

# Iowa Bridge Backwater Software

## **User's Manual**

Version 3.0

2016

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## **Iowa DOT Bridge Backwater Program**

Version 3.0  
Software User's Manual  
2016

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Dave Claman of the Iowa DOT Office of Bridge & Structures served as the project manager. LaDon Jones was the project manager for Digital Control, Inc.

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Iowa Department of Transportation.

### Disclaimer:

Although the Iowa Bridge Backwater (Iowa DOT Bridge Backwater Program) software and user's manual have been carefully prepared and tested, the Iowa Department of Transportation and Digital Control, Inc. makes no representation or warranty regarding the accuracy, correctness, or completeness of the computer program or of the information contained in the user's manual. The Iowa Department of Transportation and Digital Control, Inc. shall not be liable for any direct, indirect, consequential, or incidental damages resulting from the use of the software or the information contained herein.

### Summary of Changes from Version 2.0 to Version 3.0

Version 2 and earlier of the software was written in Visual Basic 6.0. In version 3.0 the software has been converted to Visual Basic.NET. Visual Basic 6.0 is no longer being updated by Microsoft. Visual Basic.NET is the currently supported development environment for Windows and is likely to continue to be supported well into the future. By converting to .NET the software is more likely to run without problems on future versions of the Windows operating system.

In version 2.0 and earlier the depth at the valley cross-section and bridge cross-section were assumed to be the same. Consequently the water surface elevation at the bridge was found by adding the depth to the lowest elevation for the bridge cross-section.

In version 3.0 the water surface elevation at the bridge is found by translating the Valley Stage to the Bridge stage using the Valley Channel Slope and distance from the Valley section to the Bridge section. This allows the user more flexibility in adjusting the vertical fit of the Valley section to the Bridge section to account for unusual situations that require engineering judgement.

In version 3.0 the USGS methods (Lara, 1987 and Eash, 2001) for estimating design discharges are no longer included in the software. The user determines the design discharges separate from the software and enters the design flowrates into a Design Q table in the version 3.0 software.

The ability to do a Print Preview before printing a hard copy was added in version 3.0. In addition the output can be sent to a pdf file instead of a printer, if the user has pdf software installed on their computer. There are free pdf software programs available that the software will work with if they are installed on the user's computer.

### Summary of Changes from Version 1.X to Version 2.0

#### Addition of Bridge Scour Estimation

This is the major addition that is new for version 2.0 and was not present in previous versions. Bridge scour estimation (contraction, abutment and pier) can now be done using methods employed by the Iowa Department of Transportation. These methods are primarily based on techniques from HEC-18, Evaluating Scour at Bridges, published by the Federal Highway Administration (2001). The information required for scour estimation is the same information (Design Q, Valley Cross-Section, Bridge Cross-Section, Pier Information, etc.) required for backwater computations. Little additional information beyond that required for bridge backwater estimation is needed for bridge scour estimation.

The remaining changes were modifications and updates to the existing bridge backwater software, but did not involve the addition of completely new features.

#### Road Grade Profiles

The previous version allowed the input of 1 road grade profile for overtopping. Overtopping was limited to the total overbank flow without consideration of whether the road grade profile was on the same overbank as the overbank flow. After some reflection it was felt that overtopping on a particular overbank should be limited to the overbank flow on that side. This has been incorporated into version 2.0. Version 2.0 allows for the input of 2 road grade profiles, a "Left Overbank Road Grade Profile" and a "Right Overbank Road Grade Profile". Overtopping on the Left Overbank is based on the "Left Overbank Road Grade Profile" and is limited to be no more than the left overbank flow. Overtopping on the Right Overbank is based on the "Right Overbank Road Grade Profile" and is limited to be no more than the right overbank flow.

#### Improved Convergence with Overtopping

Computing backwater with the consideration of overtopping requires balancing the distribution of flow between the bridge opening and roadway overflow. In some situations users of the previous version of the software reported situations where convergence to a solution that results in the sum of the bridge Q plus overflow Q being equal to the Design Q was not being achieved. Based on an analysis of the problems, the methodology for iterating to achieve convergence has been improved in this version of the software and convergence to a solution has been achieved for all examples tested, including the example problems tested that did not achieve convergence with the previous version of the software.

#### Improved Label Scaling on Plots and Graphs

In the previous software version the labels on plots and graphs were scaled by 1/10 of the maximum range of the data. This almost always led to labels that were fractions of a foot. The labeling and scaling has been modified in this version to produce labels in whole units (i.e. 2, 5, 25, 50, 100 feet, etc.)

### Copying Design Flowrates between Forms

In the previous software version, the design flowrates in different forms either had to be entered into each form separately, or copied using cut and paste. In version 2.0 the design flowrates in a form can be copied from any other form using a couple of button clicks. This means, for example, that the user can enter the design flowrates in a single form and easily have the same flowrates copied to any other form.

### User Manual Update

The user manual has been updated to reflect the changes made and the addition of bridge scour estimation.

## Iowa Bridge Backwater Software User's Manual

### Introduction

This manual describes how to use the Iowa Bridge Backwater software, version 3.0. It also documents the methods and equations used for the calculations. The main body describes how to use the software and the appendices cover technical aspects.

The Bridge Backwater software performs 4 main tasks:

Design Discharge Entry

Stream Rating Curves

Floodway Encroachment

Bridge Backwater

Bridge Scour

**Design discharge entry:** You enter the design discharges you have determined via method(s) not included in the software, and describe the method you used.

**Stream Rating Curves:** Stage versus discharge relationships for the Valley cross-section are estimated using the Manning Equation, and assuming uniform flow.

**Floodway:** Floodway encroachments can be computed, using the methods and assumptions of the Iowa Department of Natural Resources, Water Resources Division.

**Bridge Backwater:** The estimation of backwater from bridges is a major part of the software. The methods implemented in the software are those used by the Iowa Department of Transportation (IDOT) and Iowa Department of Natural Resources (IDNR) for Bridge Backwater Estimation. These methods are based on methodology from Hydraulic Design Series 1 (HDS-1), Hydraulics of Bridge Waterways, Federal Highway Administration (FHWA), 1970. Hydraulic Design Series 1 will be referenced throughout the manual, as HDS-1.

**Bridge Scour:** Bridge scour (contraction, abutment and pier) is estimated from methods used by the Iowa Department of Transportation. These methods are primarily based on techniques from HEC-18, Evaluating Scour at Bridges, published by the Federal Highway Administration (2001).

### Applicability

The intent of this program is to provide a simplified method for analysis of bridge backwater for rural structures located in areas with low flood damage potential.

It is recommended that this software **not** be used for locations with a detailed Flood Insurance Study or where the upstream floodplain has a high damage potential.

If the design flow inundates the superstructure, without road grade overtopping, other methodologies should be used for backwater estimation. This is a pressure flow situation and is not modeled in this software.

For Scour estimates, the computations are only applicable for the case of; Abutments at the edge of the channel.

### **Installing the Software**

The software is written in Microsoft Visual Basic.NET 2013. It will run under Windows XP or newer versions (i.e. Windows XP, Windows 7, Windows 8, Windows 10, etc.). To run the software using Windows XP will require the user install .NET framework 4.0 if it is not already present on their computer.

Instructions for installing the software will be included when you receive the software installation files.

### **Using a Version 1.X Data file in Version 3.0.**

With regard to opening and using a data file created in version 1.x, version 3.0 is mostly backwards compatible. That is, you can open a data file created in version 1.x in version 3.0. If you do this there are a few things you will need to check and possibly update: As discussed below, after opening a version 1.x data file in version 3.0 you will need to check your Road Grade Profiles, check your Bridge Piers data, enter abutment elevations for abutment scour plotting and redo your Backwater computations.

If your version 1.x data file has a road grade profile, the road grade profile in version 1.x is assumed to be the “Left Overbank Road Grade Profile” in version 3.0. If this is not correct you will need to adjust or modify your road grade profile(s). If you combined the road grade profiles on both sides of the bridge in version 1.x you will need to separate the profiles into left and right. Note that you can copy and paste the road grade profile station and elevation data (see [Appendix A](#) for copy and paste instructions).

In version 2.0 and later bridge piers have a Pier Length and the Piers have an angle of attack. If you open a version 1.x file the bridge piers will be assigned a length of 0 and the “Angle of Attack” will be assumed to the 0. After opening a version 1.x you will need to check your pier information and adjust as needed.

If you will be doing scour computations, and wish to plot the abutment scour you will need to enter the abutment elevations to use for scour plotting in the “Bridge Cross-Section” form.

After you have checked and modified your road grade profiles and bridge piers information, you will need to re-compute your backwater results. This simply means selecting the 2 forms under the “Backwater” menu item and clicking the “Compute Backwater” button in each form.

After you have re-computed the results I would suggest you do a “File, Save As” and save the version 3.0 results with a new name. This way you can keep a copy of your version 1.x data file in case you need to run version 1.x for some reason. A version 3.0 data file is not compatible with the version 1.x software.

### **Using a Version 2.X Data file in Version 3.0.**

You can open a version 2.X data file in version 3.0. Because of the change in the way the bridge stage is determined from the valley stage in version 3.0, you should re-compute the backwater results (simply click the “Compute Backwater” button in the Bridge Backwater forms), but you will not need to reenter any of your data such as Bridge Cross-Section, Valley Cross-Section, Piers, Backwater form Design Q’s, etc. Such information is preserved. Note that version 3.0 does not included the USGS methods for

generating design Q's, so that information is not preserved. You will need to enter your Design Q information in the Design Q table.

### **Saving/Opening Files**

When the software is installed a menu item will be placed in the Windows "Start" menu. To start the software click "Start" on the Windows Task Bar and select "Iowa Bridge Backwater".

While you are working on a project you can save the information to a file at any time using "File", "Save". If there is not currently an "active" file name, the "Save As" dialog box will open, and you can select a File Name and save the current information in the program to the file.

By default an extension of "ibh" is added to the file name (short for **I**owa **B**ridge **H**ydraulics). You do not need to type this extension as part of the file name, it will be automatically added. I suggest you use the default extension. When you choose to open a file, files with the default extension will be displayed automatically.

After you save the data to a file, the "active" file name is automatically displayed on the top menu bar, after the program name, "Iowa Bridge Backwater v3.0". Only the file name is displayed, not the full file path.

When there is an active file name, if you click "File", "Save" the active file is automatically updated with the current information in the program. To reduce the loss of information in the event of a software or operating system crash it is recommended you save the data to a file on a regular basis while you are working on a project.

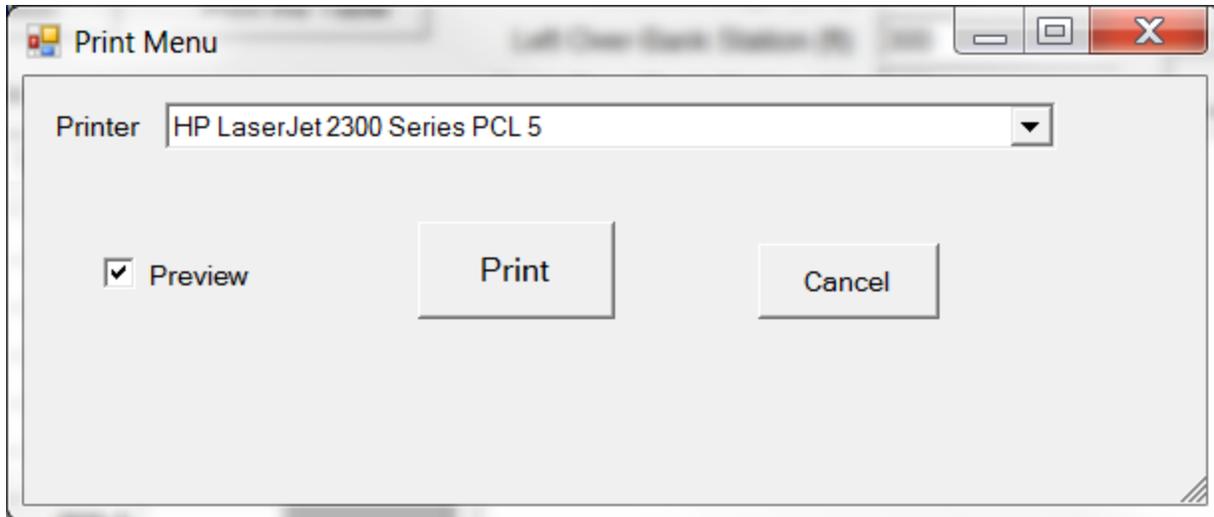
If you wish to save the information to a different file, use "File", "Save As".

To open a previously saved file, use "File", "Open". When you open a file any existing information in the program is replaced with the data in the file. If you are working on a project make sure you save the current information before you open a new file.

Selecting "File", "New" and confirming that you want to proceed with the File, New will clear all the information from the program (it does not affect information that has been saved to a file). You might use this if you are done with a bridge design project, have saved the information to a file, and wish to start on a new project, without exiting and restarting the program.

### **Printing**

Whenever you select to Print, the Print Menu will be displayed.



You can select the Printer from the dropdown menu. Note that if you have PDF creation software such as Adobe, you can also select this from the Printer dropdown and create a PDF rather than sending the output to a printer.

If you check the Preview checkbox you can Preview what will be printed before you print it or generate a PDF.

### **Exiting the Program**

To exit the program, select "File", "Exit". A message box will appear for you to confirm your choice to exit. Any unsaved data will be lost when you exit the program. Data that has been saved to a file will not be lost.

You can also exit the software by clicking the X at the upper right of the main form. This will also produce a message box for you to confirm or cancel your exit selection.

### **Example Problem File**

The rest of the manual will go through the elements of the software, step by step. An example problem file has been developed for illustration. You may wish to open the example problem file. If you have installed the software, select "File", "Open" and select "Example Problem UM v3.ibh". The example problem file already contains data that you can use to test elements of the program and view the data format.

## Site

Click “Site” on the top menu, and then click “Identification” to display the “Site Identification” form. Use this form to enter the information required to identify your site and project. You can print the information (click the “Print” button) on the form to include with your report.

**DATE:** For a new project the current date is shown by default. You can click on the down arrow to select a date from a calendar, or type the date in directly using the format of mm/dd/yyyy.

**COUNTY:** Select the county from the drop down list box with the 99 counties in Iowa.

**ADDITIONAL COMMENTS:** You can add any additional information you wish for your site.

## Design-Q's

### Design Q Table

For version 3 of the software you determine your Design Q's using methods not included in the software, then enter your design Q's into the software. The values entered in the Design Q Table can be copied to other parts of the software (i.e. Backwater, Scour, etc.) using the “Copy Q's” button on those forms. Entering your Design-Q's values in this table allows you to easily use the values in other parts of the program without having to manually reenter the values.

Click the “Design-Q's” menu item at the top of the main form, then select “Design Q Table” in the dropdown. If you have not opened the example problem, you will see the following.

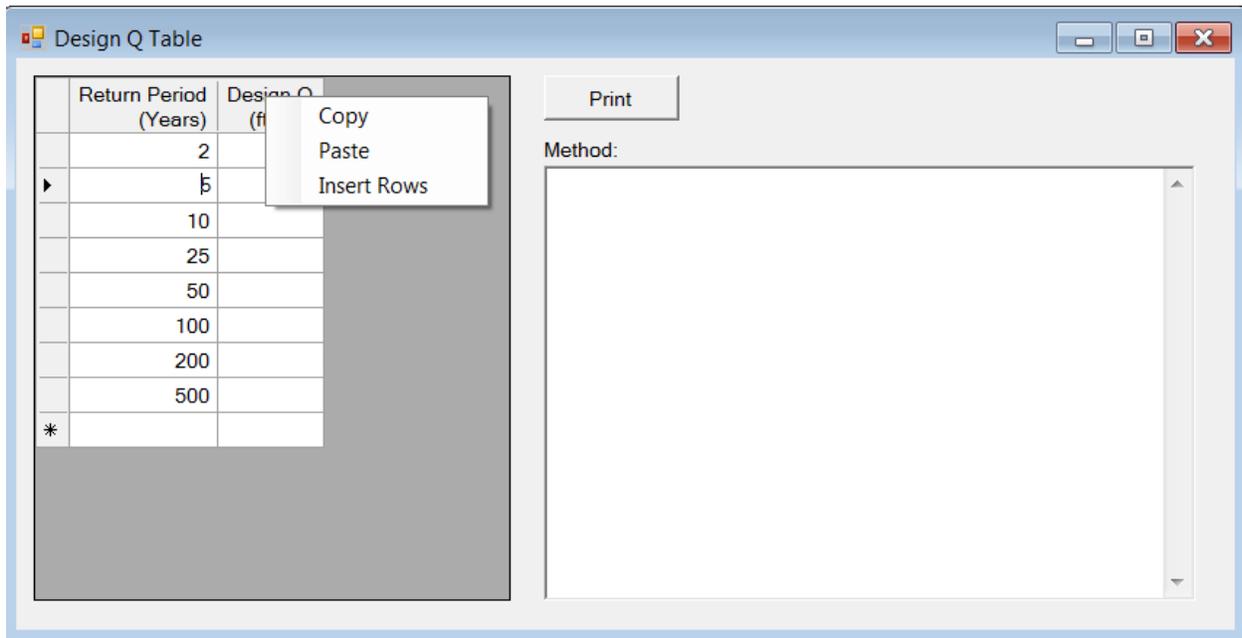
Return Period (Years)	Design Q (ft <sup>3</sup> /s)
2	
5	
10	
25	
50	
100	
200	
500	
*	

By default, the Return Periods shown are already entered to save you some typing. To enter the appropriate Design Q simply click the cell in the Design Q column and type in the value.

To enter new values, use the cell with the “\*” at the left of the row.

To delete existing rows, select the rows you wish to delete and press the Delete key.

If you right click on the header row an editing menu will be displayed with Copy, Paste and Insert Rows, as shown below.



Copy will copy the selected rows from the Design Q table to the Clipboard. Paste will paste values from the Clipboard into the table. You can, for example, copy values to the Clipboard using Excel, then Paste them into the table using this command. Insert Rows will bring up a dialog box where you can enter the number of empty rows to insert above the currently selected row. See [Appendix A](#) for more information.

## Valley

### Valley Cross-Section

The valley cross-section information is used to generate valley rating curves, and to estimate discharge versus depth for floodway encroachment, bridge backwater and bridge scour estimation. All the computations in the software require a valley cross-section.

Note that for bridge backwater calculations the valley cross-section should be a “typical” or representative cross-section for the valley in the vicinity of the bridge. You may need to edit or modify the measured cross-section if it contains features (i.e. local scour holes) that are not representative of the typical valley cross-section.

You can reach the valley cross-section form two ways. You can click “Valley”, then “Valley Cross-Section”, or click “Bridge-River-Valley”, then “Valley Cross-Section” to display the “Valley Cross-Section” form. Both methods display the same form. You can reach it from 2 locations for convenience,

in case you are doing a valley rating curve or a bridge backwater, but not both. You use this form to enter the data describing the valley cross-section.

Channel Slope:

Channel Slope is the slope of the channel bottom **in the direction of flow**. Always enter the slope as a positive ( $>0$ ) value.

Valley Cross-Section Data:

Use the grid or table on the left of the form to enter the valley cross-section data. The row with "\*" in the first column is used to enter new data.

Station values are **not** in transportation station notation. **For example, if the station location is 1256 feet, you must enter 1256, not 12+56.**

Normally, the station values are entered left to right assuming you are looking upstream. However, they can be entered with another orientation, but if you use the bridge backwater or bridge scour section, the valley cross-section and bridge cross-section must use the same orientation.

Station values must be entered in ascending (increasing) order, although the first station does not need to be zero, and can be negative.

Elevation is the elevation of the channel bottom at the station.

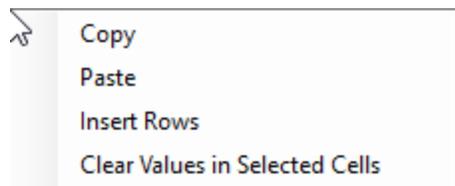
The first station must have a "Manning n" value. Manning n values apply from the station they are entered at until another Manning n value is entered. Hence, you do not need to enter Manning n values for each station. You need to enter a Manning n for the first station and then at each station where there is a change in Manning n value. The example problem only has Manning n values where there is a change in value.

Overbanks

The "Left Overbank Station" and "Right Overbank Station" only affect the calculations for Floodway Encroachment and Bridge Scour. However, you must enter a Left Overbank and Right Overbank Station even if you are not doing floodway encroachment or Bridge Scour. Overbank stations are sometimes called top of bank (TOB) stations.

The left overbank station must have a station value less than the right overbank station. **The over bank station does not have to be equal to one of the valley stations.** You can use an overbank station between valley stations and the software will interpolate the valley cross-section data between the stations to find the valley bottom elevation at that point.

If you right click the grid you will see



You can click on this menu to Copy, Paste, Insert Rows or Clear Values in Selected Cells. See [Appendix A](#) for more information.

### Printing the Valley Cross-Section Data

To print the Valley Cross-Section Data (the data in the table), click the “Print the Table” button above the table.

### Plotting the Valley Cross-Section

Click the “Plot” button to plot the Valley cross-section. The Manning n values and their range of coverage are shown at the top of the plot. The channel bottom is shown with a red line. The Left Overbank Station is shown as “LOB” and the Right Overbank Station is shown as “ROB”. The “O” in LOB is centered at the Left Overbank Station and the “O” in ROB is centered at the Right Overbank Station.

The scaling for the x and y axes are chosen automatically by the software. The right vertical axis shows depth, computed assuming the lowest elevation in the valley cross-section has a depth of 0.

### Printing the Valley Cross Section

To send a copy of the valley cross-section to the printer click the “Print the Plot” button. The scaling and placement of the cross-section is automatically selected by the software. The plot is always printed with a landscape format.

## **Valley Rating Curve**

Click “Valley”, “Valley Rating Curve” to display the “Rating Curve for the Valley Cross-Section” form. You can use this form to generate a table and plot of discharge versus water surface elevation (and depth): a so-called Rating Curve, for the Valley Cross-Section. The water surface elevation is called the “Stage”. For a given Stage (water surface elevation), the discharge (Q) is computed. The computations use the channel slope and valley cross-section information you have entered in the “Valley Cross-Section” form.

The only parameters you need to enter in this form are the “Starting Stage (ft)”, “Ending Stage (ft)” and the “Step Size (ft)”. The flowrates are computed for water surface elevations from the “Starting Stage” to the “Ending Stage”, in increments of “Step Size”.

For example, if you enter a “Step Size” of 1 foot the flowrate (Q) will be computed for the “Starting Stage” and at one-foot elevation increments of stage until the “Ending Stage” is reached. The computation stages do not have to fall evenly on the “Ending Stage”. The discharge for the Ending Stage will be computed, regardless. For example, if you have:

Starting Stage = 100.0  
Ending Stage = 103.5  
Step Size = 1.0

The discharge will be computed for 100.0, 101.0, 102.0, 103.0 and 103.5

After you have entered a “Starting Stage”, “Ending Stage” and “Step Size”, click the “Compute/Plot Rating Curve” button. This will fill the table with the results of the computations and also plot discharge

(Q) versus water surface elevation (Stage) and water surface depth (Depth). The depth is the depth of water above the lowest elevation in the valley cross-section.

