Bridge Hydraulics for 1D Modeling

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Objective

To know the nature of flow transitions through bridges, and how to model a bridge using the 1D modeling approaches in HEC-RAS

- Model Limitations
- Flow transitions through bridges
- Cross section locations
- contraction/expansion losses
- Defining Ineffective flow areas

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References

- HEC-RAS Hydraulic Reference Manual, Chapter 5, Appendices B and D, February 2016.
- Hydraulics of Bridge Waterways, HDS No. 1, US Department of Transportation, Second Edition, March 1978.
- Flow Transitions in Bridge Backwater Analysis, HEC Research Doc. 42, September 1995.
- A comparison of the One-Dimensional Bridge Hydraulic Routines from: HEC-RAS, HEC-2 and WSPRO, HEC Research Doc. 41, September 1995.

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Limitations of the HEC-RAS Bridge Routines

- HEC-RAS Bridge routines are based on one-dimensional flow assumptions.
- The 1D modules within HEC-RAS program computes a single average water surface and energy at each section.
- Losses associated with 3-dimensional flow are computed with empirical equations and coefficients.

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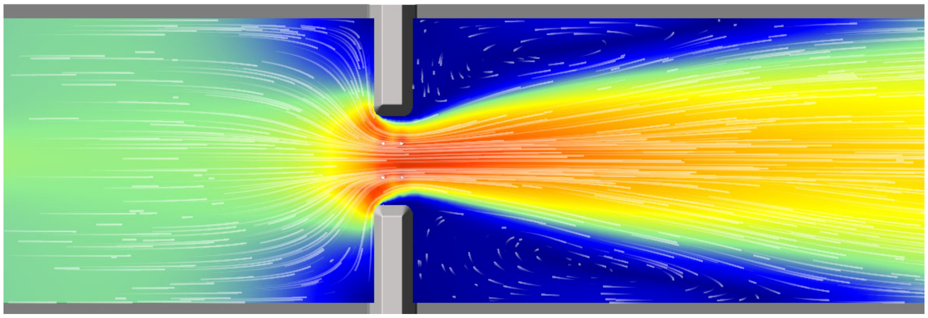
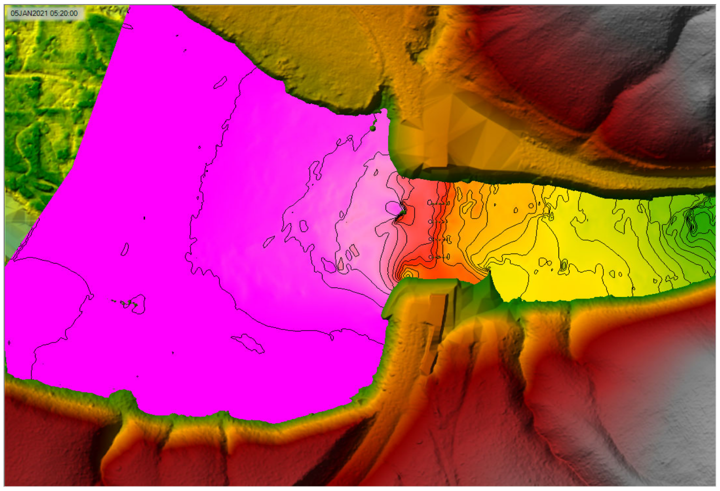
Flow Transitions Through Bridges



Example of a 2D flow model with tracers through an area that is highly constricted.
You can see the flow tracers to see that contraction and expansion zone.
We are going to trying and model this highly multidimensional situation in 1D.

2D Water Surface Contours in HEC-RAS



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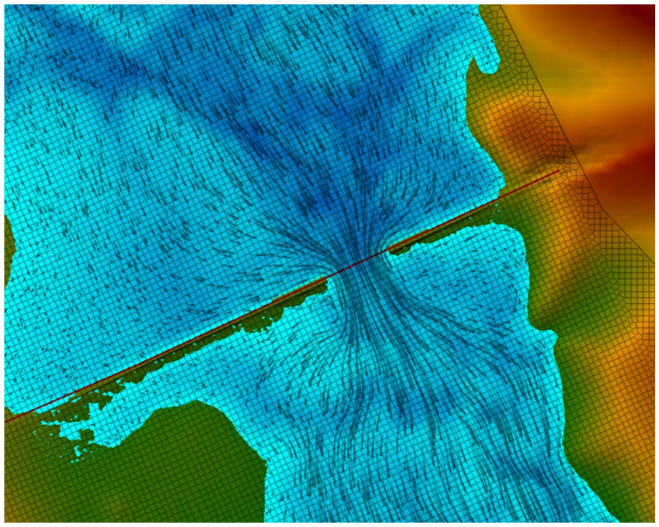
For a similar encroachment at a bridge, you can see the highly variable water surface through the bridge. 1D modeling cannot model the rapid change in water surface IN the opening; however, we can model the head loss through the bridge given a the water surface downstream of the opening and a flow rate.

