![US Army Corps of Engineers — Hydrologic Engineering Center logo]
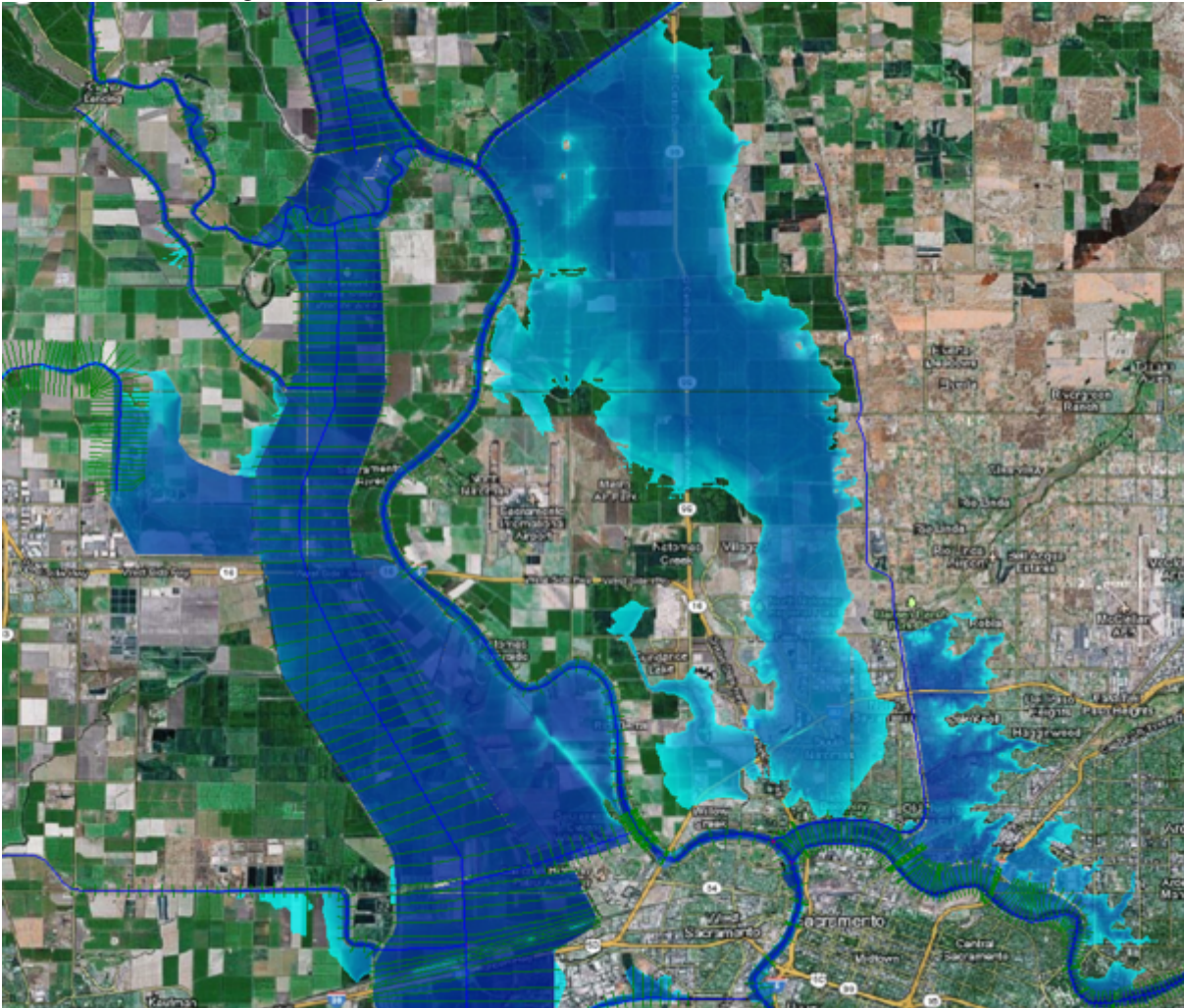
**US Army Corps
of Engineers** ®

Hydrologic Engineering Center

HEC-RAS

River Analysis System

HEC-RAS 2D User's Manual

Version 6.6
Exported - September 2024

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Welcome to HEC-RAS.

1 FOREWORD

This manual was written by Mr. Gary W. Brunner.

The U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) is software that allows you to perform one-dimensional steady flow hydraulics; one and two-dimensional unsteady flow river hydraulics calculations; quasi Unsteady and full unsteady flow sediment transport-mobile bed modeling; water temperature analysis; and generalized water quality modeling (nutrient fate and transport).

The first version of HEC-RAS (version 1.0) was released in July of 1995. Since that time there have been several major releases of this software package, including versions: 1.1; 1.2; 2.0; 2.1; 2.2; 3.0, 3.1, 3.1.1, 3.1.2, 3.1.3, 4.0, 4.1, 5.0 and now version 6.0 in 2021.

The HEC-RAS software was developed at the Hydrologic Engineering Center (HEC), which is a division of the Institute for Water Resources (IWR), U.S. Army Corps of Engineers.

The software was designed by Mr. Gary W. Brunner, leader of the HEC-RAS development team. The user interface and graphics were programmed by Mr. Mark R. Jensen, Alex Kennedy, Anton Rotter-Sieren, Cameron Ackerman, and Stanford Gibson. The steady flow water surface profiles computational module and the majority of the one-dimensional unsteady flow computations modules was programmed by Mr. Steven S. Piper. The One-dimensional unsteady flow matrix solution algorithm was developed by Dr. Robert L. Barkau (Author of UNET and HEC-UNET).

The two-dimensional unsteady flow modeling capabilities were developed by Gary W. Brunner, Ben Chacon (Resource Management Consultants, RMA), Steve S. Piper, Mark R. Jensen, Alex J. Kennedy, and Alex Sanchez.

The sediment transport interface module was programmed by Mr. Stanford A. Gibson. The quasi unsteady flow computational sediment transport capabilities were developed by Stanford A. Gibson and Steven S. Piper. The Unsteady flow sediment transport modules were developed by Stanford A. Gibson, Steven S. Piper, and Ben Chacon (RMA). Special thanks to Mr. Tony Thomas (Author of HEC-6 and HEC-6T) for his assistance in developing the quasi-unsteady flow sediment transport routines used in HEC-RAS. The two-dimensional sediment transport modules were developed by Alex Sanchez and Stanford Gibson. The Debris flow capabilities in HEC-RAS (1D and 2D) were developed by Stanford Gibson and Alex Sanchez. Most of the sediment output was designed by Stanford Gibson and Alex Sanchez and programmed by Anton Rotter-Sieren.

The new 2D plotting library and plots (Breach Plot, Hydrographs, and DSS viewer) were developed by Mark R. Jensen, Anton Rotter-Sieren, and Ryan Miles (RMA).

The new 3D visualization tool was developed by Anton Rotter-Sieren and Alex Kennedy.

The water quality computational modules were designed and developed by Mr. Mark R. Jensen, Dr. Cindy Lowney and Zhonglong Zhang (ERDC-RDE-EL-MS).

The spatial data and mapping tools (RAS Mapper) were developed by Mark R. Jensen, Cameron T. Ackerman, Alex J. Kennedy, and Anton Rotter-Sieren. Special thanks to Mr. Will Breikreutz for his assistance in developing the RAS Tile server.

The interface for channel design/modifications was designed and developed by Mr. Cameron T. Ackerman and Mr. Mark R. Jensen.

The stable channel design functions were programmed by Mr. Chris R. Goodell.

The routines that import HEC-2 and UNET data were developed by Ms. Joan Klipsch. The routines for modeling ice cover and wide river ice jams were developed by Mr. Steven F. Daly of the Cold Regions Research and Engineering Laboratory (CRREL).

Many other HEC staff members have made contributions in the development of this software, including: Vern R. Bonner, Richard Hayes, John Peters, Al Montalvo, and Michael Gee. Mr. Matt Fleming was the Chief of the H&H Division, and Mr. Chris Dunn was the director during the development of this version of the software.

HEC-RAS uses the following third party libraries:

1. Hierarchical Data Format (HDF) – HEC-RAS uses the HDF5 libraries in both the User Interface and the Computational engines for writing and reading data to binary files that follow the HDF5 standards. The HDF Group: http://www.hdfgroup.org/HDF5/
2. Geospatial Data Abstraction Library (GDAL) – HEC-RAS uses the GDAL libraries in the HEC-RAS Mapper tool. These libraries are used for all Geospatial data rendering, coordinate transformations, etc… GDAL: http://www.gdal.org/
3. Bitmiracle LibTiff .Net. LibTiff.Net provides support for the Tag Image File Format (TIFF), a widely used format for storing image data. Bitmiricle: http://bitmiracle.com/libtiff/
4. Oxyplot – 2 dimensional X-Y plots in HEC-RAS Mapper. Oxyplot: http://oxyplot.org/
5. SciChart – 2 dimensional X-Y plots. http://www.scichart.com
6. SQLite – Reading and writing database files. SQLite: https://www.sqlite.org/
7. cURL - HTTP support for GDAL http://curl.haxx.se/
8. Clipper – an open source freeware library for clipping and offsetting lines and polygons. http://www.angusj.com/delphi/clipper.php
9. SharpDX – .Net DirectX graphics library for 2D and 3D support. https://www.sharpdx.org
10. ZeroFormatter – Use to read and write HEC-RAS objects to disk very quickly. https://github.com/neuecc/ZeroFormatter

2 INTRODUCTION

HEC-RAS can perform two-dimensional (2D) hydrodynamic routing within the unsteady flow analysis portion of the software. Users can now perform one-dimensional (1D) unsteady-flow modeling, two-dimensional (2D) unsteady-flow modeling (Shallow Water equations (SWE) or Diffusion Wave equations (DWE)), as well as combined 1D and 2D unsteady-flow routing. The 2D flow areas in HEC-RAS can be used in number of ways. The following are some examples of how the 2D flow areas can be used to support modeling with HEC-RAS:

- 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).

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.

> ⓘ **Note:** This document assumes that the reader already knows how to use HEC-RAS to perform 1D unsteady flow modeling. This document focuses on how to use the new 2D modeling capabilities and the new HEC-RAS Mapper features. For assistance with 1D unsteady flow modeling, and how to use the user interface, please review the main HEC-RAS User's Manual and Hydraulic Reference Manual.

HEC-RAS 2D Modeling Advantages/Capabilities

The 2D flow routing capabilities in HEC-RAS have been developed to allow the user to perform 2D or combined 1D/2D modeling. The 2D flow modeling algorithm in HEC-RAS has the following capabilities:

- **Can perform 1D, 2D, and combined 1D and 2D modeling.** HEC-RAS can perform 1D modeling, 2D modeling (no 1D elements), and combined 1D and 2D modeling. The ability to perform combined 1D/2D modeling within the same unsteady flow model will allow users to work on larger river systems, utilizing 1D modeling where appropriate (for example: the main river system), and 2D modeling in areas that require a higher level of hydrodynamic fidelity.
- **Shallow Water Equations (SWE) or Diffusion Wave Equations (DWE) in 2D.** The program solves either the 2D Shallow Water equations (with optional momentum additions for turbulence, wind forces, mud and debris flows, and Coriolis effects) or the 2D Diffusion Wave equations. This is user selectable, giving modelers more flexibility. In general, the 2D Diffusion Wave equations allow the software to run faster and have greater stability properties. The 2D Shallow Water equations are applicable to a wider range of problems.

However, many modeling situations can be accurately modeled with the 2D Diffusion Wave equations. Because users can easily switch between equation sets, each can be tried for any given problem to see if the use of the 2D Shallow Water equations is warranted over the Diffusion Wave equations.

- **Implicit Finite Volume Solution Algorithm.** The 2D unsteady flow equations solver uses an Implicit Finite Volume algorithm. 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. The wetting and drying of 2D cells is very robust. 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 (flow passing through critical depth, such as a hydraulic jump) without any special options to turn on.

- **1D and 2D Coupled Solution Algorithm.** 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. This allows for direct feedback each time step between the 1D and 2D flow elements. For example, 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. Each time step the weir equation uses the 1D and the 2D results to compute the flow allowing for accurate accounting of weir submergence, at each time step, as the interior area fills up. Additionally, flow can go back out of the breach (from the 2D area to the 1D reach), once the river stages subside.

- **Unstructured or Structured Computational Meshes.** The software was designed to use unstructured computational meshes but can also handle structured meshes. A structured mesh is treated the same as an unstructured mesh. The software assumes that cells are orthogonal to each other (the face between two cells is perpendicular to a line connecting the two cell centers). Assuming orthogonality simplifies some of the computations required and improves computational speed. 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 mesh can be a mixture of cell shapes and sizes. The outer boundary of the computational mesh is defined with a polygon. The computational cells that form the outer boundary of the mesh can have very detailed multi-point lines that represent the outer face(s) of each cell.

- **Detailed Hydraulic Property Tables for 2D Computational Cells and Cell Faces.** 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. This type of model is often referred to in the literature as a "high resolution subgrid model" (Casulli, 2008). The term "subgrid" means it uses the detailed underlying terrain (subgrid) to develop the geometric and hydraulic property tables that represent the cells and the cell faces. 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. 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. Therefore, a cell can be partially wet with the correct water volume for the given water surface elevation (WSEL) based on the 2ft grid data. Additionally, 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. This allows the modeler to use larger computational cells, without losing too much of the details of the underlying terrain that govern the movement of the flow. 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. The net effect of larger cells is fewer computations, which means much faster run times. An example computational mesh overlaid on detailed terrain is illustrated in Figure 1-1.
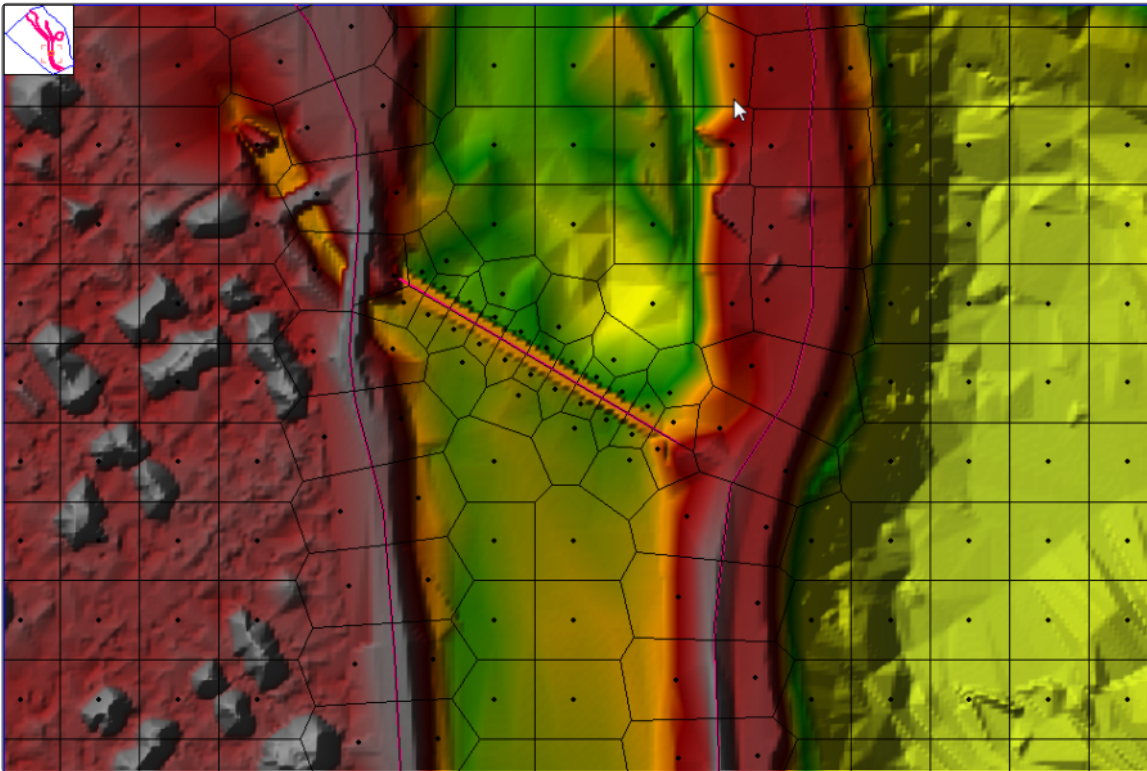
Figure 1-1. Unstructured computational mesh with detailed sub-grid terrain data.