You can send a copy of the table to the printer using the “Print the Table” button, and print a copy of the plot using the “Print the Plot” button. The table results and plot are not saved when you save the data to a file, but all the information needed to reproduce the results are saved. So, if you open a previously saved file, you only need to click “Compute/Plot Rating Curve” to reproduce the results.

The rating curve table shows:

Stage: The elevation of the water surface.

Depth: Depth of the water surface. The depth of water above the lowest elevation in the valley cross-section.

Q: The flowrate or discharge, computed using the Manning Equation and assuming uniform flow.

Velocity: The average velocity, computed from the discharge (Q) divided by the cross-sectional area of flow (Area).

Area: The cross-sectional area of flow at the given stage.

Conveyance: The conveyance at the given stage, which can be found from Q divided by  $S^{0.5}$ .

The computations use the Manning Equation,

$$Q = \frac{1.49AR^{2/3}S^{1/2}}{n}$$

where n is the Manning coefficient, A is the cross-sectional area of flow, R is the hydraulic radius and S is the slope of the energy grade line. The slope of the energy grade line (S) is assumed equal to the channel slope (the value you entered for channel slope in the “Valley Cross-Section” form).

The Manning Equation can be written as,

$$Q = KS^{1/2}$$

where K is the conveyance,

$$K = \frac{1.49AR^{2/3}}{n} = \frac{Q}{S^{1/2}}$$

[Appendix B](#) contains additional information on the Stage-Discharge computations.

## Valley Q-Stage Calcs

Click “Valley”, “Valley Q-Stage Calcs” to display the “Q-Stage Calculations for the Valley Cross-Section” form. You can use this form to compute the stages for discharges you select. This may be more convenient than interpolating values from a rating curve. Or you can have the discharges computed for stages you select.

All computations use the Valley Cross-Section and Channel Slope information you have entered in the “Valley Cross-Section” form. The Manning equation is used, and it is assumed the slope of the energy grade line is equal to the slope of the channel bottom (uniform flow).

### Calculator Pad

The grid on the left is a “calculator” pad you can use as needed. The computation options are shown in the “Select Calculation Option” frame below the grid.

For example, if you enter Q values in the “Q” column, set the option below the grid to “Given Q, Find Stage and Depth”, then click “Compute”, the software will compute the water surface stage and depth for the Q’s in the “Q” column, and display the computed Stages and Depths in the appropriate columns.

If the option is set to “Given Stage, Find Q and Depth”, when “Compute” is clicked the Stage values will be read from the table, and the computed Q’s and Depths for the given Stages will be displayed in the table.

If the option is set to “Given Depth, Find Q and Stage”, when “Compute” is clicked the Depth values will be read from the table, and the computed Q’s and Stages for the given Depths will be displayed in the table.

You can type values directly into the table, or use the “Copy Q’s” button to copy Q values from the Design Q Table.

If you right click on the table you can copy from, paste into, or insert empty rows into the table. See [Appendix A](#) for more information.

### Printing the Results

To print the results in the calculator pad grid, click the “Print the Table” button in the “Select Calculation Option” frame below the grid.

### Plotting/Printing a Selected Stage

To plot a selected stage, you must first select the row in the calculator pad with the stage value you want to plot. To select a row in the grid, simply click on any column in the row with the left mouse button. Then click “Plot Selected Stage”. This will produce a plot of the valley cross-section with the stage shown with a blue line, and the notation “Valley Stage”. To send a copy of the plot to the printer, click “Print the Plot”.

All the plot does is take the stage value in the selected row of the grid and plot it against the valley cross-section. It also displays the other information in the row (Return Period, Q, and Depth) on the plot. It is assumed that the data in the table was generated using the software (using “Compute”), which means it is assumed it was generated using the valley cross-section entered into the software.

## Valley Floodway

Click “Valley”, then “Valley Floodway” to display the “Floodway for the Valley Cross-Section” form. This form can be used to estimate the encroachment floodway limits for the valley. These limits are established by allowing encroachment on the flood plain of a stream, subject to the maximum backwater from encroachment not exceeding the stage for the natural conditions for a 100-year flood by more than an allowable limit (usually 1 foot).

The methods for floodway encroachment, and regulation of floodway encroachment, are defined as part of the floodplain management program of the Water Resource Section of the Iowa Department of Natural Resources. [Appendix C](#) is a copy of information from the Water Resource Section used as the basis for the computations in this form. You are encouraged to review this information.

The floodway encroachment is applied to the valley cross-section. If you have not already done so, you will need to first enter a valley cross-section (“Valley”, Valley Cross-Section”).

### Design Q’s

You will need to enter your floodway Design Q’s in the Design Q’s grid at the top left of the form. You can type them into the table, using the “\*” row to enter new values. If you have entered values into the Design Q Table you can use “Copy Q’s” button to copy the values from the Design Q Table.

Normally, the 100-year flood discharge is used as the Design Q.

When “Compute Floodway” is clicked, the computations will be done for the rows that have “Use” checked in the Design Q’s table.

### Auto Mode

In “Auto Mode” the software automatically finds the encroachment limits that meet the allowable rise due to encroachment. “Auto Mode” is specified by selecting “Find Encroachment Stations (Auto Mode)” as the “Specify Computation Option”.

You need to enter the “Allowable rise due to encroachment”. This is normally 1.0 foot, and this is the default value.

With this selection, click the “Compute Floodway” button to have the software find the encroachment limits for the Design Q’s with “Use” selected, subject to the allowable rise.

### Floodway Results for Auto Mode

We will use the example problem to discuss the floodway results. After you click “Compute Floodway”, the results are shown in the frame and grid beneath the button.

The “Computation Option Used” shows the criteria used for the floodway results. For “Auto Mode”, the “Mode” will be “Automatic”. The “Allowable Rise” used for the computations is shown.

The grid (table) shows the results of the computations, in column format: a single column shows the results for a single design Q. There is a column for each design Q in the design Q grid where “Use” is checked. The column headers “R1”, “R2”, etc. stand for Result 1, Result 2, etc.

We will discuss the results shown in the table, using the results for the example problem for the 100-year flood (Return Period = 100, Design Q = 21877). Again, all computations are applied to the valley cross-section.

The rows in the table are:

Return Period:

The return period, in years. This is simply a copy of the value you entered in the “Design Q’s” grid.

Design Q:

The design Q, in cfs. This is simply a copy of the value you have entered in the “Design Q’s” grid.

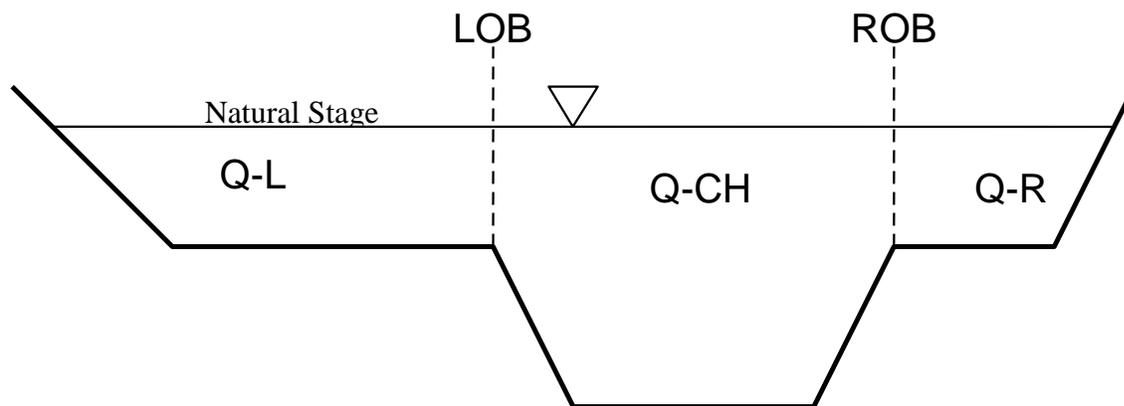
Natural Stage:

This is the computed water surface elevation (stage), for the “Design Q” applied to the valley cross-section, with no encroachment. This computation uses Manning’s equation, with the assumption of steady, uniform flow. This is the same methodology used for computing the valley rating curve. The floodway stage is actually computed to 1/1000 of a foot (0.001), but the solution is rounded off to the nearest 1/100 (0.01) of a foot for display.

Natural Depth:

The depth of the natural stage above the lowest elevation of the valley cross-section.

The notation that follows is that of the Water Resource Section of the IDNR, as shown in the figure below.



Q-L: For the natural stage and design Q, Q-L is the discharge to the left of the left overbank (LOB).

Q-CH: For the natural stage and design Q, Q-CH is the Q in the channel between the left overbank (LOB) and the right overbank (ROB).

Q-R: For the natural stage and design Q, Q-R is the discharge to the right of the right overbank (ROB).

Q-Chk: A check on the Q values.  $Q\text{-Chk} = Q\text{-L} + Q\text{-CH} + Q\text{-R}$ . The left overbank and right overbank are simply used to determine the distribution of the Design Q across the valley. Hence, “Q-Chk” should be

equal to the “Design Q”. It may be slightly different due to round off, but even with round off it should be within 1 or 2 cfs of the Design Q.

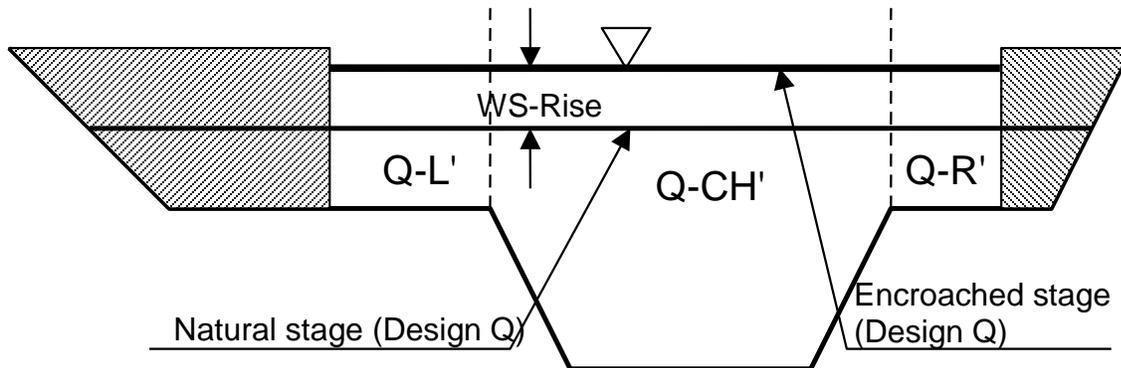
Q-OB: The sum of the overbank flows for the Design Q and natural stage:  $Q-OB = Q-L + Q-R$ .

Q-L OB%: The percentage of Q-L of the total overbank flow:  $Q-L\ OB\% = 100*(Q-L)/(Q-OB)$ .

Q-R OB%: The percentage of Q-R of the total overbank flow:  $Q-R\ OB\% = 100*(Q-R)/(Q-OB)$ .

$Q-L\ OB\% + Q-R\ OB\% = 100$  (subject to round off).

The above describe the conditions for the natural stage, the stage in the valley cross-section for the Design Q, without encroachment. If there is encroachment into the floodplain into the natural flow area, this will lead to an increase in the stage required to pass the Design Q. The concept of the floodway is; what encroachment will produce the allowable rise for the Design Q? This concept is illustrated in the following figure. In other words, after encroachment, the Design Q must be passed, and the increase in stage must not exceed the allowable water surface rise. In fact, we would like to know what encroachment will result in an increase in stage equal to the allowable (or target) water surface rise.



There are many encroachment locations that can result in the same increase in stage. For example, you might decrease the encroachment on the left overbank and increase the encroachment on the right overbank, and have the same increase in stage. Hence, additional criteria are applied.

The criteria are discussed in [Appendix C](#). In brief, after encroachment each overbank should convey the same percentage of the total overbank flow, as before encroachment. This criterion is applied in “Auto Mode”.

WS-Rise: The water surface rise due to encroachment, or the maximum allowable water surface rise that can be caused by encroachment. For “Auto Mode” this is simply a copy of the “Allowable rise due to encroachment”. For “Auto Mode” the encroachment limits will be determined, subject to meeting this allowable increase in the elevation of the natural stage.

Encroachment Stage: The stage with encroachment. This is simply the stage elevation that results from adding the “WS-Rise” to the ‘Natural Stage’. For “Auto Mode” the encroachment limits will be determined, subject to meeting this stage.

Q-CH': The discharge in the channel at the encroachment stage: the discharge in the channel (between the left and right overbanks) with the stage equal to the "Encroachment Stage". This will, of course, be larger than the channel discharge ("Q-CH") for the "Natural Stage". This is computed by the software, using the valley cross-section, the Design Q, the Manning's equation with steady, uniform flow, and the locations of the left and right overbanks.

Q-OB': The overbank discharge, after encroachment. The Design Q is the same both before and after encroachment. With more discharge in the channel, there will be less discharge in the overbanks. And since the Design Q remains the same, Q-OB' can be found from:

$$Q-OB' = (\text{Design } Q) - (Q-CH')$$

It is possible that the channel flow (Q-CH') may be greater than the Design Q, with the WS-Rise. In this situation, Q-OB' is shown as 0.

Q-L': The left overbank flow, after encroachment. By policy, this is to have the same percentage, or fraction, of overbank flow prior to encroachment (Q-L OB%). Q-L' is computed from:

$$Q-L' = (Q-OB') * (Q-L \text{ OB}\%)/100 = (Q-OB') * (Q-L)/((Q-L)+(Q-R))$$

Q-R': The right overbank flow, after encroachment. By policy, this is to have the same percentage, or fraction, of overbank flow prior to encroachment (Q-R OB%). Q-R' is computed from:

$$Q-R' = (Q-OB') * (Q-R \text{ OB}\%)/100 = (Q-OB') * (Q-R)/((Q-L)+(Q-R))$$

Q-L' OB%: The percentage of left overbank flow (of total overbank flow), after encroachment. This provides an easy check on the criteria. Q-L' OB % should be equal to Q-L OB%. The left overbank fraction of total overbank flow is set, by policy, to be equal before and after encroachment. Q-L' OB% is computed from  $Q-L' \text{ OB}\% = 100 * (Q-L') / (Q-OB')$

Q-R' OB%: The percentage of right overbank flow (of total overbank flow), after encroachment. This provides an easy check on the criteria. Q-R' OB % should be equal to Q-R OB%. The right overbank fraction of total overbank flow is set, by policy, to be equal before and after encroachment. Q-R' OB% is computed from  $Q-R' \text{ OB}\% = 100 * (Q-R') / (Q-OB')$

Q'-Chk: A check on the discharges before and after encroachment.

$$Q'-\text{Chk} = (Q-L') + (Q-CH') + (Q-R')$$

This should be, under normal conditions, equal to the Design Q. The exception is when the new channel discharge (Q-CH') is greater than the original Design Discharge.

### **Finding the Encroachment Limits**

Having defined the discharges required in the overbanks (Q-L' and Q-R') after encroachment, the real work is in finding the left and right encroachment locations, such that the target discharges occur. This is done by the software by iteration. Encroachment locations are selected and adjusted until the discharge between the encroachments and overbanks match the target discharges (Q-L' and Q-R').

Left Encroachment Limit: The station location where the discharge between this station and the left overbank is equal to (Q-L'). This is found by iteration. For an assumed left encroachment station the discharge between that station and the left overbank is computed and compared to the target discharge (Q-

L'). The left encroachment limit iteration starts at the left overbank and is then moved to the left until the discharge matches the target discharge (Q-L').

Q-L' Calc.: The actual computed discharge between the Left Encroachment Limit and the Left Overbank, rounded to the nearest cfs. This should match Q-L'. Any difference should be no more than a few cfs, due to round-off.

Right Encroachment Limit: The station location where the discharge between this station and the right overbank is equal to (Q-R'). This is found by iteration. For an assumed right encroachment station the discharge between that station and the right overbank is computed and compared to the target discharge (Q-R'). The right encroachment limit iteration starts at the right overbank and is then moved to the right until the discharge matches the target discharge (Q-R').

Q-R' Calc.: The actual computed discharge between the Right Encroachment Limit and the Right Overbank, rounded to the nearest cfs. This should match Q-R'. Any difference should be no more than a few cfs, due to round-off.

Left Floodway Width: The horizontal distance between the Left Encroachment and the Left overbank.  
 Left Floodway Width = Left Overbank Station – Left Encroachment Station. The distance to the left of the left overbank that should not be encroached.

Right Floodway Width: The horizontal distance between the Right Encroachment and the Right overbank.  
 Right Floodway Width = Right Encroachment Station - Right Overbank Station. The distance to the right of the right overbank that should not be encroached.

### **Printing the Floodway Results**

To send a copy of the floodway results to the printer, click “Print the Data”. This will print all results in the table, in a tabular form.

### **Plotting the Floodway Results**

To plot the floodway, you must first select the results you wish to plot. To select a result, click with the left mouse button the column in the grid you want to plot. You may click on any row in your column of interest. Then click “Floodway Plot”. This will display the “Valley Floodway Plot” form, which provides a visual representation of the results.

The valley cross-section is shown, with the channel bottom in red. The left overbank (LOB) is shown with the “O” in LOB centered on the left overbank location. The right overbank (ROB) is shown with the “O” in ROB centered on the right overbank location.

The “Natural Stage” is shown as a blue line. The red horizontal line above the “Natural Stage” shows the “Encroached Stage”. The vertical green lines show encroachment limits. The left vertical green line shows the “Left Encroachment Limit”. The station for the “Left Encroachment Limit” is shown at the top of the line. The right vertical green line shows the “Right Encroachment Limit”. The station for the “Right Encroachment Limit” is shown at the top of the line.

To send a copy of the plot to the printer, click “Print the Plot”.

To return to the floodway calculation form, click “Close”, or the “X” at the top right of the form.

## Manual Mode for Floodway Calculations

In “Auto Mode”, the encroachment locations that will produce the target rise in the stage for the Design Q’s are determined, subject to the overbank percentages being the same for the natural and encroached stage.

In Manual mode, you enter encroachment locations and the increase in stage and overbank percentages are determined. Manual mode may be useful to estimate the stage increase from a proposed or existing encroachment.

To use manual mode:

Enter the Floodway Design Q’s in the grid at the top left.

Enter the “Allowable rise due to encroachment”. Note that this number can represent your allowable target. The actual rise will be computed, based on the encroachment stations you enter.

Select “Input Encroachment Stations (Manual Mode)” for “Specify Computation Option”.

Enter the “Left Encroachment Station (ft)”.

Enter the “Right Encroachment Station (ft)”.

Click “Compute Floodway”.

The rise and overbank percentages are computed for the encroachment stations you have entered.

The “Computation Option Used” shows that the results are from “Manual” mode and the encroachment stations that were used for the computations.

Keep in mind that for Manual mode, the calculations are based on the encroachment stations you entered. Whereas for Auto Mode, the encroachment stations that meet the allowable rise and overbank criteria are found by the software.

The rows in the results table for manual mode are:

Return Period: the return period, in years. This is simply a copy of the value you entered in the “Design Q’s” grid.

Design Q: the design Q, in cfs. Again, this is simply a copy of the value you have entered in the “Design Q’s” grid.

Natural Stage: This is the computed water surface elevation (stage), for the “Design Q” applied to the valley cross-section. This computation uses Manning’s equation, with the assumption of steady, uniform flow. This is the same methodology used for computing the valley rating curve.

Natural Depth: The depth of the natural stage, measured above the lowest elevation in the valley cross-section.

Q-L: For the natural stage and design Q, Q-L is the discharge to the left of the left overbank (LOB).

Q-CH: For the natural stage and design Q, Q-CH is the Q in the channel, which is between the left overbank (LOB) and the right overbank (ROB).

Q-R: For the natural stage and design Q, Q-R is the discharge to the right of the right overbank (ROB).

Q-Chk: A check on the Q values.  $Q\text{-Chk} = Q\text{-L} + Q\text{-CH} + Q\text{-R}$ . The left overbank and right overbank are simply used to determine the distribution of the Design Q. Hence, “Q-Chk” should be equal to the “Design Q”. It may be slightly different due to round off, but even with round off it should be within 1 or 2 cfs of the Design Q.

Q-OB: The sum of the overbank flows for the Design Q and natural stage:  $Q\text{-OB} = Q\text{-L} + Q\text{-R}$ .

Q-L OB%: The percentage of Q-L of the total overbank flow:  $Q\text{-L OB}\% = 100 \cdot (Q\text{-L}) / (Q\text{-OB})$ .

Q-R OB%: The percentage of Q-R of the total overbank flow:  $Q\text{-R OB}\% = 100 \cdot (Q\text{-R}) / (Q\text{-OB})$ .

$Q\text{-L OB}\% + Q\text{-R OB}\% = 100$  (subject to round off).

The above describe the conditions for the natural stage, the stage in the valley cross-section for the Design Q, without encroachment.

The encroached results are based on the encroachment locations you have entered.

WS-Rise: The water surface rise due to encroachment limits you have entered. This is the computed water surface rise for the manual encroachment limits. It will not be, except by chance, equal to the “Allowable Rise”. For manual mode, using the encroachment limits you have entered, the water surface rise is the increase in stage that will result in the Design Q as the discharge between the left and right encroachment stations.

Encroachment Stage: The stage with encroachment. This is simply the stage elevation that results from adding the “WS Rise” to the “Natural Stage”. At the encroachment stage, the discharge is equal to the design Q between the left and right encroachment stations.

Q-CH’: The discharge in the channel at the encroachment stage: the discharge in the channel (between the left and right overbanks) with the stage equal to the “Encroachment Stage”. This will, of course, be larger than the channel discharge (“Q-CH”) for the “Natural Stage”. This is computed by the software, using the valley cross-section, the Design Q, the Manning’s equation with steady, uniform flow, and the locations of the left and right overbanks.

Q-OB’: The overbank discharge, after encroachment. The Design Q is the same both before and after encroachment. With more discharge in the channel, there will be less discharge in the overbanks. And since the Design Q remains the same, Q-OB’ can be found from:

$$Q\text{-OB}' = (\text{Design Q}) - (Q\text{-CH}')$$

Q-L’: The left overbank flow, after encroachment. The discharge between the left encroachment station and the left overbank. For manual mode, this is computed.

Q-R’: The right overbank flow, after encroachment. The discharge between the left encroachment station and the left overbank. For manual mode, this is computed.

Q-L' OB%: The percentage of left overbank flow (of total overbank flow), after encroachment. For manual mode, it is not required that this be equal to Q-L OB%. You can compare this value to Q-L OB% to see how the left overbank percentage has changed for the encroachment stations you have entered.

