Modeling Dam and Levee Breaching with HEC-RAS

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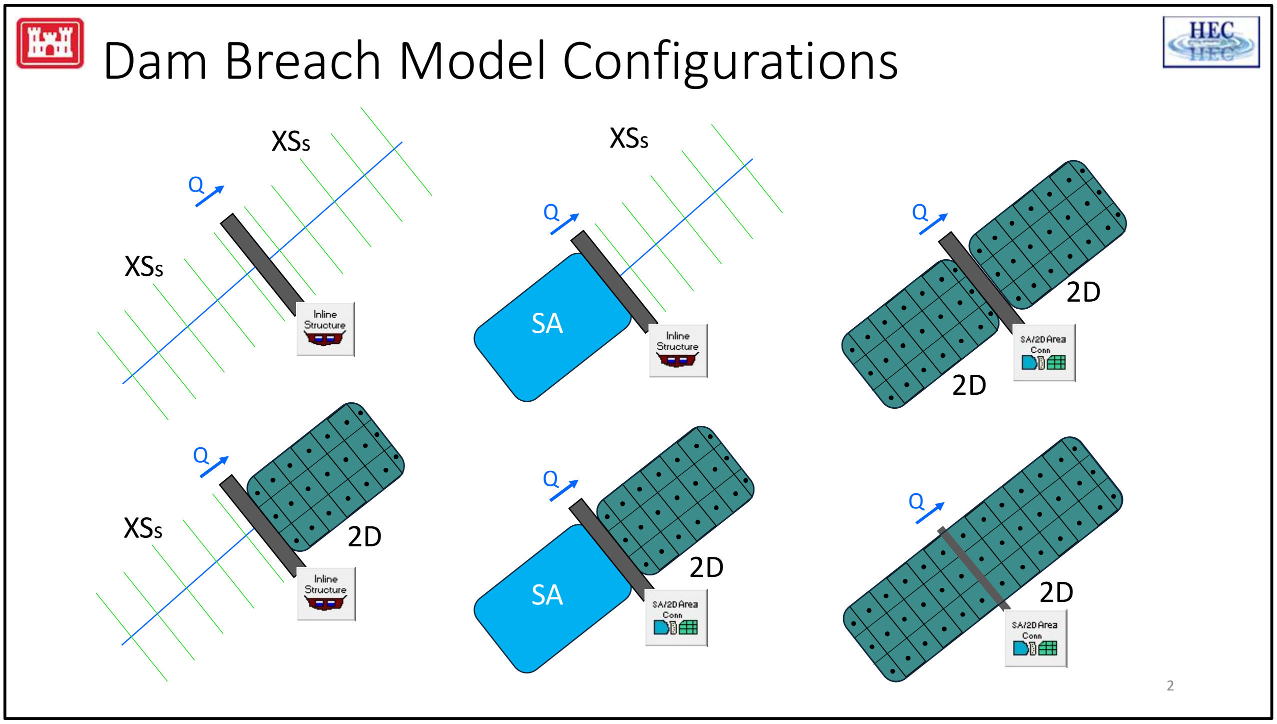
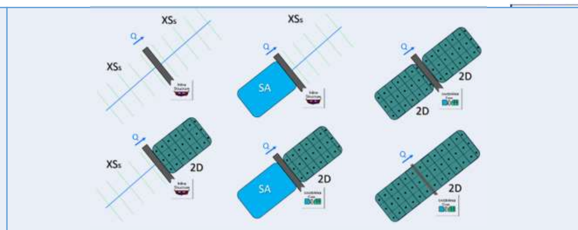
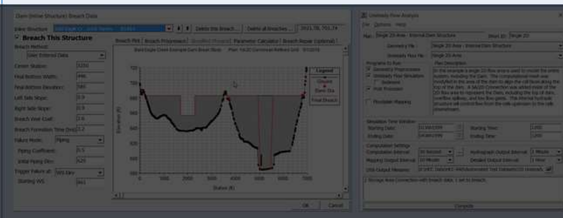


As shown in the previous presentation, there are many ways to set up a RAS model to perform dam breach analysis. Depending on the reservoir layout and the type of data available will help determine how you should set up your model.
The most common/easy way to set up a model for breach analysis is to use a Storage Area to represent the reservoir. An Inline structure is then used to represent the dam. Lastly, the downstream portion of the model can be represented by either cross sections or a 2D Flow Area.

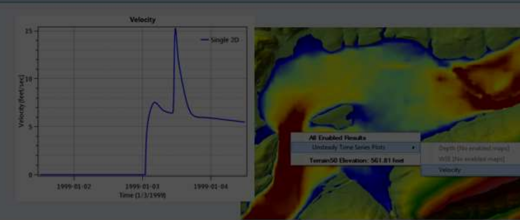
1. Dam Breach Model Configurations



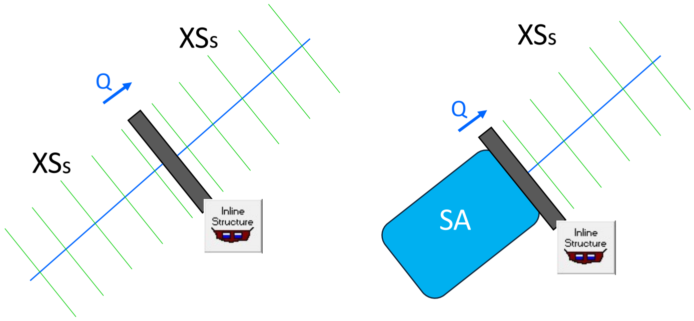
2. Breach Simulation Options and Parameters



3. Breach Simulation Results, and Visualization

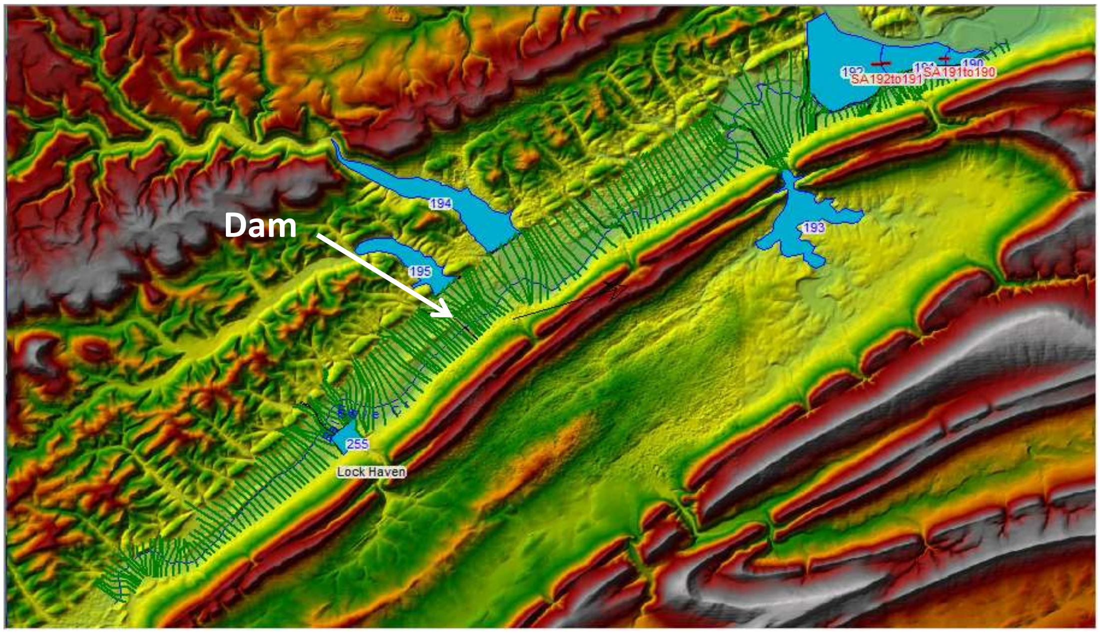


Breach Model Configurations



- 1D Model Configurations

1D Dam Breach Analysis
Cross Sections for Pool and Downstream



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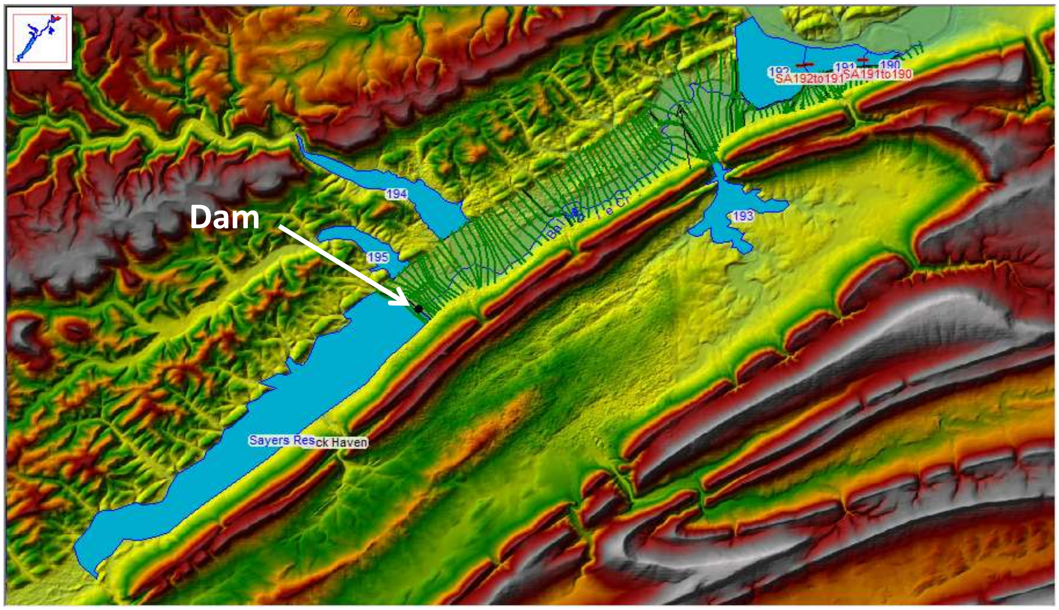
This is a typical layout for modeling a Dam breach scenario with entirely 1D elements (River reaches and Storage areas). In this example the reservoir pool and the downstream river are modeled as a single reach with cross sections. There is a downstream levee system modeled with Lateral Structures, and the area behind the levee is modeled with interconnected storage areas. There are a few tributaries in which water will back up into during a dam break analysis, these have been modeled in a simple way with storage areas.

1D Dam Breach Analysis
Storage Area Pool and XS Downstream



Inline Structure

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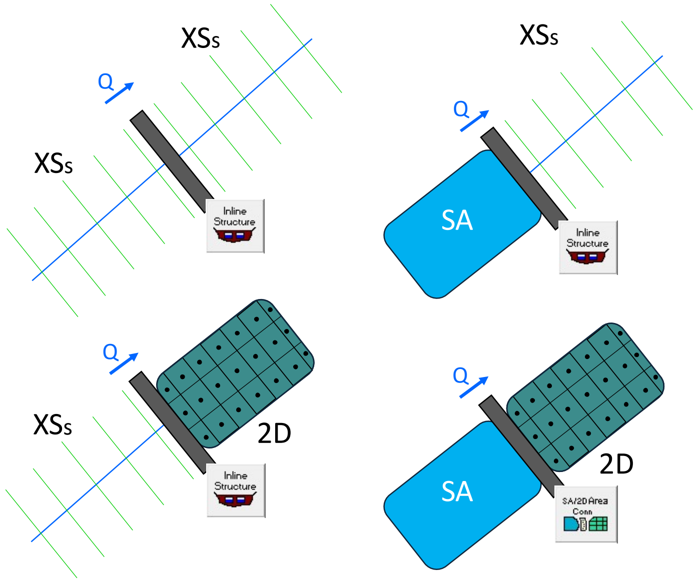
This is another 1D only approach. The only difference in this model to the previous slide is that the reservoir pool is being modeled with a storage area (level pool routing).

Breach Model Configurations



- Combined 1D/2D

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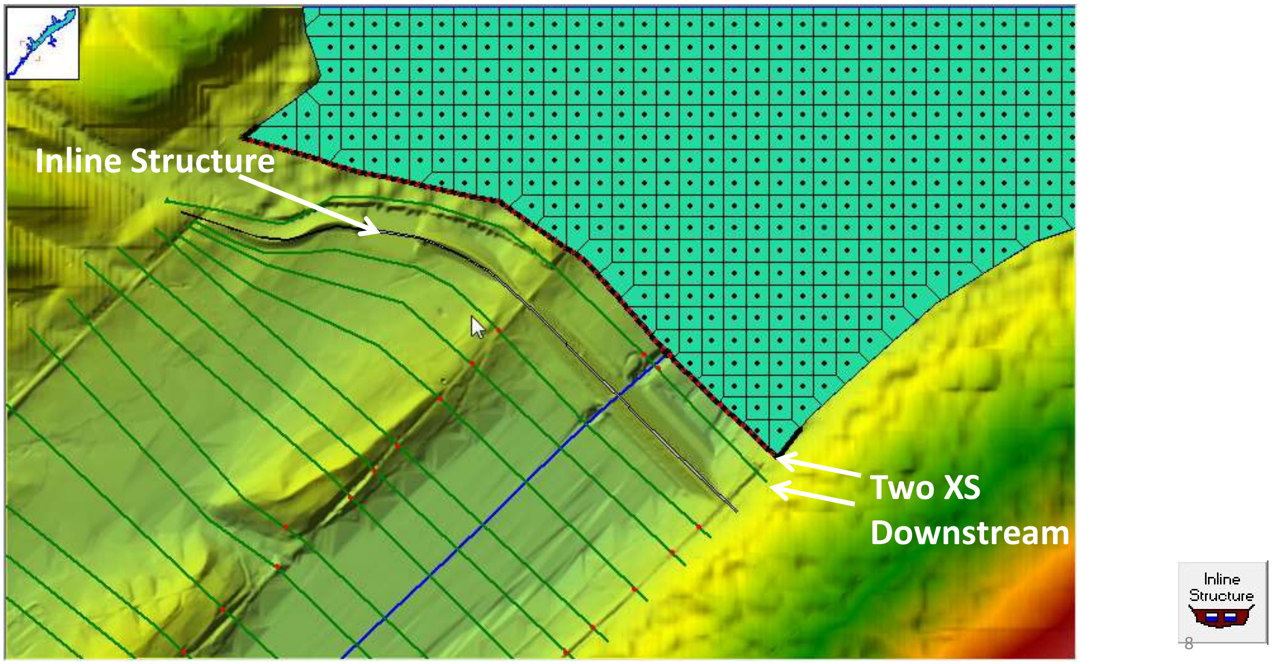
Cross Sections (1D) for Pool and 2D Downstream

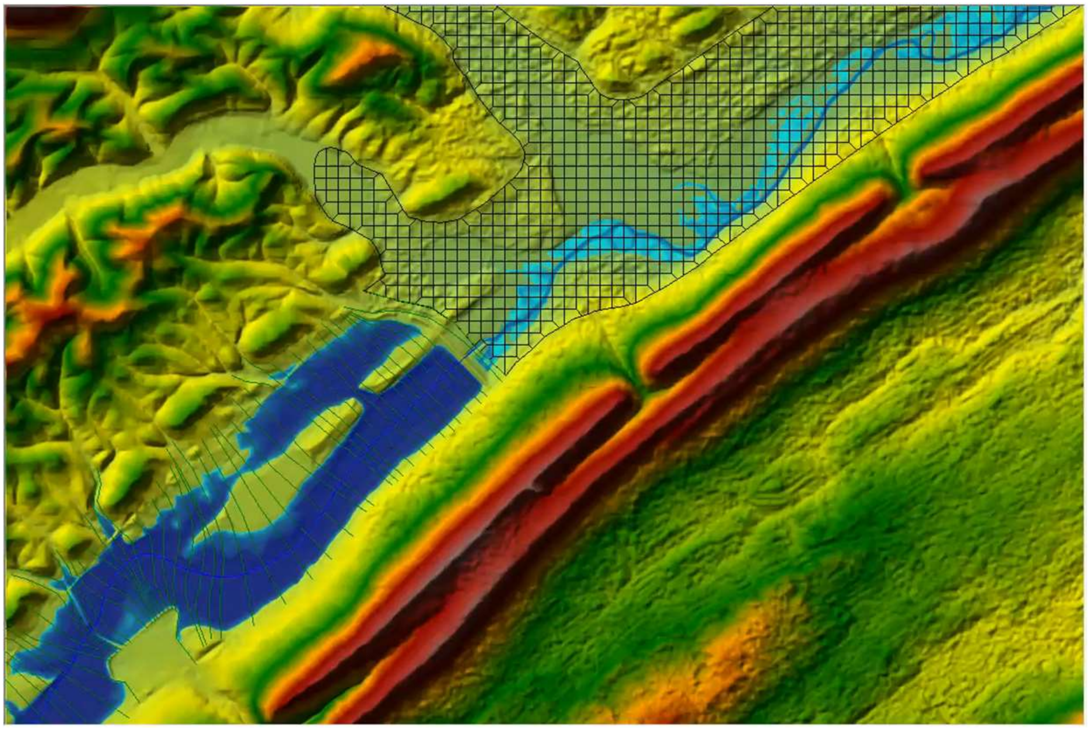


To connect a 1D river reach to a 2D Flow Area, do the following:
1. Draw the 2D area polygon such that the outer boundary at the upstream end is right on top of the last cross section of the 1D river reach.
2. Go to the **Edit** menu of the Geometric Editor, and turn on the Option to "Move Points/Objects".
3. Move the last point of the stream centerline inside of the 2D Area. The software will ask you if you want to connect the 1D River Reach to the 2D Flow Area. Select "Yes".