Shown in Figure 1-1 is an example computational mesh over terrain data depicted with color shaded elevations. The computational cells are represented by the thick black lines. The cell computational centers are represented by the black dots and are the locations where the water surface elevation is computed for each cell. The elevation-volume relationship for each cell is based on the details of the underlying terrain. Each cell face is a detailed cross section based on the underlying terrain below the line that represents the cell face. This process allows for water to move between cells based on the details of the underlying terrain, as it is represented by the cell faces and the volume contained within that cell. Therefore, 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. This means water can run through larger cells, but still be represented with its normal channel properties. An example of a small channel running through much larger grid cells is shown in Figure 1-2. The example shown in Figure 1-2 has several canals that are much smaller than the average cell size used to model the area (cell size was 500 x 500 ft, where the canals are less than 100 ft wide). However, as shown in Figure 1-2, flow is able to travel through the smaller canals based on the canal's hydraulic properties. Flow remains in the canals until the stage is higher than the bank elevation of the canal, then it spills out into the overbank areas.
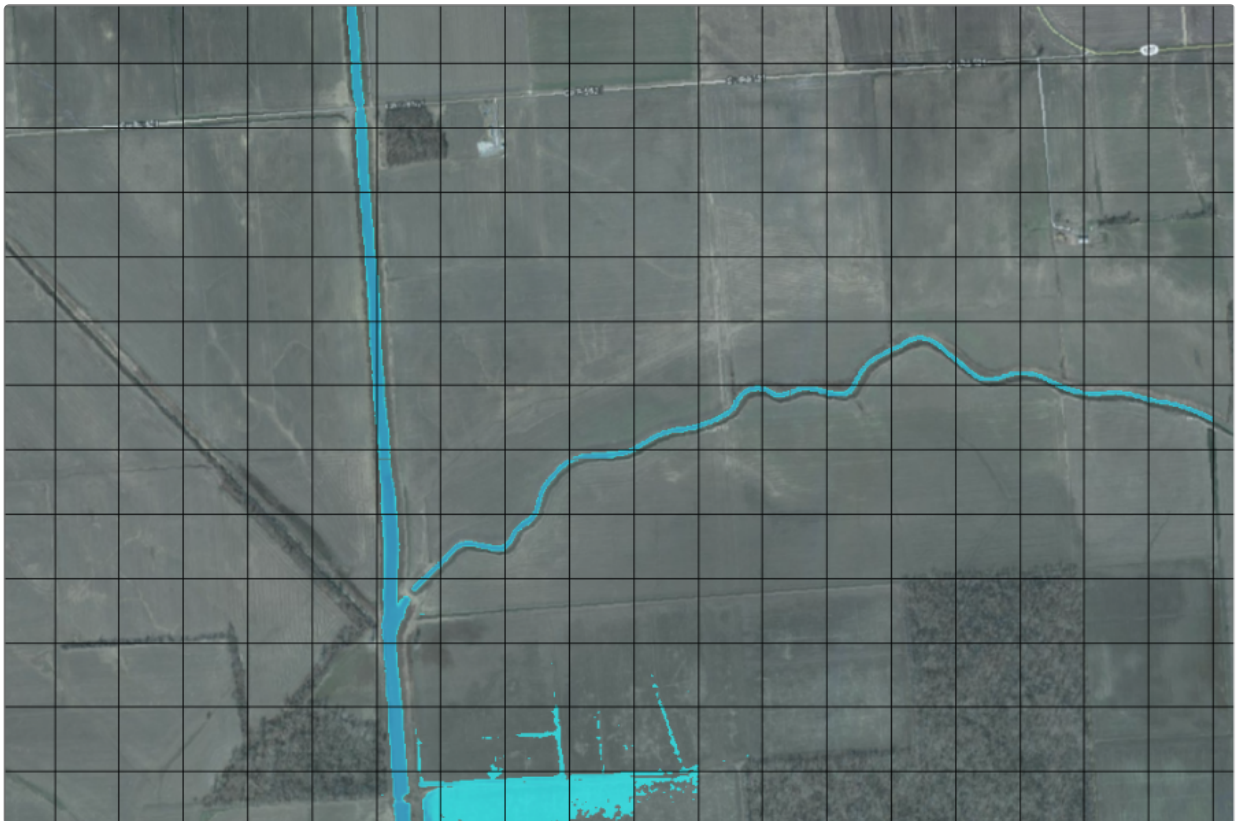
- **Detailed Flood Mapping and Flood Animations.** Mapping of the inundated area, as well as animations of the flooding can be done inside of HEC-RAS using the RAS Mapper features. The mapping of the 2D flow areas is based on the detailed underlying terrain. This means that the wetted area will be based on the details of the underlying terrain, and not the computational mesh cell size. Computationally, cells can be partially wet/dry (this is how they are computed in the computational algorithm). Mapping of the results will reflect those details, rather than being limited to showing a computational cell as either all wet or all dry.
- **Multi-Processor Based Solution Algorithm (Parallel Computing).** 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.
- **64-Bit Computational Engines.** HEC-RAS now comes with 64-bit computational engines. The 64-bit computational engines run faster than the previous 32-bit and can handle much larger data sets. 32-bit computations are no longer supported, and user's must be running a 64-bit operating system.

Developing a 2D or 1D/2D Unsteady Flow Model

Overview

Using HEC-RAS to perform 2D modeling or combined 1D/2D modeling is very easy and straight forward. The following are the basic steps for performing 2D (or combined 1D/2D) modeling within HEC-RAS:

1. Establish a Horizontal Coordinate Projection to use for your model, from within HEC-RAS Mapper. This is normally done by selecting an existing projection file from an ESRI shapefile or another mapping layer.

2. Develop a terrain model in HEC-RAS Mapper. The terrain model is a requirement for 2D modeling, as it is used to establish the geometric and hydraulic properties of the 2D cells and cell faces. A terrain model is also need in order to perform any inundation mapping in HEC-RAS Mapper.
3. Build a Manning's n layer data set within HEC-RAS Mapper, using land cover data layers and polygon layers, in order to establish Manning's n values within the 2D Flow Areas. Additionally, HEC-RAS has an option for user defined polygons that can be used to override the base Manning's n values. These user defined polygons could be used as calibration zones.
4. Add any additional mapping layers that may be needed for visualization, such as aerial photography, levee locations, road networks, etc.
5. From within the HEC-RAS Mapper draw a boundary polygon for each of the 2D Flow Areas to be modeled. Or you can import the X, Y boundary coordinates from another source.
6. Layout any break lines within the 2D flow area to represent significant barriers to flow, such as: levees, roads, natural embankments, high ground between main channel and overbank areas, hydraulic structures, etc.
7. Using the 2D Flow Area editor, create the 2D computational mesh for each 2D Flow Area.
8. Edit the 2D Flow Area mesh in order to improve it, such as: add additional break lines; use the refinement regions option to increase or decrease cell density as needed; Add, Move, or Delete cell centers where needed. Use the mesh refinement region tool to make a nice channel mesh.
9. Add any internal hydraulic structures or bridges inside of the 2D flow area(s) using the SA/2D Area Hydraulic Connection feature.
10. Run the 2D geometric pre-processor from RAS Mapper in order to create the cell and face hydraulic property tables.
11. Connect the 2D Flow Areas to 1D Hydraulic elements (river reaches, Lateral structures, storage area/2D flow area hydraulic connections) as needed.
12. From the RAS Mapper or the Geometric Data editor, draw any external boundary condition lines along the perimeter of the 2D flow areas.
13. Enter all of the necessary boundary and initial condition data for the 2D flow areas in the Unsteady Flow data editor.
14. From the Unsteady Flow Simulation window, set any necessary computational options and settings needed for the 2D flow areas.
15. Run the Unsteady flow simulation.
16. Review the combined 1D/2D output in RAS Mapper, as well as using the existing output capabilities for the 1D portions of the model.

Current Limitations of the 2D modeling Capabilities

The following is a list of the current limitations of the HEC-RAS 2D flow modeling software. These are items actively being worked on to improve the software, and will be available in future versions:

1. Cannot perform water quality modeling in 2D flow areas.

3 DEVELOPING A TERRAIN MODEL AND GEOSPATIAL LAYERS

It is 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. Terrain data comes from many different sources, formats, and levels of detail. Currently HEC-RAS uses gridded data for terrain modeling. It is up to the user to gather data from multiple sources, then convert/export it into a gridded data format that can be read in by HEC-RAS.

It is necessary to create a terrain model in HEC-RAS Mapper before the user can perform any model computations that contain two-dimensional (2D) flow areas, or before the user can visualize any one-dimensional (1D), 2D, or combined 1D/2D mapping results. This section of the document describes how to create a terrain model in RAS Mapper, as well as other optional geospatial layers. The user can develop one or more terrain models that can then be associated with a specific geometry input file, or a specific results output file. Additionally, users have the option in RAS Mapper to create a Landcover data layer, Soils layer, and an Infiltration layer. Once a Landcover layer is created, users can associate Manning's n values with each of the landcover types. Optionally users can specify a percent impervious for each landcover type (% impervious is only necessary if the user is modeling precipitation and infiltration within HEC-RAS). Soils data can be imported from gridded Soil Survey Geographic (gSSURGO) database files or the information can be imported from existing shape files. Soils data can be specified as either Soil Conservation Service (SCS) hydrologic soil groups (HSG) or more detailed soil texture classes. An Infiltration layer can be derived from a landcover and Soils layer, just landcover, or just a soils layer. In RAS Mapper, users have the option of three different infiltration methods for creating an infiltration layer: Deficit-Constant, SCS Curve Number, or Green and Ampt.

For more details on creating terrain models and other geospatial layers with HEC-RAS Mapper, please review the HEC-RAS Mapper User's manual.

Opening RAS Mapper

The first step in developing a terrain data set is to open RAS Mapper. Opening RAS Mapper is accomplished by selecting **GIS Tools** from the HEC-RAS main window, then selecting **RAS Mapper**,

or by pressing the **RAS Mapper** button ⬙ on the HEC-RAS main window. When RAS Mapper is selected, the window shown in Figure 2-1 will appear (the users window may be blank at first).
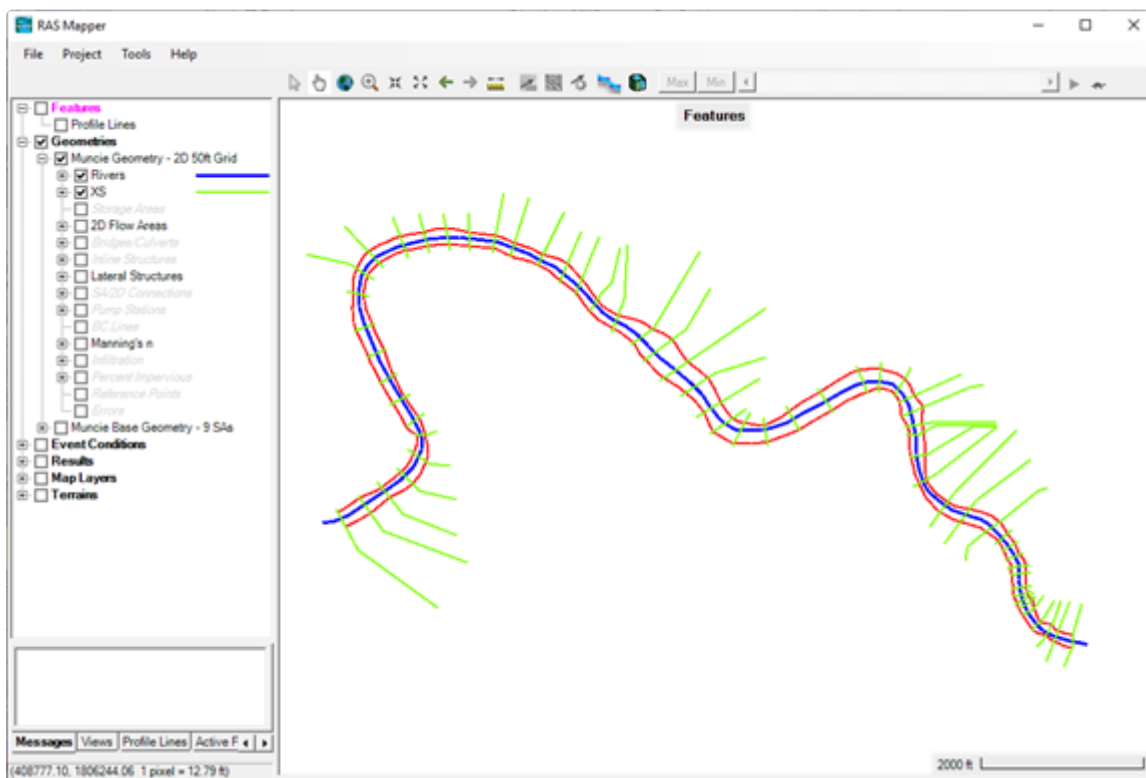
Figure 2-1. RAS Mapper with no terrain or other map layers loaded.

Setting the Spatial Reference Projection

Once RAS Mapper is open, if the data is in a specific spatial coordinate projection, that projection should be set in RAS Mapper. Setting a spatial coordinate system is not required (i.e., maybe the user is just doing some testing of hypothetical data), but setting the coordinate system has many advantages in HEC-RAS and HEC-RAS Mapper.   To set the spatial reference system for the project, from the RAS Mapper menu bar, select the **Project | Set Projection** menu item. When the **Set Projection** option is selected, the window shown below will appear.
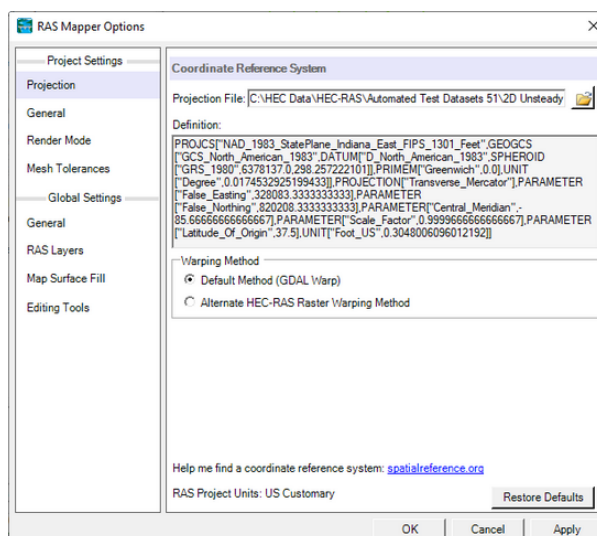
To set the spatial reference system (coordinate system), browse and select an existing ".prj" file (ESRI projection file) that contains the correct coordinate system. If using ESRI's ArcGIS® Version 10.0 (or earlier), browse to the ArcGIS directory that contains a listing of all the available coordinate systems and select the appropriate one. Otherwise, locate an ArcGIS projection file (*.prj) within one of the GIS project directories (look for a shapefile that has a projection file defined). Unfortunately, the directory of coordinate systems was removed at ArcGIS version 10.1 and newer. So, users will have to create one with ArcGIS or search on the internet for an ArcGIS projection file. For the example provided in Figure 2-2, the Coordinate Reference System selected was "*NAD_1983_StatePlane_Indiana_East.prj*".