Q-R' OB%: The percentage of right overbank flow (of total overbank flow), after encroachment. For manual mode, it is not required that this be equal to Q-R OB%. You can compare this value to Q-R OB% to see how the right overbank percentage has changed for the encroachment stations you have entered.

Q'-Chk: A check on the discharges before and after encroachment.

$$Q'-Chk = (Q-L') + (Q-CH') + (Q-R')$$

This should be equal to the Design Q, within round-off (at most a couple of cfs).

Left Encroachment Limit: In manual mode, this is simply the value you entered as the left encroachment station.

Q-L' Calc.: The actual computed discharge between the Left Encroachment Limit and the Left Overbank, rounded to the nearest cfs. This should match Q-L'. In manual mode, this is somewhat redundant.

Right Encroachment Limit: In manual mode, this is simply the value you entered as the right encroachment station.

Q-R' Calc.: The actual computed discharge between the Right Encroachment Limit and the Right Overbank, rounded to the nearest cfs. This should match Q-R'. In manual mode, this is somewhat redundant.

Left Floodway Width: The horizontal distance between the Left Encroachment and the Left overbank.  
Left Floodway Width = Left Overbank Station – Left Encroachment Station.

Right Floodway Width: The horizontal distance between the Right Encroachment and the Right overbank.  
Right Floodway Width = Right Encroachment Station - Right Overbank Station.

## Bridge Backwater Overview

When a bridge is placed in a floodway it does not normally span the entire floodplain. Hence, under flood conditions, say the 100-year flood, compared to the natural floodplain the bridge opening is likely to restrict the area of flow, (See Figure 1 and Figure 2 in [Appendix E](#)). Under such conditions we need to estimate the backwater caused by the bridge, and the flow conditions through the bridge, in order to protect both the upstream area from excessive flooding (above natural conditions) and, perhaps more importantly, to insure the bridge will not be damaged.

The purpose of the Bridge Backwater section of the software is to estimate the backwater due to a bridge and the flow conditions through the bridge (depth, velocity, etc.). For these computations, the software implements methodologies employed by the Iowa Department of Transportation and the Iowa Department of Natural Resources. The methodologies are based on the reference: Hydraulics of Bridge Waterways, Hydraulic Design Series No. 1, published by the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1978. This reference is often referred to as “HDS-1” from “Hydraulic Design Series No. 1”, and we will also refer to it as HDS-1. The user who performs bridge backwater

computations is encouraged to obtain a copy of this reference and read it. You can download a copy of HDS-1 in pdf format from the FHWA at:

<http://www.fhwa.dot.gov/engineering/hydraulics/pubs/hds1.pdf>

The hydraulics of bridges is complicated. Trying to solve the full 3-dimensional flow equations is difficult. HDS-1 is an approximate method based on theory, laboratory experiments and field studies, and requires much less information than would be required for a full 3-dimensional model. On the other hand, given the uncertainties in modeling real world processes (what is the design Q?, what are the Manning's n values?, etc.), using more sophisticated models would not necessarily guarantee a more accurate solution. When the uncertainty in the magnitude of the 100 year flood can easily be 30%, some approximations in the solution of the backwater seem reasonable.

The information required for estimating the bridge backwater includes:

The valley cross-section. This is the natural cross-section of the channel and floodplain, **without the bridge**. This cross-section is typically taken 100 or more feet downstream or upstream of the proposed bridge location. At a proposed bridge location, the valley cross-section must be surveyed outside the earthwork for the bridge. The valley cross-section should represent a "typical" cross-section in the vicinity of the bridge. If your valley cross-section contains features that are not typical (i.e. a scour hole, etc.) you may need to edit the cross-section data.

The bridge cross-section. The cross-section at the bridge, taken along the road centerline. This is a survey of the bridge opening.

Bridge abutments and piers. The type of bridge abutments and the types and locations of the piers need to be defined.

Location of the bridge opening with respect to the valley cross-section. The horizontal and vertical location of the bridge opening with respect to the valley cross-section must be defined. The distribution and amount of flow that must contract to pass through the bridge opening has a major, usually the largest, impact on the magnitude of the backwater.

Bridge to river skew. The angle of the river flow direction with respect to the bridge opening, abutments and piers will affect the backwater.

The Design Discharges (Q).

The forms for Bridge Backwater are under 2 main menu items: "Bridge-River-Valley" and "Backwater".

In order to compute the bridge backwater, you must have entered in the required information in the forms under the **Bridge-River-Valley** menu item. These are:

- "Valley Cross-Section",
- "Bridge Cross-Section",
- "Bridge Piers"
- "Bridge-River-Valley Relationship"
- "Road Grade Profiles (for Overtopping)"

You can then compute the bridge backwater, using the items under **Backwater**;

“Bridge Backwater (Without Roadway Overtopping)”

“Bridge Backwater (With Roadway Overtopping)”

If you wish to compute the backwater with allowance for roadway overtopping, you will first need to define the “Road Grade Profiles (For Overtopping)”.

## Bridge-River-Valley

### Valley Cross-Section

Click “Bridge-River-Valley”, then “Valley Cross-Section” to display the “Valley Cross-Section” form. There is only one valley channel cross-section form in the software. The same form is displayed when you select “Valley”, “Valley Cross-Section”. For convenience the valley cross-section data form can be reached from both places. You may have already entered the appropriate valley cross-section data. If not, you need to do it here.

Again, we want to emphasize the cross-section represents the natural channel conditions that exist **without the bridge**, and should be “typical” of the valley in the vicinity of the bridge.

Entering information into this form has already been covered in **The Valley Cross-Section, under Valley Computations**. Please refer to this section, if you need additional information on using this form for entering your valley cross-section data (it is the same form).

### Bridge Cross-Section

Click “Bridge-River-Valley”, then “Bridge Cross-Section” to display the “Bridge Cross-Section” form. This is where you enter the information required to define the water way opening through the bridge.

In the grid (table) of the left side of the form, enter the stations and elevations defining the sides and bottom of the bridge opening, along the centerline of the roadway. You should start at the top of the left bridge abutment (looking upstream), at the bottom of the bridge deck, and define the bottom elevation of the bridge opening to the top of the right bridge abutment at the bottom of the bridge deck.

Right clicking on the grid will bring up the Copy, Paste, and Insert Rows options. See [Appendix A](#) for more information on these options.

#### Bottom of Bridge Deck Location

Enter the station and elevation for the bottom of the bridge deck at the left and right abutments, in the “Bottom of Bridge Deck Location (looking up-stream)” frame. Use the same stationing origin as used for the bridge channel cross-section. This data is mainly used to plot the approximate location of the bridge deck. Even if the bottom of the bridge deck is curved, you are only entering the two end points of the bridge deck, and it will be plotted as a straight line.

#### Low Structure Elevation (ft.)

Enter the elevation of the lowest deck structure between the abutments. This is sometimes referred to as the “low steel”. This elevation is used to determine the freeboard: the vertical distance between the water surface elevation and the low structure elevation.

### Bridge Abutment Type

Select the bridge abutment type from the drop-down list in the “Bridge Abutment Type” frame. Most bridge abutments in Iowa are spill through, but if you have a Wing Wall, select the closest degree angle from the list.

### For Abutment Scour Plotting

In the frame “For Abutment Scour Plotting” enter the left abutment elevation (Left Abutment Elev.) and right abutment elevation (Right Abutment Elev.). These elevations are *only* used for plotting the bridge abutment scour. On the plot for abutment scour, the abutment scour depths are subtracted from these elevations to estimate abutment scour elevations.

### Printing the Data

To send a copy of the data you have entered to your printer, click the “Print the Data” button at the top-left corner of the form.

### Plotting the Bridge Cross-Section

After you have entered all the bridge information you can plot the data by clicking the “Plot the Cross-Section” button. This will give you a visual display of the bridge cross-section. Keep in mind that the vertical and horizontal scales are selected by the software to make the plot as large as possible, so the plot may not appear have the same relative x-y appearance as the site plans, and will almost certainly have a vertical exaggeration.

To send a copy of the plot to your printer, click “Print the Plot”.

## Bridge Piers

The backwater and bridge scour are affected by the type and angle of the piers. You need to enter the information for the piers. Click “Bridge-River-Valley”, then “Bridge Piers” to display the “Bridge Piers” form.

You use this form to define the piers for your bridge. The table at the top-left of the form displays the piers you have entered. This table is used only for display; you do not enter or edit data directly in this table.

To enter, edit or delete piers you use the buttons (“Add A New Pier”, “Edit Selected Pier”, “Delete a Pier(s)”) and the “Pier Information” frame below the table.

### To “Add A New Pier”

To add a new pier, click the “Add A New Pier” button. You enter the pier information in the boxes in the frame below the button, the “Pier Information” frame. This information includes:

Pier #: This is selected automatically by the software. There is nothing for you to enter here.

Station: This is the station location for the center of the pier, relative to bridge cross-section stationing, and along the centerline of the bridge road deck. You must use the correct station location, relative to the bridge cross-section. The pier will be plotted against the bridge cross-section, and the software will automatically locate where the pier intersects the bridge channel bottom, using the bridge cross-section data you have entered, and the station you have entered for the pier.

Elevation at Top of Pier: Enter the elevation for the **top** of the pier, using the datum for the bridge cross-section.

Pier Type: Select the pier type from the “Pier Type” drop-down list box. The Pier Types are:

- Single Round Column
- Round Nose Elongated
- Two Round Columns
- Pile Bent-Round
- Pile Bent-Square
- Pile Bent-Steel H
- Frame Pier
- T Pier
- Pile Bent Encased

Width of Pier ( $W_p$ ): Enter the width of the pier.

Length of Pier ( $L_p$ ): Enter the length of the pier. You must enter a length for the Pier, but if the Angle of Attach is 0 degrees, you can enter a length of 0.

Angle of Attack. Select the angle of attack for the river with regard to the pier.

If the pier is not aligned with the river flow (angle of attack greater than 0), then the software determines a projected width; the width of pier “the river sees”, from the angle of attack and the pier width and length. When the angle of attack is greater than 0, the length of the pier affects the computations for bridge backwater and bridge scour.

When you are done entering the pier information, click the “Update” button to add the new pier to the list of piers. The new pier will be displayed in the list of piers. Piers are automatically sorted by “Station”, and listed in order, from smallest station to largest station.

#### Editing a Pier

To edit a pier, first select the pier you want to edit. To select a pier, click on any column in the row containing the pier information you want to edit. When you click on a row in the table containing pier information, the information for that pier is displayed in the “Pier Information” frame. Click the “Edit Selected Pier” button to enable the frame for you to make changes. Make the changes you want. To save the changes, click “Update”. If you wish to cancel your changes and restore the original information, click “Cancel”.

#### Deleting a Pier(s)

If you wish to delete a pier or piers, first select the piers you want to delete. If you want to delete a single pier, simply left click on any column in the row containing the information for the pier. If you wish to select multiple piers to delete, first select the rows you want to delete. To select multiple rows, click on the row you want to start with using the left mouse button, and hold down the left mouse button. Drag the mouse to the row you want to end with and release the left mouse button.

After selecting the row or rows for the piers you want to delete, click the “Delete a Pier(s)” button. A message box will show the pier #'s you have selected for deletion, and confirm you want to delete.

#### Printing the Data

To print a copy of the pier data, in tabular form, click “Print the Data”.

#### Plotting the Piers

To plot the Bridge Cross-Section with the Piers, click the “Plot the Cross-Section” button. You need have previously entered the bridge cross-section information. The piers are plotted at the station location you have entered. The software determines where the piers intersect the bridge channel bottom by interpolating the pier station against the bridge cross-section. The width of the pier is shown to scale, using the horizontal scaling of the Station (x) axis.

To send a copy of the plot to your printer, click “Print the Plot”.

### **Bridge – River – Valley Relationship**

One of the most important contributions to bridge backwater and scour is the flow contraction caused by the bridge, which is influenced by the location and orientation of the bridge in the natural valley cross-section.

Click “Bridge-River-Valley”, then “Bridge-River-Valley Relationship” to display the “Bridge-River-Valley Relationship” form. You use this form to define the location of the bridge cross-section relative to the valley cross-section, both horizontally and vertically. You also define the skew of the bridge to the river flow direction.

In order to define the relationship you must have already entered the Valley Cross-Section and the Bridge Cross-Section.

#### **Bridge Skew**

The bridge skew is defined by the angle between the bridge road centerline and the river flow direction. Note that bridge skew does not refer to the alignment of abutments and piers with the river flow direction, but to the alignment of the bridge roadway centerline with the river flow direction.

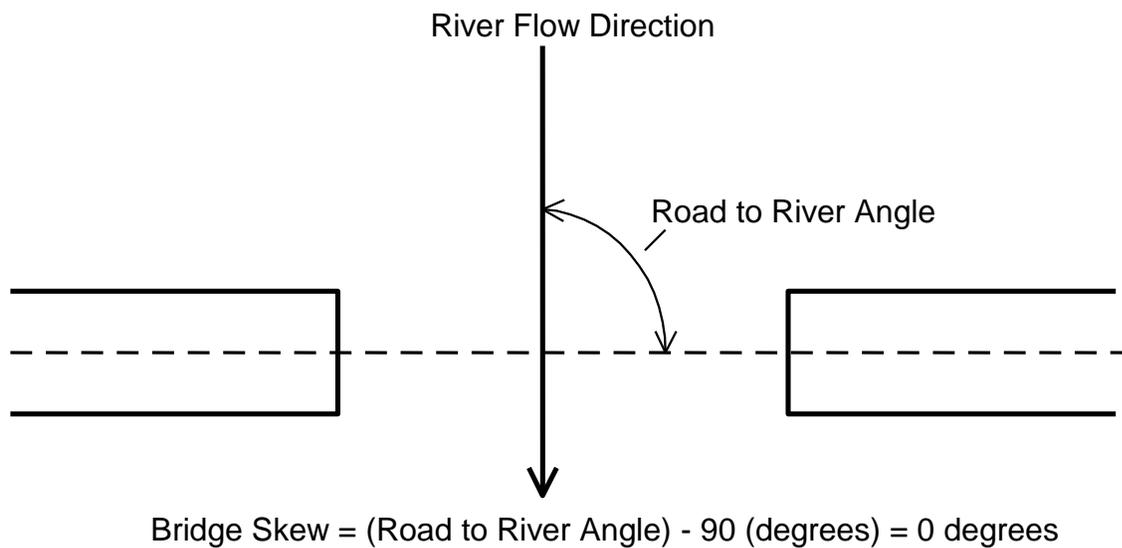
For our purposes, the angle entered into the software is the angle (in degrees) between the road and river. You must determine the bridge skew and enter it into the software. To see a visual representation of the skew click the “Plot the Skew” button. The plot is a representation of the skew between the river flow direction and the bridge road center line, using the “Bridge Skew” you have entered. If the skew amount or direction (left abutment ahead, versus right abutment ahead) is incorrect, correct the skew value and click “Plot the Skew”.

If the bridge road centerline and the river flow direction are normal (perpendicular), then enter a bridge skew angle of 0 degrees, as illustrated below.

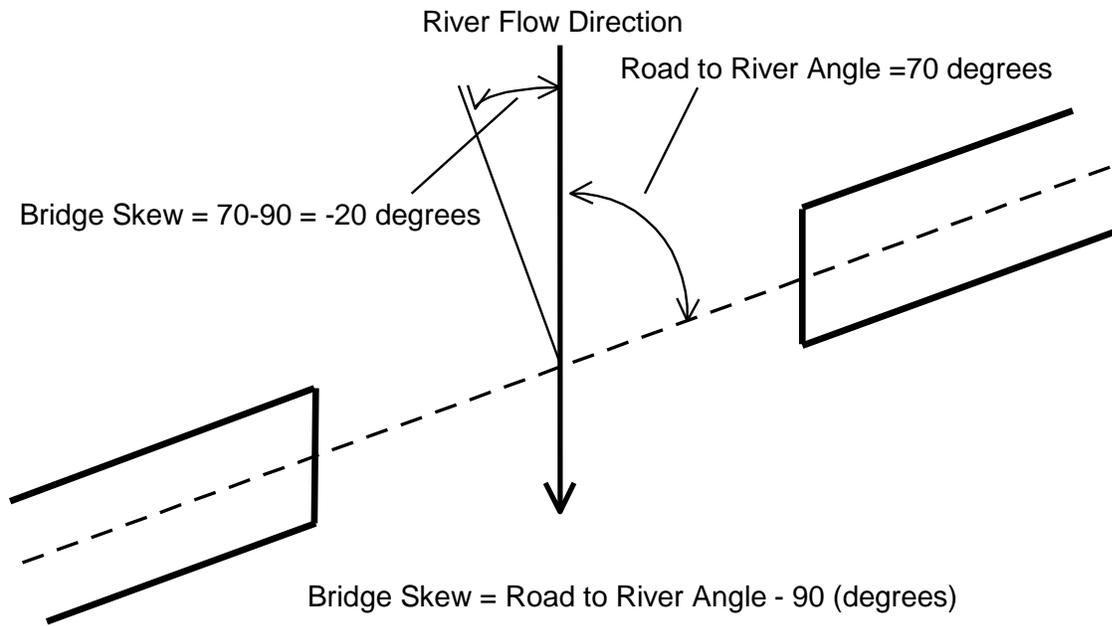
Looking up-stream, if you measure the angle between the roadway centerline and the river flow direction, as shown below, then the bridge skew is,

$$\text{Bridge Skew (degrees)} = \text{Road to River Angle (degrees)} - 90 \text{ (degrees)}$$

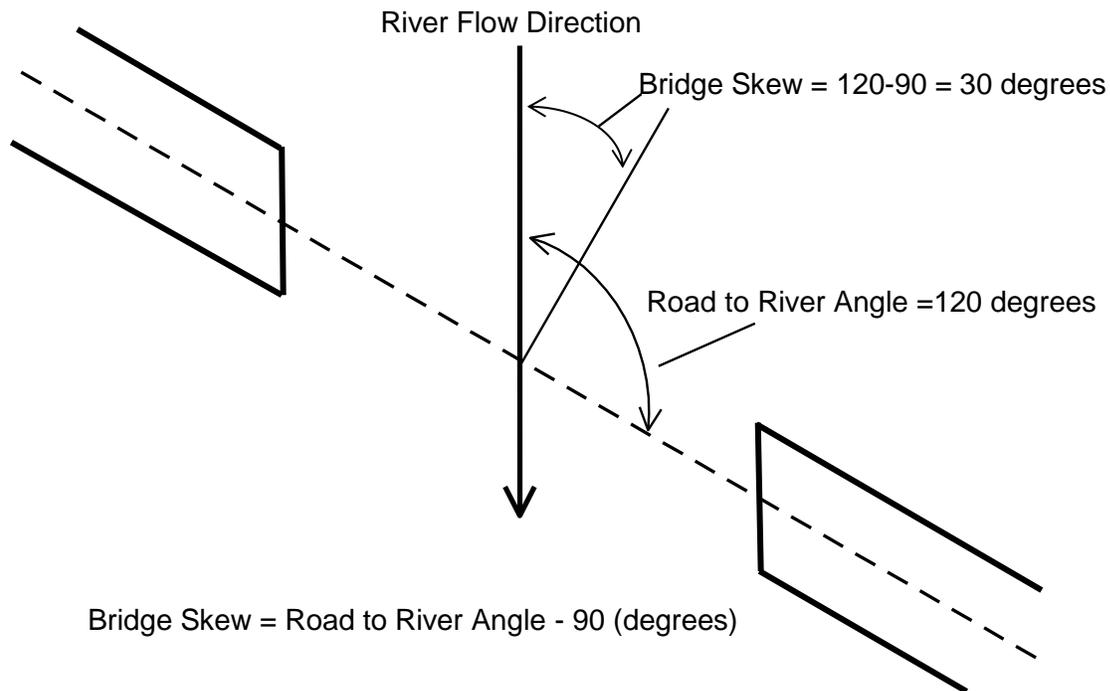
When the angle between the bridge road centerline and the river flow direction is 90 degrees, then the bridge skew = 0 degrees.



If the roadway and river flow direction are not at right angles (the Bridge Skew is not zero), then measure the Road to River angle, using the orientation shown below, and compute the bridge skew. The first figure below shows a bridge skew of -20 degrees (a minus value means right abutment ahead). The second figure below shows an example with a bridge skew on 30 degrees.



An example with the left abutment ahead (a positive bridge skew) is shown below,



## STATIONING

The “STATIONING” is used to define the horizontal alignment between the bridge and river cross-sections. That is to place the bridge cross-section at the correct horizontal location with respect to the valley cross-section.

Often, a different stationing origin is used for the valley and bridge cross-sections. In order to relate the bridge and valley stationing you must define the relationship between the bridge and valley stationing. You do this in the frame titled “STATIONING”.

To define the station relationship:

Select a convenient bridge station, based on the stationing you have entered for the Bridge Cross-Section, and enter it as “The Bridge STATION”.

For “The Bridge STATION” you have selected, determine the station for this point on the valley cross-section and enter it as “is equal to the Valley STATION”. This can be the center of the bridge with thalweg or the center of the channel.

To check your alignment click “Plot the Cross-Sections” and the bridge cross-section will be superimposed on the valley cross-section, using the Stationing relationship you have entered. Changing the “STATIONING” will shift the Bridge Cross-Section plot to the left or right (it will not shift the vertical placement).

Note: It is assumed the valley cross-section is perpendicular to the river flow direction. If the bridge is skewed, then the bridge cross-section shown in the plot has been adjusted to account for

the skew as it is projected onto the plane for the valley (a plane perpendicular to the river, as illustrated in Figure 4 of [Appendix E](#)).

## **DATUMS**

Normally the same “datum” is used to measure elevations for the Bridge and Valley Cross-Sections. If this is the case, you can leave the values in the “DATUMS” field blank. Or you can enter the same value for “A Bridge ELEVATION of “ and “is equal to a Valley ELEVATION of “. It is the difference in elevations that is important, not the actual values. If the same value is used this is equivalent to having the same datum for the bridge and valley cross-section elevations.

Note that this section is for a difference in the “DATUM” used to measure the elevations at the bridge and valley cross-sections, not a difference in elevations. We would expect the elevations to be different.

If the datums used for the bridge and valley cross-sections are different, then you must;

Pick any convenient bridge elevation and enter the value as “A Bridge ELEVATION of“.

For the bridge elevation you have selected, determine the elevation this point would have using the valley cross-section datum, and enter value as “is equal to a Valley ELEVATION of “.

