HEC-RAS 2D Workshop

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The City College of New York

CUNY

Surface Dynamics Modeling Lab

The University of Alabama 1831

US Army Corps of Engineers®

NWC National Water Center

Introduction

The hydraulic modeling is the application of fluid dynamic to simulate the movement of water. Hydraulic models are applied to determine the extent of a floodplain and probability of a flood occurrence.

By 2D hydraulic model, we can determine what would happen if, for instance, the dam failed and given that information how far the extent of the flood inundation goes, how fast the floodwave propagates, thus we can prepare evacuation maps, emergency action plans, etc. On the other hand, the 1D models, cannot determine the direction of flow, where the floodwave goes, and this is based upon the engineers judgment to address these unknowns. The 1D models can be useful in domains having confined corridors, steep valleys, etc., while 2D models are considered to be more practical in flat terrain, highly urbanized area where floodwave flowing around the buildings and through roads in various directions.

2D hydraulic models have been around for over 15-20 years, however, the real problems that consulting firms and municipalities have not been using the 2D modeling software were due to difficulties of setting up the 2D models and lack of required information, e.g. terrain models, landcover variation, etc., while setting up the model.

Introduction

HEC-RAS 2D software developed by Hydrologic Engineering Center of U.S. Army Corps of Engineer is an free advanced two-dimensional flow simulator and hydraulic analyst where allows user to perform 2D and combined 1D/2D unsteady flow routing.

The 2D flow simulation by HEC-RAS 2D can be performed in number of ways. The following are examples:

- Detailed 2D channel modeling
- Detailed 2D channel and floodplain modeling
- Combined 1D channels with 2D floodplain areas
- Combined 1D channels/floodplains with 2D flow areas behind levees
- Directly connect 1D reaches into and out of 2D flow areas
- Directly connect a 2D flow area to 1D Storage Area with a hydraulic structure
- Multiple 2D flow areas in the same geometry
- Directly connect multiple 2D flow areas with hydraulic structures
- Simplified to very detailed Dam Breach analyses
- Simplified to very detailed Levee Breach analyses
- Mixed flow regime. The 2D capability (as well as the 1D) can handle supercritical and subcritical flow, as well as the flow transitions from subcritical to super critical and super critical to subcritical (hydraulic jumps).

Objectives of This Workshop

1. Introduction to HEC-RAS 2D and two dimensional modeling advantages relative to 1D models

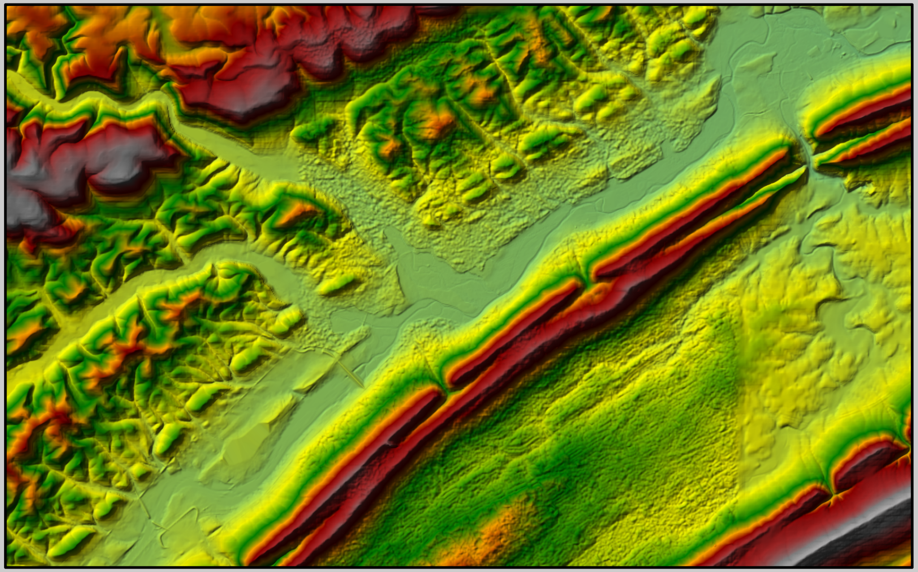
2. Required geophysical and flow information for setting up HEC-RAS 2D models

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

5. Overview of how to demonstrate the result of a combined 1D/2D unsteady flow model in HEC-RAS and RAS Mapper output capabilities

Study Domain



Location:
Bald Eagle Creek, Pennsylvania

Existing Structures:
Dam, Levee, man-made and/or geophysical Obstructions

Required Operating Systems:
Windows XP, Vista, 7, 8, 8.1, and 10 both 32-bit and 64-bit

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1. **Introduction to HEC-RAS 2D and two dimensional modeling advantages relative to 1D models**

- HEC has added the ability to perform two-dimensional (2D) hydrodynamic routing within **the unsteady flow analysis portion of HEC-RAS**.

- Users can now perform one-dimensional (1D) unsteady-flow modeling, two-dimensional (2D) unsteady-flow modeling (Saint Venant equations or Diffusion Wave equations), as well as combined 1D and 2D unsteady-flow routing.

- 2D flow modeling is accomplished by adding 2D flow area elements into the model in the same manner as adding a storage area.

- A 2D flow area is added by drawing a 2D flow area polygon; developing the 2D computational mesh; then linking the 2D flow areas to 1D model elements and/or directly connecting boundary conditions to the 2D areas.

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b) Saint-Venant or Diffusion Wave Equations in 2D.
c) Implicit Finite Volume Solution Algorithm.
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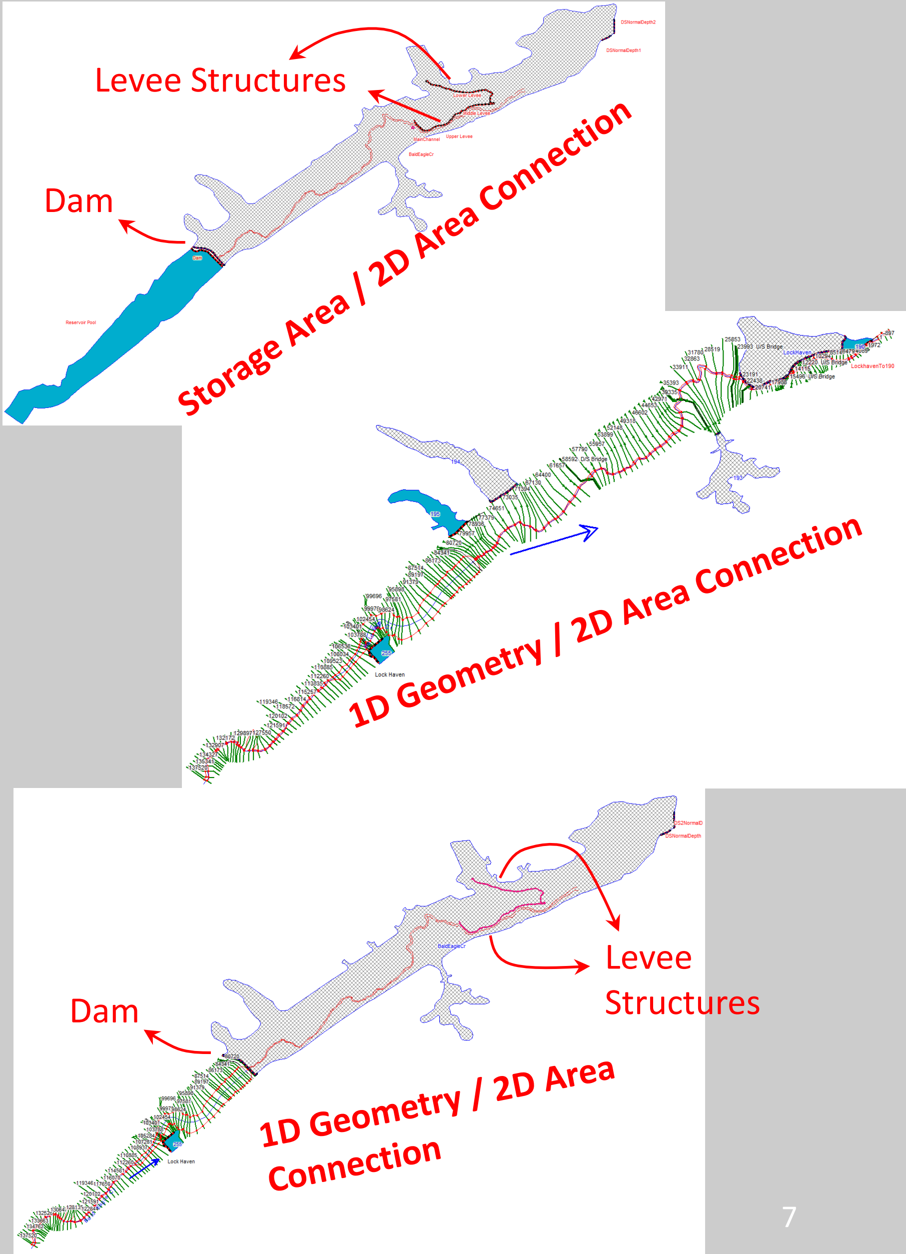
Different Association of 1D - 2D Geometries



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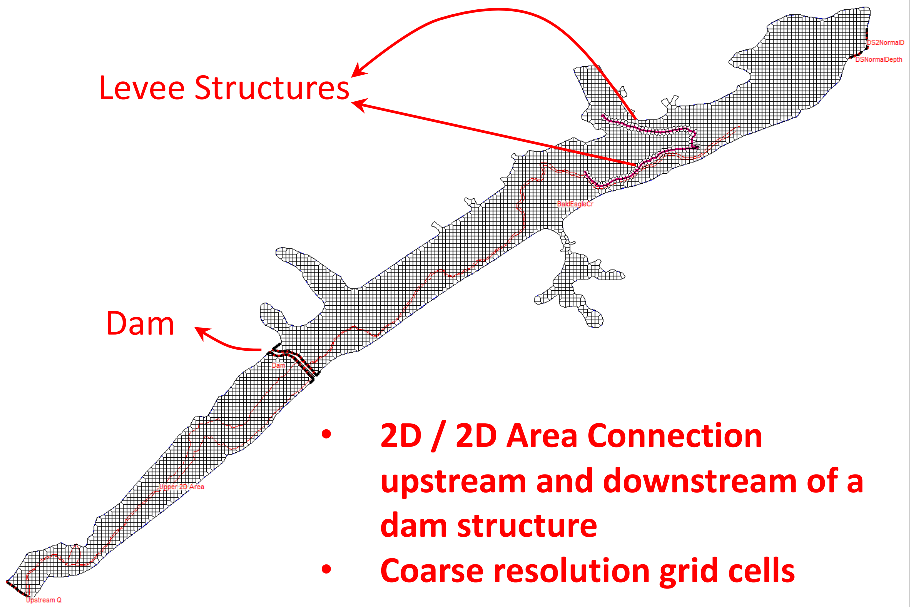

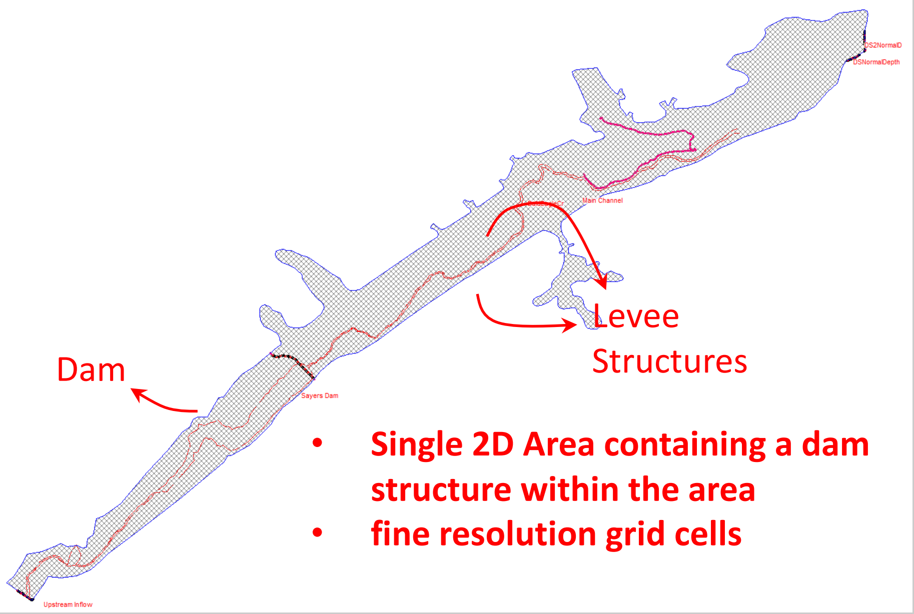

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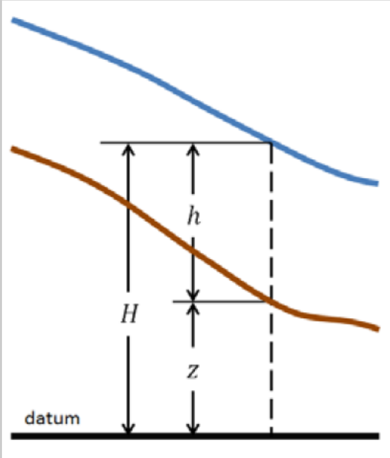

$$H(x,y,t) = z(x,y) + h(x,y,t)$$

z: bed elevation
h: water depth
H: water surface elevation
u , v : x , y velocities

g : gravi. accel. ; v_t *: horz. Eddy. Coeff.*
c_f *: bed friction coeff. ; f : Coriolis par.*

Full Saint-Venant (Dynamic Wave) equation:

$$\frac{\partial H}{\partial t} + \frac{\partial hu}{\partial x} + \frac{\partial hv}{\partial y} + q = 0 \quad \textit{continuity equ.}$$

Momentum equs.

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial H}{\partial x} + v_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - c_f u + f v$$

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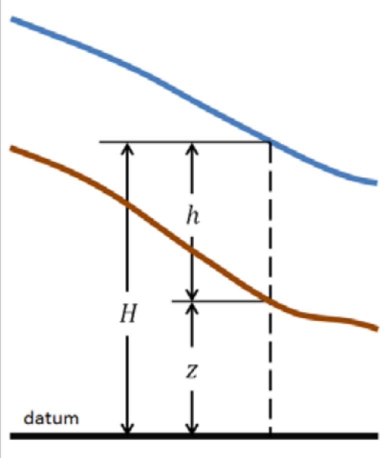
Unsteady, advection, turbulence, and Coriolis Terms can be disregarded to arrived at simplified form



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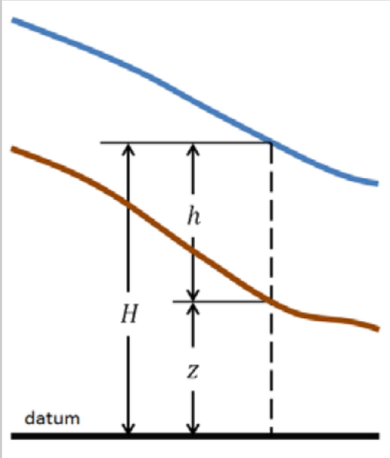

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Diffusion Wave equation:

$$\frac{\partial H}{\partial t} + \frac{\partial hu}{\partial x} + \frac{\partial hv}{\partial y} + q = 0 \quad \textit{continuity equ.}$$

Momentum equs.

$$g\frac{\partial H}{\partial x} + g(S_x - S_f) = 0$$

$$g\frac{\partial H}{\partial y} + g(S_y - S_f) = 0$$

$$S_x = \frac{dz}{dx} \; ; S_y = \frac{dz}{dy} \; ; S_f = \frac{\tau}{\rho g R}$$

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- The implicit solution algorithm allows for larger computational time steps than explicit methods.
- The Finite Volume Method provides an increment of improved stability and robustness over traditional finite difference and finite element techniques.
- 2D flow areas can start completely dry, and handle a sudden rush of water into the area.
- Additionally, the algorithm can handle subcritical, supercritical, and mixed flow regimes.

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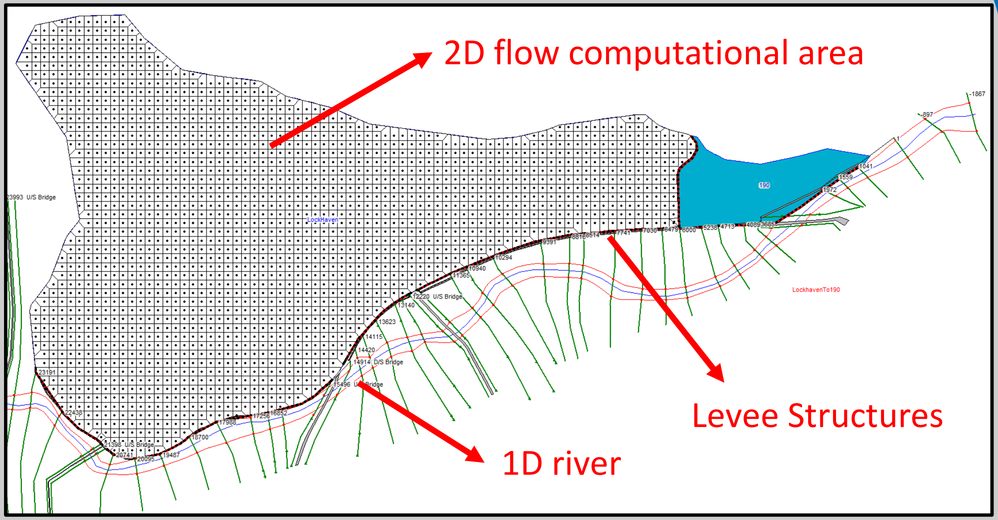

- The 1D and 2D solution algorithms are tightly coupled on a time step by time step basis with an option to iterate between 1D and 2D flow transfers within a time step.

- For Instance, consider a river that is modeled in 1D with the area behind a **levee** is modeled in 2D (connected hydraulically with a Lateral Structure). Flow over the **levee** (Lateral Structure) and/or through any **levee** breach is computed with a headwater from the 1D river and a tailwater from the 2D flow area to which it is connected. The weir equation is used to compute flow over the levee and through the breach.

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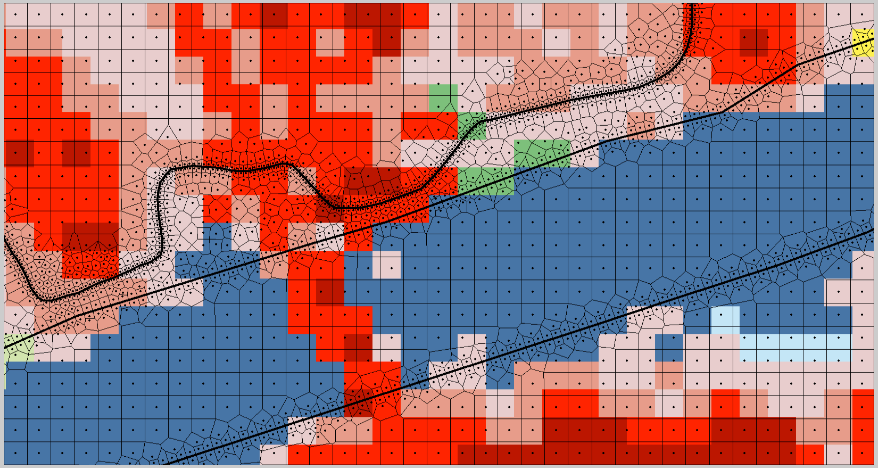
- The software was designed to use unstructured computational meshes, but can also handle structured meshes.
- This means that computational cells can be triangles, squares, rectangles, or even five and six- sided elements (the model is limited to elements with up to eight sides). The computational mesh does not need to be orthogonal but if the mesh is orthogonal the numerical discretization is simplified and more efficient.



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- Within HEC-RAS, computational cells do not have to have a flat bottom, and cell faces/edges do not have to be a straight line, with a single elevation.

- Instead, each Computational cell and cell face is based on the details of the underlying terrain.

- HEC-RAS has a 2D flow area pre-processor that processes the cells and cell faces into detailed hydraulic property tables based on the underlying terrain used in the modeling process.

- This type of model is often referred to in the literature as a "high resolution subgrid model" (Casulli, 2008).

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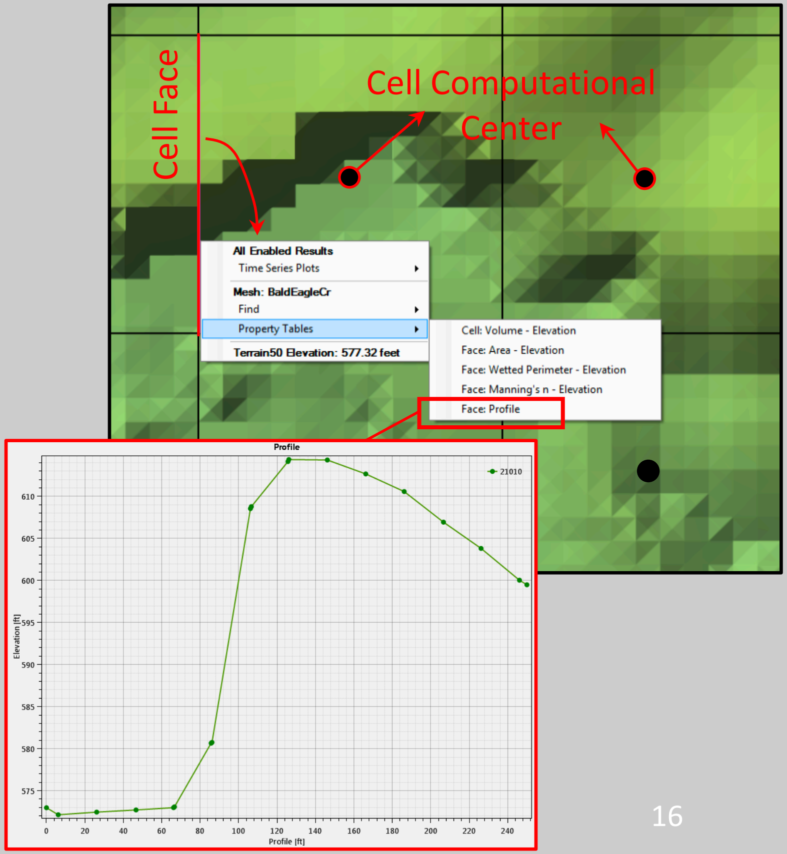
- For an example, consider a model built from a detailed terrain model (2ft grid-cell resolution) with a computation cell size of 200x200 ft. The 2D flow area pre-processor computes an elevation-volume relationship, based on the detailed terrain data (2ft grid), within each cell.



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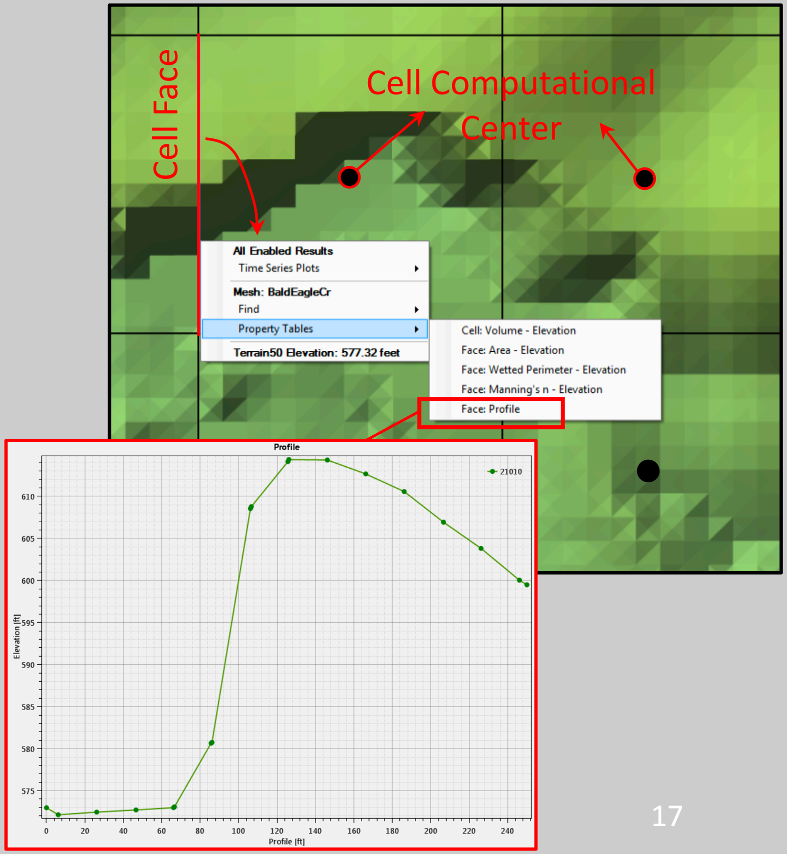
- The cell computational centers are the locations where the water surface elevation is computed for each cell.
- Each cell face is a detailed cross section based on the underlying terrain below the line that represents the cell face.



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- A cell can be partially wet with the correct water volume for the given water surface elevation (WSEL).
- Each computational cell face is evaluated similar to a cross section and is pre-processed into detailed hydraulic property tables (elevation versus - wetted perimeter, area, roughness, etc...).
- The flow moving across the face (between cells) is based on this detailed data.
- A small channel that cuts through a cell, and is much smaller than the cell size, is still represented by the cell's elevation volume relationship, and the hydraulic properties of the cell faces.
- Additionally, the placement of cell faces along the top of controlling terrain features (roads, high ground, walls, etc...) can further improve the hydraulic calculations using fewer cells overall. (application of ***breakline***)

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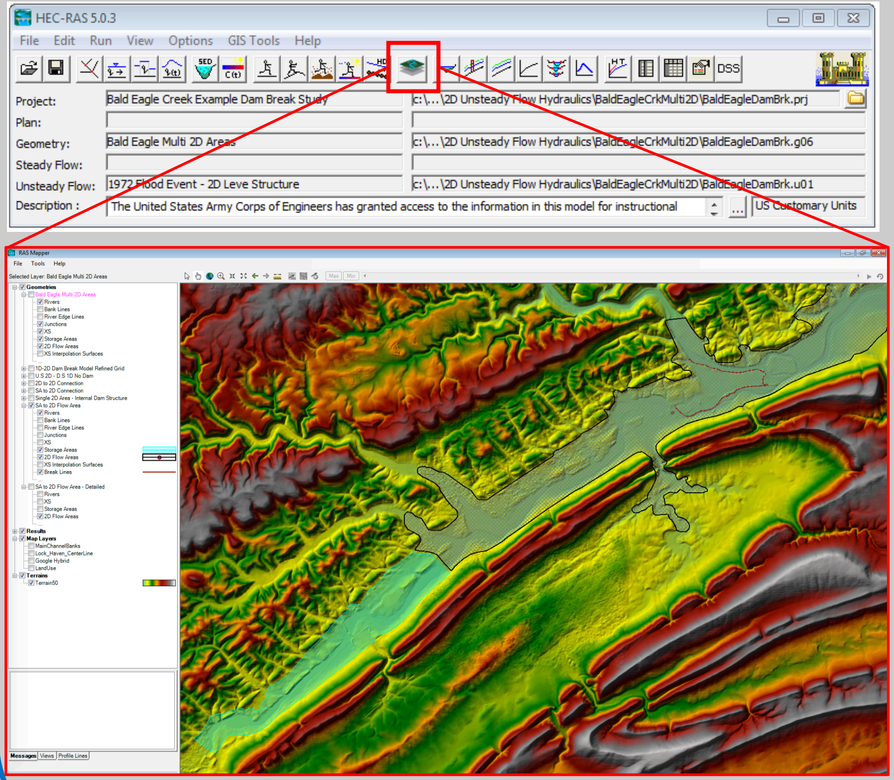
- Mapping of the inundated area, as well as animations of the flooding can be done inside of HEC-RAS using the RAS Mapper features.

- The mapping of the 2D flow areas is based on the detailed underlying terrain.



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- The 2D flow area computational solution has been programmed to take advantage of multiple processors on a computer (referred to as parallelization), allowing it to run much faster than on a single processor.

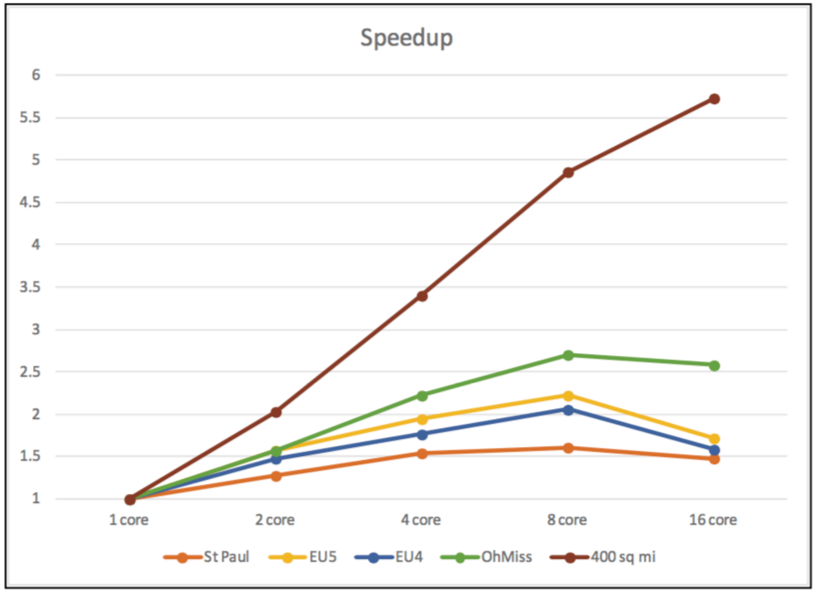

Figure 4-5. Number of processor cores vs. computational speed.

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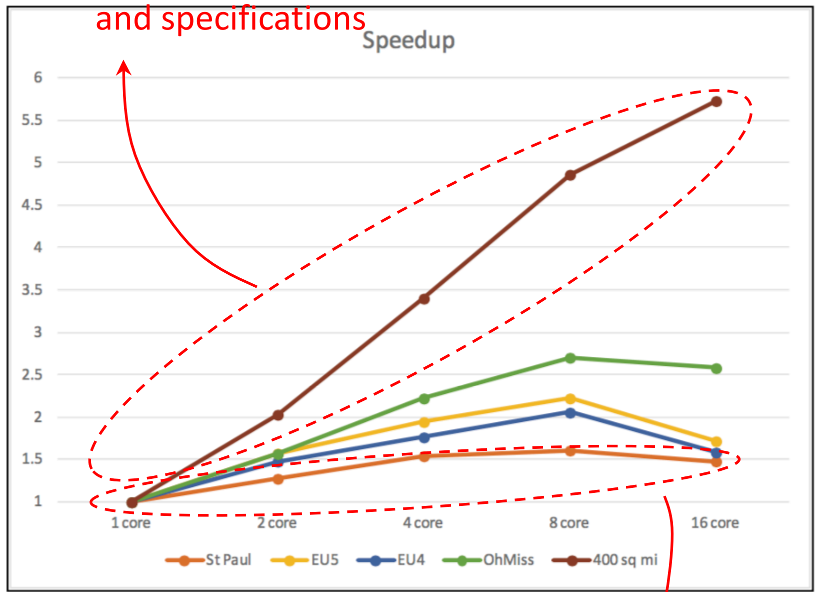
- 2D model made over larger area
- 2D model having the most geometrical details and specifications



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- HEC-RAS now comes with both 64 bit and 32-bit computational engines. The software will use the 64-bit computational engines automatically if installed on a 64-bit operating system.

- The 64-bit computational engines run faster than the 32-bit and can handle much larger data sets.

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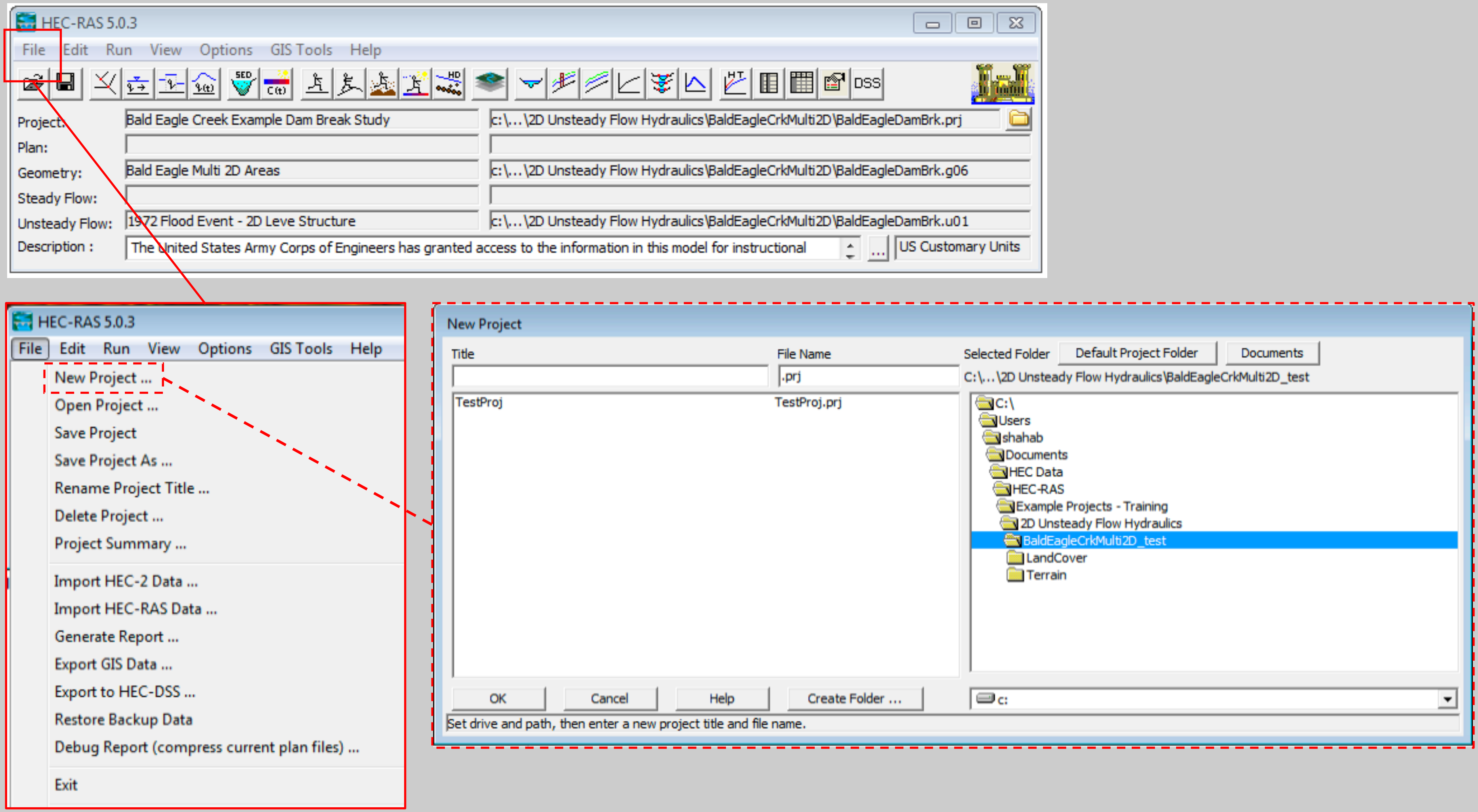
2. Required geophysical and flow information for setting up HEC-RAS 2D models

- Define a project:

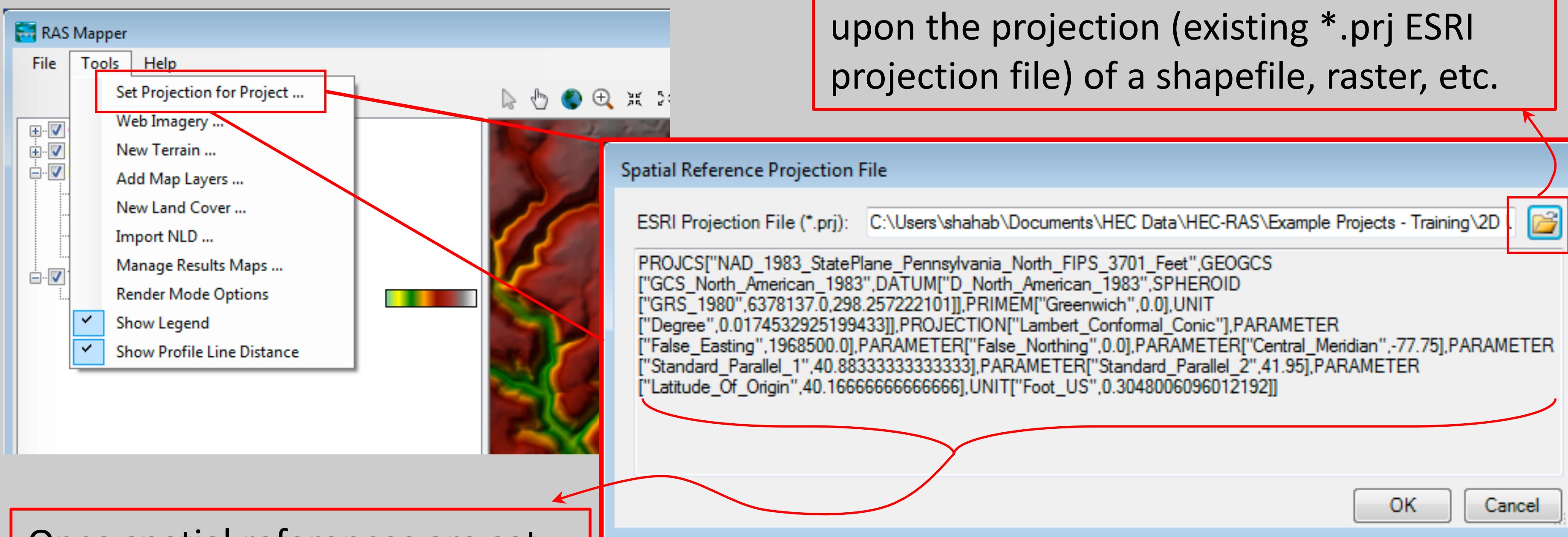


2. Required geophysical and flow information for setting up HEC-RAS 2D models

- Establish a Horizontal Coordinate Projection to use for your model, from within **HEC-RAS Mapper**:

If the data is in a specific spatial coordinate projection, that projection should be set in RAS Mapper.

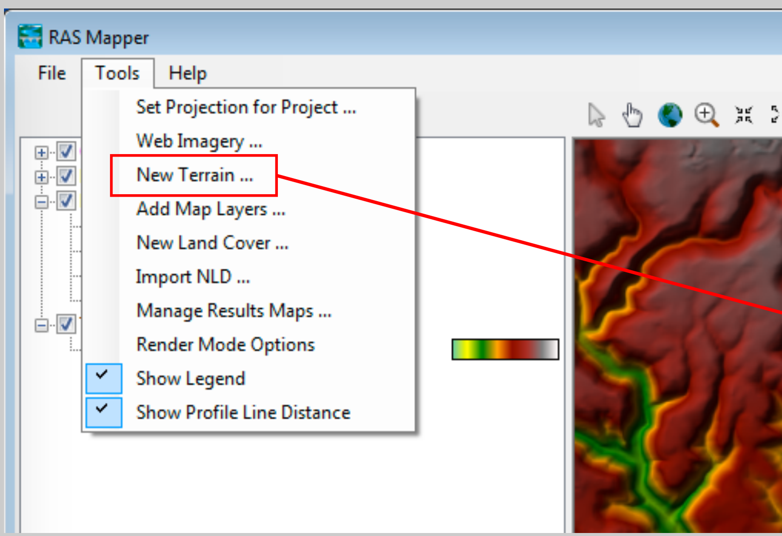
You can set the mapping projection based upon the projection (existing *.prj ESRI projection file) of a shapefile, raster, etc.



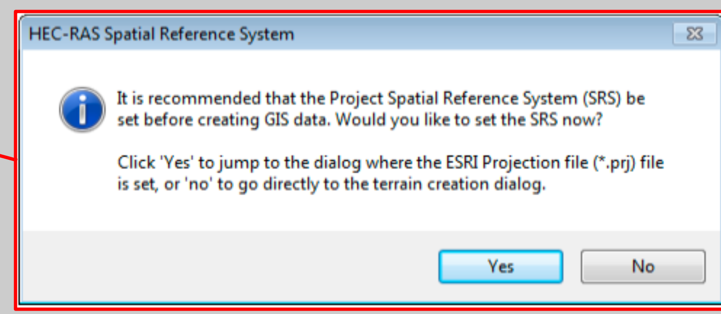
Once spatial references are set and assigned, a summary of the their geospatial information will be highlighted.

2. Required geophysical and flow information for setting up HEC-RAS 2D models

- Developing a Terrain Model for use in 2D Modeling and Results Mapping:
  - It is absolutely essential to have a detailed and accurate terrain model in order to create a detailed and accurate hydraulics model. The quality of the terrain data can be a limiting factor in the quality of the hydraulics model the user can create.
  - **<u>HEC-RAS uses gridded data for terrain modeling.</u>**
  - It is necessary to create a terrain model in HEC-RAS Mapper before the user can perform any model computations that contain 2D flow areas, or before the user can visualize any 1D, 2D, or combine 1D/2D mapping results.

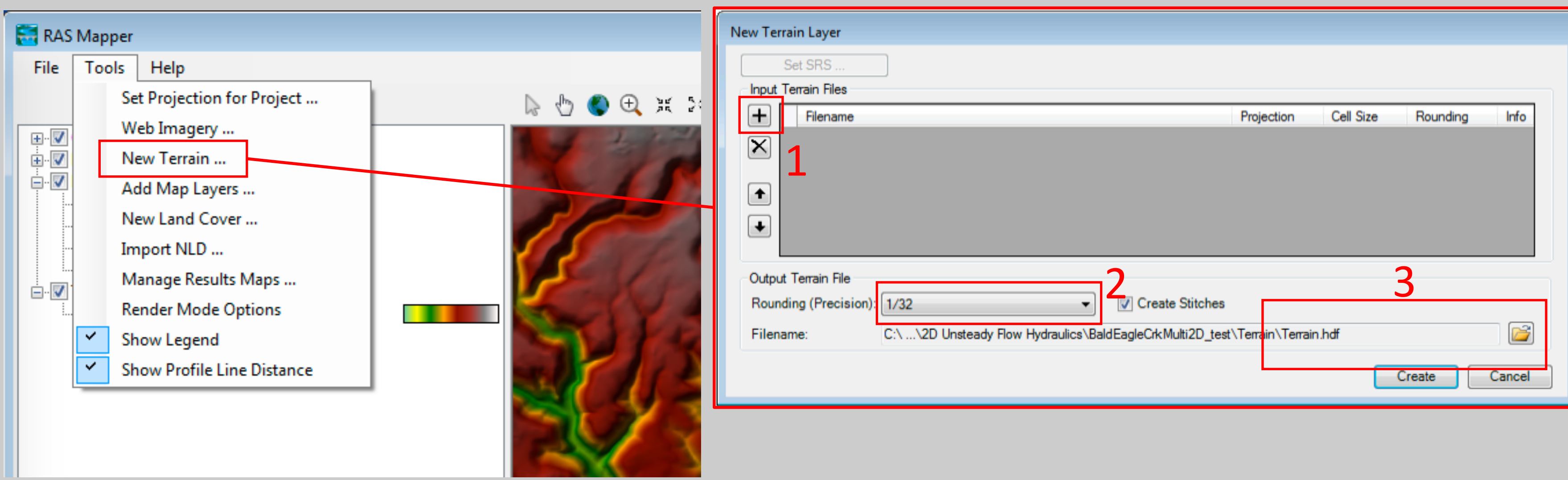


If you have not established a Horizontal Coordinate Projection yet, then this will pop-up



2. Required geophysical and flow information for setting up HEC-RAS 2D models

- Developing a Terrain Model for use in 2D Modeling and Results Mapping:
  1. RAS Mapper can import terrain data that is in the **floating point grid format (*.flt)**; **GeoTIFF (*.tif)** format; **ESRI grid (*.adf)** files;
  2. Define the elevation precision of the new terrain data layer (**Rounding [Precision]** field, 1/32 is the default for English units)
  3. This allows the user to provide a name for the new Terrain Layer (**Filename** field, the default name is "Terrain")



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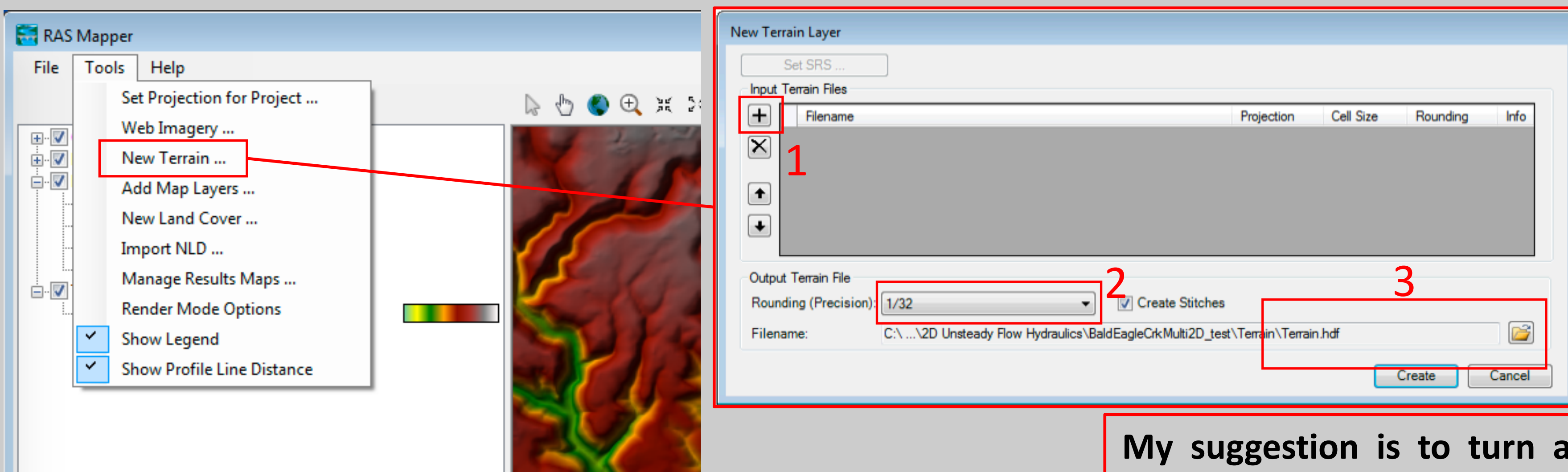
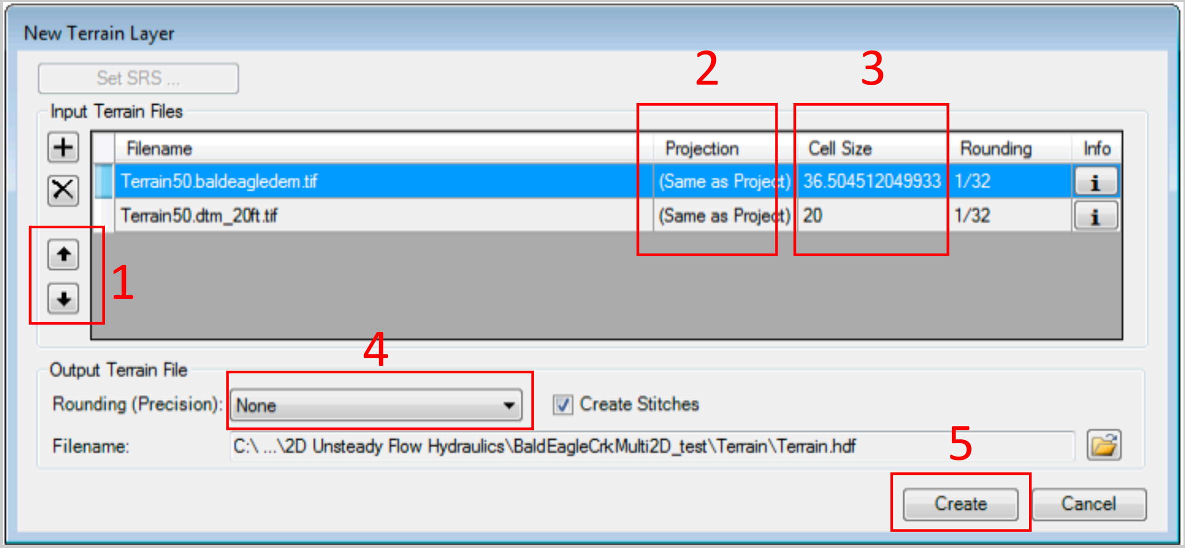


Floating point grids consist of a main file with the ***.flt** file extension, and they also have a ***.hdr** file, and possibly a ***.prj** file that goes along with it. Note: if the ***.flt** file is not in the same projection as what has been set in RAS Mapper, then the user must have a ***.prj** file that describes the projection of the ***.flt** file).