Loading Terrain Data and Making the Terrain Model

The next step is to load the terrain data that will be used in creating the terrain model for HEC-RAS. To develop a new terrain data set (terrain model), from the RAS Mapper main window (Figure 2-1), right click on the Terrains layer and from the shortcut menu select **Create New RAS Terrain**. The **New Terrain Layer** dialog (Figure 2-3) opens. This dialog allows the user to provide a name for the new Terrain Layer (**Filename** field, the default name is "Terrain"); select a directory for storing the terrain (**Folder** button); define the elevation precision of the new terrain data layer (**Rounding (Precision)** field, 1/32 is the default for English units); and select the files to be used in building the new terrain layer (**Plus (+)** button).

At this time, RAS Mapper can import terrain data that is in the floating-point grid format (*.flt); GeoTIFF (*.tif) format; ESRI grid files; and several other formats (for example, a USGS DEM file). A list of file formats supported by the RAS Mapper software is contained in **Appendix B** of this manual. NOTE: Limited testing of the terrain file formats listed in Appendix B has been conducted by HEC; however, the GDAL library being utilized by RAS Mapper identifies the file formats listed in Appendix B, which are supported by GDAL. However, the data being imported must be in a gridded format, in order to be used to make a terrain model.

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**). ESRI grid files will have *.adf file extensions. **Note: there are several *.adf files that make up an ESRI grid. Pick any one of them and the program will process all of them as needed.**

Add Input Terrain Files to the **New Terrain Layer** dialog by clicking the **Add Files** button (Figure 2-3), to open a browser window. Select the appropriate terrain grid or grids (more than one grid can be used simultaneously to form a tiled terrain model) and click **Open**. The selected gridded file(s) are added to the **New Terrain Layer** dialog (Figure 2-3).

From the **Output Terrain File** section, define the elevation precision of the new terrain data layer (**Rounding (Precision)** field (1/32 is the default for English units), and select a directory for storing the terrain (**Folder** button).
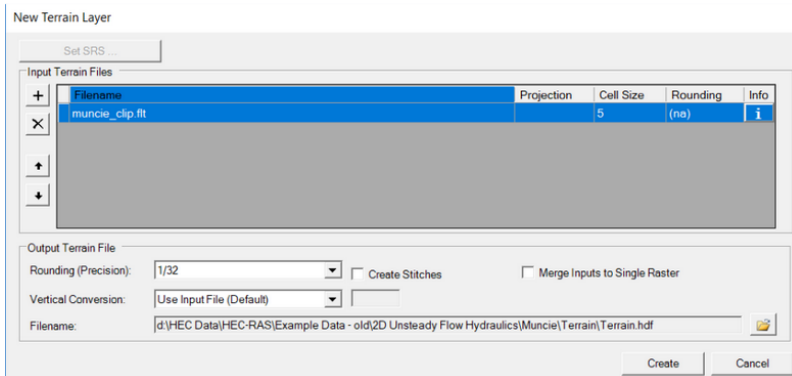
Example New Terrain Layer dialog.

> ⓘ **NOTE:** If more than one grid file is loaded, use the up and down arrow buttons to the left of the table 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. If there is only one Terrain layer, which will be the case for many studies, the name may be left as "Terrain", or another name can be given.

Once the grid files are selected, and placed in the appropriate priority order, click the **Create** button to create the new Terrain Layer and add the terrain to the RAS Mapper map window. RAS Mapper will convert the grids into the GeoTIFF (*.tif) file format. The GeoTIFF file structure supports tiled and pyramided data. Tiled data uses less area of the terrain by removing the "NoData" values, while pyramided data stores multiple terrain layers of varying resolutions. Additionally, the GeoTIFF files are automatically stored in a compressed form (using the zip format), which makes the file storage much smaller. In general, the GeoTIFF files will be 2 to 20 times smaller than the original FLT or ESRI grid files. The GeoTIFF file format allows for smaller storage space, faster computational speed (in generating flood maps), as well as "dynamic mapping" of the results (depth grids that are created on the fly in memory, as the user zooms in or zooms out, pans, or animates the flood maps).

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 ArcGIS will know about all of the raster files that make up the terrain layer. Additionally, when the raster files are plotted in ArcGIS the same scale and color ramp will be used. Once RAS Mapper has completed the conversion of the files to GeoTIFF and created the HDF and VRT file, the new terrain layer will be visible in the RAS Mapper map window (show below).
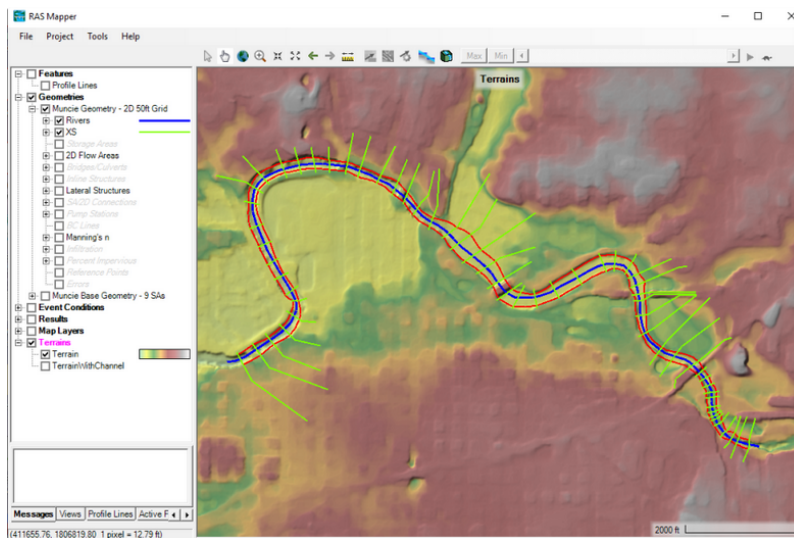
Once the terrain model is created the user can enhance the look of the terrain data by right clicking on the terrain layer and selecting **Image Display Properties**. The **Image Display Properties** window (Figure 2-5) allows the user to: select and control the Surface Color Ramp; Transparency; Create and plot Contour Lines; and shade the terrain using a Hill Shading algorithm (Hill Shading makes the visualization of the terrain much more realistic and semi 3D).
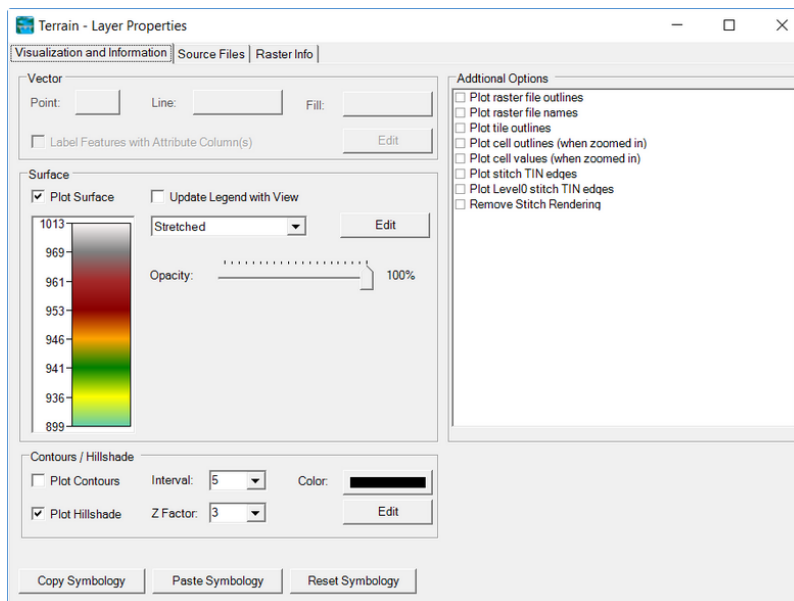
An example of terrain data with some of the layer properties enhancements (Hill Shading and Contour Lines) turned on is shown in Figure 2-6.

> ⓘ **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.
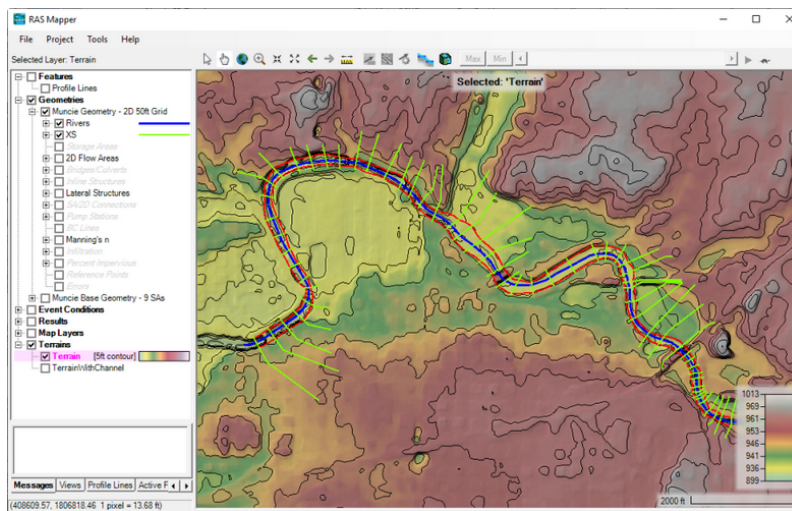
Using Cross Section Data to Modify/Improve the Terrain Model

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. However, RAS Mapper can be used to create a terrain model of the channel region from the HEC-RAS cross sections and the Cross-Section layer's Interpolation Surface. The created channel terrain model can then be combined with the general surface terrain model (that does not accurately depict the terrain below the water surface) to create an improved terrain model for hydraulic modeling and mapping.

> ⓘ **Note:** RAS Mapper now has a wide set of vector-based terrain modification tools that can be applied to any HEC-RAS terrain model. To learn about the vector-based terrain modification tools, and how to use them, please see the HEC-RAS Mapper User's manual.

The following sections provide the instructions for creating the channel terrain model using the HEC-RAS cross sections layer and interpolation surface cross sections sublayer, and for adding the created channel terrain to the general surface terrain model.

Creating a Terrain Model of the Channel

From RAS Mapper, turn on the Geometry layer for the 1D cross section geometry data to be used in creating the channel terrain model. Also turn on the following sublayers: **River (stream centerline)**; **River - Bank Line**; **XS** (cross sections); and **XS - Interpolation Surface**. Review the stream centerline (River); Bank Lines, XS (cross sections); and the XS Interpolation Surface to ensure they are correct, and what the user wants for a new channel terrain model.

> ⓘ **NOTE:** it is generally a good idea to make a copy of the 1D cross sections geometry that will be used to make the channel terrain. Then move the main channel bank stations inside of the channel down to the level at which the terrain model information is not correct. By doing this, when you export the 1D channel data as a terrain model, it will only create a terrain model of the area that is not defined well in the original terrain model. This approach will also prevent good

terrain data from being overwritten by terrain data created from the interpolation of 1D cross sections. See an example with the desired geometry sublayers selected in the figure below.
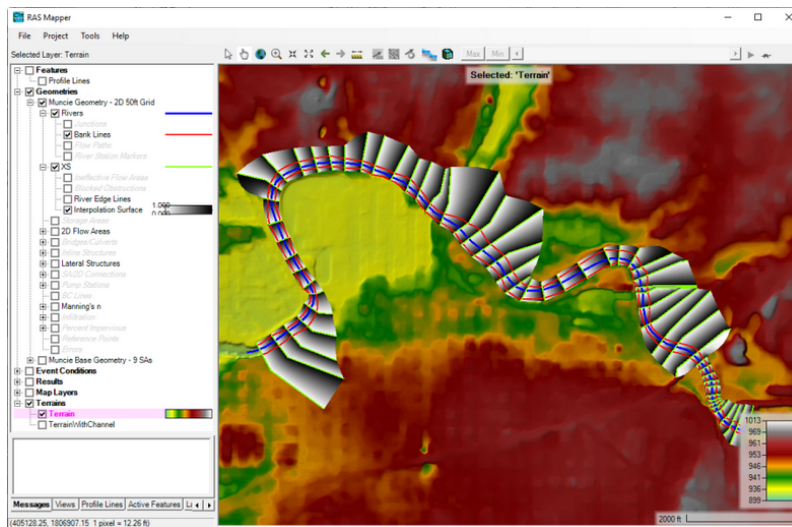
Once the geometry layers are completed, the channel terrain model is created by right clicking on the Geometry layer (parent name) and selecting **Export Layer**, then **Create Terrain GeoTIFF from XS's (channel only)**. Alternatively, the user can make a terrain model out of the entire cross section region (channel and overbank area), but if the base terrain model has good overbank terrain information, the user will not want to do that. Once the **Export** option is selected, a file selector will appear, in which the user will need to give the new terrain model a name, and choose a directory to put it in. See the file selector in the figure below.
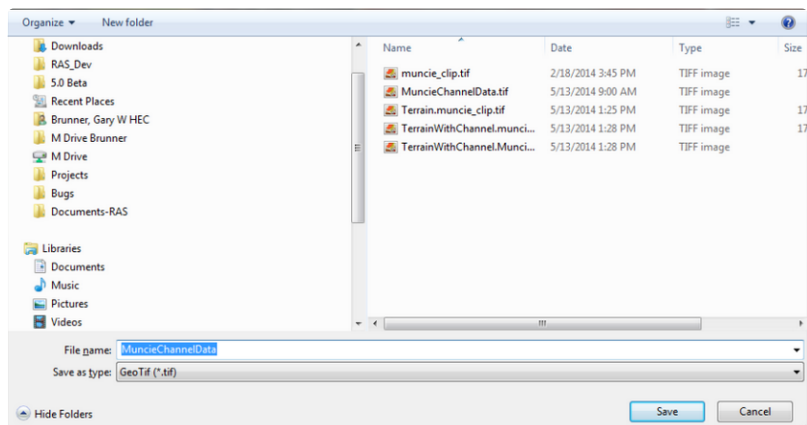
Once a directory is chosen and a filename is entered, click the **Save** button to create the channel terrain model. An HEC-RAS Mapper **Export Terrain** message window will open and ask the user to enter the raster cell size to use for the created channel terrain model. For example, if the user enters "2.0", then the created channel terrain model will have grids that are 2 ft x 2 ft. RAS Mapper creates the terrain model 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. When the user selects the **Export Layer | Create Terrain GeoTIFF from XS's (Channel Only)** shortcut menu

command, then this new surface is clipped at the main channel bank stations and written as a terrain grid in the GeoTIFF file format.