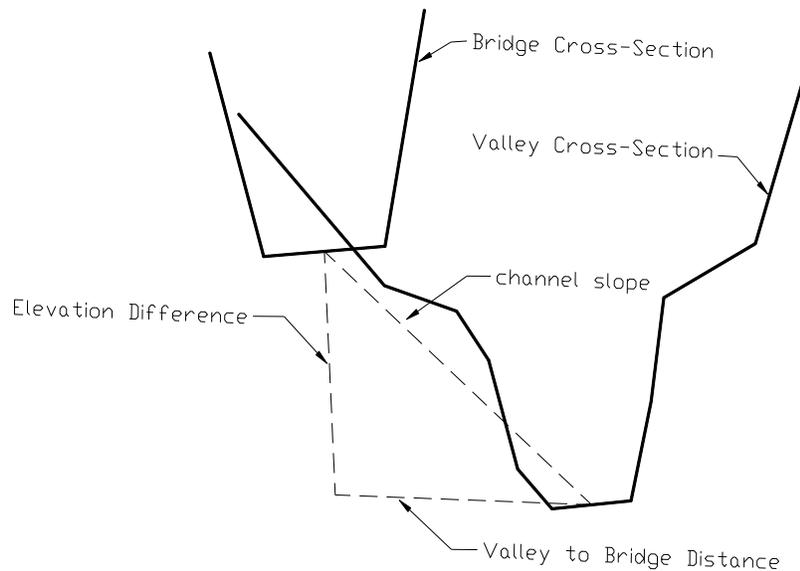
## **ELEVATION DIFFERENCE**

The “ELEVATION DIFFERENCE” is an estimate of the change in channel bottom elevation from the valley cross-section to the bridge cross-section. This elevation difference will be used to “move” the valley cross-section to the bridge, as illustrated in the following figure. The values are;

**Valley Channel Slope:** This is the channel slope you entered for the valley cross-section in the Valley Cross-Section form. It is repeated here for convenience.

**Distance from Valley Section to the Bridge:** You need to enter the distance from the valley cross-section to the bridge cross-section, along the main channel. If the valley cross-section is down stream of the bridge cross-section, enter the distance as a positive value. If the valley cross-section is upstream of the bridge cross-section, enter the distance as a negative value.

**Elevation Difference:** This is computed by the software and is simply:



Elevation Difference = (Channel Slope) x (Distance from Valley Section to the Bridge)

For example, if the channel slope is 0.01 ft/ft and the Distance from the Valley Section to the Bridge is 100 feet, then,

Elevation Difference = 0.01 x 100 = 1.0 feet

In short, if the Valley Cross-Section is moved to the location of Bridge Cross-Section, and the slope between the two is equal to the channel slope, the elevation difference is the amount that would be added to the valley cross-section to account for the channel slope and distance.

### Printing the Data and Skew Plot

To print a copy of the data you have used to define the Bridge – Valley –River relationship, click the “Print the Data” button at the top-left of the form. This will also print a copy of the bridge-river skew plot.

### Plot the Cross-Sections

To plot the super-imposed bridge and valley cross-sections, click the “Plot the Cross-Sections” button. This will bring up the “Bridge – Valley Relationship Plot”. The plot represents the super-position of the bridge and valley cross-section, using the data you have entered.

The x-axis is Valley Stationing. The Valley Cross-Section is shown in red, using its own stationing.

The Bridge Cross-Section is plotted in blue-green, using the equivalent valley stationing. The equivalent valley stationing is determined using the values you have entered for “STATIONING”, and also account for the “BRIDGE SKEW”. The result of this is to allow for the horizontal placement of the bridge cross-section in the valley cross-section. It is important that this horizontal alignment is correct. The horizontal alignment has a large impact on the backwater and scour calculations, and the horizontal placement of the bridge in the valley cross-section must be a reasonable approximation for your site conditions. The horizontal placement affects the computation of the flow distribution upstream of the bridge, as illustrated as  $Q_a$ ,  $Q_b$  and  $Q_c$  in Figures 1 and 2 in [Appendix E](#). In turn, the values of  $Q_a$ ,  $Q_b$  and  $Q_c$  affect the amount of backwater and scour.

The y-axis uses the “Elevation at the Bridge”. The bridge cross-section is plotted using the elevations you have entered for the bridge cross-section.

The valley elevations are plotted as if the valley “has been moved” to the bridge. That is, the computed “Elevation Difference” has been added to the valley elevations and these adjusted valley elevations values are plotted to represent the valley elevations at the bridge, if the valley is moved to the bridge, using the channel slope and distance from the valley to the bridge you have entered.

If the computed “Elevation Difference” is equal to the elevation difference between the lowest elevations in the valley and bridge cross-section then the valley and channel bottoms will have the same elevation on this plot. In practice, this is seldom the case. Often the bridge cross-section is taken at an existing bridge and the channel bottom has been reshaped by flow or man, and no longer presents the natural channel conditions. It may be that the valley cross-section is also not typical, and needs to be edited. Also, the channel slope estimated for the river in the vicinity of the bridge may not be representative of the channel slope between the bridge and valley cross-section. You can expect the bridge channel bottom and valley channel bottom not to line up exactly (vertically), but should be concerned if the difference is large.

The “Offset Difference”, shown at the top of the plot, is the difference between the lowest elevation for the bridge cross-section and the lowest adjusted valley elevation (the lowest valley elevation after the “Elevation Difference” has been added to the valley elevations).

If, after moving the valley to the bridge, the lowest bridge channel elevation and adjusted lowest valley channel elevation differs by more than 1 foot (If the “Offset Difference” is more than 1 foot), you are alerted to this by a message box. If you get this message, you may want to review your valley cross-section data and bridge cross-section data to ensure they are reasonable.

### **Printing the Cross-Section Plot**

To print a copy of the super-imposed bridge-valley plot, click the “Print the Plot” button.

### **Road Grade Profiles (For Overtopping)**

To enter the road profiles to check for overtopping click “Bridge-River-Valley”, followed by “Road Grade Profiles (For Overtopping)” to display the “Road Grade Profiles for Overflow” form.

Note that there are 2 tabs at the top of the form, one for the “**Left Overbank Road Grade Profile**” and one for the “**Right Overbank Road Grade Profile**”. It is assumed that left and right are based on looking up-stream, and that you have entered the valley and bridge cross-sections also using this same orientation.

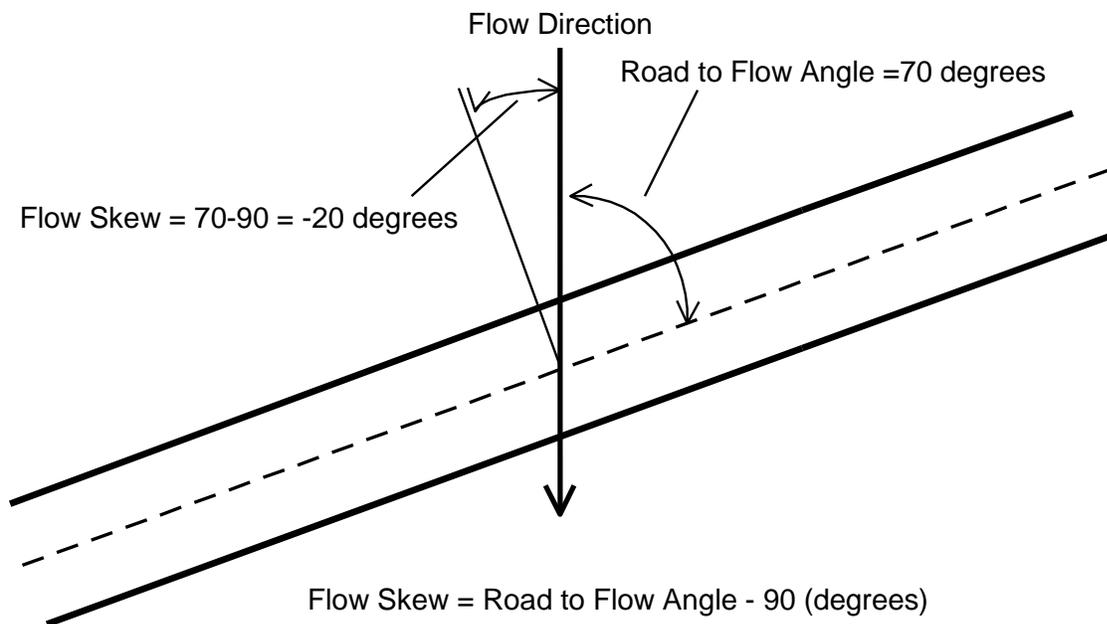
Since the overbank flow is likely different for the left and right overbanks, and the road grade profiles may be different to the left and right (looking upstream) of the bridge, the overtopping is likely to be different. The amount of overtopping on the left overbank is a function of the left overbank flow ( $Q_a$ ), the backwater elevation and the left overbank road grade profile. The amount of overtopping on the right overbank is a function of the right overbank flow ( $Q_c$ ), the backwater elevation and the right overbank road grade profile. That is, the Left Overbank Road Grade Profile is only used for computing the overtopping on the left, where  $Q_a$  is the flowrate available for overtopping on the left. The Right Overbank Road Grade Profile is only used for computing the overtopping on the right, where  $Q_c$  is the flowrate available for overtopping on the right.

You enter a road profile as a series of Station and Elevation points. Note that a road grade profile is not necessarily the profile for the bridge. The road grade profile you should enter for a side is the profile for the first location that would be overtopped by the backwater on that side. This would often be the bridge approach on that side.

Enter the stage and elevation data that describes the profile. The roadway is assumed straight line between points, so enter as many points as you feel are necessarily to capture the vertical curvature of the road.

If you right click on the table this will bring up the Copy, Paste, Insert Rows menu (See [Appendix A](#) for more information).

Flow Skew: If the flow direction over the road is not perpendicular to the road way centerline, you need to enter the amount of skew (degrees) from perpendicular. An example is shown below. In short, the flow skew is the amount (in degrees) the flow over road differs from perpendicular.



To plot a profile, click the “Plot the Profile” button. Keep in mind a profile will have a vertical exaggeration. To print a copy of a profile, click the “Print the Profile” button.

## Backwater

### Iowa DOT Bridge Backwater Limitations

Click “Backwater”, followed by “Iowa DOT Bridge Backwater Limitations” to display the “Iowa DOT Bridge Backwater Limitations” form. This form spells out the limitations on the use of the software for estimating backwater:

- (1) The channel is relatively straight.
- (2) The floodplain cross section is fairly uniform.
- (3) The stream slope is approximately constant.
- (4) The flow is free to contract and expand.
- (5) There is no appreciable score hole in the bed at the constriction.
- (6) The flow is in the sub critical range (Type I, non-pressure flow).
- (7) The bridge superstructure is not inundated sufficiently to create pressure flow.

### Bridge Backwater (Without Roadway Overtopping)

Click “Backwater”, followed by “Bridge Backwater (Without Roadway Overtopping)” to display the “Bridge Backwater – No Overtopping” form.

You use this form to compute the Bridge Backwater. Roadway overtopping is not considered. For many sites, this may be sufficient. The methodology for computing backwater is essentially the same methodology that is used by the IDOT for doing hand calculations. An example of a calculation worksheet is shown as Figure 3 in [Appendix E](#).

In order to compute the backwater you need to have entered:

- The Valley Cross-Section
- The Bridge Cross-Section
- The Bridge Piers
- The Bridge-River-Valley Relationship

#### Design Q's

Enter the Design Q's in the upper-left table. The backwater will be computed for each Design Q value in the table where “Use” has been checked. You can type the Q values directly into table. You can also click on the “Copy” button to copy the Q values from the Design Q Table.

#### Compute Backwater

To compute the backwater results click the “Compute Backwater” button. The backwater will be computed for each Design Q in the table where “Use” is checked, and the results displayed in the table beneath the “Compute Backwater” button. The results are displayed in columns. There will one column for each Design Q.

The results displayed in the table for each Q, starting with the top row are:

### Return Period

This is simply a copy of the value you entered for the return period in the Design Q's table.

### Design Q

A copy of the value you entered into the Design Q table, rounded to the nearest integer value. (If example, if you entered 10,000.99 this would be shown as 10,001). The results in the column are the results for this Design Q.

### Backwater: $h^*$

The calculated bridge backwater for the Design Q. In HDS-1 backwater is calculated from

$$h_1^* = K^* \alpha_2 \frac{V_{n2}^2}{2g} + \alpha_1 \left[ \left( \frac{A_{n2}}{A_4} \right)^2 - \left( \frac{A_{n2}}{A_1} \right)^2 \right] \frac{V_{n2}^2}{2g}$$

However, for the IDOT and IDNR a modified equation is used, and we use the modified equation in this software to compute backwater. The backwater equation used in this software is,

$$h^* = 1.5(K^*) \left( \frac{V_{n2}^2}{2g} \right)$$

This equation is the same as the equation used in the IDOT backwater determination sheet (Figure 3 in [Appendix E](#)). The modified equation is a reasonable approximation for the HDS-1 equation. The differences are in ignoring the second term on the right hand side of the HDS-1 equation (which makes a minor contribution to the backwater), and we assume  $\alpha_2$  is equal to 1.5.  $\alpha_2$ , the velocity head coefficient at the bridge, is difficult to calculate in a consistent manner, and 1.5 is assumed for practical purposes.

The backwater is calculated from many of the results shown below this row, but is shown as the third row of the results because it is the most important result.

### Free Board

The difference between the Low Structure Elevation you entered for the bridge cross-section and the Bridge Stage for the design Q. Or, how far the computed Bridge Stage is below the Low Structure Elevation (for a positive Free Board). If the Freeboard is negative, the Bridge Stage is above the Low Structure Elevation.

### Valley Stage

The calculated stage (water surface elevation) for the valley cross-section for the Design Q, without the bridge. In HDS-1 this is called the normal stage. This is computed using the Manning's equation and assuming steady, uniform flow (it is assumed the slope of the energy grade line is equal to the slope of the

channel bottom). This is the same method used for the rating curve calculations for the valley cross-section. Figure 2 in [Appendix E](#) illustrates the normal water surface (normal W.S.).

#### Valley Depth

The depth for the valley stage. This is really the maximum depth. It is the difference between the valley stage and lowest elevation in the valley cross-section.

#### Bridge Stage

The Bridge Stage is assumed to be equal to the Valley Stage, after adjustment for the slope and distance between the valley cross-section and the bridge cross-section. The “Elevation Difference” shown in the “Bridge – River – Valley Relationship” form is added to the valley stage to determine the bridge stage.

That is the bridge stage is assumed to be the same as the normal valley water surface, without the bridge. If you examine Figure 2 in [Appendix E](#) you can see that the stage at the bridge (at Sect. 2) is approximately equal to normal stage (the stage without the bridge). Of course, because of the bridge a backwater is created upstream of the bridge to generate sufficient energy to force the design Q through the reduced flow area created by the bridge. In HDS-1, the stage at the bridge is equal to the natural stage at the bridge (the stage without the bridge).

#### An2

The gross cross-sectional area (including the area occupied by the piers) of flow in the bridge cross-section at the bridge stage. Section C in Figure 2 in [Appendix E](#) provides an illustration.

#### Projected An2

If the bridge is skewed from the perpendicular, this is the area of flow projected onto the plane perpendicular to the river flow direction. This is the water flow area that “the river sees” at the bridge. If the bridge skew is 0, then the Projected An2 is equal to An2. If the bridge is skewed then the Projected An2 will be less than An2. Figure 4 in [Appendix E](#) illustrates the projection of the bridge opening on a plane perpendicular to the river cross-section.

#### Vn2

The average velocity in the bridge cross-section.

$$Vn2 = \frac{\text{Design } Q}{\text{Projected An2}}$$

#### b-Width Estimation (this heading is not a row in the table)

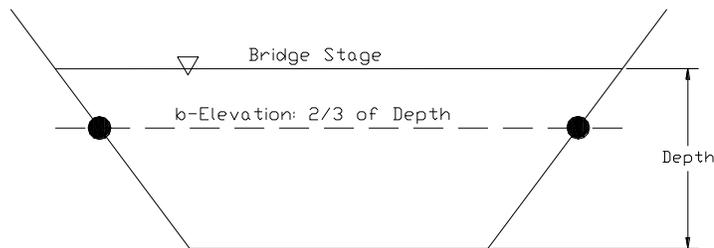
The b-width is an estimate of the effective width of the bridge opening for the purpose of passing the design flow, as illustrated in Figures 1 and 2 in [Appendix E](#). For vertical wingwalls the b-width is simply the distance between the wingwalls. For spill-through abutments the b-width must be estimated to account for the fact that the flow area above the spill-through abutments does not convey the full depth of flow. The flowing items are used to estimate the b-width.

#### Bridge b-Width Elev.

The bridge b-width elevation. The “b” points are used to determine the distribution of flow upstream of the bridge. That is, the distribution of upstream flow between the main channel (the bridge opening) and left and right of the effective bridge opening. The bridge b-width elevation is assumed to be equal to 2/3 of the depth water at the bridge. This is illustrated in the following figure.

#### Bridge b-Width Left Station and Bridge b-Width Right Station

After the bridge b-width elevation has been determined, the intersection of this elevation with the bridge cross-section is found, as illustrated in following figure. The left intersection is known as the Bridge b-Width Left Station and the right intersection is known as the Bridge b-Width Right Station.



#### Valley b-Width Left Station and Valley b-Width Right Station

Using the information you have defined for the relationship between the valley and bridge stationing, the valley b-Width Left Station and the Valley b-Width Right Station are determined from the Bridge b-Width Left Station and the Bridge b-Width Right Station. In other words, the equivalent valley stations are determined from the bridge stations and the relationship you defined for Valley-Bridge STATIONING in the Bridge – River – Valley Relationship form. The left and right “b” stations are used to determine the distribution of flow upstream of the bridge, as illustrated in Figures 1 and 2 in [Appendix E](#).

#### b-Width

Simply the distance between Valley b-Width Right Station and the Valley b-Width Left Station.

$$\text{b-Width} = \text{Valley b-Width Right Station} - \text{Valley b-Width Left Station.}$$

#### Qa, Qb, Qc

The distribution of flow in the valley upstream of the bridge, as a function of the design flowrate, the valley cross-section, the bridge cross-section and the location of the bridge cross-section in the valley cross-section, as Figure 1 and 2 in [Appendix E](#).

#### Q-Chk

This provides a check on the calculations.

$$Q\text{-Chk} = Q_a + Q_b + Q_c$$

Q-Chk should be equal to the “Design Q”, within a few cfs.

## M

The bridge opening ratio, it defines the degree of stream constriction due to the bridge, expressed as the ratio of the flow which can pass unimpeded through the bridge constriction to the total flow of the river. This is calculated as,

$$M = \frac{Q_b}{Q_a + Q_b + Q_c} = \frac{Q_b}{\text{Design } Q}$$

## Kb

The backwater coefficient. Usually the most significant factor in backwater is the constriction caused by the bridge. The flow on the banks ( $Q_a, Q_c$ ) must “squeeze” through the bridge. The backwater coefficient is a function of M. Figure 5 in [Appendix E](#) shows the backwater coefficient plot from HDS-1. For the software, the curves on the graph have been converted to equations, and Kb is calculated as a function of M and the type of abutment.

## e

The eccentricity of the upstream flow with regard to the bridge, as illustrated in Figure 6 in [Appendix E](#). A measure of the balance of the overbank flow ( $Q_a, Q_c$ ). If  $Q_a = Q_c$  the eccentricity is zero. Eccentricity is computed from,

$$e = \left(1 - \frac{Q_c}{Q_a}\right) \text{ where } Q_c < Q_a$$

$$e = \left(1 - \frac{Q_a}{Q_c}\right) \text{ where } Q_a < Q_c$$

## Ke

The incremental backwater coefficient due to eccentricity (e). This factor is found from Figure 6 in [Appendix E](#) (Figure 8 in HDS-1), and is a function of both M and e. The curves in the figure have been converted to equations for use in the software. For e values not represented as a curve the software interpolates between the curves. Ke is only applicable if 80% or more of the flow is conveyed on either overbank.

## A-Piers

The projected area of the piers normal to flow, between the normal water surface and the streambed. The software computes this using the Bridge Stage, the Bridge cross-section and the Pier information you have entered. This is the pier area the river “sees” at the bridge, at normal stage. This is illustrated in Figure 7 of [Appendix E](#).

## J

The ratio of the area obstructed by piers to the gross area of bridge waterway below the normal water surface, at the bridge.

$$J = \frac{\text{Pier Area}}{An^2}$$

## Kp

Incremental backwater coefficient due to the Piers. This is a function of the Pier Type and J, and is determined from Figure 7 in [Appendix E](#) (also Figure 7 in HDS-1).

## Skew (Deg.)

This is simply a repeat of the value you entered for the skew between the bridge opening and the river, in the Bridge – River – Valley relationship form.

## Ks

The incremental backwater coefficient due to the skew between the river and the bridge. This is determined from Figure 8 in [Appendix E](#) (Figure 10 in HDS-1) and is a function of M and the skew. It is assumed that the abutments are aligned with the river flow, so only plot A is used.

## K\*

The total backwater coefficient for subcritical flow. This is simply a sum of the factors that effect backwater, including constriction (Kb), eccentricity (Ke), Piers (Kp) and skew (Ks).

$$K^* = Kb + Ke + Kp + Ks$$

## Plotting the Backwater Results

After you compute the backwater you can produce 3 plots to illustrate the results; a plot for the bridge, a plot for the valley and a plot with the bridge and valley super-imposed. Before you can plot the results the results must have been computed and displayed in the grid.

## Selecting a Result to Plot

You must tell the software which results you want to plot. To do this you click on any row in the column containing the results you want to plot. Simply place the mouse cursor on any row in the column that contains the results you want to plot, and click once with the left mouse button.

## Bridge Backwater Plot

If you have opened the example problem, click in the column with a “Return Period” of 100 and click the “Bridge Backwater Plot” button. This will plot the:

Bridge cross-section, including the piers.

Stage at Bridge. The computed stage at the bridge, shown as a blue horizontal line. This is the estimated stage at the bridge for the design Q.

Stage at Bridge +  $h^*$ . This is the stage at the bridge, plus the backwater ( $h^*$ ), shown as a thin red horizontal line.

b-Left and b-Right. These are the station locations where a horizontal line that is  $2/3$  of the depth at the bridge, strikes the bridge cross-section. The actual intersection points are shown as black circles. The b-left and b-right locations are shown by black vertical lines extending upward from the black circles. The distance between b-Left and b-Right is assumed to be the effective opening width of the bridge (b-width), for the purpose of distributing flow upstream of the bridge ( $Q_a$ ,  $Q_b$  and  $Q_c$ ).

Included at the top of the plot is a data for which the plot applies, including

RP (Return Period)  
 Q (the Design Q)  
 $h^*$  (backwater)  
 and so on.

To send a copy of the plot to the printer click the “Print the Plot” button.

Click the “Close” button or the “X” in the upper right of the form to close the form and return to the backwater results.

### **Valley Backwater Plot**

To plot the results for the valley, select the results you want to plot (click in the column) and click the “Valley Backwater Plot” button.

Displayed are:

The valley cross-section, with a red line.

Stage at Valley: The computed valley stage, plotted as a horizontal blue line.

b-Left and b-Right: The b-Left and b-Right locations at the bridge after they have been super-imposed on the valley cross-section. These are used to determine the distribution of the design Q upstream of the bridge. Flow between b-Left and b-Right is assumed to pass directly through the bridge opening. Flow to the left of b-Left and the right of b-Right must be diverted in order to pass through the bridge opening.