Once the 2D area and the 1D River Reach are connected, the software will draw a black line along the 2D Flow Area cells outer boundary to show you how it is connected. That is all that needs to be done for the connection.

Note: When a 1D River Reach is connected to a 2D area, the user will need to define the initial conditions for the 1D Reach and the 2D area. Initial conditions for the 2D Area can be: Dry; set to a single water elevation; set using a "Restart" file from a previous run; or the user can select to run a warm-up period at the beginning of the run, in which flow and stage boundaries connected to the 2D area will be applied slowly over time.

Animation 1D Pool - 2D Downstream



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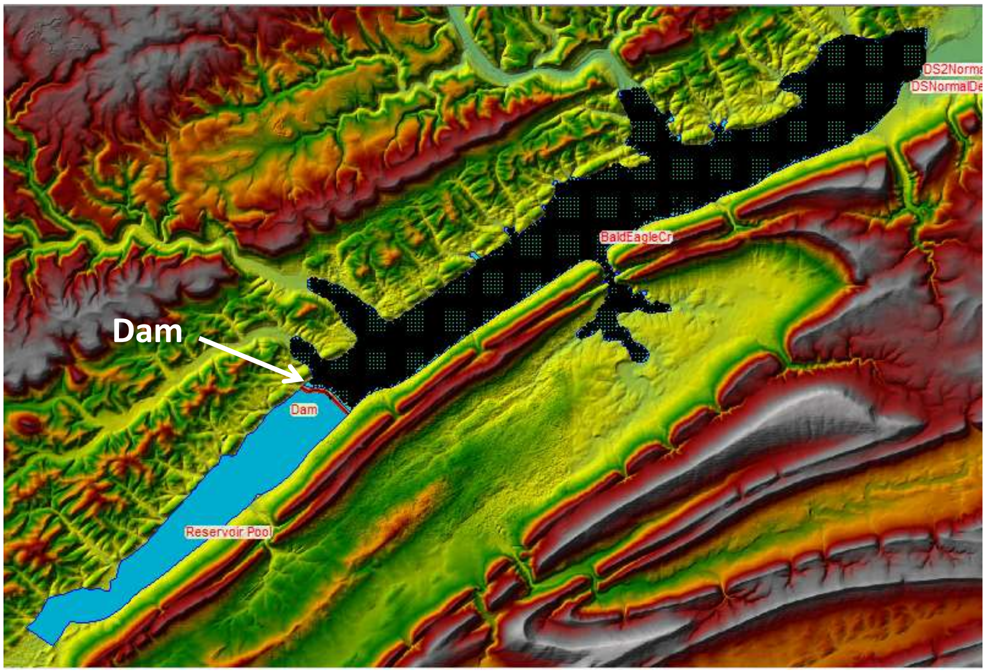
This is an animation of a Dam breaching analysis with a 1D River reach used for the reservoir pool, an Inline structure for the Dam, an then it is connected to a 2D Flow Area for modeling the area below the dam.

1D Storage Area Pool and 2D Downstream



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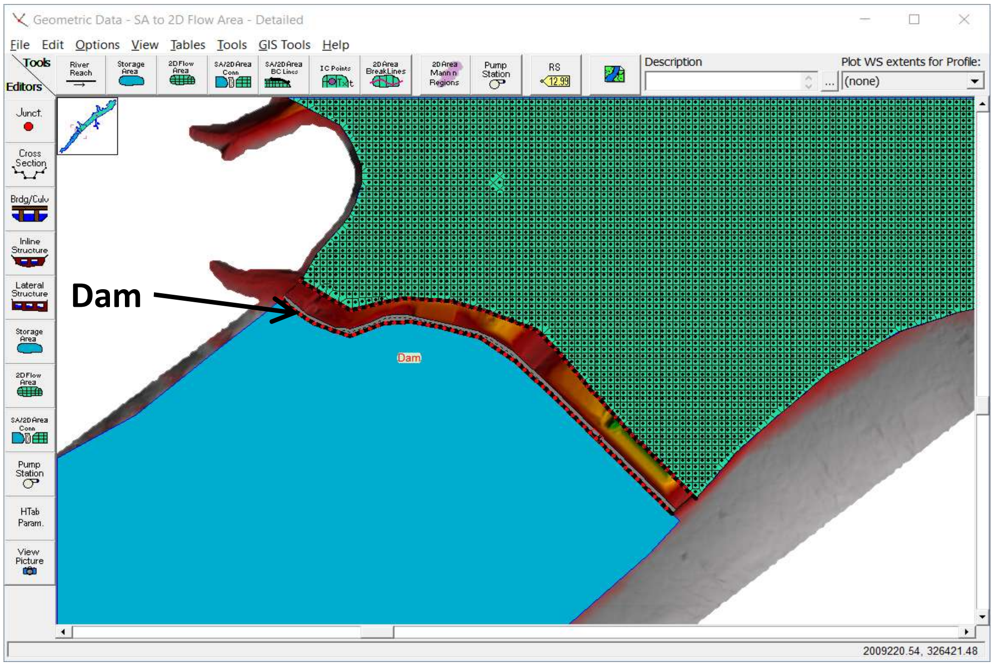
A 2D Flow Area can be directly connected to Storage Area by using a hydraulic structure called a Storage Area/ 2D Flow Area Hydraulic Connector (**“SA/2D Area Conn”**).

1D Storage Area Pool and 2D Downstream



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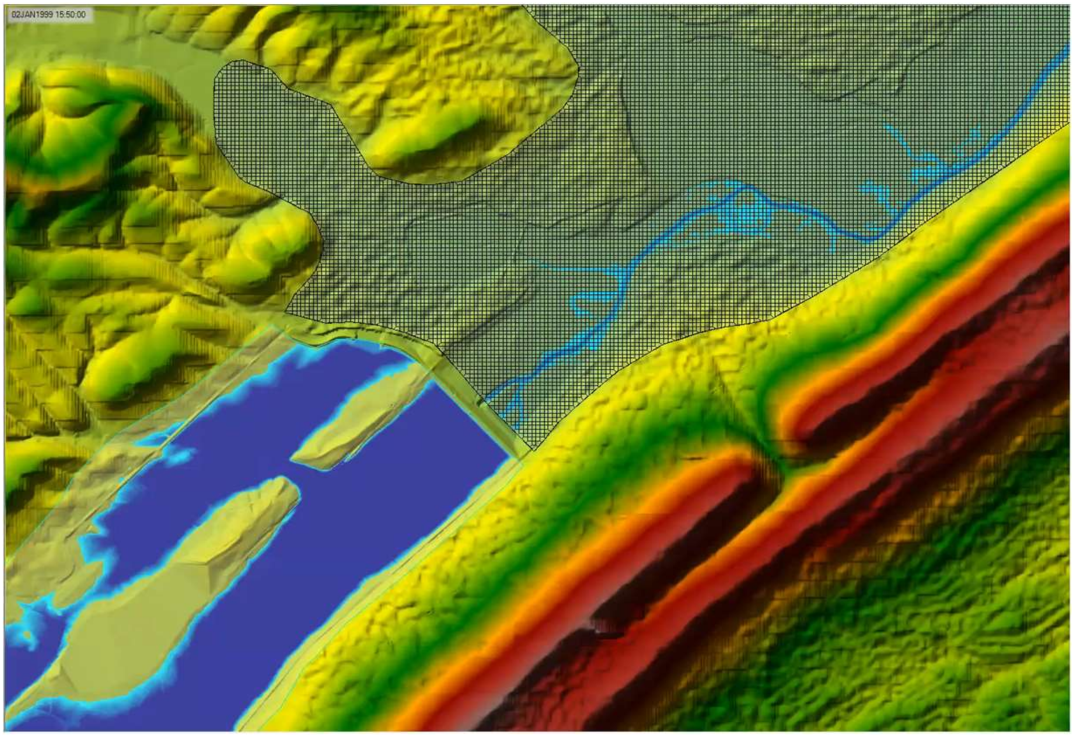
In the example shown in the Figure above, the Storage Area is upstream of the 2D Flow Area, so the positive flow direction is from the storage area to the 2D Flow Area. Therefore, when defining the hydraulic structure that connects the two areas, the Storage Area will be considered the Headwater side, and the 2D Flow Area will be considered the Tailwater side. This can also be done the other way, in which the 2D Flow Area is on the upstream side (Headwater) and the Storage Area is on the downstream side (Tailwater). For the example shown, a Storage Area is being used to represent a reservoir pool. The hydraulic connection between the Storage Area and the 2D Flow Area is a dam (SA/2D Area Hydraulic Connection) in this example. The 2D Flow Area is being used to model the hydraulics of the flow downstream of the dam.

1D Storage Area Pool - 2D Area Downstream



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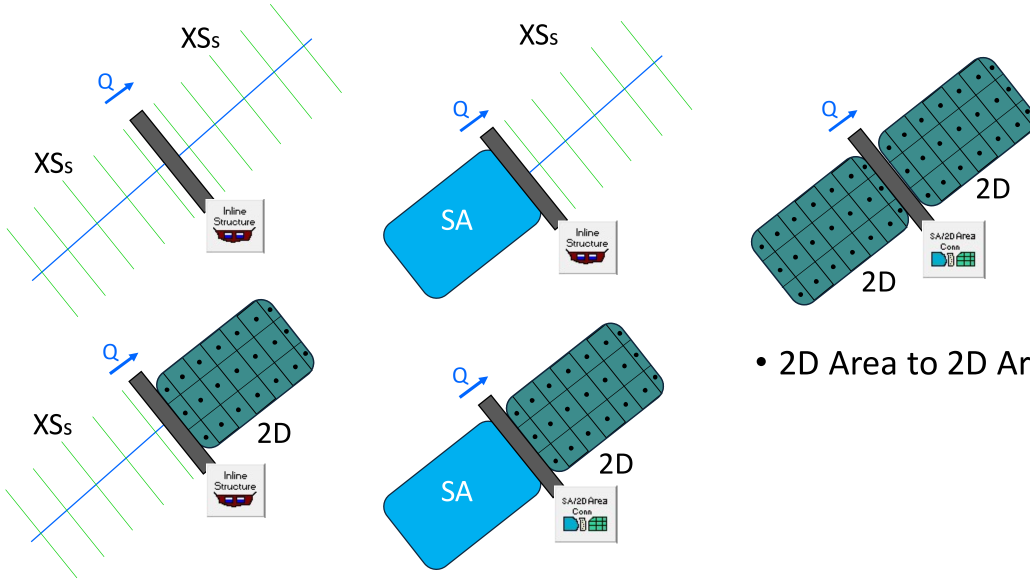
This is an animation of a Dam Breaching analysis done with a Storage Area for the reservoir pool, a SA/2D Area Hydraulic Connection for the Dam, and a 2D Flow Area for the downstream area below the dam. This is a very quick and easy way to model a dam. A user can put together a preliminary Dam Break model with this approach very easily. Rough answers could be developed very quickly with this type of approach. However, remember a detailed model would require refinement of the 2D Flow Area mesh, such that all of the levees, roads, and high ground barriers to flow were incorporated into the computational mesh. Also, any bridges, culvert weirs, and gated structures would also need to be added to have a detailed model.

