

# SA/2D Connections

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## Internal SA/2D Area Conn

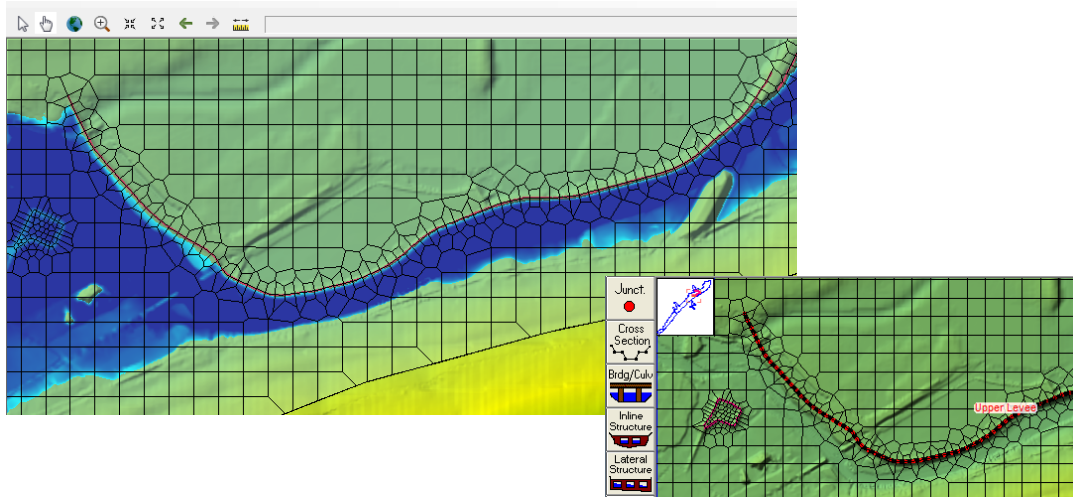
- Discuss using SA/2D Area Conn inside of 2D areas
  - aka Hydraulic Structures (HS)

2

A hydraulic structure (HS) is a type of Storage Area/2D Connection. The term hydraulic structure is used for convenience when the connection is entirely inside of a 2D area (as opposed to a connection between 2D areas). However, it should be noted that the RAS GUI and all the documentation refers to it as a Storage Area/2D Connection even when it is inside of a 2D area.



## Hydraulic Structure Example



3

The above example shows a hydraulic structure that has been added and the cell mesh has been adjusted using a breakline from the National Levee Database.



## Hydraulic Structures (HS)

- User entered station/elevation data overrides terrain data
- Can add breaches
- Can add culverts and gates
  - Culvert/Gates can be georeferenced
- Can model with weir equation or 2D equation
- HS centerline is also a breakline

4

A hydraulic structure (HS) can be placed inside of a 2D area.

The top of the HS is based on the user entered data. (It does not use the terrain data.)

A HS can be placed across a river channel to model a dam. Just like an inline structure, a HS can also be used to model a dam break scenario. A HS along side of a channel can be used to model a levee and it can also be used to model levee breaks.

Culverts and gates can be added to a HS and the HS can be solved using either a 1D weir equation or the 2D equations. Non-georeferenced culverts and gates transfer flow from cells immediately adjacent to the HS. Georeferenced culverts and gates can transfer flow from remote cells.

The HS centerline also acts as a breakline.



## Levees With HS

- When:
  - Bad Terrain data
  - Structure too high for 2D equations (i.e. waterfall), Weir equation is a better solution
  - Need Culverts, Gates, or Breaching
- Create the HS and enter the Station/Elevation (SE) data
- The user entered SE data controls the flow over the structure

5



## “Levees” Without HS

- Breaklines may be all that is needed!
- IF
  - The terrain data is good enough
  - The Faces line up accurately
  - Normal 2D Equation is appropriate
  - No culverts, gates, breaches, etc.
- THEN
  - No HS required!

6

Since the flow between adjacent cells is controlled by the Face/Cell edge, the hydraulic structure itself may not need to be added.

In order for this to work: the terrain data must be detailed and accurate enough to represent the high ground; the Faces must be lined up accurately enough with this high ground; the normal 2D solution must be appropriate; there cannot be any culverts, gates, or levee breaches.

Note: This option is not restricted to built up “levees”. For example, a natural ridge line or a slightly elevated road bed might be situations where it is desirable to align the Faces without entering an HS.



## Overview Data Entry

- Create HS Centerline
  - Convert existing breakline (if breakline already exists)
  - Download centerline (if available)
  - Or draw by hand
- HS goes left to right looking downstream (for positive flow convention)
- Edit Centerline/Breakline and Cell Mesh, as needed (the centerline is also a breakline)
- Enter station/elevation of weir
- Enter culverts, gates, breach, etc.
- Select 2D Domain or Weir Eq.

7

The general steps for entering an HS are:

Download the levee centerline from the National Levee Database, if it is available. If a digital centerline is available, create the HS by drawing a couple of dummy points. Next, open up the GIS Centerline table and paste in the actual coordinates of the centerline.

If a digital centerline is unavailable, the centerline can be carefully drawn with the mouse pointer based on the terrain image.

The HS has a “headwater” side and a “tailwater” side. Flow from headwater to tailwater is reported as positive and “reverse” flow from tailwater to headwater is reported as negative. The structure should be drawn left-to-right looking in the “downstream” direction.

The HS centerline is also breakline that can be edited just like a normal breakline. Edit and inspect the breakline and make any adjustments to the cell mesh.

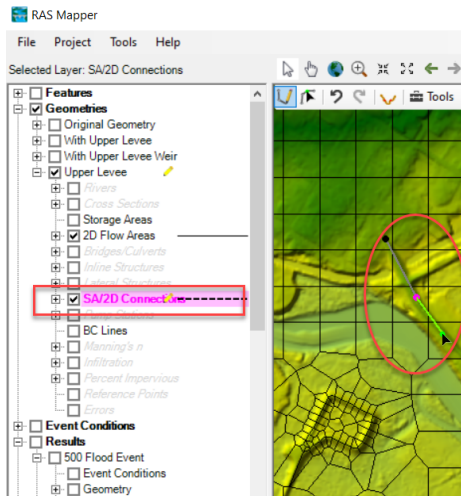
Enter the station/elevation data for the weir.

Enter any additional options such as culverts, gates, and breaches.

Select to use either the 2D Domain equation or the Weir equation.



## SA/2D Connection Layer



- Add in RAS Mapper
- Positive flow direction – “left to right, positive flow is downstream”
- Line can be imported from shapefile
- Override Weir data still on 2D Conn Editor/Geometric Data Editor

8

The HS can be added by clicking on **SA/2D Area Conn** button and drawing the location with the mouse pointer. Click the left mouse button to add points (for the next line segment) and right click to re-center the image.

Double click to finish drawing the centerline and enter the name of the HS.

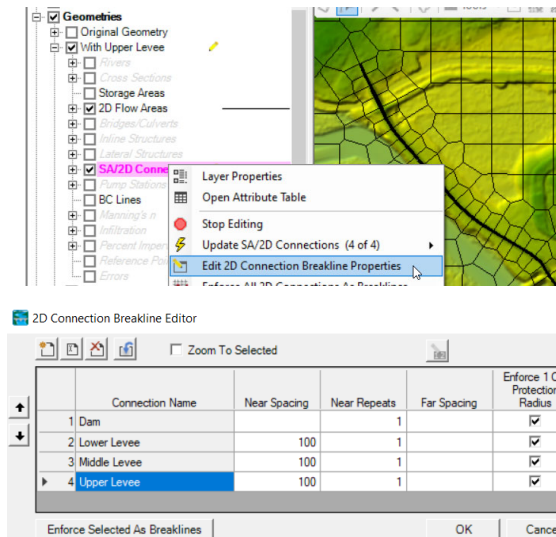
The centerline can also be imported as a shapefile by right clicking on the SA/2D Connection layer and selecting Import Features from Shapefile.

