

Combined 1D River and 2D Floodplain/Levee Areas

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of Engineers®



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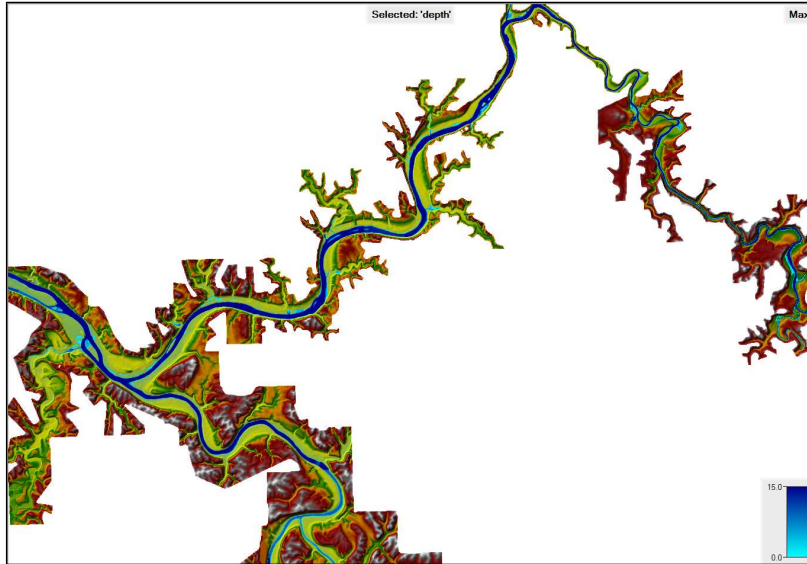


Review of HEC-RAS Capabilities

- 1D Steady Flow Hydraulics
 - Depth, velocity, discharge treated as constant with time (gradually varied)
 - Solves for stage
 - Relies on 'hydrologic routing'
- 1D Unsteady Flow Hydraulics
 - Depth, velocity, discharge changes with time
 - Solves for flow and stage
 - Computes 'hydraulic routing'
- 2D Unsteady Flow Hydraulics
 - Direction of flow changes
 - More detailed account of forces
 - Energy losses directly accounted for
 - Mapping more accurate
 - Velocities more accurate

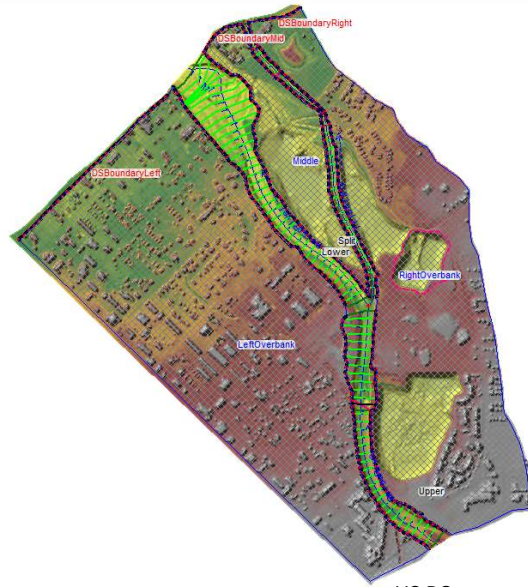


Example of a highly one-dimensional system

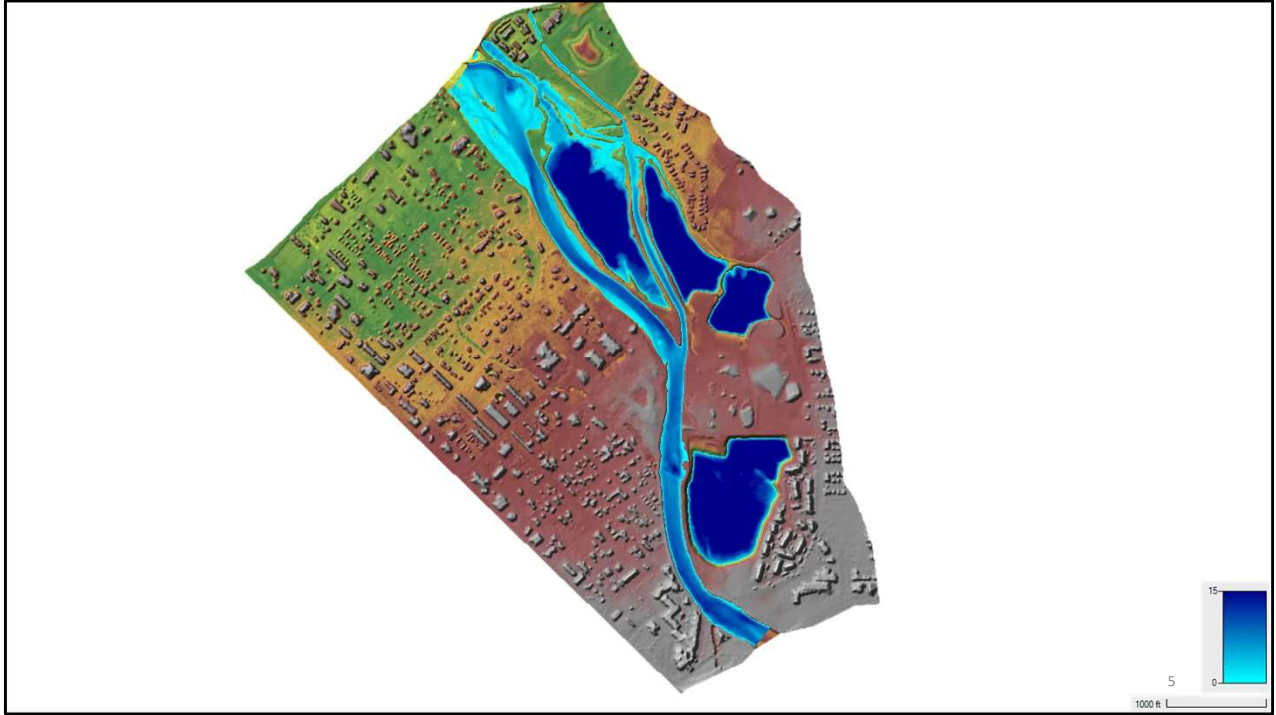




2D Unsteady Flow



US BC





2D Modeling Advantages

- Water flow path does **not** have to be known ahead of time
 - Direction of the flow can change during the event
 - Water can move in any direction, based on energy and momentum of the flow
- However, the extent of the flooding does need to be correctly defined
- Velocity, momentum, and the direction of the flow are more accurately accounted for. This is especially true for flow going over roads, levees, barriers, structures, around bends, and at junctions/splits. Additionally, 2D models can be used to analyze eddy zones within the flow. Around bends, 2D models produce accurate water surface elevations, but velocity distribution might be erroneous due to the existence of helical flow.
- Energy and force losses due to contractions and expansions, etc. are directly accounted for, not require empirical coefficients, increased roughness, or user defined ineffective flow area
- Mapping of the inundated areas, as well as velocities, and flood hazards (depth x velocity) is accurate
- Detailed modeling of hydraulic structures, in a 2D modeling approach, can provide more insight into the flow distribution approaching, going through, and coming out of a structure

The question of 1D versus 2D hydraulic modeling is a much tougher question than steady versus unsteady flow. There are definitely some areas where 2D modeling can produce better results than 1D modeling, and there are also situations in which 1D modeling can produce as good as or better results than 2D models... with less effort and computational requirements. Unfortunately, there is a very large range of situations that fall into a gray area, and one could list the positive and negative aspects of both methodologies for specific applications. Here are some areas where I think 2D modeling can give better results than 1D modeling:

When modeling an area behind a leveed system, and the levee will be overtopped and/or breached, the water can go in many directions. If that interior area has a slope to it, water will travel overland in potentially many directions before it finds its way to the lowest point of the protected area, and then it will begin to pond and potentially overtop and/or breach the levee on the lower end of the system. However, if a protected area is small, and ultimately the whole area will fill to a level pool, then 1D model is fine for predicting the final water surface and extent of the inundation.