Breach Model Configurations



- 2D Area to 2D Area

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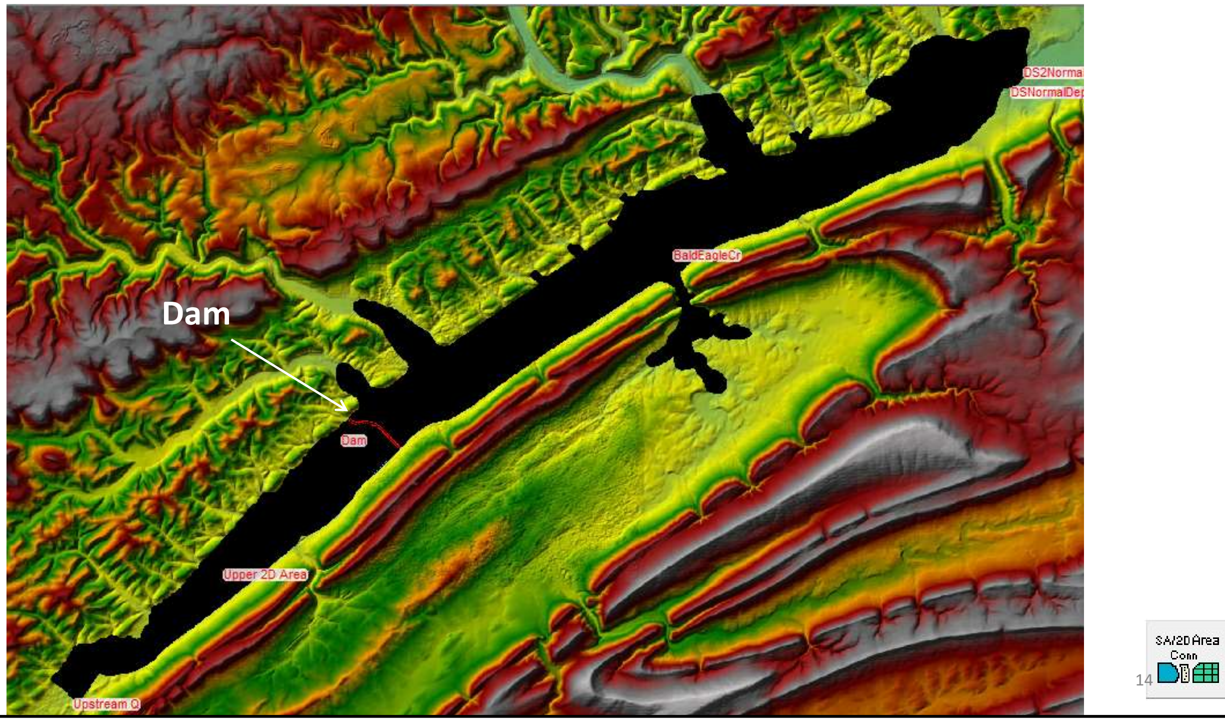
2D Reservoir Pool and 2D Downstream



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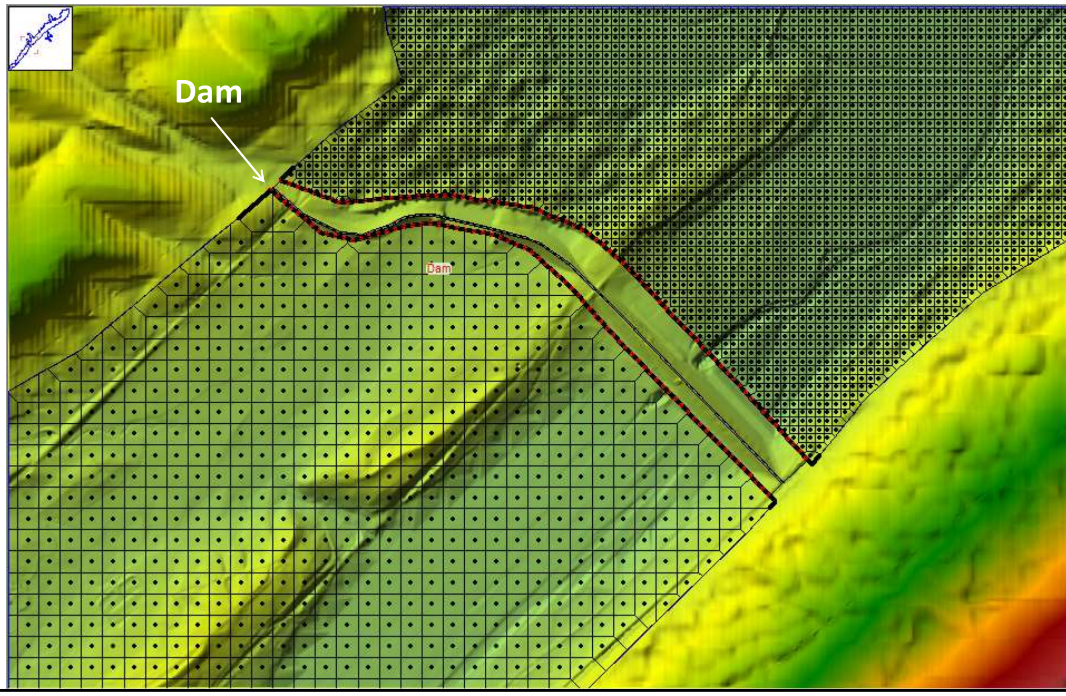
2D Flow Areas can be directly connected to other 2D Flow Areas by using a hydraulic structure called a Storage Area/ 2D Flow Area Hydraulic Connector (**"SA/2D Area Conn")**. In the example shown in the Figure above, there is a 2D Flow Area upstream of another 2D Flow Area, so the positive flow direction is from the upstream 2D Flow Area to the downstream 2D Flow Area. When defining the hydraulic structure that connects the two areas, the upstream 2D Flow Area will be considered the Headwater side, and the downstream 2D Flow Area will be considered the Tailwater side.

2D Reservoir Pool and 2D Downstream



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To hydraulically connect one 2D Flow Area to another 2D Flow Area, do the following:

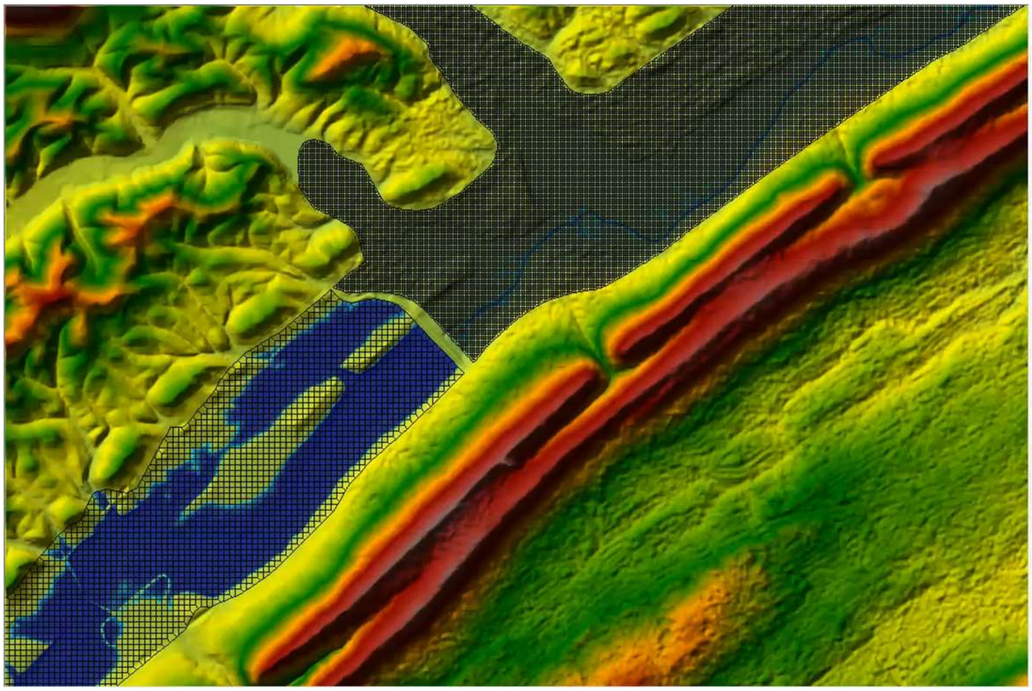
Draw the upstream 2D Flow Area polygon right up to the edge of the hydraulic structure. This should be relatively close to the hydraulic structure for mapping purposes.

Draw the outer boundary of the downstream 2D Flow Area right up to the other side of the hydraulic structure. This can also be very close to the hydraulic structure, however, keep in mind that the computed water surface elevations of the boundary cells of the 2D area will be used in the hydraulic calculations over/through the structure (i.e., don't put very small cells down the face of a steep embankment). Generally, the 2D cells computed water surfaces should represent what you want to be used for the water surface in the hydraulic calculations of flow over and through the hydraulic structure.

Select the Drawing tool at the top of the Geometric editor labeled "**SA/2D Area Conn**". Then draw a line directly down the center of the hydraulic structure that will be used to connect the two flow areas. The interface will ask you for a label to define the hydraulic structure. See the red line shown in the Figure above.

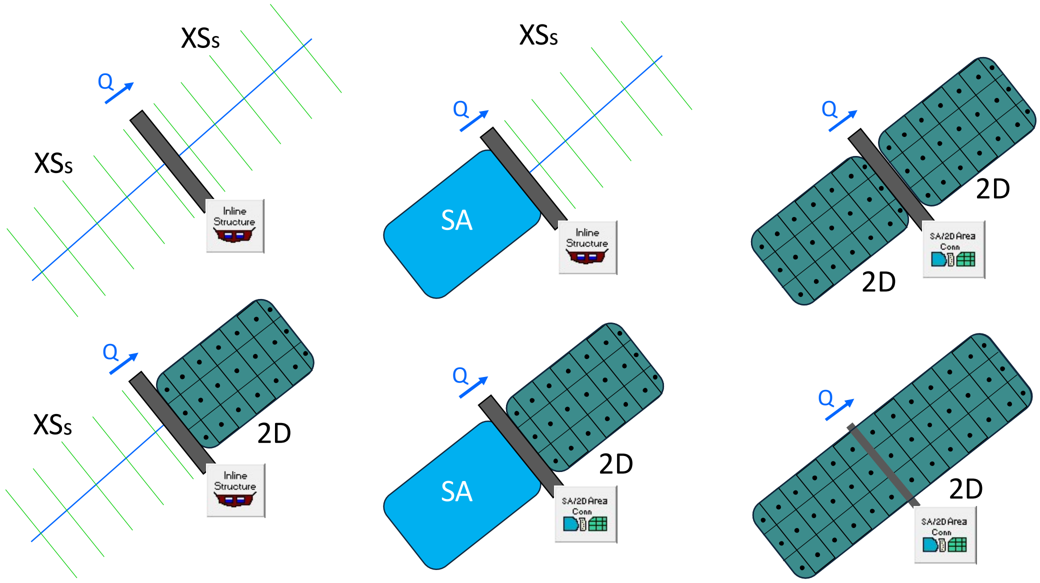
Next, select the Storage Area/ 2D Flow Area Hydraulic Connection (**SA/2D Area Conn**) editor on the left panel of the Geometric data editor. This will bring up the Hydraulic Structure editor, which will allow you to enter all of the data for the Dam, spillway, gates, etc…

Animation of 2D Reservoir Pool and 2D Downstream



This is an animation of a Dam Breaching analysis done with two 2D Flow Areas. The upstream 2D Flow Area represents the reservoir pool, and was done with a courser mesh. The downstream 2D Flow Area is used to model the area below the dam, this was dine with a finer mesh for more detail.

Breach Model Configurations



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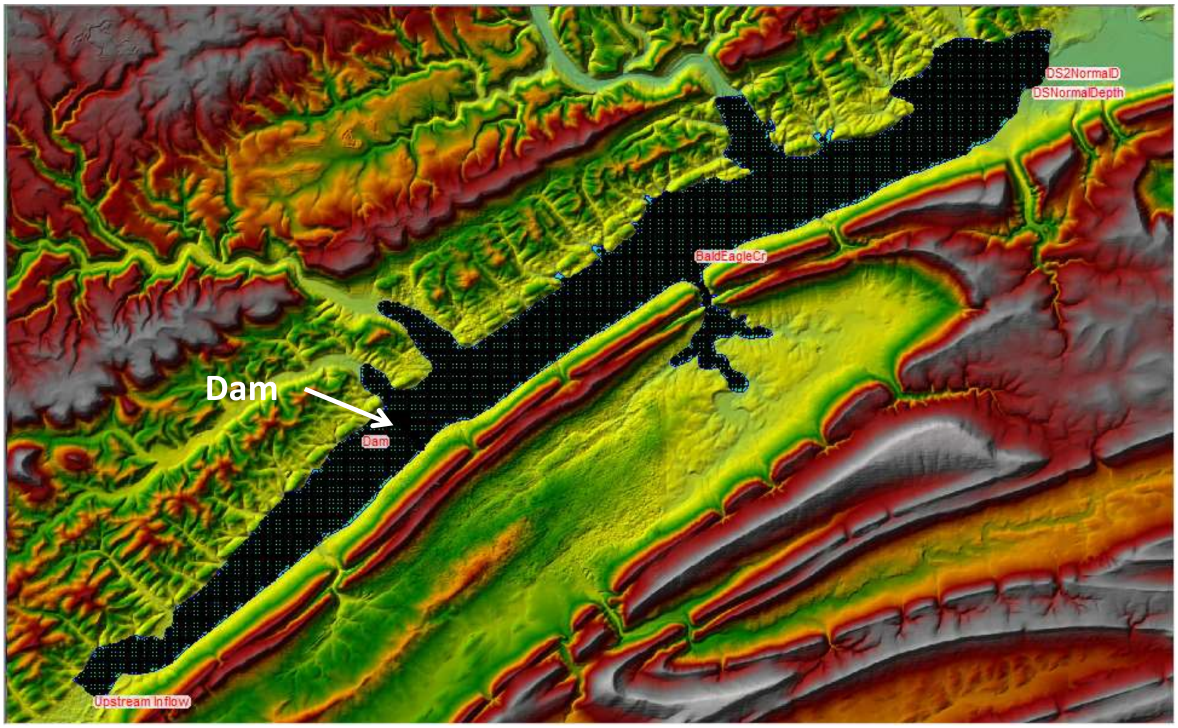
Single 2D Flow Area with Internal Hydraulic Structure for the Dam



SA/2D Area Conn

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This is an example of performing a Dam breaching analysis with a single 2D Flow Area for the entire model.

Single 2D Flow Area with Internal Hydraulic Structure for the Dam

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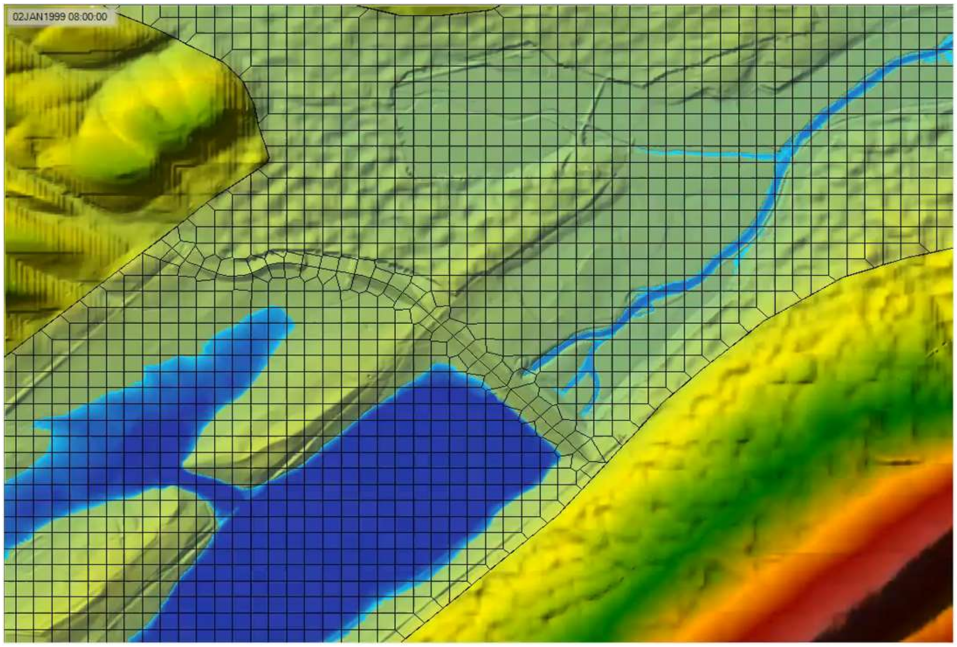
HEC-RAS has the ability to add hydraulic structures inside of 2D Flow Areas. This is accomplished by using the "**SA/2D Area Conn**" option to make a hydraulic structure in the middle of a single 2D Flow Area. The hydraulic structure must be laid out along the Faces of the 2D Cells (2D Cell Faces control flow movement).
To add a hydraulic structure inside of a 2D Flow Area do the following:

First modify the 2D Flow Area mesh so that the faces of the cells go along the centerline of the top of the hydraulic structure. For example, as shown in the Figure above, a Dam is being modeled inside of a single 2D Flow Area. The 2D Flow Area mesh was modified (cell center points were added and moved) to have cells on both sides of the Dam, such that the faces between the Dam lined up on top of the Dam. This requires adding enough cells to get the correct detail, as well as placing cell centers at equal distances apart on each side of the structure. [Note: currently this is tedious with the HEC-RAS mesh editing tools. However, future versions of HEC-RAS will allow you to draw a break line on top of the levee (or hydraulic structure) and it will automatically modify the mesh to align the cell faces with the structure].