The weir station/elevation data (and any culverts and gates) will still have to be entered from the 2D Connection editor on the Geometric Editor.





## HS Cell Spacing



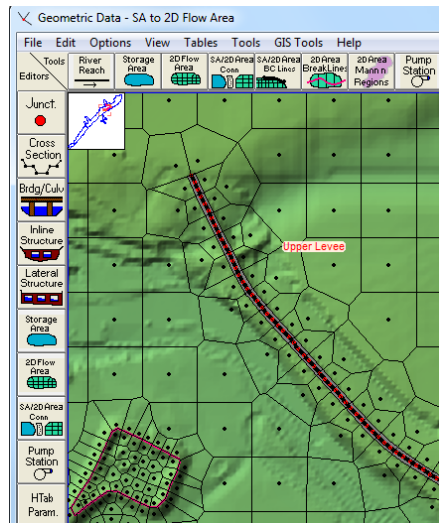
- HS/Breakline can be enforced while still in Edit mode
- Additional Cells can be added along the HS centerline
- Cell spacing should not be made too small!

9

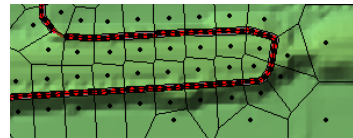
The centerline of the hydraulic structure can be enforced while still in edit mode. The number of cells along the breakline can be increased. Increasing the number of cells will generally allow the cell mesh to more accurately align with the breakline. However, the cell spacing should not be made too small. If the cells are made too small, then there may be multiple cells going down the face of the levee. (Instead of a single cell extending from the top of the levee all the way down to the toe, there are multiple cells between the top of the levee and the toe of the levee.) This may cause computational problems as discussed later in this presentation. The break line/cell spacing should be adjusted using the editing tools from RASMapper because it has greater functionality than the break line/cell spacing option available from the geometry editor.



## Inspect Cells Around HS



- RAS will show the HS as a black line w/ red dots
- Inspect the line for problems
  - Start/End of HS!
  - Tight Curves

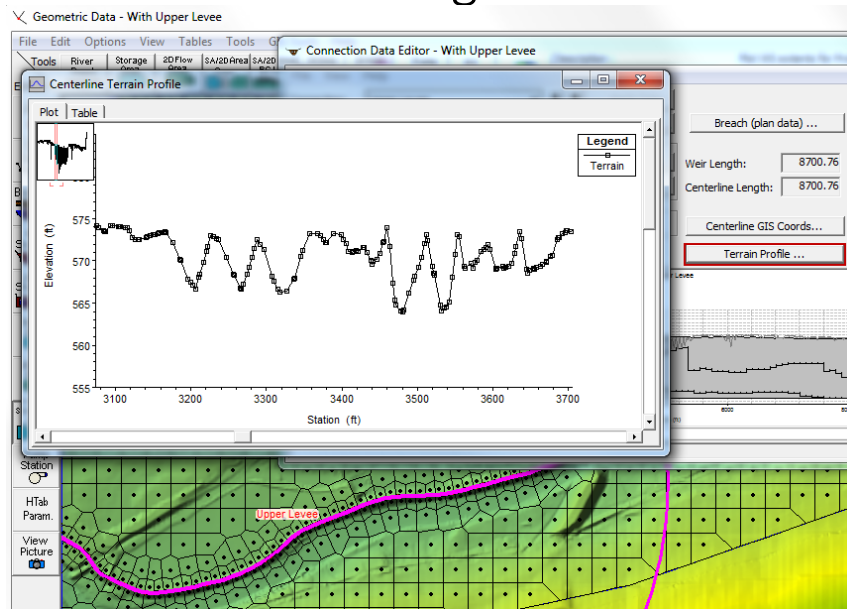


10

When the user enters a centerline/breakline, RAS will usually modify the mesh so that the breakline starts and stops at a node (cell intersections). However, this is not always the case. There are some situations (near boundaries or other breaklines) where the breakline start/end is not at a node. There can be other problems. Around a tight curve, the cell mesh may not be correct. The HS is supposed to start and end exactly at a node (which is the typical situation). If the HS is more than a foot from the node, it may trigger a run time message. The breakline/HS should be inspected for problems. The most common problem is that the start and/or end of the line is in the middle of a cell instead of being at a facepoint. If the line has a very tight curve, that can also sometimes cause a problem. In this situation, the user may need to adjust the cell mesh by hand.

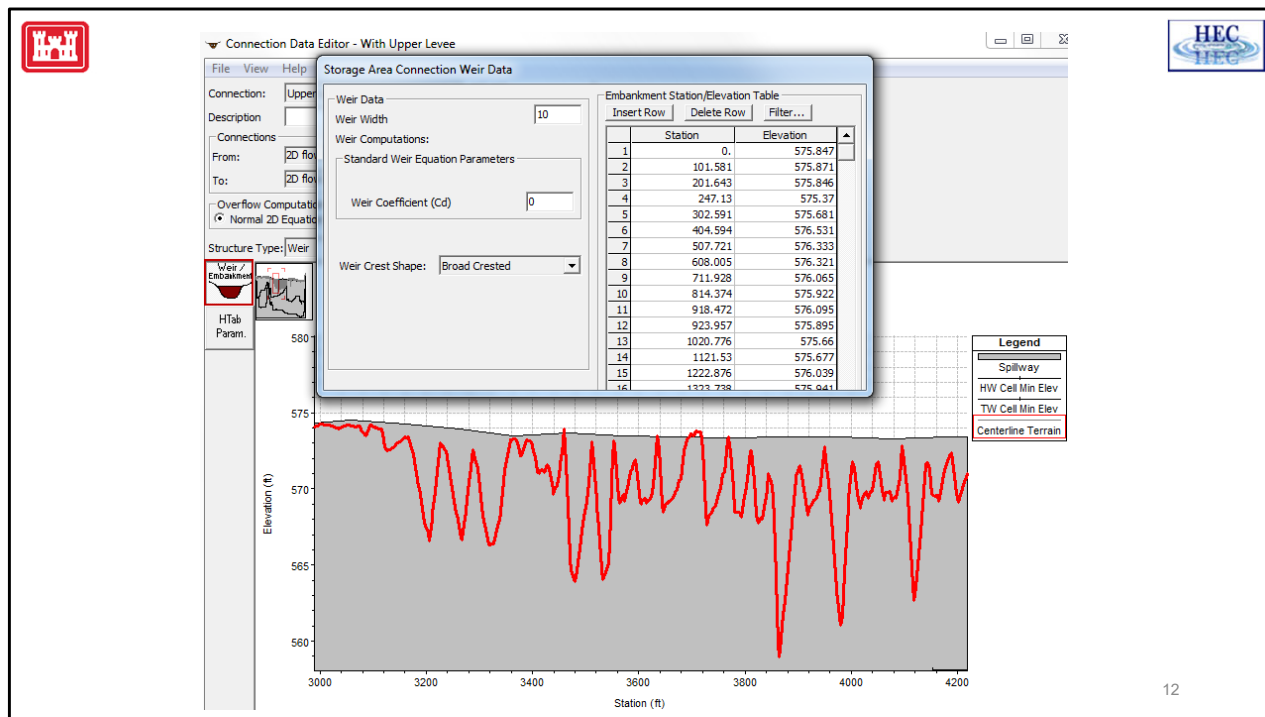


## Terrain CL Profile Missing Levee



11

The terrain profile along the centerline can be plotted by clicking on the **Terrain Profile** button. The steep, jagged valleys is strong evidence that either the underlying terrain does not have the full levee data and/or that the centerline does not stay on the top of the levee. In either case, a hydraulic structure can be added to fix the problem.