Bridge Flow Animation in HEC-RAS



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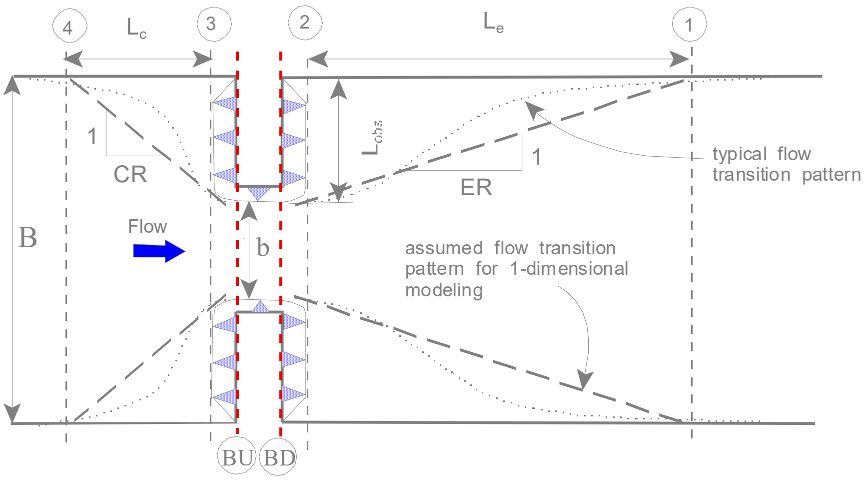
Here is an example of an HEC-RAS 2D model at a highly constricted bridge. Note the areas of contraction and expansion.

Cross Section Locations



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Here is a layout of how we thinking about laying out cross sections in a 1D modeling approach.

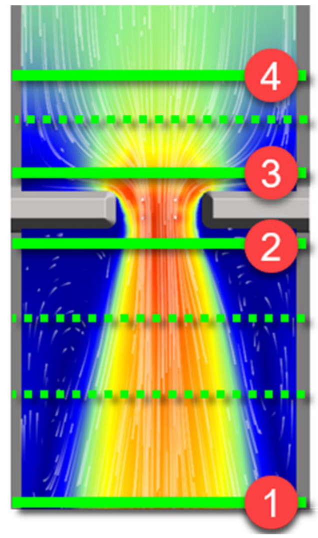
Four user-defined cross sections required.

During the hydraulic computations, the program automatically formulates two additional cross sections inside of the bridge structure.

Cross Section 1

- Cross Section 1 is located sufficiently downstream from the structure so that the flow is not affected by the structure (i.e. the flow has fully expanded).

- If the distance between cross section 1 and 2 is too great for accurate friction loss calculations, then intermediate cross sections should be entered with ineffective flow areas defined.



Expansion Reach Lengths

		nob / nc = 1	nob / nc = 2	nob / nc = 4
b/B = 0.10	S = 1 ft/mile	1.4 – 3.6	1.3 – 3.0	1.2 – 2.1
	5 ft/mile	1.0 – 2.5	0.8 – 2.0	0.8 – 2.0
	10 ft/mile	1.0 – 2.2	0.8 – 2.0	0.8 – 2.0
b/B = 0.25	S = 1 ft/mile	1.6 – 3.0	1.4 – 2.5	1.2 – 2.0
	5 ft/mile	1.5 – 2.5	1.3 – 2.0	1.3 – 2.0
	10 ft/mile	1.5 – 2.0	1.3 – 2.0	1.3 – 2.0
b/B = 0.50	S = 1 ft/mile	1.4 – 2.6	1.3 – 1.9	1.2 – 1.4
	5 ft/mile	1.3 – 2.1	1.2 – 1.6	1.0 – 1.4
	10 ft/mile	1.3 – 2.0	1.2 – 1.5	1.0 – 1.4

b/B = ratio of bridge opening width to total floodplain width

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In Table 1, b/B is the ratio of the bridge opening width to the total floodplain width, n_{ob} is the Manning n value for the overbank, n_c is the n value for the main channel, and S is the longitudinal slope. The values in the interior of the table are the ranges of the expansion ratio. For each range, the higher value is typically associated with a higher discharge.

The expansion ratio should not exceed 4:1, nor should it be less than 0.5:1 unless there is site-specific field information to substantiate such values.

Slower velocities in the overbanks from higher nvalues allows for more rapid expansion. So when n values are same tend to have higher velocities and flow won't expand as fast.

Expansion reach length equation

$$L_e = -298 + 257\left(\frac{F_{c2}}{F_{c1}}\right) + 0.918\overline{L}_{obs} + 0.00479Q$$

For which R2 = 0.84 and S_e = 96 feet.

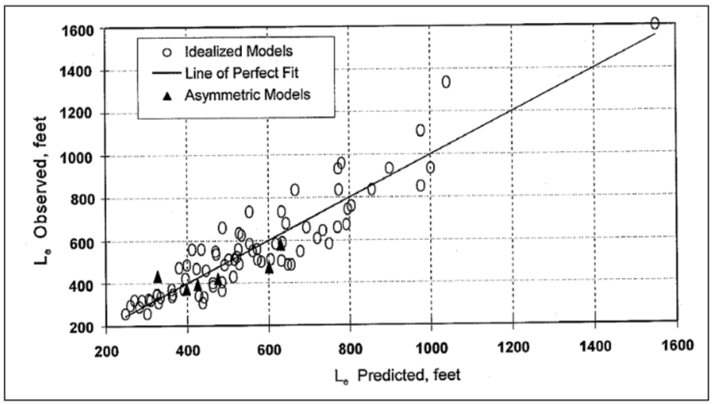

Figure 10 Goodness-of-Fit Plot for Expansion Length Regression Equation (Equation 17).