Next, select the Drawing tool at the top of the Geometric editor labeled "**SA/2D Area Conn**". Then draw a line directly down the center of the hydraulic structure along the cell faces that represent the structure (**NOTE: this line Must be drawn from left to right, while looking from what is considered to be upstream to downstream. This is how the program figures out what is considered to be the headwater side and the tailwater side.**). This line will be the hydraulic structure that will be used to connect the 2D Flow Areas cells on one side of it to the other side of it. The interface will ask you for a label to define the name of the hydraulic structure. See the black line in the Figure above.

Next, select the Storage Area/ 2D Flow Area Hydraulic Connection (**SA/2D Area Conn**) editor on the left panel of the Geometric data editor.

Animation of Single 2D Flow Area with Internal Hydraulic Structure for the Dam



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This is an animation of a Dam breaching analysis with a single 2D Flow Area for the entire model. The mesh was modified in the area of the Dam, then a SA/2D Area Hydraulic Connection was added to model the Dam. This structure allows for modeling flow going over the emergency spillway, through the low flow gates, and even through a hypothetical breaching of the Dam.

SA/2D Area Hydraulic Connection

1. Draw the Storage Area and enter its data
   - Will need to provide the Elevation-Volume curve if not supported in the terrain
2. Draw the 2D Flow Area and create Mesh
3. Draw the SA/2D Area Connection
   - Draw the line that represents the hydraulic Structure from left to right looking downstream
4. Select the SA/2D Area Conn data editor
   - Verify the "From" and "To" connections
   - Enter the top of dam and spillway profile
   - Enter any gate data, etc…

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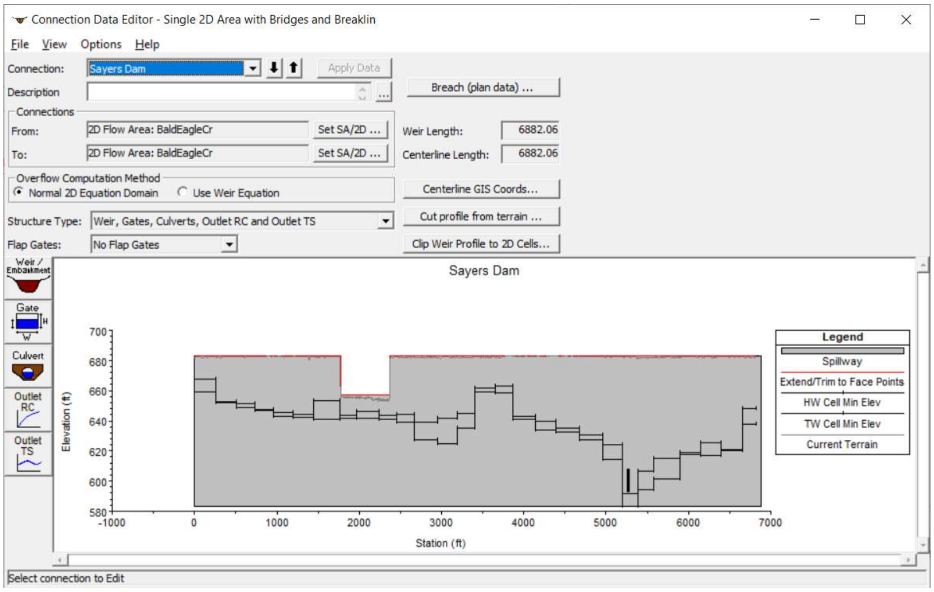
To hydraulically connect a Storage Area to a 2D Flow Area, do the following:

Draw the storage area polygon right up to the edge of the hydraulic structure. This can be as close to the hydraulic structure as you want for mapping purposes.

Draw the outer boundary of the 2D Flow Area right up to the other side of the hydraulic structure. This can also be very close to the hydraulic structure. However, keep in mind that the computed water surface elevations of the boundary cells of the 2D area will be used in the hydraulic calculations over/through the structure (don't put very small cells down the face of a steep embankment). Generally, the water surface computed for the 2D cells should represent what you want for the water surface in the hydraulic calculations of flow over and through the hydraulic structure. That is, don't put very small cells down the face of a steep embankment because the small boundary cells may end up with a transitional water surface that is between the "headwater" and the "tailwater" surfaces. If this happens, the accuracy of the hydraulic computations across the structure may be reduced. **Note: For any culverts and/or gates, the minimum elevation of the culvert/gate must not be below the minimum elevation of the cell it is connected too. This is another reason to use cells that are large enough to span at least to the bottom of the embankment.**

Select the Drawing tool at the top of the Geometric editor labeled "**SA/2D Area Conn**". Then draw a line directly down the center of the hydraulic structure that will be used to connect the two flow areas. Draw this line from left to right looking downstream. This is how HEC-RAS will detect what is upstream (headwater) and what is downstream (tailwater). The interface will ask you for a label to define the hydraulic structure. See the red line shown in Figure 40.

Modeling the SA/2D Connection



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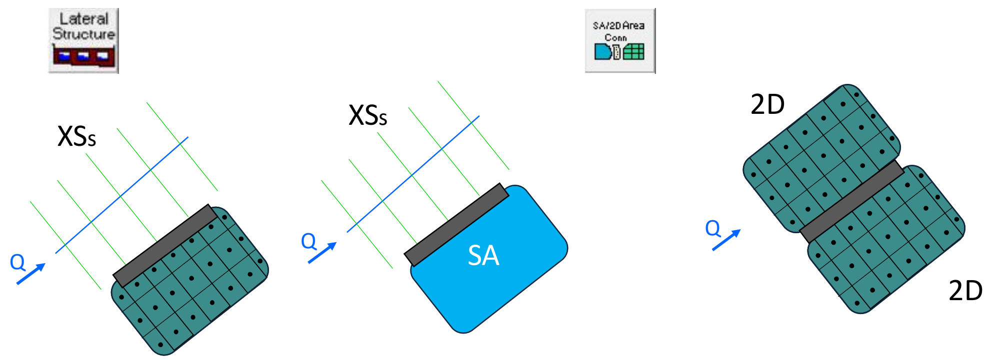
Next, select the Storage Area/ 2D Flow Area Hydraulic Connection (**SA/2D Area Conn**) editor on the left panel of the Geometric data editor. This will bring up the editor shown in the Figure above.

On the **SA/2D Area Conn** editor set the “From” and “To” by selecting the buttons labeled “Set SA/2D Area”. For this example, the Storage Area labeled “Reservoir Pool” is the “From” element, and the 2D Flow Area labeled “BaldEagleCr” is the “To” element.

Enter all the hydraulic structure information for the connection. This will consist of a Weir/Embankment profile, and any additional hydraulic outlets, such as culverts, gates, etc… In the example shown in the Figure above, there is an embankment with an emergency spillway defined, and there are also low flow gates defined.

Levee Breach Model Configurations



- River, XS and LS connecting to a 2D Flow Area or Storage Area
- SA/2D Connection within a single 2D Flow area or connecting two 2D Flow Areas

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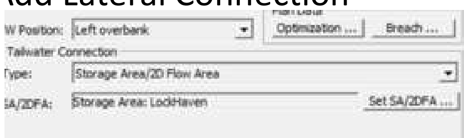
There are a few ways to model a levee breach scenario in HEC-RAS. Either in a combined 1D/2D model or in an 2D model.

Lateral Connection

Cross Sections Model

1. Draw the Cross Sections
2. Storage Area (or 2D Area) and enter its data
   - Will need to provide the Elevation-Volume curve if not supported in the terrain
3. Add Lateral Connection
   - 

   - Enter weir profile
   - Additional data

2D Flow Areas Only

1. Draw the 2D Flow Area and create Mesh
2. Draw the SA/2D Area Connection
   - Draw the line that represents the hydraulic Structure from left to right looking downstream
3. Select the SA/2D Area Conn data editor
   - Verify the “From” and “To” connections

   - Enter weir profile
   - Enter additional data

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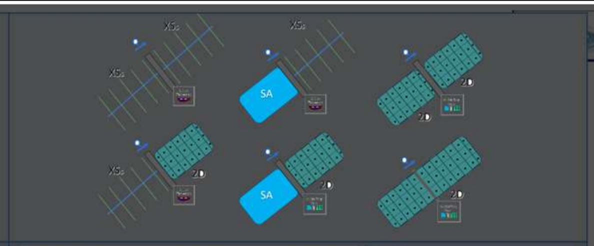
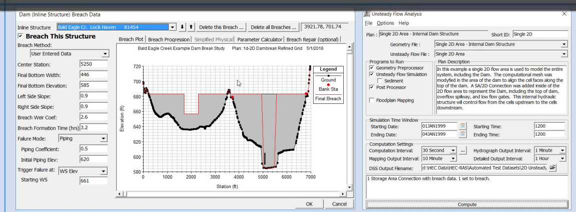
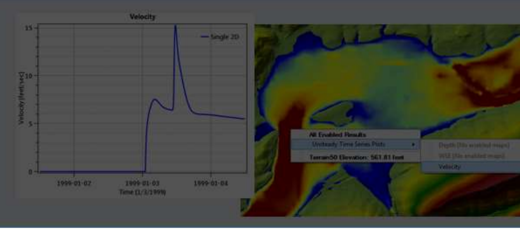
1. Dam Breach Model Configurations



2. Breach Simulation Options and Parameters



3. Breach Simulation Results, and Visualization



Breach Analysis in HEC-RAS

- Failure Modes
  - Overtopping and Piping
- Failure Initiation based on:
  - stage
  - simulation time
  - stage + duration, and immediate initiation stage.
- Breach progression
  - linear or nonlinear (user specified)
  - Simplified Physical Breaching Option
  - DL Breach

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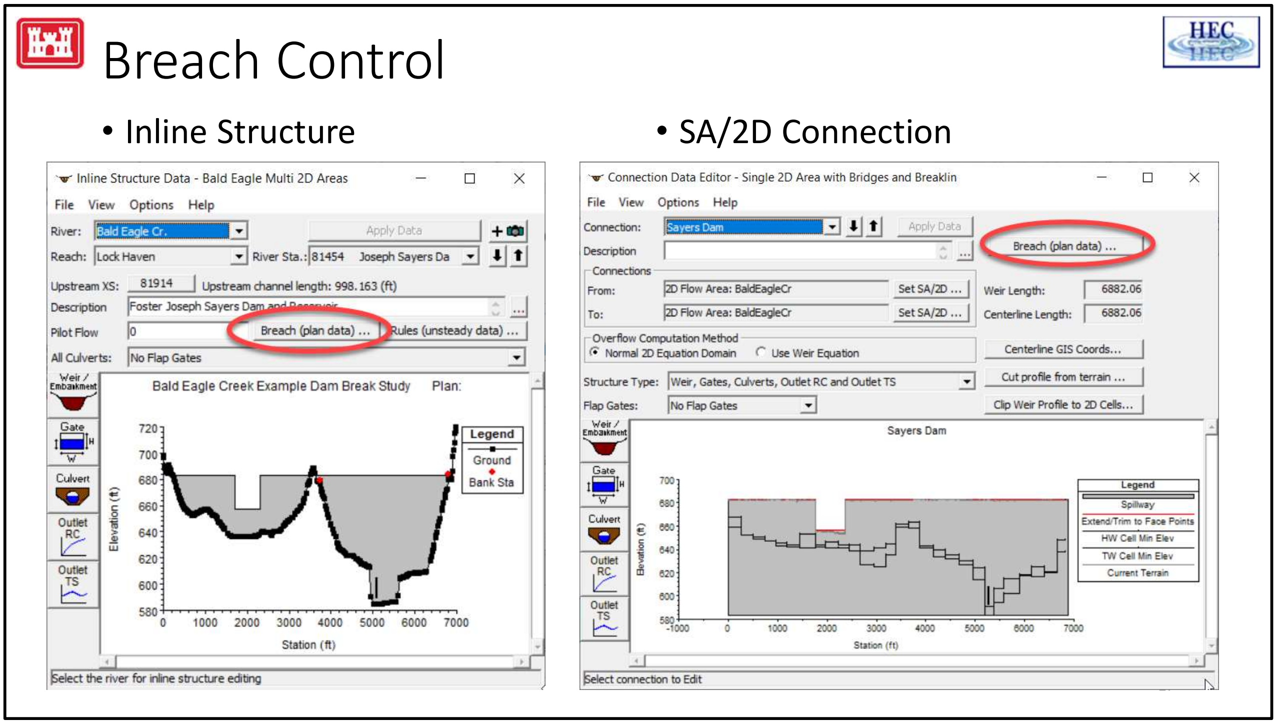
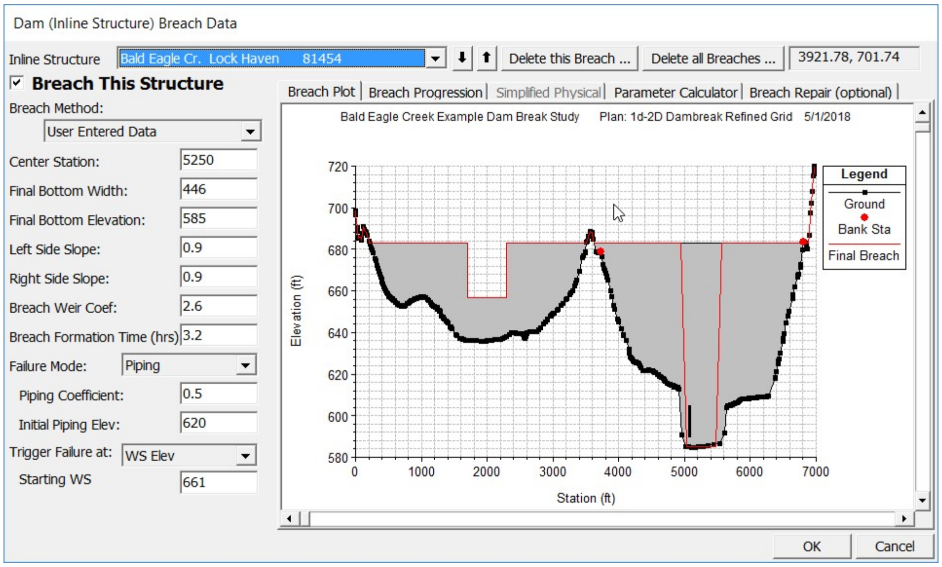


A dam breach can be performed on an inline weir (and a SA/2D Connection) and a levee breach can be performed on a lateral weir (and a SA/2D Connection. The breach editor can be accessed from either the unsteady flow analysis editor or by clicking the breach button on the inline or lateral weir editor. It is usually more convenient to just click on the button on the appropriate geometry editor, but the user should keep in mind that breach information is stored with the plan data not the geometry data. For instance, to compare a "breached" with a "not breached" run, the project should have two plans, but they can (and in many cases should) have the same geometry.

The dam breach data (next slide) is as follows:
Breach This Structure - This check box is used to decide if the program will perform the breach or not. This box was added to allow the user to turn certain breaches on or off, without loosing the user entered breach information.
Center Station - The centerline stationing of the final breach.
Final Bottom Width - The bottom width of the breach at its maximum size.
Final Bottom Elevation - The elevation of the bottom of the breach after it has been fully developed.