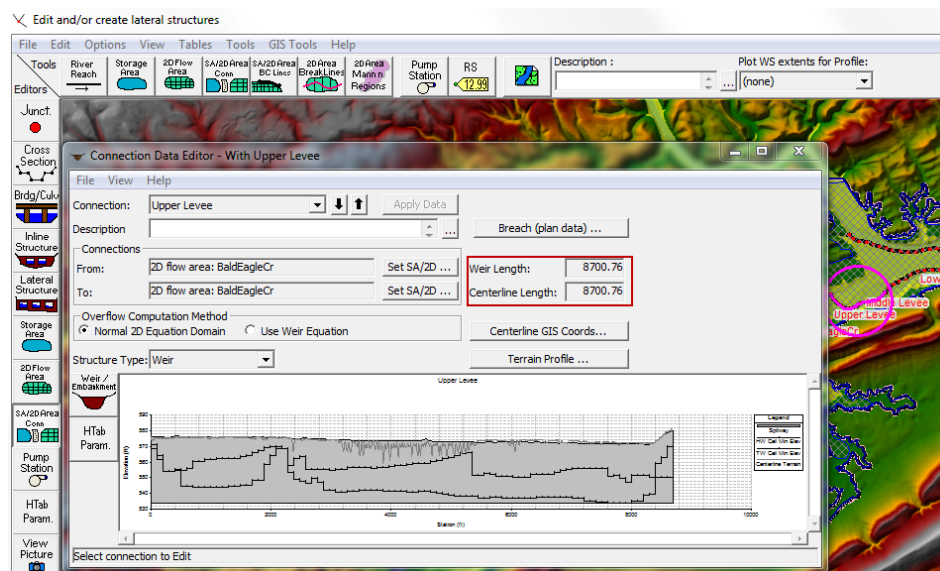
After the location of the HS has been entered, the remaining data is essentially the same as for a lateral structure or an inline structure.

Click on the **Weir** button and enter the station and elevation data for the top of the hydraulic structure. The user entered elevation data profile is shown in gray instead of the original terrain, which is shown in red in the above example.

If the user wants to initially set the weir station/elevation data to the underlying terrain: The profile information (see previous slide) can be displayed as a table by clicking on the **Table** tab. The data in this table can be copied and then pasted into the **Weir Data** editor. (Alternatively, it could first be pasted into a spreadsheet for manipulation.)



## Check Weir/GIS Length



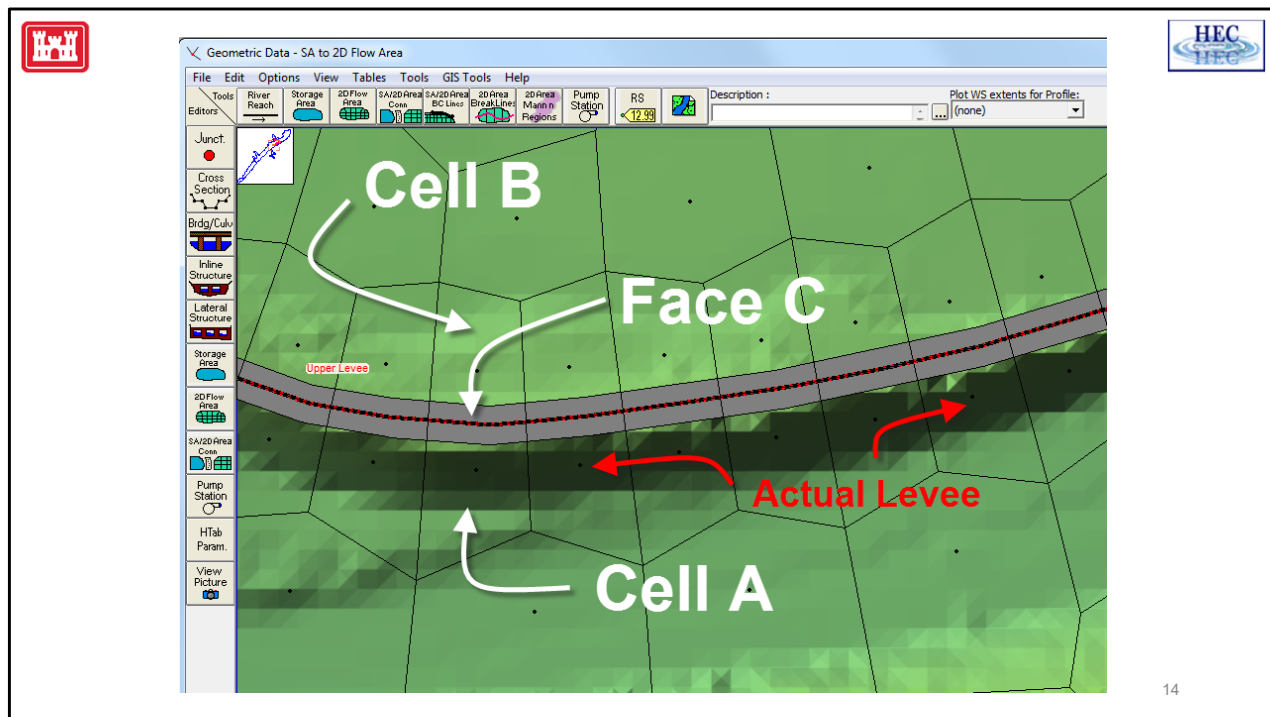
13

Another check is to compare the **Weir Length** (this is the user entered station/elevation data) with the **Centerline Length** (this is the GIS coordinates line that was drawn or downloaded).

**The length of the weir station must be the same as the length of the GIS length (to within a default 1 foot tolerance) or else the GUI will flag it as a data problem.**

As long as the weir station length matches the GIS coordinates of the centerline/breakline, there is not usually a problem. Problems arise when the weir station/elevation length does not match the centerline. For instance, if the weir station/elevation was entered based on surveyed data but the centerline was downloaded from a digitized data base they may not match.

Or the length of the GIS line that the user drew by hand may not exactly match the actual length of the levee.