My suggestion is to turn all Raster terrain files into *.tif format first and then import them as new terrain in RAS Mapper.

2. Required geophysical and flow information for setting up HEC-RAS 2D models

- Developing a Terrain Model for use in 2D Modeling and Results Mapping:
  1. The final "Terrain.hdf" can be made up of multiple "*.tif" images having different spatial resolutions. Use the up and down arrow buttons to set the priority of the grid layers. If one grid has more detail (finer resolution) than others, the user will want to give it a higher priority for creating the combined Terrain Layer.
  2. Highlights the projection of the uploaded the terrain data. If they have the projection similar to the one assigned as general reference system then it would reported as (Same as Project) which is the case for current example.
  3. This allows the user learn about the cell size (spatial resolution) of the raster image. The unit is based upon what that is set at the beginning of model set-up. Here it is in English unit.



4. Set "Rounding (Precision)" as "None" in order to keep the terrain vertical resolution as it is.
5. Once the Create button is pressed, RAS Mapper will convert the grids into the GeoTIFF (*.tif) file format.

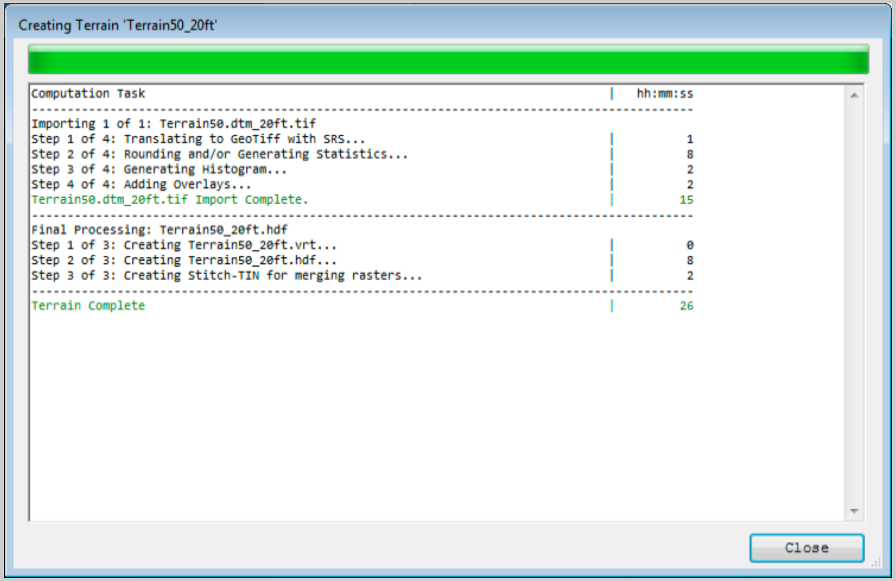
2. Required geophysical and flow information for setting up HEC-RAS 2D models

- Developing a Terrain Model for use in 2D Modeling and Results Mapping:

- Once the **GeoTIFF** files are created, RAS Mapper also creates a ***.hdf** file and a ***.vrt** file.

- The ***.hdf (Hierarchical Data Format)** file contains information on how the **multiple GeoTIFF** files are stitched together. The ***.vrt (Virtual Raster Translator)** file is an XML file that contains information about all of the raster files **(*.tif)**.

- The user can drag and drop the ***.vrt** file onto an **ArcGIS** project and it will then know about all of the raster files that make up the terrain layer. Additionally, they will have the same scale and color ramp when they are plotted.

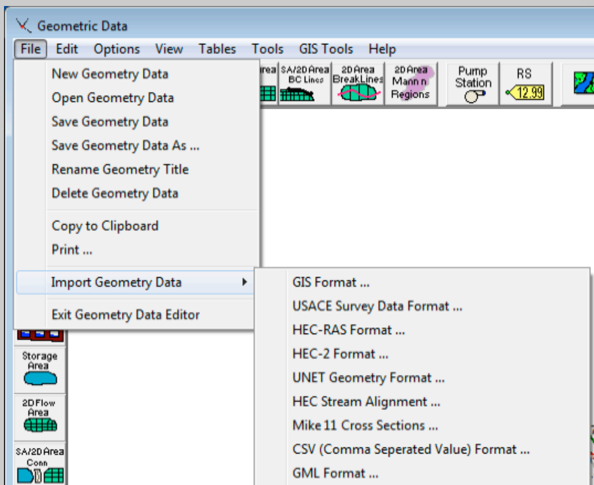


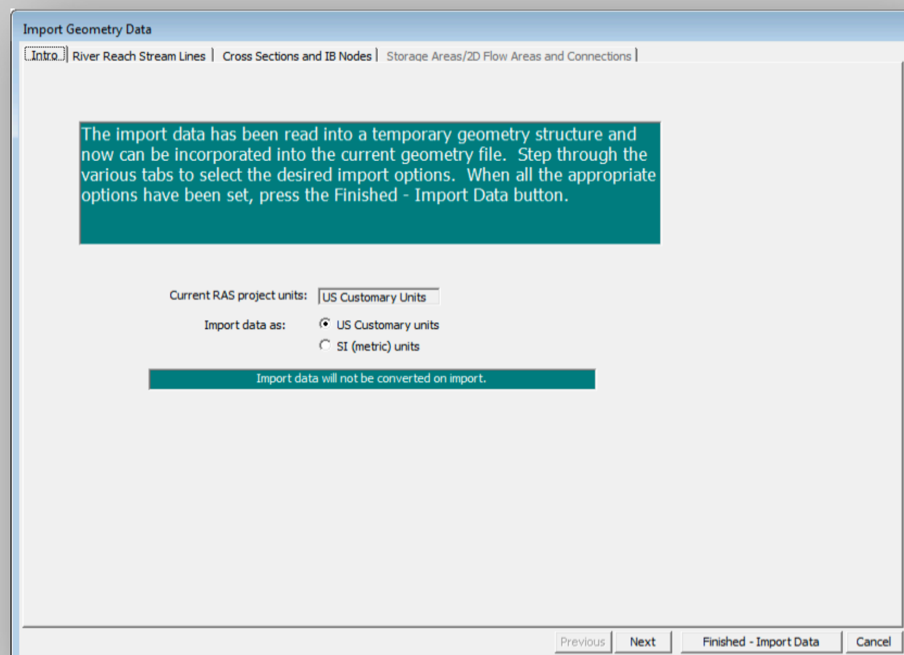
Note: After a Terrain data set is created, the user will be able to display this terrain layer as a background image in the HEC-RAS geometry editor. Terrain layers, and any other Map Layers developed in RAS Mapper are available for display in the HEC-RAS Geometry editor.

2. Required geophysical and flow information for setting up HEC-RAS 2D models

- Using Cross Section Data to Modify/Improve the Terrain Model:
- One of the major problems in hydraulic modeling is that terrain data does not often include the actual terrain underneath the water surface in the channel region.
- Mapper can now be used to create a terrain model of the channel region from the HEC- RAS cross sections and the Cross Section Interpolation Surface.

Importing Existing 1D Geometry Data





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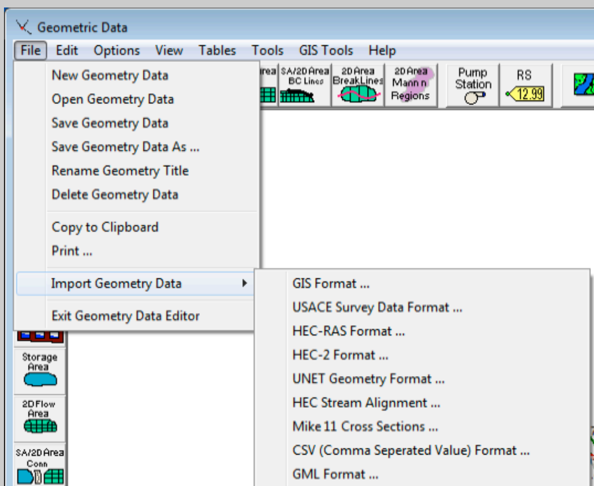

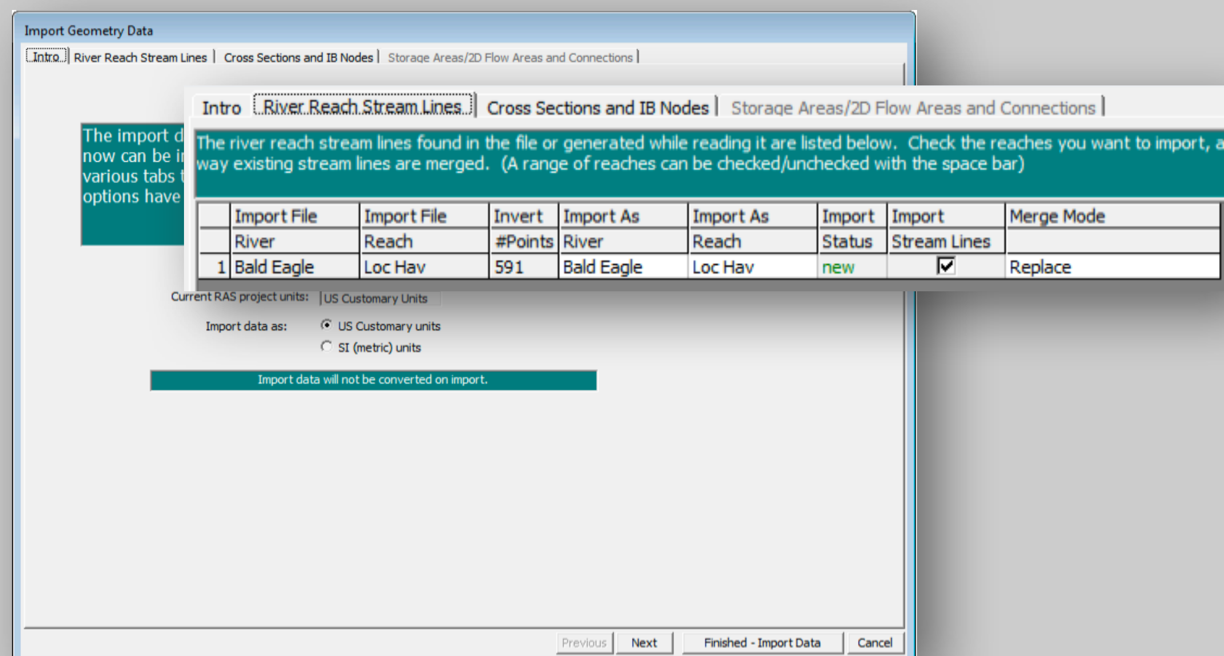

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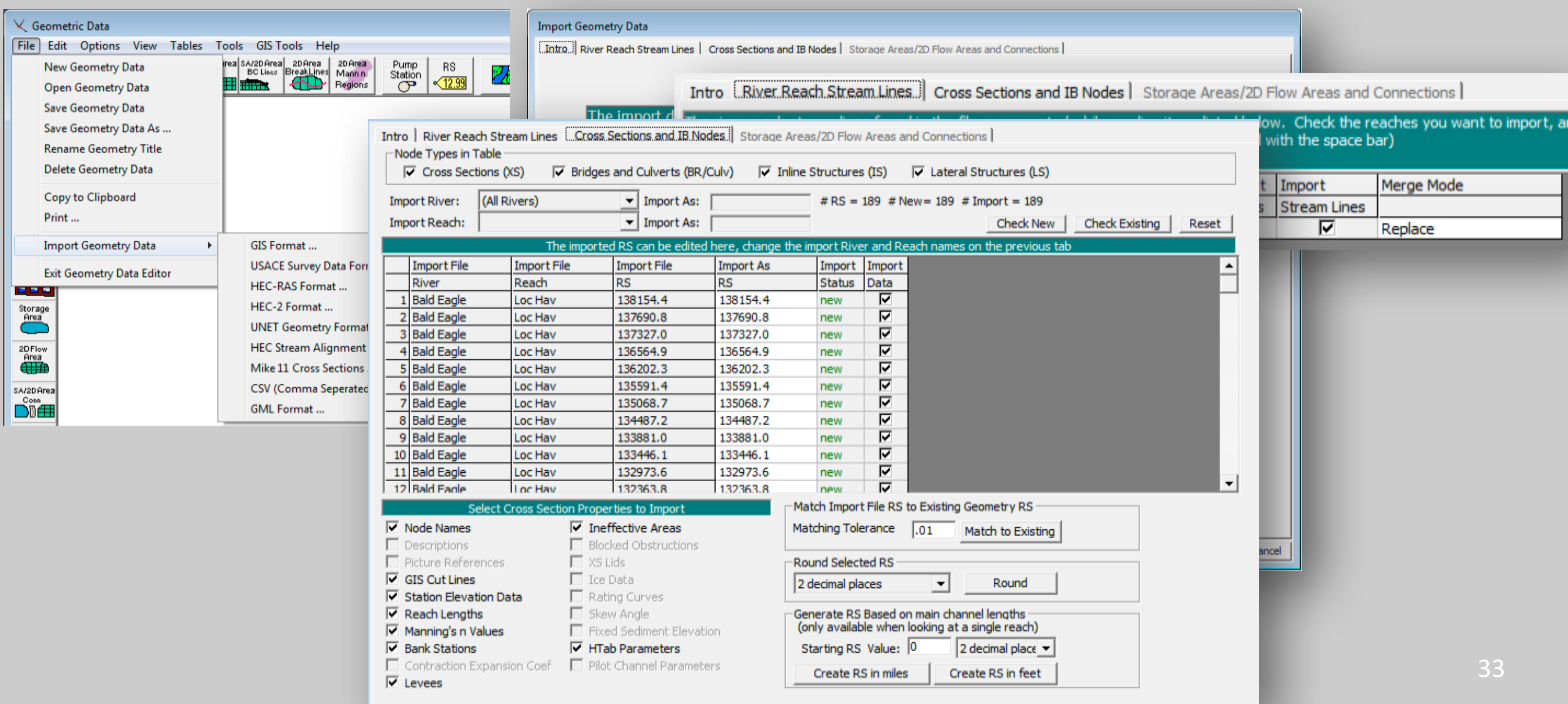

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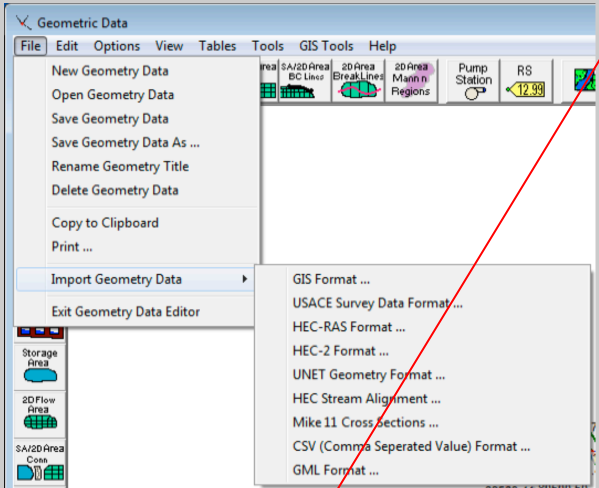
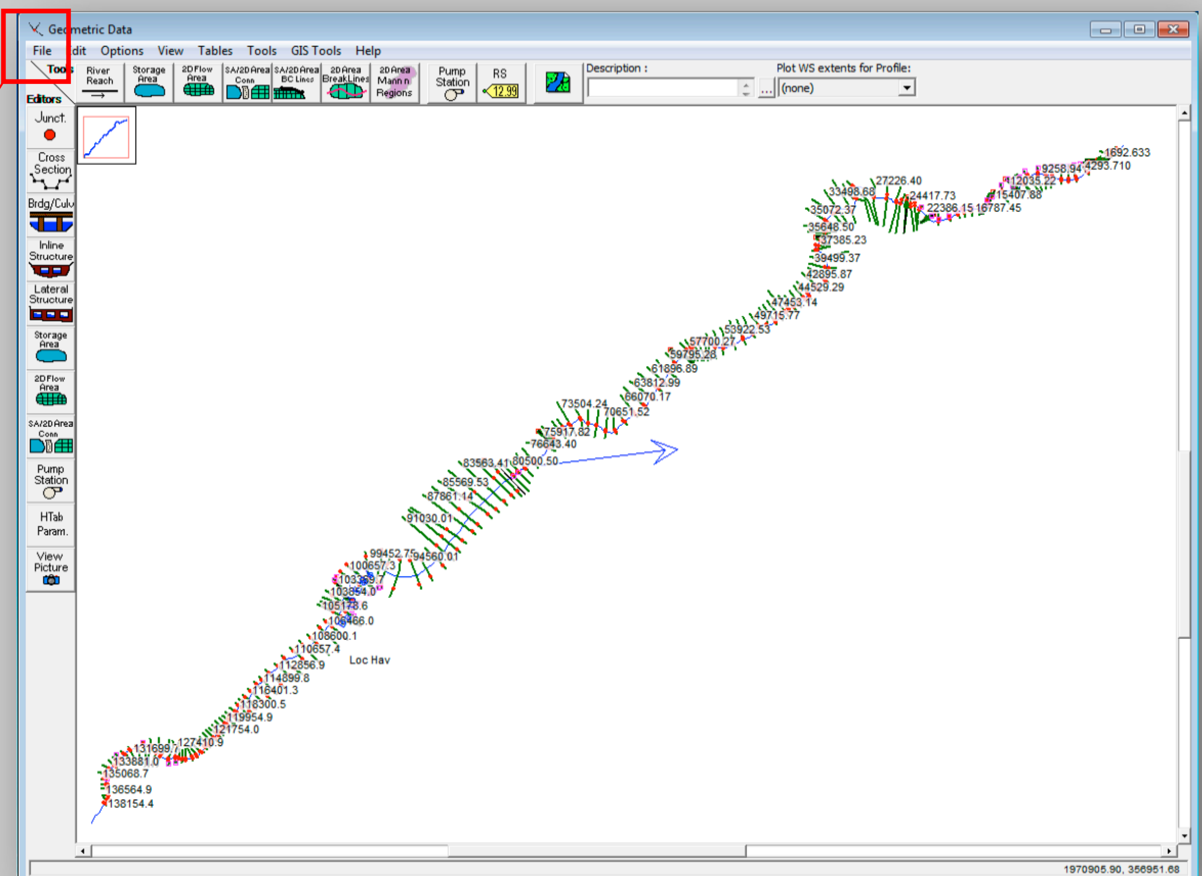


Save the geometry data immediately after being imported



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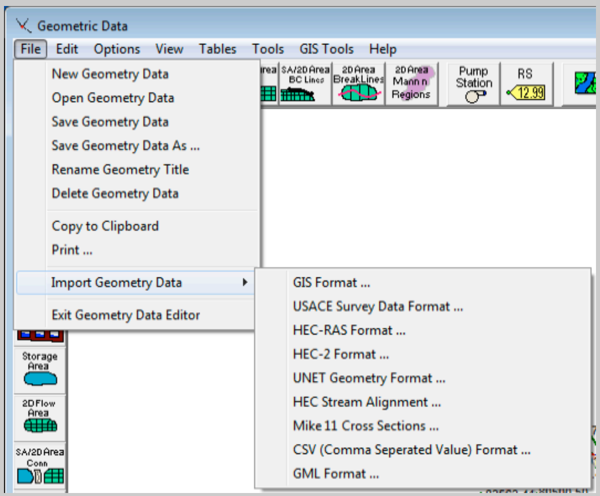

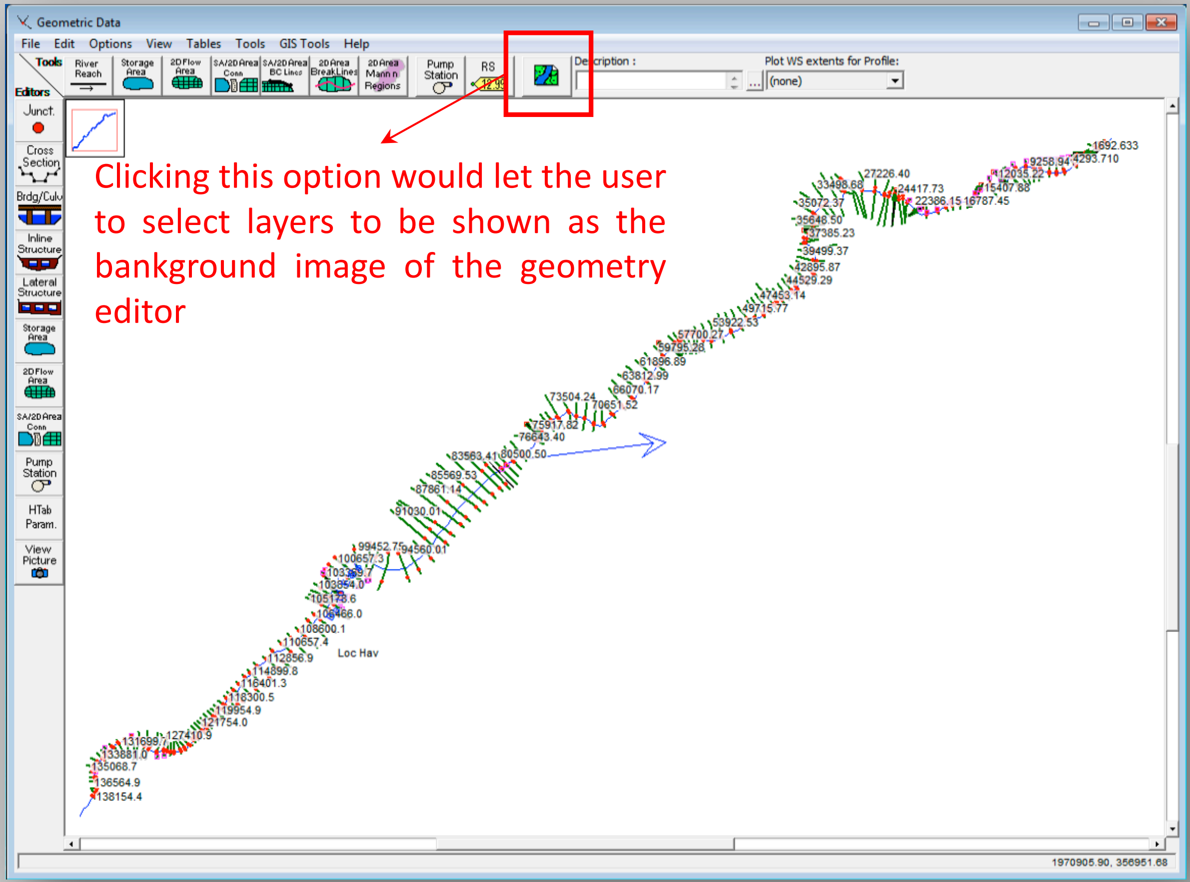

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- Using Cross Section Data to Modify/Improve the Terrain Model:
  - From HEC-RAS Mapper, turn on the Geometry layer for the geometry data to be used in creating the channel terrain model.
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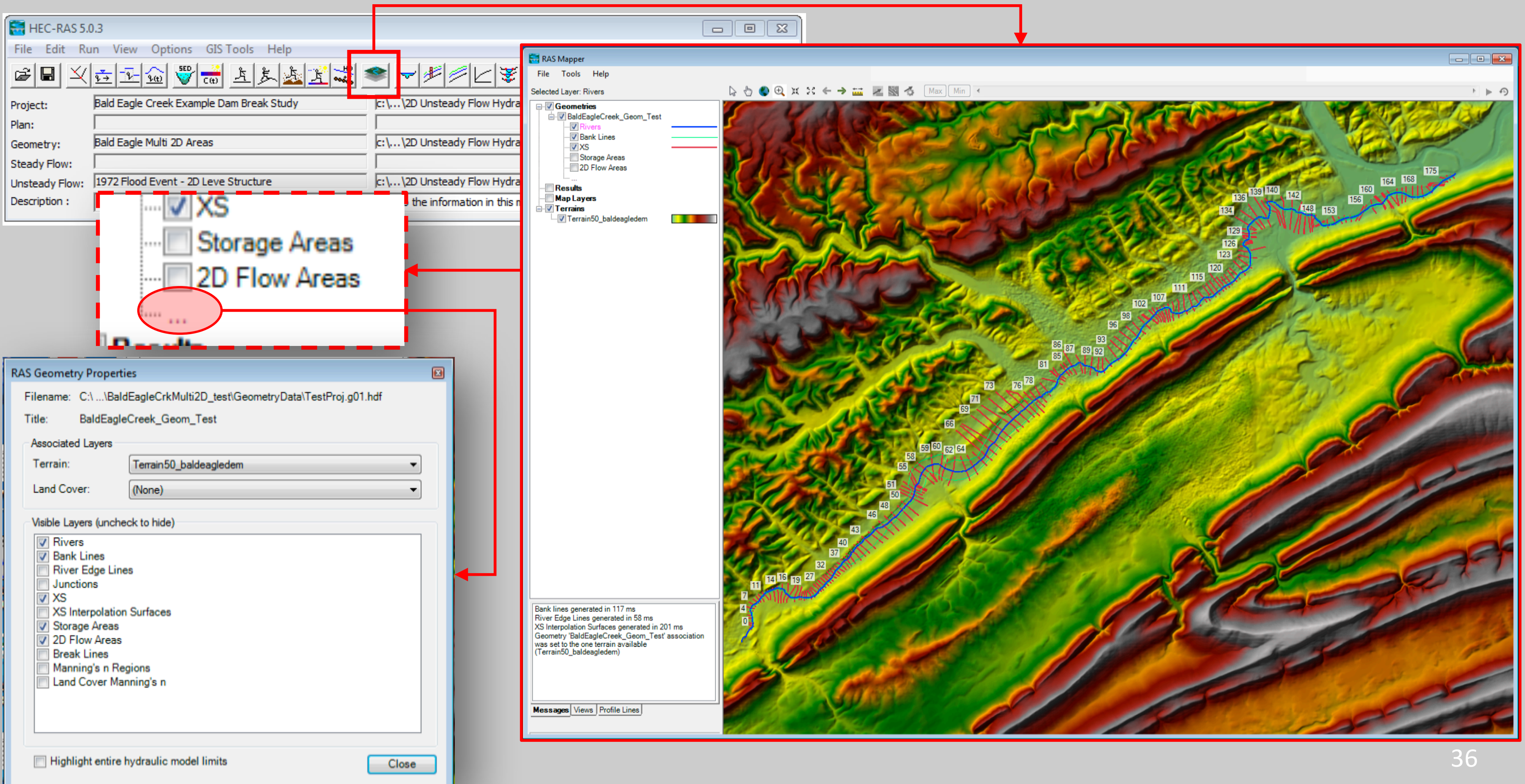

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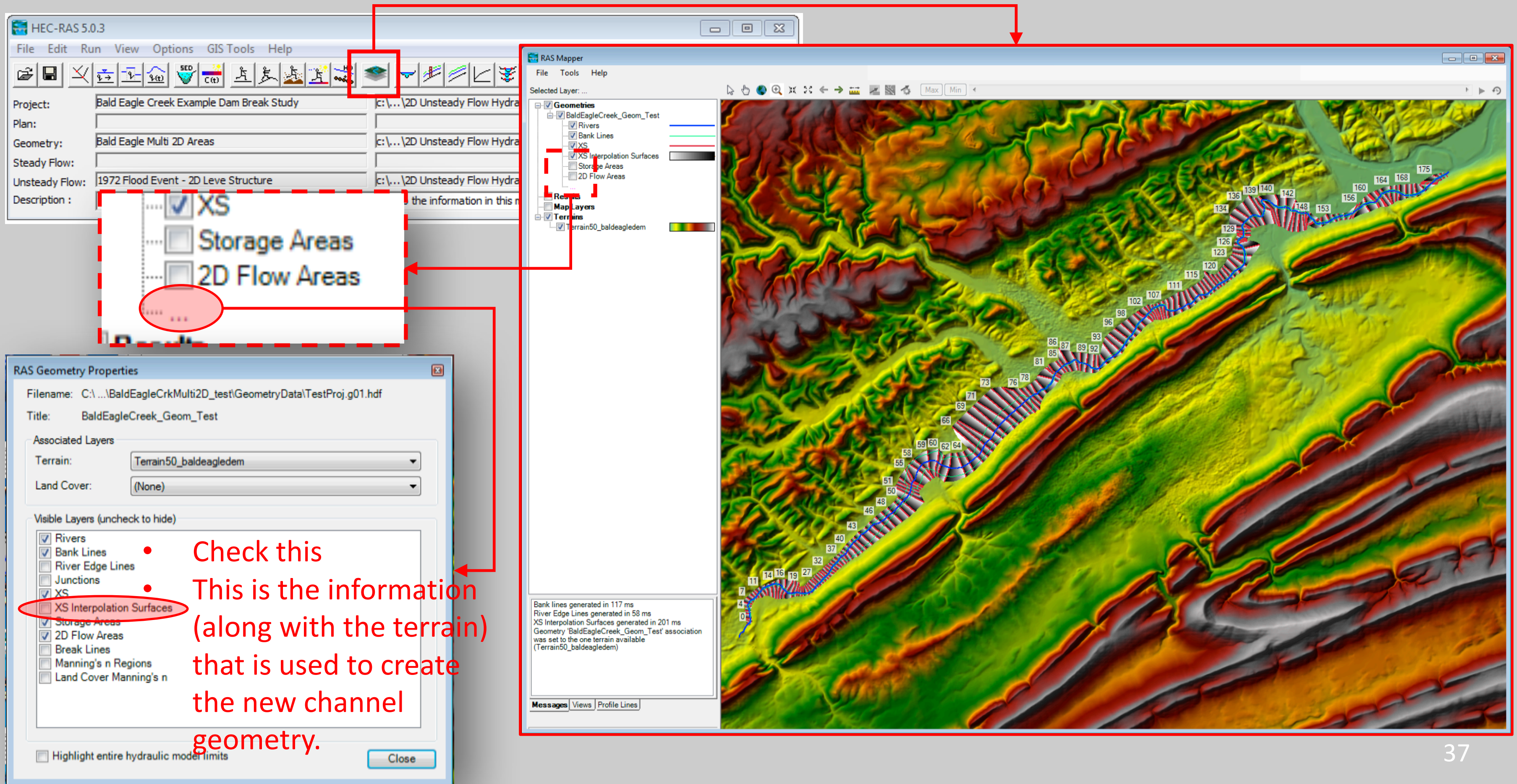

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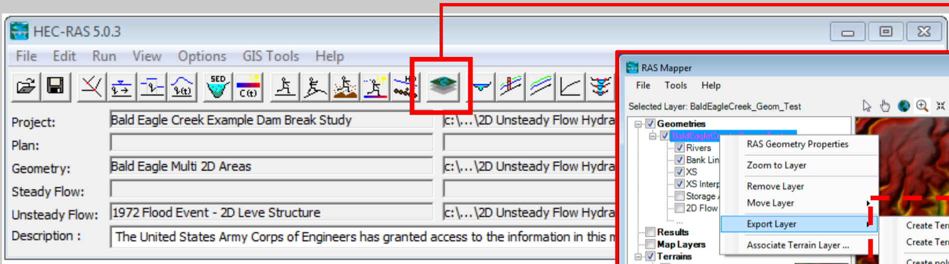

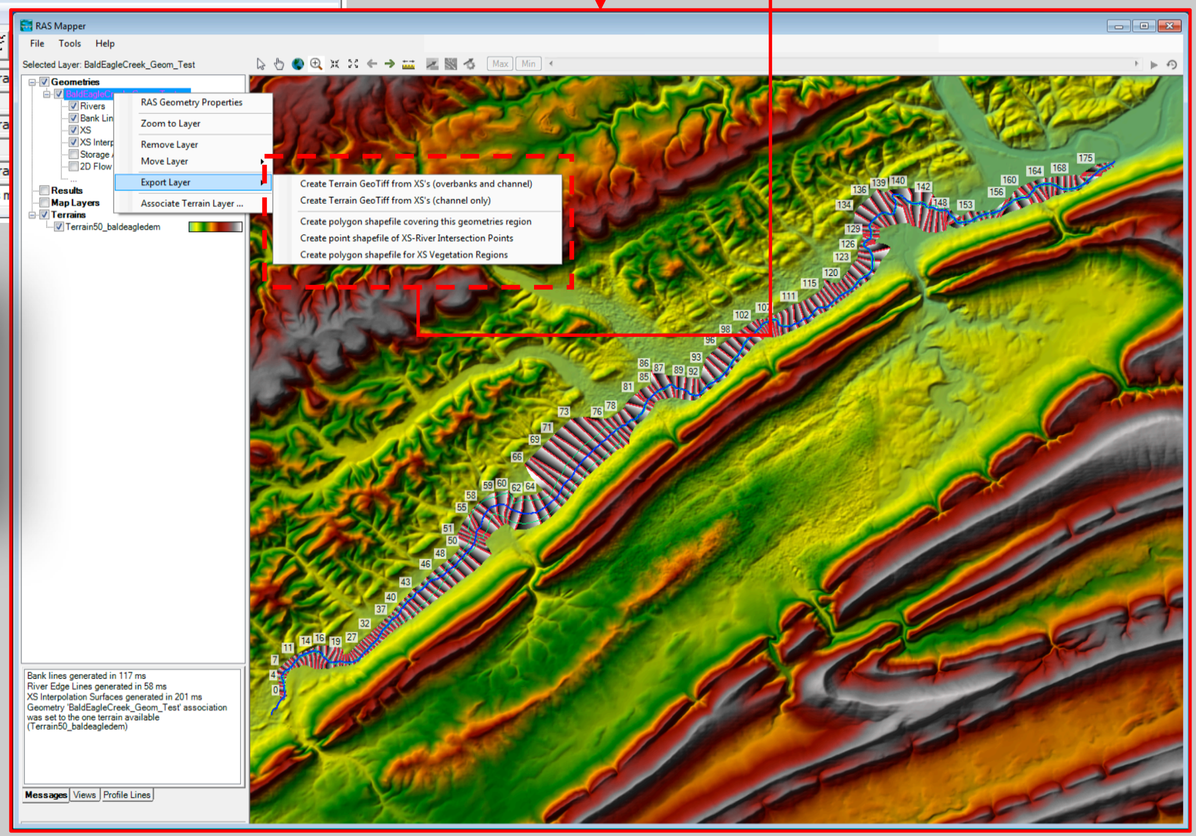

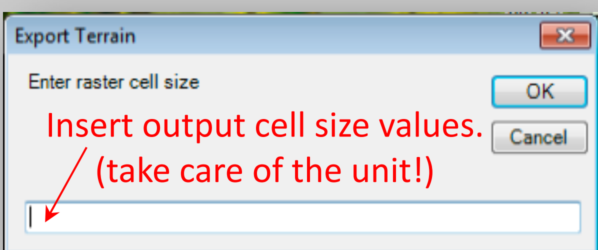

- The terrain model is created by taking the elevation data from the cross sections and using the interpolation surface to interpolate an elevation for each grid cell between two cross sections.

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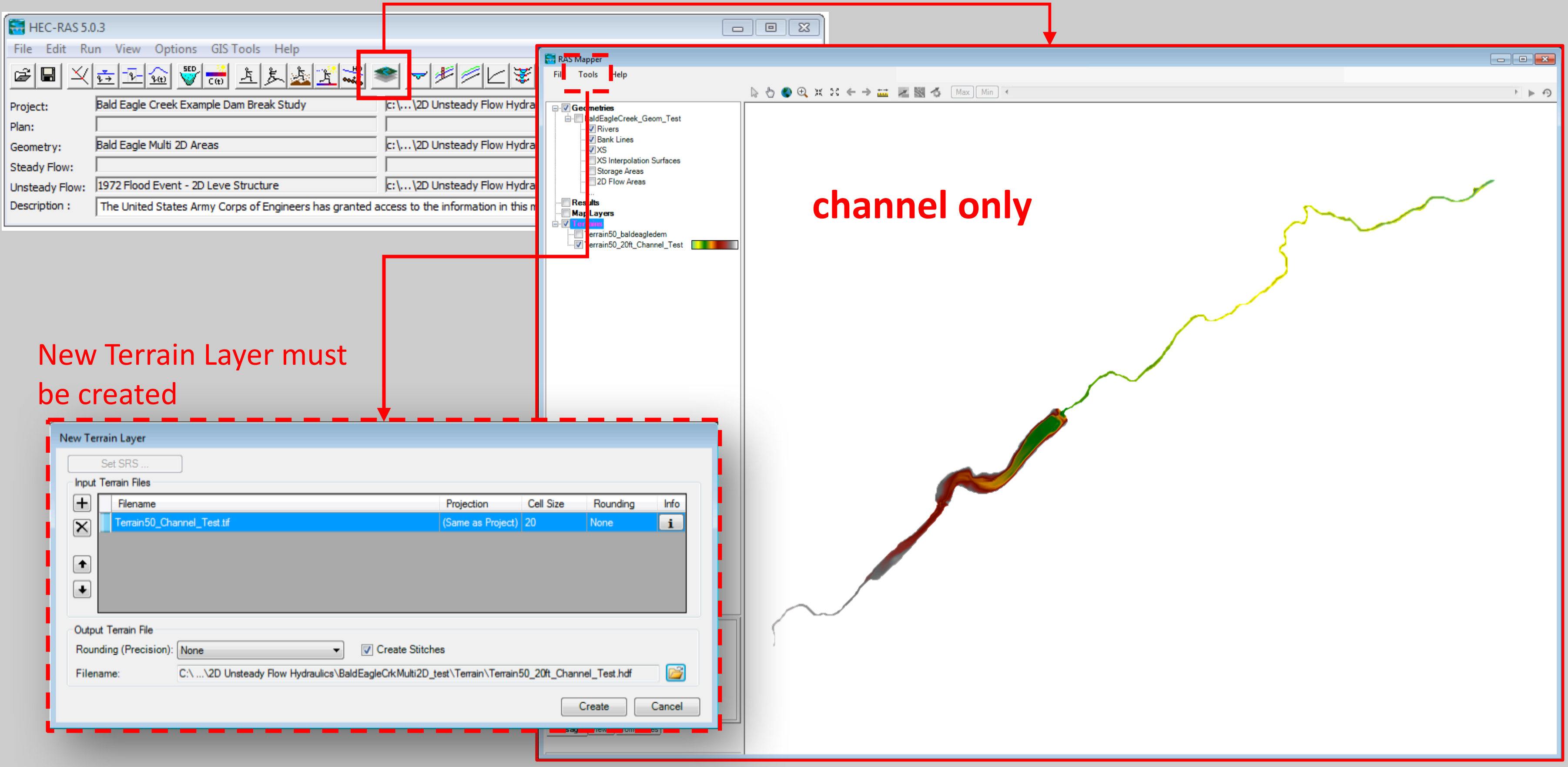
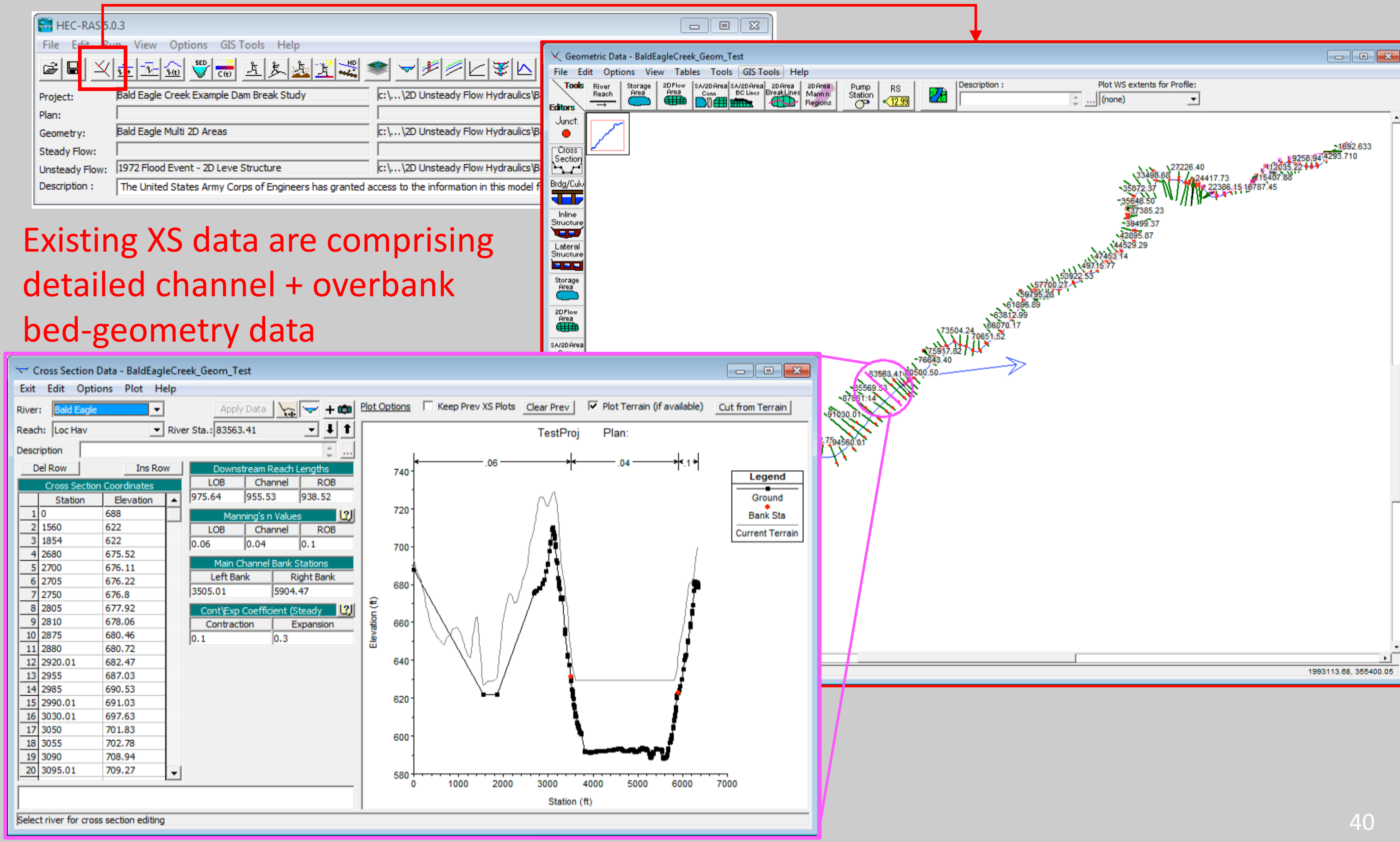


2. Required geophysical and flow information for setting up HEC-RAS 2D models

- Using Cross Section Data to Modify/Improve the Terrain Model:
  - Let’s create combined Channel and Overbank terrains

