfs | |
| Approx. Travel Time | 5.29 | min | |

*Figure 16.2: Horizontal grade inlet calculator*

The **Horizontal Grade Inlet Calculator** computes the minimum inlet perimeter and maximum allowable spacing between inlets required to capture runoff from roadways or bridge decks with curbing and a 'zero' or 'near-zero' longitudinal slope. The resulting minimum perimeter is that which is required to capture flow approaching the inlet from three directions; up-station, down-station, and from the roadway centerline. Measure the resulting maximum spacing from inlet center to inlet center.

The equations used to compute the inlet perimeter and spacing assume weir flow will occur at the inlet. (Find their derivation in Appendix B of FHWA publication HEC 21.) Also, the perimeter and spacing are independent of one another, so it is not possible to vary these parameters to determine the impact on the other.

Further details about the methods used in the bridge scour calculator are located in the following reference:

**Young, G.K., Walker, S.E., Chang, F., May 1993, Design of Bridge Deck Drainage, Hydraulic Engineering Circular No. 21, FHWA Publication No. FHWA-SA-92-010.**

**http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=21&id=46**

The calculator requires input of the following information:

- Runoff coefficient for Rational Equation, C
- 5-minute design rainfall intensity (typically 10-yr event), i (in/hr)
- Width of roadway draining to curb (ft)
- Cross slope of roadway draining to curb (ft/ft)

- Manning's roughness value for roadway surface, n
- Allowable top width of drainage against curb (ft)

After all required data is input, the calculator will provide the following results:

- Minimum inlet perimeter, P (ft)
- Maximum inlet spacing, $L_c$ (ft)
- Discharge (cfs)
- Approximate travel time (min)