$Q_a$ : The portion of the design Q to the left of b-Left. This is the valley flow left of the bridge opening which must contract in order to pass through the bridge opening.

$Q_b$ : The portion of the design Q between b-Left and b-Right. This is considered main channel flow and will pass directly through the effective bridge opening without having to contract.

$Q_c$ : The portion of the design Q to the right of b-Right. This is the valley flow to the right of the effective bridge opening which must contract in order to pass through the bridge opening.

### **Bridge-Valley Backwater Plot**

To plot the results with the Bridge and Valley super-imposed, click the “Bridge-Valley Backwater Plot” button to display the “Bridge-Valley Backwater Plot” form. This plot can be busy because it shows all the essential elements of the computed results.

The Bridge Cross-Section (blue-green) is shown super-imposed with the valley cross-section (red). This is the relationship as shown in the plot for the Bridge – River – Valley relationship. Valley stationing is used for the x-axis, and bridge elevation for the y-axis. For plotting elevation the valley has been “moved” to the bridge, using the channel slope and distance entered for the Bridge – River – Valley relationship.

The Bridge Stage is shown as the thicker blue horizontal line. The Bridge Stage +  $h^*$  (backwater) is shown as the horizontal red line.

The normal stage at the valley, translated to the bridge, is shown as the thin blue horizontal line, with the title “Valley Stage at Bridge” shown just below the line. The “Valley Stage at Bridge” and the “Bridge Stage” will have the same elevation.

### **Bridge Backwater (With Roadway Overtopping)**

You may compute the backwater for the case where there could be road grade overflow. With road grade overflow if the backwater elevation exceeds the lowest elevation of a road grade profile(s) the design discharge is balanced between flow through the bridge and flow overtopping a road grade profile or profiles. If a road grade is not overtopped, then the backwater results will be the same as the no road grade overtopping since the entire design Q passes through the bridge.

#### **Road Grade Profiles (For Overtopping)**

To enter the road profiles to check for overtopping click “Bridge-River-Valley”, followed by “Road Grade Profiles (For Overtopping)” to display the “Road Grade Profiles for Overflow” form.

For detailed information on entering Road Grade profiles, see the previous section on [Road Grade Profiles](#).

#### **Compute Backwater (With Roadway Overtopping)**

To compute the backwater with consideration of roadway overtopping, click “Backwater”, then “Compute Backwater (With Roadway Overtopping)” to display the “Bridge Backwater – With Roadway Overtopping” form. Backwater is computed here with consideration of possible overtopping of the road grade profiles that have been entered.

You first need to enter the Design Q’s. You can type in the values directly or copy the values from the Design Q Table using the “Copy” button.

After entering the Design Q’s, click the “Compute Backwater (With Overtopping)” button to compute the backwater with consideration of overtopping. The backwater will be computed for those rows in the Design Q table that have “Use” checked.

## How It Works

The software distributes the design Q as flow through the bridge, flow overtopping the left road grade profile and flow overtopping the right road grade profile. First, it is assumed the entire design Q passes through the Bridge and the backwater is computed. Then the elevation of the Bridge Stage + h\* (backwater) is compared to the lowest elevation of the Road Grade Profiles you have entered. If this elevation does not exceed the lowest road grade elevation for at least one of the road grade profiles, then no overtopping will take place and the solution is displayed (which will be the same as the solution without overtopping since no overtopping takes place).

If the Bridge Stage + h\* elevation is greater than the lowest elevation of a road grade profile then overtopping will take place, and an overtopping Q for the profile is computed, treating each road grade profile as a broad crested weir (See [Appendix D](#) for more information on overtopping computations). Note that two overtopping Qs are computed, one for the left (Q-Overtop-Left) and one for the right (Q-Overtop-Right).

However, with flow overtopping a road grade profile, the Q that passes through the Bridge will be reduced, reducing the backwater, which will reduce the overtopping, etc. The software iterates until convergence is reached: for the backwater computed for a given Bridge Q, the computed Q overtopping (the sum of Q-Overtop-Left and Q-Overtop-Right) plus the Bridge Q is equal to the design Q.

The description of many of the items shown in the results grid are the same as the grid without overtopping (although the values may be different). We will only discuss the differences in the results tables for overtopping and no overtopping.

### Q-Overtop

This is the Q overtopping the road grade profiles, at the Overtop Stage. Q-Overtop is the sum of Q-Overtop-Left and Q-Overtop-Right. These are computed treating each road profile as a broad crested weir. If Q-Overtop is "0", this means no overtopping occurred at the Design Q. The Q that overtops the road grades is assumed to **not** pass through the bridge opening.

### Overtop Stage

This is the stage at the roadway. The stage at the roadway is assumed to be equal to the bridge stage plus the backwater increment. Hence,

$$\text{Overtop Stage} = \text{Bridge Stage} + h^*$$

### Q-Overtop-Left

This is the overtopping Q for the Left Overbank Road Grade Profile. This Q is found by applying the Overtop Stage to the Left Overbank Road Grade Profile. The maximum Q available for overtopping is Qa (the valley flow left of the bridge opening which must contract in order to pass through the bridge opening). Q-Overtop-Left cannot exceed Qa.

### Max. OT Depth-Left

The maximum depth of flow over the Left Overbank Road Grade Profile. This is simply the Overtop Stage minus the lowest elevation of the left overbank road grade profile.

### Q-Overtop-Right

This is the overtopping Q for the Right Overbank Road Grade Profile. This Q is found by applying the Overtop Stage to the Right Overbank Road Grade Profile. The maximum Q available for overtopping is  $Q_c$  (the valley flow right of the bridge opening which must contract in order to pass through the bridge opening). Q-Overtop-Right cannot exceed  $Q_c$ .

### Max. OT Depth-Right

The maximum depth of flow over the Right Overbank Road Grade Profile. This is simply the Overstop Stage minus the lowest elevation of the right overbank road grade profile.

### Q-Bridge

The portion of the design Q passing through the bridge.

Design Q = Q-Bridge + Q-Overtop-Left + Q-Overtop-Right

Or

Q-Bridge = (Design Q) – (Q-Overtop-Left) – (Q-Overtop-Right)

The remainder of the results grid is the same as the backwater grid without overtopping, except the results for computing backwater for the bridge are adjusted. At convergence, Q-Overtop is going over the roadway and Q-Bridge is passing through the bridge. It is assumed the flow overtopping the road grade(s) will not pass through the bridge.

For a given Bridge Q, the backwater computation is adjusted for overtopping.

M is computed as  $Q_b/Q$ -Bridge. This will result in a larger M (compared to the no-overtopping case), and a smaller  $K_b$  value.

$V_{n2}$ : The average velocity through the bridge is computed from  $A_{n2}/(Q$ -Bridge). This will produce a smaller  $V_{n2}$  (compared to no-overtopping).

The effect of a smaller  $K_b$  value and smaller  $V_{n2}$  is a smaller backwater (compared to no over-topping).

All other factors remain the same as the no overtopping case. For example, the valley stage and bridge stage are assumed the same for the no-overtopping and overtopping situations.

### Plotting The Results

The first 3 plots have the same format as for backwater without overtopping, except that the results (backwater) are adjusted for the overtopping.

Two additional plots for overtopping has been added, one for the left road grade profile (LOB) and one for the right road grade profile (ROB). Click on the column with the results you want to plot, and click the “LOB-Road Grade Overflow Plot” or “ROB-Road Grade Overflow Plot” button to display the “Road Grade Overflow Plot” form for LOB or ROB, respectively. This form shows the road grade profile, and

the stage at the road grade as a blue horizontal line with the title “Overflow Stage (Bridge Stage +  $h^*$ )”. This stage results in the “Q-Overflow” value shown at the top of the plot. If there is no overflow, the blue line will be shown on the x-axis and “Q-Overflow” will be equal to 0.

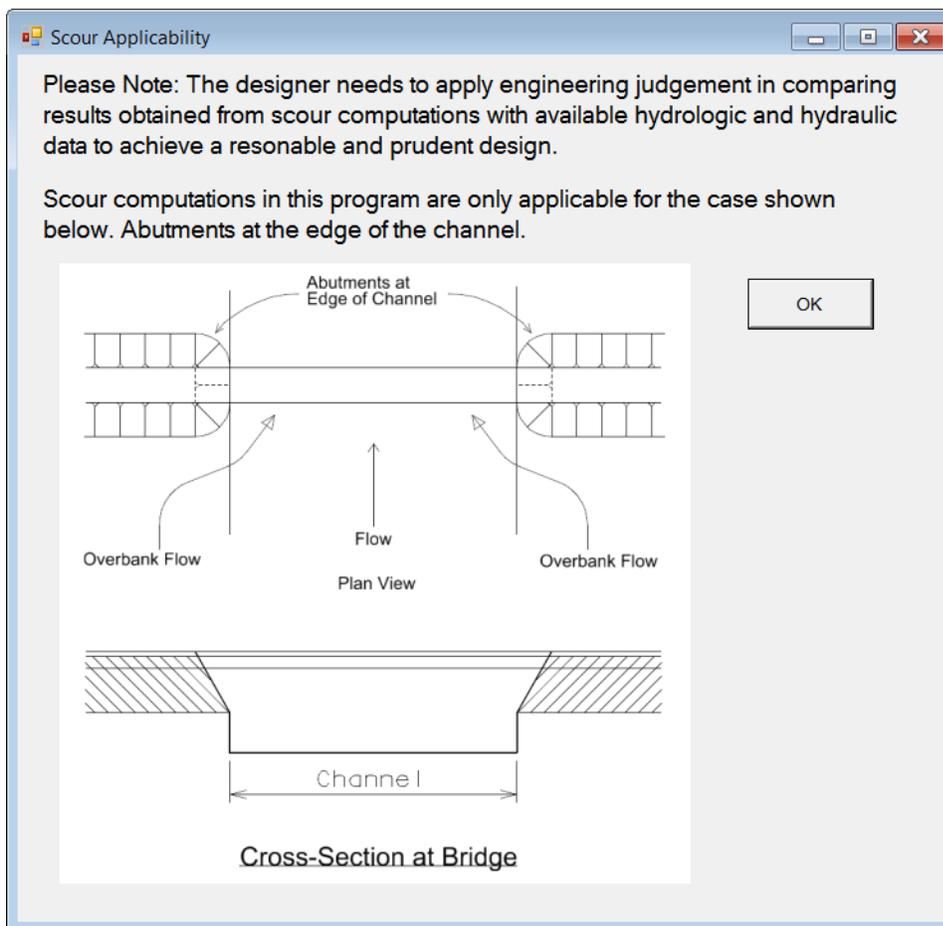
## Scour

Bridge scour estimation was added with version 2.0 of the Iowa Bridge Backwater software. The equations and methods have been primarily taken from HEC-18, Evaluating Scour at Bridges, Fourth Edition, and an Iowa Department of Transportation publication, Guidelines for Preliminary Design of Bridges and Culverts, Appendix C, Scour.

In this portion of the manual we will discuss the practical aspects of using the software for scour estimation. The details for how the calculations were done are contained in [Appendix F](#): Contraction Scour, [Appendix G](#): Abutment Scour and [Appendix H](#): Pier Scour.

## Scour – Abutment Assumptions

Click “Scour”, then “Scour – Abutment Assumptions” to display the “Scour Applicability” form.



The purpose of this form is to remind you that the scour computations in the software are only applicable for abutments at the edge of the channel. This condition is identified as Case 1B in HEC-18.

Click OK to close the form.

### **Preliminary Requirements**

Before scour computations can be done, you need to have entered, under “Bridge-River-Valley”, the following information

Valley Cross-Section  
 Bridge Cross-Section  
 Bridge Piers  
 Bridge-River-Valley Relationship

If you wish to have scour computed considering the effects of overtopping, then you will also need to input the information required under

#### Road Grade Profiles (For Overtopping)

This is the same information required for doing backwater computations.

### **Bed Material**

Click “Scour”, then “Bed Material” to display the “Bed Material: D50, D95” form. It is not required that you enter any information in this form, except if you want to compute clear water contraction scour. If you wish to compute clear water contraction scour, you need to enter a D50 (inches). You can directly enter values into the boxes in the “Clear Water” frame

You can also have the information copied from the table showing the Soil Class and associated D50. To copy the information from the table, click on a row and click Copy and the information is copied to the Soil Class and D50(inches) boxes. The table is from information provided by the Iowa Department of Transportation.

If you enter both D50 and D95 values they will be used to calculate the  $K_4$  coefficient of the CSU Pier Scour equation ([Appendix H](#)). However, this is optional. If you do not enter both D50 and D95 values a default value will be used for  $K_4$ .

### **Bridge Scour (Without Roadway Overtopping)**

To display the “Bridge Scour (Without Roadway Overtopping)” form, click “Scour”, followed by “Bridge Scour (Without Roadway Overtopping)” in the drop down menu. This form estimates bridge scour, without consideration of roadway overtopping, even if roadway overtopping is possible. The entire Design Q is assumed to pass through the bridge opening.

To compute the scour, you need to enter the Design Q's, select a Contraction Scour Method and enter the “Active Flow % for Effective Length” for Froehlich Abutment Scour.

Design Q's: Enter the Design Q values to be used for scour evaluation. You can enter the values directly, or click the "Copy" button to have the software copy the values you have entered into the "Design Q Table".

Contraction Scour Method: Select the method for computing the contraction scour, either "Live-Bed" or "Clear-Water". Most streams in Iowa are probably Live-Bed and it is recommended you start with that selection. As part of the Scour computations the "Details" tab will display whether Live-Bed or Clear-Water is indicated for the situation, and you can change your scour method selection, if needed.

Froehlich Abutment Scour: Enter the "Active Flow % for Effective Length" that will be used when computing the abutment scour by the Froehlich method. Note that 75% is recommended. How this parameter is used is discussed in [Appendix G](#).

Compute Scour: To estimate the scour depths, click the "Compute Scour (Without Overtopping)" button. Scour will be computed for Design Q values with "Use" checked.

### Scour Estimates

The "Scour Estimates" tab contains the resulting scour estimates.

The first table shows the values for Type, Soil Class, D50, D95, Active Flow % and Piers Angle of Attack that were used in the computations. The "Type" indicates whether the computations are "Live-Bed" or "Clear-Water".

For each design Q with "Use" checked, the estimated scour depths results are shown for:

#### Contraction Scour

The results are shown for either Live-Bed or Clear-Water, depending on your selection for Contraction Scour Method. [Appendix F](#) discusses the details of how contraction scour is computed.

If you click the "Details" tab you will find a row "Live-Bed or Clear-Water Calc". This indicates, based on the critical velocity, whether Live-Bed or Clear Water is recommended as the computational choice for each Q (see [Appendix F](#) for more details on this computation). Note that the results here are based on the critical velocity calculation and are not indications of the method used for the contraction scour calculations. The method used for the contraction scour calculation is the same for all flowrates and is selected by the user based on their selection in the "Contraction Scour Method" frame. The method used for the calculations is indicated by the "Type" in the Scour Estimates tab. The user may wish to check "Live-Bed or "Clear-Water Calc" results in the Details tab to determine whether their "Contraction Scour Method" selection was appropriate.

#### Abutment Scour

The scour results are shown for the left abutment, followed by the right abutment. For each, the results for two methods of estimating abutment scour are shown; Froehlich and HIRE. In some situations the HIRE method is not applicable, and when this is the case "N/A" will be shown. [Appendix G](#) covers the details of abutment scour estimation.

#### Pier Scour

Pier Scour estimates are shown for each pier entered into the software. The piers are listed in order of increasing station location. For each pier, two methods are used for estimating scour, the “Laursen” method and the “CSU” method. [Appendix H](#) covers the details of pier scour estimation.

It should be noted that for the Laursen method the scour estimation will increase with increasing  $Q$ , until the maximum depth of flow for the pier has been reached. The depth of flow for the pier will increase with increasing bridge stage, until the bridge stage exceeds the low structure elevation. Once the bridge stage exceeds the low structure elevation the depth of flow for the pier will have reached the maximum for the pier, and further increases in the bridge stage will not result in an increased scour depth.

The depth of flow at all piers is considered to be the maximum depth of flow in the bridge cross-section and is **not** the depth where the pier intersects the channel bottom. Since the software implements Case 1B in HEC-18, where the abutments are at the edge of the channel, it is assumed the channel could migrate and expose the pier to the depth based on the minimum channel bottom elevation. This implies the flow depth will be the same for all piers for a given  $Q$ .

The CSU method depends on the velocity of flow through the bridge and the scour depth will continue to increase with increasing  $Q$ , even after the maximum depth of flow for the piers has been reached. However, when the angle of attack for a pier is zero, there are some limitations on the scour depth for the CSU method that may come into play. For round nose piers aligned with the flow (angle of attack = 0) an upper limit for scour depth is applied;

$$y_s \leq 2.4(w_p) \text{ for } Fr \leq 0.8$$

$$y_s \leq 3.0(w_p) \text{ for } Fr > 0.8$$

Where  $w_p$  is the pier width,  $Fr$  is the Froude number and  $y_s$  is the scour depth. The above upper limit is applied for all pier types in the software, except for “Pile Bent – Square” and “Pile Bent – Steel H”.

### Details and Coefficients

The “Details” and “Coefficients” tabs contain results for the factors used to calculate the scour estimates. The “Details” tab has results for each  $Q$  value for factors that can vary with the flowrate. The “Coefficients” tab contains values that are not a function of  $Q$ . [Appendix F](#), [Appendix G](#) and [Appendix H](#) contain detailed information on the definition and use of the values in the “Details” and “Coefficients” tabs.

### Print The Results

To print out a copy of the scour information, click the “Print the Results” button. This will bring up the “Scour Results Print Menu” where you can choose to have any combination of the results in the Scour Estimates, Details or Coefficients tabs printed.

### Scour Plot

To plot the scour depths on the bridge cross-section, from the Scour Estimates tab, click in the column with the Design  $Q$  you want to plot the results for, then click “Scour Plot”. The “Scour Plot” button will plot the results in the column selected in the Estimated Scour Depths table at the time the button is clicked. For each value, a label is shown on the plot with 2 values. The first value is the depth of scour and the second value is the estimated scour elevation (i.e. Froelich – 6.2, 914.5).

Since the scour estimates are depths, certain assumptions have been made to plot the scour elevations.

**Contraction Scour Elevation:** The contraction scour depth is subtracted from the lowest bridge cross-section elevation.

**Abutment Scour Elevations:** The abutment scour depths are subtracted from the elevations entered by the user in the Bridge Cross-Section form in the “For Abutment Scour Plotting” frame. The left abutment scour is drawn 5 feet to the left of the minimum bridge cross-section stage and the right abutment scour is drawn 5 feet to the right of the maximum bridge cross-section stage.

**Pier Scour Elevations:** The pier scour depths are subtracted from the minimum bridge channel elevation. Since the abutments are assumed to be at the edge of the channel it is assumed the channel could migrate and expose the pier to the minimum channel bottom elevation. The minimum bridge channel elevation is shown in the “Coefficients” tab as “Bottom Elevation”. This will be the same for all piers.

To print a copy of the plot, click the “Print the Plot” button on the “Scour-Bridge” form.

### **Bridge Scour (With Roadway Overtopping)**

To estimate bridge scour with the consideration of roadway overtopping, click “Scour” followed by “Bridge Scour (With Roadway Overtopping)” in the drop down menu. The organization and processes in this form are similar to those for bridge scour without overtopping. Please see the previous section for information on the using the form.

The procedures and methods for computing the overtopping flows left and right and the reduced flow through the bridge opening are exactly the same as those for computing overtopping for Backwater.

Bridge scour with roadway overtopping takes into consideration the reduced flow through the bridge opening when overtopping takes place. With overtopping the scour estimates will in general be reduced (all other things being equal), except for Laursen Pier Scour and HIRE Abutment scour.

Laursen pier scour is based on the depth of flow in the bridge opening and this depth is assumed to be the same with and without overtopping. Hence, all other things being the same, Laursen pier scour estimates are the same with or without overtopping.

HIRE abutment scour is based on the depth and velocity of flow adjacent to and upstream of the abutment. It was felt we could not reliably estimate the effect of overtopping on the flow regime at the abutment. The same methods were used to estimate the depth and velocity of flow adjacent to and upstream of the abutment both with and without overtopping. Hence, all other things being the same, HIRE abutment scour estimates are the same with or without overtopping.

All other scour estimates – Contraction (both live-bed and clear-water), Froehlich abutment scour, and CSU pier scour – depend to some degree, directly or indirectly, on the flowrate through the bridge, and overtopping, all other things being equal, will reduce the scour estimates.

The details of how reduced flow through the bridge with overtopping is applied to the scour estimates are covered in [Appendix F](#), [Appendix G](#) and [Appendix H](#).

This completes the user manual.

## References

Eash-2001: Eash, David A., Techniques for estimating flood-frequency discharges for streams in Iowa. U.S. Geological Survey, Water-Resources Investigation Report 00-4233, Iowa Department of Transportation and the Iowa Highway Research Board (Project HR-395A), Iowa City, Iowa 2001.

Eash-2003: Eash, David A., Main-Channel Slopes of Selected Streams in Iowa for Estimation of Flood-Frequency Discharges. U.S. Geological Survey, Water-Resources Investigation Report 03-4120, Iowa Department of Transportation and the Iowa Highway Research Board (Project HR-456), Iowa City, Iowa 2003.

Guidelines for Preliminary Design of Bridges and Culverts, Appendix C, Scour, Iowa Department of Transportation publication, January 11, 1999.

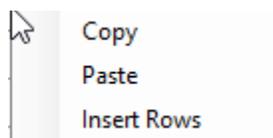
HEC-18: Hydraulic Engineering Circular No. 18, Evaluating Scour at Bridges, Fourth Edition, U.S. Department of Transportation, Federal Highway Administration, Office of Bridge Technology, Washington, D.C., 2001.

HDS-1: Hydraulic Design Series No. 1, Hydraulics of Bridge Waterways, U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, Washington, D.C., 1970. Revised 1978 Edition with Errata Sheet.

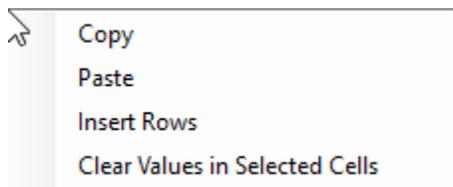
Lara-1987: Lara, Oscar G., Method for estimating the magnitude and frequency of floods at ungaged sites on unregulated rural streams in Iowa. U.S. Geological Survey, Water-Resources Investigation Report 87-4132, Iowa Department of Transportation, Highway Division, Highway Research Board, Iowa City, Iowa, 1987.