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Here you can see an equation for estimating the expansion reach length. Note it is base on the velocities in XS2 and XS1.

Expansion Rate equation

$$ER = \frac{L_e}{L_{obs}} = 0.421 + 0.485\left(\frac{F_{c2}}{F_{c1}}\right) + 0.000018Q$$

For which R2 = 0.71 and S_e = 0.26

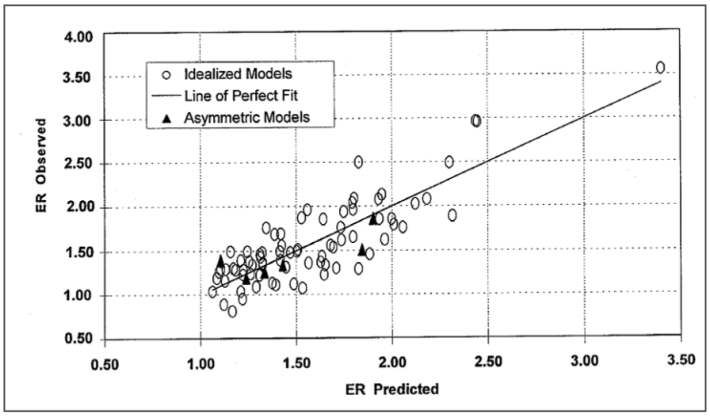

Figure 11 Goodness-of-Fit Plot for Expansion Ratio Regression Equation (Equation 18).

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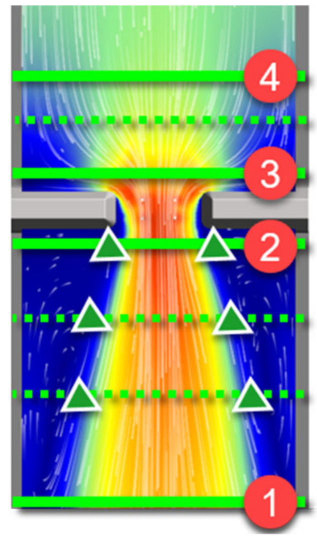
And an equation on expansion rate, again based on velocities at XS 2 and XS 1.

Cross Section 2

- Cross section 2 is located immediately downstream from the bridge (i.e. a short distance, normally placed at the toe of the embankment). This cross section should represent the effective flow area just outside the bridge and embankment.

- Ineffective flow areas are normally used at this cross section.



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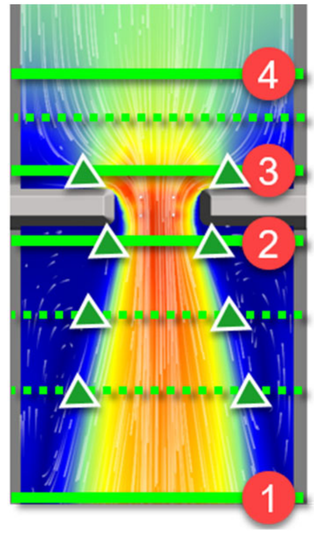
Cross Section 3

- Cross section 3 should be located just upstream from the bridge (I.e. a short distance, normally located at the toe of the embankment). This cross section should represent the effective flow area just outside the bridge and the embankment.

- Ineffective flow areas are normally used at this cross section.



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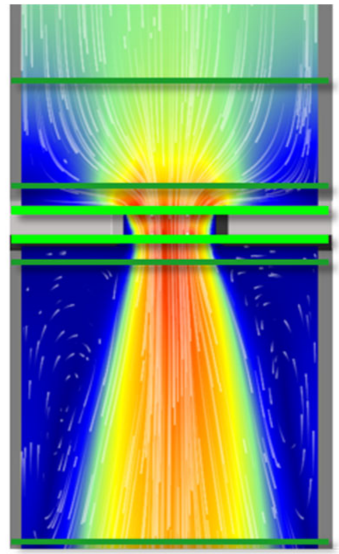
Cross Sections BU and BD

- The program automatically formulates two additional cross sections inside of the bridge structure. The geometry inside is a combination of the bounding cross sections (sections 2 and 3) and the bridge geometry.

- The interior cross sections can be edited from the bridge/culvert editor.



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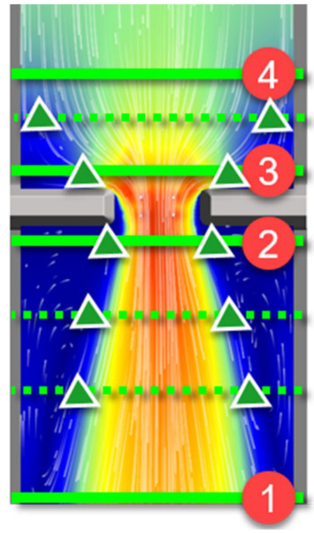
Cross Section 4

- Cross section 4 is an upstream cross section where the flow lines are approximately parallel and the cross section is fully effective.

- If the distance between cross section 3 and 4 is too great for accurate friction loss calculations, intermediate cross sections should be entered with ineffective flow areas defined.