Very wide and flat flood plains, such that when the flows goes out into the overbank area, the water will take multiple flow paths and have varying water surface elevations and velocities in multiple directions.

Alluvial fans – however, this is very debatable that any numerical model can capture a flood event accurately on an alluvial fan, due to the episodic nature of flow evolutions that can change the whole direction of the channels during the event.

Bays and estuaries in which the flow will continuously go in multiple directions due to tidal fluctuations and river flows coming into the bay/estuary at multiple locations and times.

Highly braided streams

Flow around abrupt bends in which a significant amount of super elevation will occur during the event.

Applications where it is very important to obtain detailed velocities for the hydraulics of flow around an object, such as a bridge abutment or bridge piers, etc...



2D Modeling Disadvantages

- More detailed terrain models are required in order to run a 2D model. The terrain include the details of the channels at all locations within the model.
- Defining and modifying roughness values requires more spatial definition and can be difficult and time consuming during the calibration process
- Turbulence Modeling coefficients must be calibrated
- Requires significantly more computational time and/or computational resources. Models require the purchase of a very high-level computer (many cores, fast CPU's, lots of RAM and fast hard disk), or utilizing HPC and cloud computing solutions.
- May require using larger grid sizes than desirable for the problem, in order to reduce run times to a manageable amount of time.
- May not really produce better results, if the data used to perform the modeling (terrain channel data, and roughness) do not support the level required for accurate 2D modeling.

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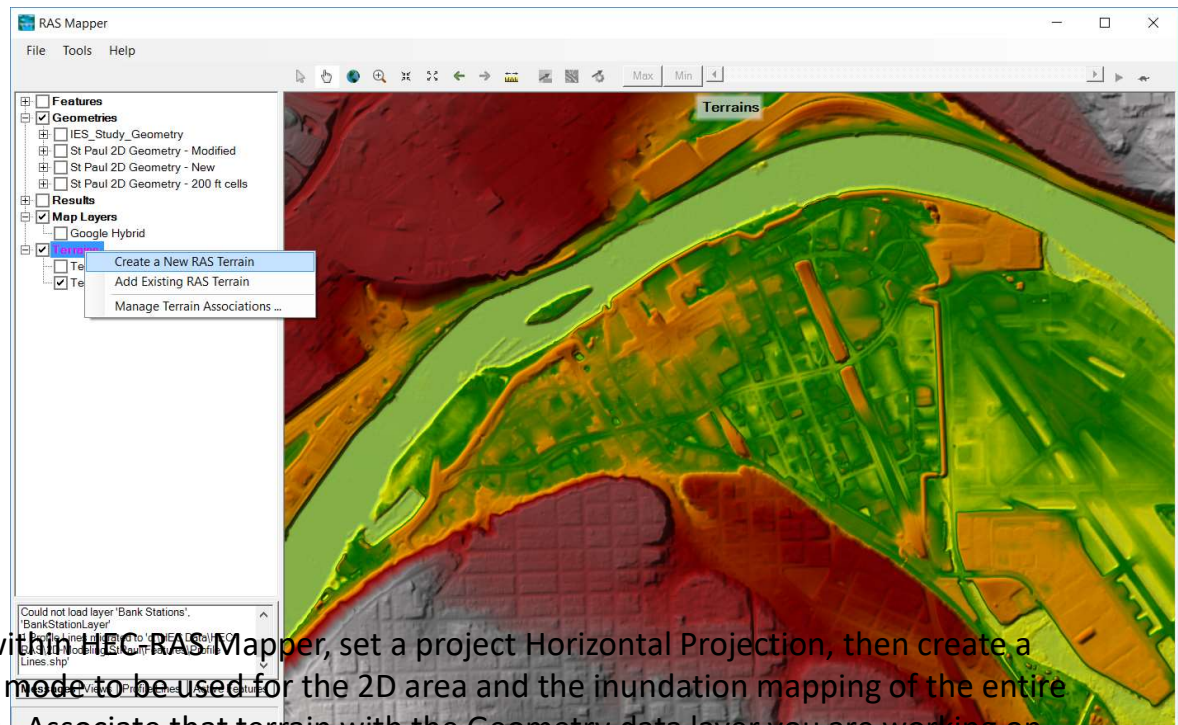


Combined 1D / 2D Modeling

- Use both 1D and 2D hydraulics in the same domain
- Leverage advantages of 1D or 2D where needed
- Common applications:
 - 2D in overbanks
 - 2D in protected areas
 - Channel transitions from 1D to 2D



Modeling a Protected Area

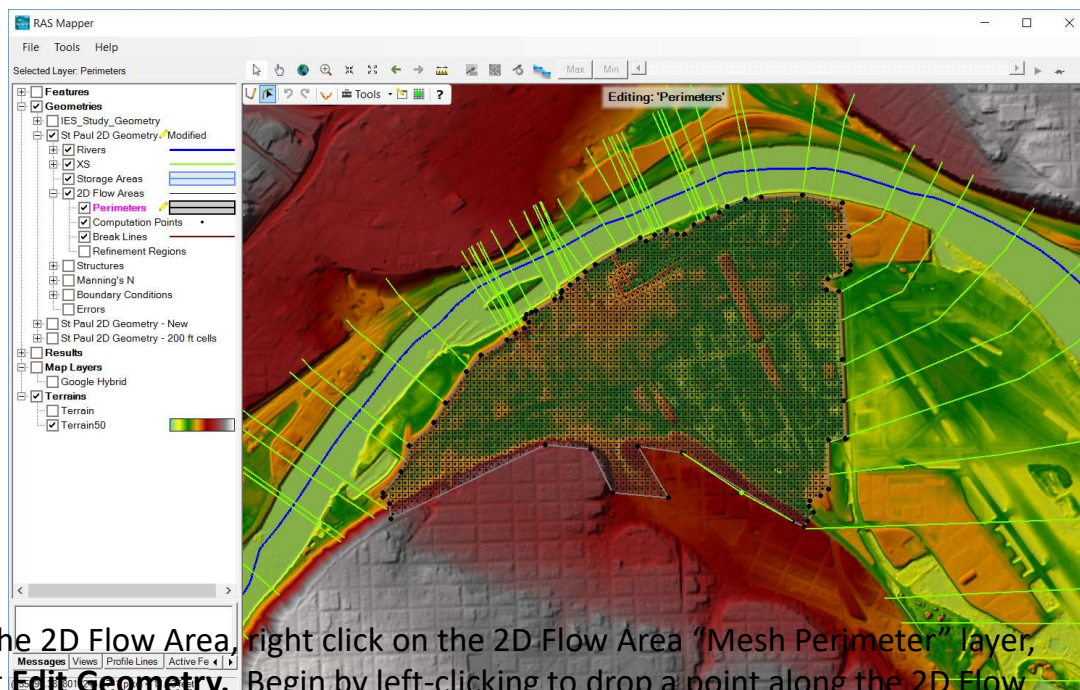


From within HEC-RAS Mapper, set a project Horizontal Projection, then create a terrain mode to be used for the 2D area and the inundation mapping of the entire project. Associate that terrain with the Geometry data layer you are working on.

Additionally you can bring in some mapping layers, such as Aerial photography, levee centerline (Shapefile), etc... Once this information is available in HEC-RAS Mapper, it can then be used as background mapping layers in the HEC-RAS Geometry editor.