Making a Combined Channel and Overbank Terrain Model

Once the user has created a channel terrain model, a new combined terrain model can be made from the base terrain model (the terrain with the overbank/floodplain data) and the newly created channel-only terrain model. To make the new combined terrain model, from the RAS Mapper menu bar, select the **Tools | New Terrain** menu item. The **New Terrain Layer** dialog opens (Figure 2-3). Note, this step is the same as previously described for creating a terrain model in RAS Mapper; however, the files used to create this terrain model will be the previously created GeoTIFF of the base terrain data, and the newly created GeoTIFF of the channel-only data. sectionOnce the **New Terrain** option is selected, the window to make a new terrain layer will appear (Figure 2-3). Enter a new Name for the new terrain model ("TerrainWithChannel" was used in this example). Select the folder for the new terrain model to be written to. Select the precision of the new terrain model, keeping in mind the precision should not be finer than the terrain files used to create this new terrain model. Then press the **Plus** (**+**) button and select the base terrain models GeoTIFF file, and the channel only terrain models GeoTIFF file. Make sure that the new channel-only terrain model has a higher priority than the base terrain model (i.e. make sure it is first in the list of the added terrain files). Then press **Create** button and a new combined terrain model will be created and added to the RAS Mapper project. See the original (terrain model without cross section data included) and the new (terrain model with cross section data included) terrain models in the figure below.
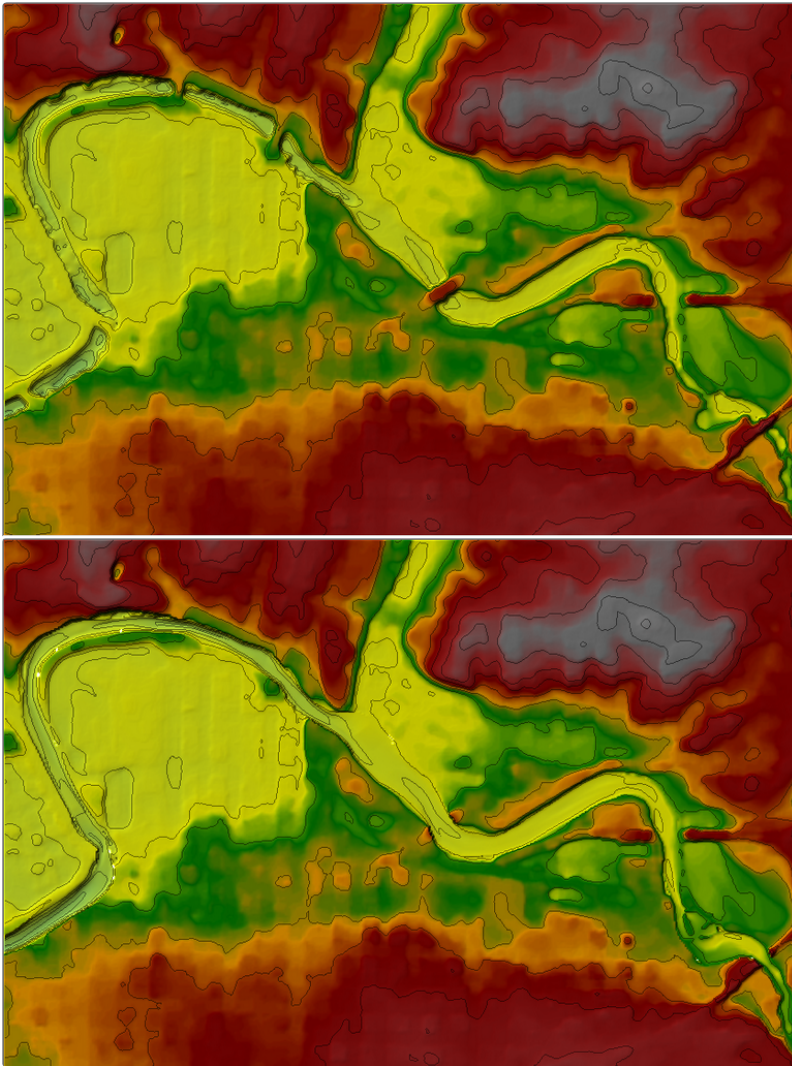
Creating Land Cover, Manning's n values, and % Impervious Layers

A spatially varying land cover layer can be created in RAS Mapper, and then associated with a specific geometry data set. Once a land cover data set is created, the user can specify Manning's n values to be used for each land cover type. Additionally, the user can create their own land cover classification polygons (user defined polygons), in which they can override the base land cover layers within that polygon and define a new land cover type. User defined classification polygons are often used for channel areas as national land cover data sets often do not adequately define the correct area for the main channels. The creation of user defined landcover classifications will allow users to create a good set of base Manning's n values for these user defined classification polygons. More than one polygon can be drawn and given the same name. However, only one Manning's n value can be set for each user defined land cover classification polygon. So, if the Manning's n values need to be different, then the polygons must have different names. Users can also specify percent impervious for each of the land cover types. Percent impervious is optional and only necessary if the user is modeling precipitation and infiltration.

Once a Land Cover layer (with Manning's n values set) is created and associated with a specific Geometry data set, the user can create Calibration Region polygons. A Calibration Region polygon is used to override all the Manning's n values associated with land cover within the polygon. Created Calibration Regions only apply to that specific Geometry, and do not change the base land cover/ Manning's n value layer. In other words, Calibration Regions allow users to come up with different Manning's n values for different calibration events, if necessary.

This section of the manual provides instructions for creating a Land Cover data set, Manning's n Values and Percent Impervious, User defined land cover classification polygons, associating Land Cover/Manning's n with Geometry Data, and Manning's n Calibration Regions.

> ⓘ **NOTE:** Users 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 defined Land Cover Classification Polygons.

Creating a Land Cover Data Set

In the current version of HEC-RAS, users can import land use information in both polygon (shapefile) and gridded formats. Custom user defined Shapefile layers can be created in HEC-RAS Mapper. Gridded landcover data can be obtained from U.S. Geological Survey (USGS) websites (National Land Cover Database, NLCD 2016 and USGS Land Use Land Cover modeling, LULC), as well as other sources. RAS Mapper allows the user to add multiple land use data input files and file types to create a single land use coverage layer in HEC-RAS. For example, a user may want to use the USGS NLCD 2016 gridded land use data as the base land use coverage data. However, a user may want to also find or generate a polygon coverage (shapefile) that is more accurate for many of the areas within their study region (i.e., the main channel regions, buildings, roads, etc…). By setting the more accurate shapefile as the higher priority, the land use from the shapefile will be used unless it does not cover portions of the area, then the USGS gridded data will be used for those areas. RAS Mapper ingests the various land use data types and creates a combined land cover layer and stores it as a GeoTIFF file (there is also a companion *.hdf file generated).

> ⓘ **NOTE:** The two example 2D data sets that come with HEC-RAS (*Muncie.prj* and *BaldEagle.prj*) contain land use information for defining Manning's n values. Please open one of these data sets and use it as a guide along with the discussion in this manual.

To create a spatially varying land cover layer within HEC-RAS, go to RAS Mapper, then right click on **Map Layers** in the tree on the left, then select **Create New RAS Layer| Land Cover Layer**. This selection will bring up the window shown in Figure 3-16. The Land Cover Layer window is broken into three sections: **Input Files**, **Unique Classification Names for Selected File**, and **Output File**. The **Input Files** section is for selecting the grid and shapefiles to be used as input, as well as setting their priority. The **Unique Classification Names for Selected File** 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. The **Output File** section is used to show what HEC-RAS will use for the RAS Classification name and numeric ID.
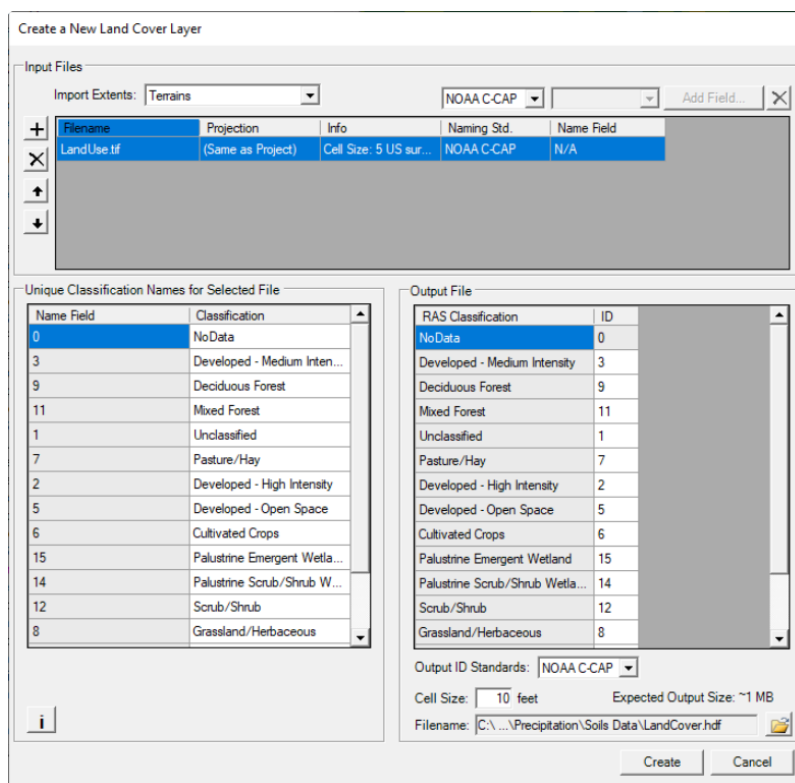
The **Create a New Land Cover Layer** editor (Figure 2-10) allows the user to select one or more land use files of varying type. This is accomplished under the **Input Files** section by selecting the **Plus (+)** button. Once the plus button is selected a file chooser will come up allowing the user to select a land use coverage file. If more than one land use file is selected, use the **Up** and **Down** arrows to select and move a file in the **Input Files** section to set the priority of the listed files. The file at the top of the list has the highest priority, and so on. Because HEC-RAS supports multiple land use files and types, the user will have to either select one of the established naming conventions or enter their own naming convention for each land use type.

To set the naming convention for a shapefile, from the **Input File** section of the editor, select (highlight) a shapefile, the **Name Field** column actives. From the dropdown list located above the input files table, select a shapefile field (column contained in the shapefile) to be used for name field. To set the naming convention for a gridded land cover data set, from the **Input File** section of the editor, select (highlight) a gridded land cover data set, and only the **Naming Std.** field activates and is available for defining the names of land use types. Currently there are three options for defining the names of the land use types: NLCD 2016 (which is from the USGS 2011 land use data coverage); Anderson II (developed by James R. Anderson, et al., from the USGS in 1976); and NOAA C-CAP. For the example provided in Figure 2-10, the *NOAA C-CAP* land use type names option is selected from the **Naming Std.** dropdown menu (located above the input files table) in the **Input Files** section.

When you select a land cover layer in the Input File section of the editor**,** the "Unique Classification Names for Selected File" section of the editor will show what is contained within the file for the **Name Field (**integer value or text label**)**, and also what HEC-RAS will use as an identifier for that specific land cover type. Because different land cover data sources use different naming conventions, if the user has more than one input file, the software must come up with a single

naming convention to use for all of the data. The combined naming convention that HEC-RAS will use is shown in the **Output File** section of the window. The Output File section shows the final naming convention it will use, along with the integer ID's. Manning's n values could have been selected from a Shapefile, or the user can edit/enter them directly into the Land cover data table.

From the **Create a New Land Cover Layer** editor (Figure 2-10), from the **Output File** section, the user can choose an **Output ID Standard** from the dropdown located below the output file table. The output ID standard is generally used when a shapefile has been selected and the user does not wish to apply one of the USGS naming standards to that file. If more than one input land cover file has been added to the **Input Files** table, then the **Naming Std.** column will automatically contain the **Custom** option, as a single standard will generally not work for multiple land cover types. Also, when using more than one land cover layer type (shapefile and grid), there will be different naming conventions within the two files for the same land cover type. USGS naming conventions use specific integer ID's for associated land cover types; however, the integer ID's get assigned to land cover types for shapefiles. If the same ID gets assigned to two different land cover types, the software will display a "**Duplicate IDs**" error message in red below the output table. The user must change one or more of the duplicate ID's to a unique integer identifier, currently not used in the table before creating the land cover layer.

From the **Create a New Land Cover Layer** editor (Figure 2-10), from the **Output File** section, the filename and output directory for the new land classification layer is shown at the bottom of the section. The user should select a directory to be used for the HEC-RAS land cover layer, and also enter a name for this new layer. RAS Mapper takes all of the input layers and creates a single land cover output layer in the *.tif file format. The last step before creating a Land Classification dataset is to enter an appropriate cell size (i.e., 1, 2, 5, 10 ft) that takes into account the computational cell size being used and the spatial accuracy needed for the land classification (and therefore roughness) values. After all the data is entered press the **Create** button, RAS Mapper will read the input file layers and convert them into a single GeoTIFF file in the user define output directory. A progress window will open displaying the file creation progress and inform the user when the file has been created. From the progress window, click the **OK** button to close the progress window and the **Create a New Land Cover Layer** editor (Figure 2-10).

Figure 2-11 provides an example of a Land Cover layer with Land Classifications created and displayed in RAS Mapper. The user can control the color of each land use category, and the transparency used to display the polygons. The display of the land use classification is controlled by right clicking on the Land Cover layer and selecting **Image display properties** from the shortcut menu. This command opens a window allowing the user to control the colors and transparency of the polygons.
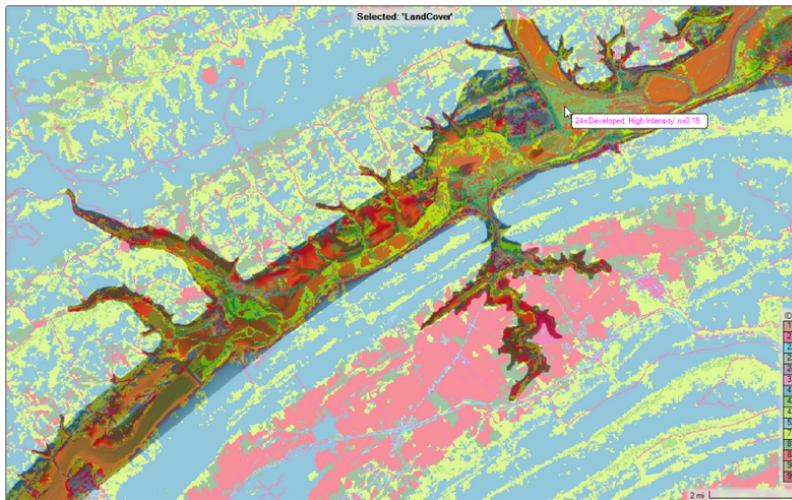
Manning's n Values and Percent Impervious

Once a Land Cover layer has been created, 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 and 1D river reaches. The created Land Cover versus roughness table is developed from within the HEC-RAS Mapper software, directly within the Land Cover layer. To create the Manning's n vs. Land Cover table, from the RAS Mapper main window, funder **Map Layers**, right click on the Land Cover layer of choice, and from the shortcut menu, click **Edit Land Cover Data**. The **Edit Land Cover Data** command opens the **Data Table Editor** (shown in the figure below).

As shown in in the figure above, the user must define Manning's n values for all of the land classification types, including the NoData field. The user entered Manning's n values will be considered to be the base Manning's n values for this land cover layer. Additionally the user can

define **Percent Impervious** for each Land Cover Classification type. Percent Impervious is only needed in the user intends to use precipitation and infiltration features within HEC-RAS.

User Defined Land Cover Classification Polygons

In addition to establishing Manning's n values for each of the land cover classifications within the land cover layer, users have to option to override these values by creating user defined **Classification Polygons**. For example, the national based land cover data sets are not well defined for the main channel areas of a river system. Users will need to create their own main channel polygons to ensure they can establish a good set of base Manning's n values for the entire channel. Typically, a river system will be broken up into many user defined polygons, one polygon for each Manning's n value region.