## Appendix A: Copying and Pasting Values

When you right click on selected tables you either see the menu



Or



**Copy**

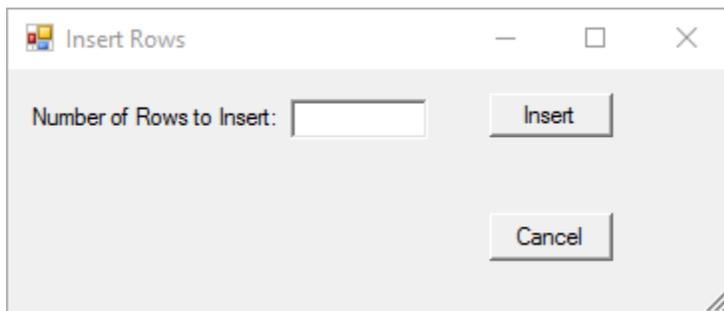
Selecting “Copy” will copy the selected items in the table to the clipboard. You can also use the keyboard shortcut Ctrl-C to copy selected items to the clipboard. Note that values copied to the clipboard can be pasted to other tables in the software or to other programs (such as Excel).

### Paste

“Paste will paste the content in the clipboard above the currently selected top row, adding rows as needed. Select the row you want to Paste content above before right clicking. Note that you can use Paste to add values that have been added to the clipboard from other programs. For example, if you copy values to the clipboard in Excel, you can then add them to the table using Excel.

### Insert Rows

“Insert Rows” will bring up the insert rows dialog,



Enter the Number of Rows to Insert, and that number of empty rows will be added above the currently selected top row.

To delete rows, select the rows you wish to delete and press the “Delete” key.

### Clear Values in Selected Cells

To erase the values in selected cells (without deleting the rows), select the items you wish to erase, then right click and select “Clear Values in Selected Cells”.

## Appendix B: Valley Stage-Discharge Computations

Valley stage-discharge computations are done using the Manning Equation,

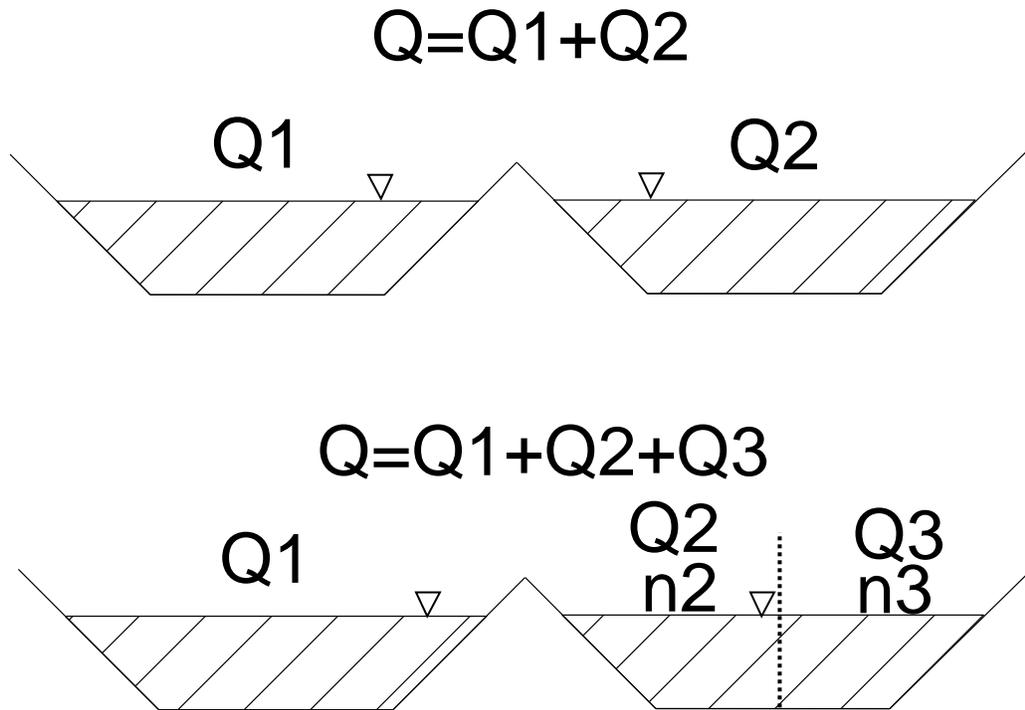
$$Q = \frac{1.49AR^{2/3}S^{1/2}}{n}$$

where A is the cross-sectional area of flow, R is the hydraulic radius, S is the slope of the energy grade line and n is the Manning coefficient. The hydraulic radius is,

$$R=A/P$$

Where P is the wetted perimeter.

In many cases, with a natural channel, the total Q is computed as the sum of sub-area Qs, as illustrated below. If there are multiple flow areas, the Q is computed for each flow area and summed. If there is a change in Manning n value, a sub-area is created and a sub-area Q is computed for each area where the Manning n is constant.



### Appendix C: Floodway Encroachment Limits

The following is taken from information provided by the Water Resource Section of the Iowa Department of Natural Resources.

#### Determination of Encroachment "Floodway" Limits

Encroachment "Floodway" limits are the limits established in the flood plain which designate the entire width of the channel and the minimum width of overbank areas needed to adequately convey the 100 year flood. These limits are established by allowing encroachment on the flood plain of a stream until a maximum of 1 foot of backwater is created over natural conditions for a 100 year flood. The concept of equal and opposite conveyance shall be applied in determining such limits. Basically, this means that the left and right overbanks shall carry the same percentage of the total overbank flow, respectively, following such encroachment as they did under natural conditions. In other words, if the left overbank carried 30 percent of the total overbank flow under natural conditions then it should carry 30 percent of the new total overbank flow after encroachment with 1 foot of backwater is included. The limits are for streams where the natural flood elevations were found by uniform, steady flow analysis (Manning's

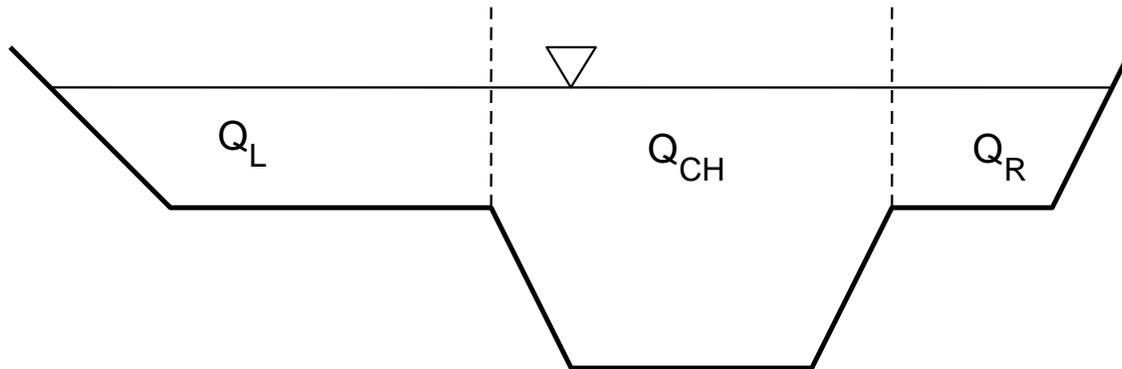
equation). HEC-2 has a special routine for determining the encroachment limits for streams where the natural flood elevations were also found by HEC-2 analysis. As for discharges, encroachment limits used for project reviews should be coordinated with the flood plain management staff to help assume consistency in regulation.

PROCEDURE:

determine 100 year discharge \*

determine 100 year flood elevation under natural conditions \*

determine left overbank, right overbank, and channel flow distribution: (this should include discharges, and percentages of total overbank flows)



$$\text{percent of total overbank flow carried by left overbank} = \frac{Q_L}{Q_L + Q_R} \times 100$$

$$\text{percent of total overbank flow carried by right overbank} = \frac{Q_R}{Q_L + Q_R} \times 100$$

$$\text{where: } Q_{\text{TOTAL}} = Q_L + Q_{\text{CH}} + Q_R$$

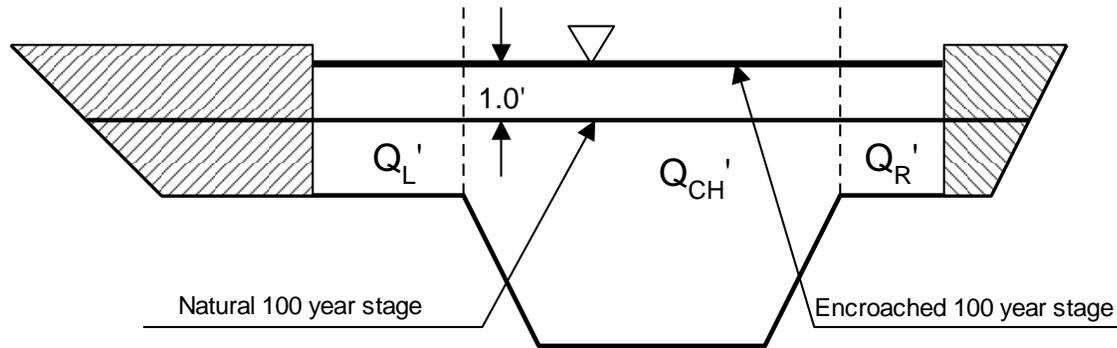
$$Q_{\text{OB}} = Q_L + Q_R$$

determine channel flow with 1 foot increase in the water surface elevation,  $Q_{\text{CH}}'$

$$Q_{\text{CH}}' = Q_{\text{CH}} + \text{additional channel flow carried by one foot increase in stage}$$

determine new left and right overbank flows, respectively, needed to assure same percentage of conveyance after encroachment as before.

$$\text{Total overbank flow with encroachment, } Q_{\text{OB}}' = Q_{\text{TOTAL}} - Q_{\text{CH}}' = Q_L' + Q_R'$$



$$Q_{\text{TOTAL}} = Q_L' + Q_{\text{CH}}' + Q_R'$$

left overbank flow with encroachment;  $Q_L' = (Q_L / Q_{\text{OB}}) \times Q_{\text{OB}}'$

right overbank flow with encroachment;  $Q_R' = (Q_R / Q_{\text{OB}}) \times Q_{\text{OB}}'$

determine encroachment limits:

This requires a certain amount of iteration on the part of the part of the review engineer. Assume a certain amount of encroachment and determine the resultant overbank flow (left or right). If the resultant flow exceeds the previously calculated overbank flow ( $Q_L'$  or  $Q_R'$ ) then more encroachment is needed. If the resultant flow is less than the previously calculated overbank flow ( $Q_L'$  or  $Q_R'$ ) then less encroachment is needed. Play with the encroachment limits for both overbanks until the resultant left and right overbank flows are approximately equal to  $Q_L'$  and  $Q_R'$ , respectively.

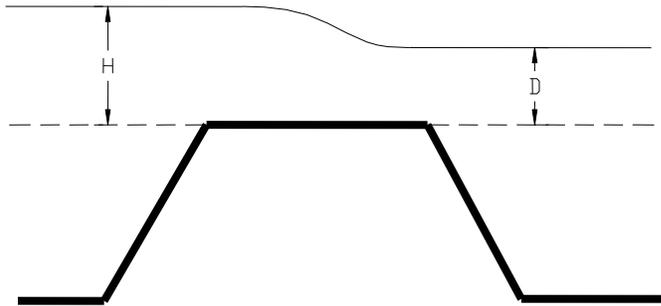
\* for agricultural levees, the 10 to 25 yr. flood should also be checked for encroachment limits.

## Appendix D: Computing Roadway Overflow

For a given or assumed stage at the roadway profile, this appendix describes how the flowrate ( $Q$ -overtop) is computed. The methodology is taken from HDS-1, section 8.5, Flow over roadway.

The  $Q$  for overtopping is computed from,

$$Q = C_f L H^{3/2} (C_s / C_f)$$



For our situation it is assumed the stage just downstream of the road is equal to the bridge stage and the stage just upstream of the road is equal to the bridge stage plus the backwater. These stages are then used to determine  $H$  and  $D$ , illustrated in the above figure.

The left most  $C_f$  value in the equation above is a function of the ratio of  $H$  to the width of the weir (top of the road). However,  $C_f$  only varies over a range from about 2.9 to 3.1. Hence, for practical purposes we have assumed a constant value for the left most  $C_f$  value of 3.0.

The  $(C_s/C_f)$  term in the equation above is the submergence factor, and varies as a function of  $(D/H)$ . The relationship is given as curve C in Figure 24 in HDS-1.

$L$  in the equation above is the length of the weir perpendicular to the flow direction, and it is assumed by the equation that the weir is horizontal; that is that  $H$  and  $D$  do not vary along the length of the weir. In our situation, as illustrated below, the roadway is generally not horizontal, and the values of  $H$  and  $D$  can change.



To account for this, the roadway overflow is divided up into sub-areas, as illustrated by the cross-hatched sub-area shown above. For each sub-area  $L$  is the width of the sub-area, and the average  $H$  and  $D$  is determined for the sub-area. Using the sub-area  $H$  and  $D$ , the sub-area  $(C_s/C_f)$  value is determined from curve C of Figure 24 in HDS-1. Using the sub-area values, the sub-area  $Q$  is determined from the above equation. The total  $Q$  is found by adding together the sub-area  $Q$ s. The sub-areas used to sub-divide the roadway overflow have a width of, at most, 1 foot.

## Appendix E: Numbered Figures

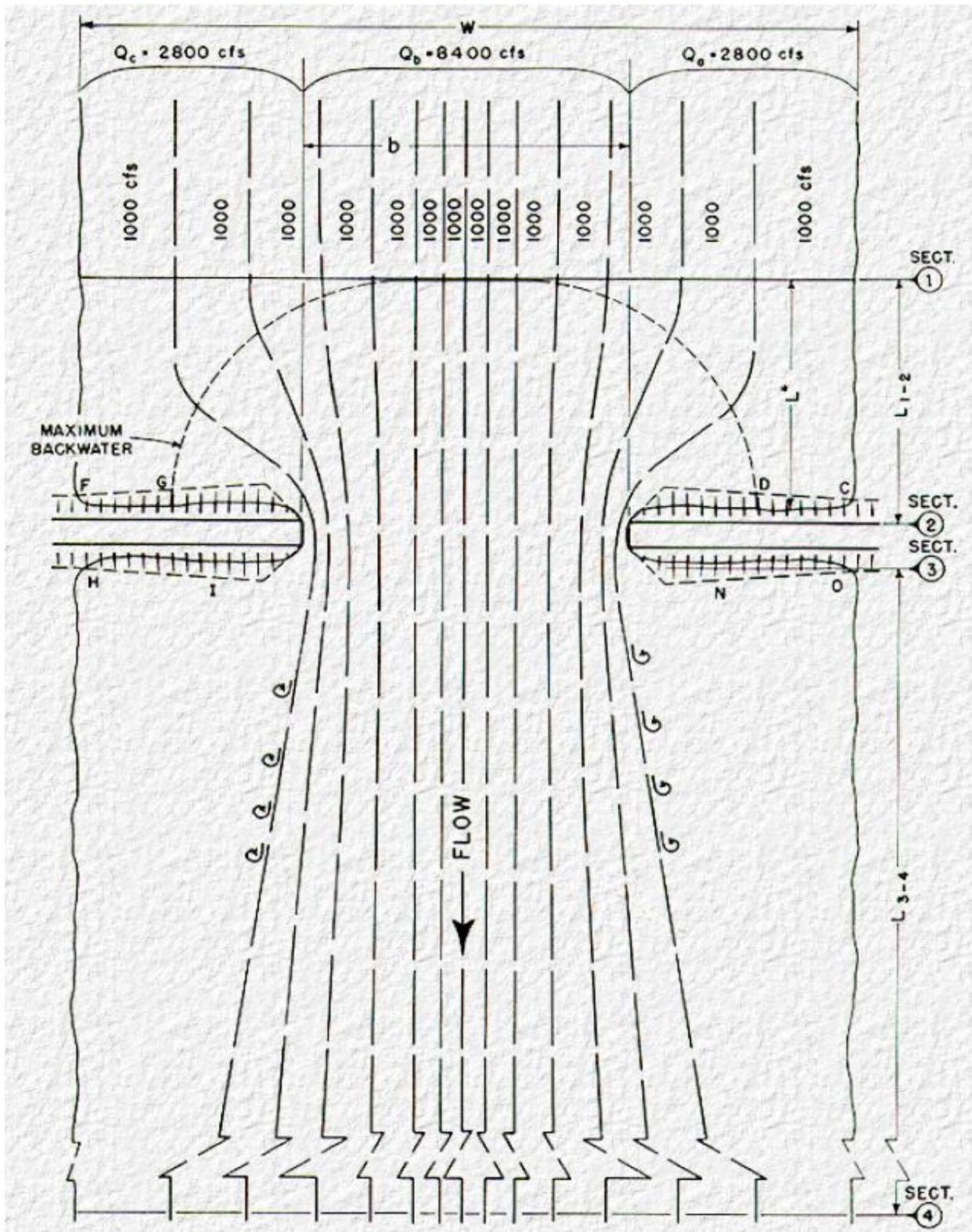


Figure 1. Flowlines for a normal crossing (Figure 1 in HDS-1)

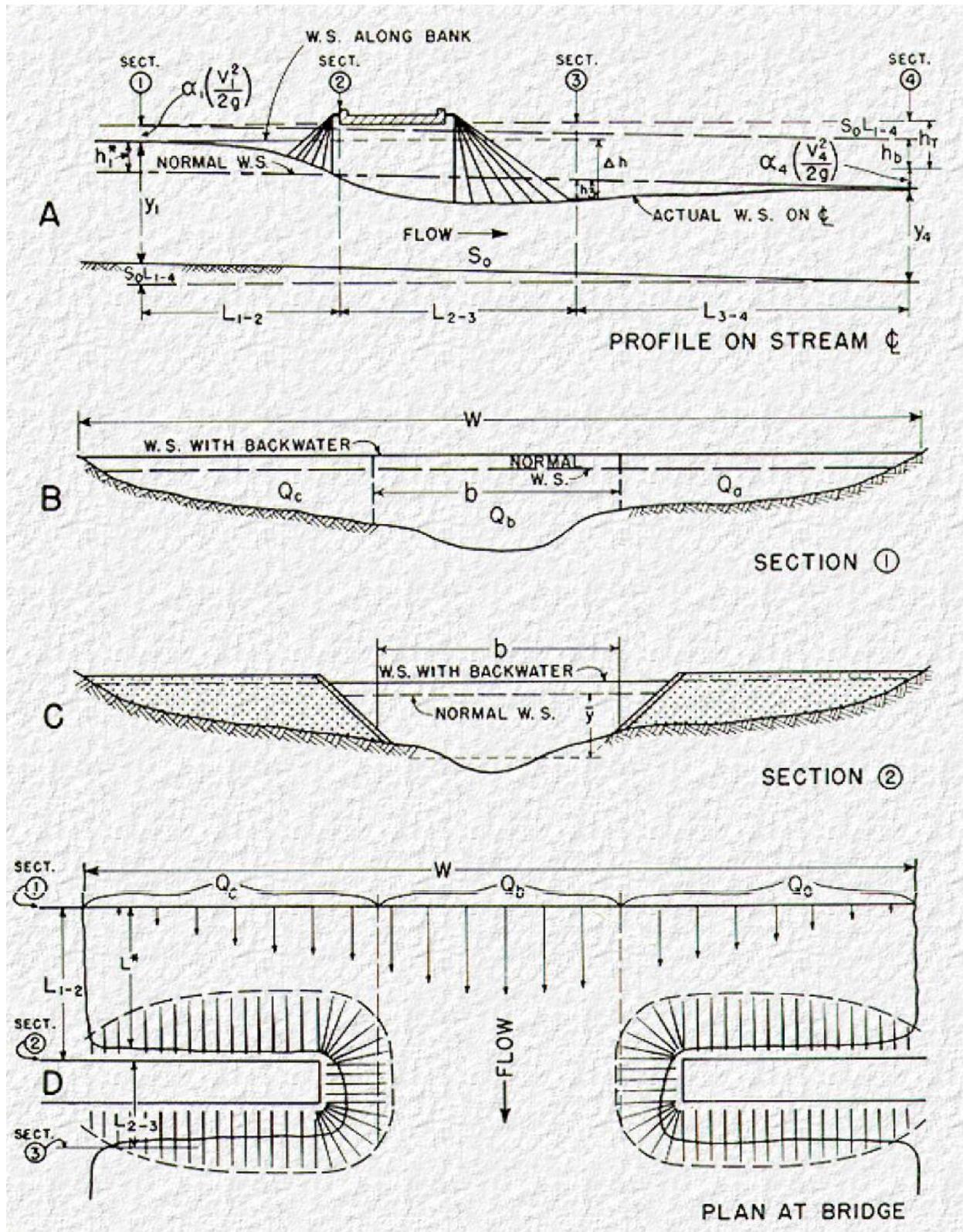


Figure 2. Normal crossings: Spillthrough abutments (Figure 3 in HDS-1)

Form 621026  
10/90

### FHWA HYDRAULIC DESIGN SERIES NO. 1 BACKWATER DETERMINATION WORKSHEET

County \_\_\_\_\_ Des. No. \_\_\_\_\_ Proj. \_\_\_\_\_  
 By \_\_\_\_\_ Date \_\_\_\_\_  
 Over \_\_\_\_\_

D.A. = \_\_\_\_\_ Slope: Reach = \_\_\_\_\_ Ft./Mi. \_\_\_\_\_ Ft./Ft.