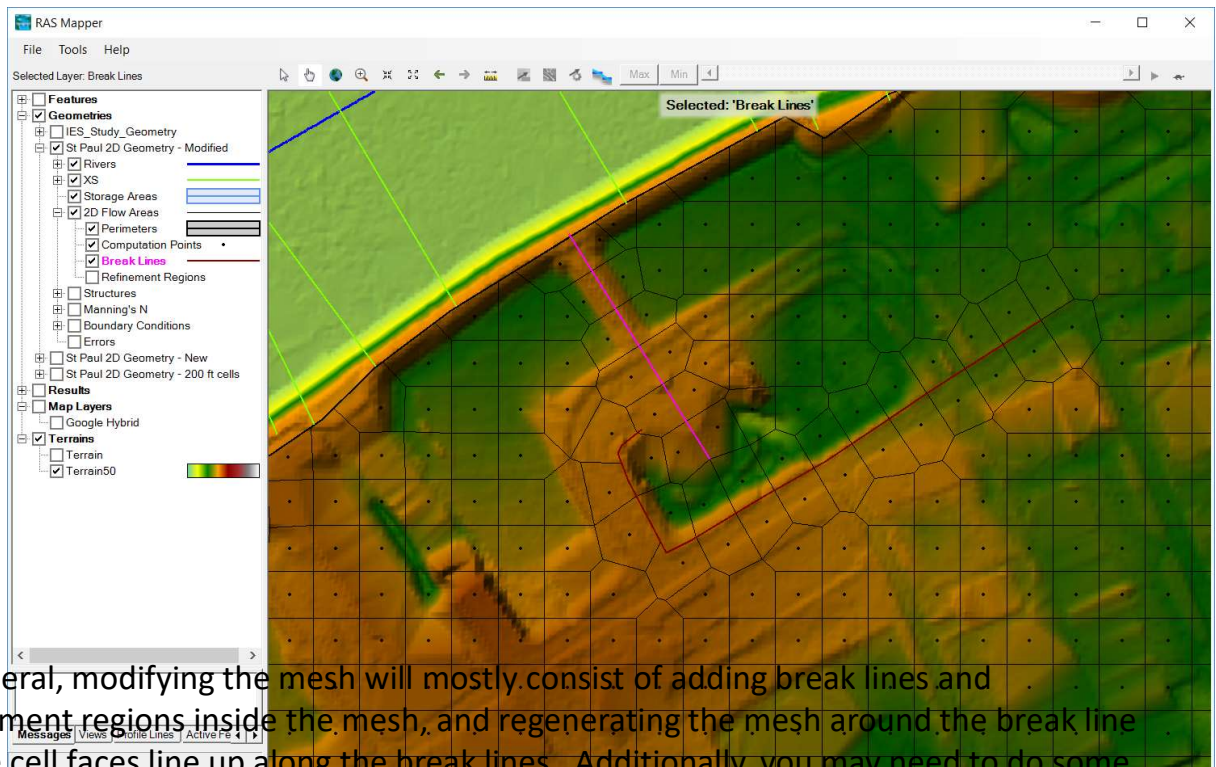
Draw a Polygon for the 2D Flow Area Boundary Inside of the Levee



To create the 2D Flow Area, right click on the 2D Flow Area "Mesh Perimeter" layer, then select **Edit Geometry**. Begin by left-clicking to drop a point along the 2D Flow Area polygon boundary. Then continue to use the left mouse button to drop points in the 2D Flow Area boundary. As you run out of screen real estate, right click to re-center the screen. Double-click the left mouse button to finish creating the polygon. Once you have finished drawing the 2D area polygon by double clicking, the interface will ask you for a Name to identify the 2D Flow Area. Shown in the Figure above is an example 2D Flow Area polygon for an area that is protected by a levee. The name given to the 2D Flow Area in this example is: "2DArea".



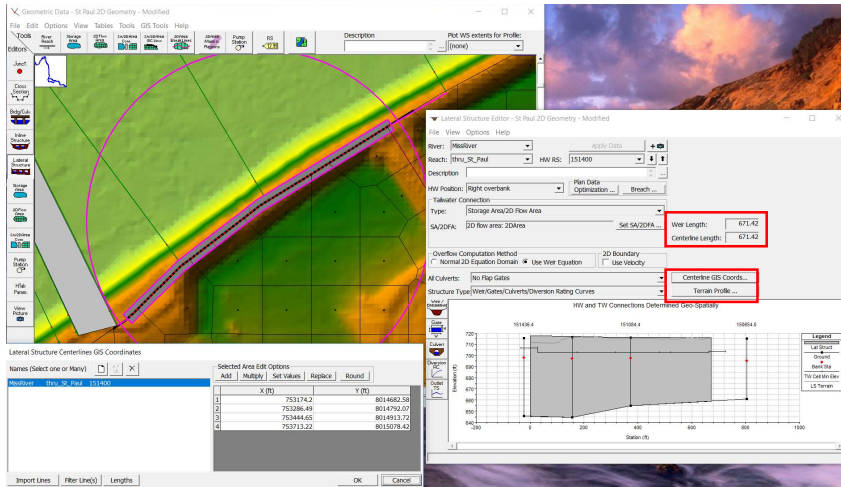
Modify The Mesh as Needed



In general, modifying the mesh will mostly consist of adding break lines and refinement regions inside the mesh, and regenerating the mesh around the break line so the cell faces line up along the break lines. Additionally, you may need to do some hand editing with the Editing tools. The Edit tools allow you to: moving points; add points, and delete points.



Using Geospatial Coordinates for Lateral Structures

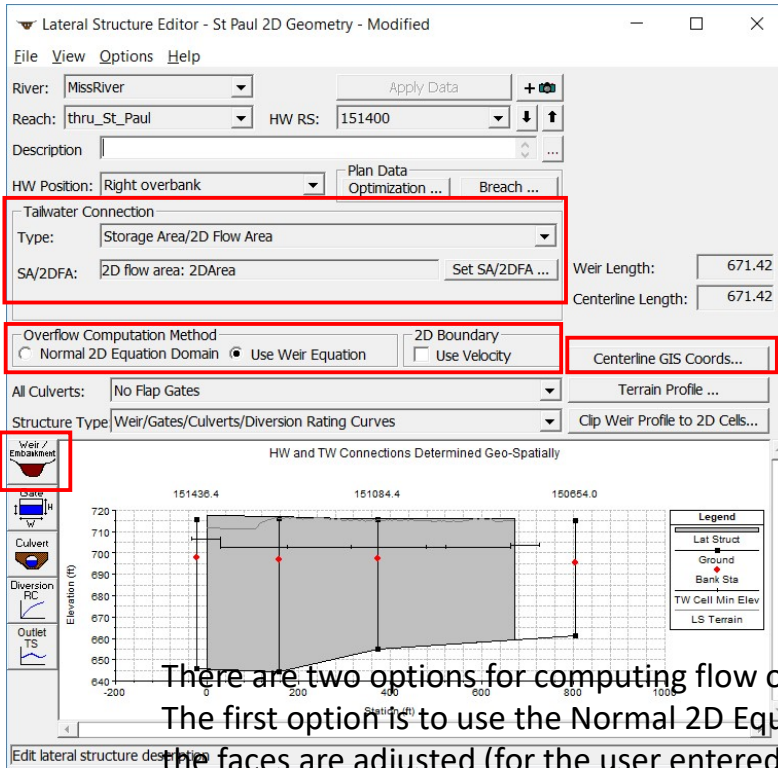


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User's can now define a set of X and Y coordinates to locate the centerline of a lateral structure in HEC-RAS. The coordinates must be drawn from upstream to downstream. Cross sections are connected to the lateral structure based on the closest point on the lateral structure centerline to the ends of the cross section. HEV-RAS automatically figures this out. Because the ends of the cross section are used, user's may need to change the locations of the cross section cut lines to ensure the ends of the cross sections link to the correct locations of the lateral structure. Additionally, the length of the geospatial centerline and the length that the user enters for the structure station/elevation data must be within 1.0 ft of each other, or the software will not run, and will issue that the structure centerline length and station/elevation data are not matched up.