To create user defined land cover classification polygons, right click on the **Classification Polygons** layer underneath the desired Land Cover layer, then select **Edit Layer**. This puts RAS Mapper into edit mode and will allow you to create new or edit existing classification polygons. An example showing a single user defined land cover Classification Polygon, for the "Main Channel," is provided in Figure 2-13. The example provided in Figure 2-13, displays the Main Channel with a user defined classification for the Manning's n value of 0.035 and a percent impervious of 100. Generally, several user defined land cover classifications will be developed for a land cover data layer to reclassify main channel areas, roads, parking lots, buildings, or anything else that is not well defined in the base land cover data layer.
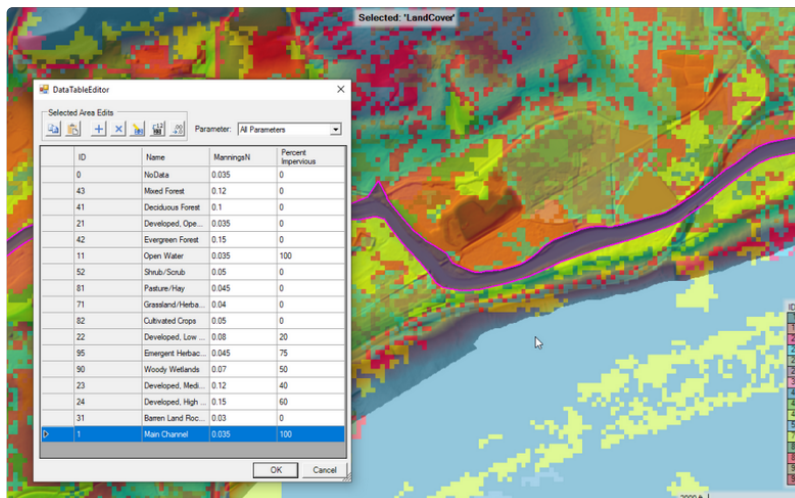
Associating Land Cover/Manning's n with Geometry Data

Once the user has created a Land Cover layer and added some of their own user defined classification regions, they must associate land cover layers with geometry file(s). To associate a Land Cover layer with a geometry file, right click on the **Geometries** layer (on the left side of the RAS Mapper window) and select **Manage Geometry Associations** from the shortcut menu. The **Manage Geometry Associations** window (Figure 2-14) opens, this window allows the user to select the desired layers to associate with each of the Geometry files in the project.
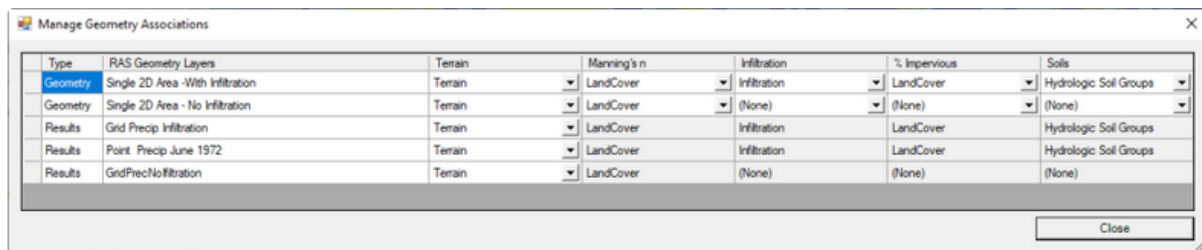
As shown in figure above, the Geometry Associations table allows the user to associate the following information:

- **Terrain:** This must be a Terrain data set created from within HEC-RAS Mapper. This layer association is required.
- **Manning's n:** Land Cover layer containing Manning's n values to use as base Manning's n values for the associated Geometry. **This layer is required** in order to have spatially varying Manning's n values within 2D Flow Areas.
- **Infiltration:**Infiltration Layer containing land cover, soils, and infiltration parameters for one of the available infiltration methods. This layer is Optional depending upon modeling approaches.
- **% Impervious:** Land Cover layer containing % Impervious values to use with associated Geometry. This layer is Optional depending upon modeling approaches.
- **Soils:** Soils Layer to be associated with Geometry. This Layer is Option, and only required for 2D Sediment Transport modeling.

Manning's n Calibration Regions

Once a Land Cover/Manning's n layer has been developed and associated with a specific Geometry data set, the user has the option to create Manning's n Calibration Regions that will only be applied to that specific Geometry data set. To calibrate a hydraulic model, it may be necessary to increase or decrease Manning's n values on a reach-by-reach basis for a specific geometry or event. This process can be accomplished by developing Manning's n calibration regions and using those regions to raise or lower all the Manning's n values contained within that region or polygon.

Manning's n Calibration regions/polygons are created within the Manning's n layer of a specific Geometry data set. To create Manning's n calibration regions, open HEC-RAS Mapper and from the Layers window expand the Geometry layer to be edited (e.g., *Expanded Model – Final Mesh* in Figure 2-15). Then expand the **Manning's n** layer for that Geometry data set. To create or edit Manning's n Calibration Regions, right click on the **Calibration Regions** sublayer and select **Edit Geometry** from the shortcut menu. This option allows the user to create new regions or edit existing regions. Once a region is created user can redefine all the Manning's n values within that region for each land cover type. An example of a model with Calibration Regions for the main channel areas is shown in the figure below.
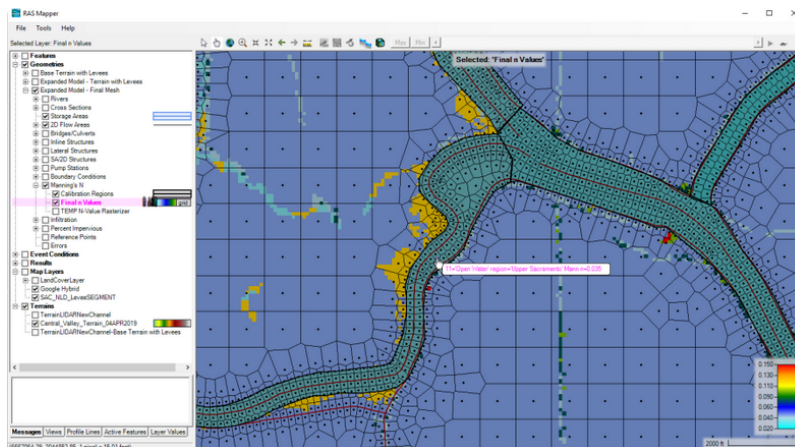
Once the user has drawn the Manning's n Calibration regions for a geometry, the Manning's n values can be edited in a table by right clicking on the **Calibration Regions** layer and selecting **Edit Manning's n Values**. When this is done, a table will appear that allows the user to edit the Manning's n values for all the calibration regions the figure below.

This Manning's n by Land Cover and the Calibration Regions will be used during the 2D flow area pre-processing stage (i.e., the process where the software creates the cell and cell face property tables). To get these Manning's n values into the 2D flow area property tables, the 2D flow area hydraulic property tables must be recomputed. When the cell faces are processed, the Manning's n value selected will be based on finding the cell face center, then the corresponding Manning's n value from the land cover layer. If there is no Land Cover layer defined for a specific cell face, then the default Manning's n value entered into the 2D flow area editor will be used for that cell face. For HEC-RAS Version 6.0, the software will select only one Manning's n value for the entire cell face. Future versions of HEC-RAS will allow for multiple Manning's n values across each cell face.

Examples of typical Manning's n value ranges for the various NLCD Land Cover types is shown in the table below. These n values are for appreciable depths of flow, and are not meant for shallow overland flow. Shallow, overland flow Manning's n values are generally much higher due to the relative roughness compared to the flow depth.

Example Manning's n values for various NLCD Land Cover Types.

NLCD Value	n Value Range	Description
11	0.025 - 0.05	**Open Water**- areas of open water, generally with less than 25% cover of vegetation or soil. This is for natural streams on mild to moderate slopes.
12	n/a	**Perennial Ice/Snow**- areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
21	0.03 - 0.05	**Developed, Open Space**- areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	0.06 - 0.12	**Developed, Low Intensity**- areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	0.08 - 0.16	**Developed, Medium Intensity** -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	0.12 - 0.20	**Developed High Intensity**-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
31	0.023 - 0.030	**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
41	0.10 - 0.20	**Deciduous Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	0.08 - 0.16	**Evergreen Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	0.08 - 0.20	**Mixed Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
51	0.025 - 0.05	**Dwarf Scrub**- Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	0.07 - 0.16	**Shrub/Scrub**- areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

NLCD Value	n Value Range	Description
71	0.025 - 0.05	**Grassland/Herbaceous**- areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
72	0.025 - 0.05	**Sedge/Herbaceous**- Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
73	n/a	**Lichens**- Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
74	n/a	**Moss**- Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
81	0.025 - 0.05	**Pasture/Hay**-areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	0.020 - 0.05	**Cultivated Crops** -areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
90	0.045 - 0.15	**Woody Wetlands**- areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	0.05 - 0.085	**Emergent Herbaceous Wetlands**- Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

> ⓘ If using high Manning's n value to represent a total loss of conveyance (such as for buildings), the large n value will dominate n value compositing equation resulting in a very high n value for the entire cell face. Manning's n values of 0.25-0.5 are suggested for modeling buildings where cell faces span both the building and a conveyance area. If buildings are predominately contained within their own cells, larger n values may be used.

Creating a Soils Data Layer

The use of soils data in HEC-RAS is optional. Soils data can be used to define infiltration parameters for rainfall runoff modeling within HEC-RAS. Soils data can also be used to define spatial sediment transport data for 2D sediment transport modeling (see the HEC-RAS Sediment Transport user's manual for information on soils data).

Importing Data from a Shapefile

Soils data information can be quite complex. Vector (shapefile) data from the Soil Survey Geographic (SSURGO) database can be downloaded from the Natural Resources Conservation Service (NRCS):

https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

The data comes as a shapefile with an abbreviated soils name and unique key. Numerous tables are also included. However, to use the tabular data first users need to have an understanding of the tables (metadata and table columns). Information regarding this data can be accessed here: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_05363. The user will need to join the data from the tables using other software like a GIS software such as ArcGIS.

Data are also available in a geodatabase format from the Gridded SSURGO (GSSURGO) database:

https://datagateway.nrcs.usda.gov/GDGOrder.aspx

RAS Mapper has the capability to import the GSSURGO data.

Creating a Soils Layer is similar to the Land Cover Layer. Select the **Map Layers | Create New RAS Layer | Soils Layer** to open the **Create a New Soils Layer** dialog (see figure below). Use the **Plus** button to add the Soils data to the **Input Files** section. If Soil data is being added in a shapefile format, from the **Input File** section, from the **Name Field**, select the field name that provides a unique name convention for the soils layer, such as "Hydrologic Group" or "Texture Class". Adding Soils data from a standard coordinate system will take a moment to load the data as all the polygons must be reprojected to the coordinate system used for the project. If using the GSSURGO geodatabase (discussed in the next section), other field choices will be provided.

Press the **Create** button, and RAS Mapper will create a "Soils" grid ("*Soils.hdf*" and "*Soils.tif*"), using the specified **Cell Size**.

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Creating an Infiltration Layer

RAS Mapper allows for the creation of an Infiltration layer. An Infiltration layer defines the Infiltration Method (Deficit Constant, SCS Curve Number, or Green and Ampt) that will be used for surface losses from a precipitation event. There are four different ways to generate an Infiltration layer in RAS Mapper: (1) using and existing RAS Land Cover layer, (2) using an existing RAS Soils layer, (3) using an intersection of a Land Cover layer and Soils layer, or (4) using a single classification shapefile layer. The approach used to create an infiltration layer for parameterization will depend on the selected infiltration method and data available.

Using a Land Cover and Soils Layer

When the Infiltration layer is created a complex table is created which cross references the Land Cover and Soils classifications from which the infiltration data can be parameterized. To create a complex Infiltration layer, select **Map Layers | Create New RAS Layer | Infiltration Layer from Land Cover / Soils Layers** menu item. The **Infiltration Layer** dialog show below will be invoked. The **Infiltration Layer** dialog allows the user to select the **Infiltration Method**, **Land Cover Layer**, and **Soils Layer** and provide the new **Infiltration Layer Name** and directory. Note, the user does not need to specify both a Land Cover layer and a Soils layer, this is a user option. However, for the SCS Curve Number Method, that is the best approach.
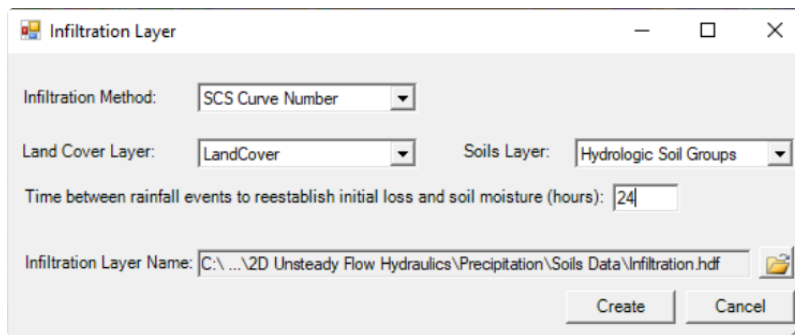
From the **Infiltration Layer** dialog (Figure 2-20), click the **Create** button to create a new raster layer that is the intersection of the land cover and soils layers. As shown in the figure below, the intersection of the layers can become quite complex, creating a Infiltration layer's table with rows for each overlapping classification from the base layers. Depending on the infiltration method selection, additional columns for the required parameters will be provided. It is the user's responsibility to fill out this table with an estimate for each of the parameters based on the Land Cover and the Soils data being used. In the example shown below, the user is required to enter an SCS **Curve Number** and an **Abstraction Ratio** (which defines initial losses). However, the **Minimum Infiltration Rate** field (Figure 2-21) is an optional parameter (which limits the infiltration rate). The **Minimum Infiltration Rate** field sets a threshold which will not allow the infiltration rate to be lower than the user entered value, even when the soil becomes saturated. This is not a standard feature of the SCS Curve number method, but an option added for HEC-RAS.

> ⓘ **NOTE:** If the user has specified Percent Impervious Data within the Land Cover layer that will be attached to the same Geometry data being used in conjunction with an Infiltration layer, then the Curve Number (CN) values in this Infiltration layer table should only be representative of the pervious land cover portion of all land cover types. Otherwise, the user will be double accounting the Impervious area in the model run. User entered Impervious Area percentages are treated separately and assumed to have no losses (i.e., CN = 100). This approach is the preferred method because it is more physically based. Runoff will occur immediately when precipitation falls on any impervious surfaces.
>
> If the user has not entered any Percent Impervious data within the Land Cover data layer, then the CN values in the Infiltration layer's table should reflect both pervious and impervious land surfaces within each Land Cover layer.

Using a Classification Shapefile Layer

To use a single classification layer, select **Map Layers | Create New RAS Layer | Infiltration Layer from Shapefile | Method** menu item. The **Infiltration Layer** dialog opens which will allow users to choose the shapefile of interest (click the **Plus** button to access the desired shapefile(s) from a browser window, and click **Open** to add the selected shapefile(s) to the **Input Files** table). Once the shapefile has been selected from the Input File table, select the unique classification name from the **Name Field** (like "Hydrologic Soils Group") to import the unique classification names (as shown in the figure below).

Click **Create** to close the **Infiltration Layer** dialog and import selected shapefile as a new Infiltration layer. Once the data has been imported, enter infiltration parameters by right clicking on the created Infiltration layer and selecting **Edit Infiltration Data** from the shortcut menu. A table will be provided with the infiltration parameters based on the Infiltration Method (Deficit Constant, SCS Curve Number, or Green and Ampt) selected.