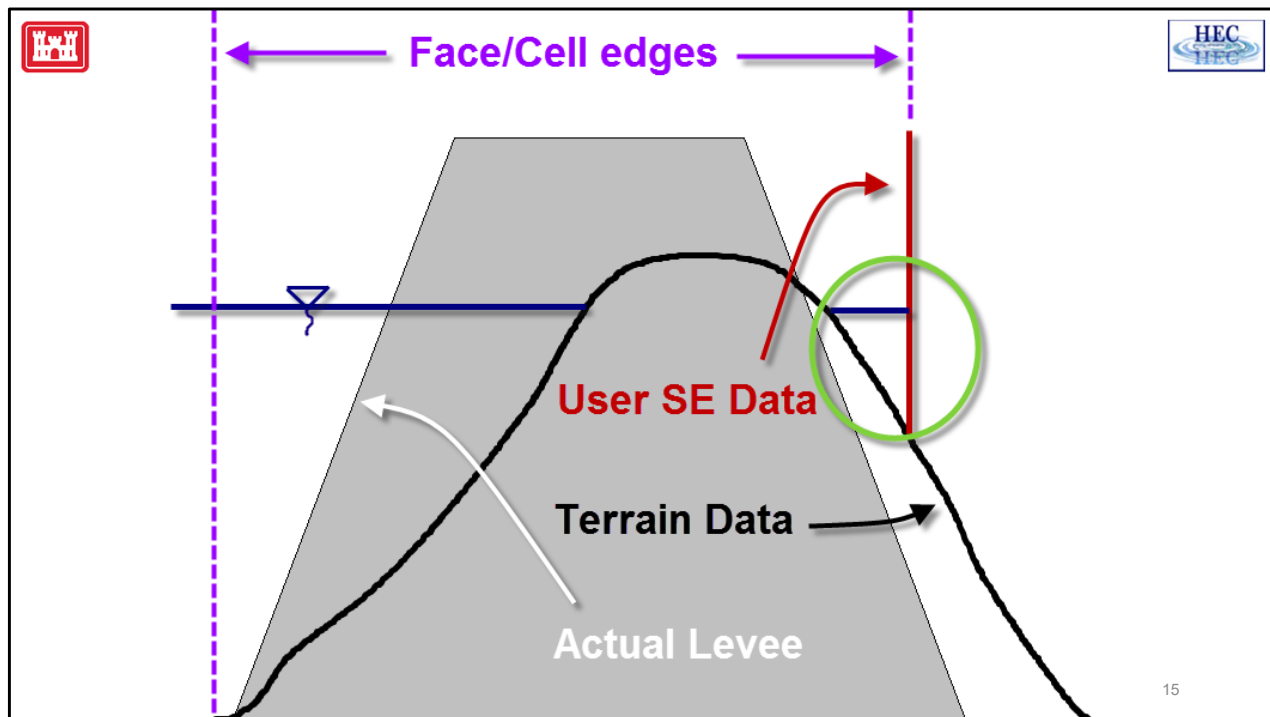
When the 2D area is solved, RAS will use the station/elevation (SE) data that the user has entered. This SE data will replace the terrain data for the Faces that make up the HS.

In the example above, the centerline of the hydraulic structure is not properly aligned with the actual levee in the terrain. The faces for the hydraulic structure are shown with the black and red dotted line. These are the faces (and the locations) where the user SE data will be applied.

Sticking with the above example, the main river channel is below the actual levee that can be seen with the thick, dark shading on the terrain. Water from Cell A will not flow directly into Cell B until the water is high enough to overtop Face C (and Face C has been modified to represent the user entered SE data).

**Note: Water can appear in the top part of Cell A (“behind” whatever part of the actual levee is in the terrain) even before the “terrain” levee is overtopped. But it will *NOT* spread past Cell A (and into Cell B) until the HS/levee really is overtopped.**

**Note also: The location of the centerline was poorly drawn to illustrate this particular situation. In general, the user will want to align the HS and the actual levee.**



The above example is a profile view of the situation in the previous slide. The terrain data does not accurately capture the top of the levee and the location of the face edge/cell boundary is not properly aligned with the top of the levee.

The red line is the user entered station/elevation data. The elevation of this face (face C in the previous slide), or more accurately the profile of this face, has been adjusted so that it represents the top of the levee.

The user SE data only adjusts the face itself, it does not change the underlying terrain that is used by the cell (cell A in the previous slide).

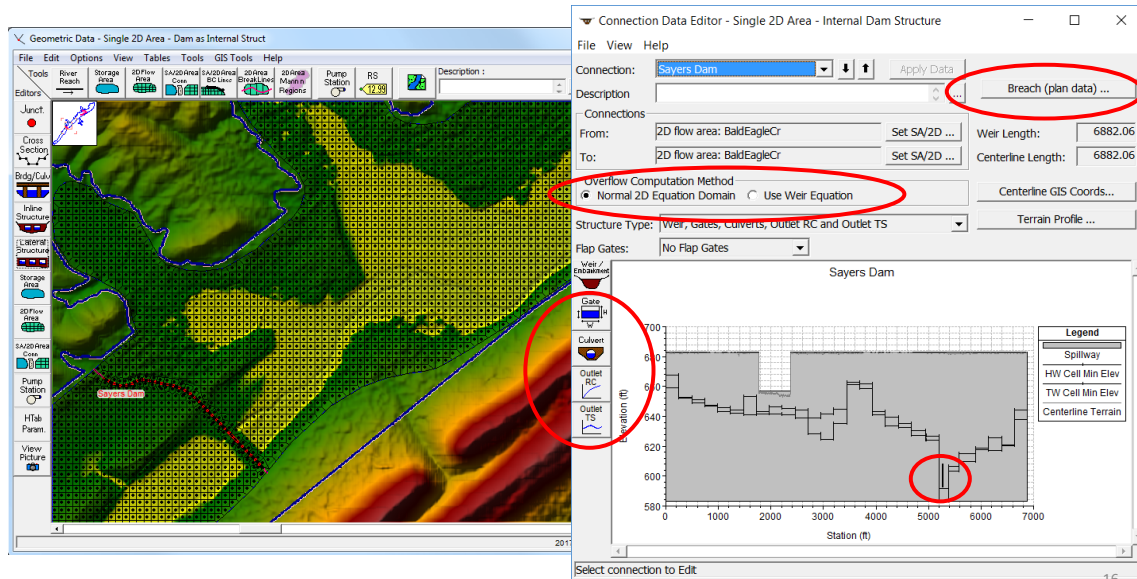
Since the face in this example is poorly aligned with the actual top of levee, water can appear on the “far side” of the levee even though it has not been overtopped (green circle). However, it will not go beyond this face until it gets above the top of the red line.

Note that the top of the terrain is lower than the top of the actual levee. This is not atypical.

**Note also: The location of the centerline was poorly drawn to illustrate this particular situation. In general, the user will want to align the HS and the actual levee.**



# Hydraulic Structures Options

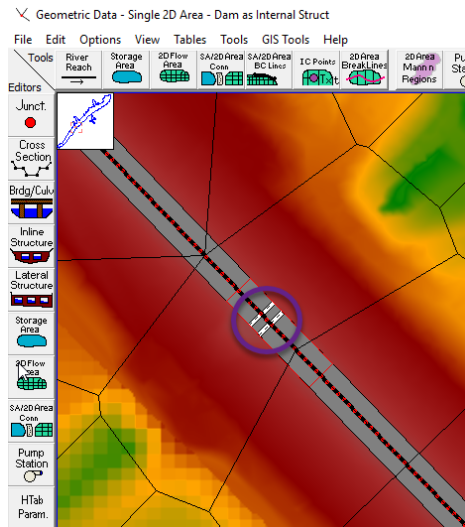


Gates, culverts, ratings curves, time series outlets, and breaches can be entered just as for a lateral structure or an inline structure. User's can choose between the Weir equation or the full 2D Flow equations for computing the flow going over the structure.