Lateral Structure Editor



- Weir Equation

- $Q = CLH^{3/2}$
- Larger head difference
- Minimal submergence

- 2D Equation

- Modifies cell face properties
- Computes flow across faces using HW elevations
- Smaller head difference

There are two options for computing flow over the top of a HS: Submergence is fine
The first option is to use the Normal 2D Equation Domain. The elevation/profile of the faces are adjusted (for the user entered SE Data), but the 2D flow across the HS faces is computed like it would be for any other face. The only function that the HS is performing is to modify the terrain data. If the user entered station/elevation data exactly matched the underlying terrain data, then the HS would not affect the computed answers and the HS is not actually needed. (It might still be convenient from a user output perspective.)

The second option is to use the Weir Equation. In this case, the flow is computed using the standard $Q = CLH^{3/2}$. The computations are exactly analogous to a lateral structure that has multiple cross sections on both the headwater and tailwater side (except it is using the stages from the cells instead of the stages from the cross sections)—weir shape, weir coefficient, and weir submergence are all handled the same.



Lateral Weir/Embankment Editor

Lateral Weir Embankment

Weir Data
Weir Width: 25.
Weir Computations: Standard Weir Eqn
Standard Weir Equation Parameters
Weir flow reference: Water Surface
Weir Coefficient (Cd): 2.
Weir Crest Shape: Broad Crested

Weir Stationing Reference
HW - Distance to Upstream XS: 23.

HW Connections ... TW Connections ...

Embankment Station/Elevation Table
Insert Row Delete Row Filter...

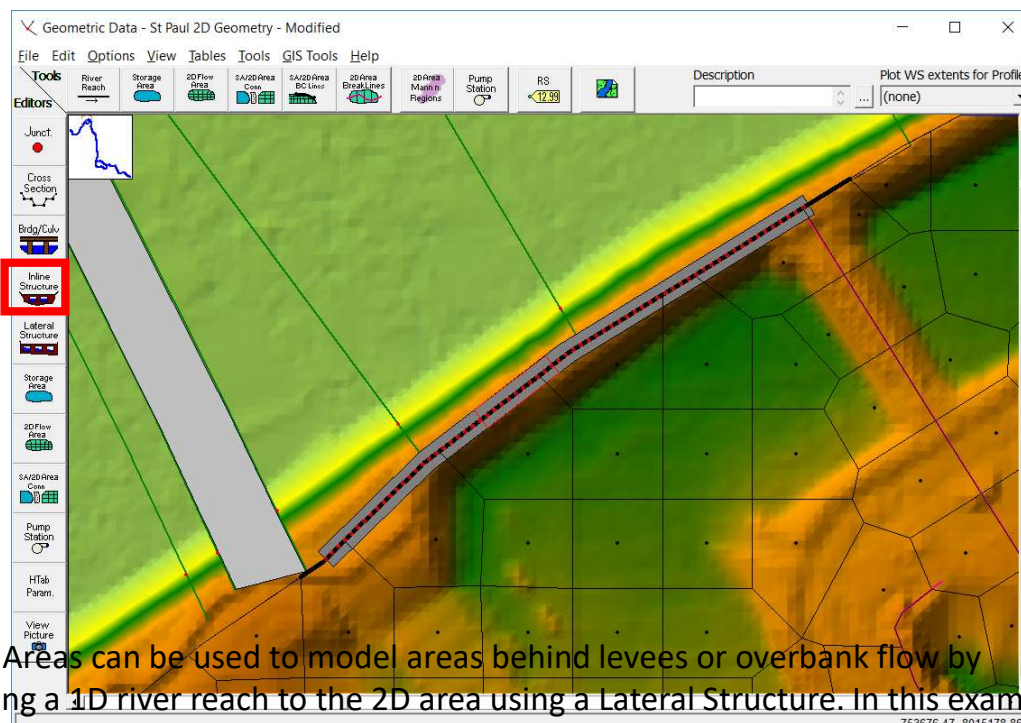
	Station	Elevation
1	0	717.52
2	160.9	717.328
3	217.23	716.861
4	239.07	716.825
5	297.36	716.253
6	477.08	716.183
7	556.99	716.042
8	671.42	716.046
9		
10		
11		
12		
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22		

OK Cancel

Next, select the **“Weir/Embankment”** button on the left side of the graphic window. This will bring up the editor that will allow you to define the top profile of the embankment, as well as line the lateral structure up with the 1D river cross sections (the headwater side of the structure), and link it to the 2D area Face Points (the tailwater side of the structure), as shown in the Figure above. As shown in the Figure above, the user goes about the normal process of entering a Lateral Structure in RAS by entering the: weir width, weir coefficient, HW Distance to Upstream XS, and the Weir Station and Elevation points. This will define the top of the lateral structure (levee) profile.



Hooking up a 2D Flow Area to a 1D River Reach with Lateral Structures



2D Flow Areas can be used to model areas behind levees or overbank flow by connecting a 1D river reach to the 2D area using a Lateral Structure. In this example, this Lateral Structure (levee) will be used to model flow going over the levee, as well as a levee breach that will be added later. The process of hooking up a Lateral Structure to a 2D Flow Area is listed below:

1. Add the Lateral Structure as you normally would in HEC-RAS (i.e. create the Lateral Structure; define the upstream River Station of the structure; enter the station/elevation points that represent the centerline of the top of the structure).
2. HEC-RAS now allows you to enter geospatial coordinates for lateral structure centerlines.



Lateral Weir Headwater Connections (HW)

HW Lateral Structure Connections

Computed Default Weir Stationing User Defined Weir Stationing

Default Computed Weir Stationing		User Defined Weir Stationing			
	XS RSs	Weir Station			
1	151436.4	-22.92	1	151354.9	5692
2	151354.9	156.84	2	151084.4	5909
3	151084.4	373.92	3	150654.0	6435
4	150654.0	803.62	4		
5			5		
6			6		
7			7	User Specified Connections	
8			8	option will not be used	
9			9	because the lateral structure	
10			10	has a geo-referenced	
11			11	centerline.	
12			12		
13			13		
14			14		
15			15		
16			16		
17			17		
18			18		
19			19		

OK Cancel

16

For the Headwater (HW) connection to the 1D cross sections, the user can use the default, which is to have RAS compute the intersection of the 1D cross sections with the Lateral Structure based on the cross section overbank reach lengths (or channel lengths if user selected) and the Lateral Structure weir profile stationing (See Chapter 6 of the User's manual, "Entering and Editing Lateral Structure Data" section, for more detailed discussion).