Infiltration Methods

SCS Curve Number

The Curve Number (CN) method is an empirical surface runoff method developed by the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS); formerly the

NRCS was called the Soil Conservation Service (SCS 1985). After the CN method was first developed by the SCS, the USDA changed SCS to Natural Resources Conservation Service (NRCS). The SCS CN method estimates precipitation excess as a function of the cumulative precipitation, soil cover, land use, and antecedent soil moisture. The input requirements for the SCS CN method within HEC-RAS are:

1. Curve Number: (scalar value for each cell).
2. Initial abstraction ratio: (scalar value for each cell) [-].
3. Length of recovery period which is only included when utilizing the recovery method (optional value for each 2D area) [hrs].
4. Minimum infiltration rate (optional value for each cell) [in/hr or cm/hr].

The curve number values range from approximately 30 (for permeable soils with high infiltration rates) to 100 (for water bodies, impervious surfaces, and soils with near zero infiltration rates). Publications from the Soil Conservation Service (1971, 1986) provide further background and details on use of the CN model. The initial abstraction may be estimated as a function of the potential maximum retention as:

$$I_a = rS$$

where **r** is the user-defined initial abstraction ratio, typically ranging between 0.05 and 0.2. The potential maximum soil retention **S** is computed from the runoff curve number **CN** as:

$$S = \frac{1000}{CN} - 10$$

where is in inches.

One thing to keep in mind, the curve number CN method was not originally developed for simulating historic events. The same loss amount will be computed for rainfall of 5 inches regardless of whether it occurred in 1 hour or 1 day. However, the CN method has been adapted to single events.

The curve number is related to soil type, soil infiltration capability, land use, and the depth of the water table. The NRCS has divided soils into four hydrologic soil groups (HSGs) according to the ability to infiltrate. The HSGs are defined as follows:

- **Group A**: Soils with high infiltration rates (low runoff potential) even when thoroughly wetted. These consist chiefly of deep, well-drained sands and gravels. These soils have a final infiltration rates greater than 0.30 in/hr (7.6 mm/hr).
- **Group B**: Soils with moderate infiltration rates when thoroughly wetted. These consist mostly of soils that are moderately deep to deep, moderately well drained to well drained with moderately fine to moderately coarse soil textures. These soils have final infiltration rates of 0.15 – 0.30 in/hr (3.8–7.6 mm/hr).
- **Group C**: Soils with slow infiltration rates when thoroughly wetted. These consist chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures. These soils have final infiltration rates of 0.05 – 0.15 in/hr (1.3 – 3.8 mm/hr).
- **Group D**: Soils with very slow infiltration rates (high runoff potential) when thoroughly wetted. These consist chiefly of clay soils with a high swelling potential, soils with a permanent high-water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious materials. These soils have final infiltration rates of less than 0.05 in/hr (1.3 mm/hr).

Selection of a hydrologic soil group should be done based on measured infiltration rates, soil survey, or judgment from a qualified soil scientist or geotechnical professional. Table 2-2 presents curve numbers for various hydrologic soil-cover complexes.

Table 2-2. Runoff Curve Numbers for Hydrologic Soil-Cover Complexes

Cover			Hydrologic Soil Group			
Land Use	Treatment or Practice	Hydrologic Condition	A	B	C	D
Fallows	Straight row		77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
		Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes or rotation meadow	Straight row	Poor	66	77	85	89
		Good	58	72	81	85
	Contoured	Poor	64	75	83	85
		Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
		Good	51	67	76	80
Pasture or range	Contoured	Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads			59	74	82	86
Roads (dirt)			72	82	87	89
Road (hard surface)			74	84	90	92

The NRCS has also developed Runoff Curve Numbers of other land cover types, including urban areas. However, some of the CN values shown in the NRCS' developed urban area tables include the percent impervious area already in the development of the Curve Number. Table 2-3 provides the NRCS' developed runoff CN values (by HSG) for urban areas.

Table 2-3. Runoff Curve Number for Urban Areas

Cover			Hydrologic Soil Group			
Land Use	**Cover Description**	**Hydrologic Condition**	**A**	**B**	**C**	**D**
Open space	(lawns, parks, golf courses, cemeteries, etc.)	Poor (<50% grass)	68	79	86	89
		Fair (50% to 75% grass)	49	69	79	84
		Good (>75% grass)	39	61	74	80
Impervious areas	Paved	parking lots, roofs, driveways, etc	98	98	98	98
	Streets and Roads	Paved; curbs and storm sewers	98	98	98	98
		Paved; open ditches	83	89	92	93
	Streets and Roads	Gravel	76	85	89	91
		Dirt	72	82	87	89
Western Desert Urban Areas	Natural Desert	Pervious areas only	63	77	85	88
	Artificial Desert	Impervious weed barrier	96	96	96	96
Urban Districts	Commercial/Business	85 % Impervious	89	92	94	95
	Industrial	72 % Impervious	81	88	91	93
Residential Districts by Average Lot Size	1/8 acre (town house)	65 % Impervious	77	85	90	92
	1/4 acre	38 % Impervious	61	75	83	87
	1/3 acre	30 % Impervious	57	72	81	86
	1/2 acre	25 % Impervious	54	70	80	85
	1 acre	20 % Impervious	51	68	79	84
	2 acre	12 % Impervious	46	65	77	82
Developing Urban Areas	Newly Graded Areas Pervious areas only No vegetation		77	86	91	94

In practice, it is much more accurate to develop runoff Curve Numbers for the pervious area only and define the impervious area separately. In HEC-RAS, impervious area will be treated as 100% runoff with no infiltration. For example, this definition is especially important for urban areas, where runoff will occur at the very beginning of storms due to impervious areas that are directly connected to the storm runoff system.

In HEC-RAS, the recovery method for the SCS CN consists of setting the cumulative rainfall depth to zero (i.e.,) after a user-specified time in which the infiltration is zero.

The SCS CN model outputs the following variables:

1. Cumulative excess (per cell) [in or cm]
2. Cumulative precipitation (per cell) [in or cm]
3. Infiltration rate (per cell) [in/hr or cm/hr]
4. Infiltration depth (per cell) [in or cm]
5. Dry time (per cell) [hrs]

Deficit and Constant

The Deficit and Constant loss method uses a hypothetical single soil layer to account for changes in moisture content. This method allows for continuous simulation when used in combination with a potential evapotranspiration time series. Between precipitation events, the soil layer will lose moisture due to evapotranspiration. Unless a potential evapotranspiration time series is supplied, no soil water extraction will occur. If the moisture deficit is greater than zero, precipitation will infiltrate into the soil layer. Until the moisture deficit has been satisfied, no percolation out of the bottom of the soil layer will occur. After the moisture deficit has been satisfied, the rate of infiltration into the soil layer is defined by the constant rate. The percolation rate out of the bottom of the soil layer is also defined by the constant rate while the soil layer remains saturated. Percolation stops as soon as the soil layer drops below saturation (moisture deficit greater than zero). Moisture deficit increases in response to evapotranspiration. The input parameters for the Deficit-Constant method are:

1. Maximum deficit (scalar value for each cell) [in or mm]
2. Initial deficit (scalar value for each cell) [in or mm]
3. Potential evapotranspiration (scalar time-series for each cell) [in/hr or mm/hr]
4. Potential infiltration rate (scalar value for each cell) [in/hr or mm/hr]

Table 2-4 provides the SCS soil groups and typical potential infiltration rates for the Deficit-Constant method.

Table 2-4. SCS Soil Groups and filtration rates (SCS, 1986; Skaggs and Khaleel 1982).

SCS Soil Group	Description	Range of Loss Rates (in/hr)
A	Deep sand, deep loess, aggregated silts	0.3 - 0.45
B	Shallow loess, sandy lam	0.15 - 0.30
C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.05 - 0.15
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00 – 0.05

The Deficit and Constant model outputs the following variables:

1. Cumulative excess (per cell) [in or mm]
2. Cumulative precipitation (per cell) [in or mm]
3. Infiltration rate (per cell) [in/hr or mm/hr]
4. Infiltration depth (per cell) [in or mm]
5. Soil moisture deficit (per cell) [in or mm]
6. Percolation rate (per cell) [in/hr or mm/hr]
7. Percolation depth (per cell) [in/hr or mm/hr]
8. Evapotranspiration rate (per cell) [in/hr or mm/hr]

Green-Ampt

Green and Ampt (1911) presented a physics-based approach to computing soil infiltration.

For the first implementation of Green-Ampt in HEC-RAS, a simple approach will be used for recovery. The approach assumes that the upper layer of the soil remains saturated even during a hiatus period and solves a simple water balance equation to compute the cumulative infiltration depth. Although simplified, the approach has several important characteristics. Specifically, it is volume conservative and represents soil infiltration, evapotranspiration, and unsaturated gravity driven flow.

The input data required for the Green-Ampt (GA) method are (Table 2-5):

1. Wetting front suction (scalar value for each cell) [in or mm]
2. Saturated hydraulic conductivity (scalar value for each cell) [in/hr or mm/hr]
3. Initial soil water content (scalar value for each cell) [-]
4. Saturated soil water content (scalar value for each cell) [-]
5. Soil Potential Evapotranspiration (time series for each cell) [in/hr or mm/hr]

The initial water content should be set by the user based upon the antecedent moisture condition of the soils.   The Soil Field Capacity is the amount of water content remaining after the excess water has been drained by gravity. Technically, the soil field capacity is the water remaining in the soil after being subjected to an atmospheric pressure of -0.33 bar (or -4.8 psi). The wilting point is the amount of water that is so tightly bound to soil particles that is cannot be evaporated or transpired. Technically, the wilting point is the water remaining in the soil after being subjected to an atmospheric pressure of -15 bar (or -217.5 psi). The wilting point must be less than the field capacity.

To utilize the Green-Ampt with Redistribution (GAR) the following additional input parameters are required in HEC-RAS (Table 2-5):

1. Residual soil water content (scalar value for each cell) [in or cm]
2. Pore-size distribution index (scalar value for each cell) [in or cm]

Table 2-5. Green-Ampt Parameter Estimates and Ranges based on Soil Texture (from Gowdish and Muñoz-Carpena 2009; Rawls and Brakensiek 1982 and Rawls et al. 1982).

Soil Texture	Residual Water Content	Wilting Point	Field Capacity	Total Porosity	Pore-size Distribution Index	Saturated Hydraulic Conductivity (mm/hr)	Wetting Front Suction(mm)
Sand	0.02	0.033	0.048	0.437	0.694	210 – 235.6	96.2 – 106

Soil Texture	Residual Water Content	Wilting Point	Field Capacity	Total Porosity	Pore-size Distribution Index	Saturated Hydraulic Conductivity (mm/hr)	Wetting Front Suction(mm)
Loamy sand	0.035	0.055	0.084	0.437	0.553	59.8 – 61.1	119.6 – 142
Sandy loam	0.041	0.095	0.155	0.453	0.378	21.8 – 25.9	215.3 – 222
Loam	0.027	0.117	0.20	0.463	0.252	13.2	175.0 – 315
Silt loam	0.015	0.133	0.261	0.501	0.234	6.8	329.6 – 404
Sandy clay loam	0.068	0.148	0.187	0.398	0.319	3.0 – 4.3	449 – 538.3
Clay loam	0.075	0.197	0.245	0.464	0.242	2.0 – 2.3	408.9 – 446
Silty clay loam	0.040	0.208	0.30	0.471	0.177	1.5 – 2.0	538.3 – 581
Sandy clay	0.109	0.239	0.232	0.430	0.223	1.2	466.5 – 636
Silty clay	0.056	0.250	0.317	0.479	0.150	0.9 – 1.0	577.7 – 647
Clay	0.09.	0.272	0.296	0.475	0.165	0.6	622.5 – 714

Note on Parameter Estimation

The values presented here are meant as **_initial estimates_**. This is the same for all sources of similar data including Engineer Manual 1110-2-1417 Flood-Runoff Analysis and the Introduction to Loss Rate Tutorials. Regardless of the source, these initial estimates **must be calibrated and validated**.

Creating a Porosity and Flow Drag Layer

The **Porosity and Flow Drag Layer** is a new feature in HEC-RAS 6.6. It is used to specify surface classifications which are assigned porosity and flow drag parameters. The approach is similar to how the Manning's roughness coefficient is specified in HEC-RAS. A surface classification layer is created which can be a mix of raster and vector data. Each classification is then assigned specific porosity and flow drag parameters which are then interpolated onto the computational mesh cells and faces.

Create a new RAS Layer

The **Porosity and Flow Drag Layer** is created in **RAS Mapper** by right-clicking on **Map layers** and selecting the drop down **Create a new RAS Layer | Porosity and Flow Drag Layer.**
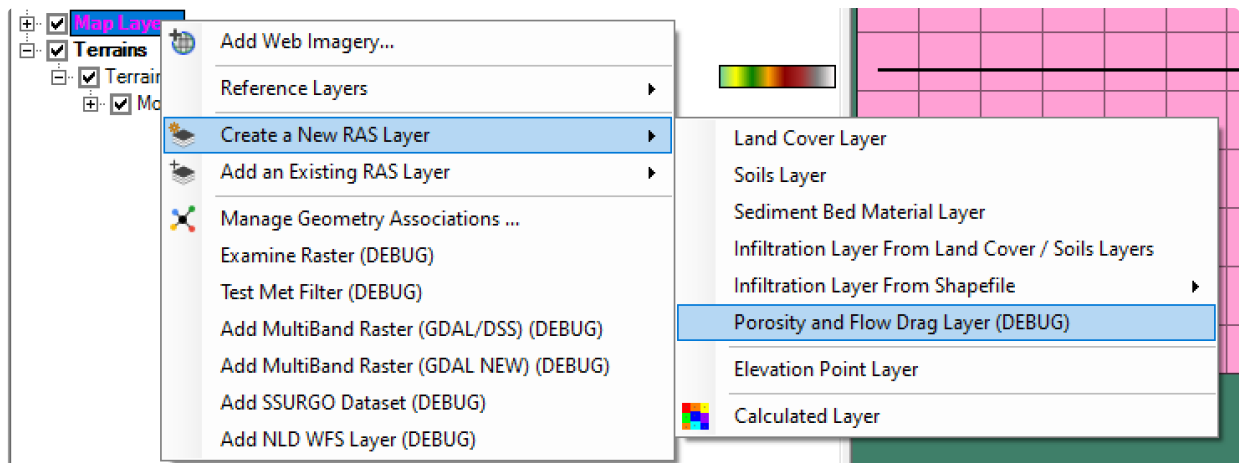
Import Classification Data or Create Empty Layer