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Contraction Reach Lengths

Table 2 Ranges of Contraction Ratios

	$n_{ob} / n_c = 1$	$n_{ob} / n_c = 2$	$n_{ob} / n_c = 4$
S = 1 ft/mile	1.0 - 2.3	0.8 - 1.7	0.7 - 1.3
5 ft/mile	1.0 - 1.9	0.8 - 1.5	0.7 - 1.2
10 ft/mile	1.0 - 1.9	0.8 - 1.4	0.7 - 1.2

Note: For each range, the higher values are typically associated with higher discharges and the lower values with lower discharges.

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There is not much different in the contraction zone upstream. Water will contract very rapidly…here mostly the numbers show that a contraction ration of 1:1 is very appropriate. With slower moving water in the overbanks water will contract even more quickly.

Contraction Length equation

$$L_c \;=\; 263 + 38.8\left(\frac{F_{c2}}{F_{c1}}\right) + 257\left(\frac{Q_{ob}}{Q}\right) - 58.7\left(\frac{n_{ob}}{n_c}\right)^{0.5} + 0.161\bar{L}_{obs}$$

For which R2 = 0.87 and S_e = 31 feet

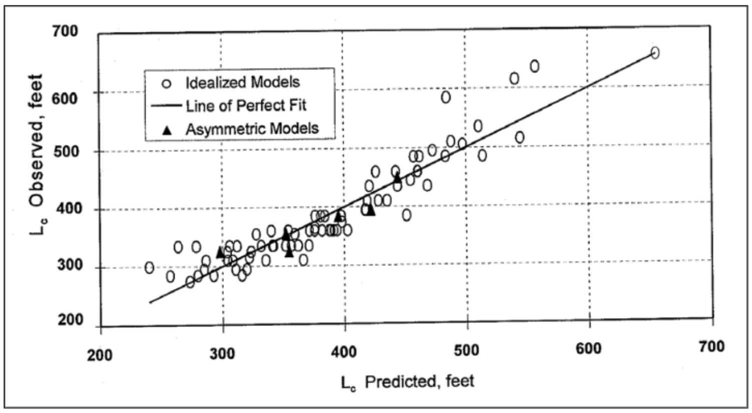

Figure 12 Goodness-of-Fit Plot for Contraction Reach Length Regression Equation

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Contraction is also based on the velocities at XS 2 and XS 1. Interesting, the tailwater conditions of a contraction control flow.

Contraction Rate equation

$$CR = \frac{L_c}{\overline{L}_{obs}} = 1.4 - 0.333\left(\frac{F_{c2}}{F_{c1}}\right) + 1.86\left(\frac{Q_{ob}}{Q}\right) - 0.19\left(\frac{n_{ob}}{n_c}\right)^{0.5}$$

For which R2 = 0.65 and S_e = 0.19

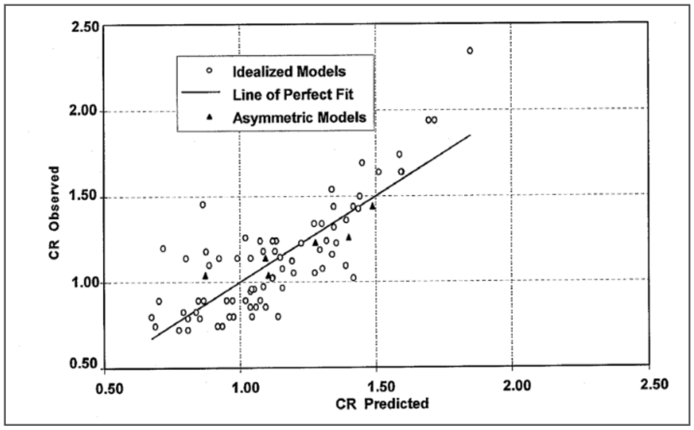

Figure 13 Goodness-of-Fit Plot for Contraction Ratio Regression Equation (Equation 20).

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And a contraction rate equation, again velocity and XS 2 and XS 1 are controlling.

Expansion Coefficient

$$C_e = -0.09 + 0.57\left(\frac{D_{ob}}{D_c}\right) + 0.075\left(\frac{F_{c2}}{F_{c1}}\right)$$

For which R2 = 0.55 and S_e = 0.10

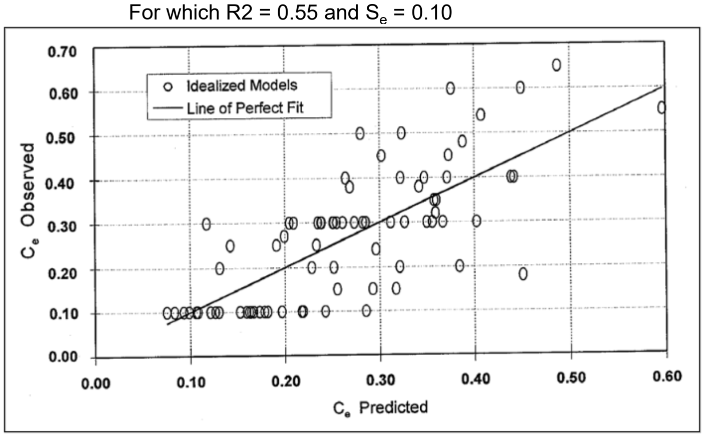

Figure 14 Goodness-of-Fit Plot for Expansion Coefficient Regression Equation (Equation 21).