## Culverts & Gates inside a HS

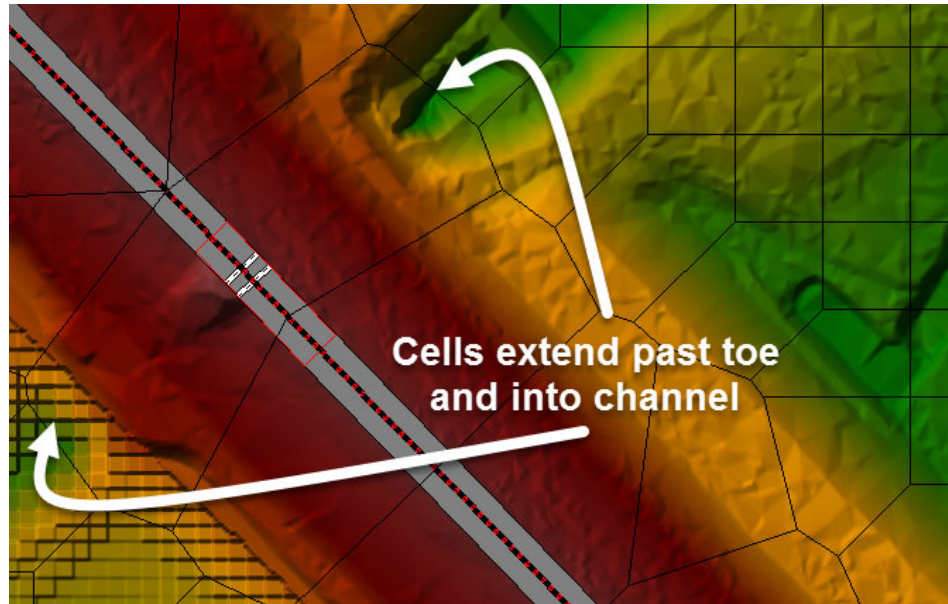


- By default, culverts/gates are not georeferenced and transfer flow from immediately adjacent cells
- In this case, cells need to extend past toe and into channel

17



## Gates/Culverts and Cell Edges

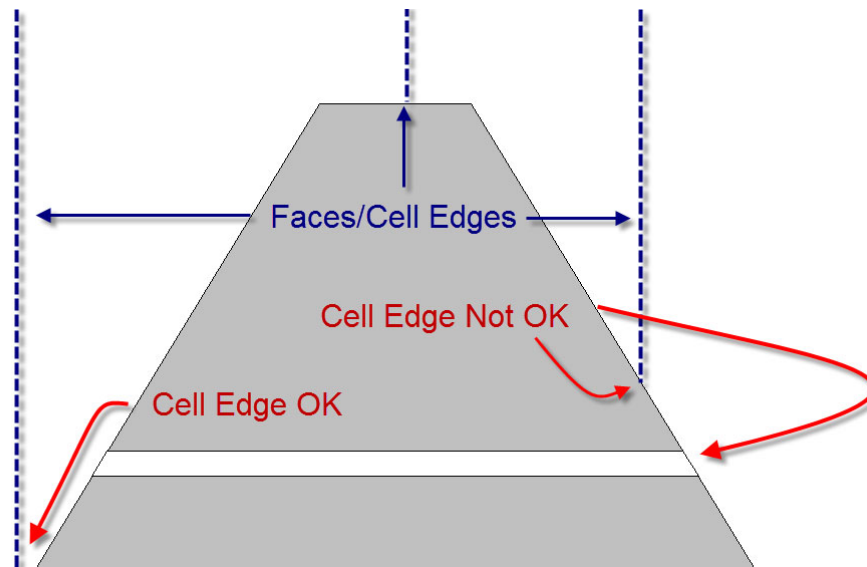


18

For the cells that are immediately adjacent to the HS, it is generally recommended to keep the cells large enough so that the cell extends past the toe of the structure. If there are any gates and/or culverts that are not georeferenced, this is a particular issue. Unless it is georeferenced, the flow through a gate or culvert is based on the cells immediately adjacent to the HS. Because of this, the invert of a given gate or culvert must not be below the invert of the cell.



## Cell Edge Location for non-georeferenced culverts/gates



•19

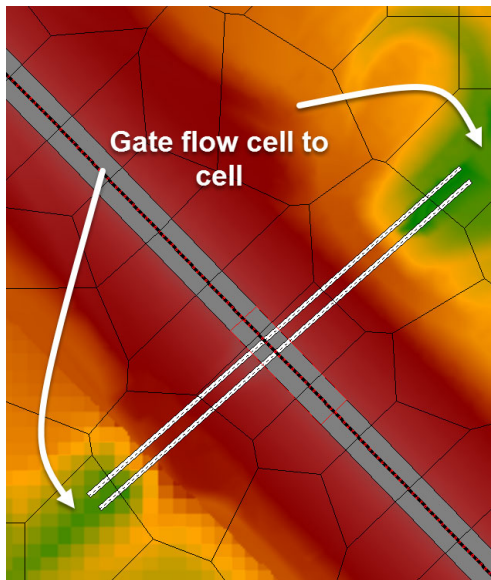
In the example above, the cell on the left side is large enough that the invert of the cell is below the invert of the gate/culvert. The cell on the right side is smaller and the edge is located up on the side of the embankment. This causes the invert of the gate/culvert to be lower than the invert of the adjacent cell. RAS will flag this as a data problem that will have to be fixed before the model can be run.

**To fix this problem, the length of the cell could be increased so the edge is past the invert of the gate/culvert or the gate/culvert could be georeferenced.**

**Note: Since the gate/culvert cannot be below the cell invert, the user may need to carefully position the centerline of the gate/culvert to line up with the deep part of the channel.**



## Georeferenced Culverts & Gates



- Georeferenced culverts & gates transfer flow from distant cells
- In this case, cells do not need to extend past toe and into channel
- Small cells can still cause problems for 1D weir flow!

20

If the cells immediately adjacent to the HS do not extend into the channel, the culvert/gate can be georeferenced.

Georeferenced culverts/gates can transfer flow between distant cells.

Care must be used to make sure that the georeferenced centerlines extend far enough and are properly aligned with the channel.

Georeferencing allows for smaller cells next to the hydraulic structure. However, small cells can still cause problems especially if the 1D weir flow option is used.



## Georeference Culverts & Gates

Connection Gate Editor

Gate Group: Gate #1

Gate type (or methodology): Sluice

Gate Flow

Sluice Gate Flow

Sluice Discharge Coefficient (0.5-0.7): 0.65

Weir Flow Over Gate Sill (gate out of water)

Weir Shape: Broad Crested

Weir Coefficient: 3

Submerged Orifice Flow

Orifice Coefficient (typically 0.8): 0.8

Head Reference: Sill (Invert)

Geometric Properties

Height: 15 Width: 7 Invert: 590

Opening Centerline Stations

Opening Name	Station	GIS Sta
Opening #1	5745	5746.035
Opening #2	5765	5765.018

Individual Gate Centerlines ...