Once the import window opens, the user can select or modify the Import Extents, import raster or vector layers, change the priority of data sources, change the Unique Classification Names, select an output file cell size and name. The the example below, there are no data sources and an empty layer is created with a cell size of 0.1 m.
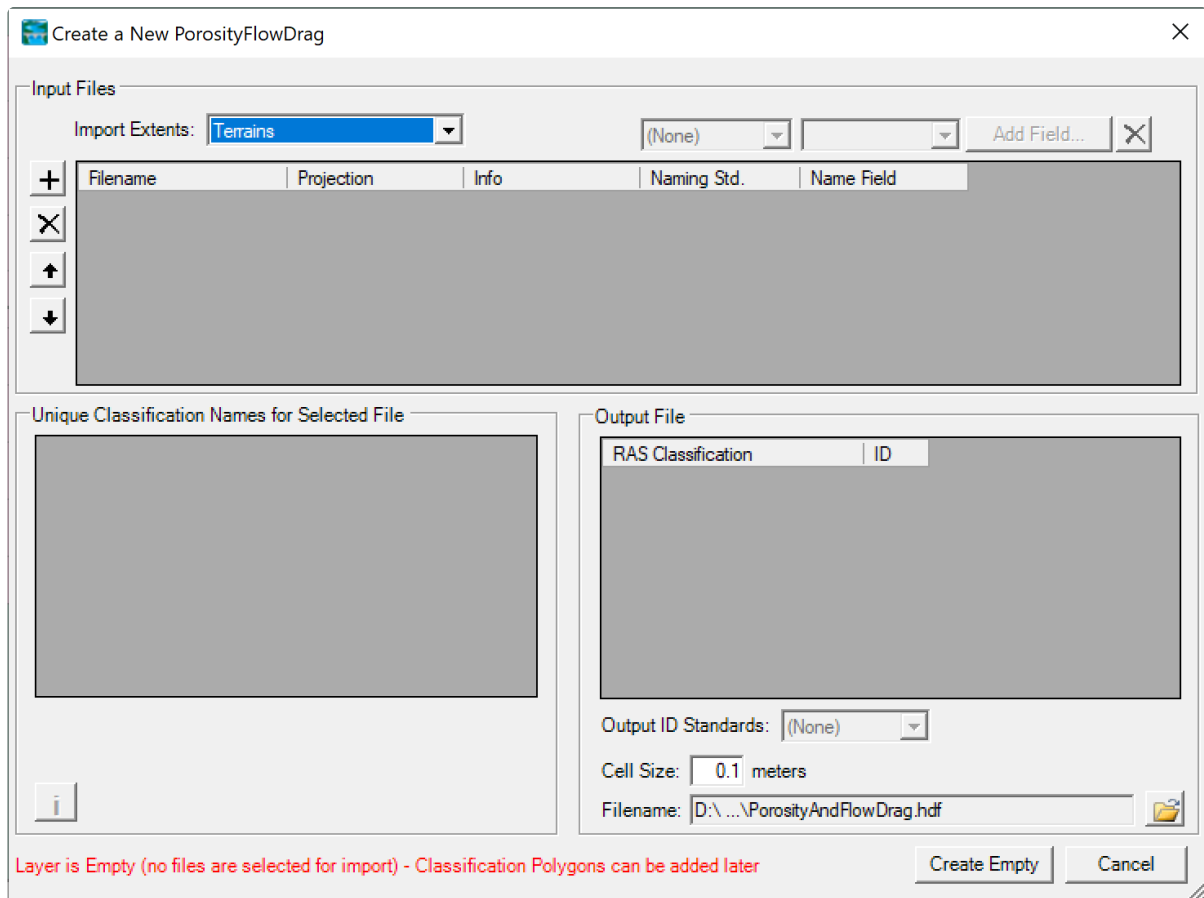
Manage Layer Associations

The next step is to associate the new RAS layer with existing RAS Geometries. The **Manage Layer Associations** window appears automatically whenever a new RAS Layer is created. The **Porosity and Flow Drag Layer** is associated to a geometry by select the layer in the drop down menu as shown in the figure below.
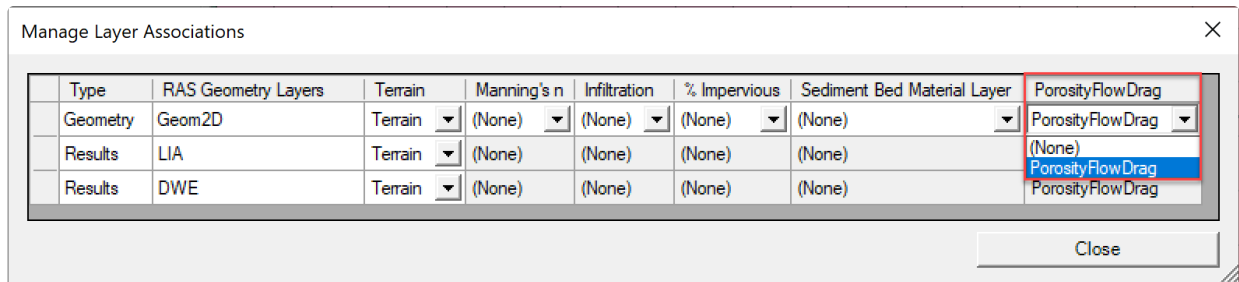
Create Classification Polygons

Once the **Porosity and Flow Drag Layer** has been associated with the correct geometries, the next step is to create any overriding **Classification Polygons**. The polygons are only necessary if no raster or vector data was imported, if the user wants to override any classifications, or to fill-in any regions not covered by the imported classifications. In the example above an empty layer was created, so **Classification Polygons** must be created to cover the entire geometry.

Enter the Porosity and Flow Drag Parameters

To enter the porosity and flow drag parameters for each surface classification, right-click on a **Porosity and Flow Drag Layer** in **RAS Mapper** and select **Edit Land Cover Data Table** as shown in the example below.
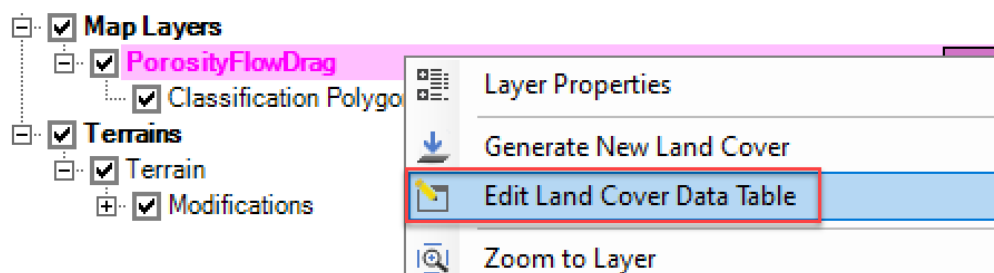
An example of porosity and flow drag layer parameters data table is shown below

Porosity and Flow Drag Parameters

The option to specify a **Porosity and Flow Drag Layer** was added in HEC-RAS 6.6. This option allows the user to specify a spatially variable porosity and flow drag parameters (see section on **Creating a Porosity and Flow Drag Layer**). The parameters are assumed to be constant over a thickness from the bed elevation. Porosity is defined as the volume of voids over the total volume of the medium. Therefore, porosity is a physical property that is relatively simple to measure. Typical values are available for various materials are available from literature and have a relatively narrow range. The flow drag parameters are much more difficult to estimate. For one, the linear and quadratic flow drag coefficients used in HEC-RAS are not variables commonly found in literature and must be computed form other variables, as described below, or calibrated. The linear and quadratic flow drag coefficients represent the viscous and inertial energy losses, respectively. The linear flow drag coefficient is useful for simulating losses through various bed materials, rocks, and rubble mound structures, while the quadratic or inertial flow drag coefficient is most useful for simulating energy losses through flow obstructions, coarse bed materials, and rubble mound structures. The sections below provide some guidance on typical values for the porosity and flow drag parameters for simulating flow through porous media, flow obstructions such as buildings, and vegetation.

Porous Media

The coefficients for flow through porous media can be calculated as (Nield and Bejan 2013)

$$a = \frac{v\phi}{k_v} = \frac{g\phi}{K_v}$$

$$b = \frac{c_F \phi^2}{\sqrt{k_v}} = \frac{\phi^2}{k_i}$$

where

a : linear (viscous) flow drag coefficient [1/T]
b : quadratic (inertial) flow drag coefficient [1/L]
v : water kinematic viscosity [L^2/T]
g : gravity [L/T^2]
k_v : viscous permeability [L^2]

k_i : inertial permeability [L]

c_F : dimensionless form-drag coefficient or Forchheimer coefficient [-]

In which the following relationship between the viscous permeability and conductivity is utilized:

$k_v = \frac{v K_v}{g}$.

Zhou et al. (2019) found an empirical formula to relate the viscous and inertial permeability coefficients

$k_i = 10^{10} k_v^{3/2}$

Hazen (1911) developed the following empirical formula for the viscous hydraulic conductivity

$K_v = C d_{10}^2$

where C is an empirical coefficient between 0 and 1.5, d_{10} is the 10th percentile diameter in mm, and K_v is in cm/s.

The viscous permeability and Forcheimer coefficient can be estimated with the empirical formulas of Ghimire (2009)

$k_v = \frac{\phi^2 d^2}{150(1 - \phi)^2}$

$c_F = \frac{1.75}{\sqrt{150\phi^3}}$

The Forcheimer coefficient ranges between 0.55 and 10.

The following table below shows common porous material porosities and viscous permeabilities.

Table 1. Common porous material properties (data from Scheidegger 1974 and Bejan and Lage 1991).

Material	Porosity	Viscous Permeability (cm^2)
Black Slate Powder	0.57 - 0.66	4.9×10^{-10} - 1.2×10^{-9}
Brick	0.12 - 0.34	4.8×10^{-11} - 2.2×10^{-9}
Limestone	0.04 - 0.10	2×10^{-11} - 4.5×10^{-10}
Sand	0.37 - 0.50	2×10^{-7} - 1.8×10^{-6}
Soil	0.43 - 0.54	2.9×10^{-9} - 1.4×10^{-7}

Buildings

The momentum loss due to subgrid building can be represented with the following expression (Guinot et al. 2017)

$$a = 0$$
$$b = C_{D,B} a_{F,B}$$

where

$C_{D,B}$: building drag coefficient [-]
$a_{F,B}$: building frontal area by unit volume [1/L]

Rubble Mound Structures

Permeable rubble mound structures, such as spur dikes and longitudinal groins, are commonly used in rivers as river training structures. Three options for computing the flow drag coefficients for rubble mound structures are:

Sidiropoulou et al. (2006)

$$a = 0.003 g D^{-1.5} \phi^{0.06}$$
$$b = 0.194 g D^{-1.265} \phi^{-1.14}$$

Kadlec and Night (1998)

$$a = \frac{255 v (1-\phi)}{\phi^{3.7} D^2}$$
$$b = \frac{2(1-\phi)}{\phi^3 D}$$

Ward (1964)

$$a = \frac{360 v}{D^2}$$
$$b = \frac{10.44}{D}$$

where

D : Rock diameter [L]
ϕ_{rm} : Porosity [-]

Vegetation

In reality, vegetation flow drag is a complex function of vegetation density, stem diameter, vegetation flexibility, frontal area, etc. As a simple example here emergent vegetation may be treated as an array of rigid circular stems with a constant diameter. In this case, the vegetation flow drag coefficients may be modeled as (Wu 2007)

1)

$$a = 0$$
$$b = \frac{1}{2} C_{D,v} N_v \alpha_v D_v$$

where

$C_{D,v}$: vegetation drag coefficient [-]
N_v : vegetation density defined as the number of vegetation elements per unit area in the horizontal plane [$1/L^2$]
α_v : vegetation shape factor [-]
D_v : vegetation diameter [L]

The vegetation shape factor, α_v , is equal to 1 for rigid cylinders but can vary as a function of the vegetation shape including the resulting shape from bending.

4 DEVELOPMENT OF A 2D OR COMBINED 1D/2D MODEL

HEC-RAS can be used to develop a 2D Model or a combined 1D/2D model. This section of the manual discusses the following:

- Development of the 2D Computational Mesh
- Creating Hydraulic Property Tables for 2D Flow Areas
- Connecting 2D Flow Areas to 1D Hydraulic Elements
- Hydraulic Structures Inside of 2D Flow Areas
- Geospatial Coordinates for Hydraulic Outlets Connected to 2D Flow Areas
- Modeling Bridges Inside 2D Flow Areas
- Modeling Pump Stations inside 2D Flow Areas
- Flow Roughness Factor Curves in Calibration Regions

Development of the 2D Computational Mesh

The HEC-RAS 2D modeling capability uses a Finite-Volume solution scheme. This algorithm was developed to allow for the use of a structured or unstructured computational mesh. This means that the computational mesh can be a mixture of 3-sided, 4-sided, 5-sided, etc… computational cells (HEC-RAS has a maximum of 8 sides in a computational cell). However, users typically select a nominal grid resolution to use (e.g., 200 ft 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, refinement regions, and the mesh editing tools. A 2D computational mesh is developed in HEC-RAS Mapper by doing the following:

Drawing a Polygon Boundary for the 2D Area

The user must add a 2D flow area polygon to represent the boundary of the 2D area using the geometry editing tools in HEC-RAS Mapper. The best way to do this in HEC-RAS is to first bring in terrain data and aerial imagery into HEC-RAS Mapper. Additionally, the user may want to bring in a shapefile that represents a protected area, if they are working with a leveed system. The terrain and background images will assist the user in figuring out where to draw the 2D flow area boundaries.

> ⓘ **Note:** 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. However, when using a lateral structure to connect a 1D main river to a 2D floodplain (when there is no actual levee), try to find the high ground that separates the main river from the floodplain. Use this high ground as a guide for drawing the 2D boundary, as well as defining the Lateral Structure Station Elevation data..

To create the 2D flow area in HEC-RAS Mapper, do the following:

1. Right click on the Geometry Layer to edit, and select **Edit Geometry**.
2. Expand the **2D Flow Areas** layer and select the **Perimeters** layer.

3. Draw the perimeter using the **Add New Feature** ⩔ tool.

Zoom in to the point at which you can see with great detail, where to draw the boundary of the 2D Flow Area. Begin by left clicking to drop a point along the 2D flow area polygon boundary. Then continue to use the left mouse button to drop points in the 2D flow area boundary. As the user runs out of screen real-estate, they can right click to re-center the screen, this will give you more area to continue drawing the 2D flow area boundary. Double click the left mouse button to finish creating the polygon. Once the 2D area polygon is finished, the interface will ask the user for a Name to identify the 2D flow area. Shown in Figure 3-1 is an example 2D flow area polygon for an area that is protected by a levee. The name given to the 2D flow area in this example is: "**2D Interior Area**".