Existing XS data are comprising detailed channel + overbank bed-geometry data



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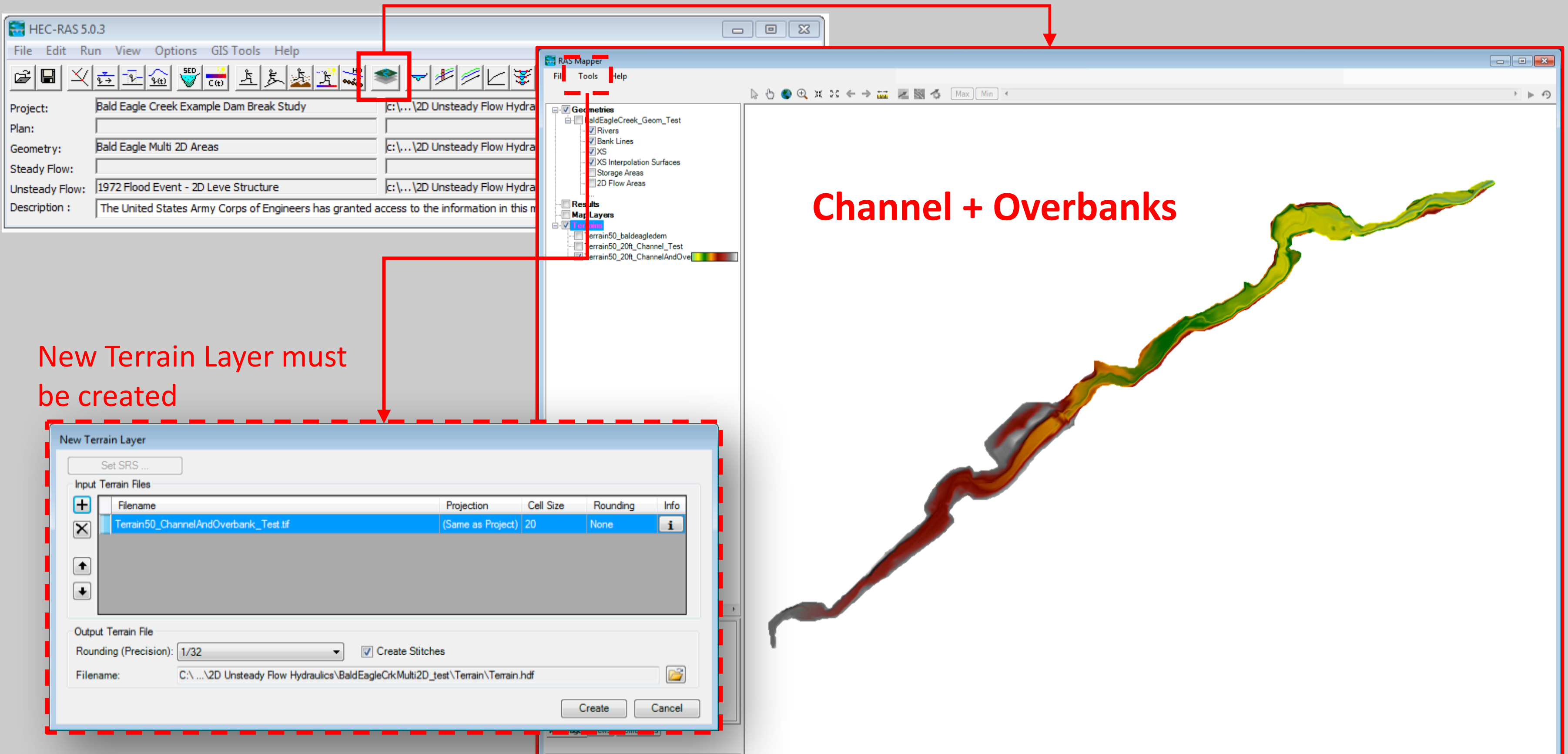


Objectives of This Workshop

1. Introduction to HEC-RAS 2D and two dimensional modeling advantages relative to 1D models

2. Required geophysical and flow information for setting up HEC-RAS 2D models

3. **Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS**

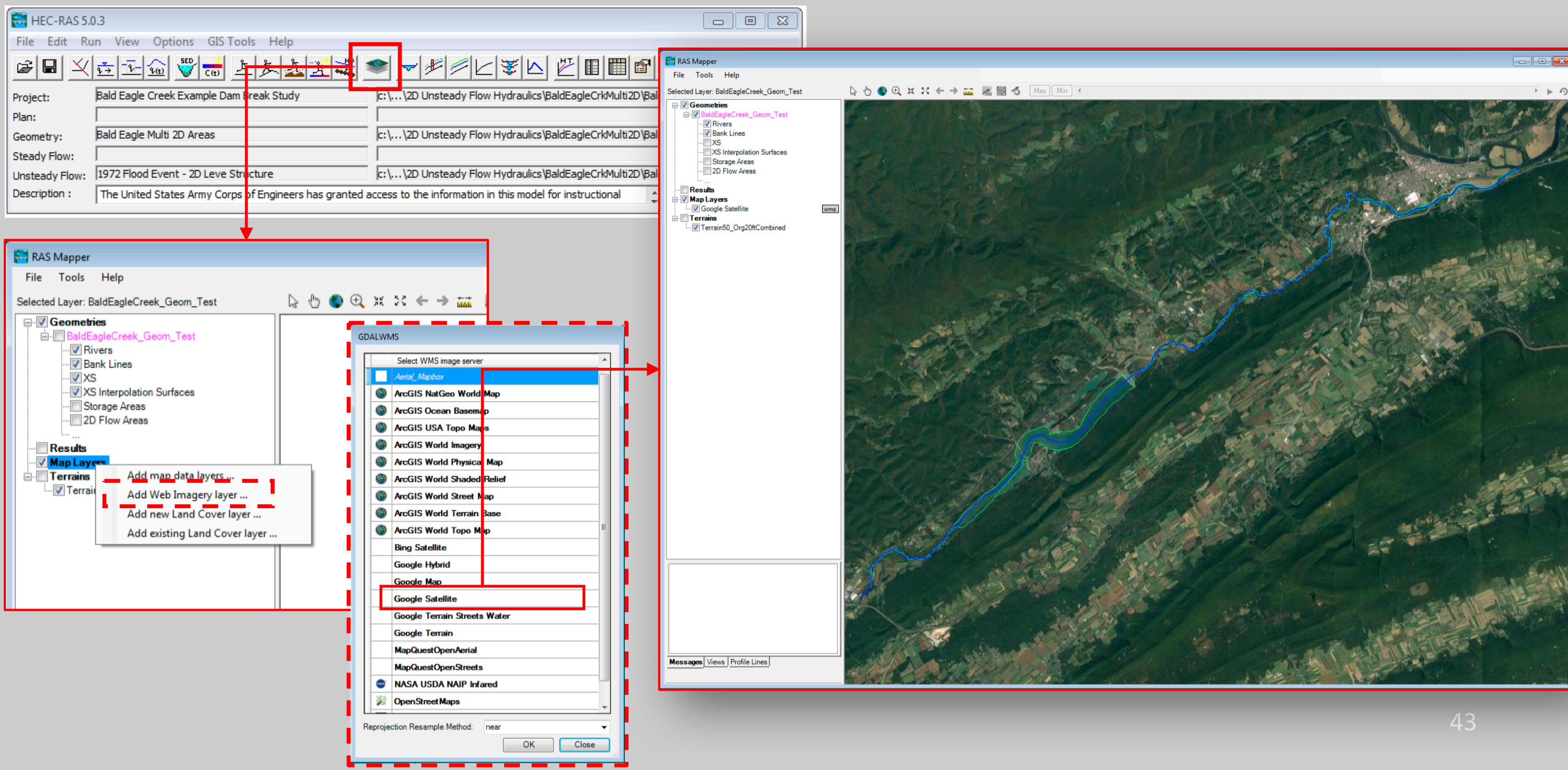
4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

5. Overview of how to demonstrate the result of a combined 1D/2D unsteady flow model in HEC-RAS and RAS Mapper output capabilities

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Development of 2D computational mesh:

- The user will most likely select a nominal grid resolution to use (e.g. 200 x 200 ft cells), and the automated tools within HEC-RAS will build the computational mesh.
- After the initial mesh is built, the user can refine the grid with break lines and the mesh editing tools.
- A background true color image of the natural topography (e.g. Google map) is really helpful in better delineating 2D Computational mesh boundaries.



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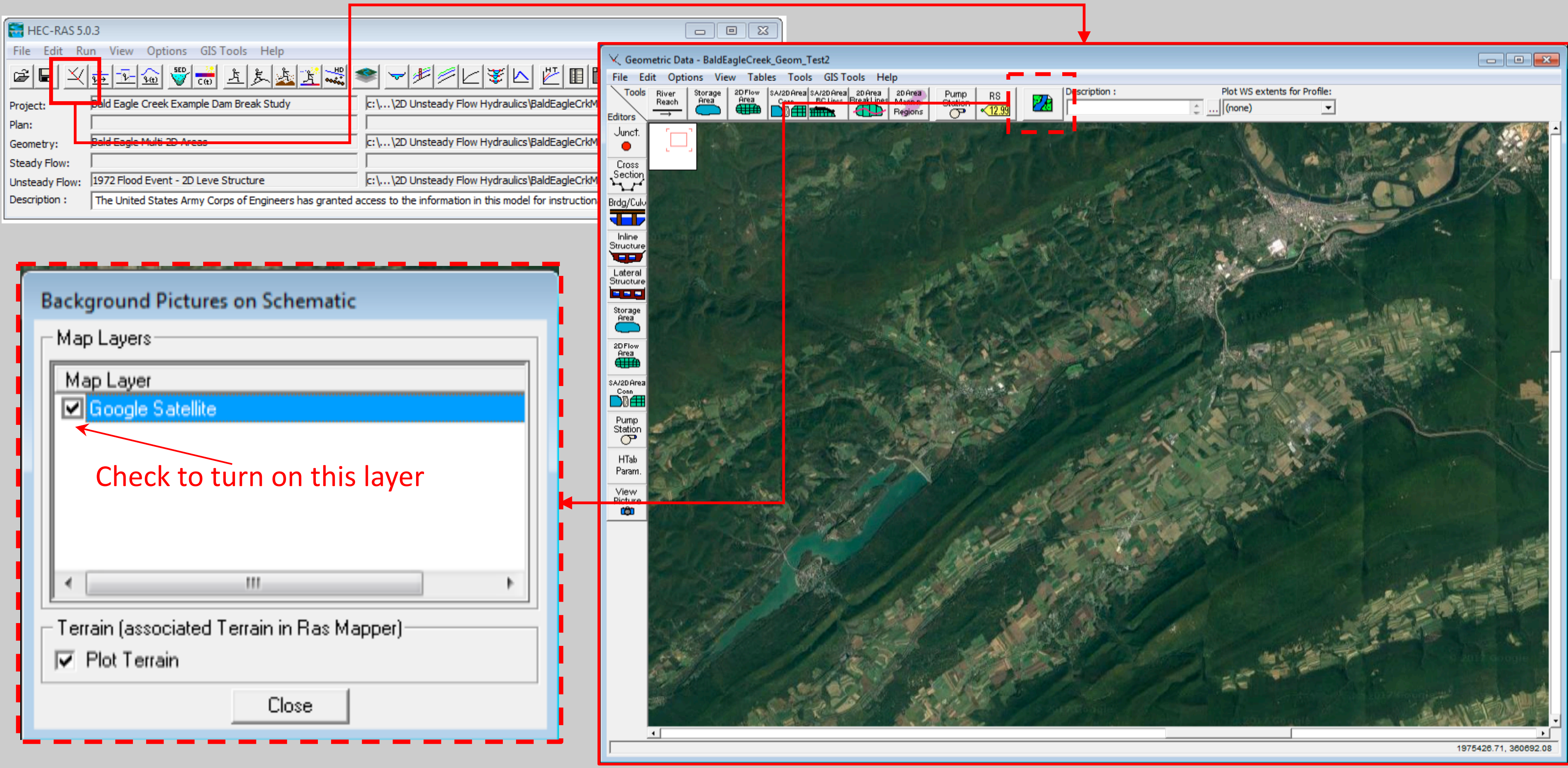
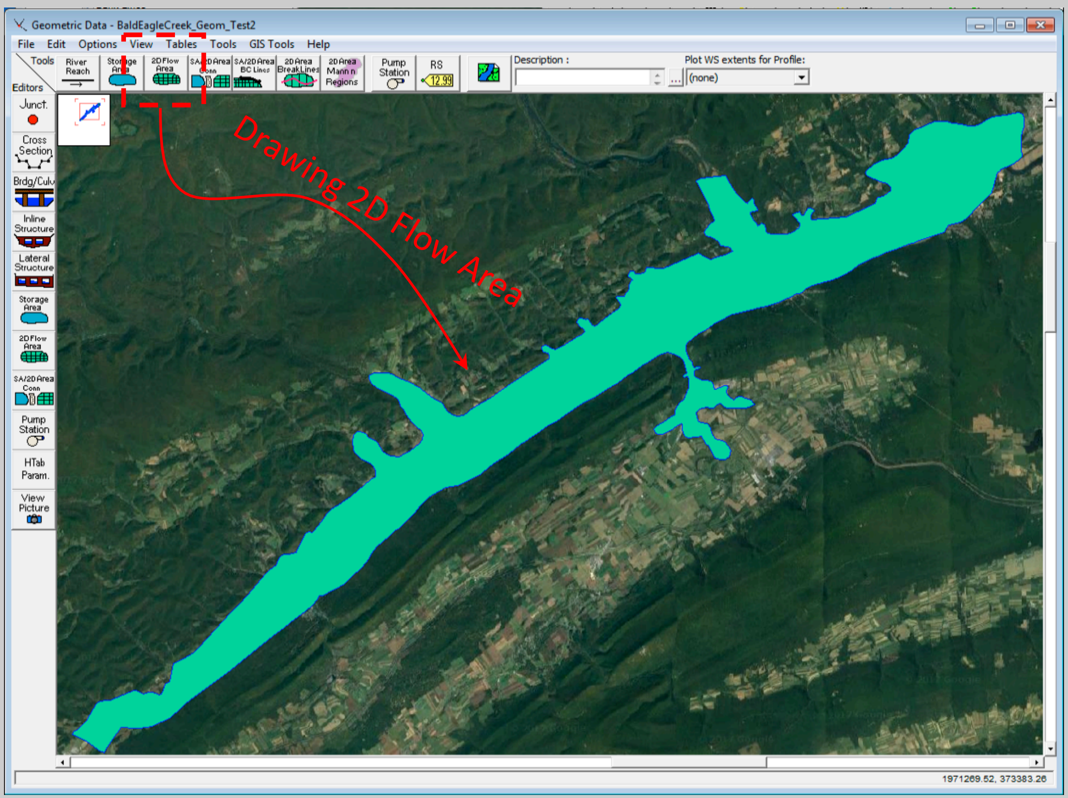


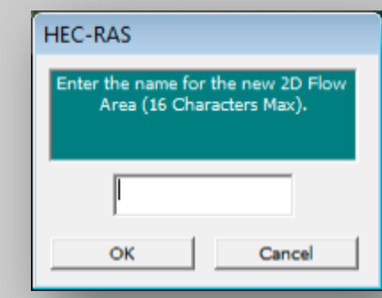
3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Development of 2D computational mesh:

- The user must add a 2D flow area polygon to represent the boundary of the 2D area using the 2D flow area drawing tool in the Geometric Data editor (just as the user would create a Storage Area).
- Additionally, the user may want to bring in a shapefile that represents the protected area, if they are working with a leveed system.
- The boundary between a 1D river reach and a 2D flow area should be high ground that separates the two. For levees and roadways this is obviously the centerline of the levee and the roadway.



You will be prompted to specify a name for the 2D flow area



NOTE: A 2D flow area must be drawn within the limits of the terrain model area being used for the study.

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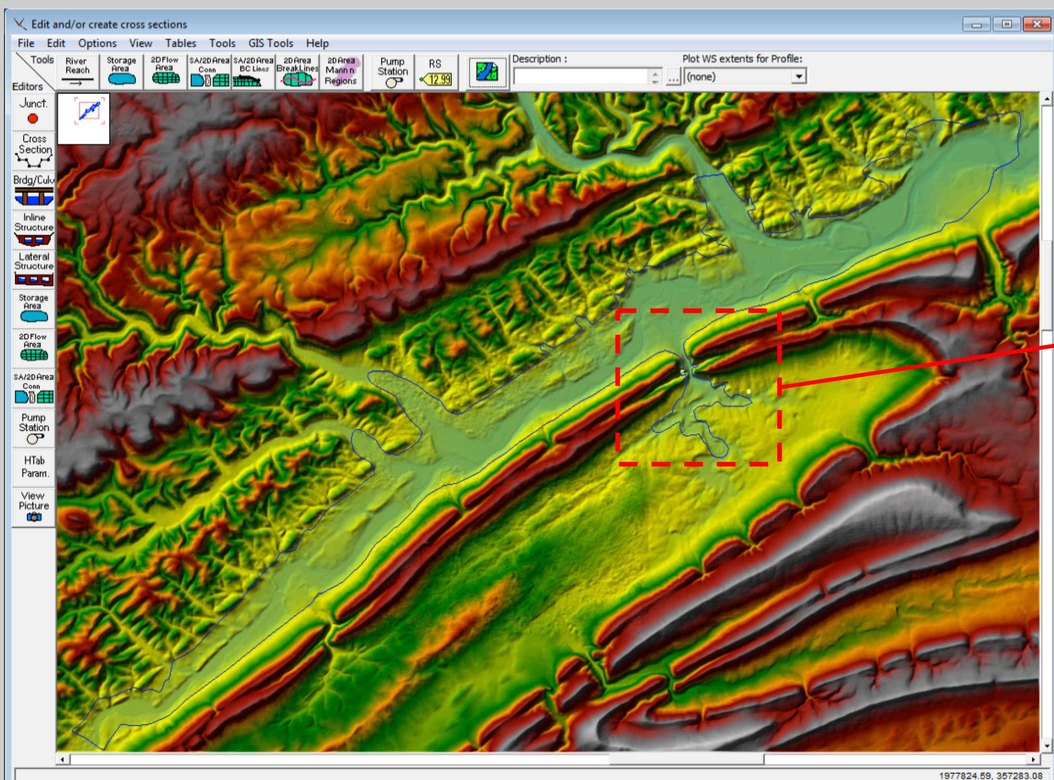

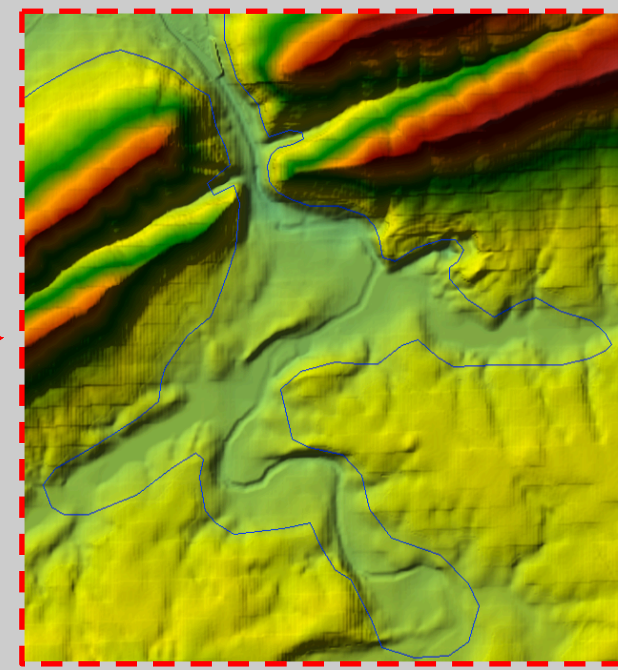

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- Adding ***breaklines*** inside 2D flow areas:

- Before the computational mesh is created the user may want to add break lines to enforce the mesh generation tools to align the computational cell faces along the break lines.
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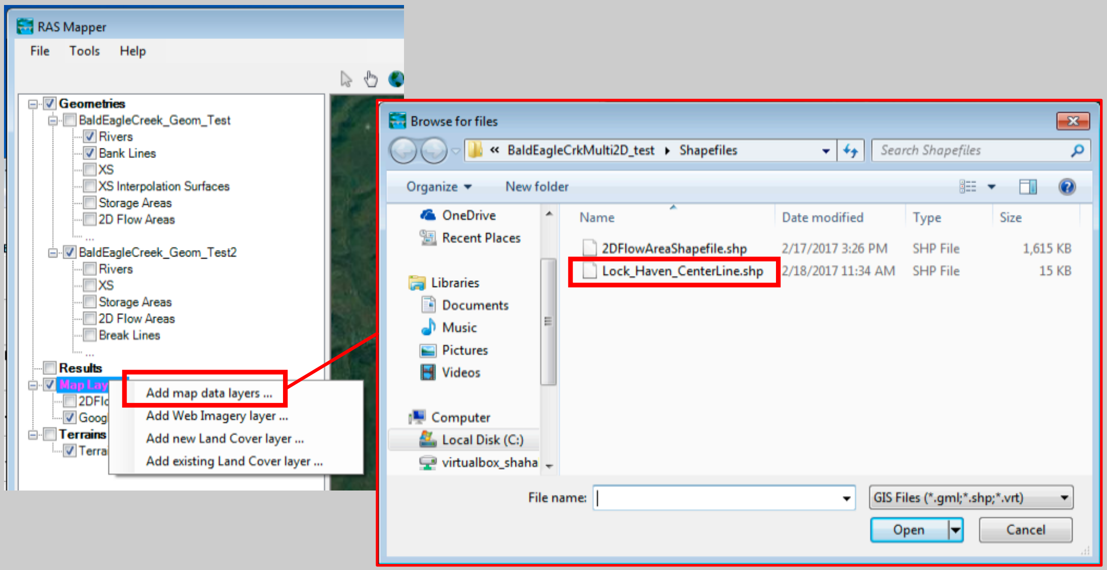

Breaklines can be imported from:

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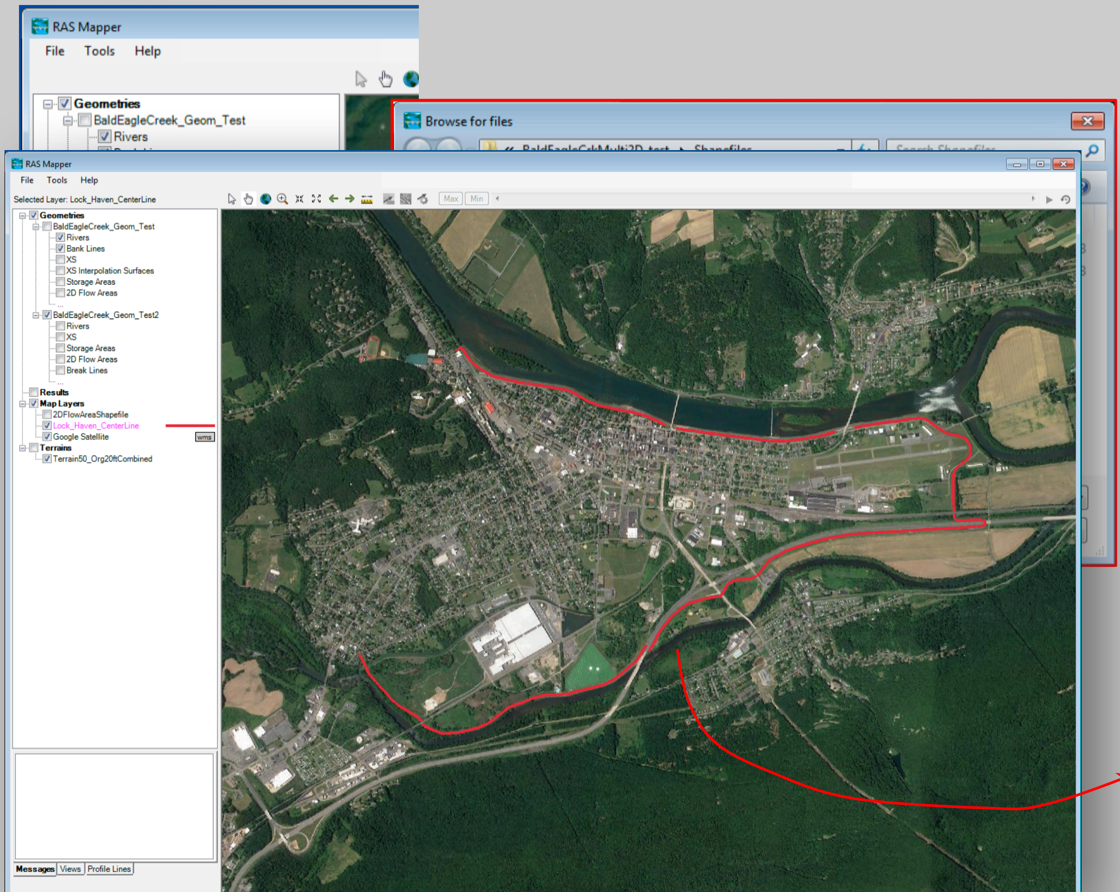

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✓ Now this also will be observable as a layer at Geometry Editor window.

✓ The outline color and line thickness can be modified. Double clicking the "Lock_Haven_CenterLine" will open up a new window where user can adjust the outline view of the line.

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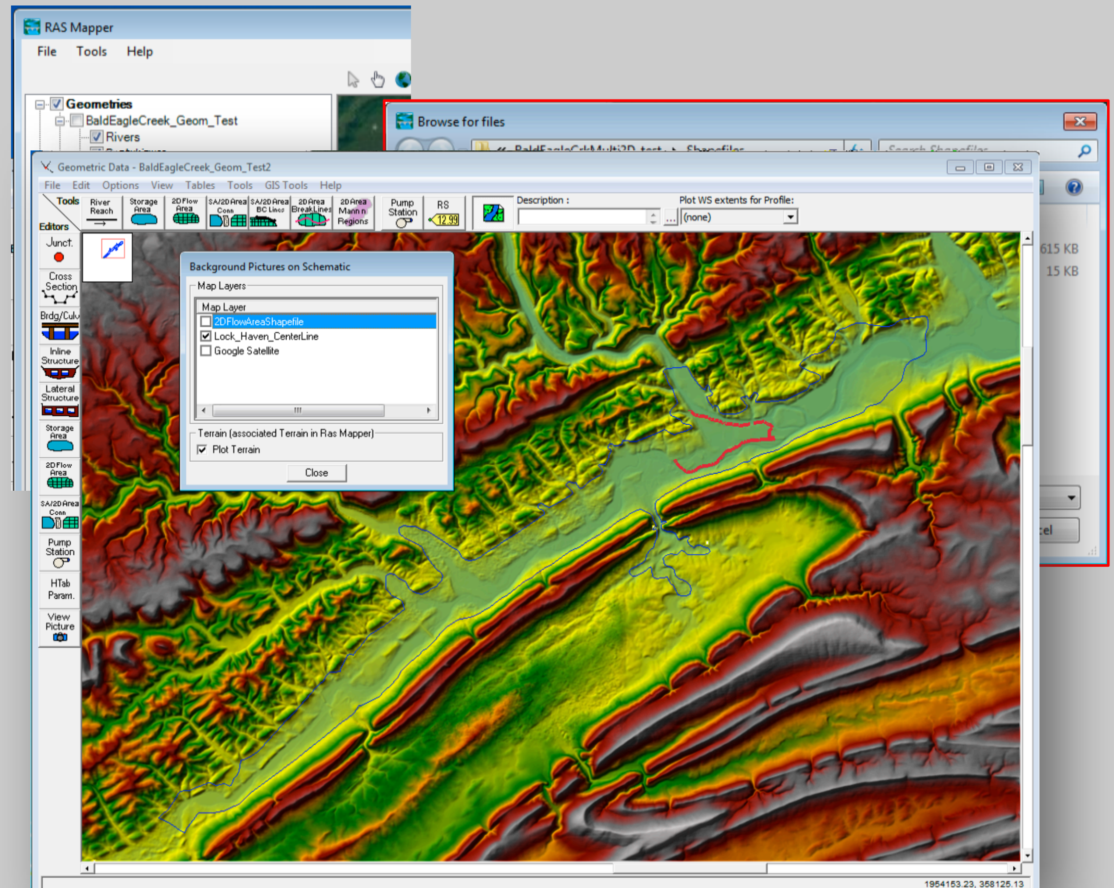

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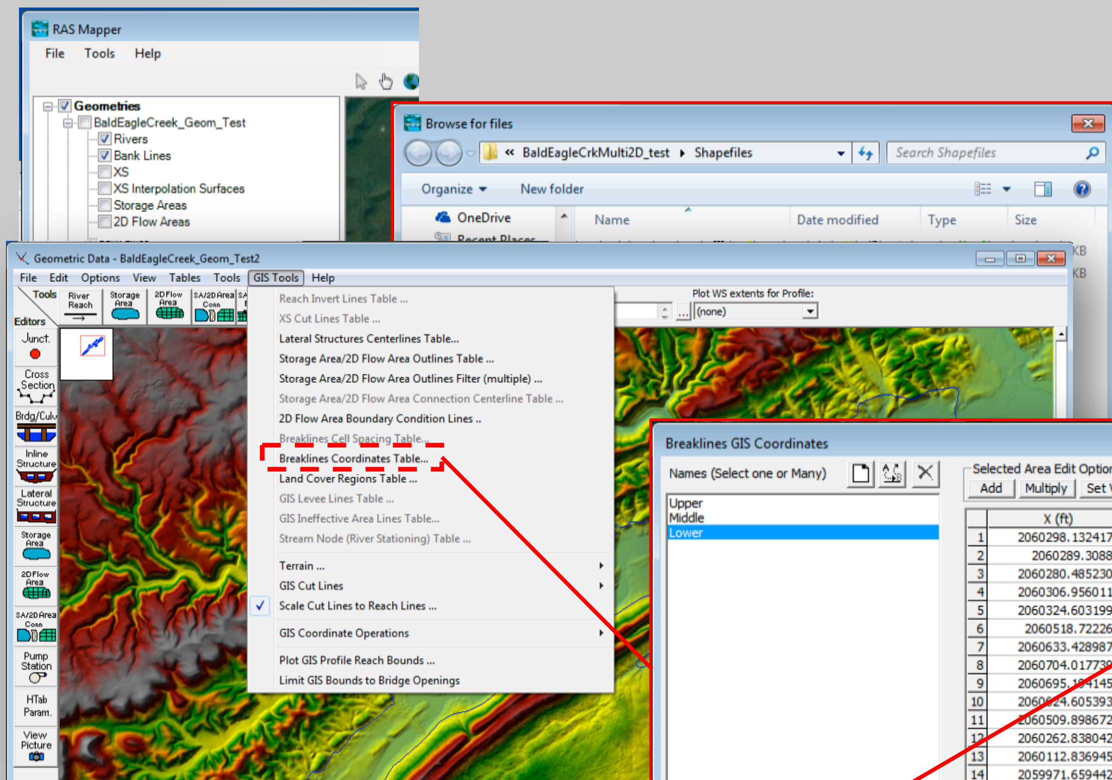

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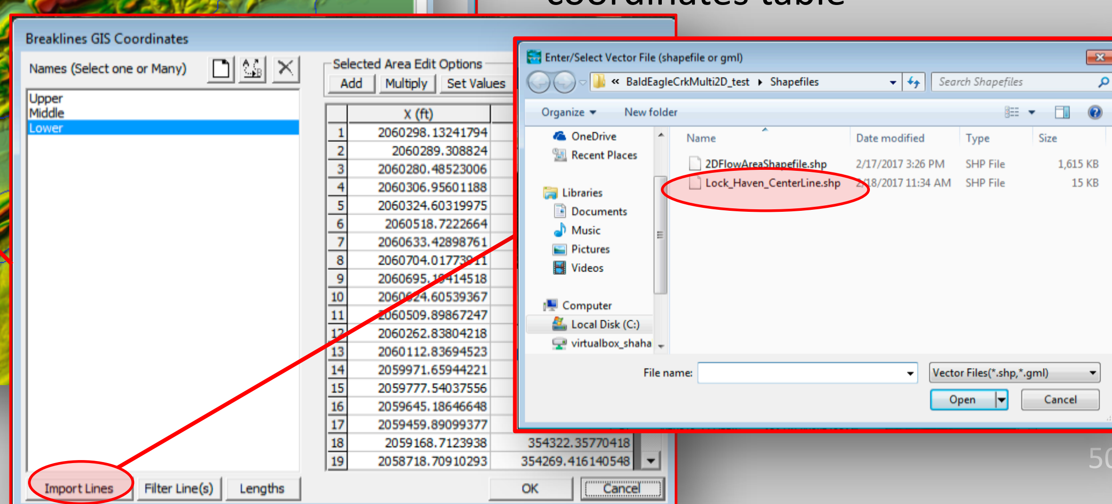

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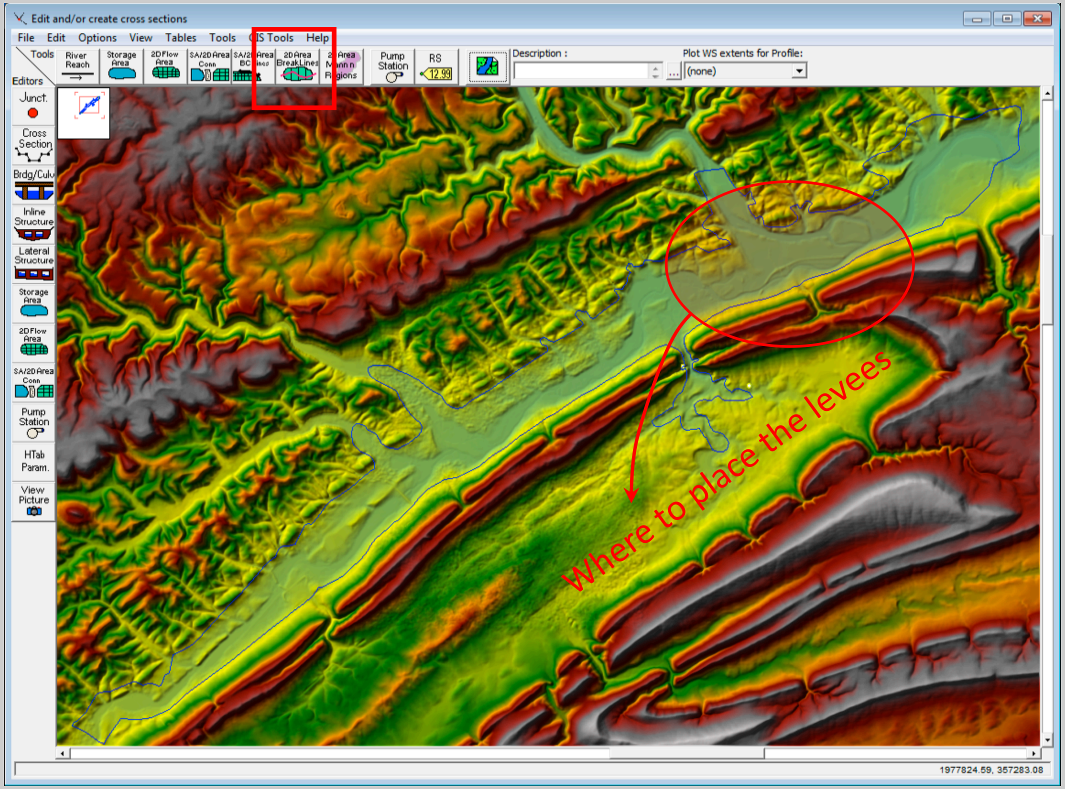

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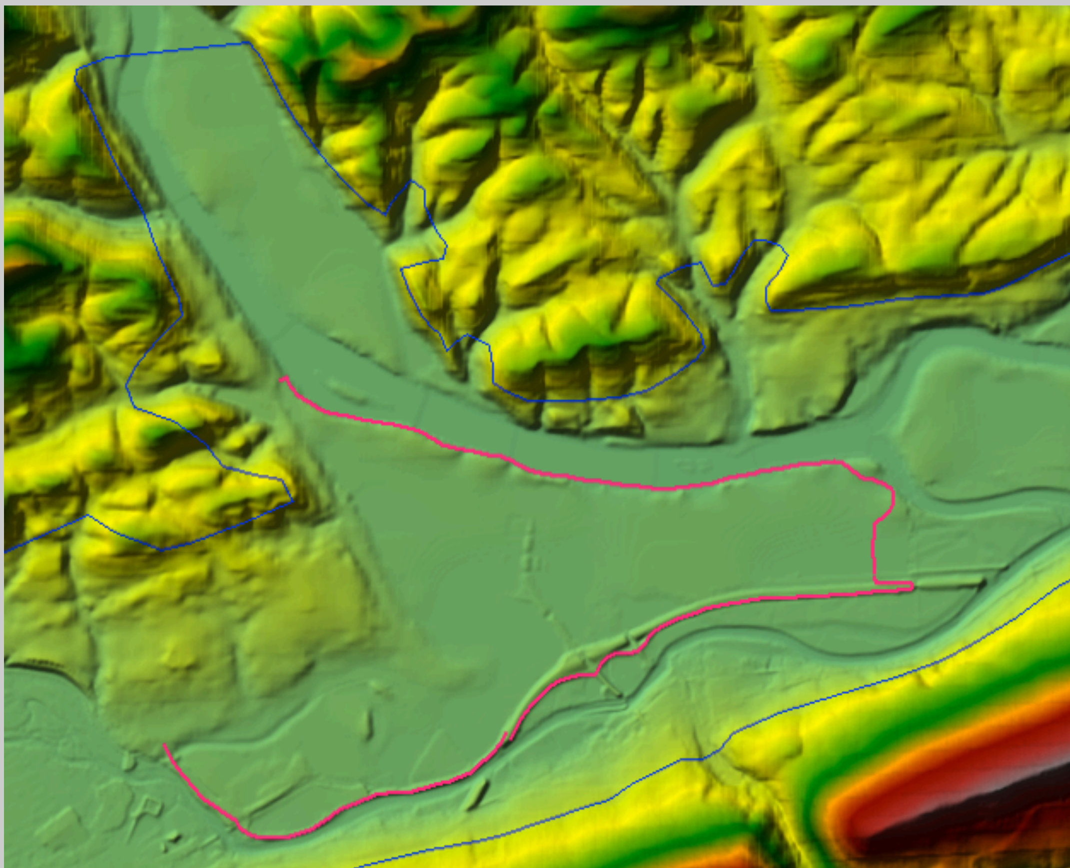

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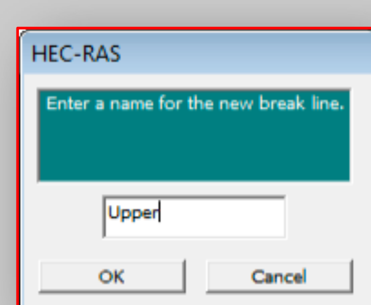


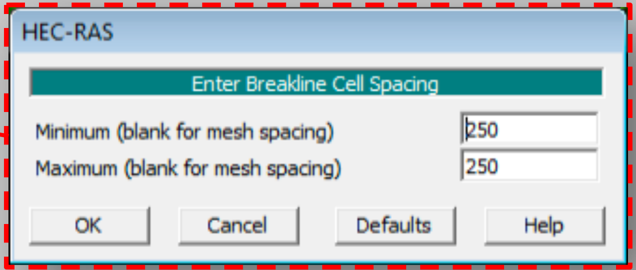
Once a break line is drawn the software will ask you to enter a name for the break line.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Adding ***breaklines*** inside 2D flow areas:
  - Before the computational mesh is created the user may want to add break lines to enforce the mesh generation tools to align the computational cell faces along the break lines.
  - Break lines should be added to any location that is a barrier to flow, or controls flow/direction.
  - Break lines can also be added after the main computational mesh is formed, and the mesh can be regenerate just around that break line.

Breaklines can be imported from:

- Shapefiles
- **Drawing by hand**
- Pasting detailed coordinates for an existing breakline into the breakline coordinates table



3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

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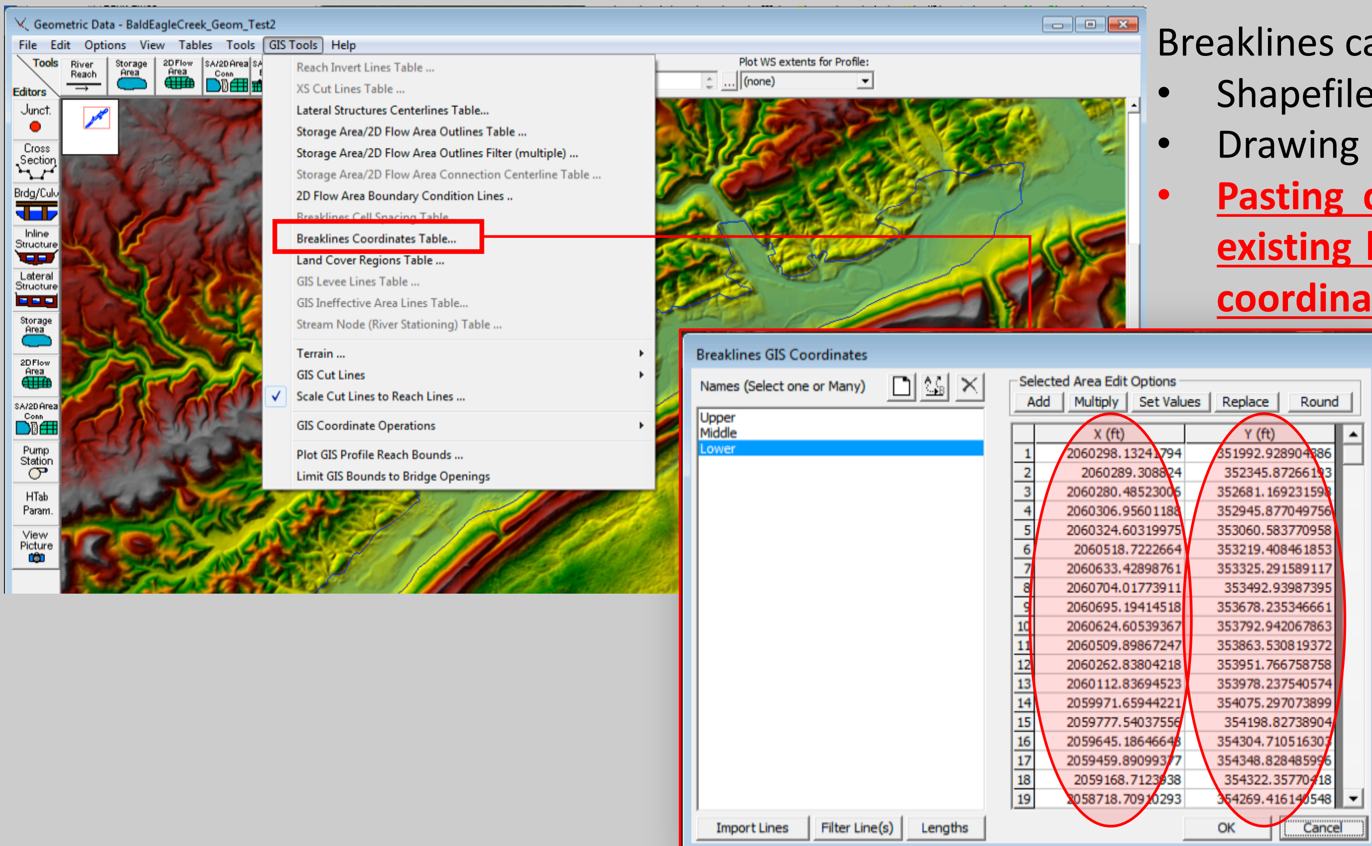

Breaklines can be imported from:

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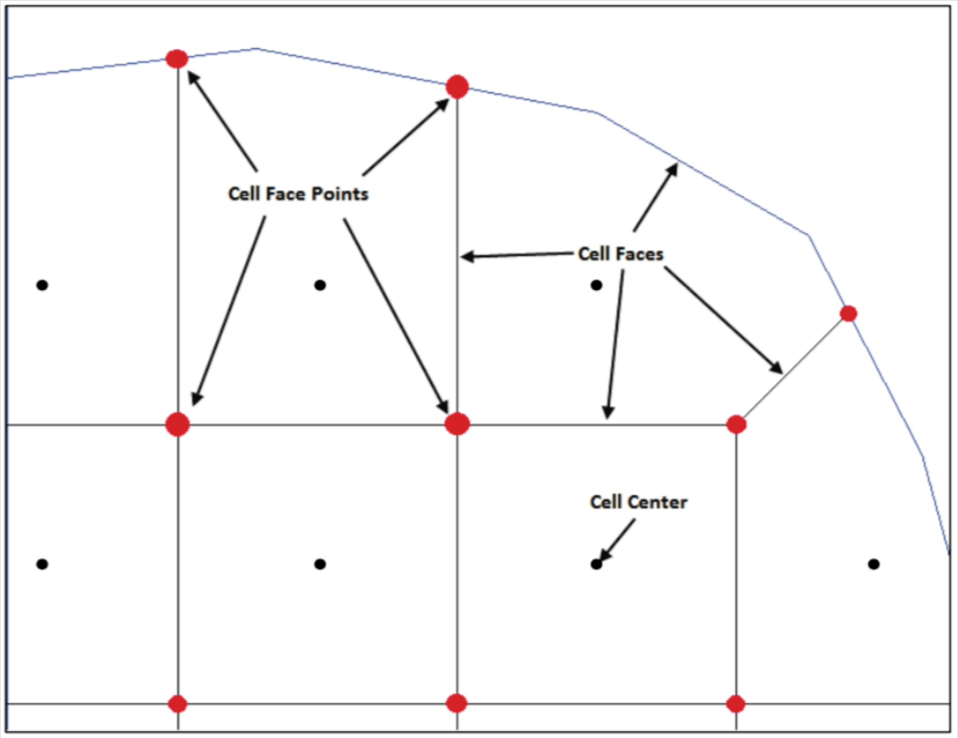
- Drawing by hand
- **<u>Pasting detailed coordinates for an existing breakline into the breakline coordinates table</u>**

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating the 2D Computational Mesh:

- After all the break lines have been added, the computational mesh can be generated. Keep in mind the user can also add additional break lines after the mesh has been generated, and the computational mesh can be refined around an individual break line at any time.
- The 2D flow area defines the boundary for which 2D computations will occur.