Roughness Coefficients (Page 62)      LOB \_\_\_\_\_ Bridge Skew \_\_\_\_\_  
 Channel \_\_\_\_\_ Pier Skew \_\_\_\_\_  
 ROB \_\_\_\_\_ Str. Bed El. \_\_\_\_\_

Flood Data: Frequency \_\_\_\_\_  
 (USGS Report #87-4132) Discharge \_\_\_\_\_  
 Nat. Stage \_\_\_\_\_

"b" Width \_\_\_\_\_

Bridge Opening:  $A_{n2}$  \_\_\_\_\_  
 (Page 6 & 7)  $A_{n2}$  Skewed \_\_\_\_\_  
 $A_{piers}$  \_\_\_\_\_

Flow Distribution:  $Q_a$  \_\_\_\_\_  
 (Page 7)  $Q_b$  \_\_\_\_\_  
 $Q_c$  \_\_\_\_\_  
 $Q_{tot}$  \_\_\_\_\_  
 $\frac{Q_b}{Q_{tot}} \rightarrow M$  \_\_\_\_\_

$K_b$  (Fig. 6) \_\_\_\_\_  
 $K_{pier}$  (Fig. 7)      J (Page 17) \_\_\_\_\_  
                                   $\sigma$  (Fig 7B) \_\_\_\_\_  
                                   $\Delta K$  (Fig. 7A) \_\_\_\_\_  
                                   $K_p$  (Page 16) \_\_\_\_\_

$K_{skew}$  (Fig. 10A) \_\_\_\_\_  
 Eccentricity (Fig. 8)      e \_\_\_\_\_  
                                   $K_e$  \_\_\_\_\_

$K^*$  ( $=K_b + K_p + K_s + K_e$ ) \_\_\_\_\_  
 (Page 19)

$V_{n2}$  ( $=Q/A_{n2}$ ) \_\_\_\_\_

$h^*$  ( $=(K^*)(1.5)(V_{n2}^2)/2g$ ) \_\_\_\_\_  
 (Page 13)

Freeboard (Low Structure El.) \_\_\_\_\_  
 (Nat. Stage El.) \_\_\_\_\_

Figure 3. IDOT Backwater Calculation Worksheet

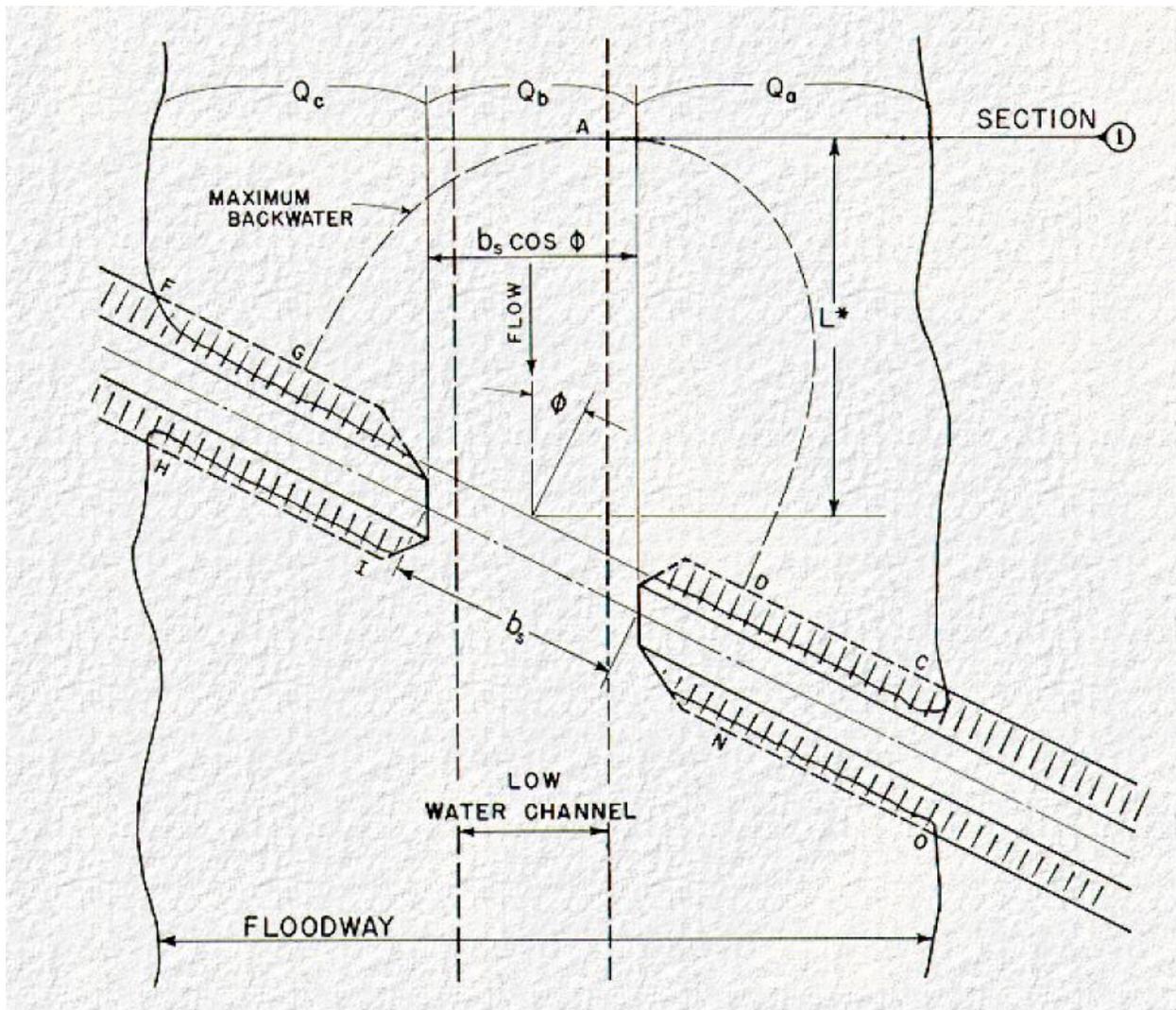


Figure 4. Skewed crossings (Figure 9 in HDS-1)

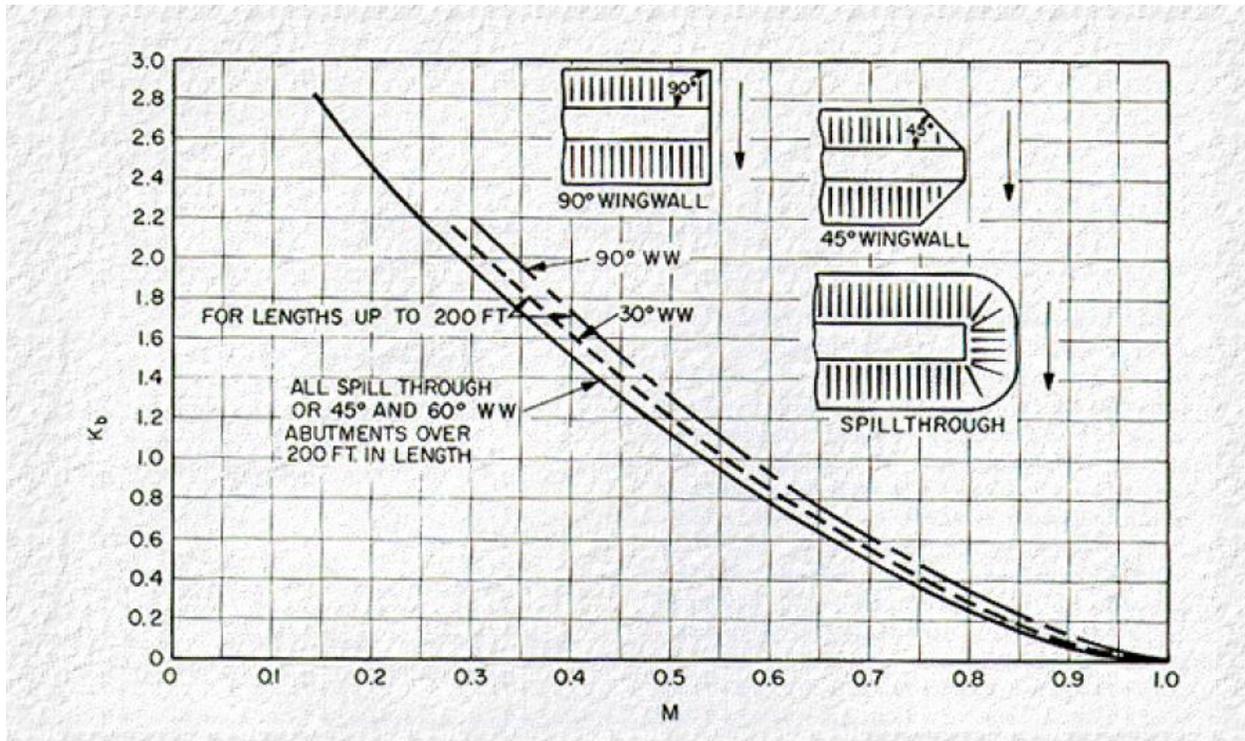


Figure 5. Backwater coefficient base curves (subcritical flow) (Figure 6 in HDS-1)

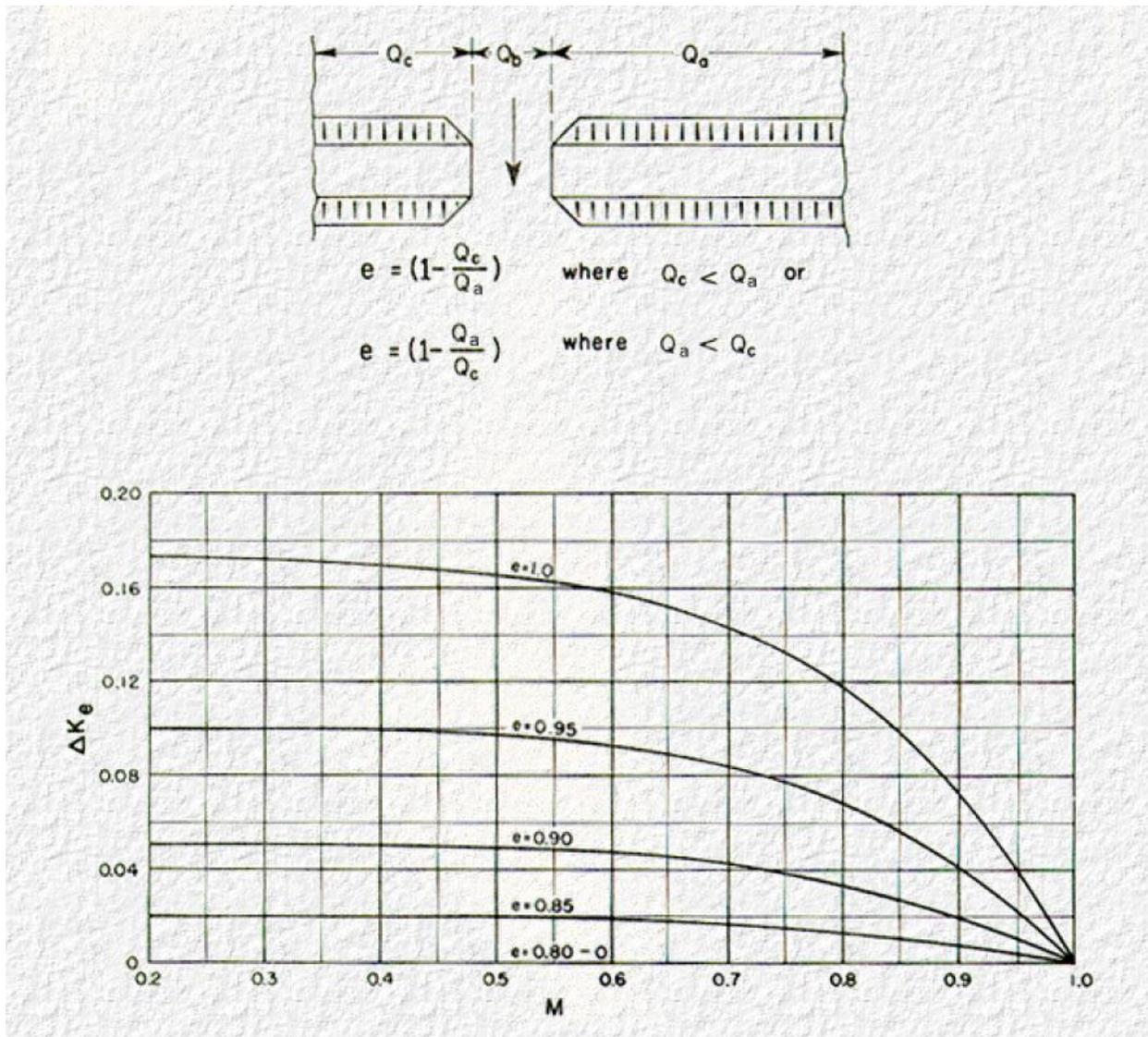


Figure 6. Incremental backwater coefficient for eccentricity (Figure 8 in HDS-1)

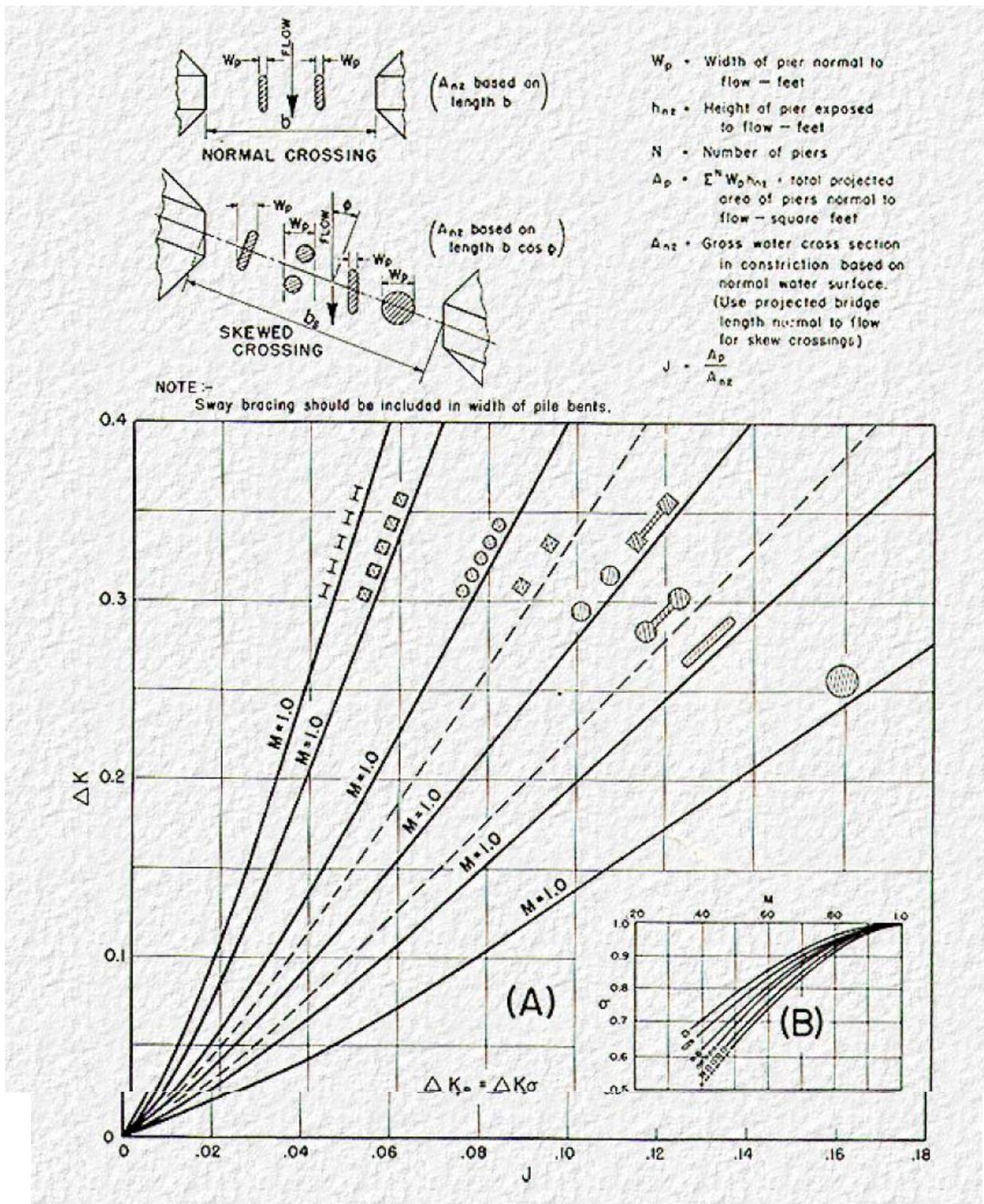


Figure 7. Incremental backwater coefficient for piers (Figure 7 in HDS-1)

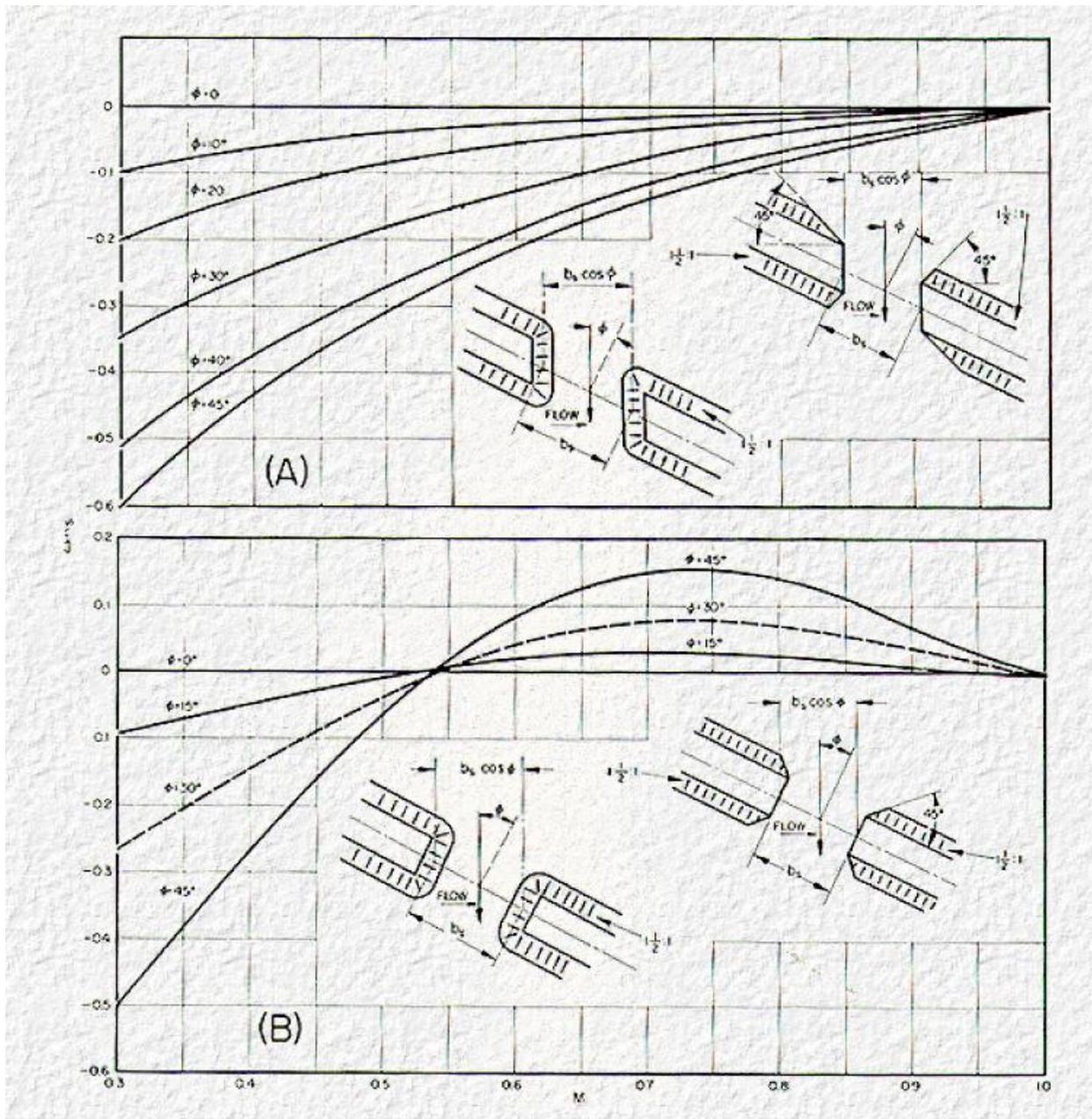


Figure 8. Incremental backwater coefficient for skew (Figure 10 in HDS-1)

## Appendix F: Contraction Scour

The Live-Bed contraction scour is computed from (Chapter 5 in HEC-18):

$$y_2 = \left[ \left( \frac{Q_2}{Q_1} \right)^{0.86} \left( \frac{W_1}{W_2} \right)^{0.64} \right] y_1 \quad (\text{Section 5.3 in HEC-18})$$

And  $y_s = y_2 - y_1$ , where  $y_s$  is the contraction scour.

Where  $y_1$  is the depth in the upstream main channel,  $y_2$  is the depth in the contracted section (i.e. bridge opening),  $W_1$  is the top width in the upstream main channel and  $W_2$  is the top width in the bridge opening,  $Q_1$  is the discharge in the upstream main channel ( $Q_1$  does not include overbank flow) and  $Q_2$  is the discharge through the bridge.

For the purposes of implementation in the software:

$y_1$  is the maximum depth in the valley cross-section (labeled as “Valley Depth:  $y_1$ ” in the Details tab).

$Q_1$  is the flowrate in the valley main channel, the flowrate between the left and right overbanks in the valley cross-section (labeled as “Main Channel:  $Q_1$ ” in the Details tab).

$Q_2$  is the discharge through the bridge (labeled as “Bridge Q:  $Q_2$ ” in the Details tab).

$W_1$  is the top width of the main channel (valley cross-section) between the left and right overbanks (labeled as “Main Channel Top Width:  $W_1$ ” in the Details tab).

$W_2$  is the b-width in the bridge opening (labeled as “b-Width:  $W_2$ ” in the Details tab).

The Clear-Water contraction scour is computed from:

$$y_2 = \left[ \frac{K_u Q_2^2}{(1.25 D_{50})^{2/3} W_2^2} \right]^{3/7} \quad (\text{Section 5.4 in HEC-18})$$

And  $y_s = y_2 - y_1$ , where  $y_s$  is the contraction scour.

$K_u = 0.0077$  for English units, and  $D_{50}$  is the median diameter of the bed material.

For both live-bed and clear-water when contraction scour is computed without the consideration of roadway overtopping,  $Q_2$  is equal to the Design  $Q$ .

### Contraction Scour with Overtopping

The computations for contraction scour with overtopping are done in the Bridge Scour (With Roadway Overtopping) form.

When estimating contraction scour with overtopping, all values are the same, except for  $Q_2$ . That is, all other things being equal, with or without overtopping, the values for  $Q_1$ ,  $W_1$  and  $W_2$  will be the same.

The value for  $Q_2$ , however, will be the Design  $Q$  less the Overtopping  $Q$ . This applies to both Live-Bed and Clear-Water computations.

$$Q_2 = \text{Design } Q - Q_{\text{Overtopping}}$$

$$\text{Where } Q_{\text{Overtopping}} = Q_{\text{Overtop\_Left}} + Q_{\text{Overtop\_Right}}$$

Where  $Q_{\text{Overtop\_Left}}$  is the overtopping due to the left overbank road grade profile and  $Q_{\text{Overtop\_Right}}$  is the overtopping due to the right overbank road grade profile. The values for  $Q_{\text{Overtop\_Left}}$  and  $Q_{\text{Overtop\_Right}}$  are shown in the Details tab using these labels.

The value for  $Q_2$  is shown in the Details tab as “Bridge  $Q$ :  $Q_2$ ”.

If overtopping occurs the reduced value for  $Q_2$  will result in a reduced value for contraction scour, when compared to the result without consideration of overtopping, all other things being equal.

### **Live-Bed versus Clear-Water**

An estimate of whether live-bed or clear-water is most appropriate can be made from consideration of the critical velocity, computed by:

$$V_c = K_u y^{1/6} D_{50}^{1/3} \quad (\text{eq. 5.1 in HEC 18})$$

Where  $y$  is the average depth of flow in the main channel (the average depth of flow in the valley cross-section between the left and right overbanks). The average depth is calculated by dividing the main channel wetted area by the main channel top width. In the Details tabs for scour with and without overtopping, the main channel top width is shown as “Main Channel Top Width:  $W_1$ ”, the main channel wetted area is shown as “Main Channel Flow Area”, the computed average depth of flow is shown as “Main Channel Avg.  $y$ ”, and the computed value of  $V_c$  is shown as “Main Channel  $V_c$ ”.