Lateral Weir Tailwater Connections (TW)

TW Lateral Structure Connections

Computed Default Weir Stationing User Defined Weir Stationing

Default Computed Weir Stationing		User Defined Weir Stationing		
	2D Face Points	Weir Station		
1	456	-34.3083	1 454	5470.98
2	412	28.59606	2 411	5537.3
3	368	174.9681	3 368	5703.08
4	319	314.8326	4 319	5861.57
5	322	479.7218	5 322	6048.15
6	325	521.3957	6 325	6095.38
7	2408	663.5559	7	User Specified Connections
8	239	725.6677	8	Option will not be used
9			9	because the lateral structure
10			10	has a geo-referenced
11			11	centerline.
12			12	
13			13	
14			14	
15			15	
16			16	
17			17	
18			18	
19			19	

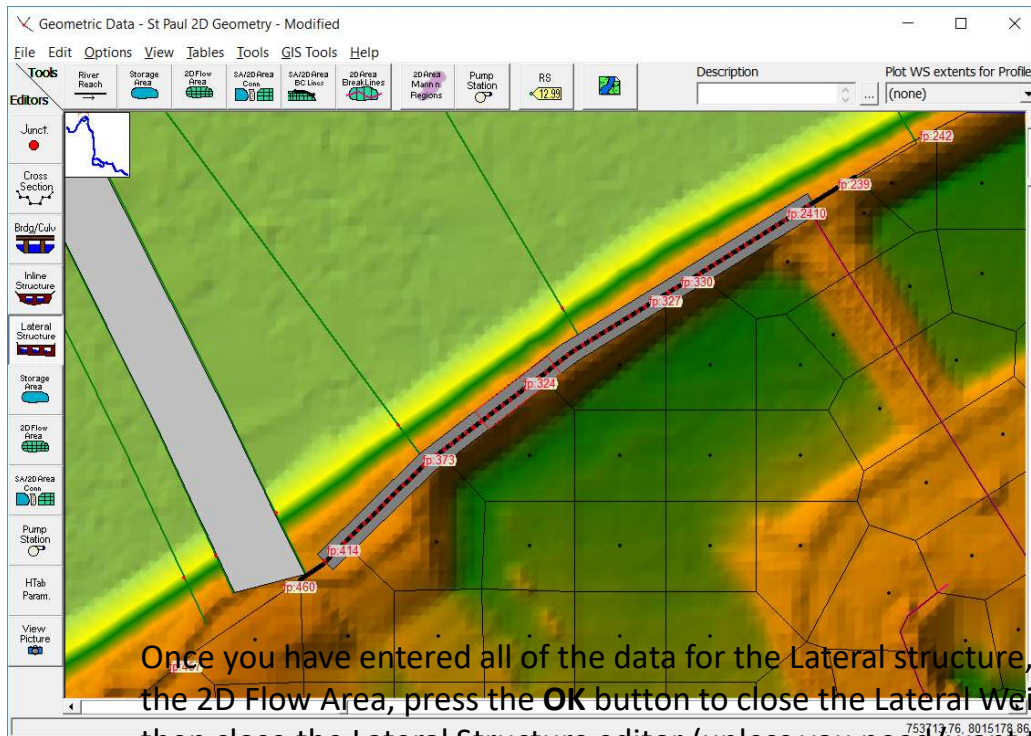
OK Cancel

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The last step is to link the 2D Flow Area Face Points to the stationing of the Lateral Structure. This is done by selecting the “TW Connection” button, and using the tailwater connection table. By default, the software will come up with the Tailwater Connection table set to “**Default computed intersections**”. In this mode, HEC-RAS will automatically determine the connections between your lateral structure and the 2D Flow Area. This means HEC-RAS will find the 2D Flow Area Face Points that start at the upstream end of the structure and go along the structure to the downstream end. Generally, a lateral structure will not start exactly at a 2D Flow Area Face Point. So, HEC-RAS will pick the Face Point just upstream of the lateral structure to start the connection. This point will normally be given a negative weir stationing, meaning that it is actually upstream of the lateral structure by that distance. So the zero weir stationing is actually in between two Face Points. The second Face Point in the table will be the next point downstream and it will have a positive weir stationing. This stationing will represent how far the upstream end of the lateral weir is from that Face Point, along the length/stationing of the lateral weir.



Connected 1D River to 2D Flow Area with Lateral Structure



Once you have entered all of the data for the Lateral structure, including the links to the 2D Flow Area, press the **OK** button to close the Lateral Weir Embankment editor, then close the Lateral Structure editor (unless you need/want to add gates, culverts, rating curves, etc... to further define the details of the lateral structure). The HEC-RAS Geometric editor will now show a thick black line along the 2D Area Face Points, to show you where the Lateral Structure is connected to the 2D Flow Area (see Figure above). If this black line does not follow all of the appropriate Face Points from the 2D Flow Area, then there is a mistake in the 2D Flow Area connection table. So the thick black line can be used as a guide to help identify if the Lateral Structure is connected correctly to the 2D Flow Area.

NOTE: If you change the computational mesh in any way, the number system will change. This may break the connection of the lateral structure with the 2D Flow Area. If you are using the “Default computed intersections” option, HEC-RAS will automatically reconnect it to the correct face points. However, if you have put in Face Points by hand, using the “User Specified Intersections” option, you will have to redo the connection again.



Weir Coefficients for Lateral Structures

What is being modeled with the Lateral Structure	Description	Range of Weir Coefficients
Levee/Roadway – 3ft or higher above natural ground	Broad crested weir shape, flow over Levee/road acts like weir flow	1.5 to 2.6 (2.0 default) SI Units: 0.83 to 1.43
Levee/Roadway – 1 to 3 ft elevated above ground	Broad Crested weir shape, flow over levee/road acts like weir flow, but becomes submerged easily.	1.0 to 2.0 SI Units: 0.55 to 1.1
Natural high ground barrier – 1 to 3 ft high	Does not really act like a weir, but water must flow over high ground to get into 2D area.	0.5 to 1.0 SI Units: 0.28 to 0.55
Non elevated overbank terrain. Lat Structure not elevated above ground	Overland flow escaping the main river.	0.2 to 0.5 SI Units: 0.11 to 0.28

In general, Lateral Structure weir coefficients should be lower than typical values used for inline weirs. Above is a table of rough guidelines for Lateral weir coefficients under different conditions.

However, weir coefficients should be calibrated to produce reasonable results whenever possible.



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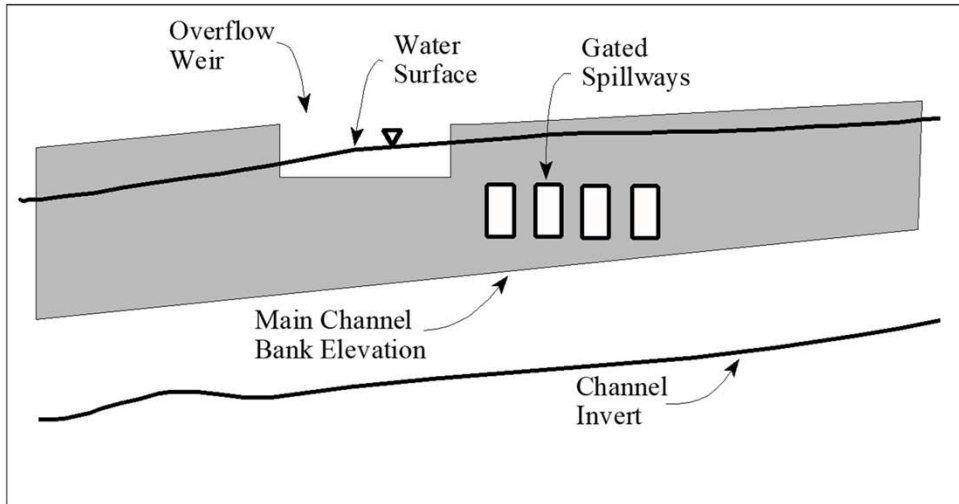
In general, Lateral Structure weir coefficients should be lower than typical values used for inline weirs. Additionally, when a lateral structure (i.e. weir equation) is being used to transfer flow from the river (1D region) to the floodplain (2D Flow Area), then the weir coefficients that are used need to be very low, or too much flow will be transferred. Above is a table of rough guidelines for Lateral weir coefficients under different conditions.