- Draw the centerline with the mouse pointer and then paste GIS coordinates for the appropriate opening
- Clicking on Individual Gate Centerlines will bring up a table that shows all of the openings

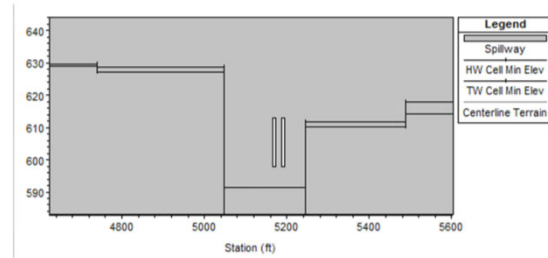
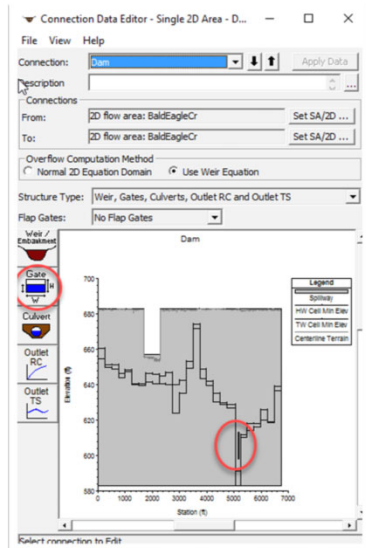
21

To georeference culverts/gates, click on the Gate Centerline button and enter the X & Y coordinates.

The centerline can be drawn with the mouse pointer and the coordinates copied and pasted into the editor in the same manner as entering the centerline for the hydraulic structure.



## Gate in channel above Cell Invert



- Non-georeferenced gate in channel above adjacent cell minimum

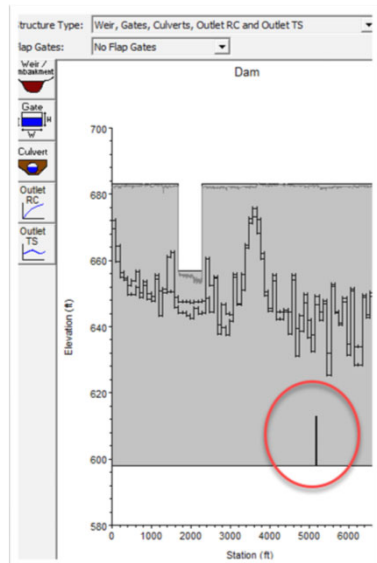
22

The connection editor shows the invert of the cells immediately adjacent to the HS centerline. If the cells extend past the toe of the structure, the location of the channel is usually apparent.

Non-georeferenced culverts/gates should [usually] be in the channel and they must be above the cell minimum as shown on the plot.



## Georeferenced Gate Below Adjacent Cell Invert



- Small HW/TW cells on abutment next to HS do not show channel location
- This plot does not show whether the georeferenced gate centerline has been properly entered or not

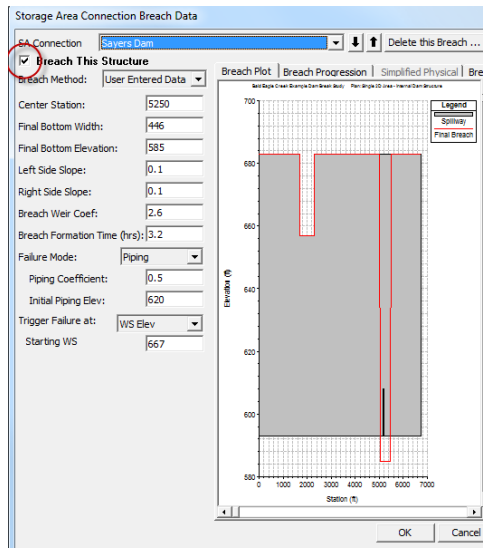
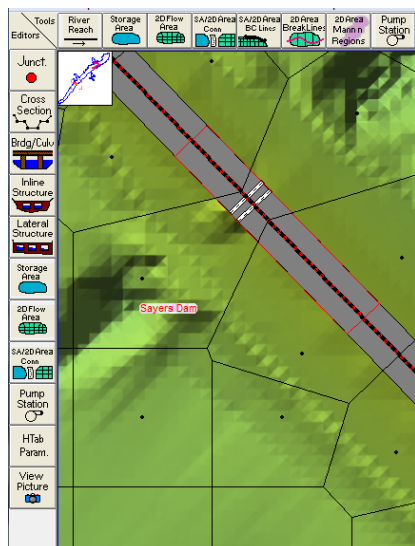
23

If the cells immediately next to the HS are small, the location of the channel is no longer apparent on this plot.

The invert of georeferenced culverts/gates must be above the invert of the cells at the upstream and downstream end of the culvert/gate. Whether this is the case or not, cannot be determined from this plot. The user should check the geometric data editor to see if the culvert/gate centerline is correct. It may be necessary to check the elevation of the terrain in RASMapper to compare the elevation of the channel with the invert of the culvert/gate.



## Breach for HS



24

The location of the breach is shown on the **Geometric Data Editor**.

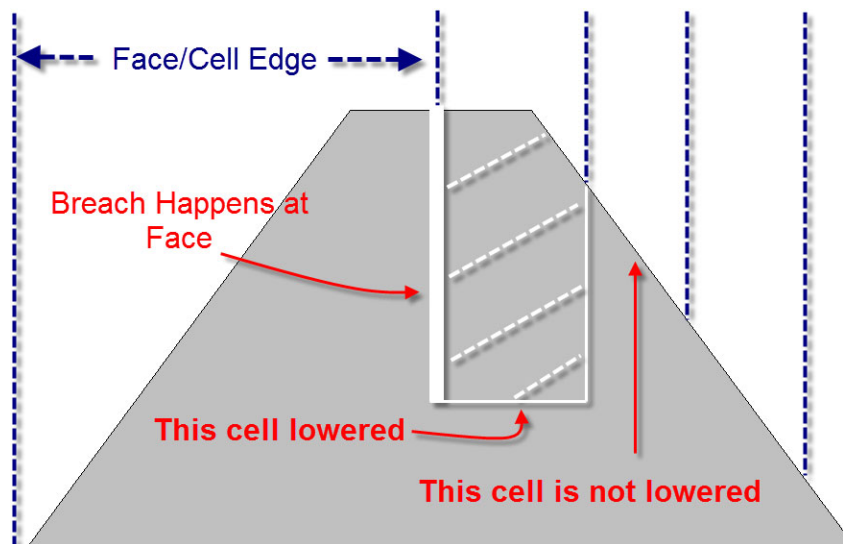
When entering the breach data information, remember to click on the **Breach This Structure** box, circled in red.

The breach will not override any gates or culverts. In the example above, the HS will continue to compute an additional gate flow even when the breach is fully formed.





## HS Breach and Cell



25

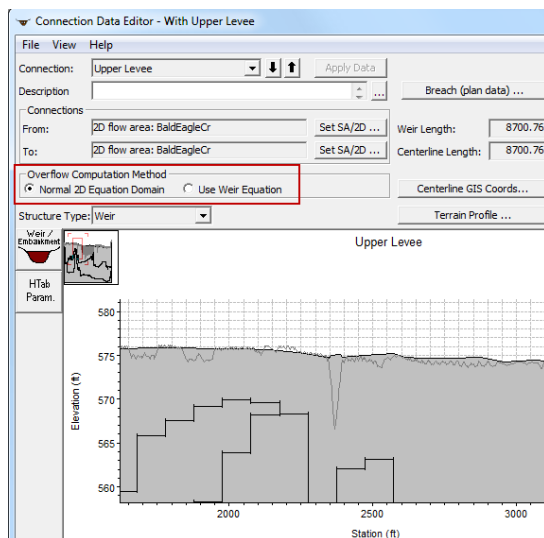
When the breach option is used with an HS, the elevation (or more accurately the profile) of the face is adjusted to represent the user entered breach. The Face/Cell edge cannot be lower than the invert of the cell that it is attached to. It is generally recommended to size the cells so that when a given face is adjusted by the breach, that face does not drop lower than either of the two cells it is attached to.