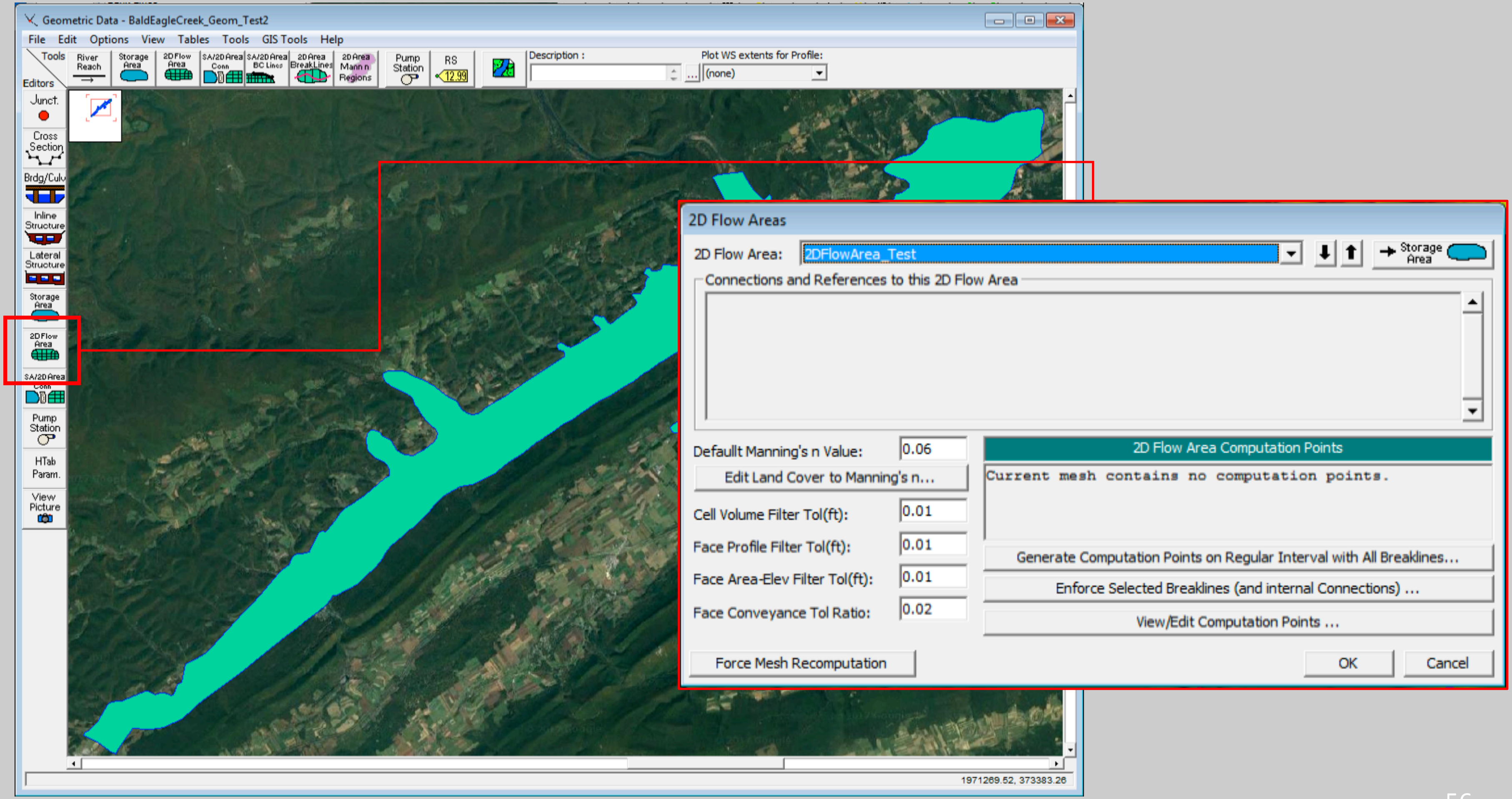


- ✓ **Cell Center:** this is where the water surface elevation is computed for the cell. The cell center does not necessarily correspond to the exact cell centroid.
- ✓ **Cell Face:** Faces are generally straight lines, but they can also be multi-point lines, such as the outer boundary of the 2D flow area.
- ✓ **Cell Face Points:** are the ends of the cell faces. The Face Point (FP) numbers for the outer boundary of the 2D flow area are used to hook the 2D flow area to a 1D elements and boundary conditions.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

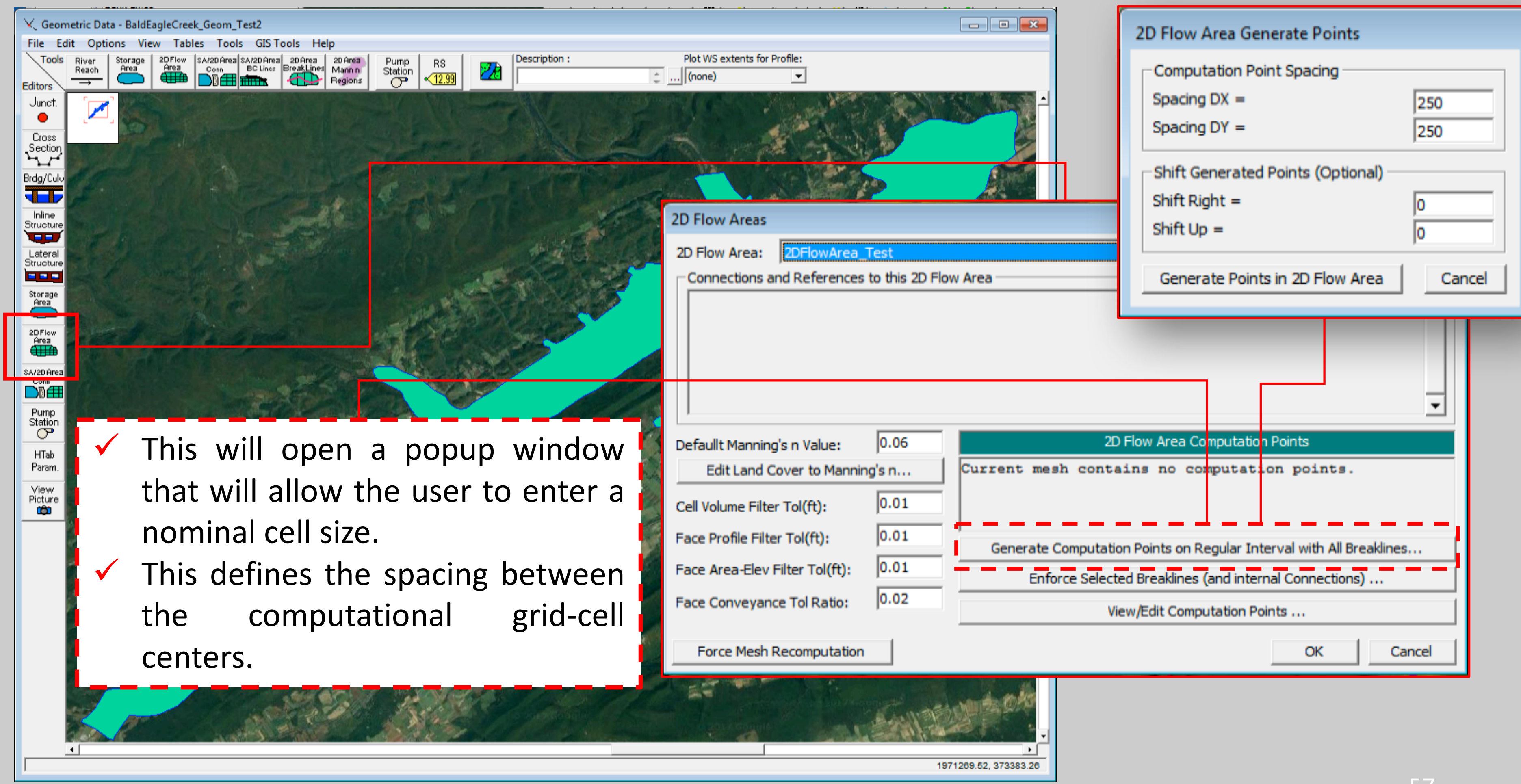
- Creating the 2D Computational Mesh:

- The 2D Flow Area editor allows the user to select a nominal grid size for the initial generation of the 2D flow area computational mesh.
- The 2D flow area defines the boundary for which 2D computations will occur.



3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

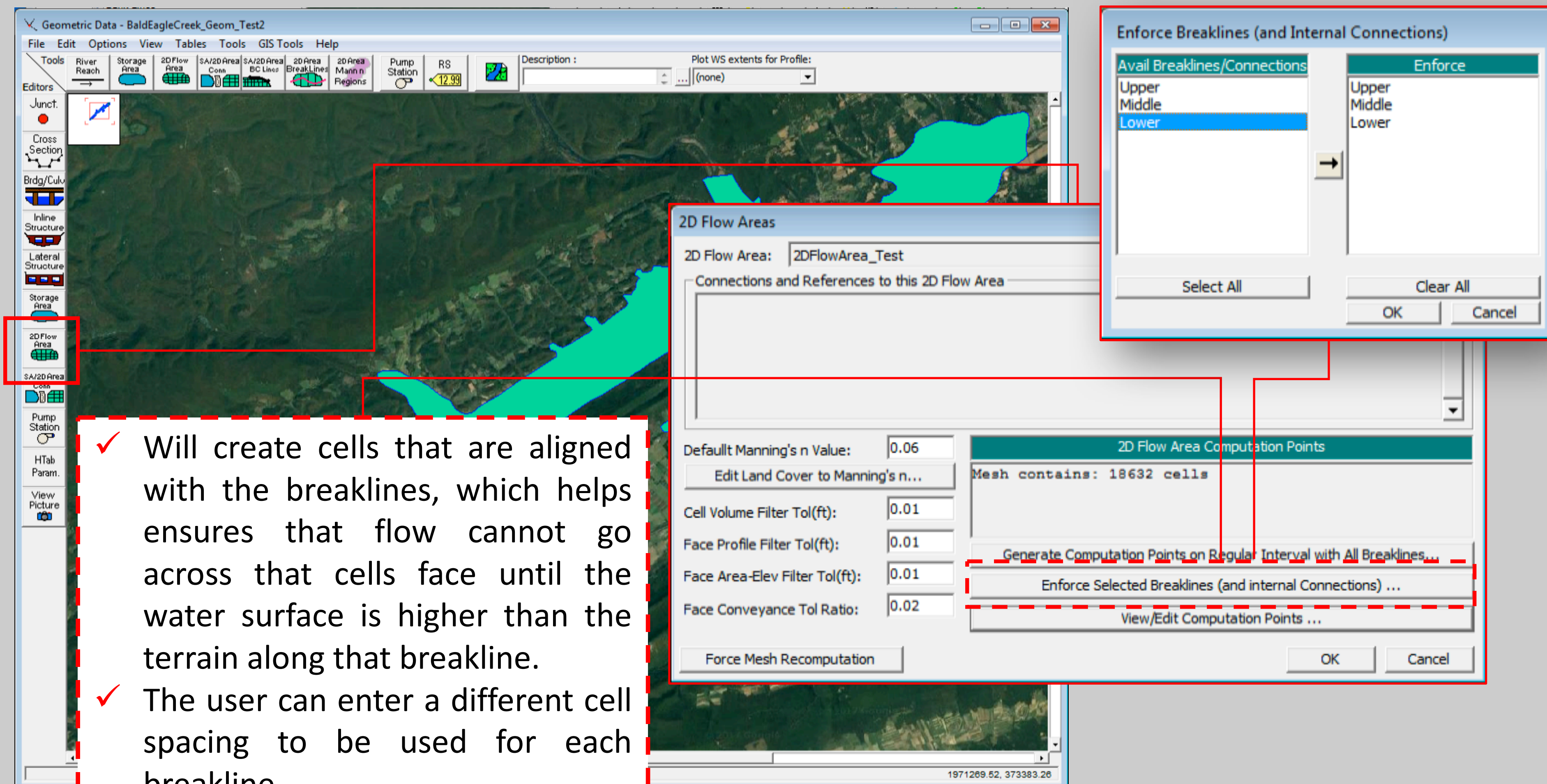
- Creating the 2D Computational Mesh:
  - For example, if the user enters **Spacing DX = 250**, and **Spacing DY = 250**, they will get a computational mesh that has grids that are 250 x 250 everywhere, except around break lines and the outer boundary.



- ✓ This will open a popup window that will allow the user to enter a nominal cell size.
- ✓ This defines the spacing between the computational grid-cell centers.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating the 2D Computational Mesh:
- Since the user can enter break lines, the mesh generation tools will automatically try to "snap" the cell faces to the breaklines. The cells formed around break lines may not always have cell faces that are aligned perfectly with the break lines.



- ✓ Will create cells that are aligned with the breaklines, which helps ensures that flow cannot go across that cells face until the water surface is higher than the terrain along that breakline.
- ✓ The user can enter a different cell spacing to be used for each breakline.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating the 2D Computational Mesh:

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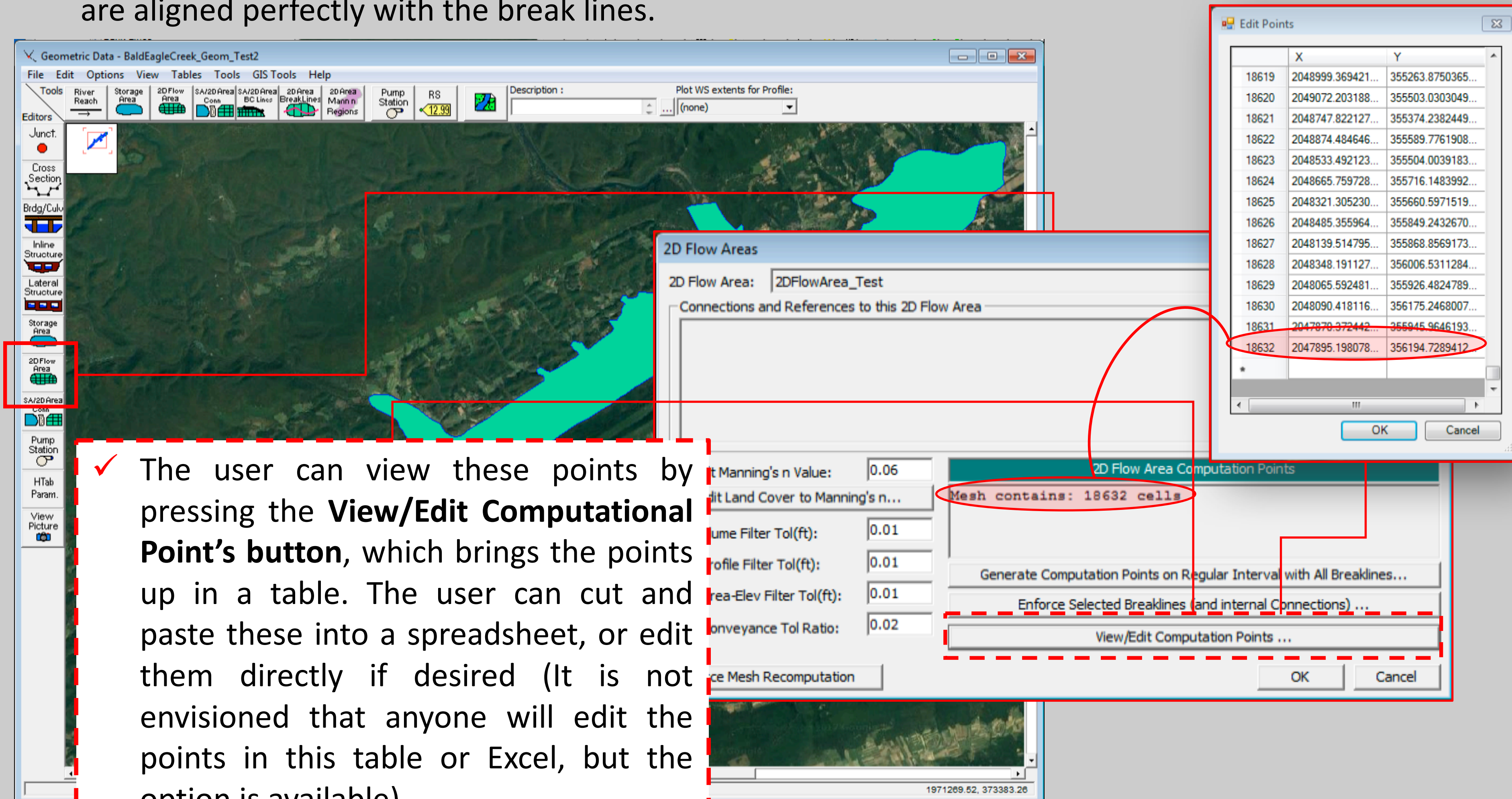

✓ The user can view these points by pressing the **View/Edit Computational Point’s button**, which brings the points up in a table. The user can cut and paste these into a spreadsheet, or edit them directly if desired (It is not envisioned that anyone will edit the points in this table or Excel, but the option is available).

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating the 2D Computational Mesh:

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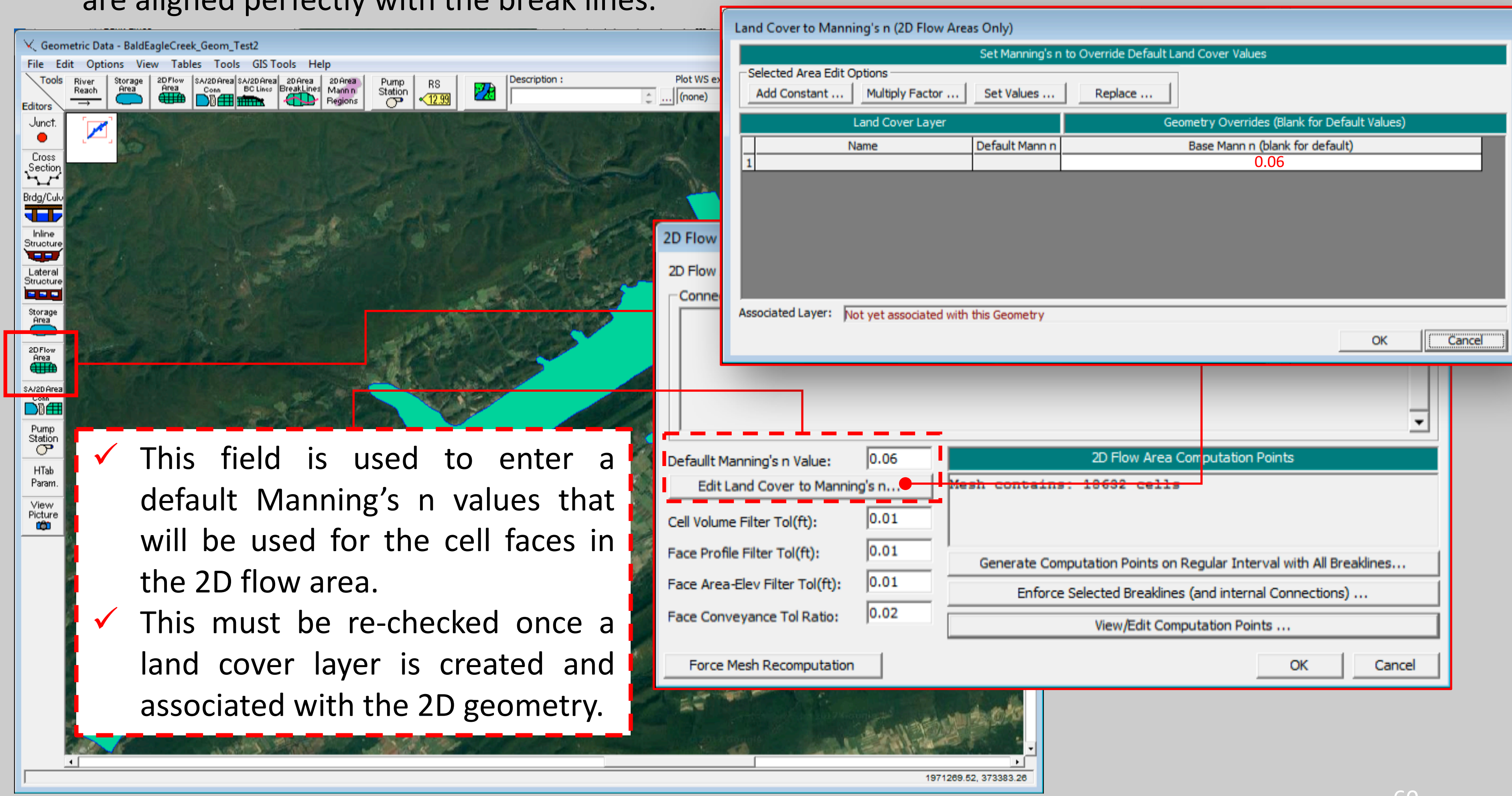
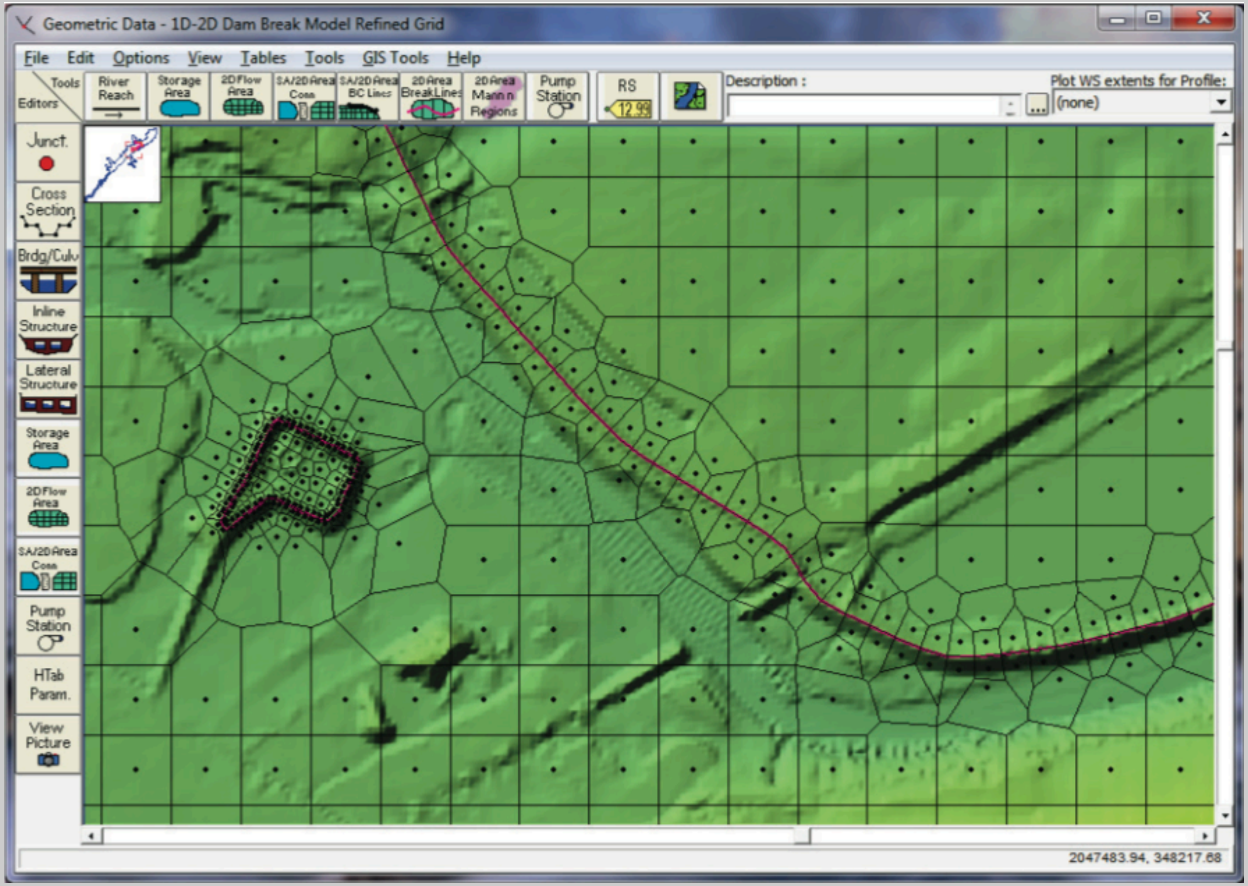


- ✓ This field is used to enter a default Manning's n values that will be used for the cell faces in the 2D flow area.
- ✓ This must be re-checked once a land cover layer is created and associated with the 2D geometry.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Assessing the 2D Computational Mesh:
  - The computational mesh will control the movement of water through the 2D flow area.
  - The computational cell faces control the flow movement from cell to cell.
  - One water surface elevation is calculated for each grid cell center at each time step.



- Within HEC-RAS, the underlying terrain and the computational mesh are preprocessed in order to develop detailed elevation–volume relationships for each cell, and also detailed hydraulic property curves for each cell face (elevation vs. wetted perimeter, area, and roughness).
- Where the water surface slope is flat and not changing rapidly, larger grid cell sizes are appropriate.
- Steeper slopes, and localized areas will require smaller grid cells to capture those changes.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

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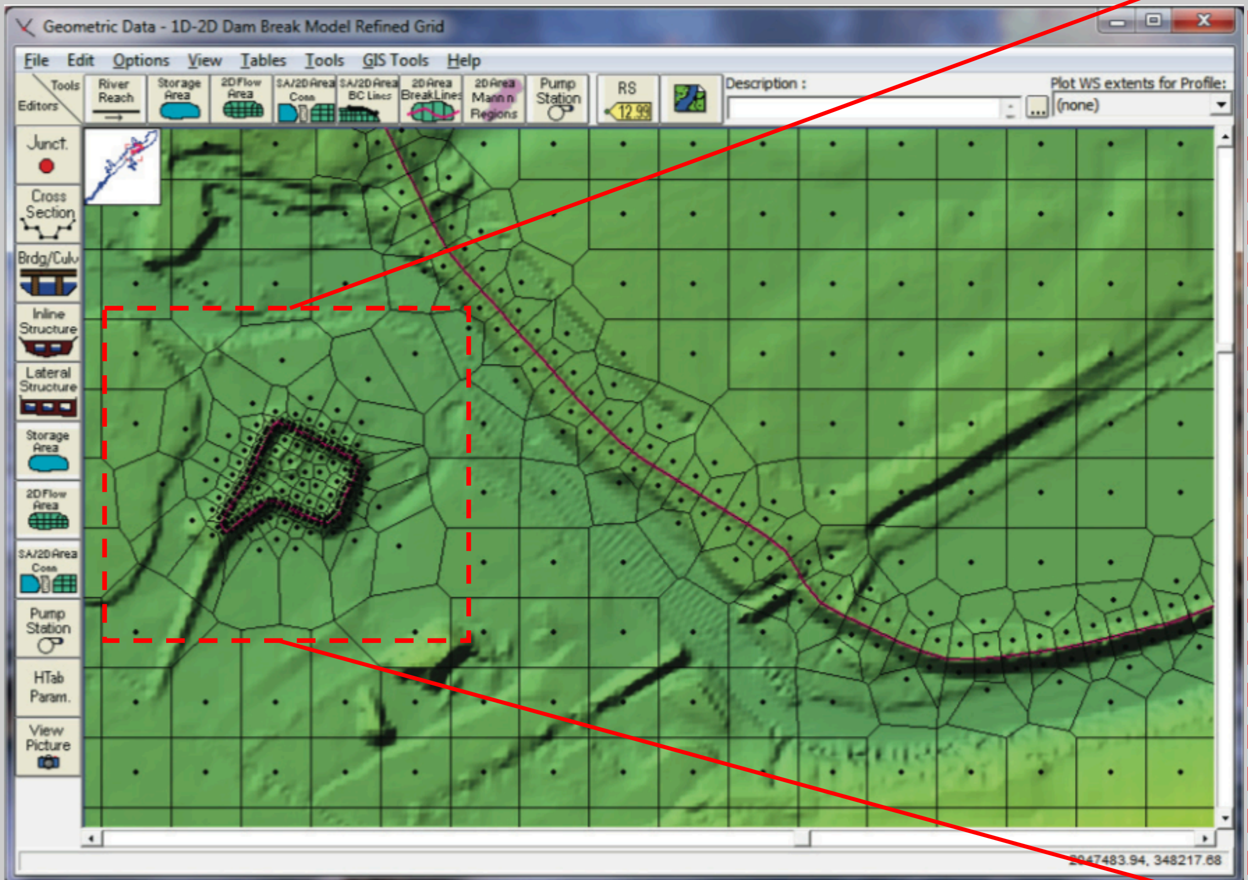
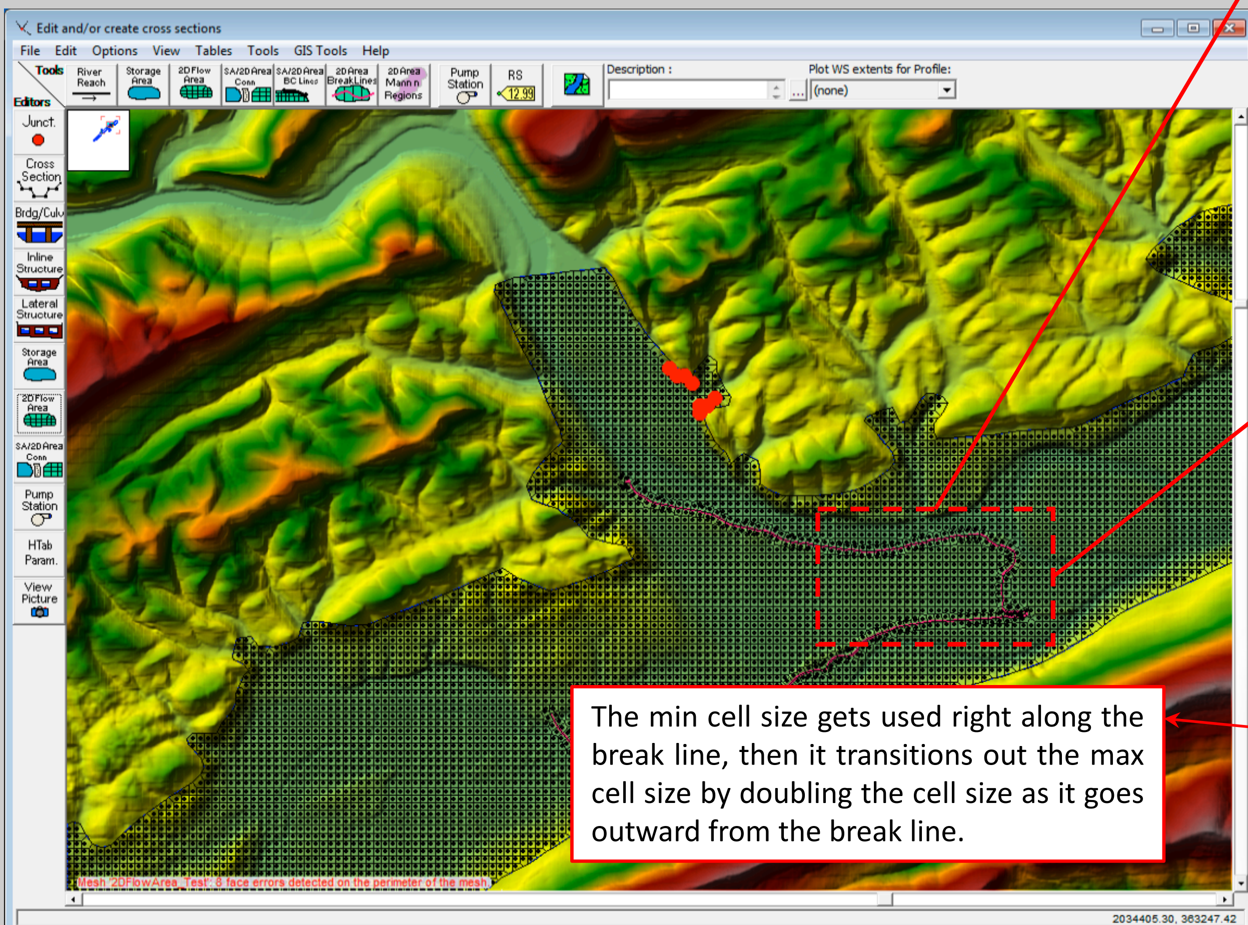
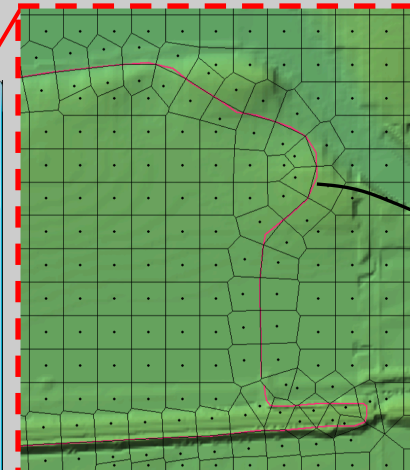


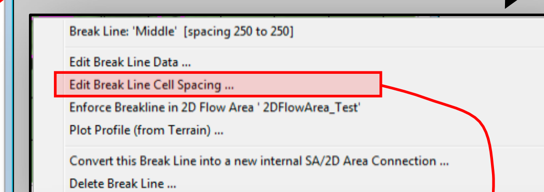
- HEC-RAS allows the user to enter a new break line on top of an existing mesh and then regenerate the mesh around that break line, without changing the computational points of the mesh in other areas.
- The user can draw a new break line, then left click on the break line and select the option **"Enforce Break line in 2D Flow Area"**. Once this option is selected, new cells will be generated around the break line with cell faces that are aligned along the break line.

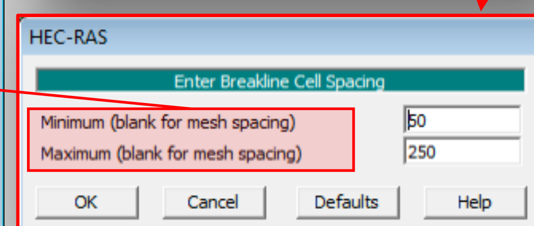
3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Assessing the 2D Computational Mesh:
  - The user can control the size/spacing of cells along the break line.
  - The option **"Edit Break Line Cell Spacing"** allows the user to enter a minimum and maximum cell spacing to be used when forming cells along that break line. The minimum cell spacing is used directly along the break line.





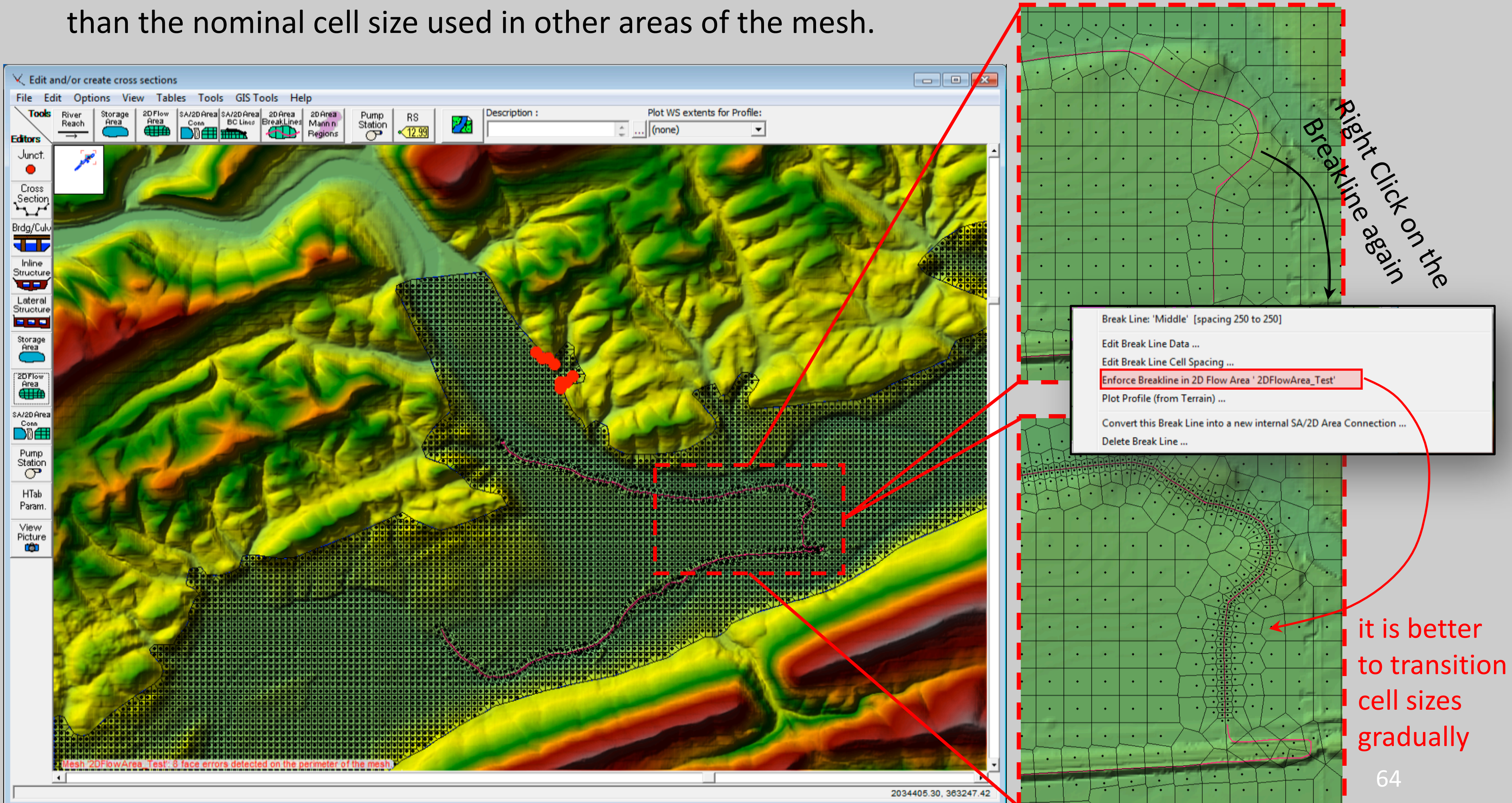




3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

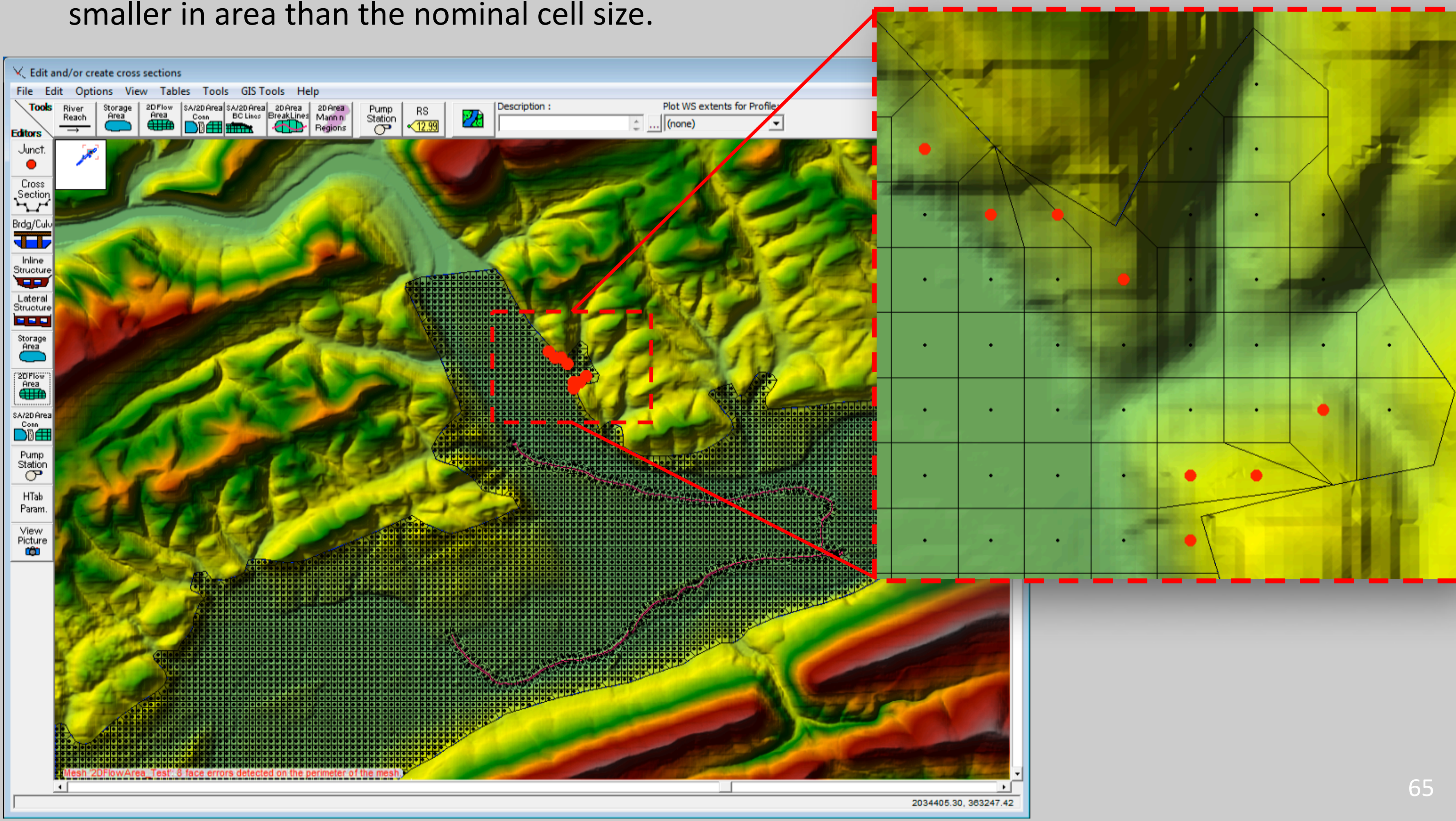
- Assessing the 2D Computational Mesh:

- After entering the break line cell spacing the user must select the **"Enforce Break line in 2D Flow Area"** option to enforce the new association of cell spacing.
- When creating a mesh around a break line, it may be desirable or even necessary to use smaller cells than the nominal cell size used in other areas of the mesh.



3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Assessing the 2D Computational Mesh:
  - Cells around the break lines and the 2D flow area boundary will typically be irregular in shape, in order to conform to the user specified break lines and boundary polygon.
  - The mesh generation tools utilize the irregular boundary, as well as try to ensure that no cell is smaller in area than the nominal cell size.