Note: The number 1 problem HEC-RAS users have been having when interfacing 1D river reaches with 2D Flow Areas, is using too high of a weir coefficient for the situation being modeled. If the lateral structure is really just an overland flow interface between the 1D river and the 2D floodplain, then a weir coefficient in the range of 0.2 to 1.0 should be used to get the right flow transfer and keep the model stable.

However, weir coefficients should be calibrated to produce reasonable results whenever possible.



Weir Computation





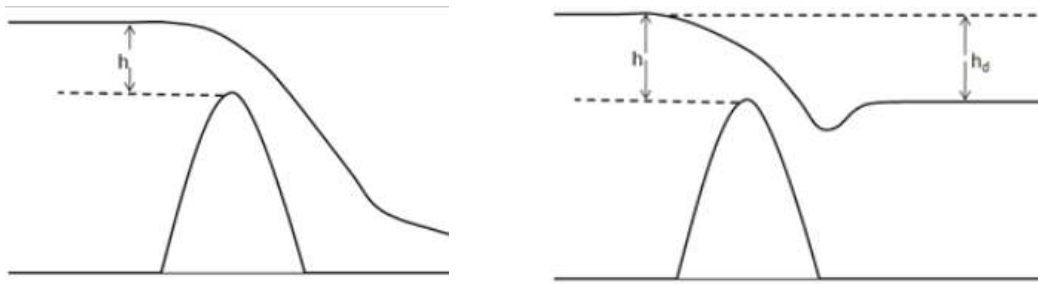
Computation Considerations

- Flow is assumed constant over the timestep
 - Long timesteps can transfer too much volume and oscillate
- Order of computations
 - 1D computes first then 2D
 - Weir flow is computed with current HW (1D) and previous TW (2D)
- Tailwater elevations
 - TW elevations of each connected cell is used
- Weir submergence



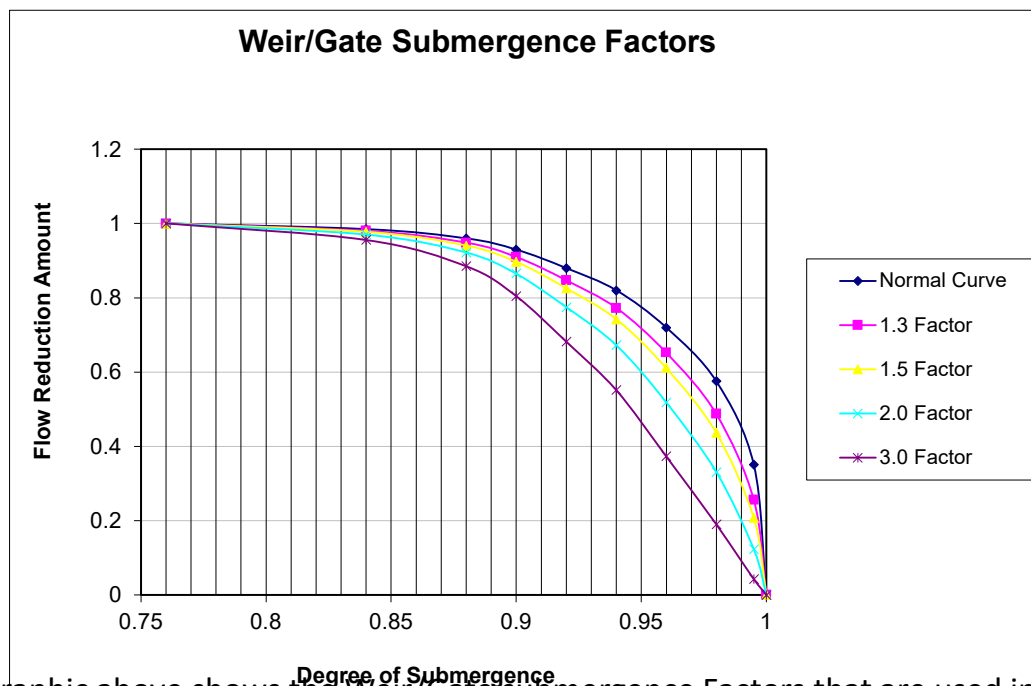
Weir Submergence

- Tailwater begins to impact flow
- A weir submergence curve is used to compute the reduction in flow
- This can be a dramatic reduction





Weir Submergence Curves



The graphic above shows the Weir/Gate submergence Factors that are used in the weir and Gate equations. The default submergence curve is shown in Black and labeled "Normal Curve". When the weir and gate flow computations start to oscillate, one solution is to pick a curve that is less steep in the high submergence range. This reduces how drastically the flow is changed for small changes in submergence.



Lateral Structure Computational Options

HEC-RAS Unsteady Computation Options and Tolerances

General | 2D Flow Options | 1D/2D Options | Advanced Time Step Control | 1D Mixed Flow Options

1D Unsteady Flow Options

Theta [implicit weighting factor] (0.6-1.0):	1.
Theta for warm up [implicit weighting factor] (0.6-1.0):	1.
Water surface calculation tolerance [max=0.2](ft):	0.02
Storage Area elevation tolerance [max=0.2](ft):	0.05
Flow calculation tolerance [optional] (cfs):	
Max error in water surface solution (Abort Tolerance)(ft):	100.
Maximum number of iterations (0-40):	20
Maximum iterations without improvement (0-40):	

1D/2D Unsteady Flow Options

Number of warm up time steps (0 - 100,000):	0
Time step during warm up period (hrs):	0.05
Minimum time step for time slicing (hrs):	0
Maximum number of time slices:	20
Lateral Structure flow stability factor (1.0-3.0):	3.
Inline Structure flow stability factor (1.0-3.0):	1.
Weir flow submergence decay exponent (1.0-3.0):	3.
Gate flow submergence decay exponent (1.0-3.0):	1.
DSS Messaging Level (1 to 10, Default = 4)	4

Geometry Preprocessor Options

Family of Rating Curves for Internal Boundaries

- Use existing internal boundary tables when possible.
- Recompute at all internal boundaries

1D Numerical Solution

- Finite Difference (classic HEC-RAS methodology)
 - Finite Difference Matrix Solver
 - Skyline/Gaussian (Default: faster for dendritic systems)
 - Pardiso (Optional: may be faster for large interconnected systems)

OK Cancel Defaults ...

This is the Unsteady Flow “Computational Options and Tolerances” editor. Show highlighted in red is the location where you can change the weir submergence decay exponent. A value of 1.0 is the default curve. As you increase the value towards 3.0 you get a curve that is less steep in the high submergence range, and will help to reduce oscillations of the flow calculations across the weir (Lateral Structure).