Left Side Slope - This is the left side slope of the trapezoidal breach.
Right Side Slope - This is the right side slope of the trapezoidal breach.

Breach Data



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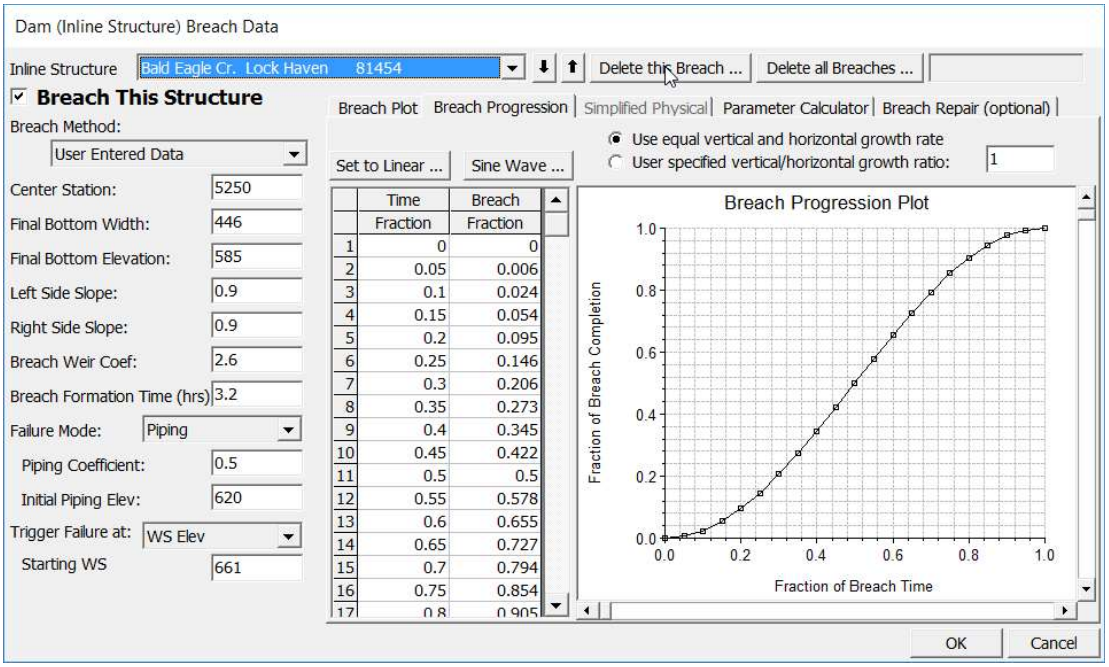
Center Station - This field is the cross section stationing of the centerline of the breach.
Final Bottom Width - Bottom width of the breach when it has reached its maximum size.
Final Bottom Elevation - Bottom elevation of the breach at its maximum size.
Left Side Slope - Left side slope for the trapezoid that will represent the final breach shape. Side slopes are entered in values representing the horizontal to vertical ratio.
Right Side Slope - Right side slope for the trapezoid that will represent the final breach shape. Side slopes are entered in values representing the horizontal to vertical ratio.
Breach Weir Coefficient –Weir coefficient used for overtopping (weir) flow in the breach area.
Failure Mode - This option allows the user to choose between two different failure modes, an Overtopping failure and a Piping failure.
Piping Coefficient - If a piping failure mode is selected, the user must enter a piping coefficient.
Initial Piping Elev. - If a piping failure is selected, the user must enter an initial piping elevation.
Trigger Failure At - This field is used to select one of two trigger methods for initiating the breach. The two trigger methods are a water surface elevation or a specific time and date.
Starting WS – If water surface elevation is the failure trigger mode, then this field represents the water surface elevation at which the breach should begin to occur.
Start Date – If starting date and time is the failure trigger mode, then this field must be entered. This field is used to enter the date at which the breach will begin to occur.
Start Time – If starting date and time is the failure trigger mode, then this field must be

entered. This field is used to enter the time at which the breach will begin to occur.

Non-Linear Breach Growth



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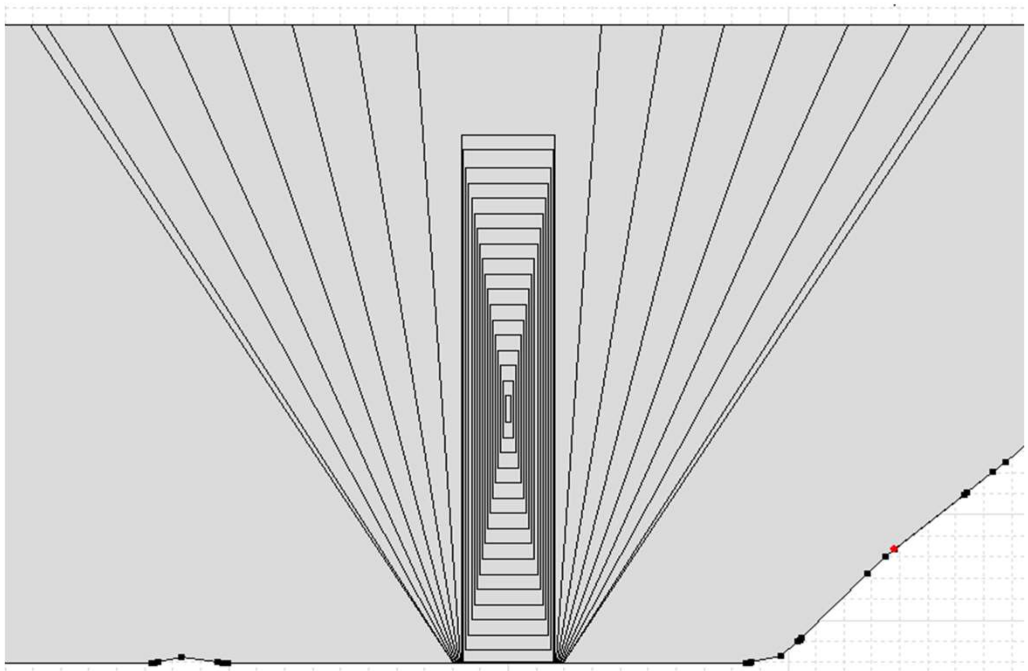
By clicking on the **Breach Progression** button, the above editor will be shown. By default, the breach growth is assumed to be linear from start to maximum size (Full Formation Time). However, a non-linear breach growth curve can be entered. This is done by entering a Time Fraction (from zero to 1.0) and a Breach Fraction (from zero to 1.0). The user-entered data is plotted in the graphic next to the table. The breach progression curve is then used during the breach formation time to adjust the growth rate of the breach.

In addition to adjusting the curve in order to have a more realistic breach growth, the curve can sometimes be used in order to improve stability. If the program is having stability problems during part of the breach growth, the rate of growth during that time can be reduced by adjusting the curve.

Piping Failure Breach Growth Geometry



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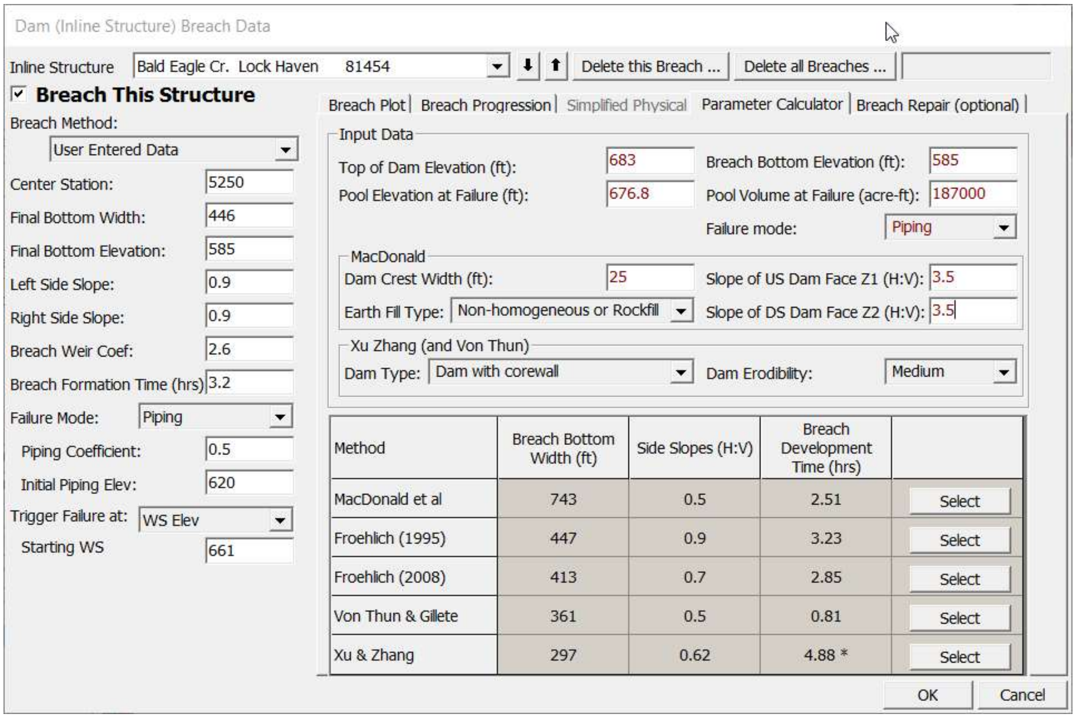
A piping breach starts out as a point—at the centerline station and elevation as specified by the user. Its growth is modeled as a rectangle growing linearly both vertically and horizontally.

When the top of the piping breach is greater than the water surface, it is assumed that the levee sloughs and the breach is modeled as an open breach. The side slopes are gradually increased until they reach the user specified values.

Breach Regression Equation Calculator



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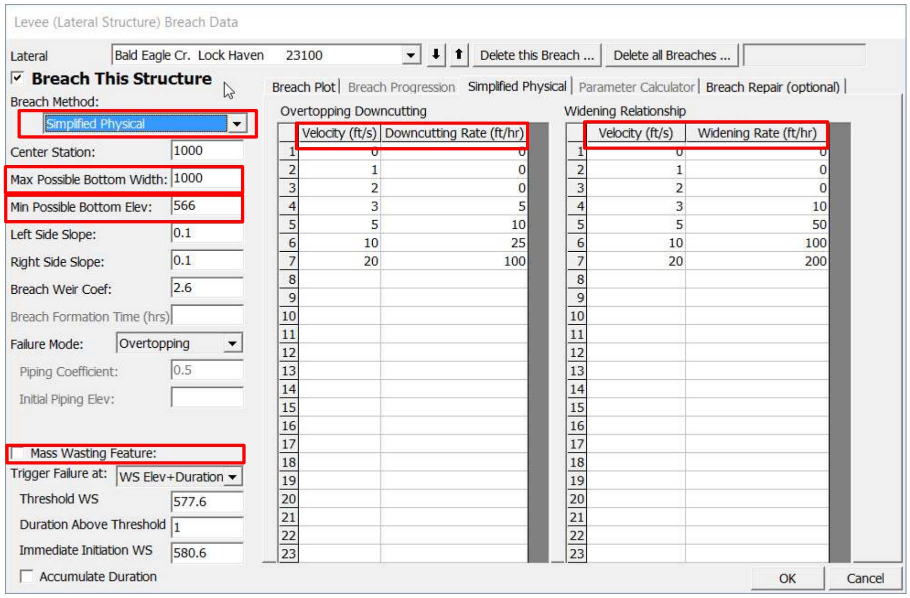
To assist users in estimating the Breach dimensions and development time, HEC has added a "Parameter Calculator" to the Breach Data editor. To use this calculator select the **Parameter Calculator** Tab from the breach editor, and the editor will look like the screen above.

As shown in the Figure above, the Breach Parameter Calculator contains five regression equations (MacDonald\Langridge-Monopolis; Froehlich 1995; Froehlich 2008; Von Thun and Gillete; and Xu & Zhang 2009). The user is required to enter several parameters that describe the Dam and the volume of water behind the structure at the time of failure. These parameters include: Top of Dam elevation; Breach Bottom Width; Pool elevation at Failure; Pool Volume at Failure; Failure Mode; Dam Crest width, upstream and downstream embankment slopes; Earth Fill Type; Dam Type; and Dam Erodibility factor. Not all values are used for all regression equations as noted on the editor. Some of the variables are specific to the MacDonald equation, and the last two are specific to the Xu & Zhang equation. Once the values are entered the calculator computes Breach Bottom Width; Side Slopes; and Breach Development Times from each of the regression equations. The user can then select the answers from one of the equations to by pressing the **Select** button next to the equation results that they would like to use.

Simplified Physical Breaching



32

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 verses 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.

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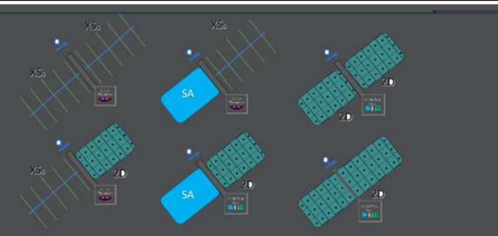
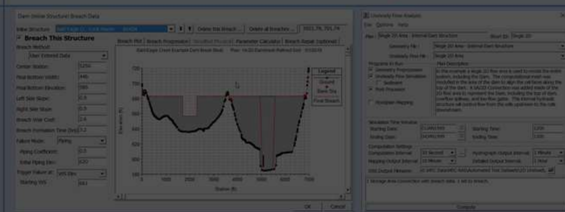
Velocity vs. Downcutting and Widening Erosion Rates. When using the “Simplified Physical” breaching option, the user is required to enter velocity versus Downcutting erosion rates, as well as velocity versus erosion widening rates. To enter this data the user selects the “Simplified Physical” breach Tab.

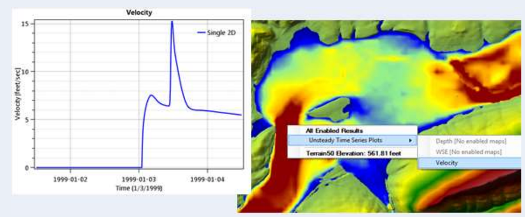
1. Dam Breach Model Configurations



2. Breach Simulation Options and Parameters



3. Breach Simulation Results, and Visualization

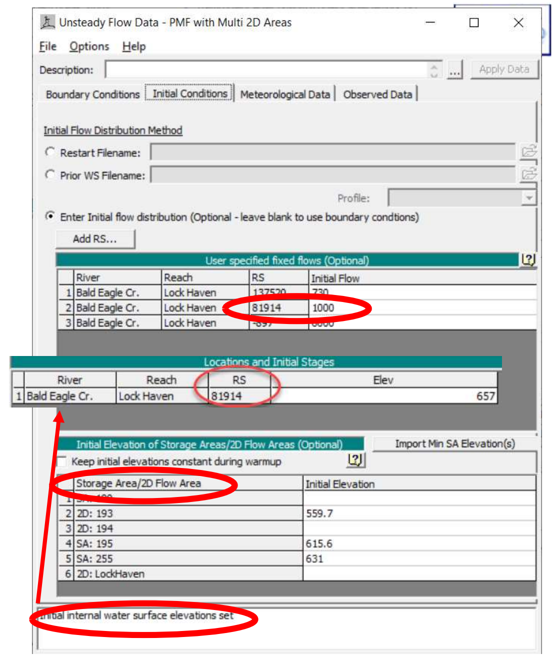


Initial Conditions

- 1D Models
  - Cross Sections downstream of the Dam must have flow
  - Water Surface upstream of the Dam
    - Cross Section   or
    - Storage Area

- 2D Models
  - Water Surface upstream of the Dam

  - Can also use Initial Conditions Points!