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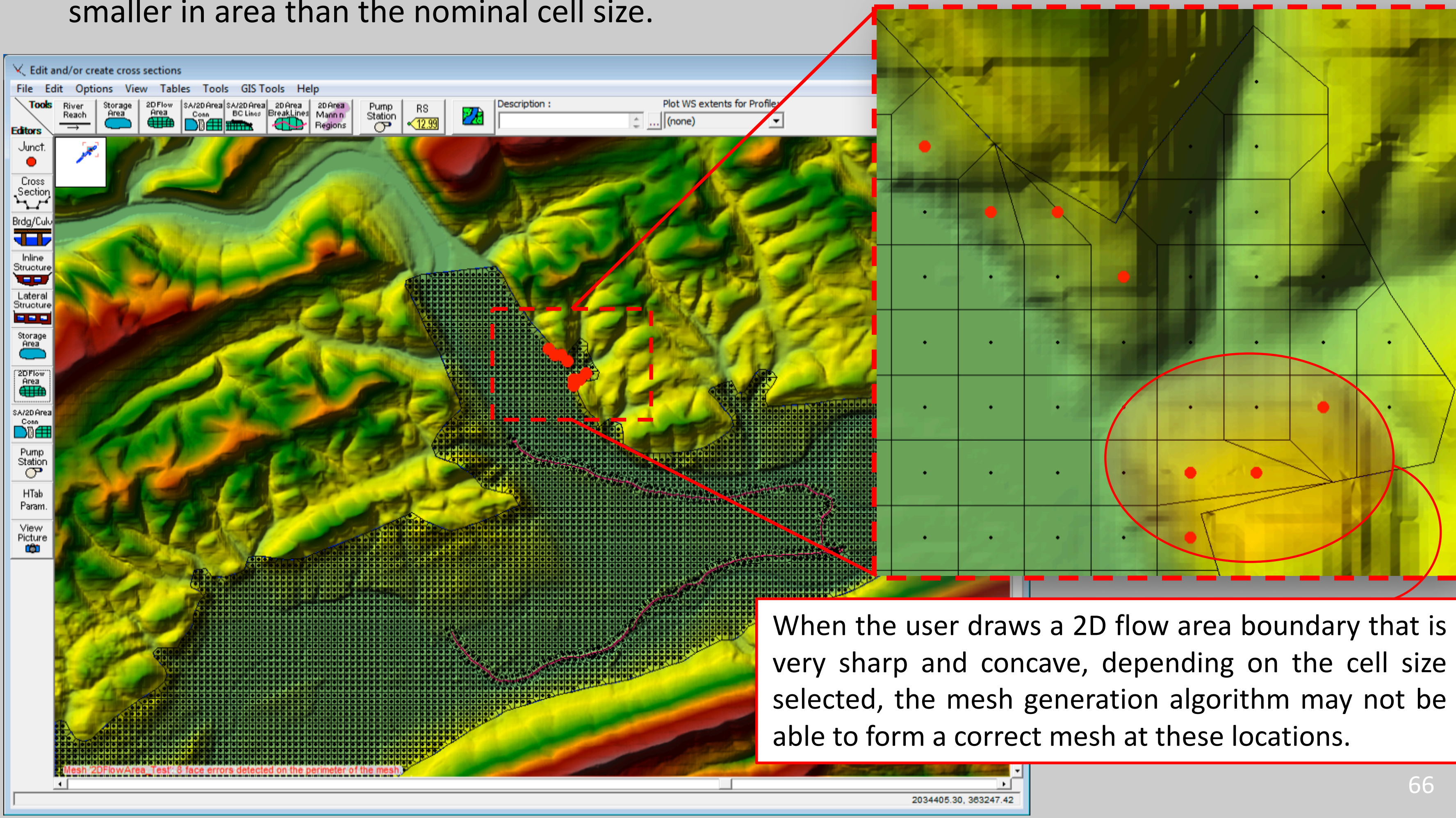

When the user draws a 2D flow area boundary that is very sharp and concave, depending on the cell size selected, the mesh generation algorithm may not be able to form a correct mesh at these locations.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

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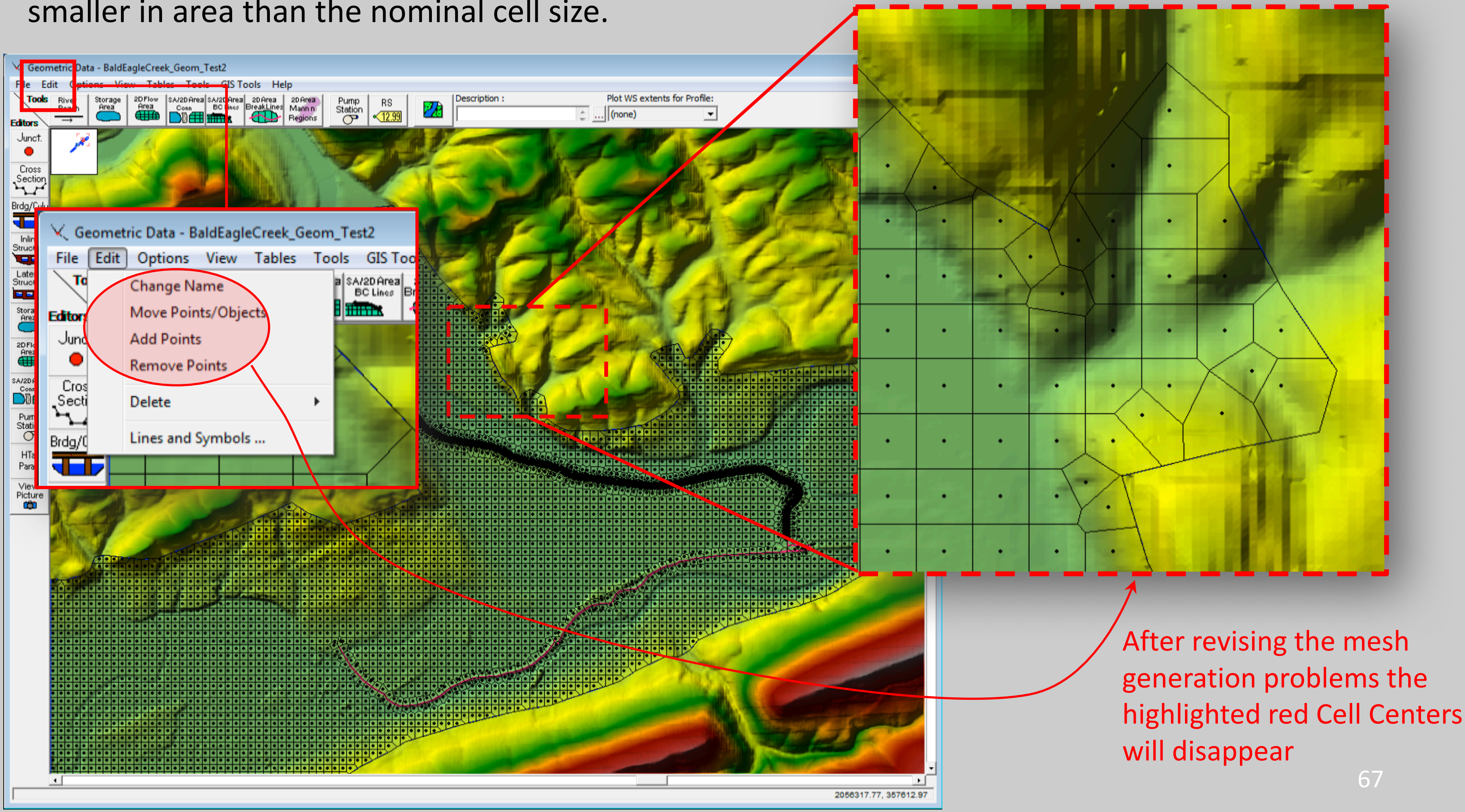
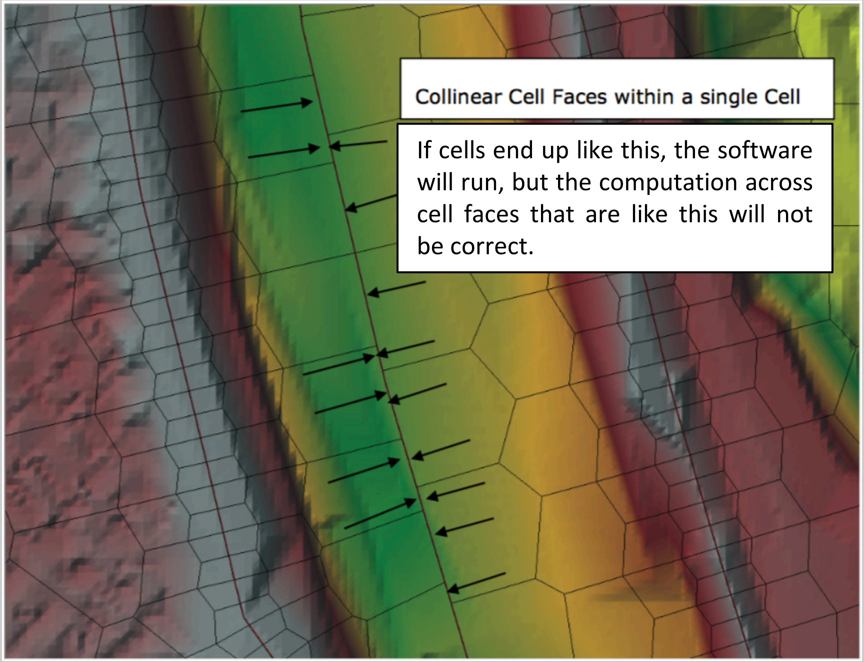
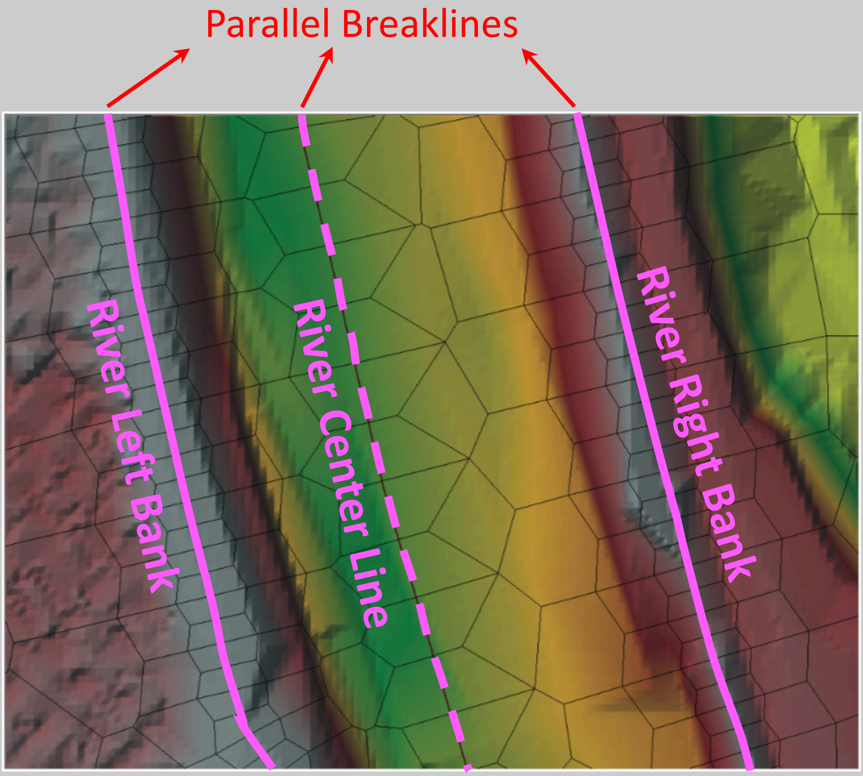


3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

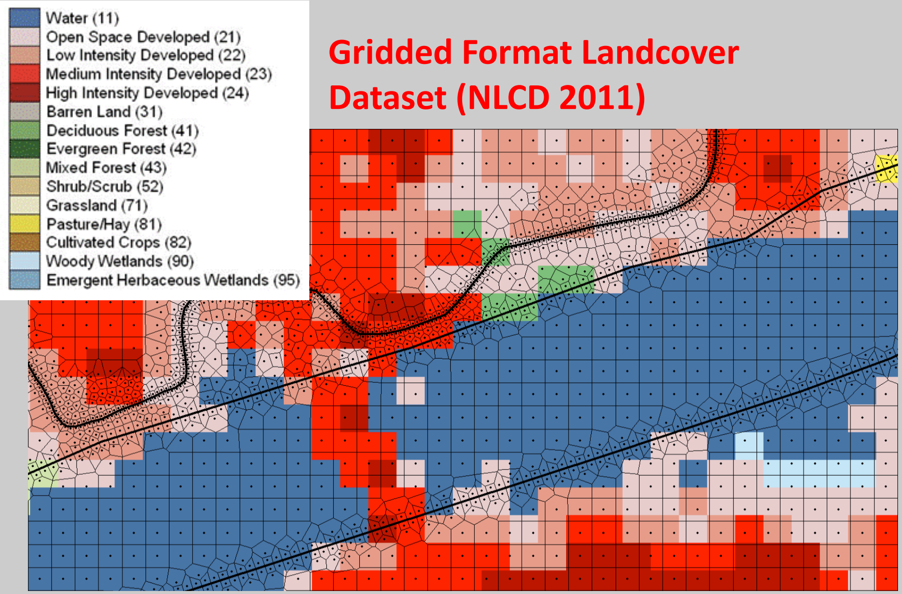
- Assessing the 2D Computational Mesh:
- Computational cells used within the HEC-RAS 2D code cannot have two faces that are collinear (i.e. they cannot form a straight line).
- The problem of **"Cell with Collinear Faces"** generally caused by placing two or more break lines parallel to each other, and close together, such that the creation of cells along one break line can create problems with cells along the other break line. (like the left figure below)
- Where two cells meet (at a face point), the outside angle formed by the two faces must be greater than 180 degrees.





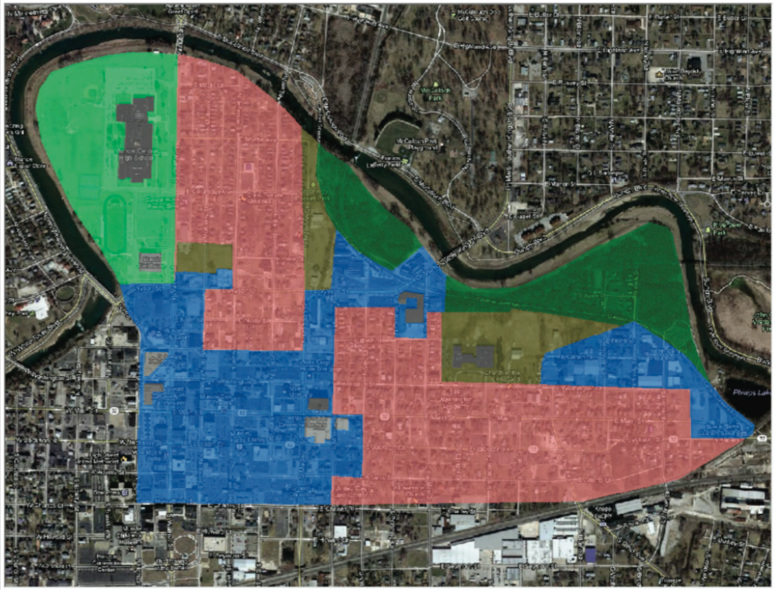
3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating a Spatially Varied Manning's Roughness Layer:
  - A spatially varying land cover data set can be created in RAS Mapper, and then associated with a specific geometry data set.
  - There are two types of land cover layers which can be applied in HEC-RAS 2D: 1. user defined polygons (shapefile) where user can override specific roughness values to a particular area, 2. Classified gridded layer (e.g. National Landcover Dataset layers).
  - **NOTE:** User's must have a land cover data set in order utilize spatially varying Manning's n values within 2D Flow Areas, and to also utilize the capability of specifying User define Manning's n Regions.
  - **RAS Mapper** allows the user to use multiple land use data files and types, to create a single land use coverage layer in HEC-RAS.
  - **RAS Mapper** ingests the various land use data types and creates a combined land-use coverage (Layer) and stores it as a **GeoTIFF file**.



Gridded Format Landcover Dataset (NLCD 2011)

User-defined polygon (shapefile) as landcover layers



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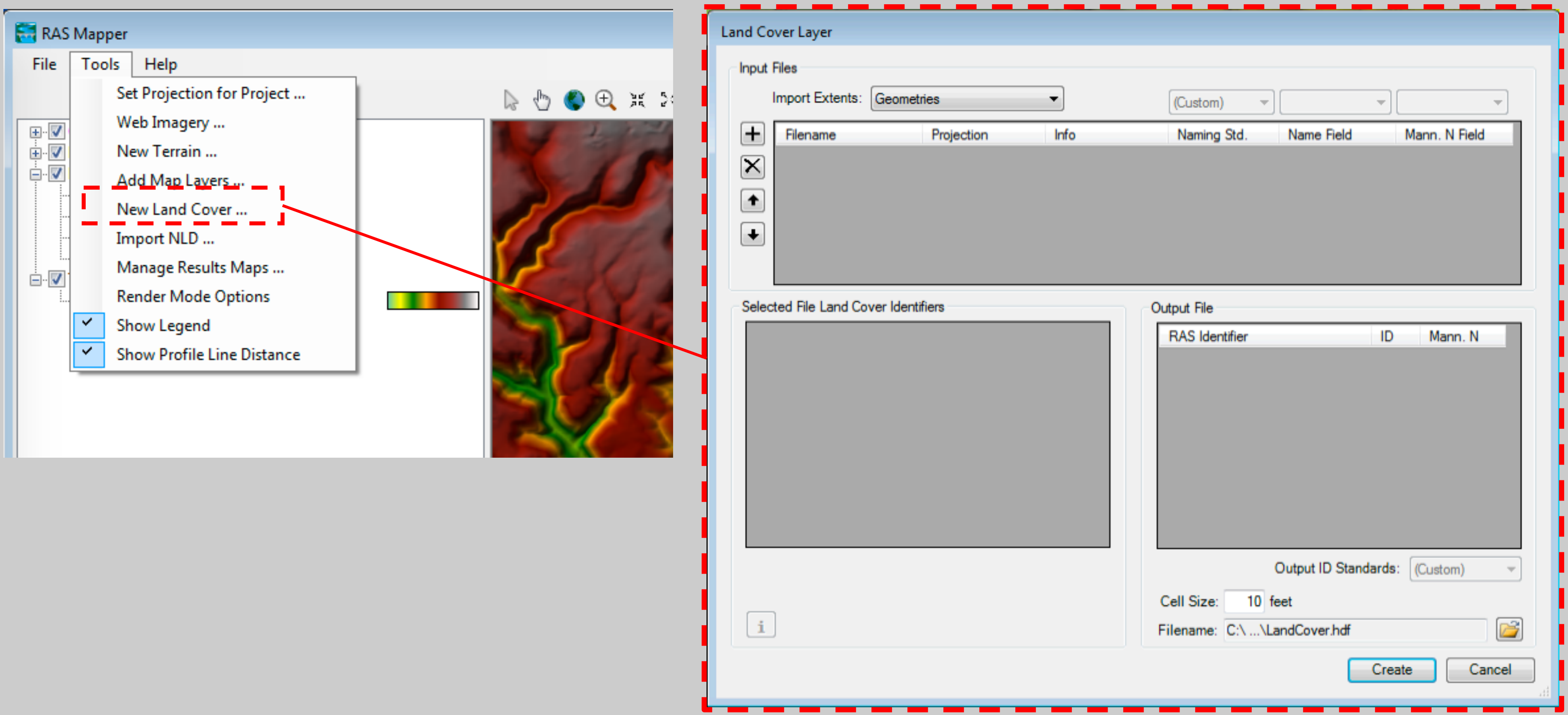

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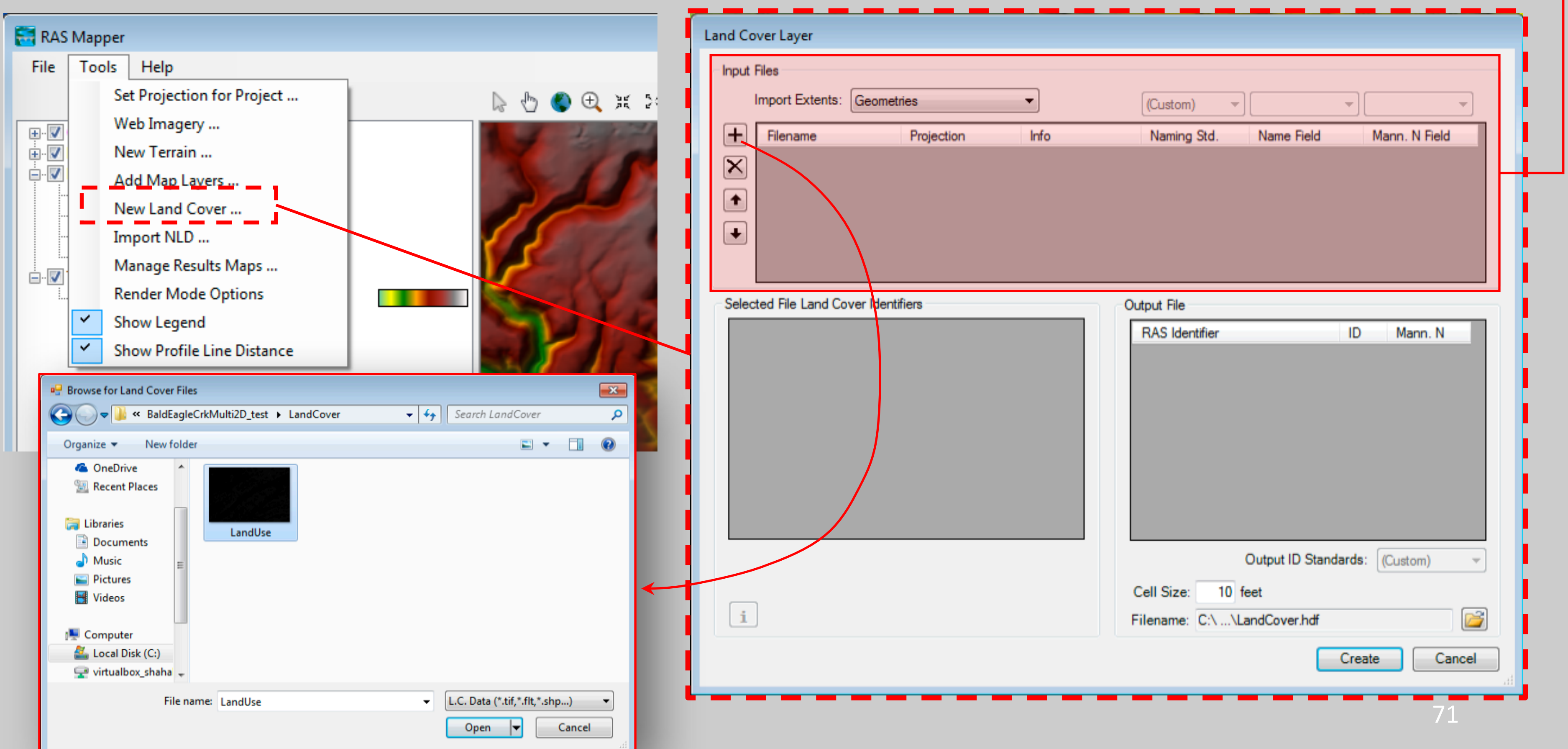
- Creating a Spatially Varied Manning's Roughness Layer:
  - A spatially varying land cover data set can be created in RAS Mapper, and then associated with a specific geometry data set.

The **"Input Files"** section is for selecting the grid and shapefiles to be used as input, as well as setting their priority.



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- Creating a Spatially Varied Manning's Roughness Layer:
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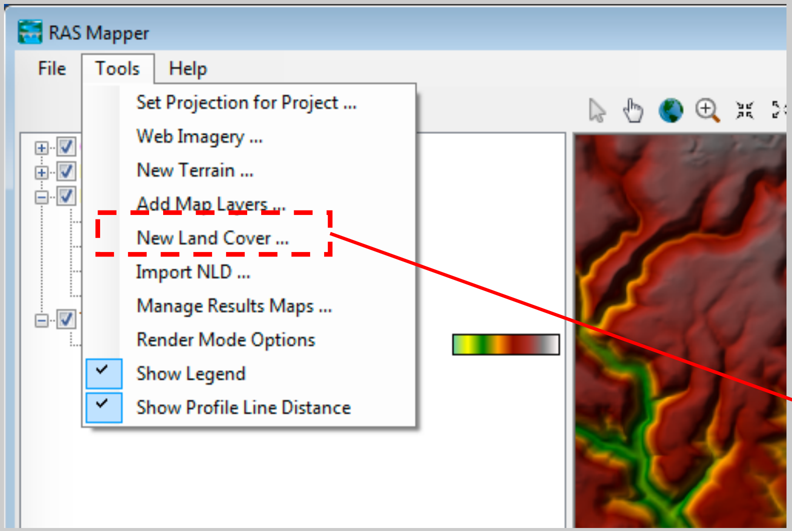
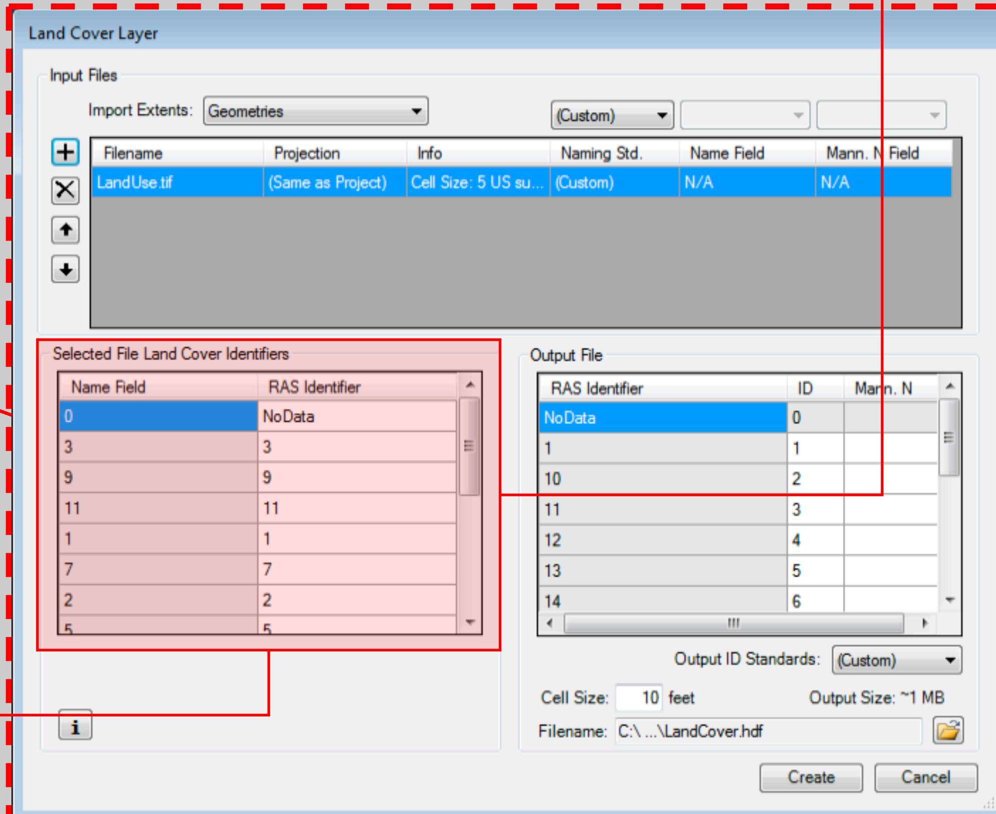
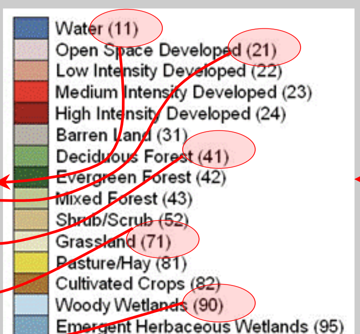
The Selected File Land Cover Identifiers section is used to display the numeric value (Integer) and the text label of the land cover data for the file currently selected (highlighted) in the Input Files section.





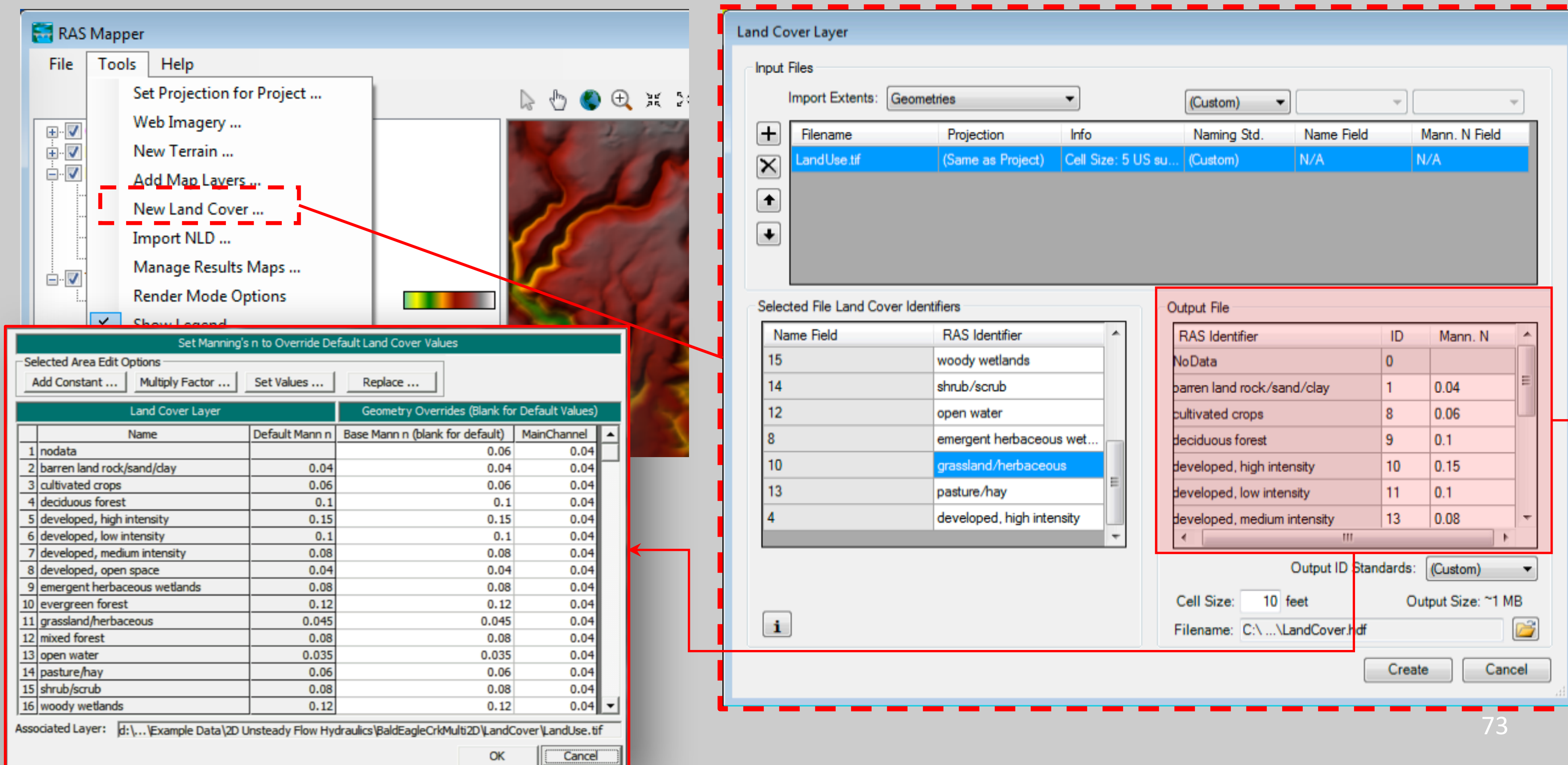
You can edit/rename the "RAS identifier" according to the **<u>NLCD 2011 landcover IDs</u>**.



3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating a Spatially Varied Manning's Roughness Layer:
  - A spatially varying land cover data set can be created in RAS Mapper, and then associated with a specific geometry data set.

The Output File section is used to show what HEC-RAS will use for the Land Cover Identifiers, their numeric ID, and optionally a user entered Manning's n value for each Land Cover type



3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating a Spatially Varied Manning's Roughness Layer:
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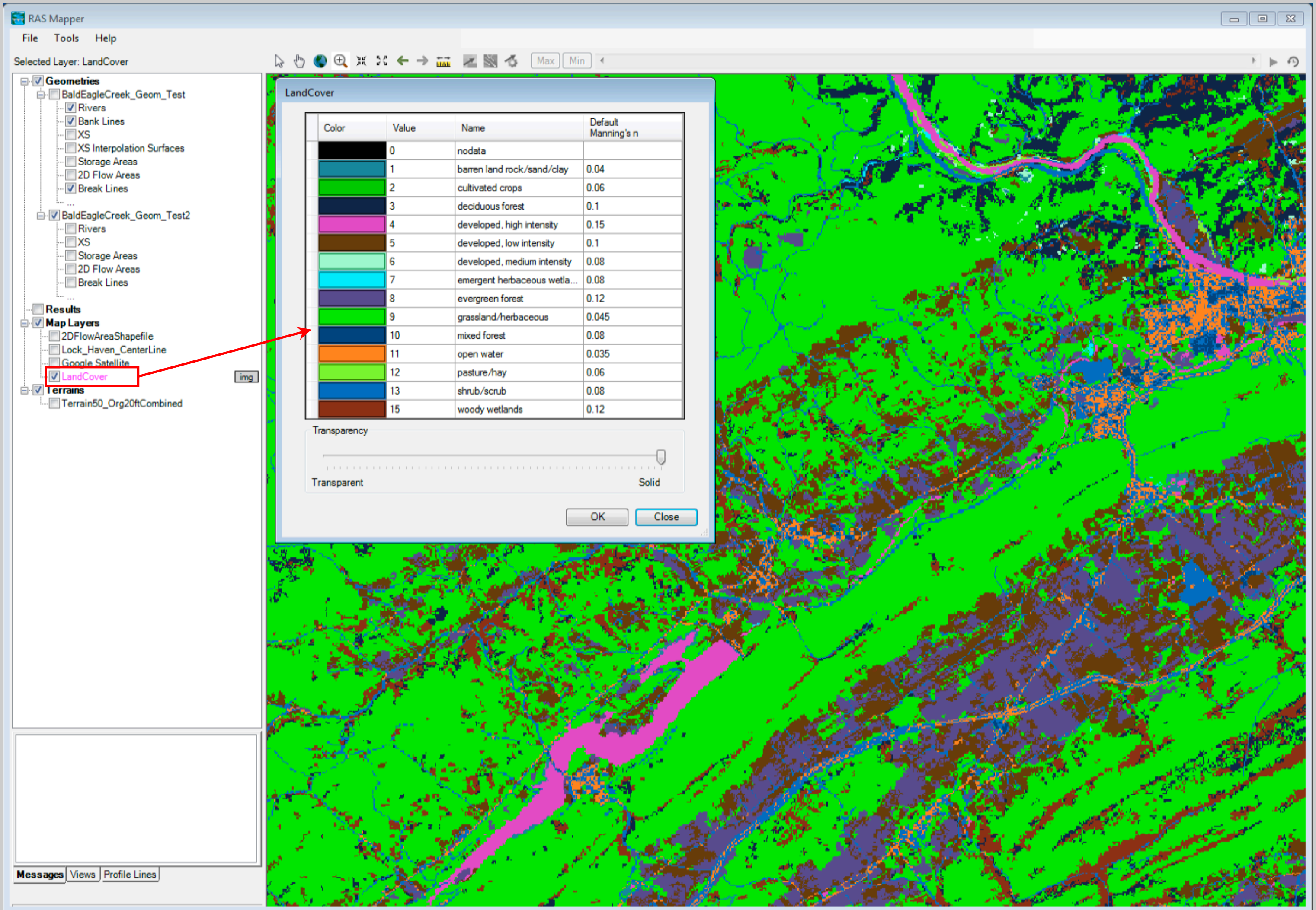

Once the user has created a Land Cover layer in the *.tif file format, then they need to associate that data layer with the geometry file(s) they want to use it with.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

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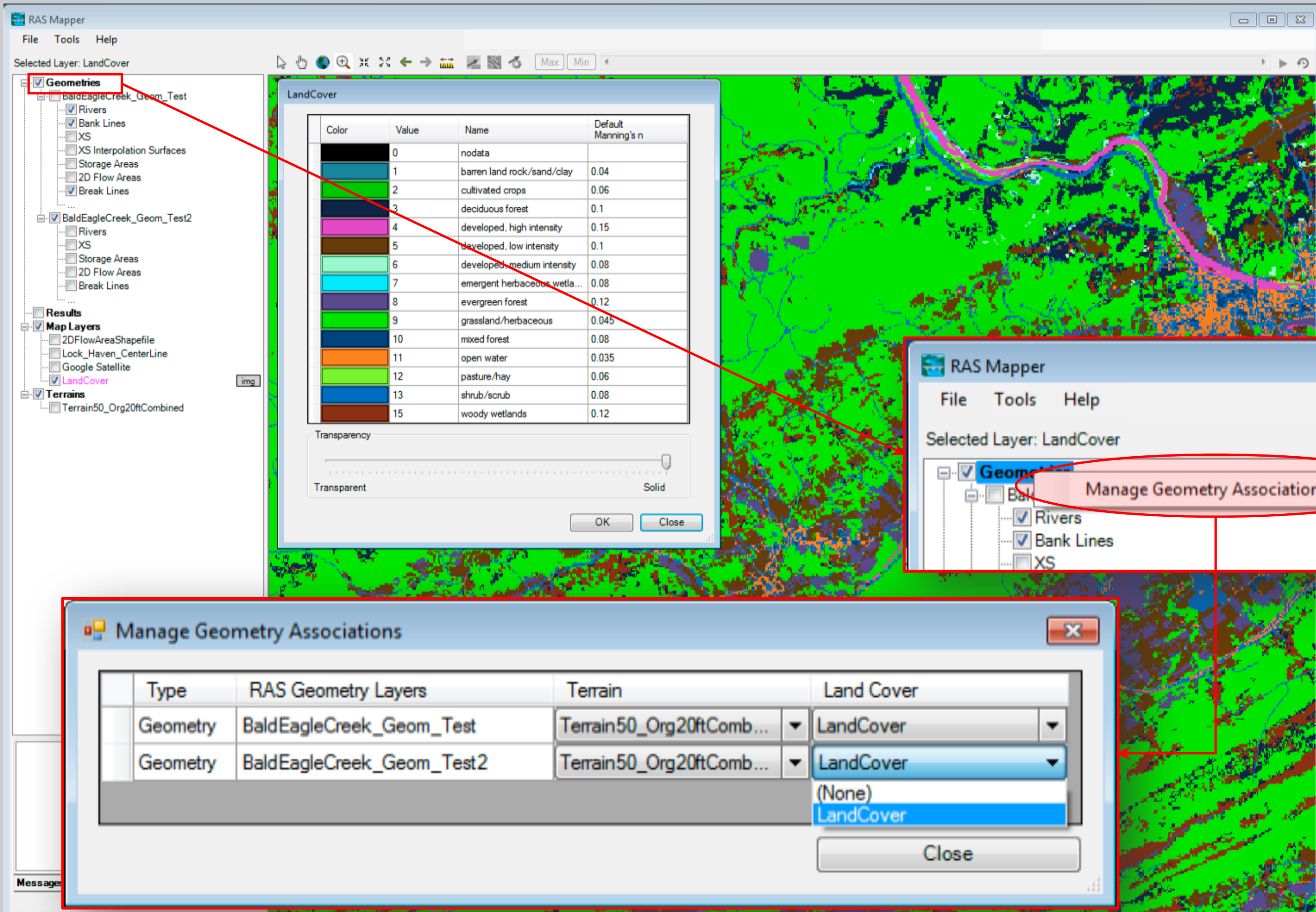
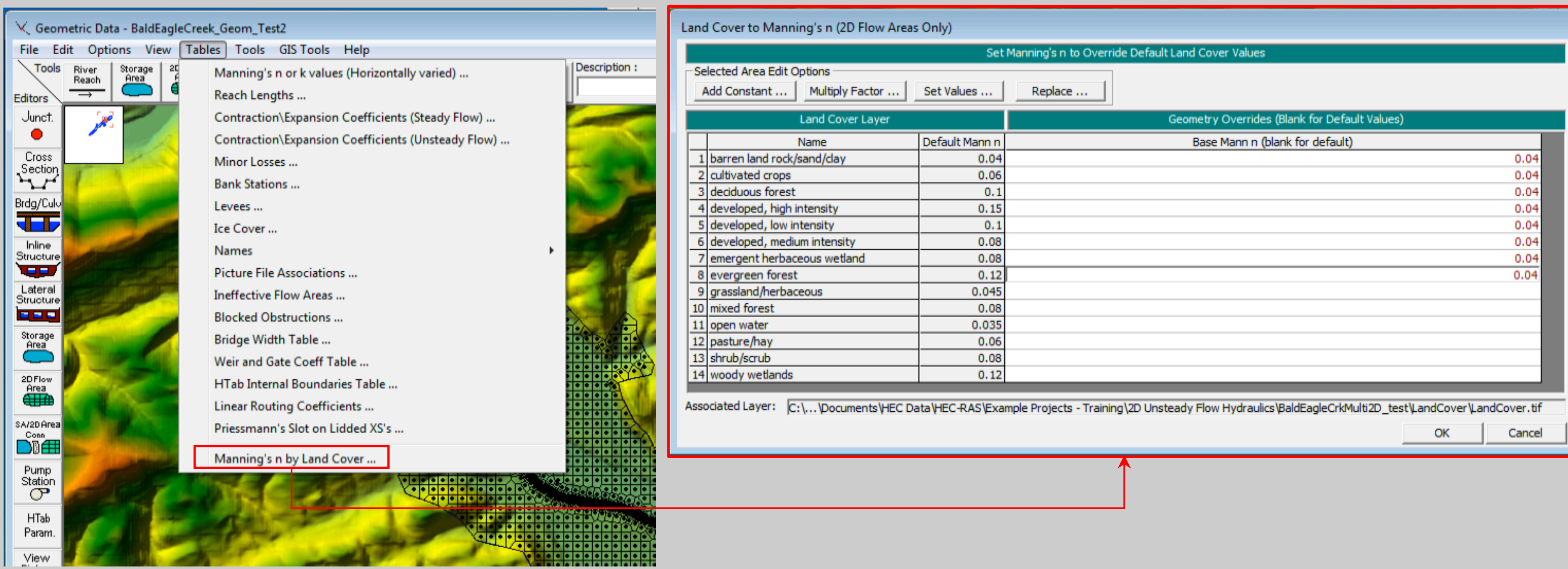


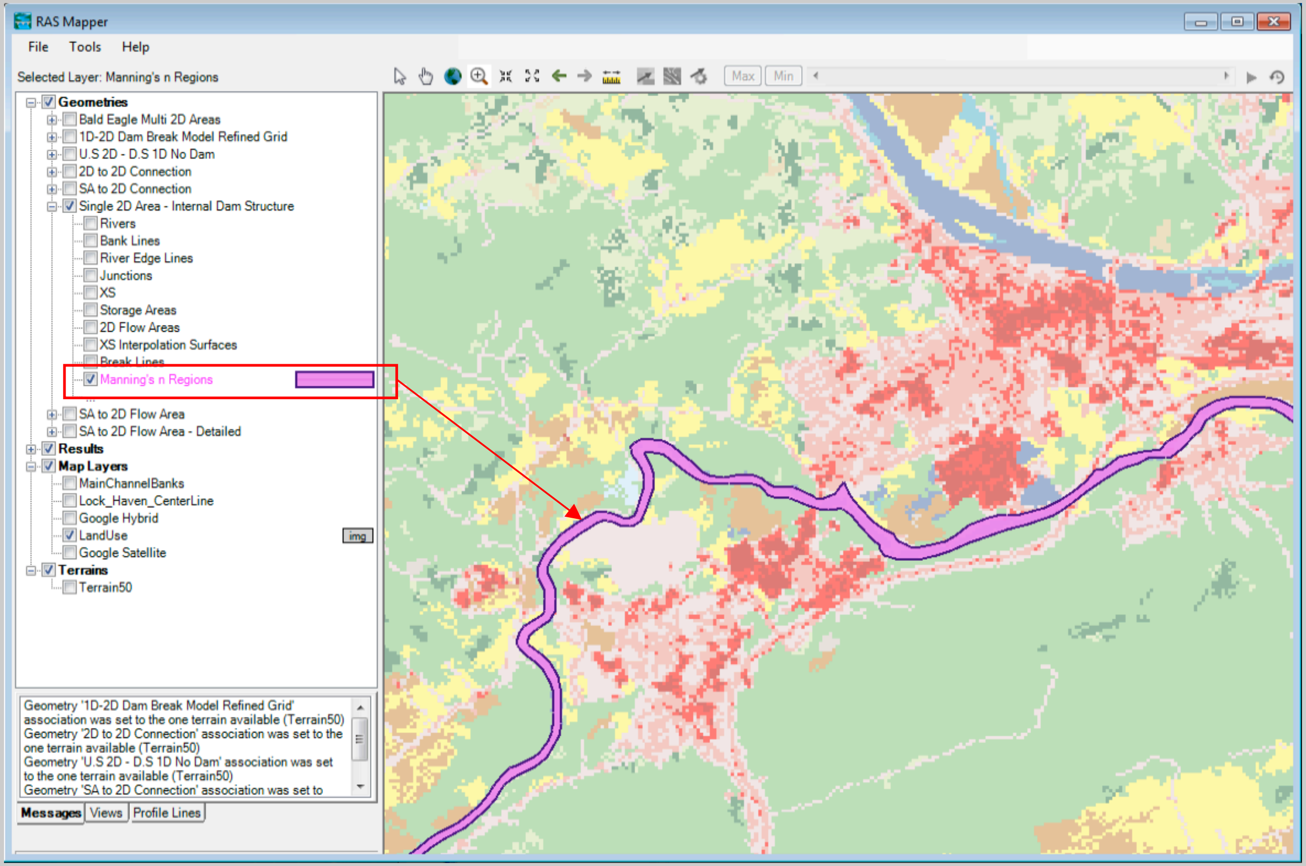
3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating a Spatially Varied Manning's Roughness Layer:
  - Once a Land Cover layer is associated with a geometry file, the user can then build a table of Land Cover versus Manning's n values, which can then be used in defining roughness values for 2D flow areas.
  - This Land Cover versus roughness table is developed from within the HEC-RAS geometric data editor for a specific geometry file.



3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating a Spatially Varied Manning's Roughness Layer:
  - In addition to defining Manning's n values by Land Cover, the user has the option to create their own 2D flow area Manning's n value regions.
  - These regions are user defined polygons that can be used to override the base Manning's n values within that polygon. They can also be used to calibrate a model.
  - The user defined 2D flow area **"Manning's n Regions"** are defined in the Geometric data editor, and apply only to that geometry file.