However, if a face is lowered below a given cell, RAS will automatically lower that cell as needed. Only the cells immediately next to the breach are ever adjusted. If a small cell size is being used, cells part way down the embankment may still “block” the breach flow.

If there are only two cells along the embankment, then things should generally be okay since the first cell is lowered ‘as needed’ and the second cell is already at or past the toe of the embankment. But problems can arise when there are three or more cells along the embankment such as on the right hand side in the example above.



## HS Equation Choice



- Normal 2D Equation Domain
  - Flow across face computed with 2D flow equations
- Use Weir Equation
  - $Q = CLH^{1.5}$

26

There are two options for computing flow over the top of a HS:

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.



## Normal 2D Equation Domain

- Face properties are adjusted for user entered SE Data, but 2D Area is solved in the normal manner
- Generally, faster, more accurate
- But not good for true weir type
- HS with culverts/gates can still use 2D for overflow
  - culvert/gate flow is computed separately

27

The main advantage of the Normal 2D option is that the flow over the HS is solved as part of the 2D solution and this avoids the trial-and-error problems that are possible with the weir equation (see discussion next slide). This allows a faster and more accurate solution, at least when the HS is highly submerged. A highly submerged weir acts the same as normal 2D unsteady flow between any two given cells and the unsteady flow equation (diffusion or full momentum) provides a robust solution. Unlike the Normal 2D option, the 1D weir does not take into account 2D effects. For instance, if the levee is on a river bend and/or the approach velocity is at an angle to the weir.

The down side with the Normal 2D option is that the 2D solution may have a problem when the HS really is acting like a weir. The normal 2D unsteady flow solution is not designed to handle a “waterfall” between adjacent cells.

The 2D equation can be used with a HS that has culverts and gates to compute the overflow. The culvert and gate flow will be computed separately from the 2D flow.



## Weir Equation

- Weir flow computed using [1D] weir equation and user SE Data
- Flow computed “just prior” to each iteration of 2D
- More appropriate for [non-submerged] weir flow
- Less desirable for submerged conditions
  - Turn on Weir Submergence Decay Exponent!
- May require “trial and error” solution causing 2D to iterate
- Gate and culvert flow are always computed “just prior” to 2D

28

The weir flow option computes the flow using the standard weir equation. This flow is computed “just prior” to each iteration of the 2D area. For situations where the flow over the weir is not submerged, the weir equation is accurate and it may be more stable than using the 2D equation.

However, the weir equation is less desirable if the weir is highly submerged. When the submergence is high enough, the flow is not “weir” flow, but rather is normal unsteady flow. The weir equation has a submergence modifier for this situation (see the RAS Hydraulic Reference Manual), but it can still be problematic.

Increasing the Weir flow submergence decay exponent (2.0~3.0) may help. From the Unsteady Flow run editor, go to Options and select Computation Options and Tolerances.

Before the 2D area is solved, the Unsteady program gets the water surface elevations on either side of the structure, it then computes the flow, and this amount of flow is transferred between cells when the unsteady solver computes the solution for the given iteration of the given time step. After the solution is performed for a given iteration, the Unsteady program checks to see if another iteration of the 2D area is required. In addition to the standard water surface tolerance check at each cell, the Unsteady program will get the updated water surfaces and recompute the flow across the HS. If the recomputed flow is significantly different than the original flow, then the 2D solver will perform another

iteration on that 2D area. (If the 2D iterates again for some other reason, the flow across the HS will be based on the latest, “recomputed” flow).

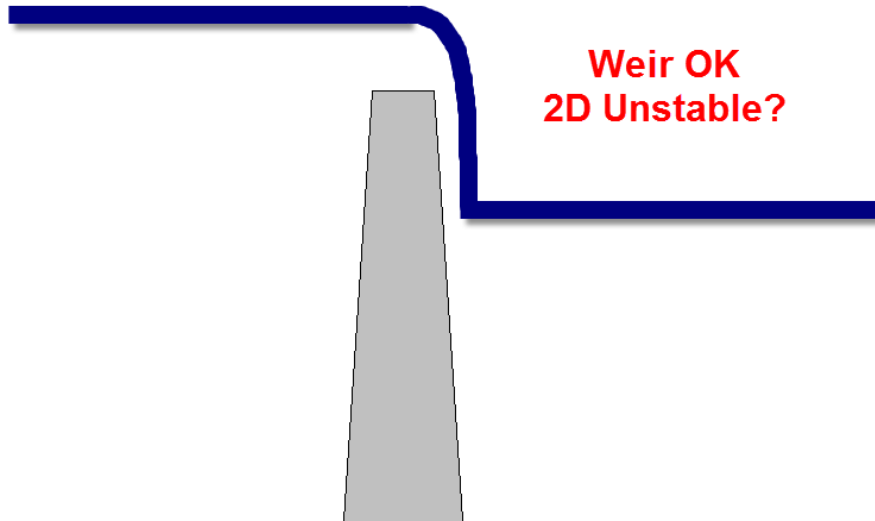
When the flow across the HS is highly submerged, using the weir equation can cause additional iterations that would not have happened if the 2D equation was being used.

For a HS using the weir equation, the gate and culvert flow is computed at the same time as the weir flow and is included in the flow checking.

For a HS using the 2D equation, the gate and culvert flow is still computed just prior to each iteration of the 2D area. So a HS with 2D equation and gates/culverts may still need a trial and error solution for the gate/culvert flow.



## HS Weir Flow



29

At some point, the assumptions that are built into the 2D solver are no longer valid and the 2D solver will not provide hydraulically valid results. The errors tend to show up as velocities and flows that are too high for the given energy head on the structure.

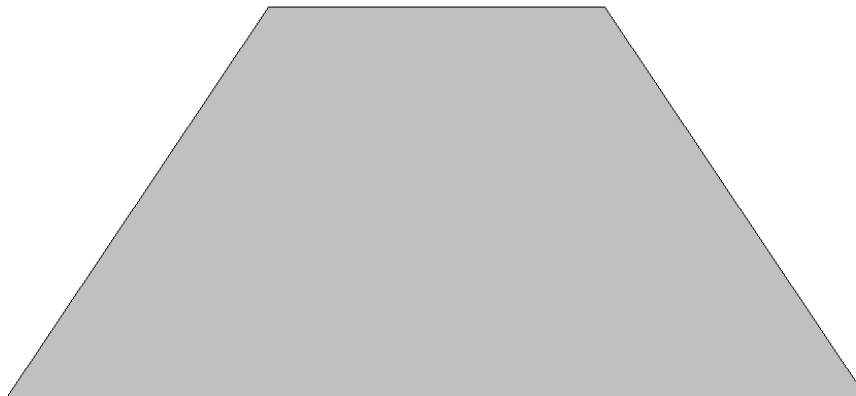
The problem is not that the flow is going supercritical per se, but rather that the weir flow is no longer within the assumptions that are built into the 2D finite volume shallow water equations.