# 17 Mapping Module

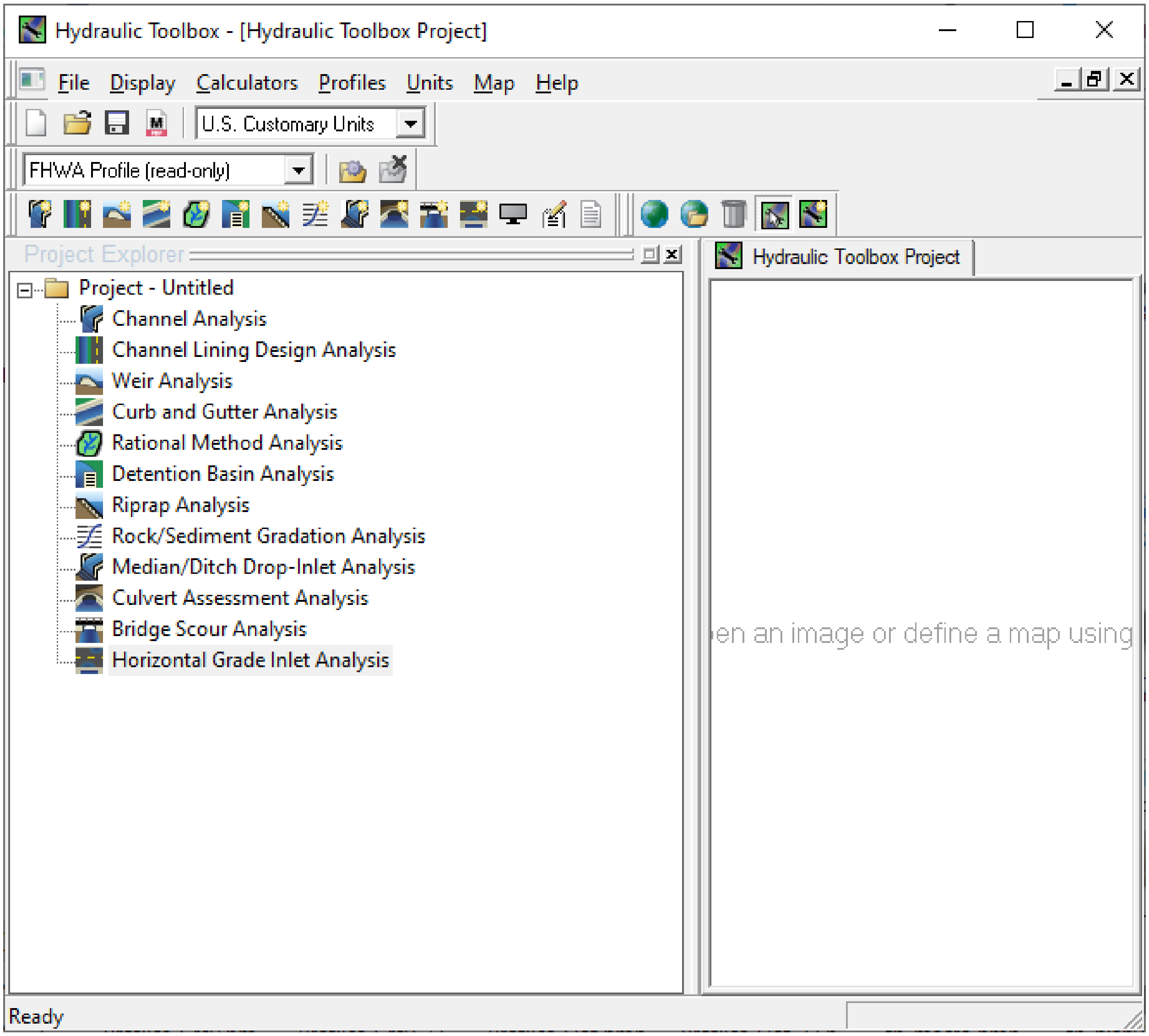



*Figure 17.1: Hydraulic toolbox window*

The Mapping Module allows users to identify the location(s) of any analyses conducted within the Hydraulic Toolbox software on a user supplied image or an image taken from current aerial photography (internet connection required). It also allows attachment of ground photos to each analysis location, as needed or desired.

Upon opening the Toolbox, one can either "right-click" as directed in the display window or select the desired icon from the set provided for this module to access the mapping options. The "globe" icon will provide a drop-down window that allows the acquisition and manipulation of an aerial image from the internet by specifying the latitude and longitude for the desired location. If the latitude and longitude are unknown, there is an option to acquire the mapping by using a site name and location under the "Map Options" tool. Additional map navigation tools are also available under "Map Options." The "Map Styles" tool allows the user to select from one of three map styles: Aerial only, Roads only, or Aerial and Roads (Hybrid). The Aerial only option is the default.

## 17.1 Mapping Module Project Location

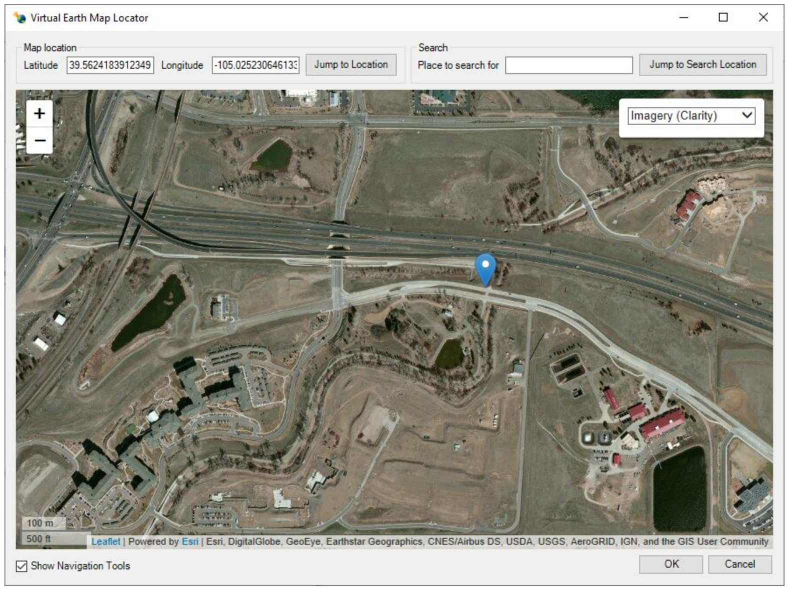



*Figure 17.2: Virtual earth map locator window*

The 'globe with folder' icon allows the user to browse and locate an image or photo file already saved within the computer. After selecting an image, size it as desired to fit the available window space. Adjust the image by 'grabbing and pulling' the borders. Upon selecting the 'Ok' button, the desired image will be 'set' within the display window. (The Toolbox saves the image as a separate file associated with the Toolbox file.) The 'trash can' icon allows the user to delete a previously selected image and start over.