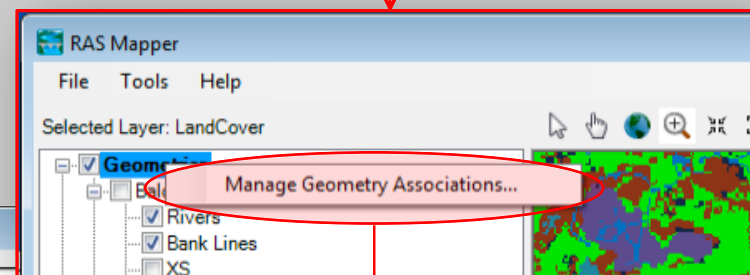


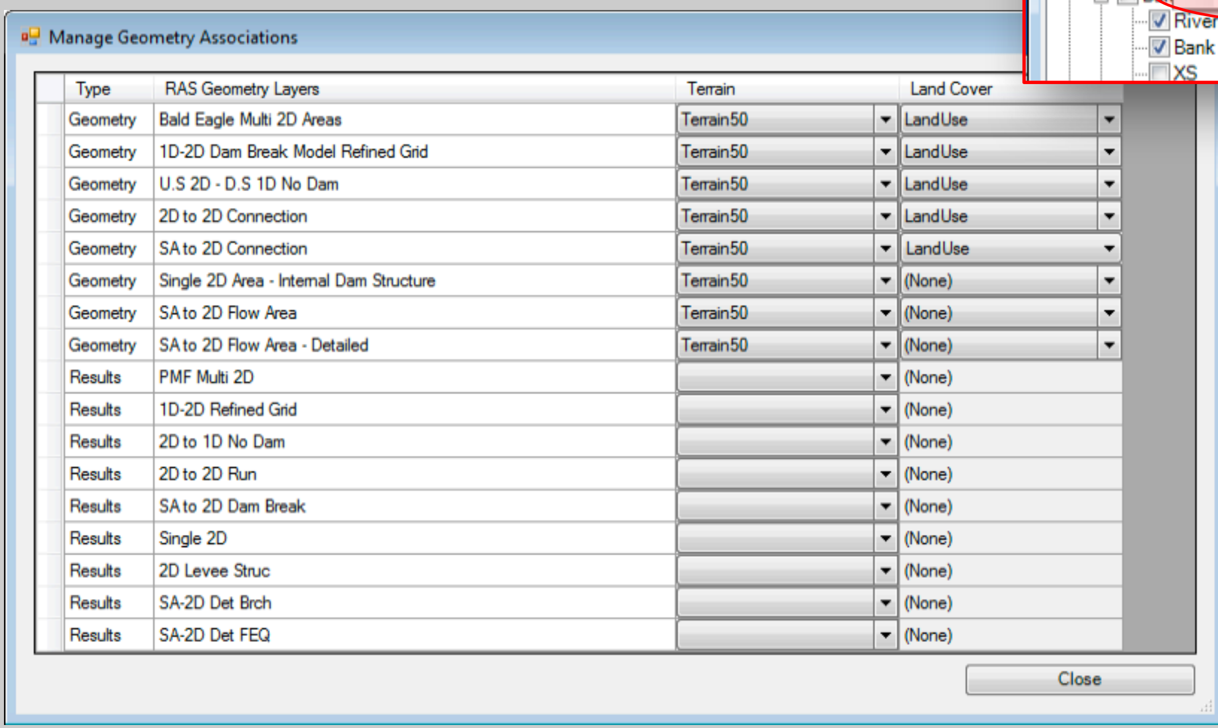
- This Manning's n by Land Cover table will be used during the 2D flow area pre- processing stage (i.e. the process where the software creates the cell and cell face table properties).
- In order to get these Manning's n values into the 2D flow area property tables, the 2D flow area Hydraulic Property tables **must be recomputed**.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating Hydraulic Property Tables for the 2D Cells and Cell Faces:

- Once a terrain model is created, and optionally a Manning's n by Land Cover table, then the following steps are required to create the hydraulic property tables for the 2D cells and cell faces, which are used in the 2D hydraulic computations:
  - ✓ **Associating a Terrain Layer with a Geometry File**
  - ✓ 2D Cell and Cell Face Geometric Preprocessor
  - ✓ Running the 2D Geometric Preprocessor





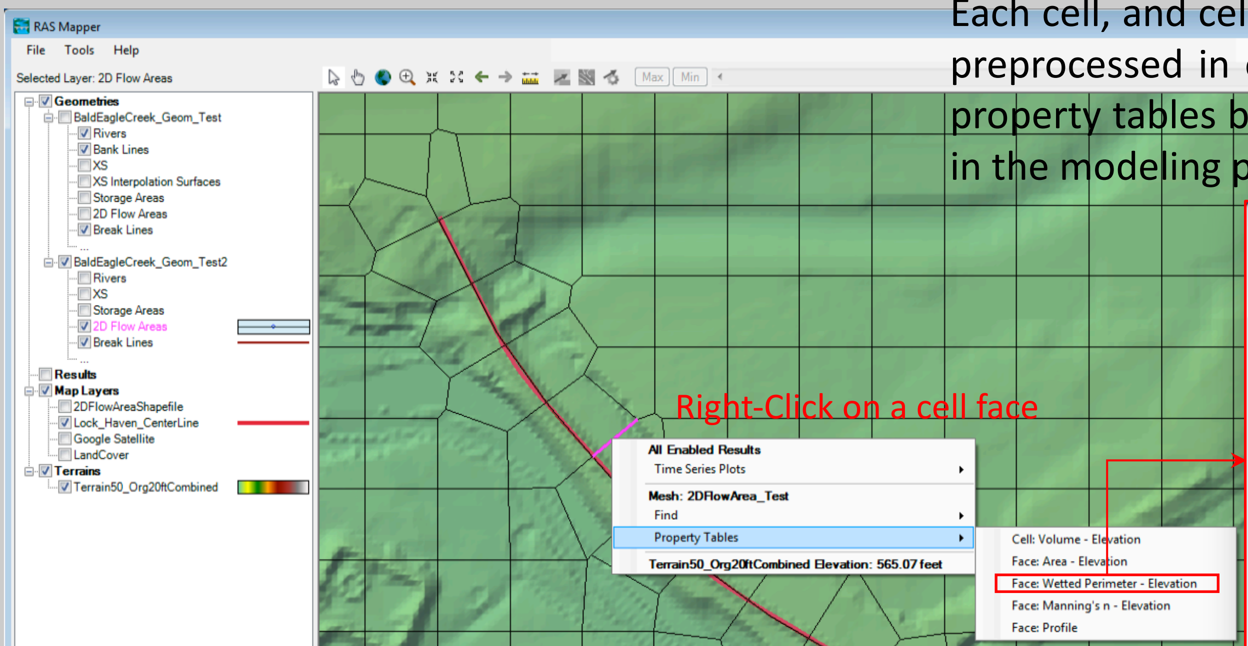
Type	RAS Geometry Layers	Terrain	Land Cover
Geometry	Bald Eagle Multi 2D Areas	Terrain50	LandUse
Geometry	1D-2D Dam Break Model Refined Grid	Terrain50	LandUse
Geometry	U.S 2D - D.S 1D No Dam	Terrain50	LandUse
Geometry	2D to 2D Connection	Terrain50	LandUse
Geometry	SA to 2D Connection	Terrain50	LandUse
Geometry	Single 2D Area - Internal Dam Structure	Terrain50	(None)
Geometry	SA to 2D Flow Area	Terrain50	(None)
Geometry	SA to 2D Flow Area - Detailed	Terrain50	(None)
Results	PMF Multi 2D		(None)
Results	1D-2D Refined Grid		(None)
Results	2D to 1D No Dam		(None)
Results	2D to 2D Run		(None)
Results	SA to 2D Dam Break		(None)
Results	Single 2D		(None)
Results	2D Levee Struc		(None)
Results	SA-2D Det Brch		(None)
Results	SA-2D Det FEQ		(None)

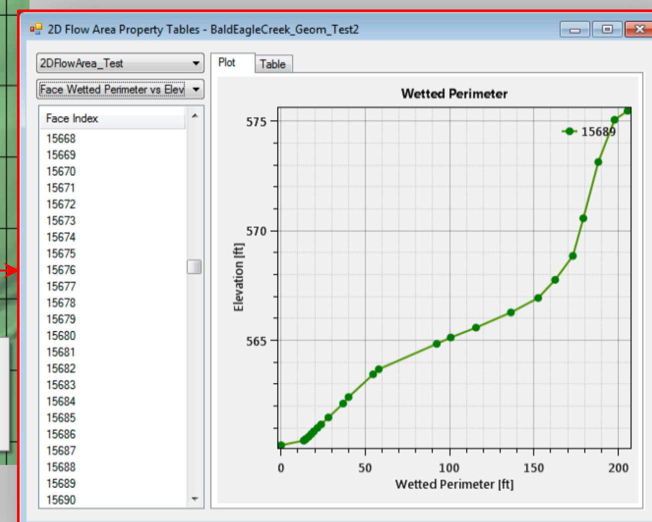
3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating Hydraulic Property Tables for the 2D Cells and Cell Faces:

- Once a terrain model is created, and optionally a Manning's n by Land Cover table, then the following steps are required to create the hydraulic property tables for the 2D cells and cell faces, which are used in the 2D hydraulic computations:
  - ✓ Associating a Terrain Layer with a Geometry File
  - ✓ **2D Cell and Cell Face Geometric Preprocessor**
  - ✓ Running the 2D Geometric Preprocessor

Each cell, and cell face, of the computational mesh is preprocessed in order to develop detailed hydraulic property tables based on the underlying terrain used in the modeling process





3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- Creating Hydraulic Property Tables for the 2D Cells and Cell Faces:
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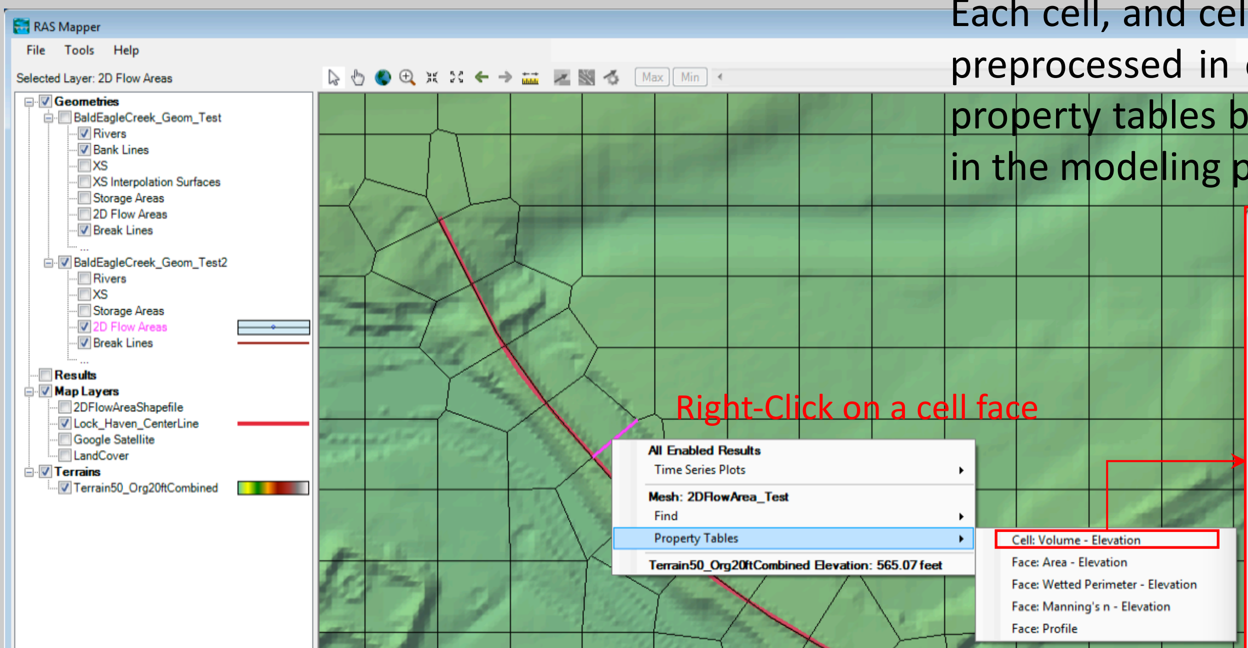

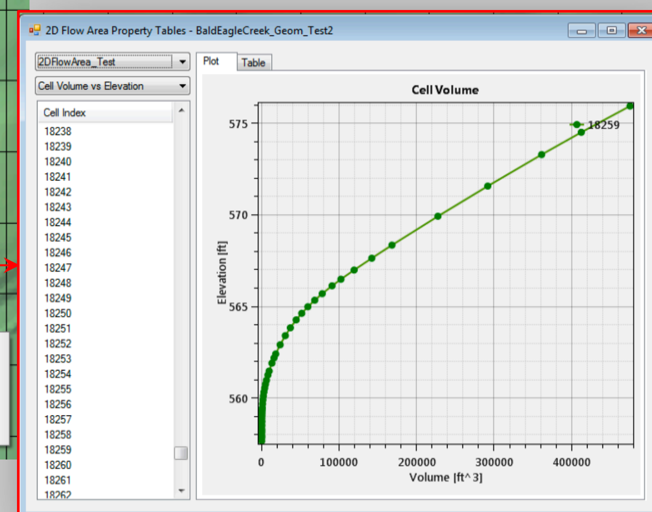

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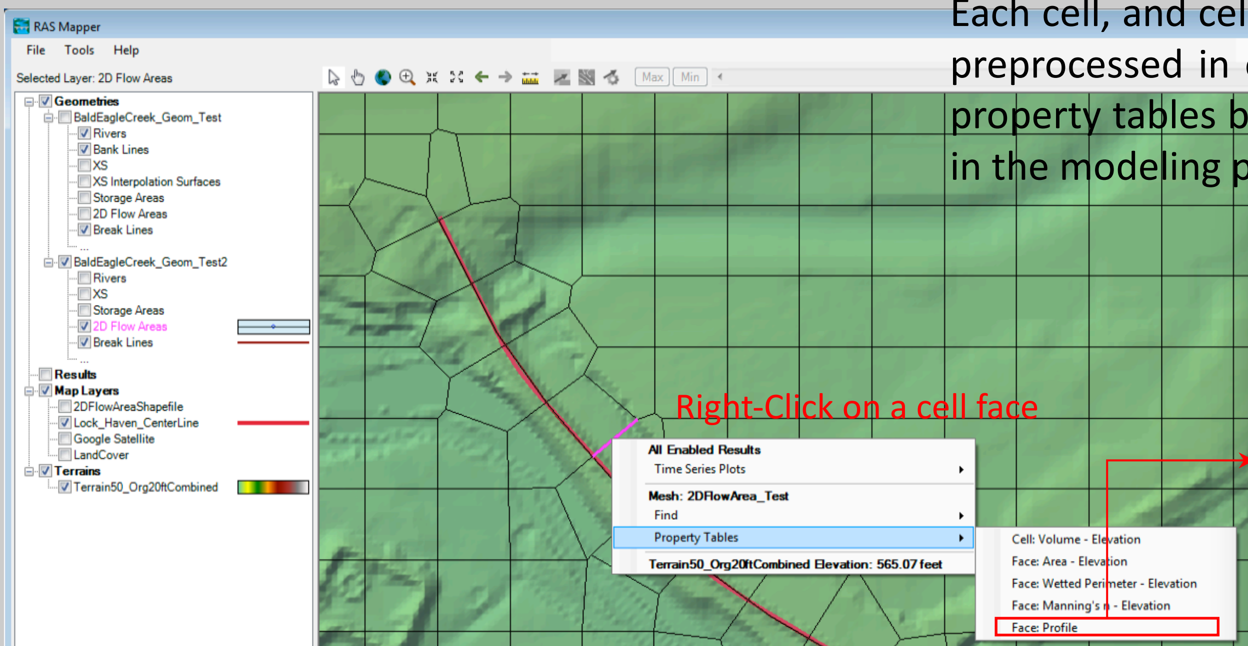

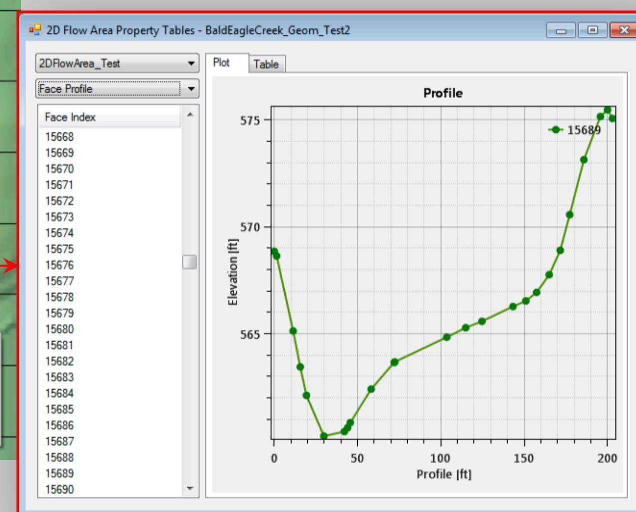

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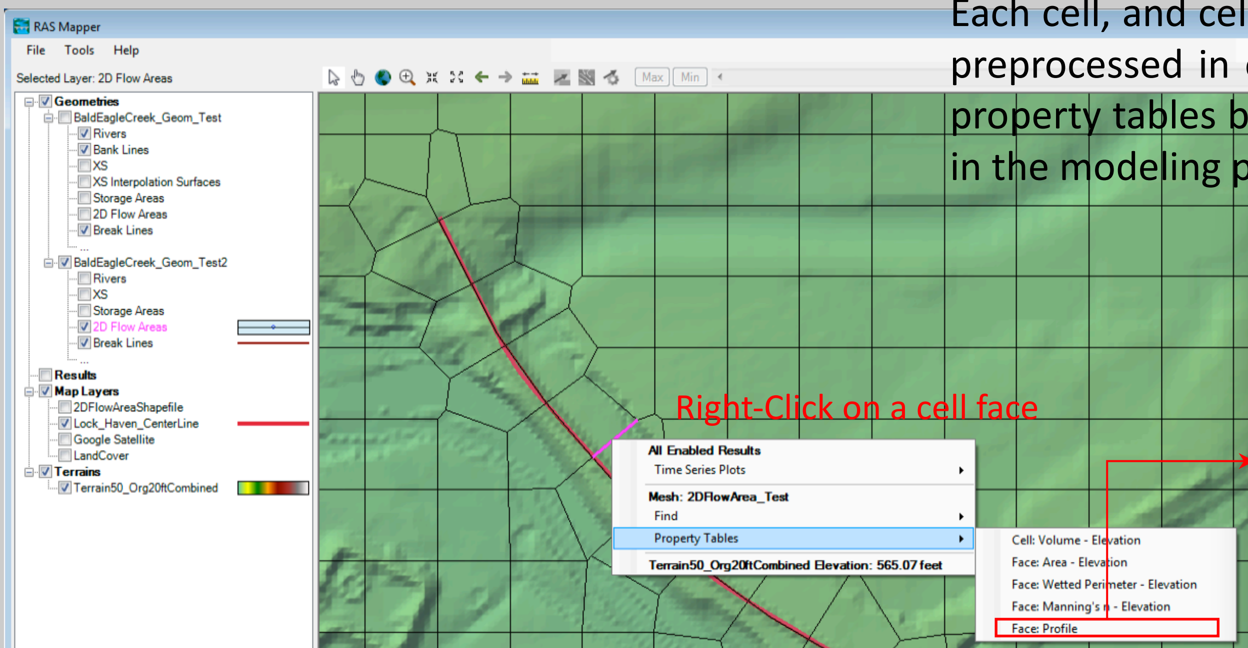

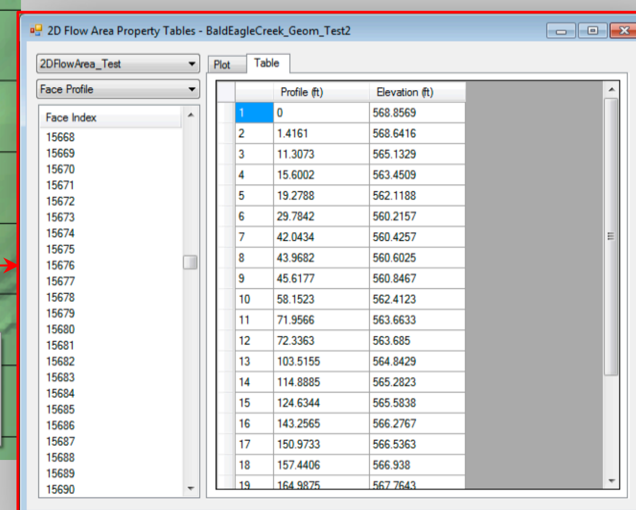

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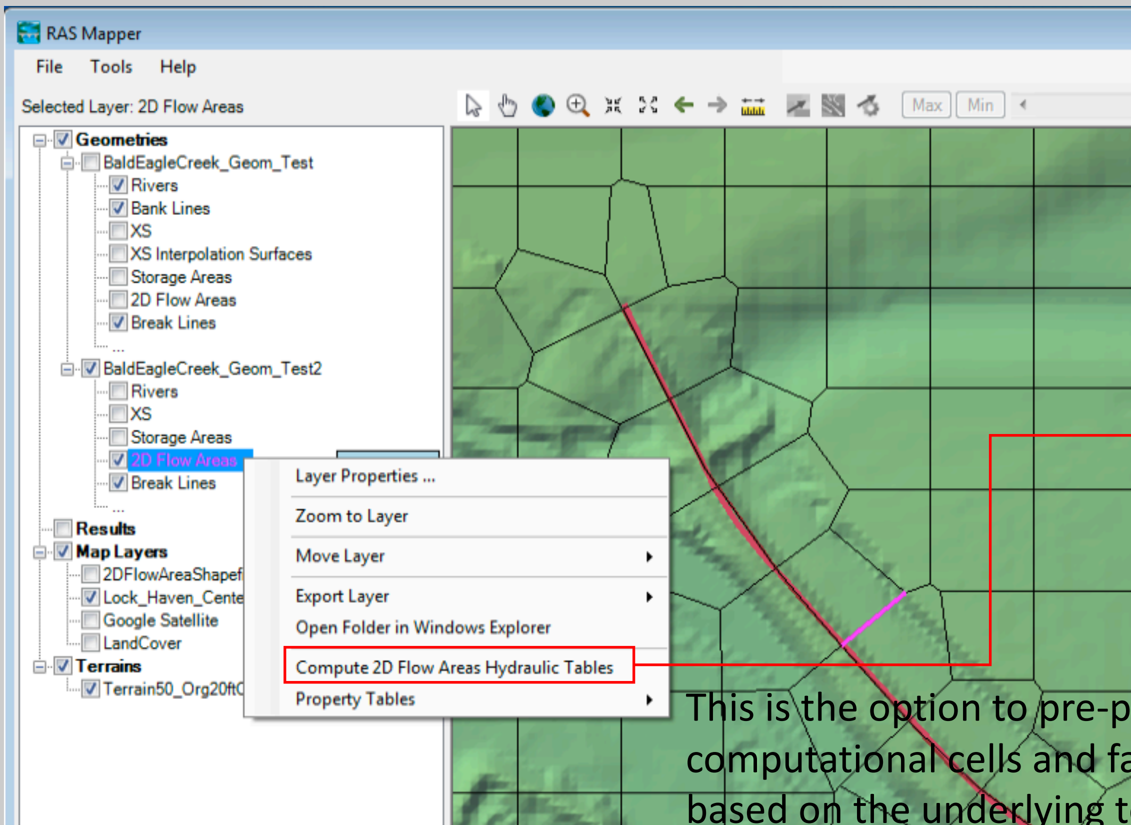
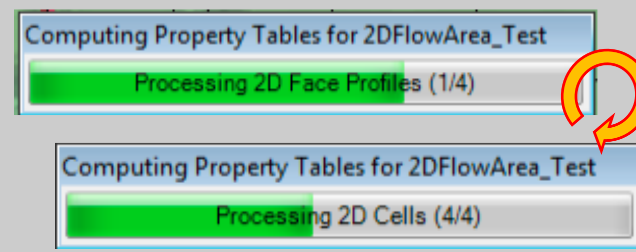
  - ✓ **Running the 2D Geometric Preprocessor**



After associating the geometry files with the terrain layer, the user can run the 2D flow area geometric pre-processor from within RAS Mapper.

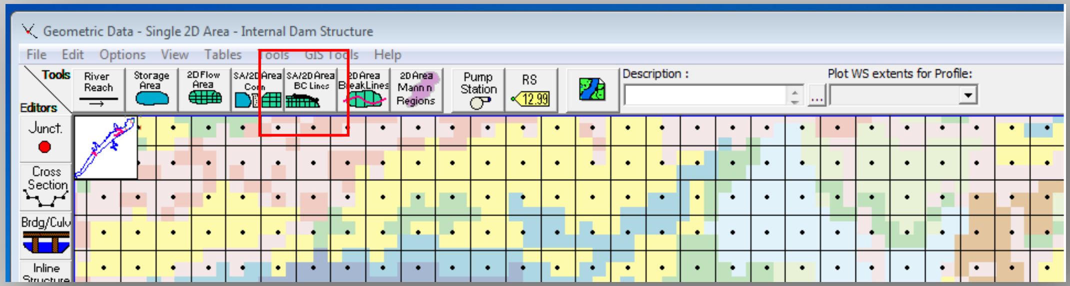


This is the option to pre-process the 2D flow area computational cells and faces into detailed tables based on the underlying terrain data.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- External 2D flow area Boundary Conditions:

- In addition to connecting a 2D flow area to 1D River Reaches and Storage Areas, there are five types of external boundary conditions that can be linked directly to the 2D flow areas:
  - ✓ Flow Hydrograph
  - ✓ Stage Hydrograph
  - ✓ Normal Depth
  - ✓ Rating Curve
  - ✓ Precipitation



- The **Normal Depth** and **Rating Curve** boundary conditions can only be used at locations where flow will leave a 2D flow area.
- The **Flow** and **Stage Hydrograph** boundary conditions can be used for putting flow into or taking flow out of a 2D flow area.
- For a **Flow Hydrograph**, positive flow values will send flow into a 2D flow area, and negative flow values will take flow out of a 2D area.
- For the **Stage Hydrograph**, stages higher than the ground/water surface in a 2D flow area will send flow in, and stages lower than the water surface in the 2D flow area will send flow out.
- If a cell is dry and the **Stage** boundary condition is lower than the 2D flow area cell minimum elevation, then no flow will transfer.
- The **Precipitation** boundary condition can be applied directly to any 2D flow area as a time series of rainfall excesses

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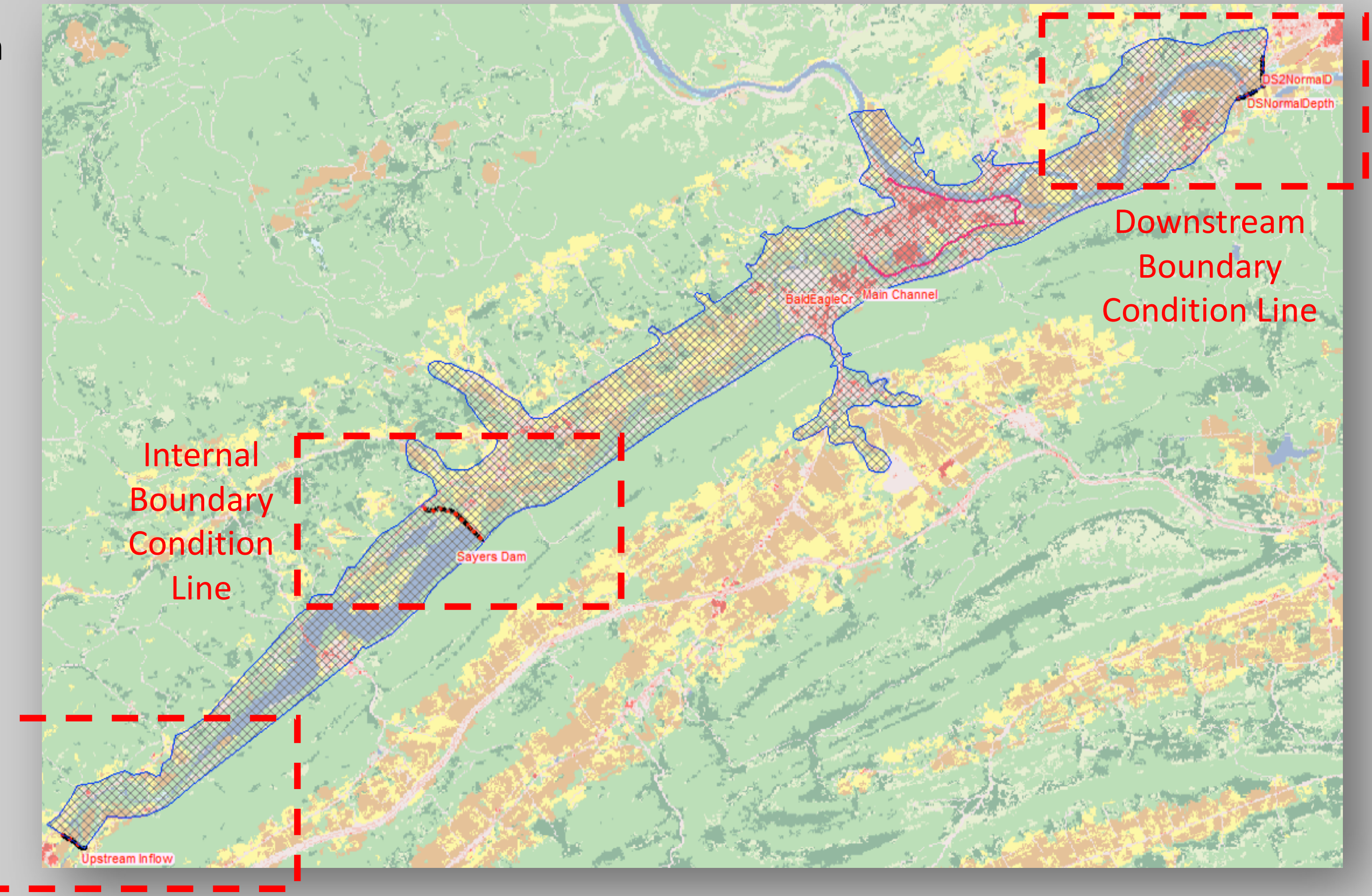

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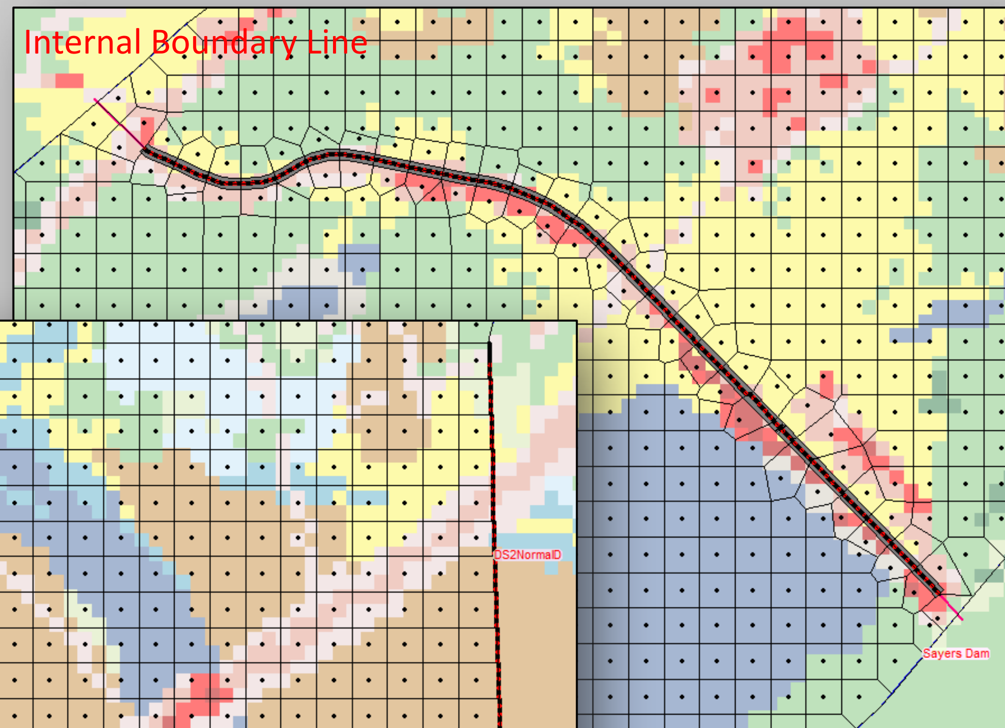

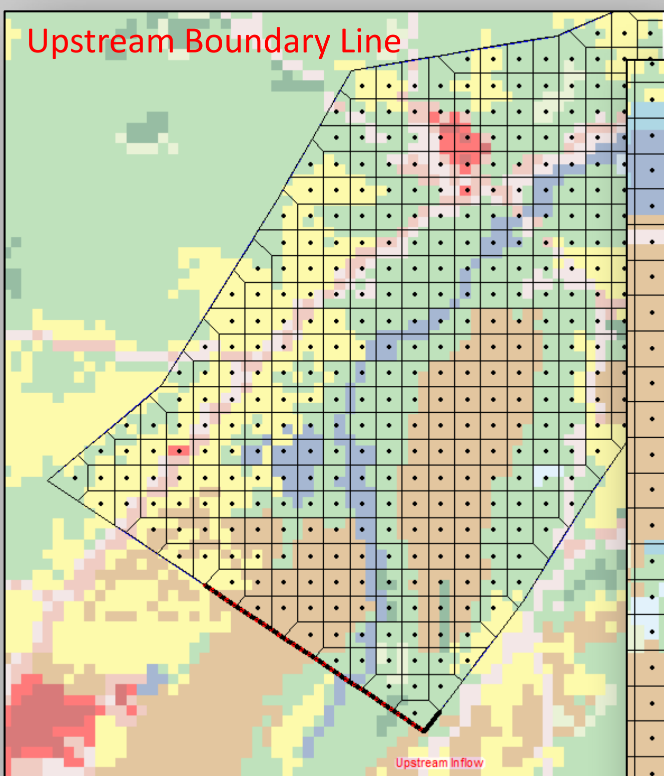

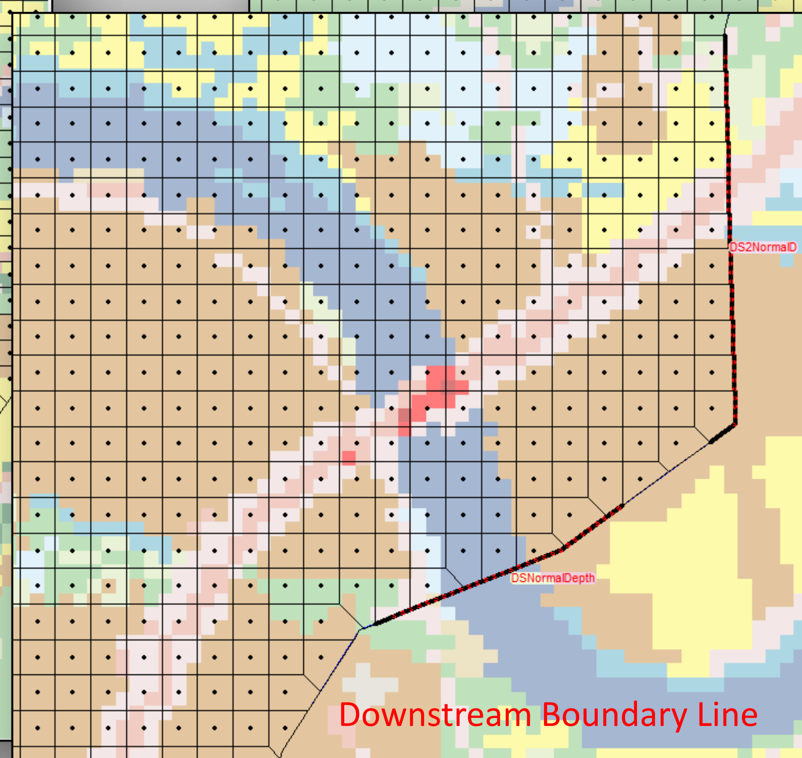

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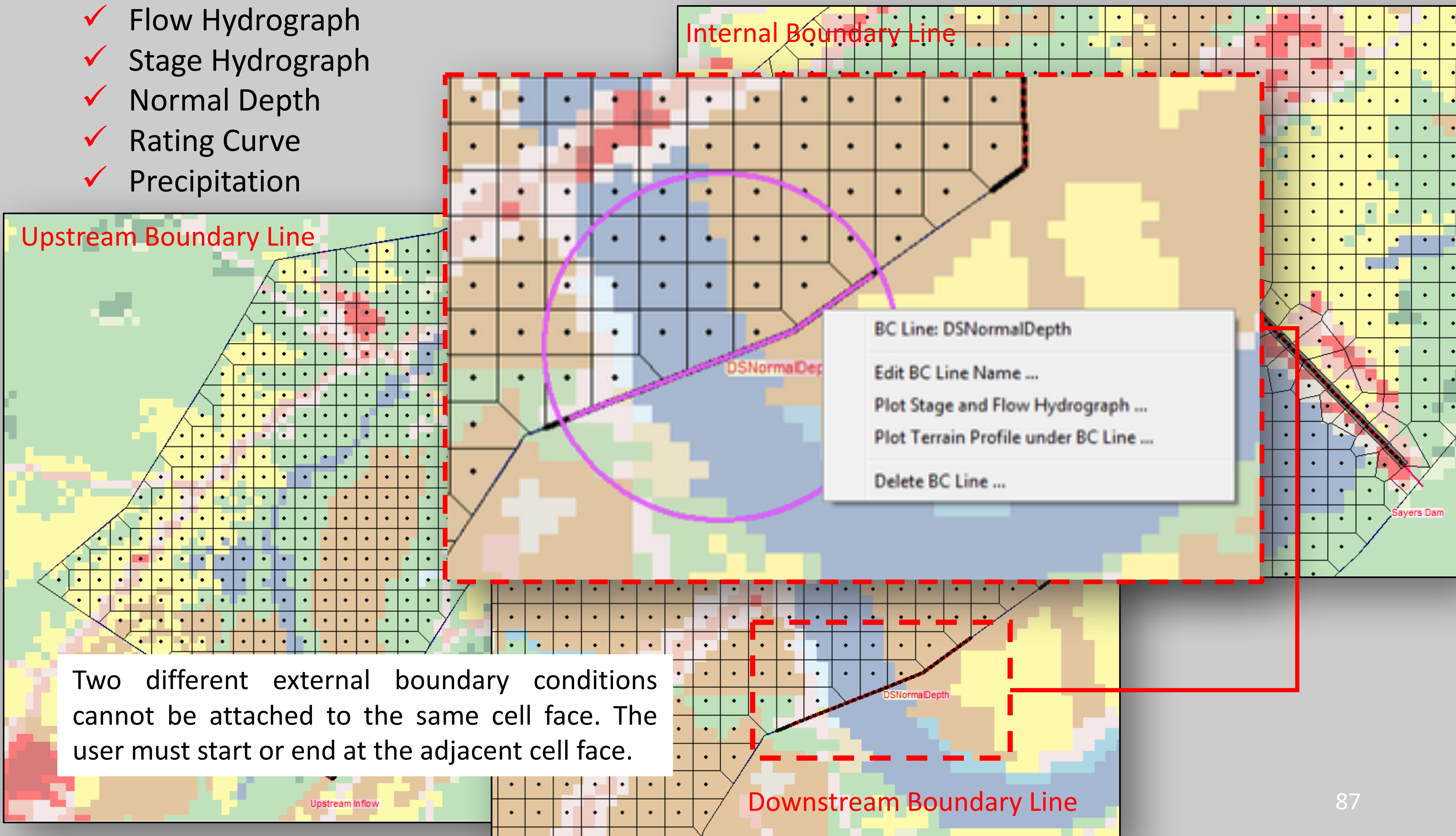
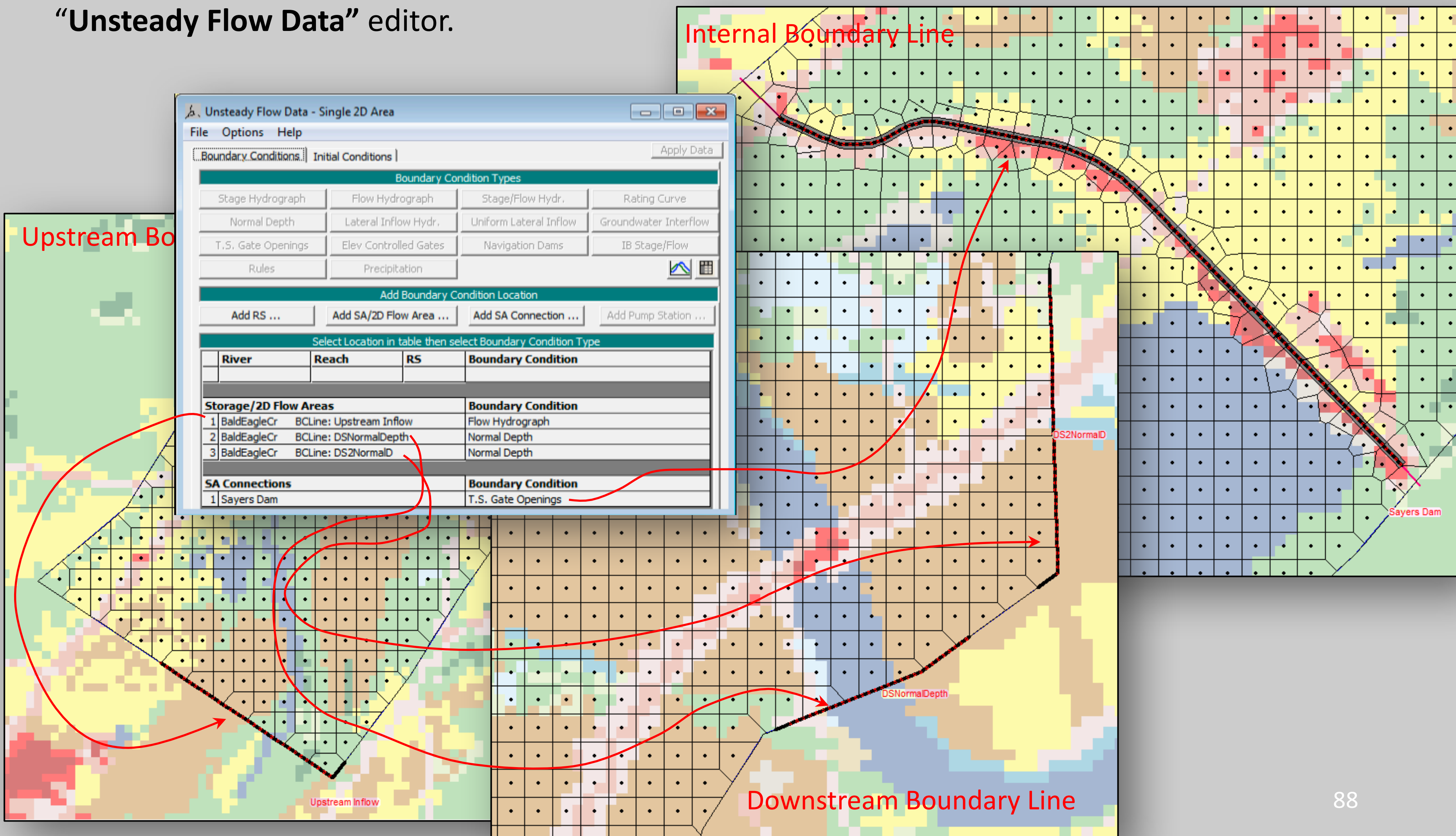


Two different external boundary conditions cannot be attached to the same cell face. The user must start or end at the adjacent cell face.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- External 2D flow area Boundary Conditions:
  - Once all of the 2D flow area boundary conditions have been identified (drawn with the "**SA/2D Area BC Lines"** tool), the boundary condition type and the boundary condition data are entered within the "**Unsteady Flow Data"** editor.