$V_c$  is compared to  $V$ , where  $V$  is the average velocity in the main channel. The average velocity in the main channel is estimated from the discharge in the main channel divided by the main channel wetted area. In the Details tabs for scour, with and without overtopping, the discharge in the main channel is shown as “Main Channel:  $Q_1$ ”, and the computed value for  $V$  is shown as “Main Channel Avg.  $V$ ”.

If  $V \geq V_c$  then live-bed contraction scour is indicated (Live\_Bed). If  $V < V_c$  then clear-water contraction scour is indicated (Clear\_Water). The results of the comparison are shown in the Details tabs as “Live-Bed or Clear-Water Calc.”

## Appendix G: Abutment Scour

Two methods are used for estimating abutment scour, the Froehlich method and the HIRE method.

### Froehlich Abutment Scour

Froehlich Abutment Scour is estimated from the equation (Chapter 7, HEC 18):

$$y_s = \left( 2.27K_1K_2 \left( \frac{L'}{y_a} \right)^{0.43} Fr^{0.61} + 1 \right) y_a$$

Where:

$K_1$  = Coefficient for abutment shape

$K_1=0.55$  for Spill-Through and  $0.82$  for all Wing Wall (from Table 7.1 in HEC 18)

$K_2$  = Coefficient for skew angle of embankment to flow

$K_2 = (\theta / 90)^{0.13}$

$\theta < 90$  if embankment points downstream

$\theta > 90$  if embankment points upstream

(See Figure 7.5 in HEC 18 for definition of  $\theta$ )

$L'$  = Length of active flow obstructed by the embankment

$A_e$  = Flow area of the approach cross section obstructed by the embankment

$Fr$  = Froude number of approach flow upstream of the abutment

$Fr = V_e / (gy_a)^{1/2}$ ,  $g$  is gravity,  $32.2 \text{ ft/sec}^2$

$V_e = Q_e / A_e$

$Q_e$  = Flow obstructed by the abutment and approach embankment

$y_a$  = Average depth of flow on the floodplain ( $A_e / L$ )

$L$  = Length of embankment projected normal to the flow

$y_s$  = Scour Depth

$K_1$ ,  $\theta$  and  $K_2$ : The computed values for  $K_1$ ,  $\theta$  (Theta) and  $K_2$  are shown in the Coefficient tab of the Bridge Scour form. These values are not functions of the flowrate ( $Q$ ).

### Froehlich Abutment Scour – Left Abutment

In applying the equation for abutment scour, the equation values for Left Abutment scour were implemented in the following manner:

$A_e$ : The cross-sectional area of flow to the left of the Left Valley B – Location (the Bridge Left – B Width location projected onto the valley cross-section, shown as “Valley b-Width Left Station” in the Details tab of the Bridge Scour form). The value of  $A_e$  is shown as “Ae-Left” in the Details tab of the Bridge Scour form.

$Q_e$ : Flow to the left of the “Valley b-Width Left Station”. This is shown as “Qe\_LA” in the Details tab of the Bridge Scour forms. In the case of no overtopping  $Q_e$  is equal to  $Q_a$  ( $Q_a$  is the entire overbank flow). When overtopping is considered,  $Q_e$  is adjusted based on the amount of overtopping (see “Froehlich Abutment Scour with Overtopping” below for details on the overtopping adjustment).

$V_e = Q_e / A_e$  This is shown as “V\_LA” in the Details tab of the Bridge Scour form.

TW: Top width of the area of flow to the left of the “Valley b-Width Left Station”. This is shown as “Left Embankment Length” in the Details tab of the Bridge Scour form.

$y_a = A_e/TW$  This is shown as “y\_LA” in the Details tab of the Bridge Scour form.

$L = TW$  This is shown as “Left Embankment Length” in the Details tab of the Bridge Scour form.

L' : The user picks an active flow % (U) to use for computing the effective length. U is between 50% and 100%, with 75% as the recommended value. The software finds the distance (to the nearest 1 foot) from the “Valley b-Width Left Station” to where the left overbank flow first equals or exceeds U% of  $Q_e$ . This distance is used as L'. The value for L' is shown as “EL\_LA” in the Details tab of the Bridge Scour form. The U% at this distance is shown as “ActiveFlow\_LA(%)”.

#### Froehlich Abutment Scour – Right Abutment

In applying the equation for abutment scour, the equation values for Right Abutment scour were implemented in the following manner:

$A_e$ : The cross-sectional area of flow to the right of the Right Valley B – Location (the Bridge Right – B Width location projected onto the valley cross-section, shown as “Valley b-Width Right Station” in the Details tab of the Bridge Scour form). The value of  $A_e$  is shown as “Ae-Right” in the Details tab of the Bridge Scour form.

$Q_e$ : Flow to the right of the “Valley b-Width Right Station”. This is shown as “ $Q_e\_RA$ ” in the Details tab of the Bridge Scour forms. In the case of no overtopping  $Q_e$  is equal to  $Q_c$ . When overtopping is considered,  $Q_e$  is adjusted based on the amount of overtopping (see “Froehlich Abutment Scour with Overtopping” below for details on the overtopping adjustment).

$V_e = Q_e/A_e$  This is shown as “V\_RA” in the Details tab of the Bridge Scour form.

TW: Top width of the area of flow to the left of the “Valley b-Width Right Station”. This is shown as “Right Embankment Length” in the Details tab of the Bridge Scour form.

$y_a = A_e/TW$  This is shown as “y\_RA” in the Details tab of the Bridge Scour form.

$L = TW$  This is shown as “Right Embankment Length” in the Details tab of the Bridge Scour form.

L' : The user picks an active flow % (U) to use for computing the effective length. U is between 50% and 100%, with 75% as the recommended value. The software finds the distance (to the nearest 1 foot) from the “Valley b-Width Right Station” to where the right overbank flow first equals or exceeds U% of  $Q_e$ . This distance is used as L'. The value for L' is shown as “EL\_RA” in the Details tab of the Bridge Scour form. The U% at this distance is shown as “ActiveFlow\_RA(%)”

#### **Froehlich Abutment Scour with Overtopping**

With overtopping all computations remain the same, except for the value of  $Q_e$ , the flow obstructed by the abutment and approach embankment. With overtopping, the value of  $Q_e$  is reduced which will result in a reduced scour estimate, all other things being equal.

For the left abutment, with overtopping,

$$Q_{e\_LA} = Q_a - Q_{\text{Overtop\_Left}}$$

where  $Q_{e\_LA}$  is the  $Q_e$  value for the left abutment,  $Q_a$  is the left overbank valley flow and  $Q_{\text{Overtop\_Left}}$  is the overtopping on the left overbank. However, the minimum value of  $Q_{e\_LA}$  is limited to 50% of  $Q_a$ , or  $Q_{e\_LA} \geq 0.5Q_a$ .

For the right abutment, with overtopping,

$$Q_{e\_RA} = Q_c - Q_{\text{Overtop\_Right}}$$

where  $Q_{e\_RA}$  is the  $Q_e$  value for the right abutment,  $Q_c$  is the right overbank valley flow and  $Q_{\text{Overtop\_Right}}$  is the overtopping on the right overbank. However, the minimum value of  $Q_{e\_RA}$  is limited to 50% of  $Q_c$ , or  $Q_{e\_RA} \geq 0.5Q_c$

Without a lower bound on  $Q_e$ , a situation could occur where the overtopping equals the overbank flow, and  $Q_e$  would be 0, resulting in no computed abutment scour. Given the limitations and assumptions of the modeling, it was felt this would be unrealistic, and a lower bound was selected for  $Q_e$ , with overtopping.

### **HIRE Abutment Scour**

HIRE Abutment Scour is estimated from the equation (Chapter 7, HEC 18):

$$y_s = \left( 4Fr^{0.33} \frac{K_1}{0.55} K_2 \right) y_1$$

Where:

$K_1$  = Coefficient for abutment shape (Same as Froehlich shape table)

$K_2$  = Coefficient for skew angle of embankment to flow calculated as for Froehlich's equation

$y_s$  = Scour depth

$y_1$  = Depth of flow at the abutment on the overbank or in the main channel

$Fr$  = Froude Number based on the velocity and depth adjacent to and upstream of the abutment

$Fr = V_o / (gy_1)^{1/2}$ ,  $g$  is gravity, 32.2 ft/sec<sup>2</sup>

The HIRE equation is applicable when the ratio of the projected abutment length ( $L$  above) to the flow depth ( $y_1$ ) is greater than 25.

HEC-18 does not define a method for determining the “depth of flow at the abutment on the overbank” or the “velocity and depth adjacent to and upstream of the abutment”.

After consultation with staff of the Iowa Department of Transportation it was decided to use the area defined by first 10% of the overbank flow to estimate the “depth of flow at the abutment on the overbank” and the “velocity and depth adjacent to and upstream of the abutment”.

### **HIRE Abutment Scour – Left Abutment**

The actual calculations for HIRE Left Abutment Scour are implemented as:

$Q_{bl}$  = Flow to the left of the “Valley b-Width Left Station”. This is shown as “Qa” in the Details tab of the Bridge Scour form.

$H_l$ : The software finds the distance (to the nearest 1 foot) from the “Valley b-Width Left Station” to where the left overbank flow first equals or exceeds 10% of  $Q_{bl}$ . We will call this location  $H_l$ . The horizontal distance between  $H_l$  and the “Valley b-Width Left Station” is shown as “HIRE\_LA\_CALC\_WIDTH” in the Details tab of the Scour form.

The software uses the overbank flow between  $H_l$  and the “Valley b-Width Left Station” to define the “depth of flow at the left abutment on the overbank” and the “velocity and depth adjacent to and upstream of the left abutment”.

$T_{hl}$ : This is the top width of the area of flow between  $H_l$  and the “Valley b-Width Left Station” for the left abutment. This is shown as “HIRE\_LA\_TW” in the Details tab of the Scour form.

$Q_{hl}$ : This is the left overbank flow between  $H_l$  and the “Valley b-Width Left Station”. This is shown as “HIRE\_LA\_Q” in the Details tab of the Scour form.

Since the software moves in 1 foot increments until  $Q_{hl}$  is greater than or equal to 10% of  $Q_{bl}$ , the ratio of  $Q_{hl}$  is greater than or equal to 10% (although it will be close to 10%) of  $Q_{bl}$ . The actual ratio (in percent) of  $Q_{hl}$  to  $Q_{bl}$  for the left overbank is shown as “HIRE\_LA\_Q\_RATIO” in the Details tab of the Scour form.

$A_{hl}$ : This is the cross-section area of flow on the left overbank between  $H_l$  and the “Valley b-Width Left Station”. This is shown as “HIRE\_LA\_WA” in the Details tab of the Scour form.

For HIRE, the Froude number for the left abutment is computed from:

$$Fr = V_{bl}/(gy_{bl})^{1/2}$$

Where

$V_{bl}=Q_{hl}/A_{hl}$ , shown as “HIRE\_LA\_V” in the Details tab of the Scour form.

$y_{bl}=A_{hl}/T_{hl}$ , shown as “HIRE\_LA\_y” in the Details tab of the Scour form

$$y_s = \left( 4Fr^{0.33} \frac{K_1}{0.55} K_2 \right) y_{bl}$$

The  $y_s$  value for HIRE for the Left Abutment is shown in the Scour Estimates tab of the Scour form.

The equation is applicable for the left abutment when the ratio of the projected abutment length (Left Embankment Length in the Details tab of the Scour form) to  $y_{bl}$  is greater than 25. The ratio of the projected left abutment length to  $y_{bl}$  is shown in the Details tab as “HIRE\_LA\_L\_to\_y\_ratio”. If this criterion is not met, “N/A” is shown in the Scour Estimates tab of the Scour form for HIRE scour depth.

HIRE Abutment Scour – Right Abutment

The actual calculations for HIRE Right Abutment Scour are implemented as:

$Q_{br}$  = Flow to the right of the “Valley b-Width Right Station”. This is shown as “Qc” in the Details tab of the Bridge Scour form.

$H_r$ : The software finds the distance (to the nearest 1 foot) from the “Valley b-Width Right Station” to where the right overbank flow first equals or exceeds 10% of  $Q_{br}$ . We will call this location  $H_r$ . The horizontal distance between  $H_r$  and the “Valley b-Width Right Station” is shown as “HIRE\_RA\_CALC\_WIDTH” in the Details tab of the Scour form.

The software uses the overbank flow between  $H_r$  and the “Valley b-Width Right Station” to define the “depth of flow at the right abutment on the overbank” and the “velocity and depth adjacent to and upstream of the right abutment”.

$T_{hr}$ : This is the top width of the area of flow between  $H_r$  and the “Valley b-Width Right Station” for the right abutment. This is shown as “HIRE\_RA\_TW” in the Details tab of the Scour form.

$Q_{hr}$ : This is the right overbank flow between  $H_r$  and the “Valley b-Width Right Station”. This is shown as “HIRE\_RA\_Q” in the Details tab of the Scour form.

Since the software moves in 1 foot increments until  $Q_{hr}$  is greater than or equal to 10% of  $Q_{br}$ , the ratio of  $Q_{hr}$  is greater than or equal to 10% (although it will be close to 10%) of  $Q_{br}$ . The actual ratio (in percent) of  $Q_{hr}$  to  $Q_{br}$  for the right overbank is shown as “HIRE\_RA\_Q\_RATIO” in the Details tab of the Scour form.

$A_{hr}$ : This is the cross-section area of flow on the right overbank between  $H_r$  and the “Valley b-Width Right Station”. This is shown as “HIRE\_RA\_WA” in the Details tab of the Scour form.

For HIRE, the Froude number for the right abutment is computed from:

$$Fr = V_{br}/(gy_{br})^{1/2}$$

Where

$V_{br}=Q_{hr}/A_{hr}$ , shown as “HIRE\_RA\_V” in the Details tab of the Scour form.

$y_{br}=A_{hr}/T_{hr}$ , shown as “HIRE\_RA\_y” in the Details tab of the Scour form

$$y_s = \left( 4Fr^{0.33} \frac{K_1}{0.55} K_2 \right) y_{br}$$

The  $y_s$  value for HIRE for the Right Abutment is shown in the Scour Estimates tab of the Scour form.

The equation is applicable for the right abutment when the ratio of the projected abutment length (Right Embankment Length in the Details tab of the Scour form) to  $y_{br}$  is greater than 25. The ratio of the projected right abutment length to  $y_{br}$  is shown in the Details tab as “HIRE\_RA\_L\_to\_y\_ratio”. If this criterion is not met, “N/A” is shown in the Scour Estimates tab of the Scour form for HIRE scour depth.

## HIRE Abutment Scour with Overtopping

HIRE abutment scour is based on the depth and velocity of flow adjacent to and upstream of the abutment. It was felt we could not reliably estimate the effect of overtopping on the flow regime at the abutment. The same methods were used to estimate the depth and velocity of flow adjacent to and upstream of the abutment both with and without overtopping. Hence, all other things being the same, HIRE abutment scour estimates are the same with or without overtopping.

## Appendix H: Pier Scour

Pier scour is estimated by two methods, the Laursen method and the CSU method.

### Laursen Pier Scour

The Laursen pier scour equation is from the Guidelines for Preliminary Design of Bridges and Culverts, Appendix C, Scour, Iowa Department of Transportation publication, January 11, 1999, referred to as the "Guidelines".

$$y_s = 1.485(K_1)(w_p) \left( \frac{y_1}{w_p} \right)^{0.314}$$

$y_s$  = the depth of scour

$y_1$  = unscoured depth of flow at the pier

$w_p$  = width of the pier column

$K_1 = K_s$ , the coefficient if the angle of attack =0, based on pier nose shape.

$K_1 = K_a$ , the coefficient if the angle of attack is not zero.

$L$  = Length of the pier.

In consultation with the Iowa DOT, the following  $K_s$  values were specified for the pier shapes contained in the software:

Pier Shape/Type	$K_s$
Single Round Column	0.9
Round Nose Elongated	0.9
Two Round Columns	0.9
Pile Bent-Round	0.9
Pile Bent-Square	1.0
Pile Bent-Steel H	1.0
Frame Pier	0.9
T Pier	0.9
Pile Bent Encased	0.9

The values for  $K_a$ , taken from the Guidelines, are:

Angle of Attack	$L/w_p$					
	4	6	8	10	12	14
5°	1.2	1.3	1.3	1.5	1.6	1.6
10°	1.4	1.5	1.7	1.9	2.1	2.3
15°	1.5	1.8	2.0	2.2	2.5	2.7
20°	1.7	2.0	2.3	2.5	2.8	3.0
25°	1.8	2.2	2.5	2.8	3.1	3.5
30°	1.9	2.4	2.7	3.1	3.4	3.8
35°	2.0	2.5	2.9	3.3	3.7	4.0
40°	2.1	2.7	3.1	3.6	4.0	4.3
45°	2.2	2.8	3.3	3.8	4.2	4.6

If  $L/w_p < 4$  the values for 4 are used. If  $L/w_p > 14$  the values for 14 are used. For  $L/w_p$  falling between the values in the table, linear interpolation is used.

In implementing the equation in the software;

$$y_1 = \text{Pier\_Stage} - \text{Minimum\_Channel\_Bottom\_Elevation}$$

Where Pier\_Stage is equal to the Bridge Stage or the Low Structure Elevation, whichever is lower. The Bridge Stage is shown in the Details tab of the Scour form as “Bridge Stage”. The Low Structure Elevation is shown the Bridge Cross-Section form.

The Minimum\_Channel\_Bottom\_Elevation is the minimum channel elevation of the bridge cross-section. The Minimum\_Channel\_Bottom\_Elevation is shown in the “Coefficients” tab of the Scour form as “Bottom Elevation”. This will be the same for all piers, since it is the minimum bridge cross-section elevation. The minimum channel bottom elevation is used, instead of the channel elevation at the pier location, because the software implements Case 1B in HEC-18 where it is assumed the abutments are at the edge of the channel. Hence, it is assumed the channel could migrate and all piers could be exposed to the minimum channel bottom elevation.

The resulting value of  $y_1$  is shown in the Details tab of the Scour form as “Depth at Pier”. The “Depth at Pier” will be the same for all piers for a given Q.

### Laursen Pier Scour with Overtopping

Laursen pier scour is based on the depth of flow in the bridge opening and this depth is assumed to be the same with and without overtopping. Hence, all other things being the same, Laursen pier scour estimates are the same with or without overtopping.

### CSU Pier Scour

The CSU Pier Scour equation is from chapter 6 of HEC-18:

$$y_s = \left( 2.0K_1K_2K_3K_4 \left( \frac{y_1}{a} \right)^{0.35} Fr_1^{0.43} \right) a$$

Where:

$y_s$  = scour depth

$y_1$  = flow depth directly upstream of the pier

$K_1$  = Correction factor for pier nose shape

$K_2$  = Correction factor for the angle of attack of the flow to the pier

$K_3$  = Correction factor for bed condition

$K_4$  = Correction factor for armoring by bed material size

$a$  = Pier width

$L$  = Length of pier

$Fr_1$  = Froude number directly upstream of the pier =  $V_1/(gy_1)^{1/2}$

$V_1$  = Mean velocity of flow directly upstream of the pier

$g$  = acceleration of gravity

For round nose piers aligned with the flow ( $\theta=0$ ) an upper limit for scour depth is applied;

$$y_s \leq 2.4(a) \text{ for } Fr_1 \leq 0.8$$

$$y_s \leq 3.0(a) \text{ for } Fr_1 > 0.8$$

The above upper limit is applied for all pier type, except for “Pile Bent – Square” and “Pile Bent – Steel H”.

In consultation with the Iowa DOT, the following  $K_1$  values were specified for the pier shapes contained in the software:

Pier Shape/Type	$K_1$
Single Round Column	1.0
Round Nose Elongated	1.0
Two Round Columns	1.0
Pile Bent-Round	1.0
Pile Bent-Square	1.1
Pile Bent-Steel H	1.1
Frame Pier	1.0
T Pier	1.0
Pile Bent Encased	1.0

If the angle of attack ( $\theta$ ) is greater than 5 degrees,  $K_2$  will dominate, and a  $K_1$  value of 1.0 is used.

The correction factor,  $K_2$ , for the angle of attack of the flow,  $\theta$ , is calculated using

$$K_2 = \left( \cos(\theta) + \frac{L}{a} \sin(\theta) \right)^{0.65}$$

If  $L/a$  is greater than 12, then  $L/a=12$  is used in the equation for  $K_2$ . The upper limit for  $K_2$  is 5.

For  $K_3$ , based on bed condition (see Table 6.3 in HEC-18), it was decided to use a constant value of  $K_3=1.1$  in the software.

The values of  $K_1$ ,  $K_2$  and  $K_3$  for each pier are shown in the “Coefficients” tab of the Bridge Scour form.

The value of  $y_1$  at a pier is the same for the Laursen and CSU methods and has already been described in the Laursen Pier Scour section.

The average velocity in the bridge opening is used for  $V_1$ , in place of the mean velocity of flow directly upstream of the pier. The  $V_1$  for each flowrate is shown as “CSU-V1” in the “Details” tab of the Bridge Scour form. The average bridge velocity is estimated by dividing the bridge flowrate (shown as “Bridge Q: Q2” in the “Details” tab) by the flow area in the bridge (shown as “Projected An2” in the “Details” tab).

The correction factor  $K_4$  decreases scour depth for armoring of the scour hole for bed materials that have a  $D_{50} \leq 2.0$  mm and a  $D_{95} \geq 20$ mm. The default value for  $K_4$  is 1. If values for both  $D_{50}$  and  $D_{95}$  are entered and meet the criteria of  $D_{50} \leq 2.0$  mm and  $D_{95} \geq 20$ mm, a value for  $K_4$  is computed using equations 6.5 through 6.8 in HEC – 18. The equations are not repeated here. The minimum value for  $K_4$  is 0.4.  $K_4$  is a function of velocity so the value of  $K_4$  for each design Q for each pier is shown in the “Details” tab as “CSU\_K4”.

The total for the adjustment factors ( $K_1K_2K_3K_4$ ) multiplied together is shown in the “Details” tab as “CSU\_K\_Total”.

### **CSU Pier Scour with Overtopping**

With overtopping all computations for CSU Pier Scour are the same, except for  $V_1$ , the average velocity in the bridge opening. With overtopping, the bridge Q is reduced by overtopping, resulting in a reduced  $V_1$ . All other things being equal, with overtopping the CSU Pier Scour estimate will be reduced.

The  $V_1$  for each flowrate is shown as “CSU-V1” in the “Details” tab of the Bridge Scour with Overtopping form. The average bridge velocity is estimated by dividing the bridge flowrate (shown as “Bridge Q: Q2” in the “Details” tab) by the flow area in the bridge (shown as “Projected An2” in the “Details” tab). The bridge flow rate is found by subtracting the overtopping from the Design Q. The overtopping flowrates for the left and right are shown in the “Details” tab as “Q\_Overtop\_Left” and “Q\_Overtop\_Right”.