After deciding on the image, the user selects the 'Add' icon button in the mapping toolbar for a dialogue box that allows the user to select the analysis label(s) of interest, as well as attach desired ground photos. The Toolbox saves the photos in a separate folder associated with the Toolbox file. After selecting the label of interest, the user simply 'clicks' on the image at the desired location and the label will appear on the image. Repeat this process as many times as necessary/desired. If a label is incorrect or mislocated, the user can choose the 'Select' icon on the mapping toolbar to move the label by clicking, holding, and dragging. If the user 'right-clicks' on the label an 'edit' option appears that will allow the node content to be changed or deleted altogether.

When creating a report for an analysis or group of analyses, selecting "Node Data" in the report dialogue will capture the image, labels, and repeat the input and output data of the associated analyses. After creating and saving the report, edit this information as desired.

This image shows how a user can document a project by using an overhead image to show the locations of the individual calculations used to complete a project. Use the node properties dialog box to assign ground photos to the individual "nodes" or calculations in the project. This graphic illustrates how to use an overhead image to show the locations of the calculations in the project as well as a photograph taken at one of the nodes of an existing drop inlet.

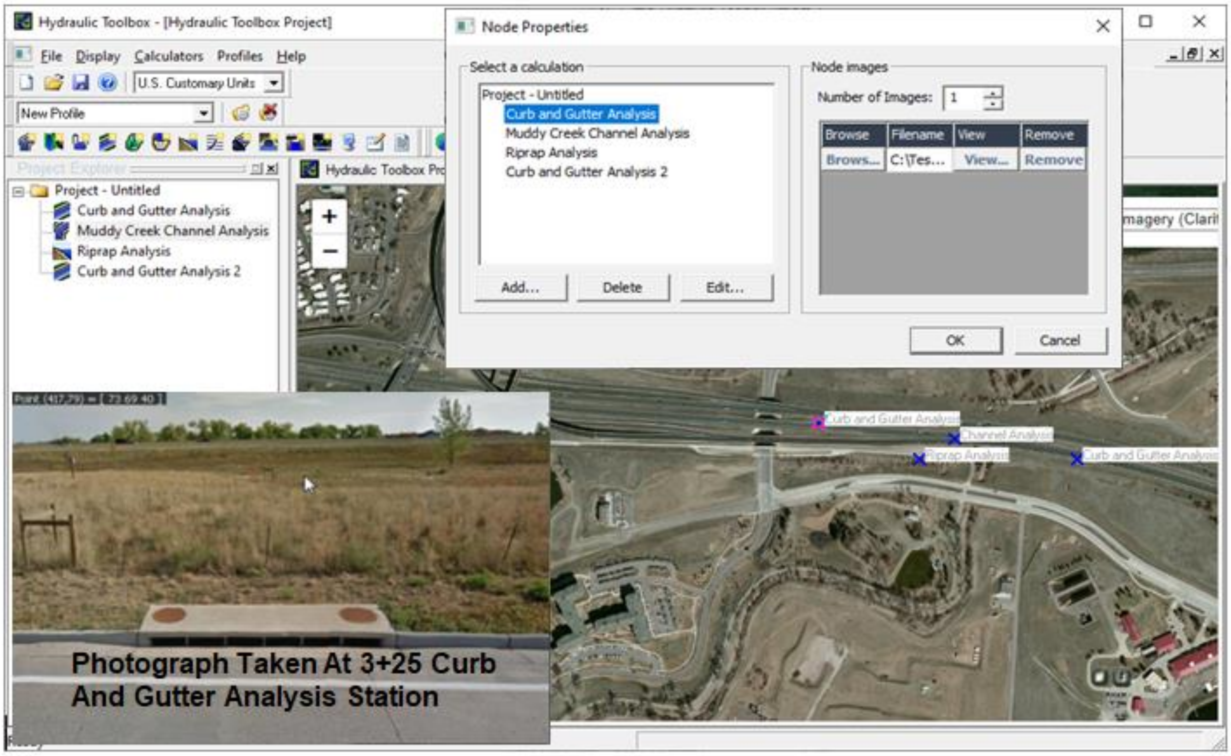



*Figure 17.3: Node properties with image window*

# 18 Project Notes

Add **Notes** describing a project using the notes feature accessed from "Calculators" pull down menu or from the notes icon on the macro bar. A window will open where the designer provides information that describes an analysis. Save the notes with the data file that will also show up in the project report.

Notes can be defined for the entire project or for an individual project calculation.