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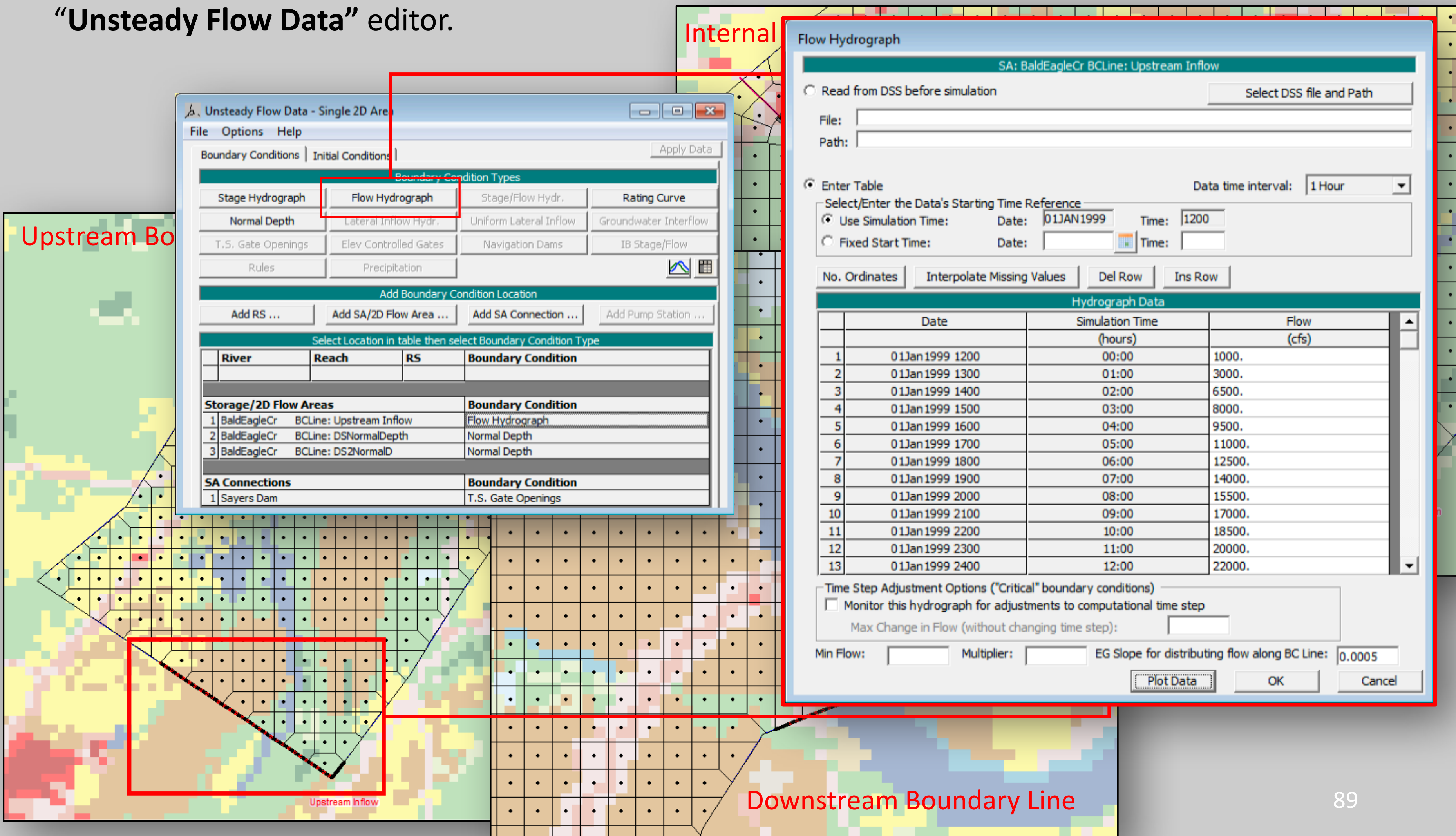

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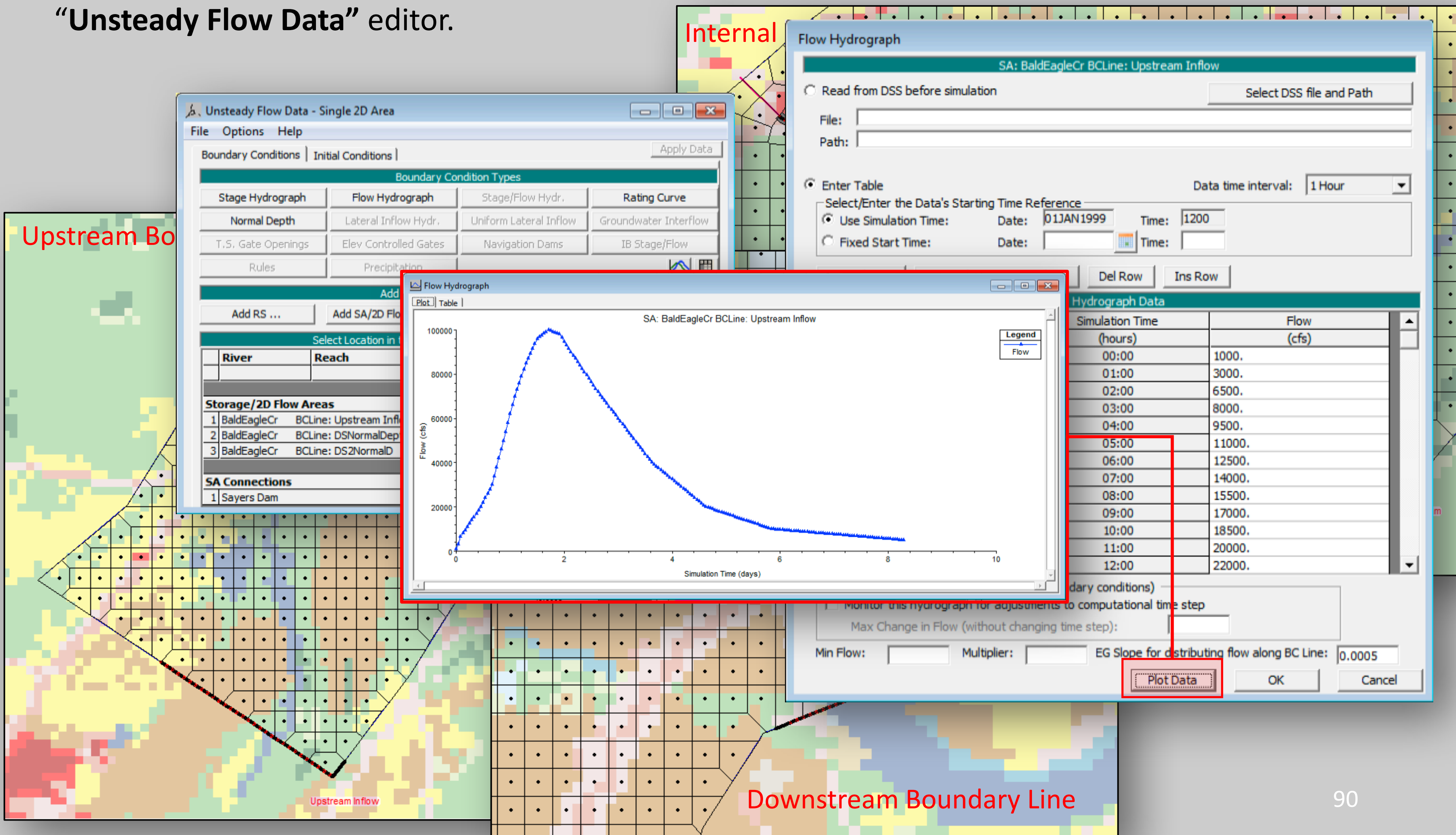

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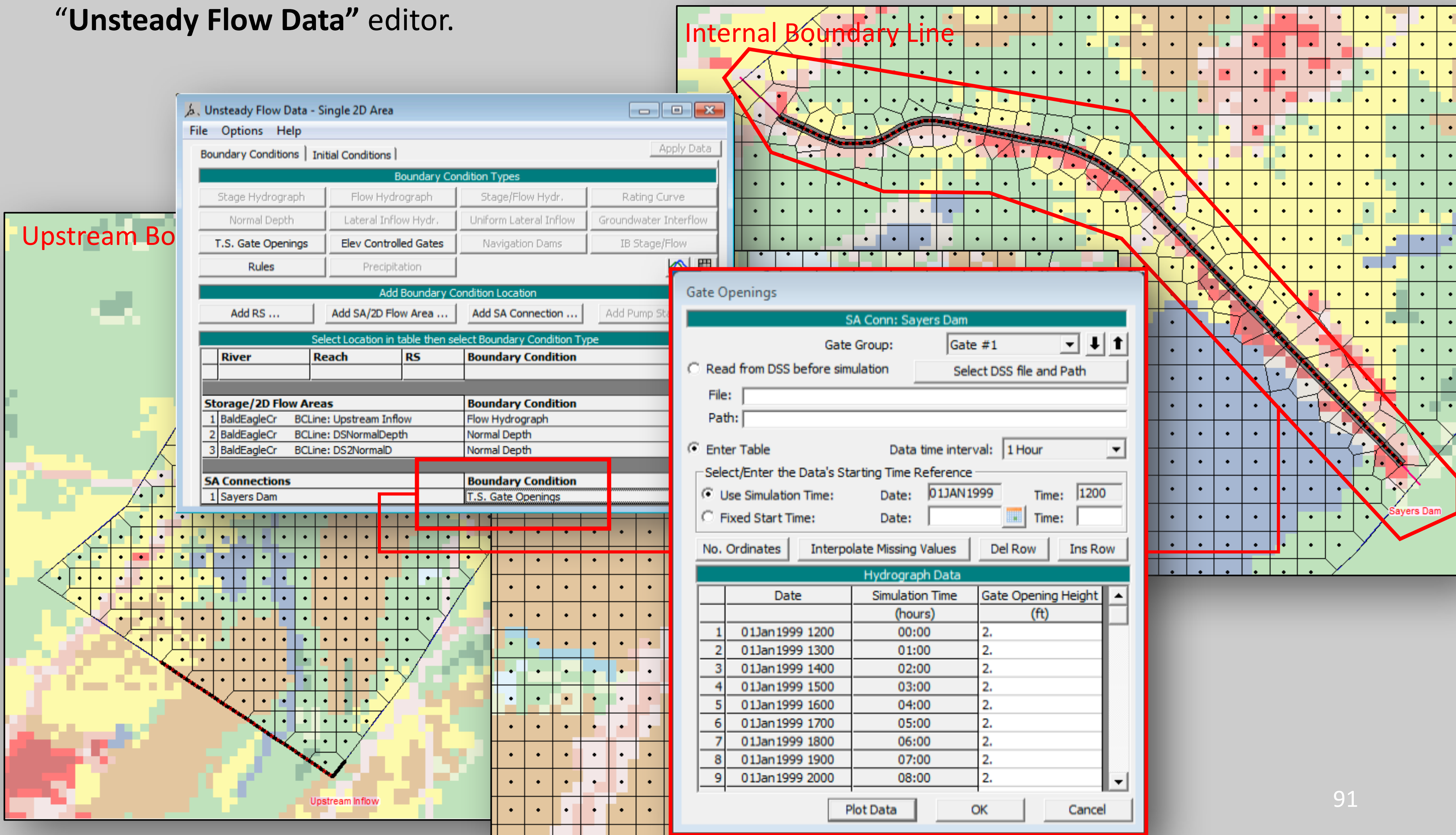
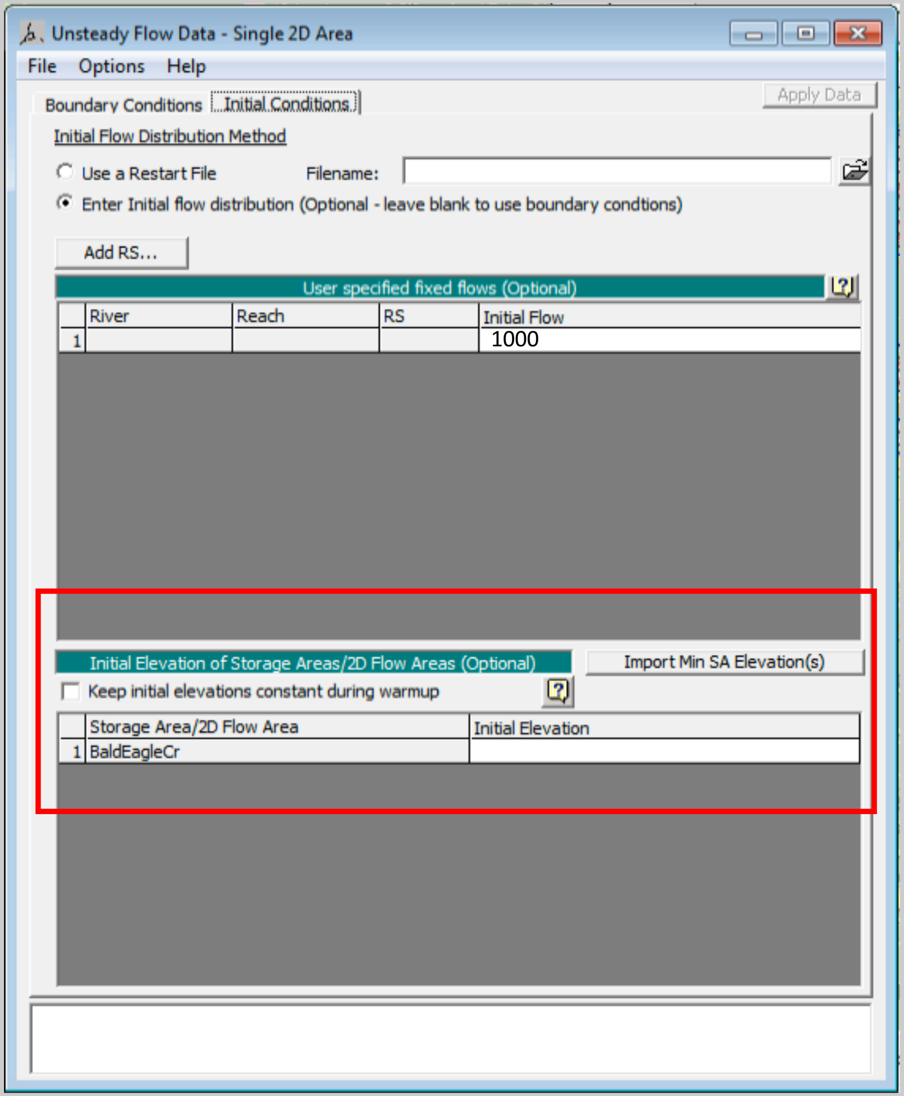


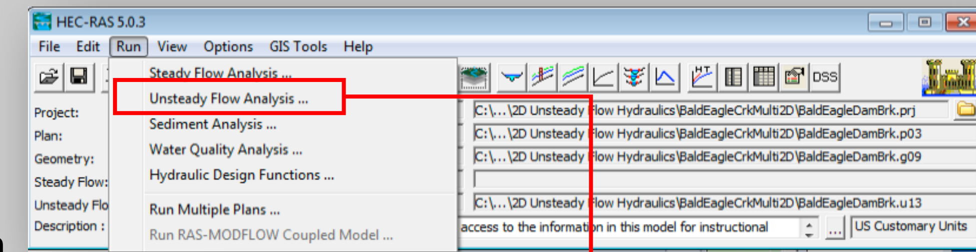
3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

- 2D Flow Area Initial Conditions:
  - 2D flow areas can:
    - ✓ start completely dry
    - ✓ be set to a single water surface elevation
    - ✓ set by using a Restart File from a previous run
    - ✓ they can be established using the 2D Initial Conditions Ramp up Time option at the beginning of the run.



- Nothing needs to be done to start a 2D flow area in a dry condition, this is the default option.
- The model starts with the initial conditions, it then holds all of the boundary conditions constant, based on their value at the beginning of the simulation, and then it runs a series of time steps with the constant inflow.
- This allows the model to settle down to water surface elevations and flows that are consistent with the unsteady flow equations being applied.

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS



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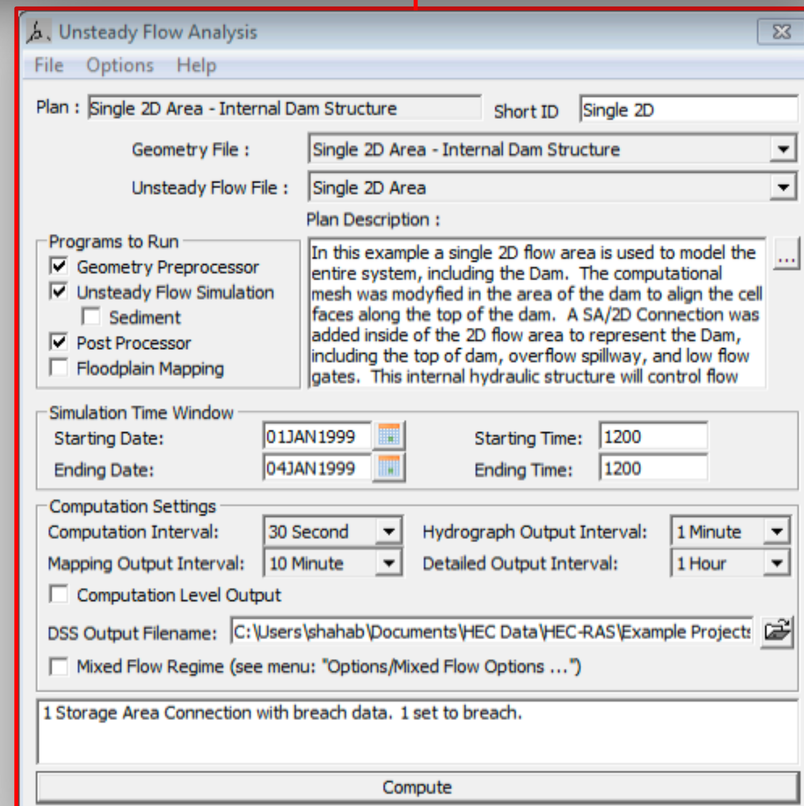
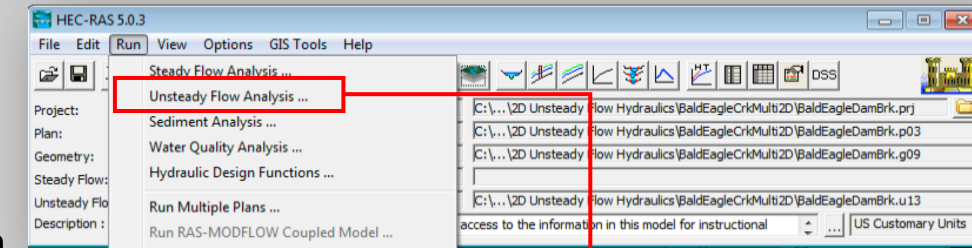


- A **Restart File** can be used to establish initial conditions for an entire HEC-RAS model.
- If a previous run has been made, and the option to write out a **Restart File** was used, then a Restart File can be used as the initial conditions for a subsequent run.
- For 2D modeling, the **Restart File** will contain a water surface elevation for every cell in the model.
- **Restart files** can be generated using either of the 2D equation sets (full Saint Venant or Diffusion Wave), and can be used to start a model with a different equation set

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS



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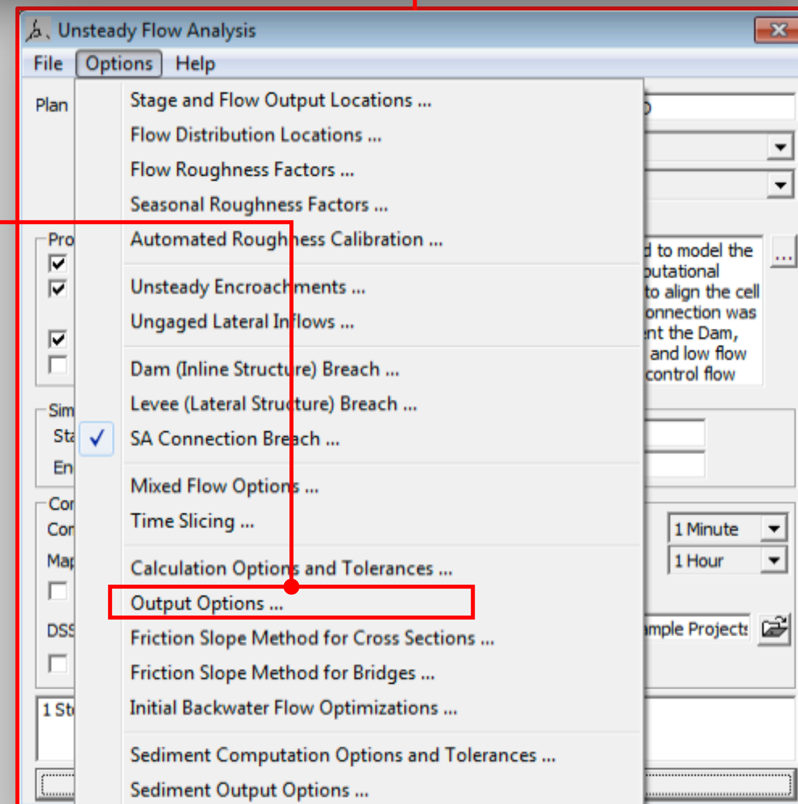

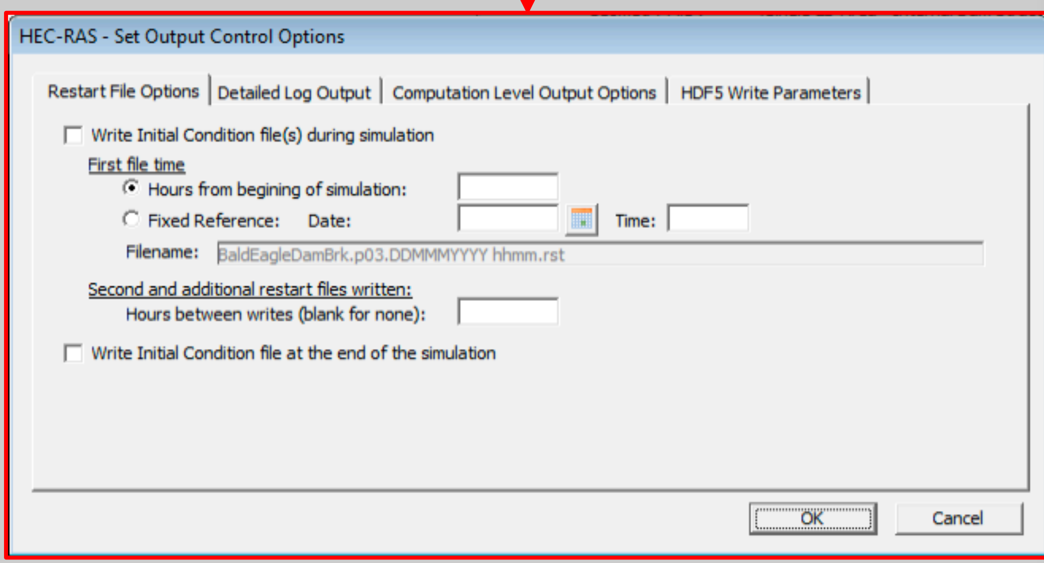

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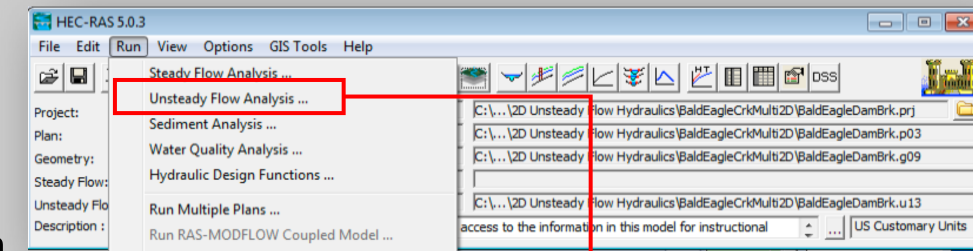

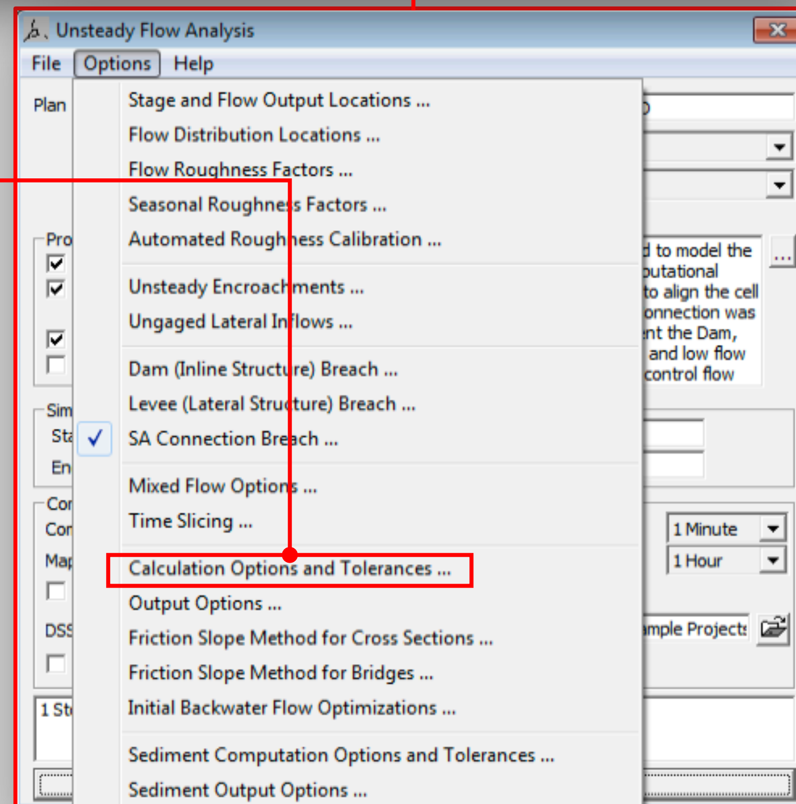

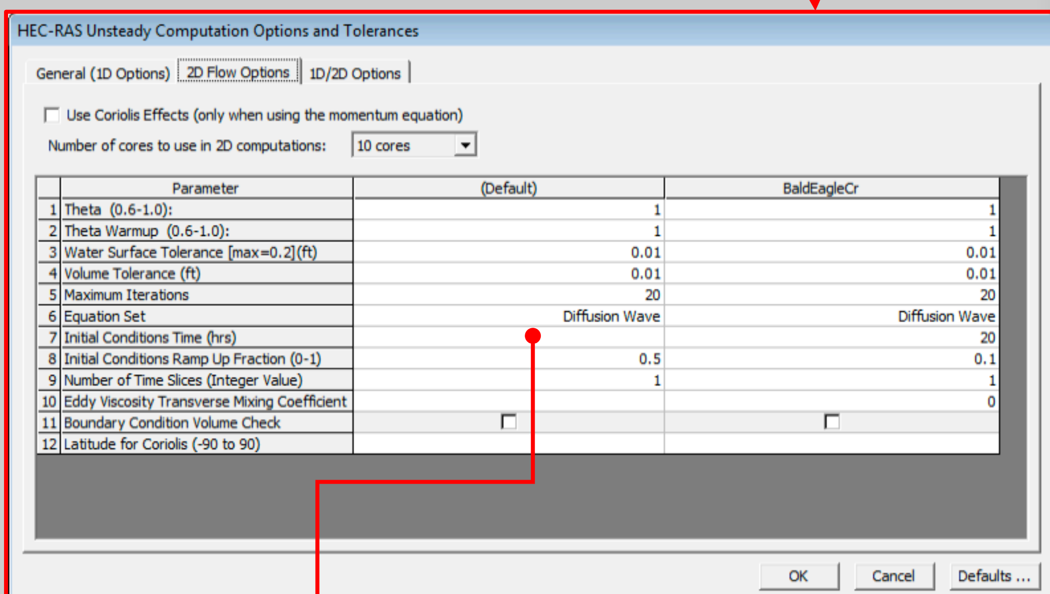

If a 2D area has external boundary conditions (flow hydrographs or stage hydrographs) then the 2D flow area "**Initial Condition Ramp Up Time**" must be turned on to get flow through the 2D area in order to establish its initial conditions before the start of the simulation (or even before the start of the overall model warm-up time).

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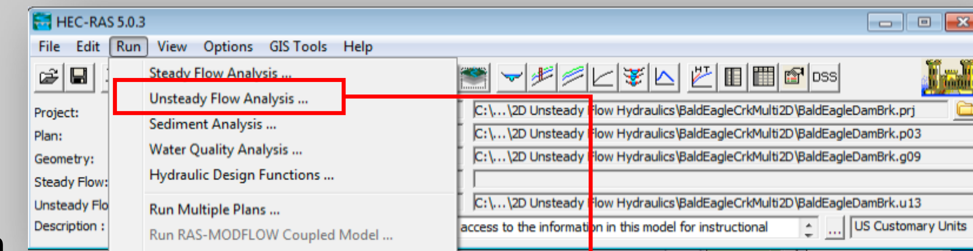
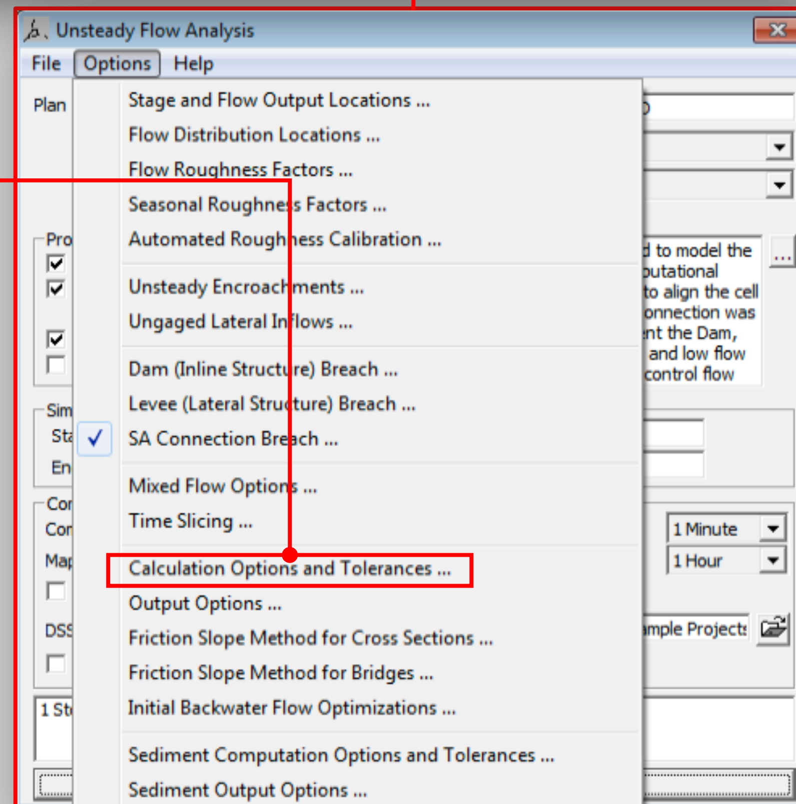
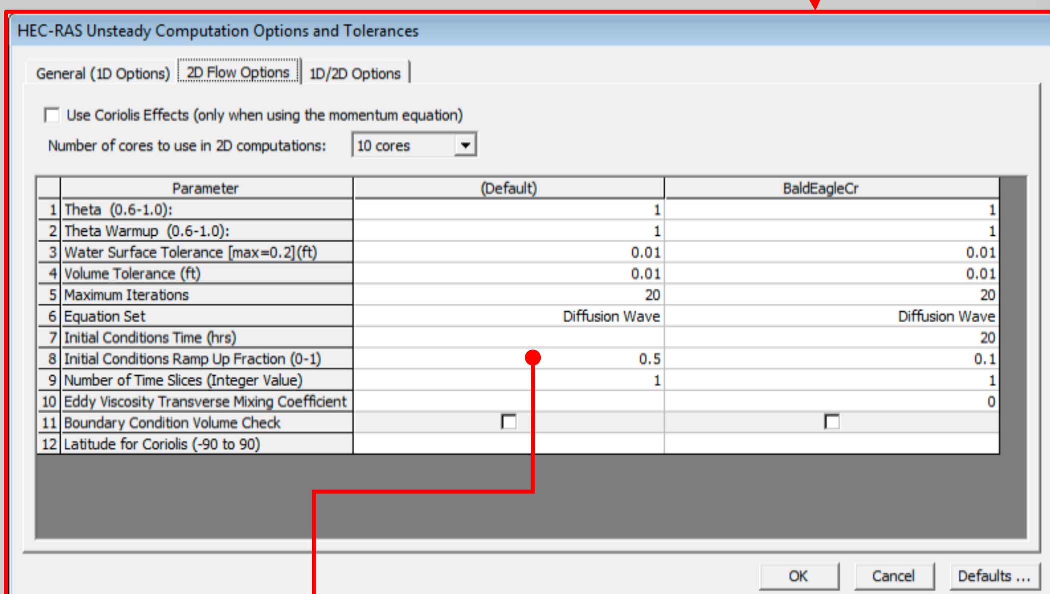






	Parameter	(Default)	BaldEagleCr
1	Theta (0.6-1.0):	1	1
2	Theta Warmup (0.6-1.0):	1	1
3	Water Surface Tolerance [max=0.2](ft)	0.01	0.01
4	Volume Tolerance (ft)	0.01	0.01
5	Maximum Iterations	20	20
6	Equation Set	Diffusion Wave	Diffusion Wave
7	Initial Conditions Time (hrs)		20
8	Initial Conditions Ramp Up Fraction (0-1)	0.5	0.1
9	Number of Time Slices (Integer Value)	1	1
10	Eddy Viscosity Transverse Mixing Coefficient		0
11	Boundary Condition Volume Check	☐	☐
12	Latitude for Coriolis (-90 to 90)		

- Additionally, the user must enter what fraction of that time is used for ramping the 2D boundary conditions up from zero to their first value (i.e. a stage or a flow coming in).

Objectives of This Workshop

1. Introduction to HEC-RAS 2D and two dimensional modeling advantages relative to 1D models

2. Required geophysical and flow information for setting up HEC-RAS 2D models

3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

4. **Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS**

5. Overview of how to demonstrate the result of a combined 1D/2D unsteady flow model in HEC-RAS and RAS Mapper output capabilities

4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

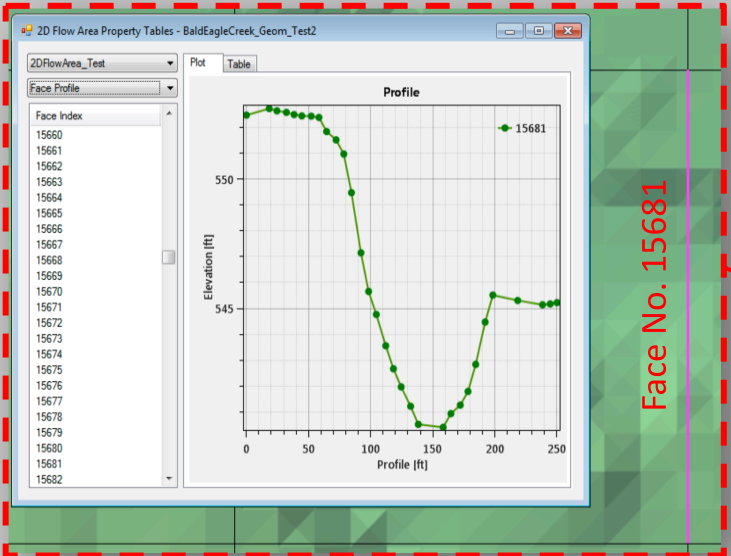
- Running a combined 1D/2D unsteady flow model in HEC-RAS is no different than running a standalone 1D unsteady flow model.
- HEC-RAS has the ability to perform two-dimensional unsteady flow routing with either the Full Saint Venant equations (with added terms for turbulence modeling and Coriolis effects) or the Diffusion wave equations.
- Within HEC-RAS the Diffusion Wave equations are set as the default, however, the user should always test if the full Saint Venant Equations are need for their specific application.
- **<u>A general approach is to use the Diffusion wave equations while developing the model and getting all the problems worked out</u>**
- Once the model is in good working order, then make a second HEC-RAS Plan and switch the computational method to the Full Momentum equation option
- **<u>Full Momentum will generally require a smaller computation interval than the Diffusion wave method to run in a stable manner. If there are significant differences between the two runs, the user should assume the Full Momentum (Saint Venant equations) answer is more accurate</u>**

- There are some obvious situations that the Full Momentum equation set should always be used:
  - ✓ **Highly Dynamic Flood Waves** (e.g. dam breaching or flash flood analysis)
  - ✓ **Abrupt Contractions and Expansions** (e.g. In areas of very abrupt contractions and expansions)
  - ✓ **Tidally Influenced Conditions** (e.g. modeling a bay, estuary, or a river that is tidally influenced)
  - ✓ **General Wave Propagation Modeling** (e.g. wave run-up on a wall or around an objects)
  - ✓ **Super Elevation around Bends** (a tight bend in either a natural or designed channel, and you want to see if there is any super elevation of the water surface on the outside of the bend)
  - ✓ **To compute a detailed velocity distribution at or near a hydraulic structure** (e.g through a bridges and around the abutments and piers; through a gate or culvert; etc.)

4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

- Selecting an Appropriate Grid Size and Computational Time Step

- Assigning an appropriate mesh cell size (or sizes) and computational time step (ΔT) is very important to getting accurate answers with 2D flow areas.
- It is very important to understand the way the computational mesh is representing the underlying terrain in order to make a good decision on how many cells, and of what size, will be necessary to model the terrain and the event accurately.
- The HEC-RAS cell faces are detailed cross sections, which get processed into detailed elevation versus area, wetted perimeter, and roughness.
- The key to making a good computational mesh in HEC-RAS is ensuring that the faces of the cells capture the high point of barriers to the flow.
- A single water surface elevation is computed in the center of each cell. So the larger the cell size, the further apart are the computed values of the water surface, and thus the slope of the water surface is averaged over longer distances (in two dimensions)



- If the water surface slope will vary rapidly, smaller cell sizes must be used in that area to capture the changing water surface and its slope.
- HEC-RAS allows the user to vary the cell size and shape at all locations in the model.
- It is also recommended to align grid cells along the main channel by means of adding **Breaklines.**

250 ft. X 250 ft. mesh grid laid over the **20 ft. X 20 ft.** terrain model

4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

- Selecting an Appropriate Grid Size and Computational Time Step
- The cell size must be adequate to describe the water surface slope and changes in the water surface slope.
- If the water surface slope does not change rapidly, larger cell sizes can be used to accurately compute the water surface elevation and slope. If the water surface slope changes rapidly, then smaller cell sizes need to be used to have enough computation points to describe the changing water surface
- While cell sizes (and shapes) can vary, transitioning from larger to smaller cell sizes should be done gradually to improve computational accuracy.

- Picking an adequate time step is a function of the cell size and the velocity of the flow moving though those cells.
- **Users should always test the consistency of their computational mesh and selected time step. The consistency principle requires a reduction of both the space (grid) and time steps in order to guarantee convergence of a solution.**

Diffusion Wave Equations:

$$C = \frac{V\Delta T}{\Delta X} \leq 2.0 \quad (with\ a \max C = 5.0)$$

Or

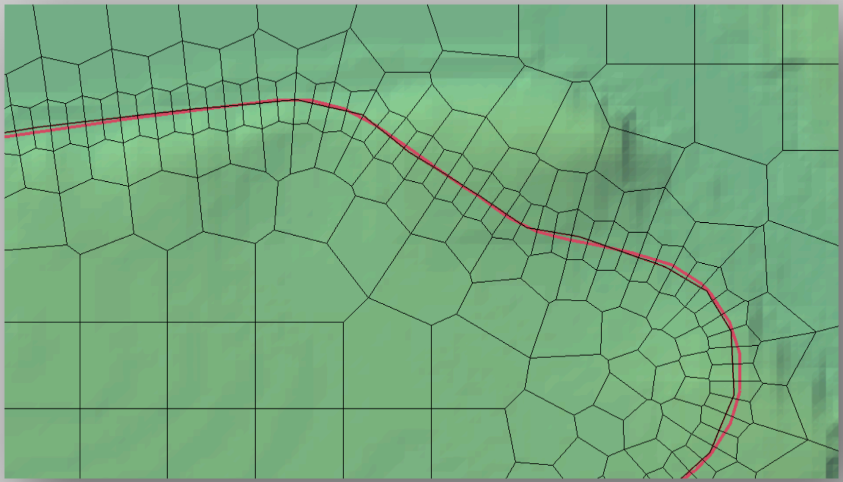
$$\Delta T \leq \frac{2\Delta X}{V} \quad \text{(With C = 1.0)}$$

Saint Venant Equations (full momentum):

$$C = \frac{V\Delta T}{\Delta X} \leq 1.0 \quad (with\ a \max C = 3.0)$$

Or

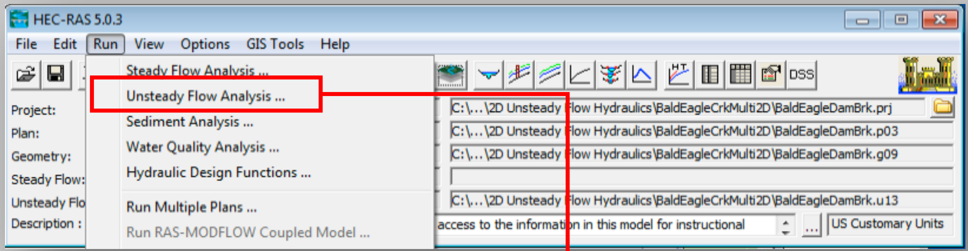
$$\Delta T \leq \frac{\Delta X}{V} \quad \text{(With C = 1.0)}$$

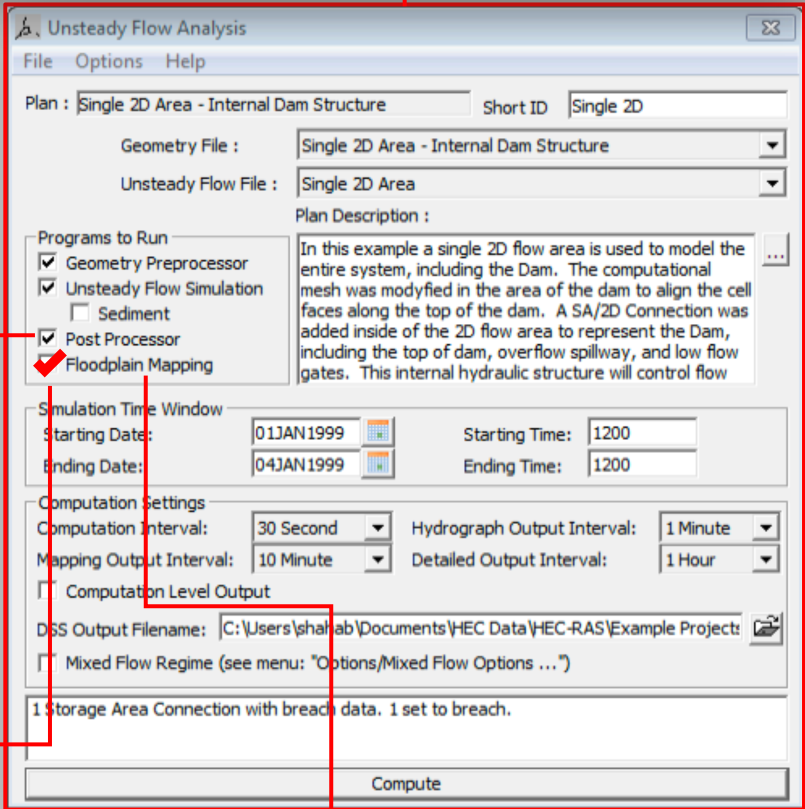


Where:	C	=	Courant Number
	V	=	Flood wave velocity (wave celerity) (ft/s)
	ΔT	=	Computational time step (s)
	ΔX	=	Average cell size (ft)

4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

- Performing the computation
  1. make a Plan by selecting the geometry that contains the combined 1D and 2D data
  2. select an unsteady-flow file for the event to run, and give the Plan a Title and a Short ID
  3. recheck the association of the terrain model and landcover layer
  4. The post processor option provides additional (and detailed) output for 1D areas and it is only applicable for 1D data sets and mixed 1D/2D data sets.
  5. If this option is turned on, after the program has completed the unsteady flow computations and the post processing, the last thing it will do is run a separate process called "ComputeFloodMaps.exe" in order to generate a depth grid (stored to disk) of the maximum inundation that occurred at all locations in the model. **<u>This option is not required for flood mapping.</u>**





In general, this option will most likely not be used when running HEC-RAS in standalone mode.

4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

- Performing the computation
  1. make a Plan by selecting the geometry that contains the combined 1D and 2D data
  2. select an unsteady-flow file for the event to run, and give the Plan a Title and a Short ID
  3. recheck the association of the terrain model and landcover layer
  4. The post processor option provides additional (and detailed) output for 1D areas and it is only applicable for 1D data sets and mixed 1D/2D data sets.
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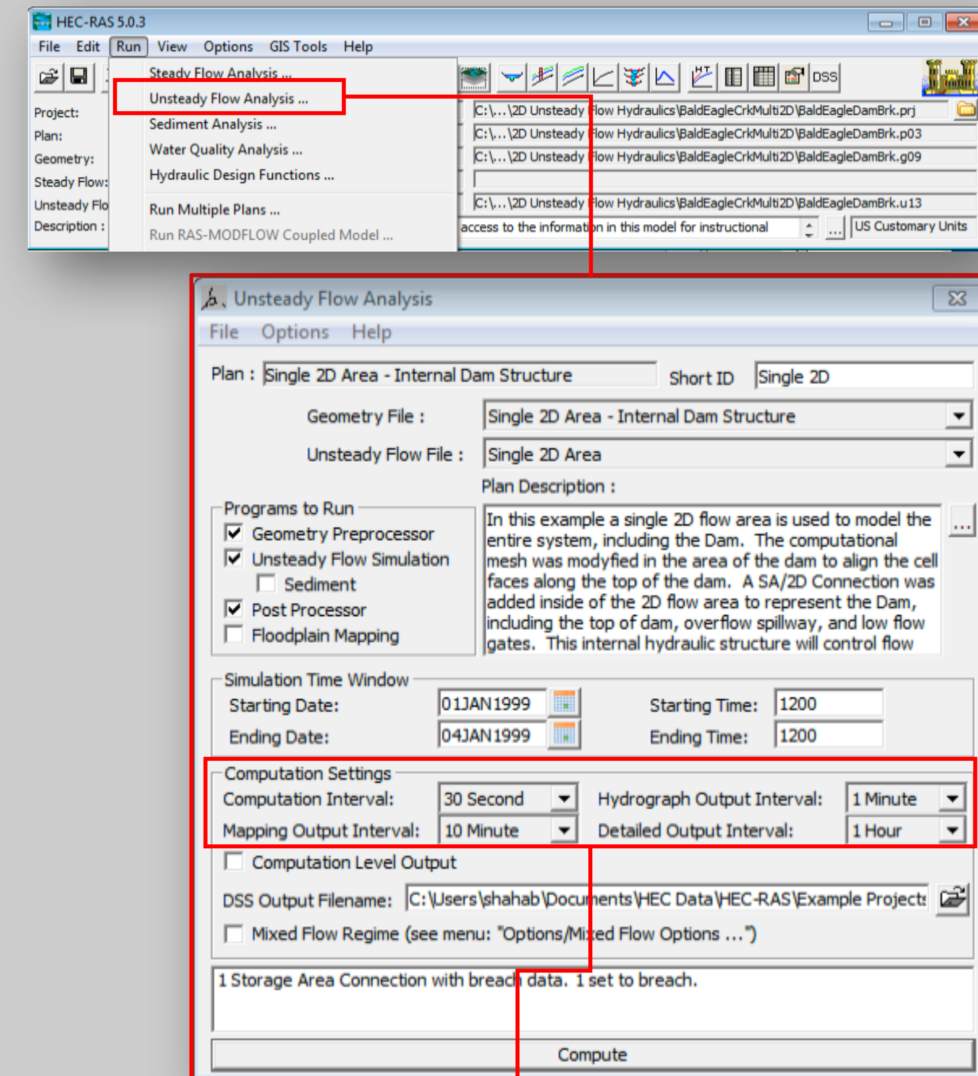
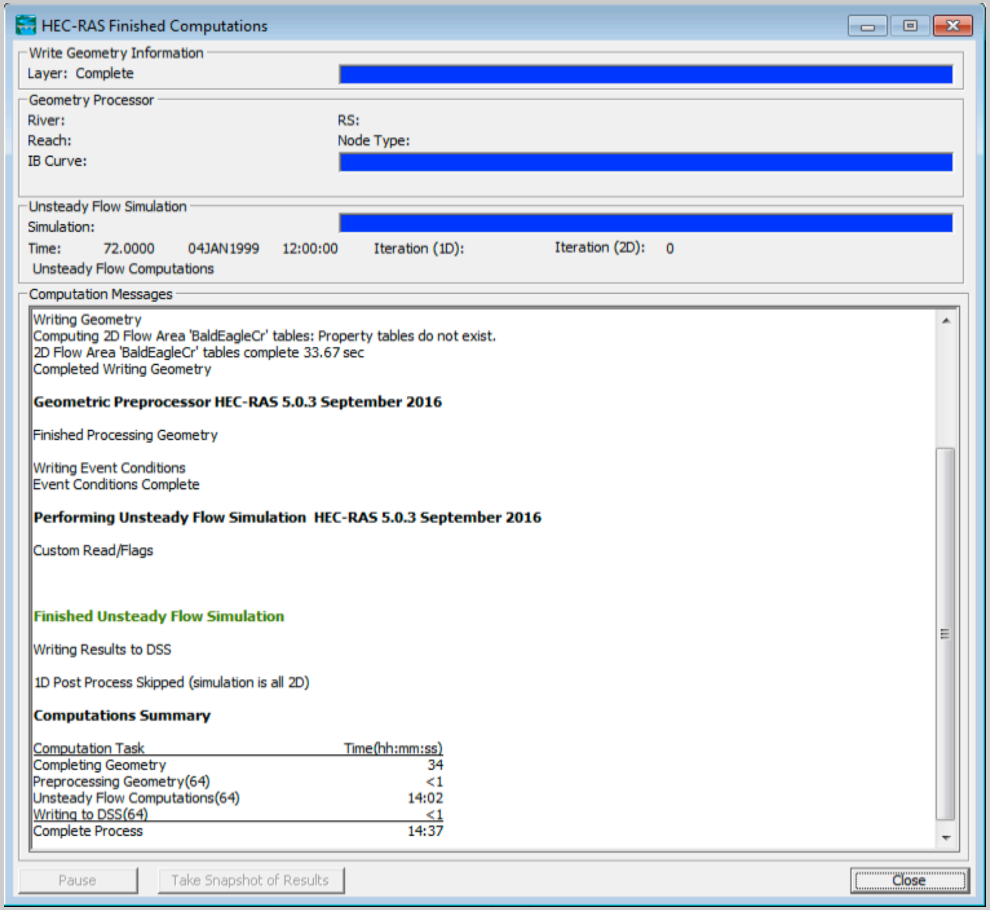


- Setting **Computation**, **Hydrograph**, and **Mapping Output Intervals** (to be applied in **RAS Mapper**).
- **Computation Interval < Hydrograph and Mapping Output Intervals**

4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

- Computation Progress, Numerical Stability, and Volume Accounting
  - As the Unsteady flow simulation runs, information is provided as to the progress of the run, how many iterations the 1D and 2D components are using to solve a particular time step, and numerical stability messages are written to the Computational Messages window.
  - If any 1D or 2D element (cross section, storage area, or 2D cell) is not solved to within the pre-defined numerical tolerance during a time step, a message will be written to the message window. This message will provide information as to which cross section, storage area, or 2D cell had the greatest amount of numerical error for that time step.