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The analysis of the data with regard to the expansion coefficients did not yield a regression equation which fit the data extremely well. The Equation above was the best equation obtained for predicting the value of this coefficient. It is recommended that the modeler use the expansion coefficient Equation to find an initial value, then perform a sensitivity analysis using values of the coefficient that are 0.2 higher and 0.2 lower than the value from the Equation. The plus or minus 0.2 range defines the 95% confidence band for the equation. The expansion coefficient should not be higher than 0.80.

Dob = hydraulic depth (flow area divided by top width) for the overbank at the normal flow section (section 1)
Dc = hydraulic depth for the main channel at the normal flow section (section 1)

Contraction Coefficient

- Coefficients range from 0.1 to 0.5
- The mean was 0.12

Degree of Constriction	Recommended Contraction Coefficient
0.0 < b/B < 0.25	0.3 - 0.5
0.25 < b/B < 0.50	0.1 - 0.3
0.50 < b/B < 1.0	0.1

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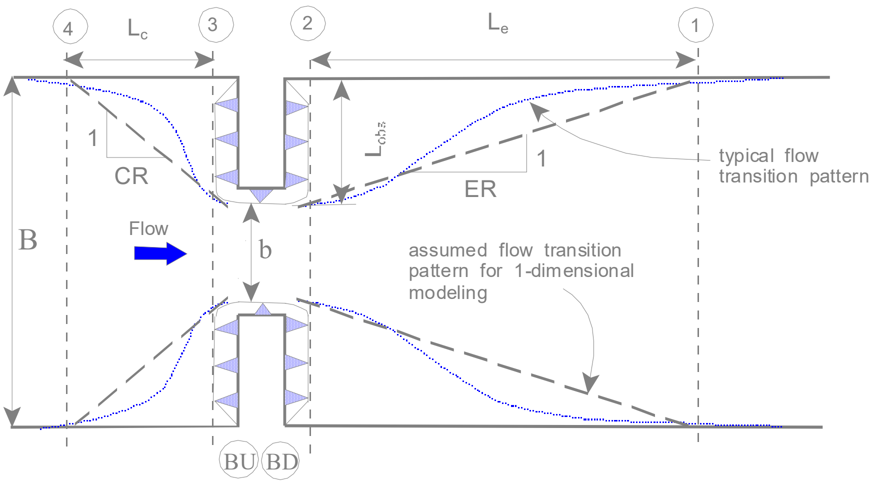
The data of this study did not lend itself to regression of the contraction coefficient values. For nearly all of the cases the value that was determined was 0.1, which was considered to be the minimum acceptable value. The table above presents recommended ranges of the contraction coefficient for various degrees of constriction, for use in the absence of calibration information. These recommendations are based on model data which, like all data, have a limited scope of direct application. Certain situations, such as highly skewed bridge crossings and bridges at locations of sharp curvature in the floodplain were not addressed by this study. Even so, these recommendations may be applicable.

Defining Ineffective Flow Areas



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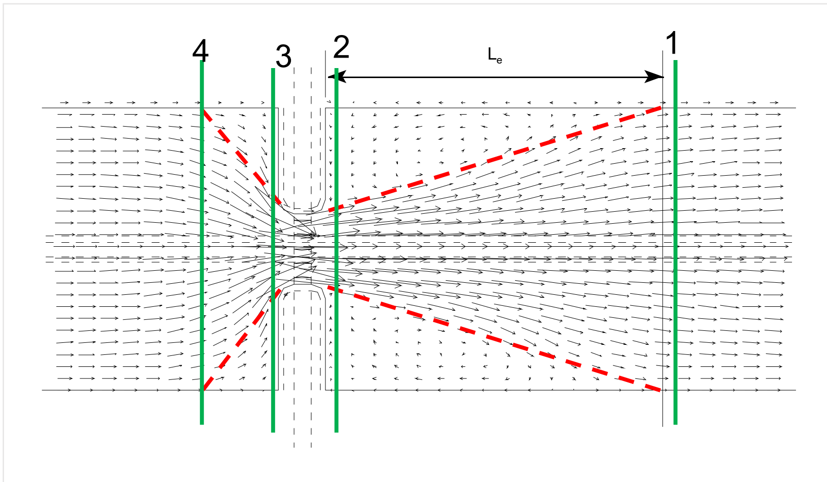
Referring to the Figure above, the dashed lines represent the effective flow boundary for low flow and pressure flow conditions. For cross sections 2 and 3, ineffective flow areas to either side of the bridge opening should not be included as part of the active flow area for low flow or pressure flow.

The **ineffective area option** is used at sections 2 and 3 to keep all the flow in the area of the bridge opening while all the flow is passing under the bridge. The elevations specified for ineffective flow should correspond to elevations where significant weir flow passes over the bridge.

The **ineffective area option** allows the overbank areas to become effective as soon as the ineffective-area elevations are exceeded. The flow in the overbank will pass over the bridge-roadway.