1D/2D Iterations Option

- Monitors WSEL and Flow Tolerance at boundaries
- Iterates the 1D and 2D domain until tolerances are met
- Off by default (0 iterations)

HEC-RAS Unsteady Computation Options and Tolerances

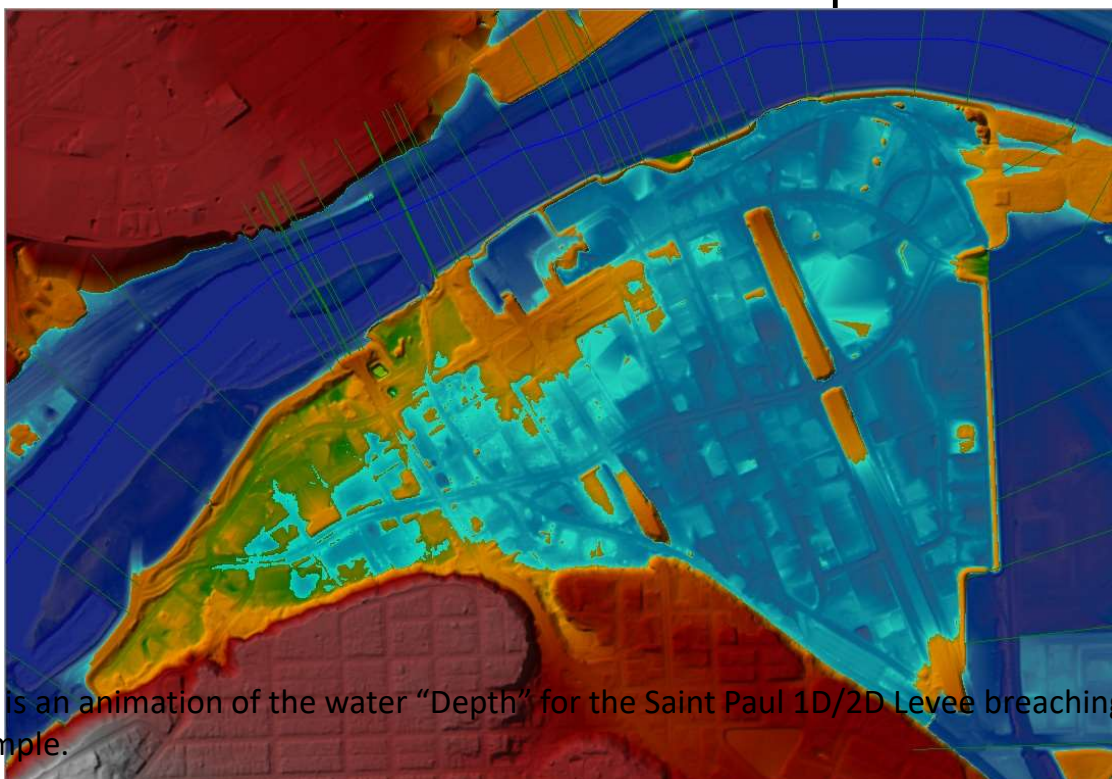
General | 2D Flow Options | **1D/2D Options** | Advanced Time Step Control | 1D Mixed Flow Options

Maximum iterations between 1D and 2D (0=off, 1 to 20):	<input type="text" value="0"/>
Water surface tolerance (ft):	<input type="text" value="0.01"/>
Flow Tolerance (%)	<input type="text" value="0.1"/>
Minimum flow tolerance (cfs):	<input type="text" value="1."/>

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Saint Paul Levee Breach Example

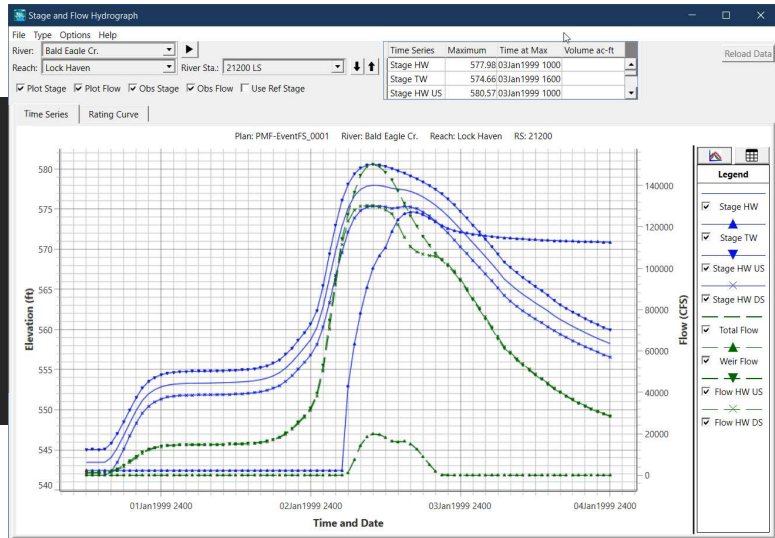
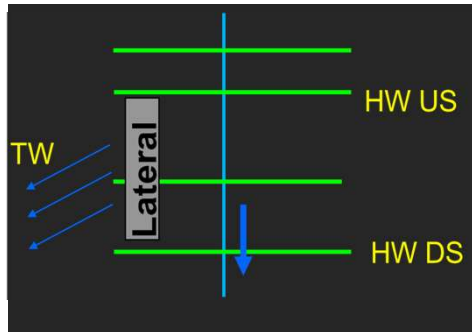


This is an animation of the water “Depth” for the Saint Paul 1D/2D Levee breaching example.

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Hydrograph – Lateral Structure



Discuss tailwater



Lateral Structure Detailed Output

The screenshot shows a software window titled "Lateral Structure Output". At the top, there are dropdown menus for "River" (MissRiver), "Profile" (13FEB2099 0600), "Reach" (thru_St_Paul), "RS" (151400), and "Plan" (2D Run Modified). Below these is a table with two columns of data. The table is titled "Plan: 2D Run Modified MissRiver thru_St_Paul RS: 151400 Lateral Structure Profile: 13FEB2099 0600".

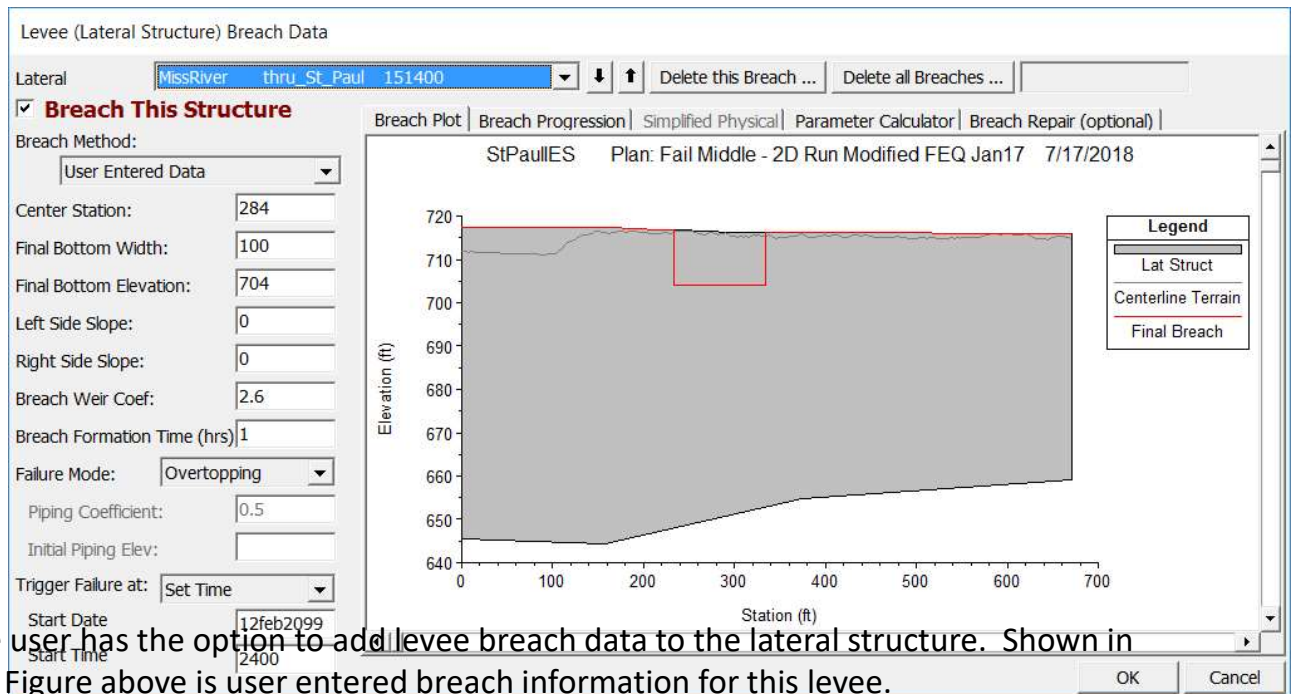
Parameter	Value	Parameter	Value
E.G. US. (ft)	716.10	Weir Sta US (ft)	5750.00
W.S. US. (ft)	715.28	Weir Sta DS (ft)	5850.00
E.G. DS (ft)	716.08	Min El Weir Flow (ft)	704.00
W.S. DS (ft)	714.80	Wr Top Wdth (ft)	100.00
Q US (cfs)	281458.70	Weir Max Depth (ft)	11.22
Q Leaving Total (cfs)	4332.12	Weir Avg Depth (ft)	11.14
Q DS (cfs)	277159.10	Weir Flow Area (sq ft)	1113.82
Perc Q Leaving	1.54	Weir Coef (ft ^{-1/2})	2.600
Q Weir (cfs)	4332.12	Weir Submerg	0.95
Q Gates (cfs)		Q Gate Group (cfs)	
Q Culv (cfs)		Gate Open Ht (ft)	
Q Lat RC (cfs)		Gate #Open	
Q Outlet TS (cfs)	0.00	Gate Area (sq ft)	
Q Breach (cfs)	4332.12	Gate Submerg	
Breach Avg Velocity (ft/s)	3.89	Gate Invert (ft)	
Breach Flow Area (sq ft)	1113.82	Gate Weir Coef	
Breach WD (ft)	100.00		
Breach Top El (ft)			
Breach Bottom El (ft)	704.00		
Breach SSL (ft)	0.00		
Breach SSR (ft)	0.00		