Objectives of This Workshop

1. Introduction to HEC-RAS 2D and two dimensional modeling advantages relative to 1D models

2. Required geophysical and flow information for setting up HEC-RAS 2D models

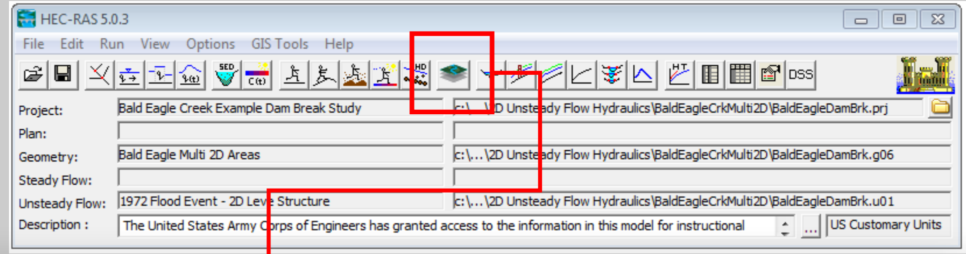
3. Overview of how to set-up a combined 1D/2D unsteady flow model in HEC-RAS

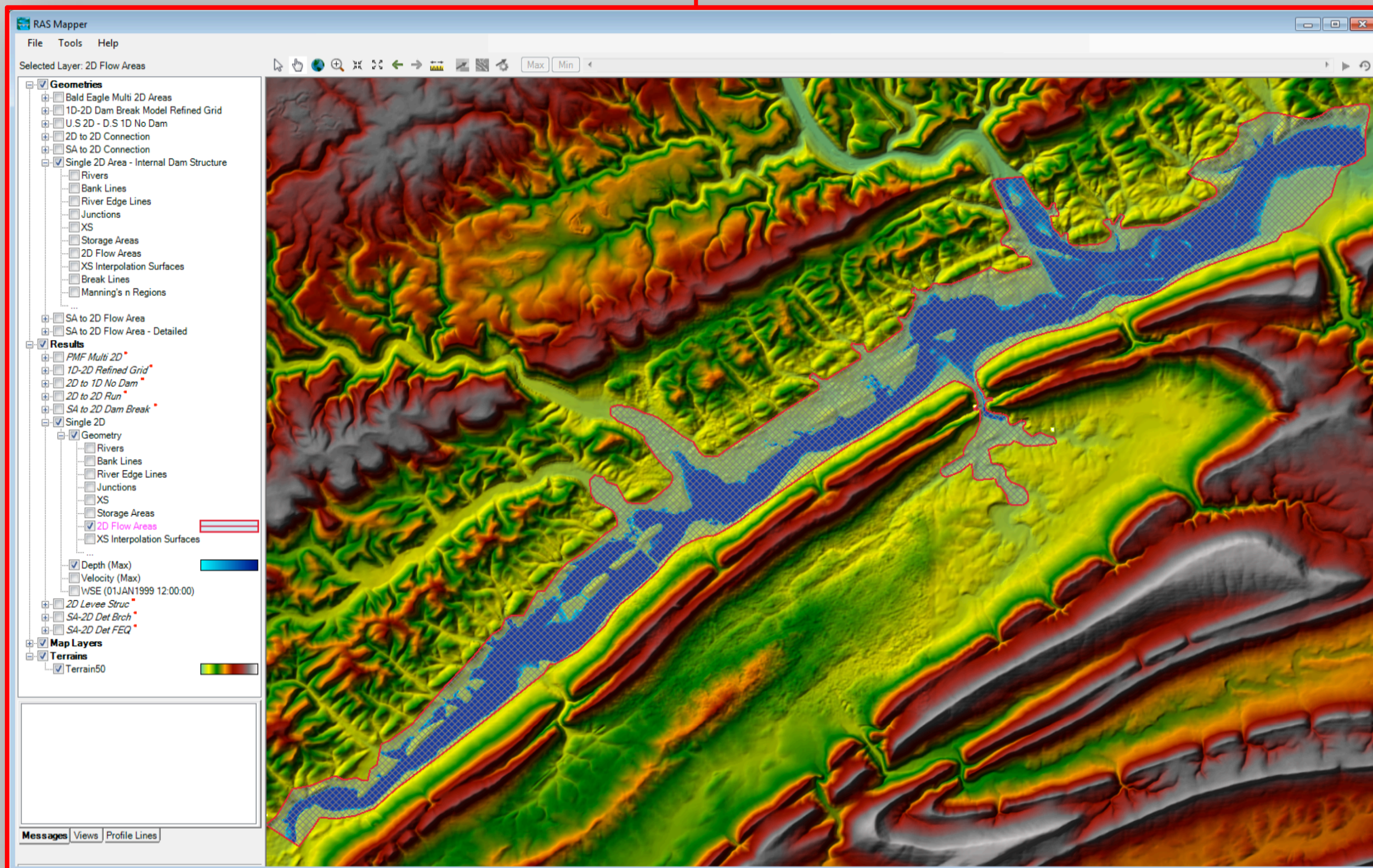
4. Overview of how to execute a combined 1D/2D unsteady flow model in HEC-RAS

5. **Overview of how to demonstrate the result of a combined 1D/2D unsteady flow model in HEC-RAS and RAS Mapper output capabilities**

5. Overview of how to demonstrate the result of a combined 1D/2D unsteady flow model in HEC-RAS and RAS Mapper output capabilities

- Once the user has completed an unsteady-flow run of the 1D/2D model, results can be viewed within **RAS Mapper**

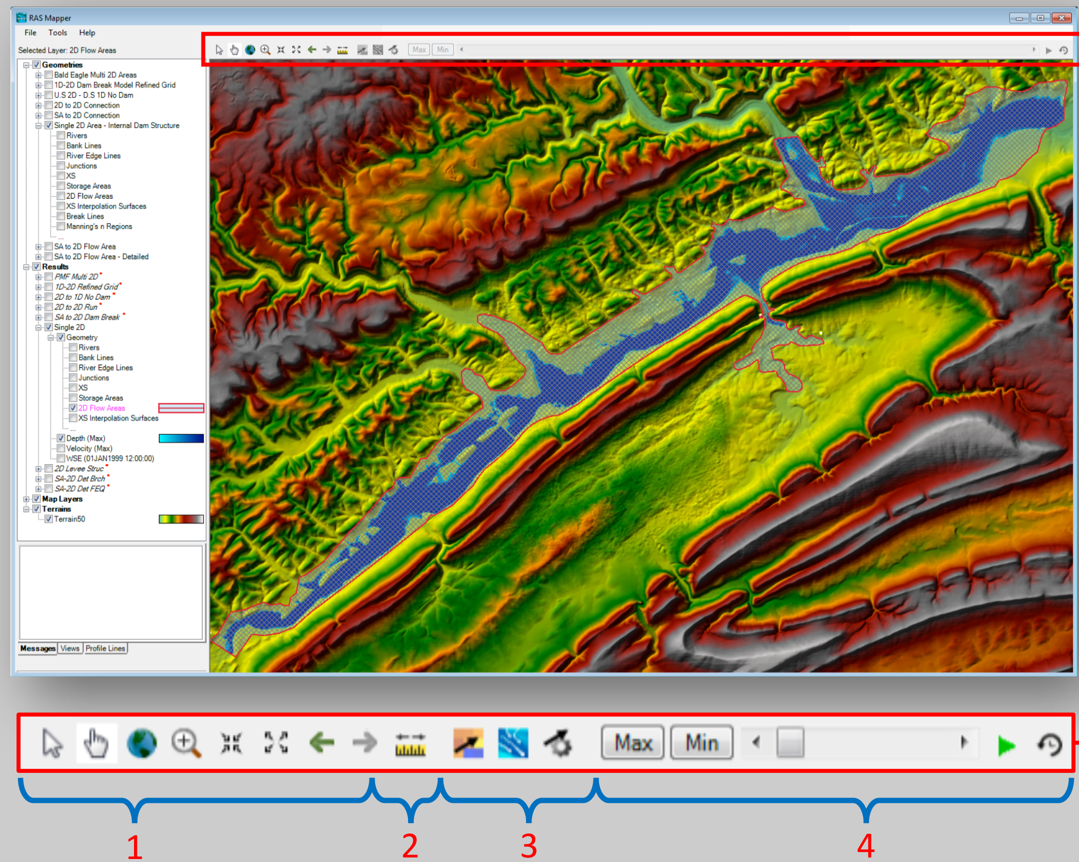




5. Overview of how to demonstrate the result of a combined 1D/2D unsteady flow model in HEC-RAS and RAS Mapper output capabilities

RAS Mapper has the following capabilities:

- Develop terrain models for use in 2D modeling and visualizing 1D/2D model results. Terrain models can be developed from one or more terrain tiles, and these tiles can have different grid resolutions.
- Develop Land Cover Layers for use in defining Manning's n values for 2D flow areas.
- Various types of map layer results can be generated (shapfiles and rasters)
- Computed model results can be displayed dynamically on the fly, or they can be written to a static (stored to disk) map layer/depth grid.
- Computed model results can be animated (dynamic mapping) or shown for a specific instance in time.
- Time series plots and tables can be displayed for 1D and 2D output directly from RAS Mapper, at any location where there is a map layer result.



1. Navigation tools
2. "Measure Distance" tool; produce terrain XS profile
3. "Static Velocity Arrows" and "Particles Tracing"
4. Animation tools; "Max" and "Min" will set cell values to their reported minimum and maximum values

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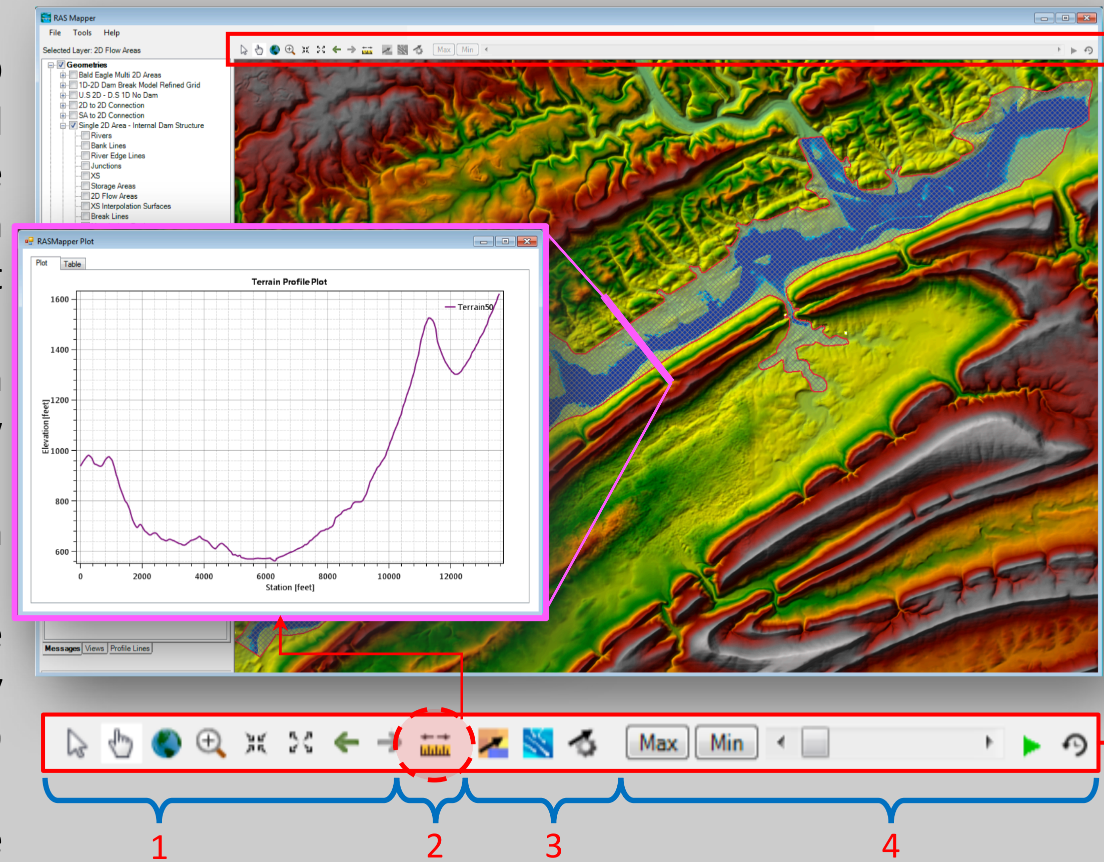

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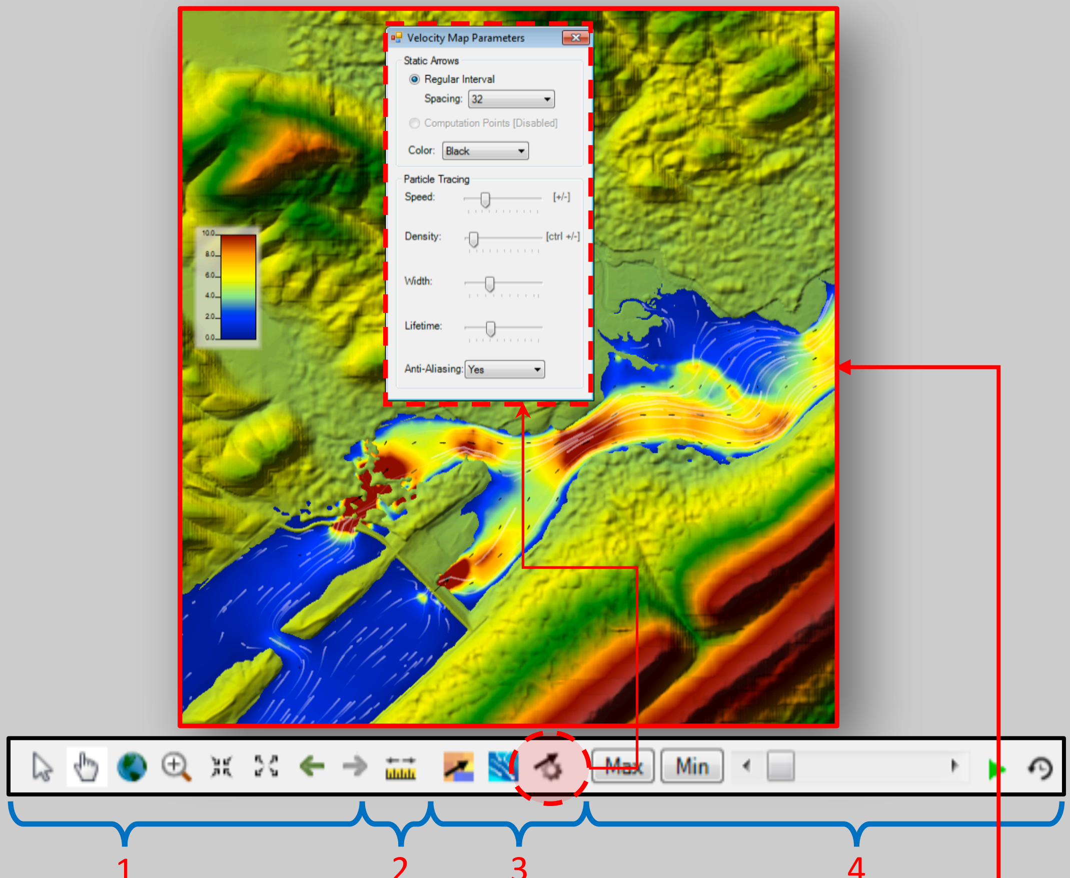

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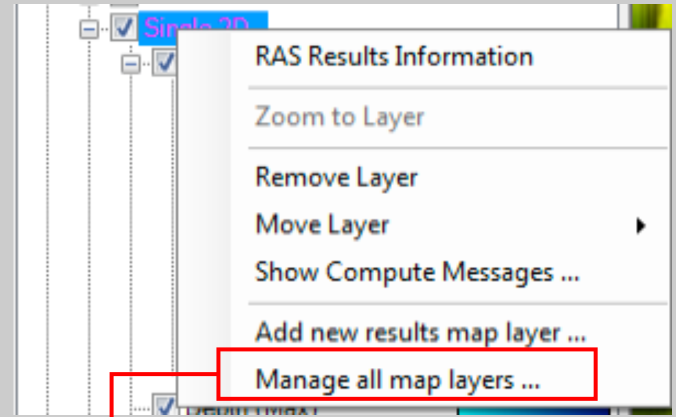
5. Overview of how to demonstrate the result of a combined 1D/2D unsteady flow model in HEC-RAS and RAS Mapper output capabilities

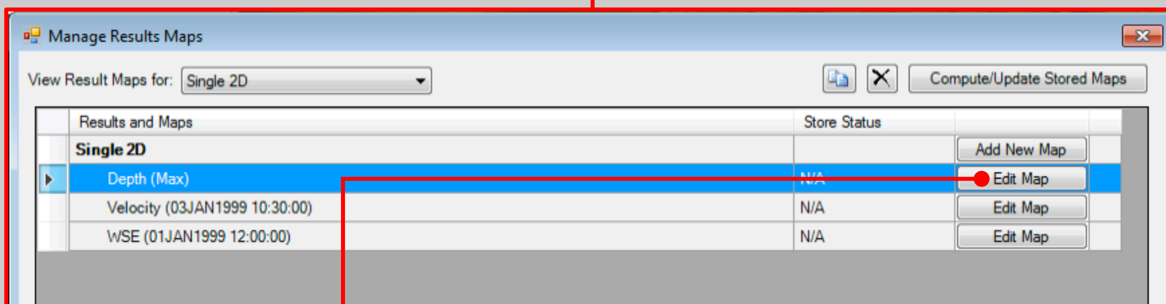
Creating Static (Stored) Maps

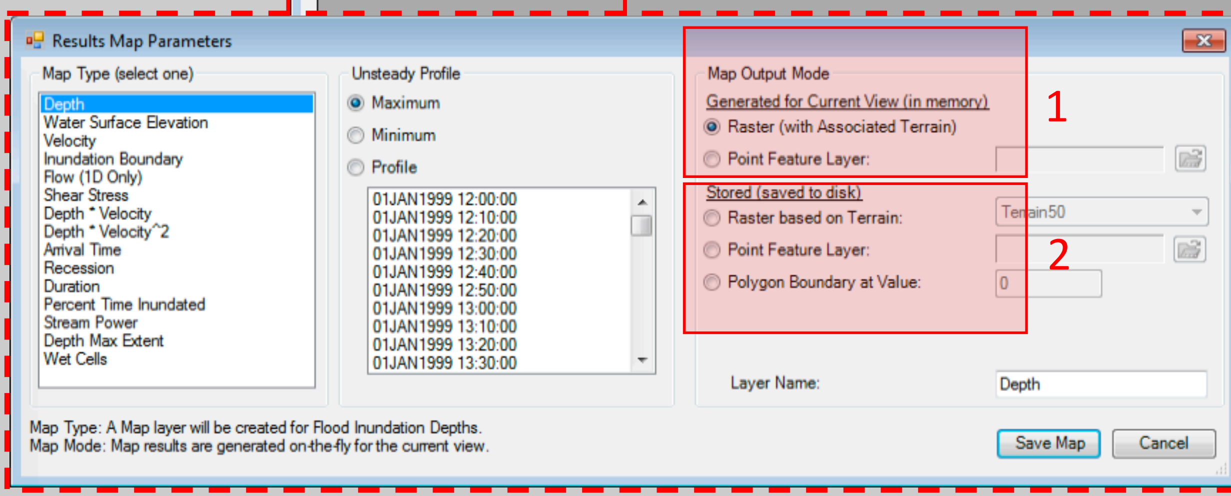
- this editor will allow the user to create new map layers (Add New Map), as well as generate stored maps to a file
- Only the map layers that are turned on will be available to plot.



Results Map Parameters: Map Output Mode

1. Layers generated to be used and visualized only within RAS Mapper platform
2. Saving Layers (Raster or Shapefiles) generated from computed maps and layers to a local disk.

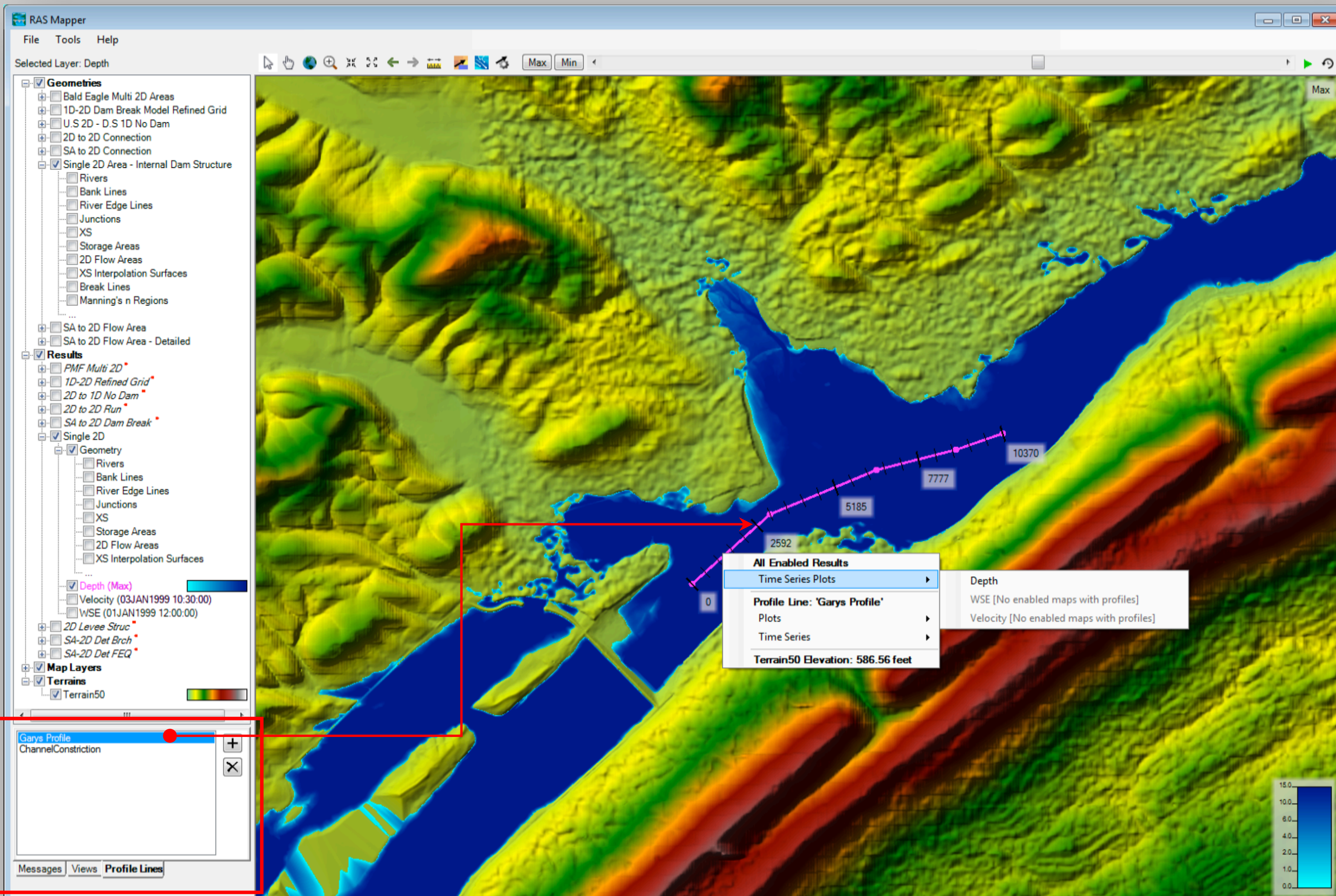




5. Overview of how to demonstrate the result of a combined 1D/2D unsteady flow model in HEC-RAS and RAS Mapper output capabilities

Profile Lines

- HEC-RAS Mapper has the option for user to draw a line on the map, give that line a name, then use that line to plot whatever results is turned on over top of the line.



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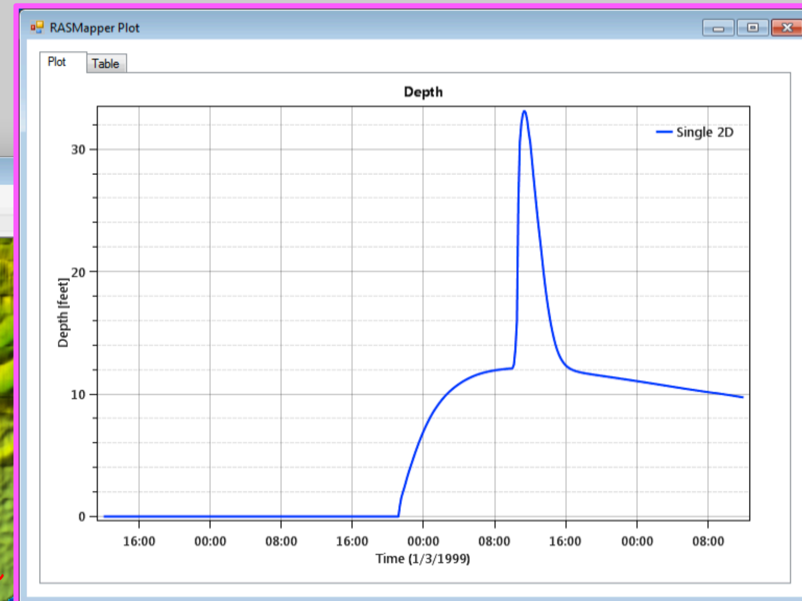

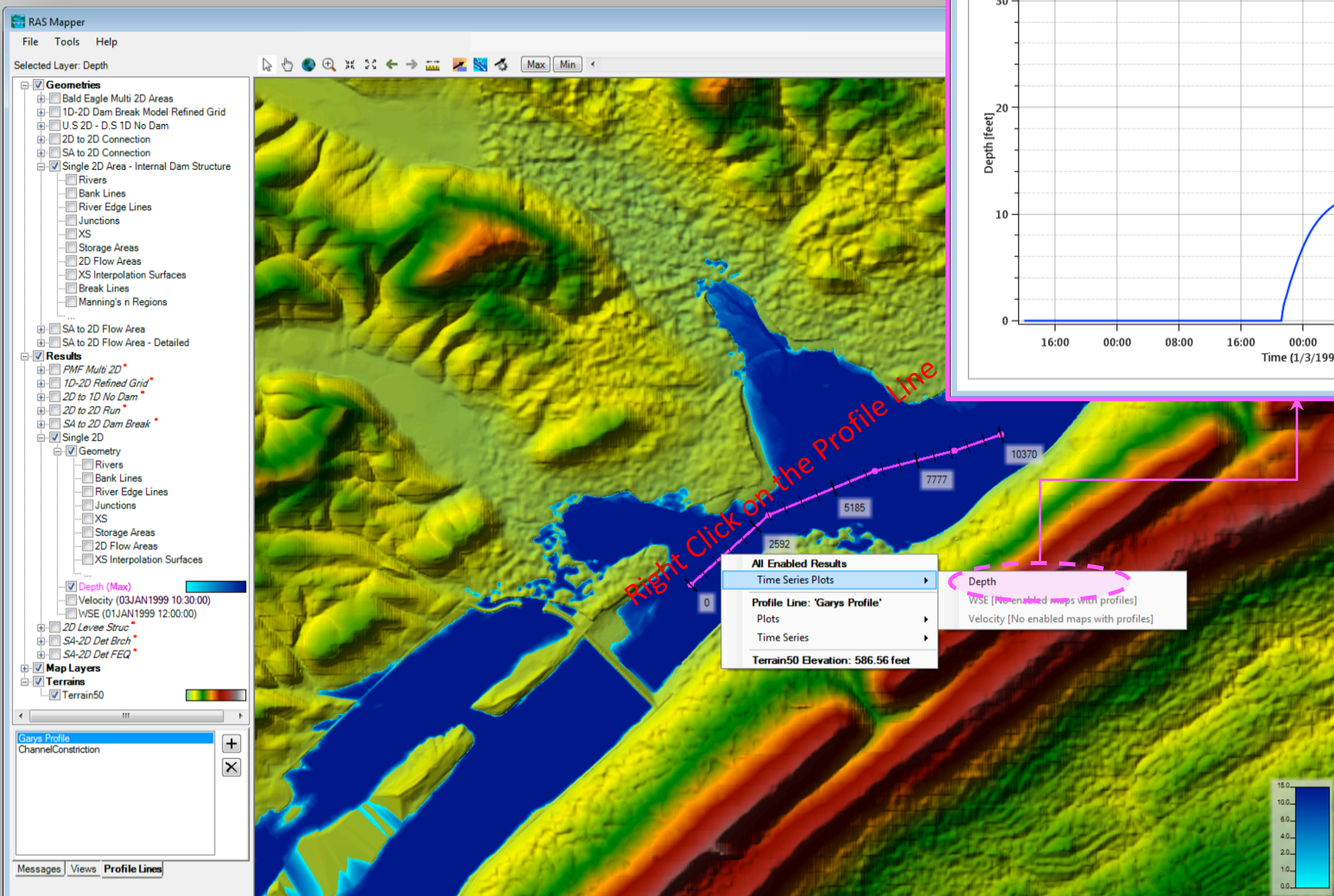

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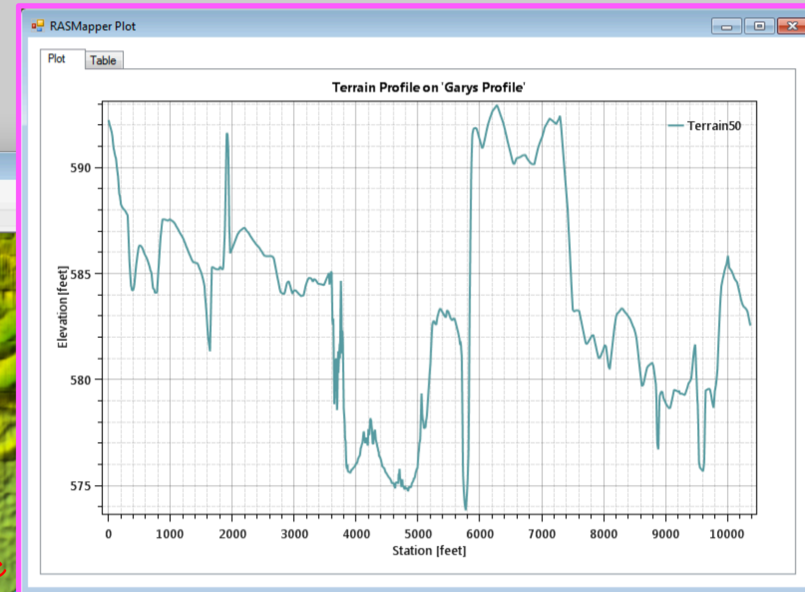

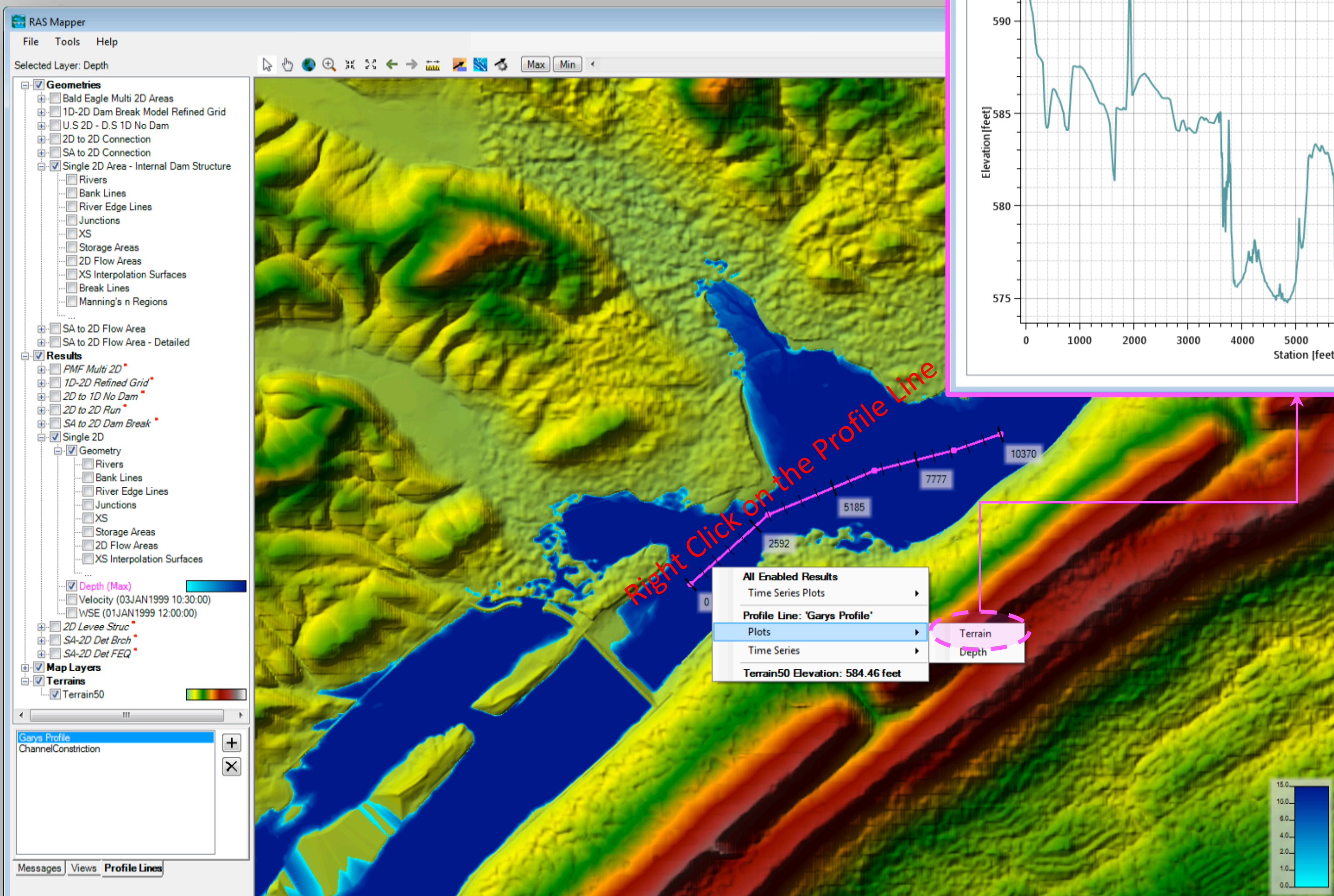

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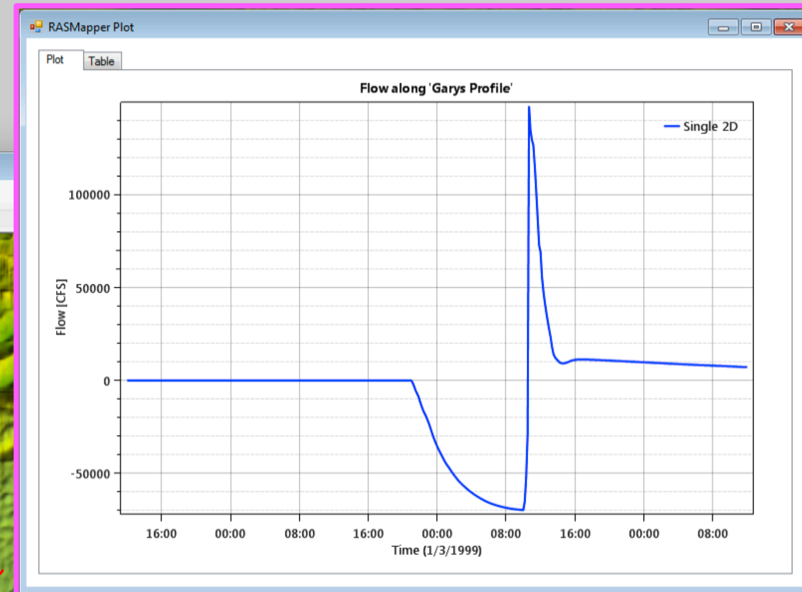

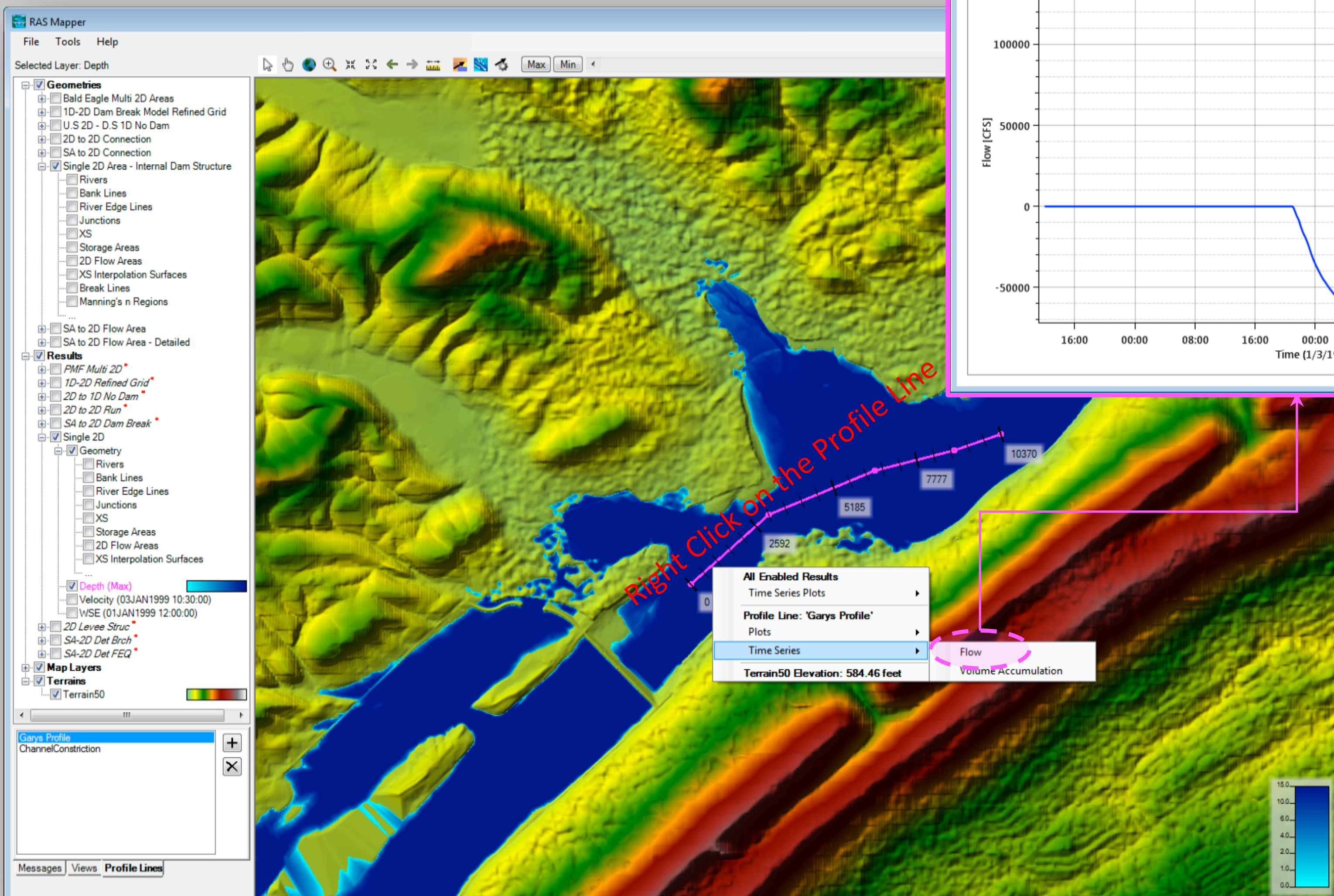

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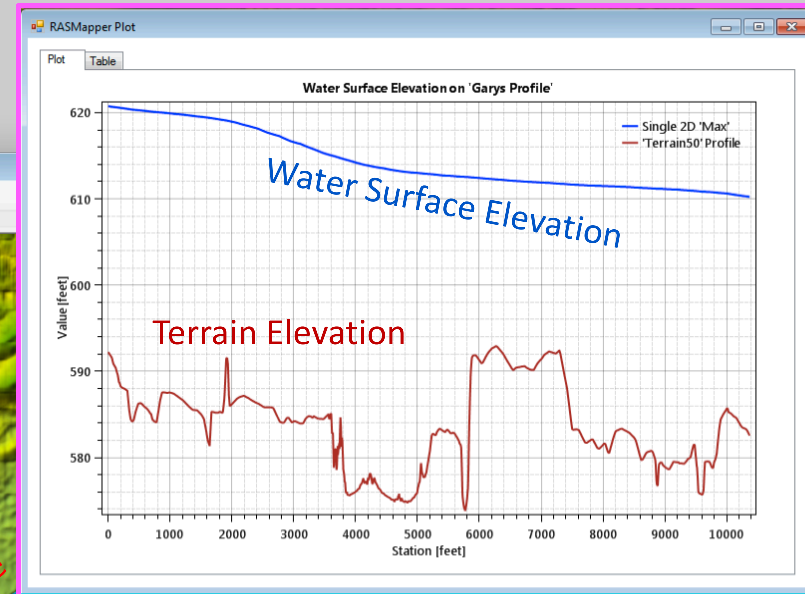

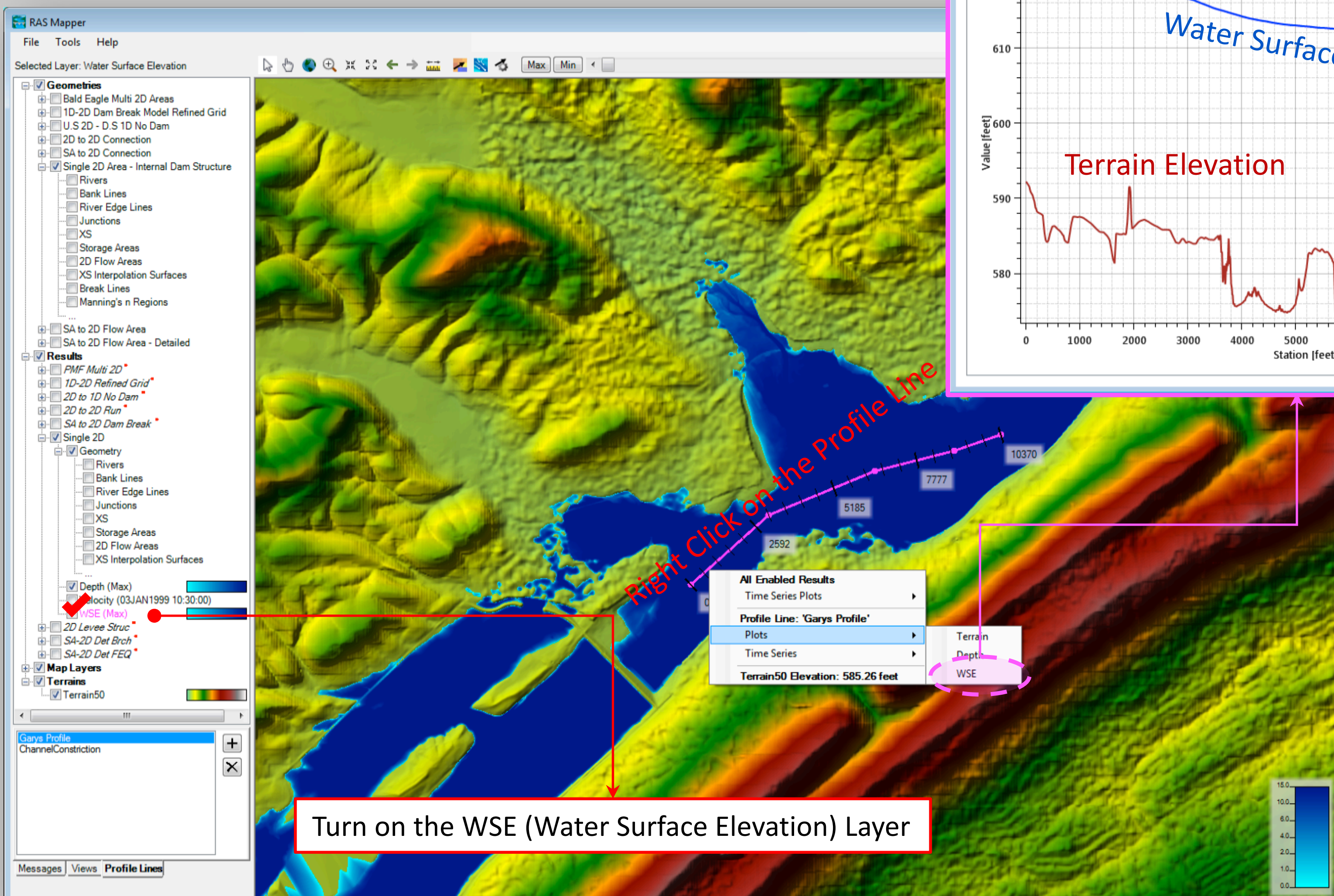

Thank You ☺

References:

- HEC-RAS 5.0 User's Manual
- HEC-RAS 5.0 2D Modeling User's Manual
- The RAS Solution, http://hecrasmodel.blogspot.com/

The City College of New York

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Surface Dynamics Modeling Lab

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