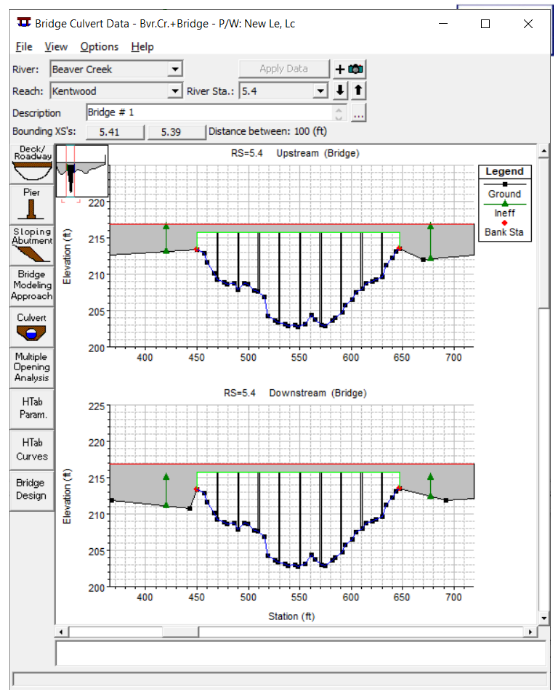
Ineffective Flow Areas at Bounding Cross Sections



General Cross Section setup for modeling effective and ineffective flow areas – showing the non-conveying areas.

Ineffective Area Option

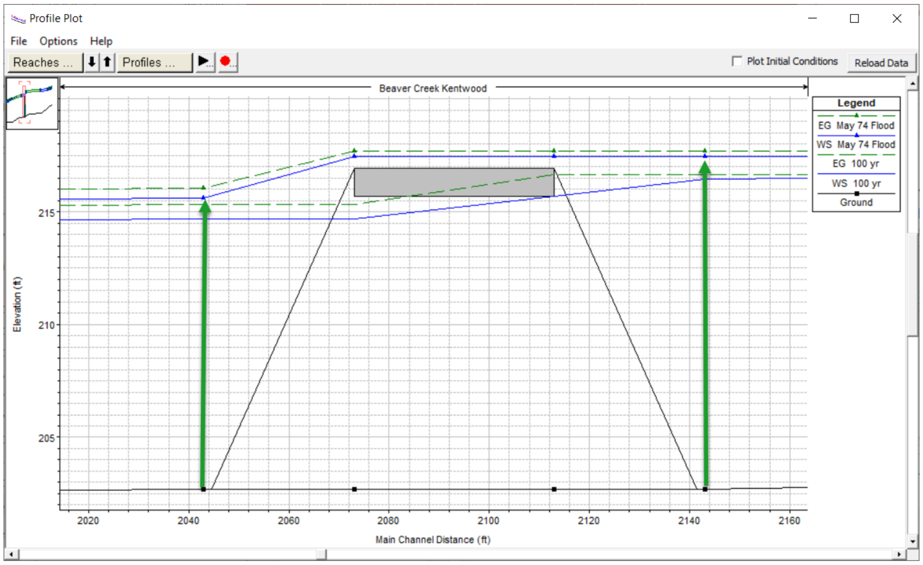
- Access from Bridge Editor or XS editor
- Adjust lateral distance for bounding sections, based on distance from bridge and contraction and expansion rates
- Define trigger elevations (i.e. when they turn off) based on when flow will overtop the bridge.



The trigger elevation of the ineffective flow areas for cross-section 3, (the upstream cross section) is usually the overflow elevation of the top-of-road. Because there is energy loss between the sections, cross section 2 will often have an ineffective flow area trigger elevation lower than cross section 3. Model results must be reviewed to ensure that the ineffective flow trigger elevations are consistent with the bridge hydraulics solution.

Using the ineffective area option in this manner provides for a constricted section when all of the flow is going under the bridge. When the water surface is higher than the control elevations used, the entire cross section is used. It is often necessary to raise the Manning's n values in the left and right overbank (For cross sections just upstream and downstream of the bridge) in order to get the conveyance of the cross section overbank areas to be consistent with the weir flow computed over the roadway. Raise the Mannings n in the left and right overbank until the flow in the overbank areas is around the same as the weir flow computed at the bridge for the overbank areas. Sometimes this may require Manning's n values in the range of (.06 to 0.3), depending how much the road embankment is blocking the flow (Conveyance) in the cross sections just upstream and downstream of the bridge.