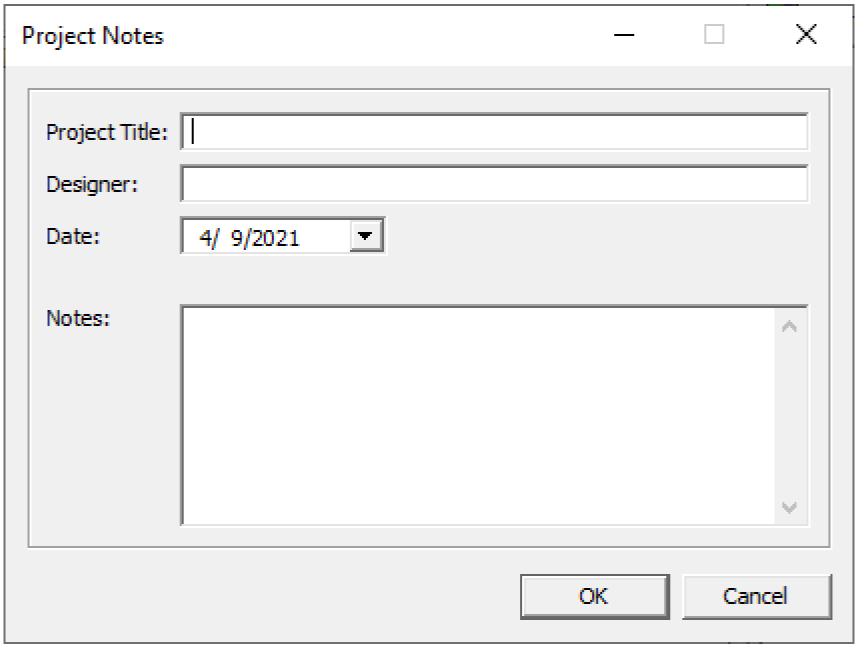



*Figure 18.1: Project notes window*

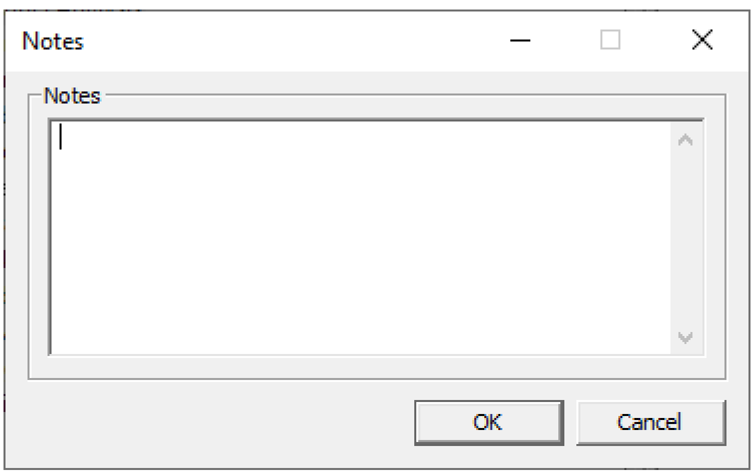



*Figure 18.2: Calculator notes window*

# 19 Troubleshooting

## 19.1 Troubleshooting

If you have problems running Hydraulic Toolbox, 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.

#### 19.1.1.1 Registering Libraries

Previous versions of HY-8 had libraries created by a company named Gnostice for report generation. However, in Hydraulic Toolbox v 5.1 the report options were updated to a new library, called HyReport.

Hydraulic Toolbox relies on the following Libraries:

- Microsoft Visual C++ 64-bit Redistributable dll files
- PEGRP64E.DLL
- OpenCV dlls files
- VirtualEarth.html & WinformsEarthV2.exe
- HyReport

If Hydraulic Toolbox 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 Hydraulic Toolbox installation directory.

If Hydraulic Toolbox crashes or has errors in the Map Viewer

- Check that the VirtualEarth.html & WindormsEarthV2.exe files are located in the Hydraulic Toolbox installation directory.
- Install the Virtual Earth Registry lines by running 'vearth.reg' file in the Hydraulic Toolbox installation directory with administrator rights.

If Hydraulic Toolbox 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 Hydraulic Toolbox installation directory.

### 19.1.2 Contacting FHWA

If you still have trouble installing or running Hydraulic Toolbox, 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 the contacts listed on the Hydraulic Toolbox website: https://www.fhwa.dot.gov/engineering/hydraulics/software/toolbox404.cfm

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

# 20 References

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