## HS 2D Flow



**2D Solution is better**

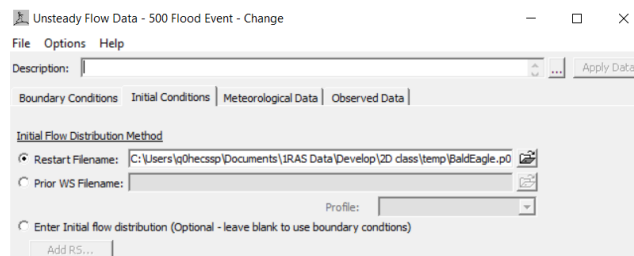
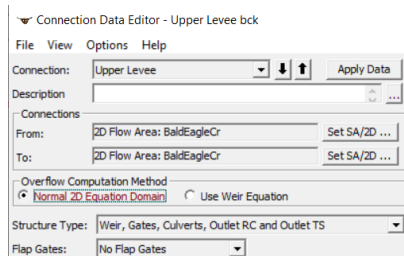


30

The 2D equation will give better results when the structure is highly submerged. The weir equation does not take into account the approach velocity or 2D considerations such as the velocity being at an angle. Additionally, the weir flow equation is very sensitive to the tailwater depth. So a highly submerged weir can cause the unsteady flow solver to iterate and/or it may not converge to an accurate answer.



## Use Restart/Prior WS to Switch



- Can switch methods while when using a restart/prior WS method
- Really only viable for a single location such as a levee breach

31

When using a restart and/or a prior water surface file, the user can switch the computation method. So, for instance, it would be possible to break a run into two or more parts. The first part of the run the levee could be modeled using the weir equation. As the leveed area filled up and the weir started to submerge, a restart file could be written out. A second run could be made using this restart file with the 2D equation.

This approach would probably only be viable for a single location such as modeling a levee breach.

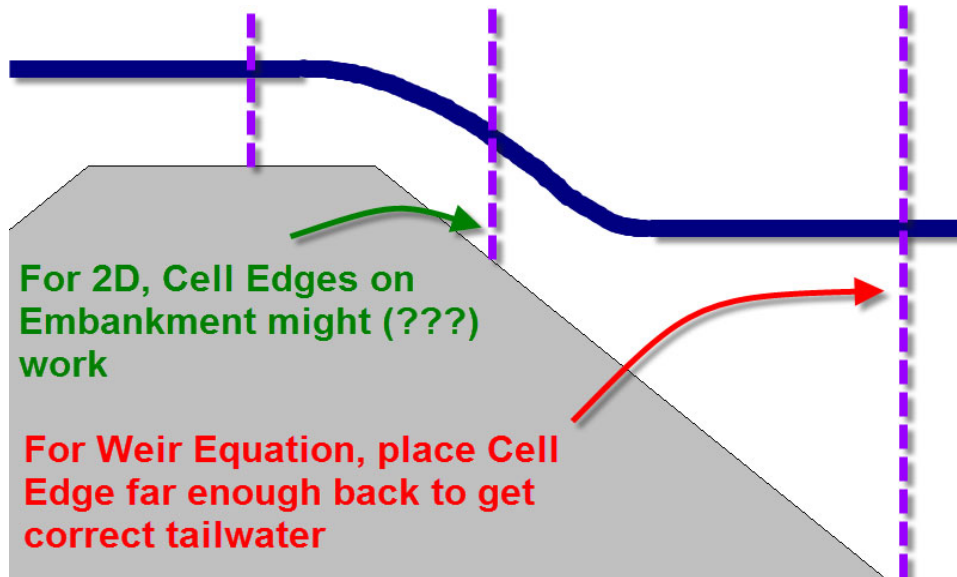
For a future version, RAS may be able to automatically switch between the weir equation and the 2D domain solution depending on whether the flow is submerged or not.

Or alternately, RAS may be able to recognize and compute the weir flow inside of the 2D solver.





## HS Tailwater Considerations



32

If the weir equation is being used, the cell edge needs to be set back far enough so that the tailwater is correct. In the example above, the weir is not submerged. However, if the cell edge is too high up on the embankment, then, the tailwater that is used during the weir computations may be too high and the computed flow will be, incorrectly, reduced for submergence.

The 2D domain solution does not have this problem. In theory, having small cells up the side of the embankment could produce better answers and prevent stability from “waterfall” type flow. In practice, it may still be problematic especially if the terrain does not accurately represent the size and shape of the embankment. But it may be worth experimenting with cell size and shape, especially if the levee is accurately represented in the terrain data.



## Overtopping Weir Coefficient Guidance for LS

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 flow area. Flow does not pass through critical depth	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

33

You need to evaluate the direction of flow and the impact of momentum to the structure. If the water is moving in the direction of flow with large head, the weir will act efficient and a higher coefficient may be appropriate. If the 2D Connections is acting like a Lateral Structure (lateral to flow), the weir will not be efficient and therefore the weir coefficient should be reduced (2.0 or lower). If the structure is more acting like a natural ground barrier and not like weir flow, the 2D domain method should be used.



# Breach Weir Coefficient Guidance for LS

Cd	C
1	5.35
0.95	5.08
0.9	4.81
0.85	4.55
0.8	4.28
0.75	4.01
0.7	3.74
0.65	3.48
0.6	3.21
0.55	2.94
0.5	2.67
0.45	2.41
0.4	2.14
0.35	1.87
0.3	1.60
0.25	1.34
0.2	1.07
0.15	0.80
0.1	0.53
0.05	0.27

Figures from: Estimates of Discharge Coefficient in Levee Breach Under Two Different Approach Flow Types

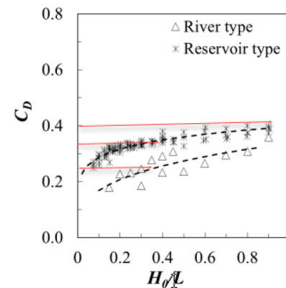


Figure 7. Discharge coefficient with non-dimensional variable  $H_0/L$ .

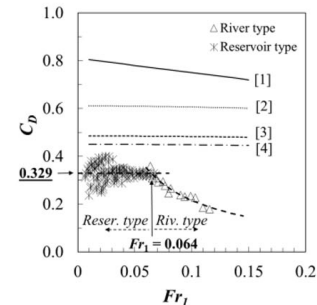


Figure 8. Discharge coefficient with approach Froude number ( $Fr_1$ ).

$H_0$  = Height above opening,  $L$  = opening bottom width

Estimates of Discharge Coefficient in Levee Breach Under Two Different Approach Flow Types  
Seung Oh Lee 1 , Kwang Seok Yoon 2 , Jun Seon Lee 3 and Seung Ho Hong 3,  
In Sustainability

**Abstract:** The amount of released water (discharge) in a levee breach is a primary input variable to establish an emergency action plan for the area next to the levee. However, although several studies have been conducted, there is still no widely applicable discharge coefficient formula; this needs to be known to estimate discharge amount through an opening caused by a levee breach. Sometimes, the discharge coefficient developed for a sharp crested side weir is used to rate the discharge, but, in case of a levee breach, the resulting geometry and flow types are similar to that over a broad crested weir. Thus, in this study, two different openings—rectangular and trapezoidal shape—are constructed in the center of a levee at a height of 0.6m to replicate levee breach scenarios, and the effect of two different approach flow types—the river type approach and reservoir type approach—are explored to suggest a discharge coefficient formula applicable for discharge rating for a levee breach. The results show that the ratio of head above the bottom of an opening and the opening width is a key variable for calculating the discharge coefficient of a reservoir type, but the approach Froude number should also be considered for a river type approach. The measured data are used to improve rating equations and will be useful in the future to validate computational fluid dynamics simulations of wave propagation during levee failure into the inundation area

$$C \leftrightarrow C_d. [C = 2/3 * C_d * (2g)^{1/2}].$$

# Questions?



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35