Ineffective Area Trigger Elevations



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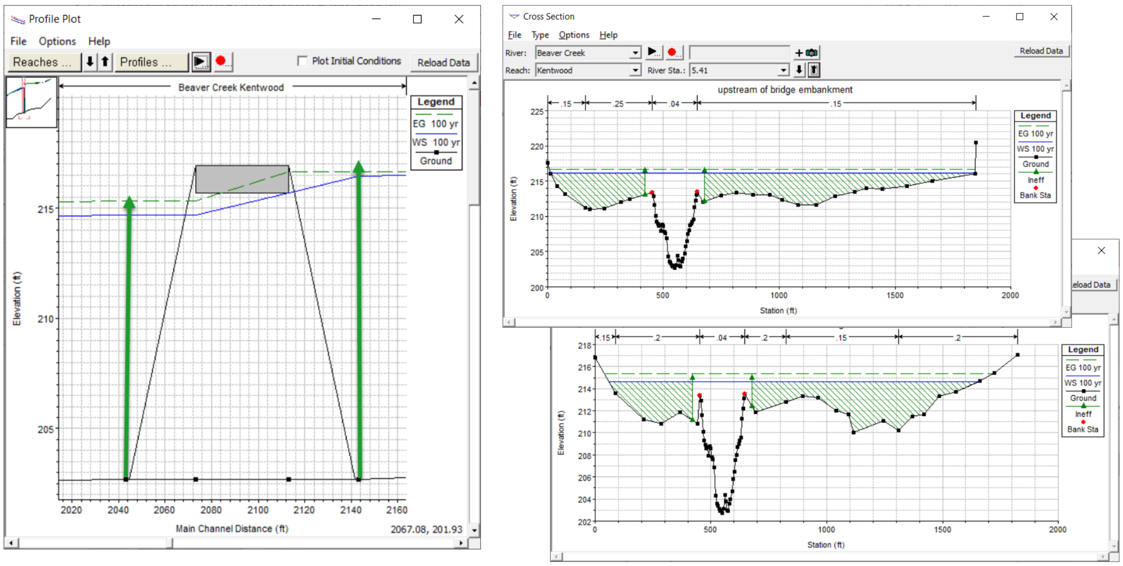
Trigger Elevations are used to “Turn OFF” ineffective flow areas. These must be set such that the ineffective flow areas around bridges turn off in unison based on the water surface profiles.

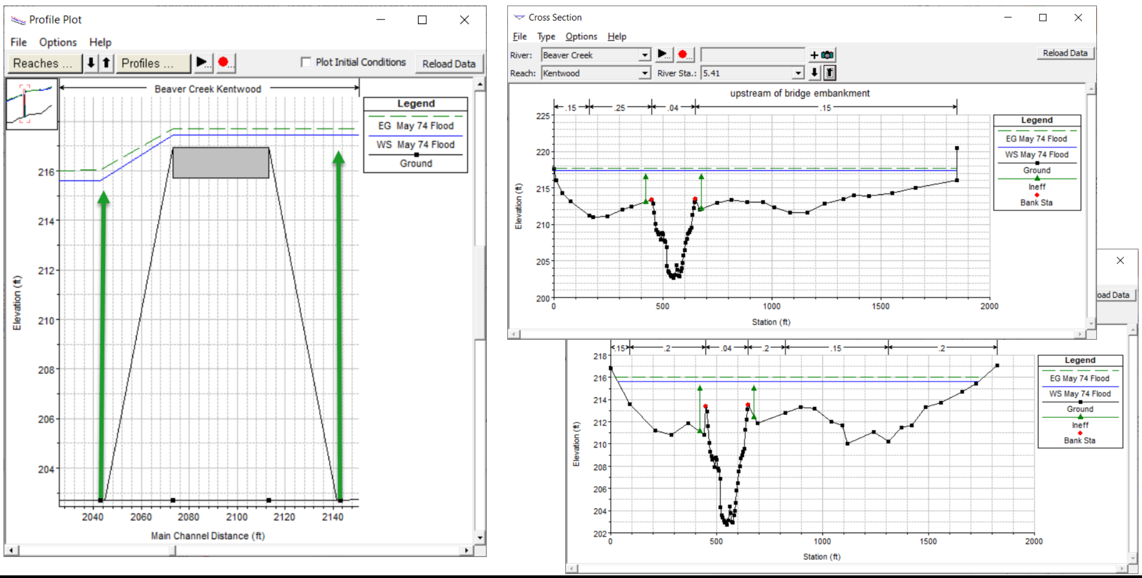
Non Over-Topping Profile



The Energy Grade is used to compute Weir flow over the bridge.
The Water Surface is used to Tigger the Ineffective Flow areas.
You must make sure the Ineffective Flow Areas are turned off together.

In the figure above, you can see the ineffective flow areas are ON together.

Over-Topping Profile



As the water surface rises….

In the figure above, you can see the ineffective flow areas are OFF together.

Review Bridge Solution

Profile Output Table - Bridge Only

File Options Std. Tables Locations Help

HEC-RAS Plan: Pre+NewLeLc River: Beaver Creek Reach: Kentwood | Reload Data

Reach	River Sta	Profile	E.G. US. (ft)	Min El Prs (ft)	BR Open Area (sq ft)	Prs O WS (ft)	Q Total (cfs)	Min El Weir Flow (ft)	Q Weir (cfs)	Delta EG (ft)	BR Sluice Coef
Kentwood	5.4	25 yr	213.39	215.70	1600.36		5000.00	216.94		0.25	
Kentwood	5.4	100 yr	216.65	215.70	1600.36	216.19	10000.00	216.94		1.31	0.34
Kentwood	5.4	May 74 Flood	217.68	215.70	1600.36	221.61	14000.00	216.94	3047.83	1.64	0.34

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

- Bridge Only shows all profile results
- Review the bridge solutions and weir flow
- Check continuity upstream and down from bridge to ensure “balanced” solution

Six Section Bridge Table

- Does the bridge solution check with the cross section solution?
- Is the flow distribution consistent?