Below the table is a section titled "Errors, Warnings and Notes" which is currently empty.

This is the Detailed Lateral Structure output table. You can use these to see the detailed numbers of what happened for each post processing time step.



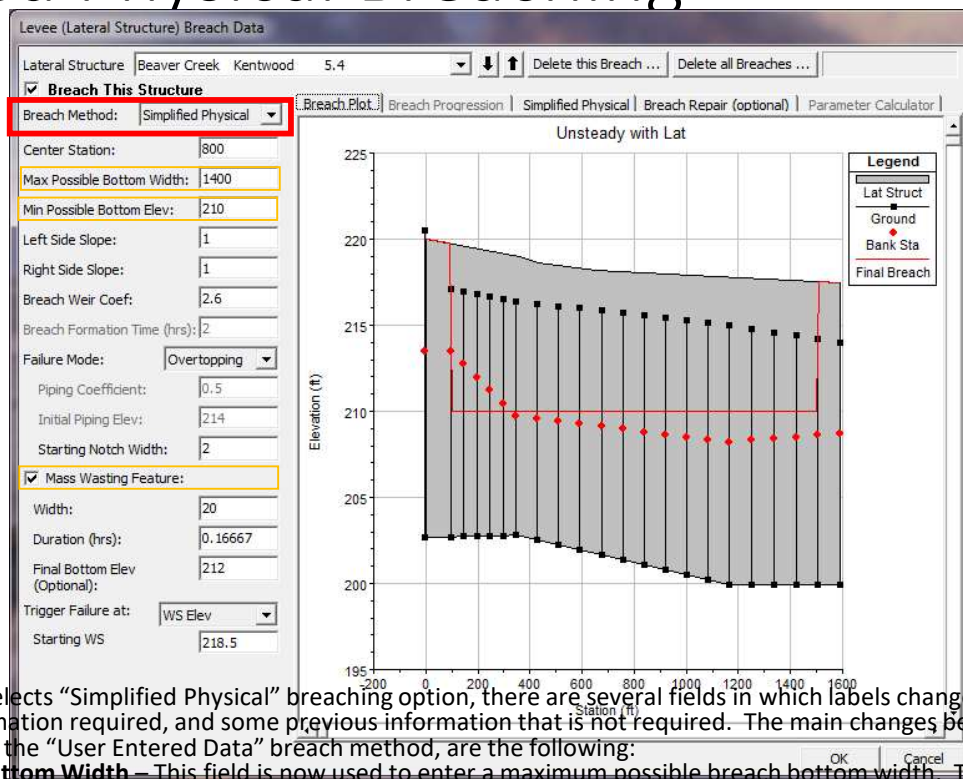
Levee Breaching



The user has the option to add levee breach data to the lateral structure. Shown in the figure above is user entered breach information for this levee.



Simplified Physical Breaching



Once the User selects "Simplified Physical" breaching option, there are several fields in which labels change, some additional information required, and some previous information that is not required. The main changes between this method and the "User Entered Data" breach method, are the following:

Max Possible Bottom Width – This field is now used to enter a maximum possible breach bottom width. This does not mean this will be the final breach bottom width, it is really being used to limit the breach bottom width growth to this amount. The actual bottom width will be dependent on the velocity versus erosion rate data entered, and the hydraulics of flow through the breach. This field is used to prevent breaches from growing larger than this user set upper limit during the run.

Min Possible Bottom Elev – This field is used to put a limit on how far down the breach can erode during the breaching process. This is not necessarily the final breach bottom elevation, it is a user entered limiter (i.e. the breach cannot go below this elevation). The final breach elevation will be dependent on the velocity versus erosion rate data entered, and the hydraulics of flow through the breach.

Starting Notch Width or Initial Piping Diameter – If the Overtopping failure mode is selected, the user will be asked to enter a starting notch width. The purpose of this is that the software will use this width at the top of the dam to compute a velocity, from the velocity it will get a down cutting erosion rate (based on user entered data), which will be used to start the erosion process. If a Piping Failure model is selected, the user must enter an initial piping diameter. Once the breach is triggered to start, this initial hole will show up immediately. A velocity will be computed through it, then the down cutting and widening process will begin based in user entered erosion rate data.

Mass Wasting Feature – This option allows the user to put a hole in the Dam or the Levee at the beginning of the breach, in a very short amount of time. This option would probably most often be used in a levee evaluation, in which a section of the levee may give way (Mass Wasting), then that initial hole would continue to erode and widen based on the erosion process. The required data for this option is a width for the mass wasting hole; duration in hours that this mass wasting occurs over (this would normally be a short amount of time); and the final bottom elevation of the initial mass wasting hole (it is assumed that the hole is open all the way to the top of the levee or Dam if this option is used).



Velocity vs. Downcutting and Widening

Overtopping Downcutting		Widening Relationship	
Velocity (ft/s)	Downcutting Rate (ft/hr)	Velocity (ft/s)	Widening Rate (ft/hr)
1	0	1	0
2	2	2	0
3	3	3	20
4	4	4	50
5	5	5	100
6	7	6	150
7	10	7	200
8	20	8	300
9		9	
10		10	
11		11	
12		12	
13		13	
14		14	
15		15	
16		16	
17		17	
18		18	
19		19	
20		20	
21		21	
22		22	
23		23	
24		24	

As shown in the Figure above, the user is required to enter Velocity versus Downcutting erosion rates and velocity versus erosion widening rates. This data is often very difficult to come by. User's will need to consult with Geotechnical engineers to come up with reasonable estimates of this data for your specific Levee or Dam.

Another way to estimate this information is to try to derive it by simulating a historic Levee or Dam breach, and adjusting the velocity versus erosion rate data until the model simulates the correct breach width and time. This is obviously an iterative process, and may require the user to perform this at multiple locations to see if there is a consistent set or erosion rates that will provide a reasonable model for simulating Levee breaches (or Dams) in your geographical area.

We realize that this data is not readily available for any specific levee or dam. The hope is that over time we will be able to develop guidelines for these erosion rates based on analyzing historical levee and dam breaches. The MMC is currently working on trying to provide guidelines for these erosion rates.

Questions?



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