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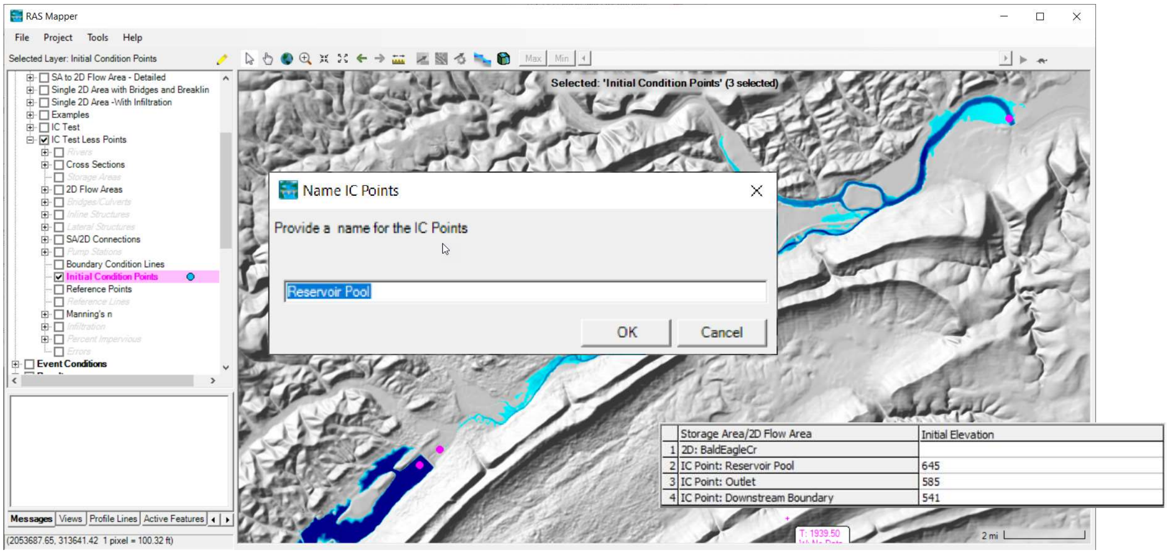
Initial Conditions – Points (2D)



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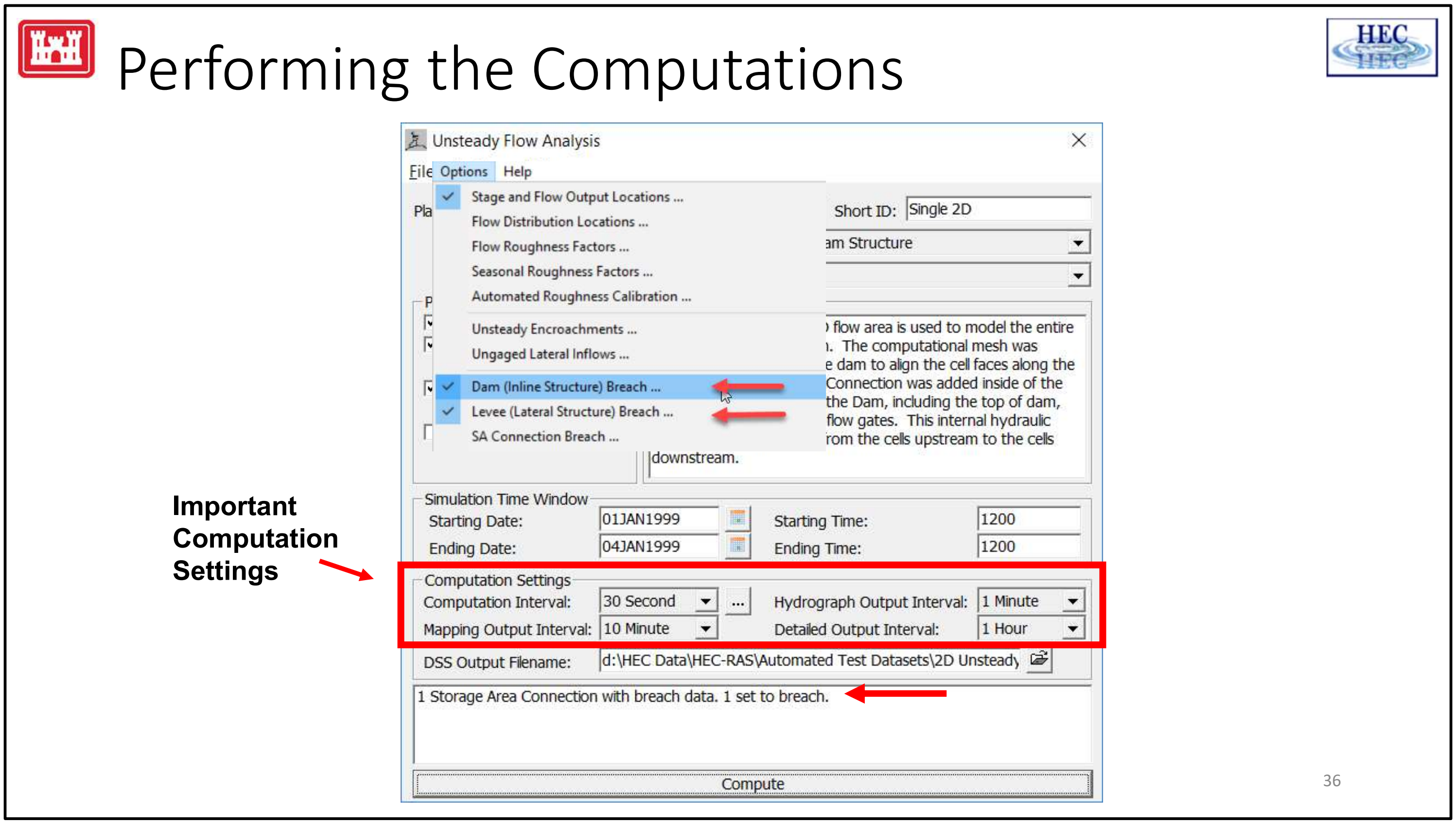
We also added a geospatial option for setting the initial conditions water surface for 2D Models. You can specify Initial Conditions Points and RAS will compute a water surface. This option essentially lets you set a known water surface along the river.

This is done by establishing IC Points in RAS Mapper. You then set the Initial Elevation through the unsteady-flow data editor.



When performing a Dam Breach simulation the user must pay close attention to the Computational Setting that they apply.

Computational Interval: This is probably the most important parameter that will be entered by the user. The computational Interval will generally need to be very small when performing a dam breach analysis, on the order of 1 second to 1 minute. Consideration needs to be given to cross section spacing and 2D Cell size, as well as flood wave velocity, when choosing this parameter.

Hydrograph Output Interval: This interval controls the time interval at which the flow and stage hydrographs will be written out at. This should generally be small in order to capture the peak outflow coming out of the dam, as well as at various locations downstream. Generally, around 5 to 15 minutes.

Detailed Output Interval: This is the interval at which detailed post processing of model output will be computed at, it will also control what snapshots in time can be sent to the GIS for inundation mapping. This is also the interval at which cross section and profile graphics can be viewed with animation of the results.

Mapping Output Interval: This is the interval that will be used by RAS Mapper for performing Dynamic Mapping of the flood inundation area.

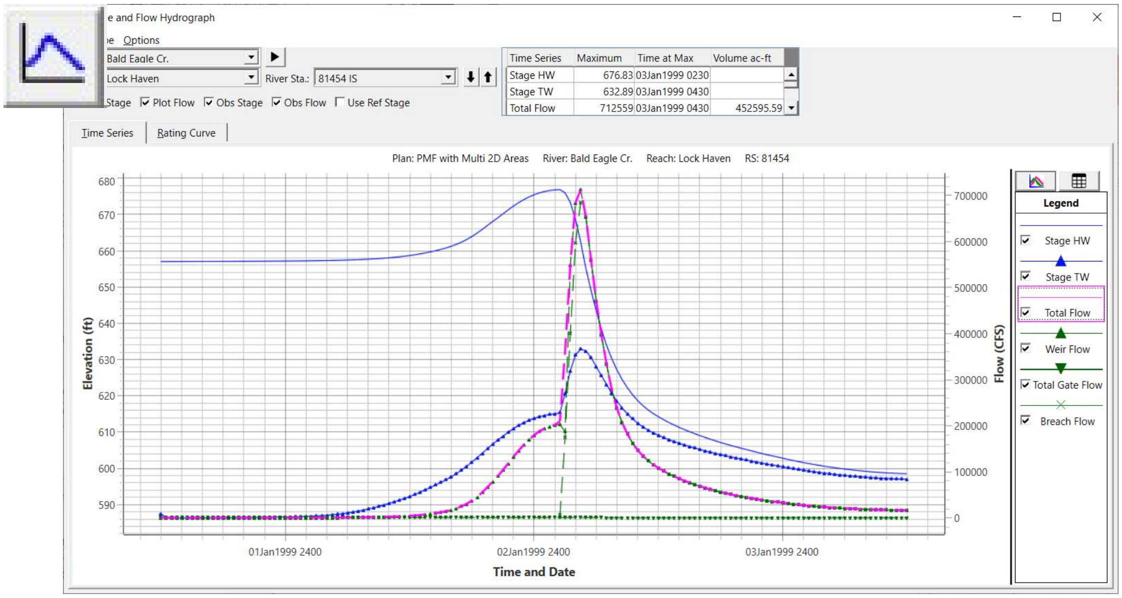
Computation Level Output: This option instructs the model to write out stage and flow at all locations for every computational time interval to a binary file. This should only be used as a tool for debugging model stability problems. **Turning this option on could generate a huge output file depending on the size of your model and the duration of the simulation.**

Mixed Flow Regime Analysis: This option allows the model to run in a mixed flow regime mode. This option should only be used in steep stream areas and/or areas where you have supercritical flow in the middle of the simulation.

Breach Results and Visualization

- Hydrographs at Inline Structures, SA/2D Hydraulic Connections, and Storage Areas
- Profile Plots for 1D Reaches
- Flow Hydrographs at 2D Area Boundaries
- Inundation Maps/Animations in RAS Mapper
- Stage Hydrograph Plots in RAS Mapper
- Velocity Time Series in RAS Mapper

Hydrograph Plots



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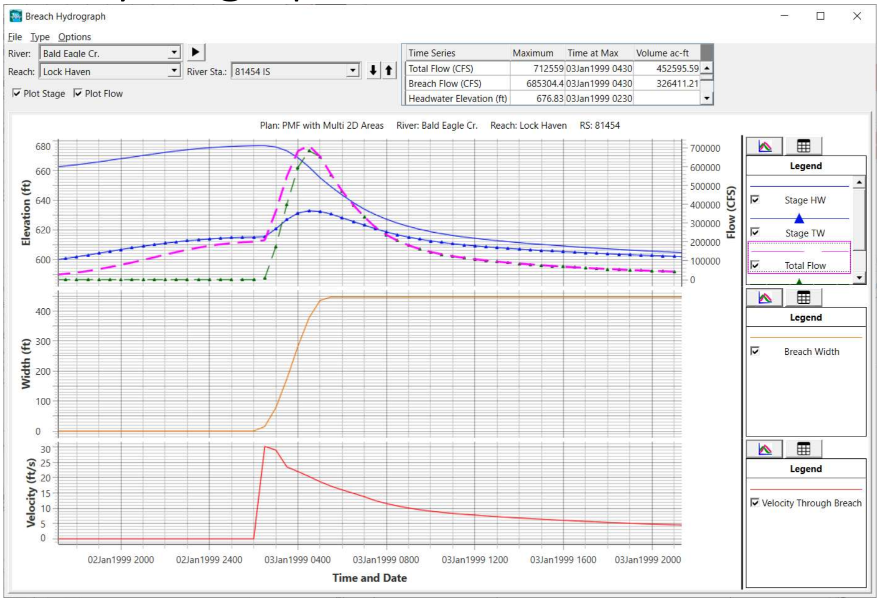
Breach Hydrograph Plot



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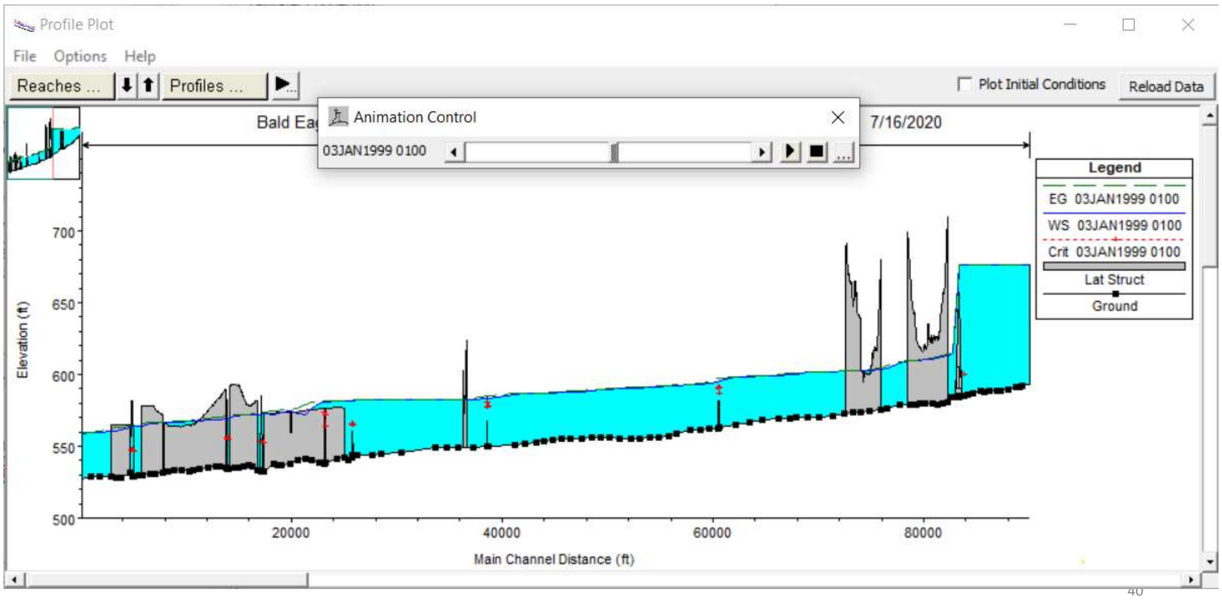
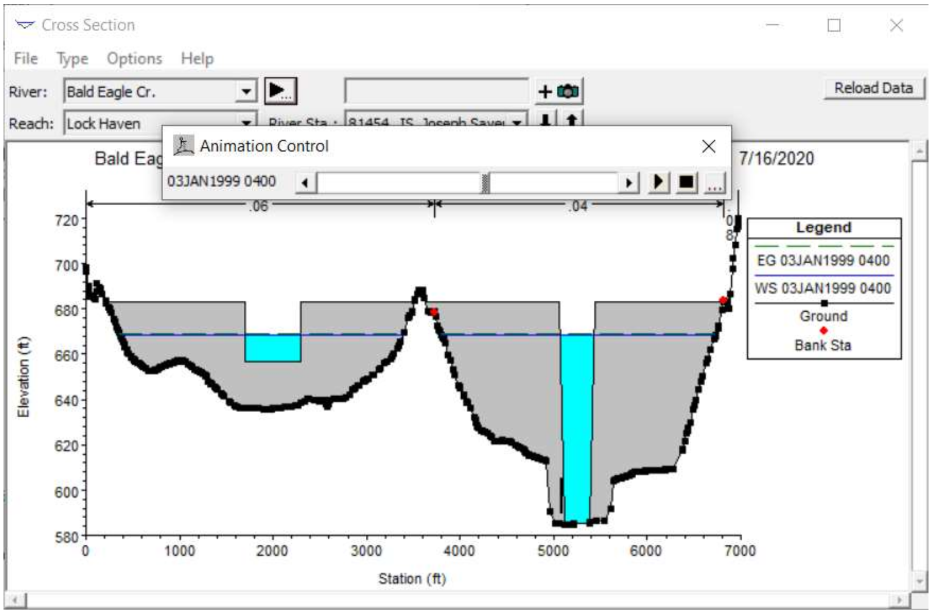
Profile Plot