Profile Output Table - Six XS Bridge

File Options Std. Tables Locations Help

HEC-RAS Plan: Pre+NewLeLc River: Beaver Creek Reach: Kentwood

Reach	River Sta	Profile	E.G. Elev (ft)	W.S. Elev (ft)	Crit W.S. (ft)	Frctn Loss (ft)	C & E Loss (ft)	Top Width (ft)	Q Left (cfs)	Q Channel (cfs)	Q Right (cfs)	Vel Chnl (ft/s)
Kentwood	5.49*	25 yr	213.99	213.75	211.95	0.60	0.00	1254.85	1351.15	2769.19	879.66	5.19
Kentwood	5.49*	100 yr	217.02	216.95	213.38	0.33	0.04	1877.53	3083.15	2748.12	4168.73	3.61
Kentwood	5.49*	May 74 Flood	217.98	217.91	214.40	0.29	0.02	1910.11	4180.23	3239.32	6580.44	3.90
Kentwood	5.41	25 yr	213.39	213.12	208.92	0.05	0.02	1038.01		4995.53	4.47	4.17
Kentwood	5.41	100 yr	216.65	216.19	210.95			1836.20	36.42	9878.01	85.58	5.48
Kentwood	5.41	May 74 Flood	217.68	217.44	212.24			1847.06	1228.04	9653.69	3118.27	4.71

Profile Output Table - Six XS Bridge

File Options Std. Tables Locations Help

HEC-RAS Plan: Pre+NewLeLc River: Beaver Creek Reach: Kentwood Profile: May 74 Flood

Reach	River Sta	Profile	E.G. Elev (ft)	W.S. Elev (ft)	Crit W.S. (ft)	Frctn Loss (ft)	C & E Loss (ft)	Top Width (ft)	Q Left (cfs)	Q Channel (cfs)	Q Right (cfs)	Vel Chnl (ft/s)
Kentwood	5.49*	May 74 Flood	217.98	217.91	214.40	0.29	0.02	1910.11	4180.23	3239.32	6580.44	3.90
Kentwood	5.41	May 74 Flood	217.68	217.44	212.24			1847.06	1228.04	9653.69	3118.27	4.71
Kentwood	5.4 BR U	May 74 Flood	217.68	217.44	212.52			1847.06	755.33	11282.84	1972.79	6.64
Kentwood	5.4 BR D	May 74 Flood	217.68	217.44	212.52			1824.00	755.33	11282.84	1972.79	6.64
Kentwood	5.39	May 74 Flood	216.04	215.62	212.26	1.12	0.14	1702.87	1073.65	10252.92	2673.43	6.07
Kentwood	5.24*	May 74 Flood	214.77	214.64	211.52	0.98	0.03	1633.34	2335.75	2506.36	9157.89	5.26

Energy gradeline for given WSEL.

Check the Six Cross Section Bridge Table to evaluate flow continuity from upstream of the bridge, through the bridge, and downstream of the bridge. Check to make sure that the flow in the left overbank, main channel, and right overbank, is consistent between what is shown for the cross sections just upstream and downstream of the bridge, as well as what is computed by the bridge hydraulic computations shown inside of the bridge. Are the ineffective flow areas staying or turning off consistently from upstream to downstream for each overbank area. If the cross sections just upstream and downstream of the bridge are showing way more overbank flow than the bridge sections, increase the Manning's n values in the overbank areas at these cross sections, until the flow/conveyance is consistent with the bridge hydraulics. This is necessary, because once the ineffective flow areas turn off, the cross sections distribute flow based on the cross section shape and roughness values. The cross sections just upstream and downstream of the bridge do not take into account that the bridge embankment is blocking the flow and will reduce the overbank flow/conveyance. So increasing the Manning's n values is necessary to get the right flow distribution in the cross sections bounding the bridge.

Final Bridge Solution – High Flow

- Utilize Ineffective Areas to remove conveyance for bounding cross sections where bridge is NOT overtopped.
- Ineffective Flow Areas turn off in unison.
- Utilize increased Manning's n values to control flow in bounding cross sections.
- If using pressure/weir flow solution, weir flow should be consistent with channel and overbank flow.

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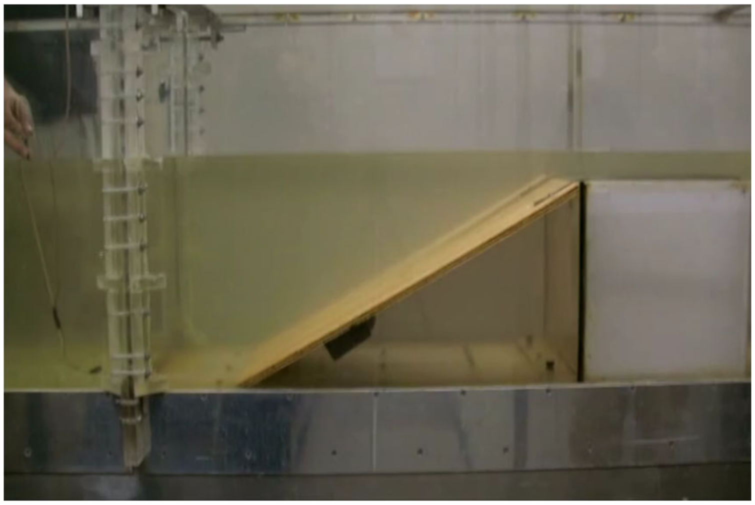
Ineffective Flow Area Video



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Questions?

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