XS Plot


Cross Section
File Type Options Help
River: Bald Eagle Cr.
Reach: Lock Haven
Reload Data
Animation Control
03JAN1999 0400
7/16/2020
Legend
EG 03JAN1999 0400
WS 03JAN1999 0400
Ground
Bank Sta
Elevation (ft)
Station (ft)

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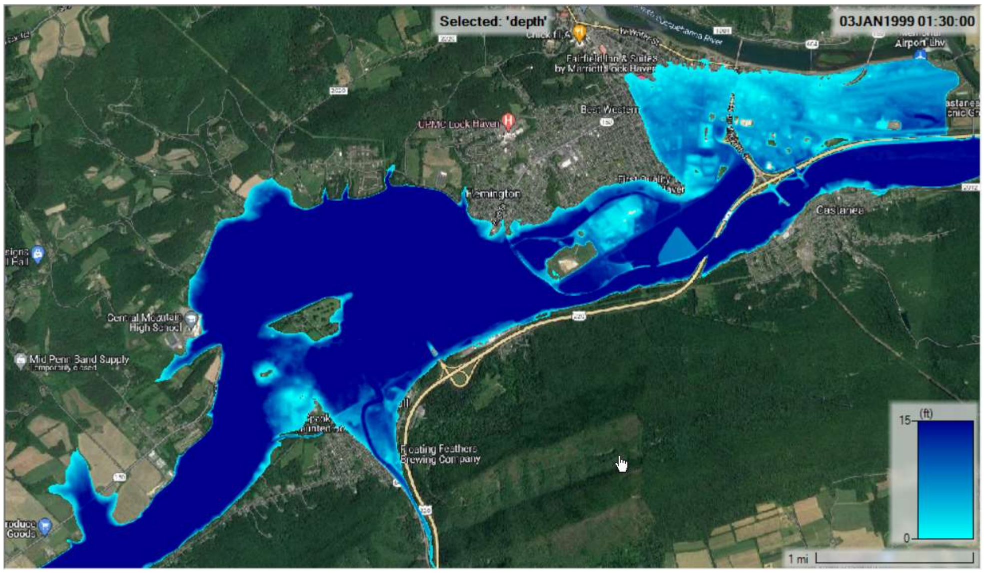
Inundation Maps



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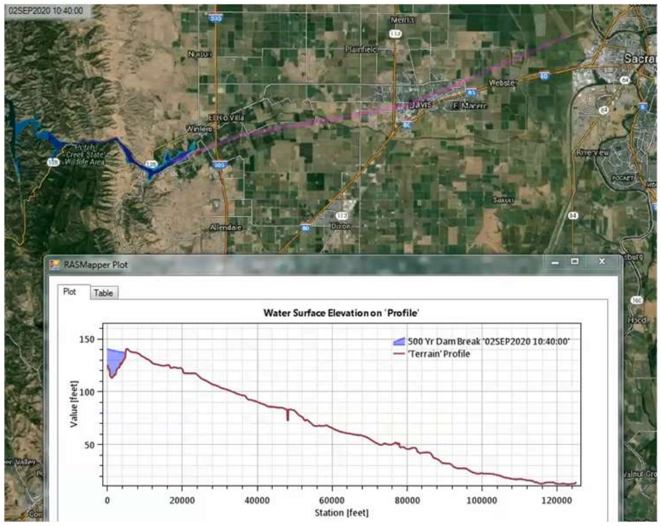
Profile Lines + Spatial Results



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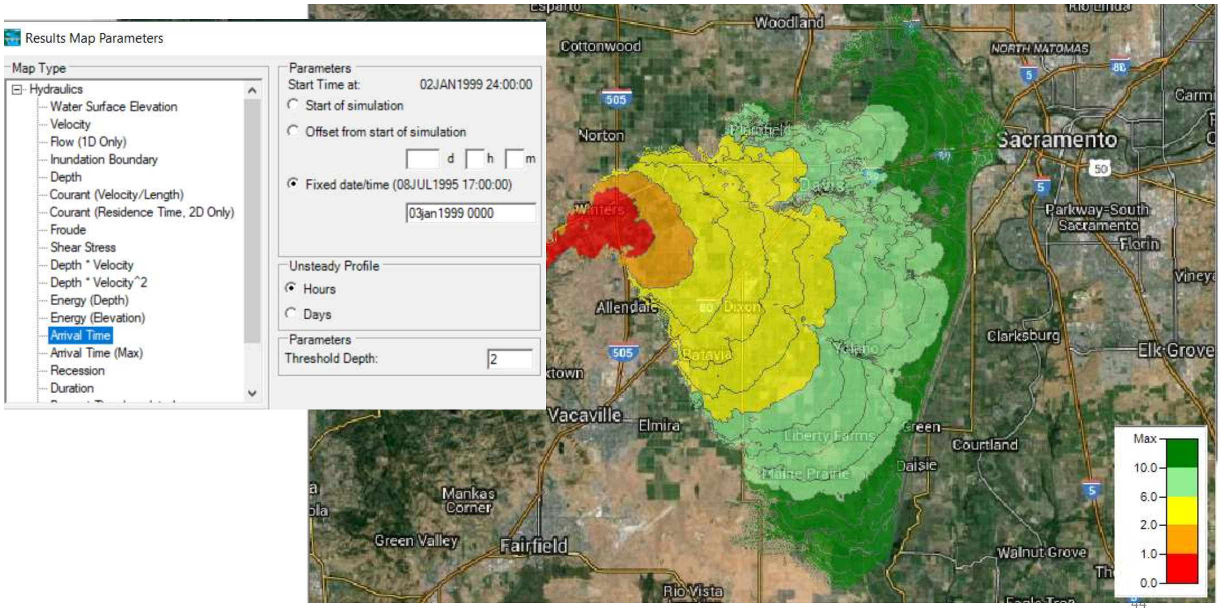
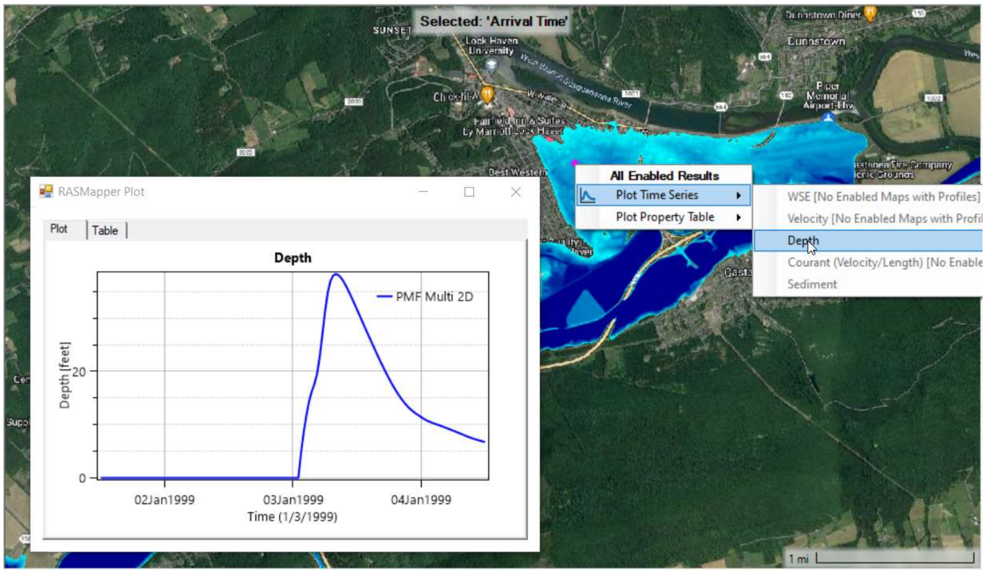
Arrival Time



Stage and Depth Hydrograph Plots



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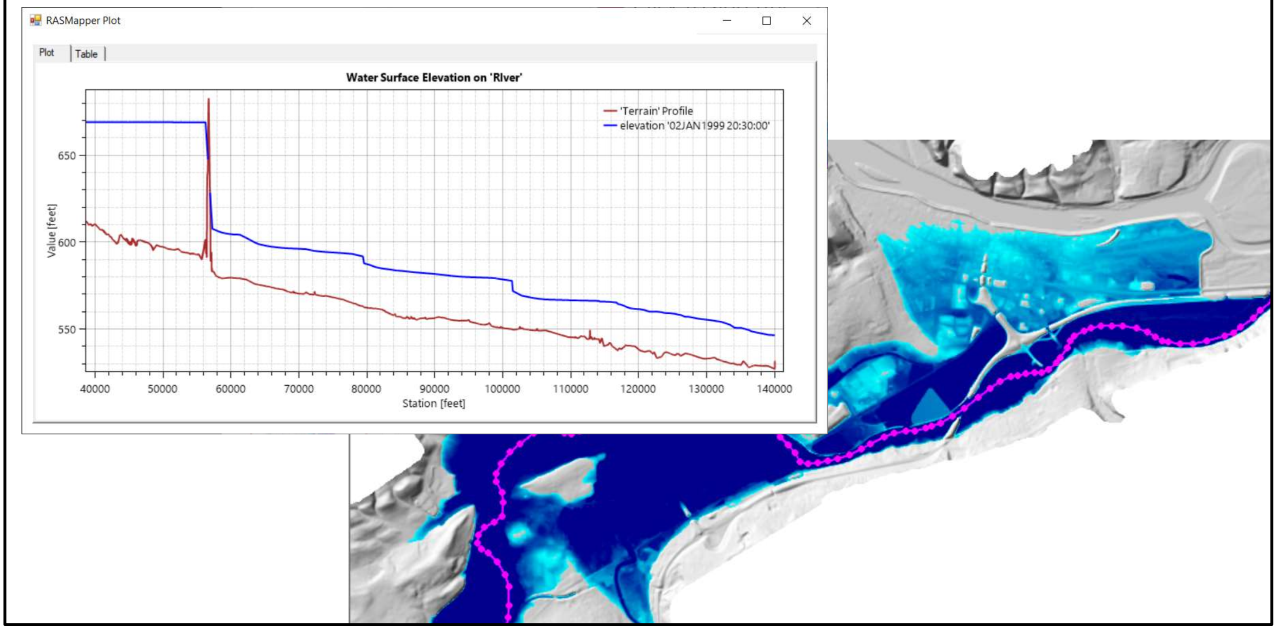
Profile Plots



Questions?

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Determination of Breach Parameters

US Army Corps of Engineers

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Three Breach Approaches

- User Entered Data
  - -Parameter Estimation
- Simplified Physical
- DL Breach

User Entered Data

Simplified Physical

Physical Breaching (DLBreach)

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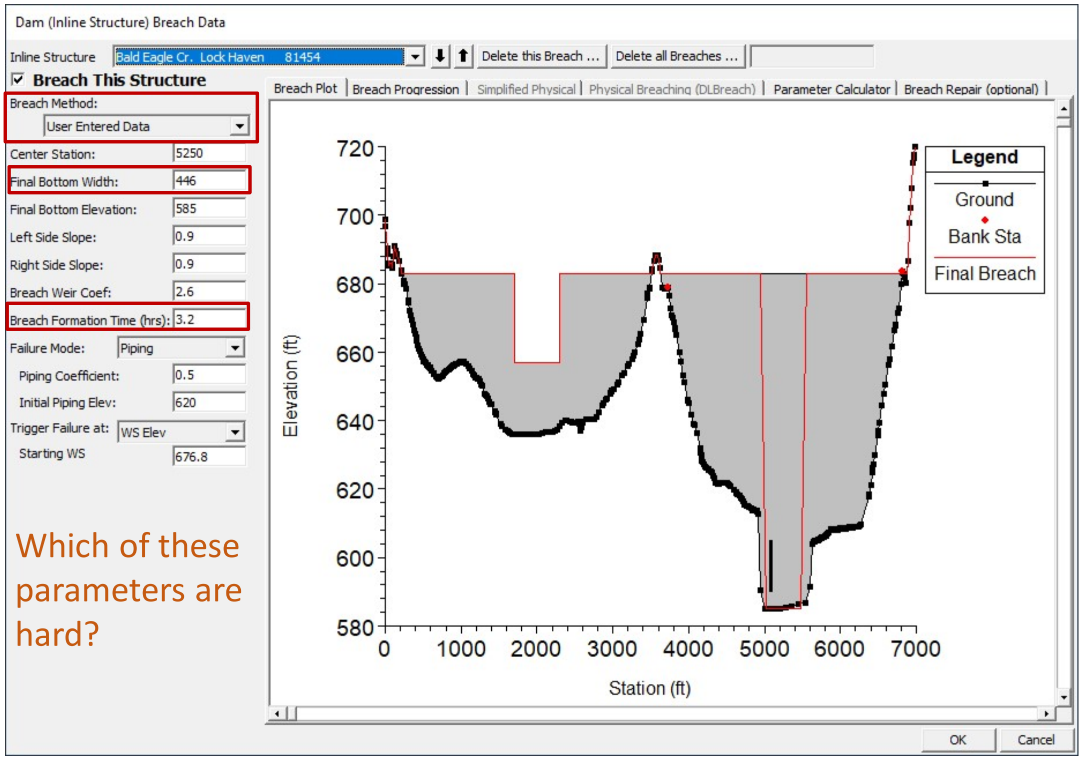
Dam breach models are theory-limited and data-limited. Often we don’t have a strong understanding of the processes at play and lack the necessary data for validation. Dam breach modeling therefore requires a consideration of uncertainty and trying out multiple approaches.

HEC-RAS Breach Data

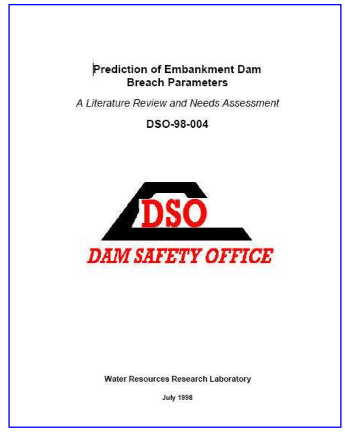


Which of these parameters are hard?

Estimating the Breach Parameters

- Literature And Guidance
  - Existing COE guidance
  - Prediction of embankment dam breach parameters: USBR (1998) Dam Safety Research Report

- Empirical Methods -
  - MacDonald and Langridge-Monopolis (1984)
  - Froehlich (1995b)
  - Von Thun and Gillette (1990)
  - Xu and Zhang (2009)


Prediction of Embankment Dam Breach Parameters

A Literature Review and Needs Assessment

DSO-98-004

DSO

DAM SAFETY OFFICE

Water Resources Research Laboratory

July 1998

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Determining the size and growth rate for breaches is a very inexact endeavor. The Bureau of Reclamation's "Dam Safety Research Report," (1998) offers an excellent literature review of the subject.

MacDonald and Langridge-Monopolis developed best-fit and envelope curves for breach parameters and peak outflow from breached earthfill dams as a function of a breach formation factor.

Froehlich developed a best-fit regression equation for peak flow based on a breach formation factor.

NWS-BREACH is a physically based model that uses sediment transport equations to simulate the evolution of a breach in an earthfill dam.

The use of several different procedures, to get a range of values, is generally recommended.

Reference: Wahl, Tony L., "Prediction of Embankment Dam Breach Parameters – A Literature Review and Needs Assessment," DSO-98-004, Dam Safety Research Report, U.S. Department of the Interior, Bureau of Reclamation, Dam Safety Office, July 1998.

Suggested Breach Parameters

Dam Type	Average Breach Width (B_{ave})	Horizontal Component of Breach Side Slope (H) (H:V)	Failure Time, t_f (hours)	Agency
Earthen/Rockfill	(0.5 to 3.0) x HD	0 to 1.0	0.5 to 4.0	USACE 1980
	(1.0 to 5.0) x HD	0 to 1.0	0.1 to 1.0	FERC
	(2.0 to 5.0) x HD	0 to 1.0 (slightly larger)	0.1 to 1.0	NWS
	(0.5 to 5.0) x HD*	0 to 1.0	0.1 to 4.0*	USACE 2007
Concrete Gravity	Multiple Monoliths	Vertical	0.1 to 0.5	USACE 1980
	Usually ≤ 0.5 L	Vertical	0.1 to 0.3	FERC
	Usually ≤ 0.5 L	Vertical	0.1 to 0.2	NWS
	Multiple Monoliths	Vertical	0.1 to 0.5	USACE 2007
Concrete Arch	Entire Dam	Valley wall slope	≤ 0.1	USACE 1980
	Entire Dam	0 to valley walls	≤ 0.1	FERC
	(0.8 x L) to L	0 to valley walls	≤ 0.1	NWS
	(0.8 x L) to L	0 to valley walls	≤ 0.1	USACE 2007
Slag/Refuse	(0.8 x L) to L	1.0 to 2.0	0.1 to 0.3	FERC
	(0.8 x L) to L		≤ 0.1	NWS

***Note:** Dams that have very large volumes of water, and have long dam crest lengths, will continue to erode for long durations (i.e., as long as a significant amount of water is flowing through the breach), and may therefore have longer breach widths and times than what is shown in Table 3. HD = height of the dam; L = length of the dam crest; FERC - Federal Energy Regulatory Commission; NWS - National Weather Service

Where: HD = Height of the dam.

L = Length of the dam crest.

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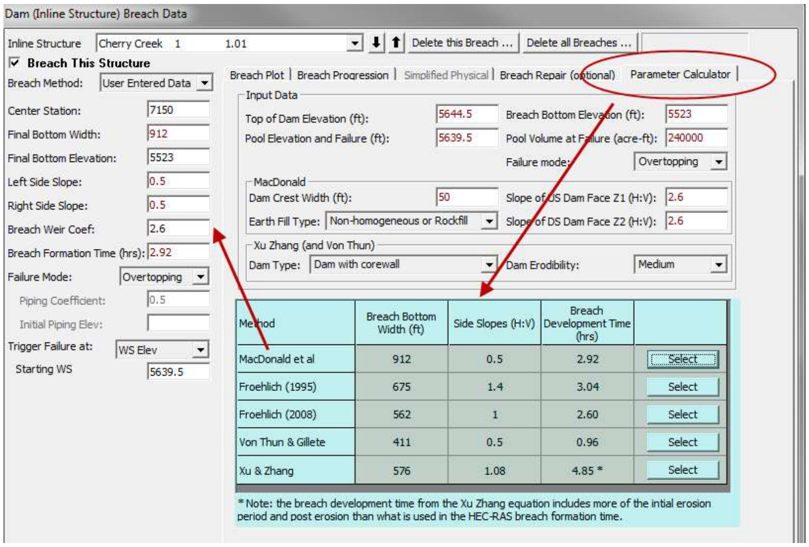
Original COE reference is HEC (1980). This information was expanded in Chapter 16 of EM 1110-2-1420, "Hydrologic Engineering Requirements for Reservoirs," 1997. Behavior of roller compacted concrete (RCC) dams has only recently been studied. WEST Consultants has recently (2006) done some investigation and reported a consensus that RCC dams should behave similar to normal concrete gravity dams except there are no predefined vertical joints where a breach would preferentially develop. Analysis of sensitivity of the results of the various models to these parameters is important.

RMC Publication/HEC TD

Breach Parameter Calculator



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Important Ideas

- Do not mix and match breach width and time.
- Xu and Zang do not have the same breach development time

Method	Breach Bottom Width (ft)	Side Slopes (H:V)	Breach Development Time (hrs)	
MacDonald et al	122	0.5	2.57	Select
Froehlich (1995)	628	1.4	3.44	Select
Froehlich (2008)	544	1	3.04	Select
Von Thun & Gillete	363	0.5	0.81	Select
Xu & Zhang	499	1.06	5.05 *	Select

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Consider …

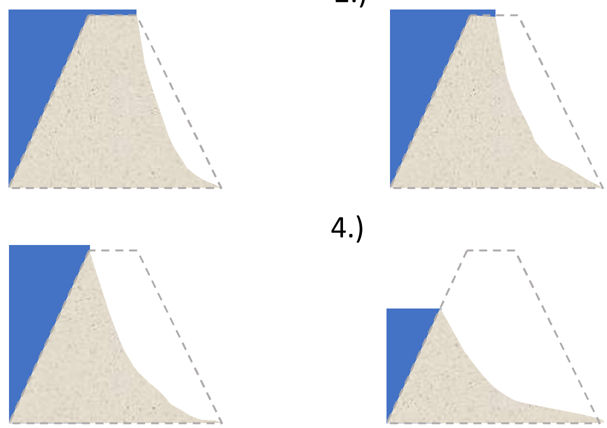
- When does the breach time START in HEC-RAS?

1.)

2.)

3.)

4.)



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Important Ideas

- Do not mix and match breach width and time.
- Xu and Zang do not have the same breach development time
- When does the breach formation time start in HEC-RAS?
- Does the breach progression makes sense?
  - Does it keep eroding at low head?
  - Does it stop eroding with despite high head and velocity?

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Evaluate Breach Progress

- Breach parameter estimation is uncertain.

Method	Breach Bottom Width (ft)	Side Slopes (H:V)	Breach Development Time (hrs)	
MacDonald et al	122	0.5	2.57	Select
Froehlich (1995)	628	1.4	3.44	Select
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Xu & Zhang	499	1.06	5.05 *	Select

- We can use HEC-RAS hydraulic results to inform our decision on breach parameter selection.

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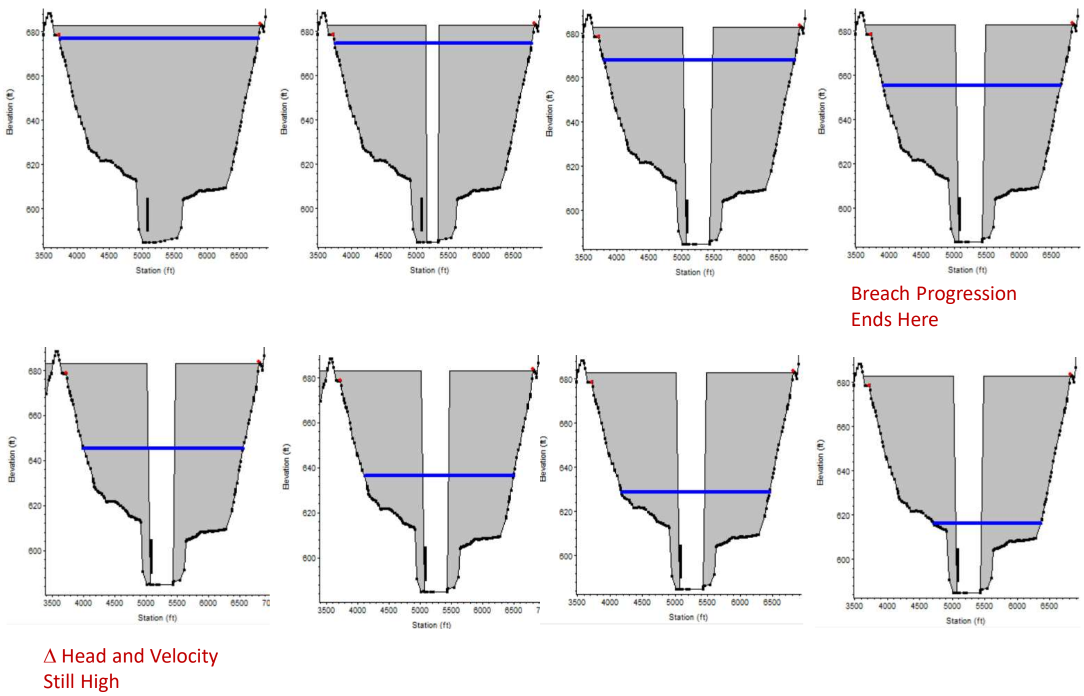
Do you have any concerns about this simulation?



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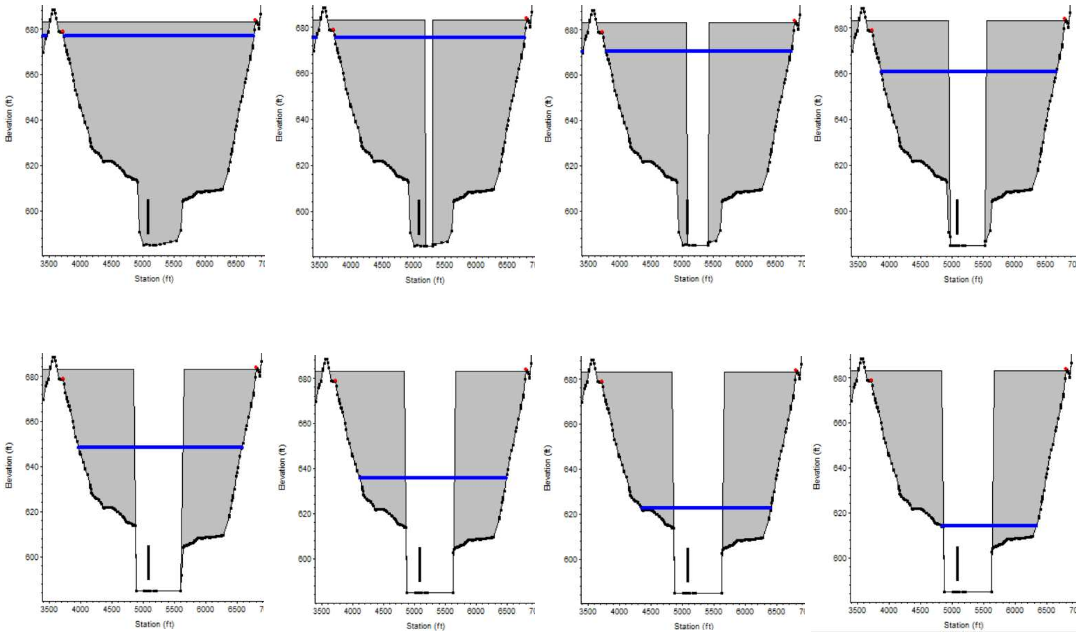
“VTG Breach Parameters”
1 hr breach development time
Top row 30min intervals
2nd row, 1hr intervals

This Simulation Continues to Widen for High ΔHead and Velocities



Widening rate in this method is not connected to hydraulics.
The user must check to make sure results make physical sense.

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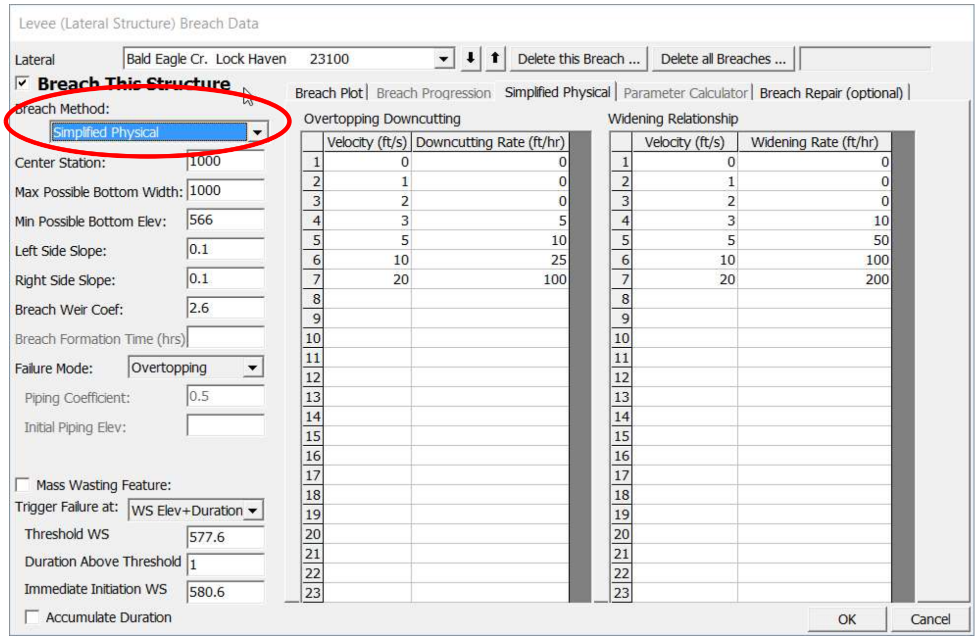
"MacDonald et al Breach Parameters"
3 hr breach development time
Top row 30min intervals
2nd row, 1hr intervals

Simplified Physical Breaching



	Velocity (ft/s)	Downcutting Rate (ft/hr)
1	0	0
2	1	0
3	2	0
4	3	5
5	5	10
6	10	25
7	20	100

	Velocity (ft/s)	Widening Rate (ft/hr)
1	0	0
2	1	0
3	2	0
4	3	10
5	5	50
6	10	100
7	20	200

60

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:

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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**	~Ogee
0.7	3.74	
0.65	3.48	
0.6	**3.21**	~Sharp Crested
0.55	2.94	
0.5	**2.67**	~Broad Crested
0.45	2.41	
0.4	2.14	Study max (Reservoir type)
0.35	***1.87***	**C_{ave},** Deep water, v close to 0
0.3	1.60	Study max (River type)
0.25	***1.34***	**C_{ave},** river conditions
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

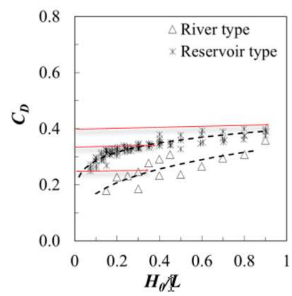

Figure 7. Discharge coefficient with non-dimensional variable H_0/L.

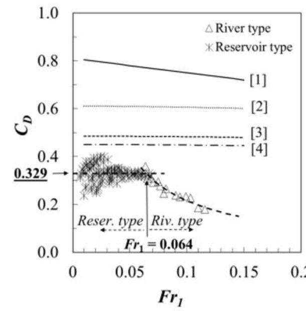

Figure 8. Discharge coefficient with approach Froude number (Fr_1).

Ho = Height above opening, L = opening bottom width

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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 <>Cd. [C = 2/3*Cd*(2g)^1/2].