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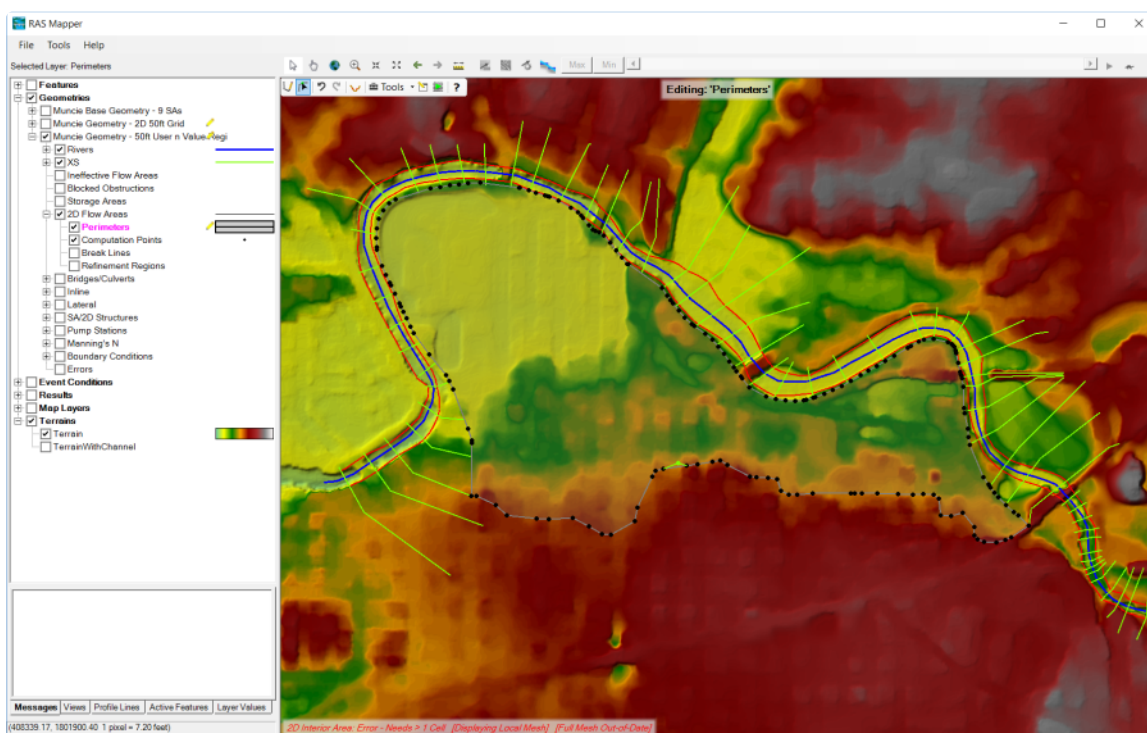

Figure 3-1. Example 2D flow area polygon.
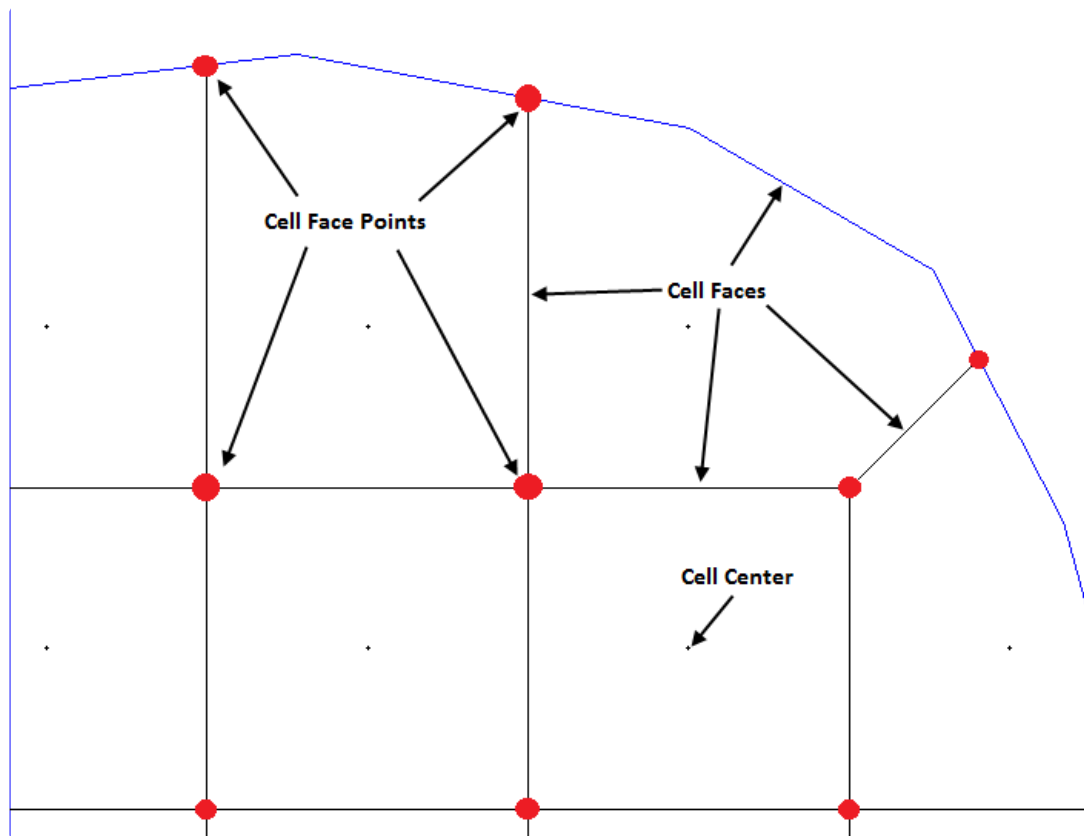
Create the 2D Computational Mesh

The HEC-RAS terminology for describing the computational mesh for 2D modeling begins with the 2D flow area. The 2D flow area defines the boundary for which 2D computations will occur. A computational mesh (or computational grid) is created within the 2D flow area. Each cell within the

computational mesh has the following three properties (Figure 3-2).

Cell Center: The computational center of the cell. 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 Faces: These are the cell boundary faces. 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: The cell Face Points (FP) 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.

After the 2D Flow Area polygon boundary is created, the next step is to begin creating the computational mesh. In general, the user should decide on a base cell size to use for the 2D flow area. Keep in mind that you will be able to refine the mesh with breaklines and refinement regions where needed. To create the base mesh, do the following:
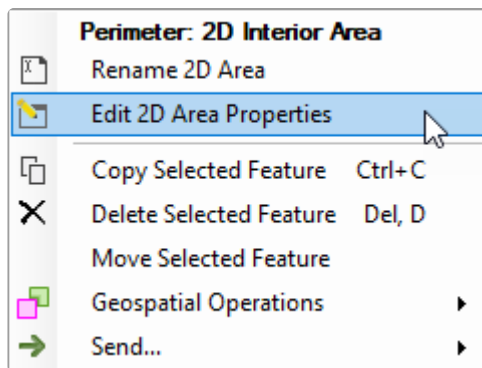
1. Select the 2D Flow Area polygon to be edited.
2. Right click on the 2D Flow Area and select **Edit 2D Area Properties**.
3. Once that menu option is selected a window will appear as shown in Figure 3-3 below.
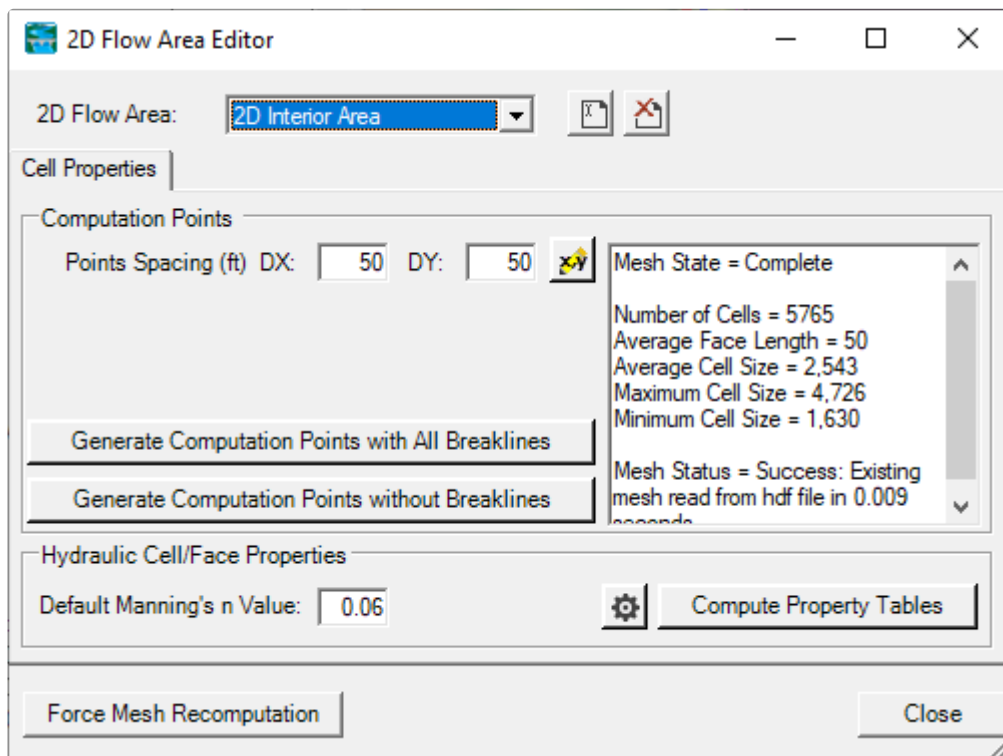
4. In the **Computational Points** portion of the editor, enter the **Points Spacing DX and DY values.** Press the **Generate Computation Points with All Breaklines** button to generate the base mesh. Pressing this button will cause the software to compute a series of X and Y coordinates for the cell centers. 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).

> ⓘ Warning: If there is an existing computational mesh and the "Generate Points in 2D Flow Area" option is used, all of the existing mesh points will be replaced with the newly generated points. Any hand editing that was done by the user will be lost.

5. If you want to have a default Manning's n value for the 2D Flow Area, it can be entered under the **Hydraulic Cell/Face Properties** area of the editor. The **Default Manning's n Value** will be used for the cell faces in the 2D flow area. Users have the option of adding a spatially varying Land Use classification versus Manning's n value table (and a corresponding Land Classification layer in RAS-Mapper), which can be used to override the base Manning's n values where polygons and roughness are defined. Even if a Land Use Classification versus Manning's n value table is defined, for any areas of the 2D flow area not covered by that layer, the base/default Manning's n value will be used for that portion of the 2D flow area.

Additionally, there is a gear button ⚙ that can be used to bring up an editor that allows the user to change the tolerances used when creating the hydraulic property tables for the 2D cells and faces. The following is a description of these tolerances:

- **Cell Elev-Vol Filter Tol:** This tolerance is used to reduce the number of points in the 2D cell elevation volume curves that get developed in the 2D pre-processor. Fewer points in the curve will speed up the computations but reduce the accuracy of the elevation volume relationship. The default tolerance for filtering these points is 0.01 ft.
- **Cell Minimum Area Fraction:** This field is used to enter a fraction that is multiplied by the cell area to establish a minimum area at the lowest elevation of the cell. The purpose of this field is to prevent the cell elevation volume curves from going down to an extremely small area at the bottom of the cell, and then creating a curve that is very abrupt at the lowest end. Establishing a reasonable minimum area for the cell helps out with the stability of solving that cell when it first starts to get water. The default is 0.01 (1 %).
- **Face Profile Filter Tol:** This filter tolerance is used to reduce the number of points that get extracted from the detailed terrain for each face of a 2D cell. The default is 0.01 ft.
- **Face Area-Elev Filter Tol:** This filter tolerance is used to reduce the number of points in the cell face hydraulic property tables. Fewer points in the curves will speed up the computations but reduce the accuracy of the face hydraulic property relationships. The default is 0.01 ft.
- **Face Conveyance Tol Ratio:** This tolerance is used to figure out if more or less points are required at the lower end of the face property tables. It first computes conveyance at all of the elevations in the face property tables. It then computes the conveyance at an elevation half way between the points and compares this value to that obtained by using linear interpolation (based on the original points). If the computed value produces a conveyance that is within 2% (0.02) of the linear interpolation value, then no further points are needed between those two values. If linear interpolation would produce a value of conveyance that is more than 2% from the computed value at that elevation, then a new point is added to that table. This reduces the error in computing hydraulic properties, and therefore conveyance due to linear interpolation of the curves. A higher tolerance will result in fewer points in the hydraulic property tables of the cell faces, but less hydraulic accuracy for the flow movement across the faces. The default value is 0.02, which represents a 2% change.
- **Face Laminar Depth (ft):** At very shallow depths on planar surface (e.g. A parking lot or a road) the flow can be laminar instead of turbulent. If the flow is assumed to be turbulent all the way to a zero depth, then the program will underestimate the velocity of flows down a plane at very shallow depths. This field is used as the transition point from turbulent to laminar flows. Anything below this depth will assumed to be laminar flow and treated as such.

6. You have the option to run the 2D Flow Area pre-processor right from this editor if you want to. This is accomplished by pressing the **Compute Property Tables** button. This step is not necessary, until the mesh is further refined, and you plan on performing a computation. The 2D pre-processor will automatically run when the user performs a Compute if the tables are out of date.

7. Press the **Close** button to close the editor and accept the mesh and property settings. An example of a base mesh, with not break lines or refinement regions, is shown in Figure 3-4.
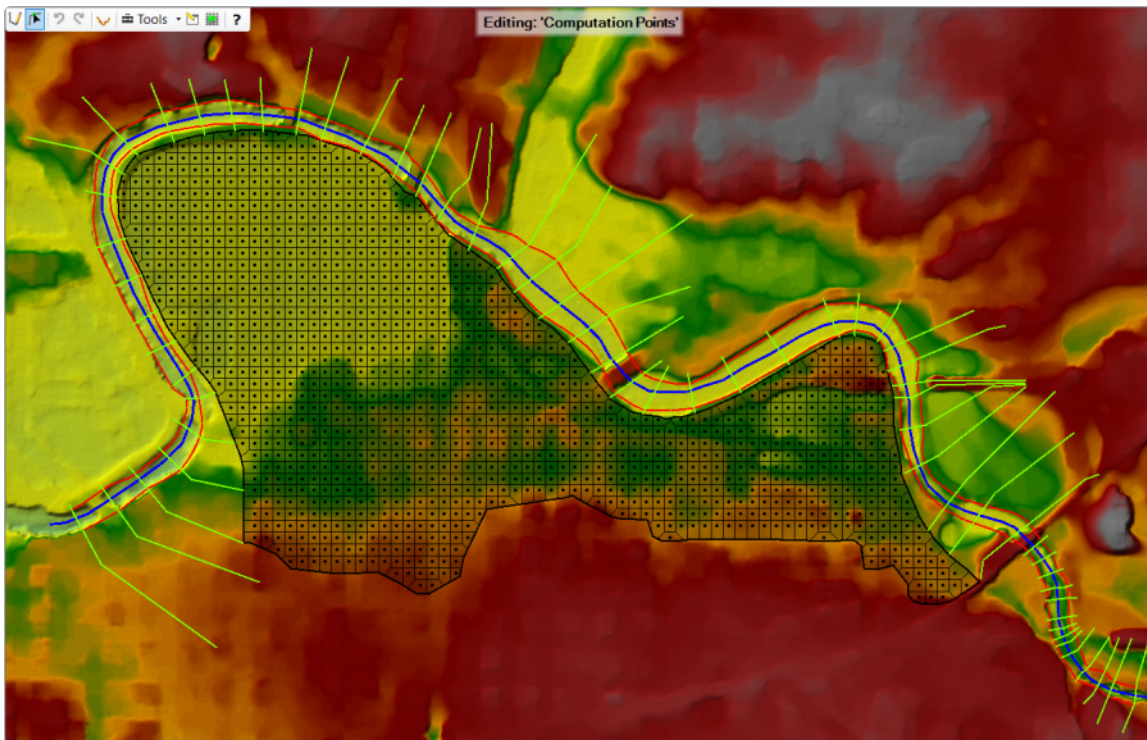

Figure 3-4. Example 2D Mesh with no Break Lines or Refinement Regions.

Editing/Modifying the Computational Mesh.

The computational mesh will control the movement of water through the **2D flow area**. Specifically, one water surface elevation is calculated for each grid cell center at each time step. The computational cell faces control the flow movement from cell to cell. Within HEC-RAS, the underlying terrain and the computational mesh are preprocessed in order to develop detailed elevation–volume relationships for each cell, and detailed hydraulic property curves for each cell face (elevation vs. wetted perimeter, area, and roughness). By creating hydraulic parameter tables from the underlying terrain, the net effect is that the details of the underlying terrain are still considered in the water storage and conveyance, regardless of the computational cell size. However, there are still limits to what cell size should be used, and important considerations for where smaller detailed cells are needed versus larger coarser cells.

In general, the cell size should be based on the slope of the water surface in a given area, as well as barriers to flow within the terrain. Where the water surface slope is flat and not changing rapidly, larger grid cell sizes are appropriate. Steeper slopes, and localized areas where the water surface

elevation and slope change more rapidly will require smaller grid cells to capture those changes. Since flow movement is controlled by the computational cell faces, smaller cells may be required to define significant changes to geometry and rapid changes in flow dynamics.

HEC-RAS makes the computational mesh by following the Delaunay Triangulation technique and then constructing a Voronoi diagram (see Figure 3-5 below, taken from the Wikimedia Commons, a freely licensed media file repository):
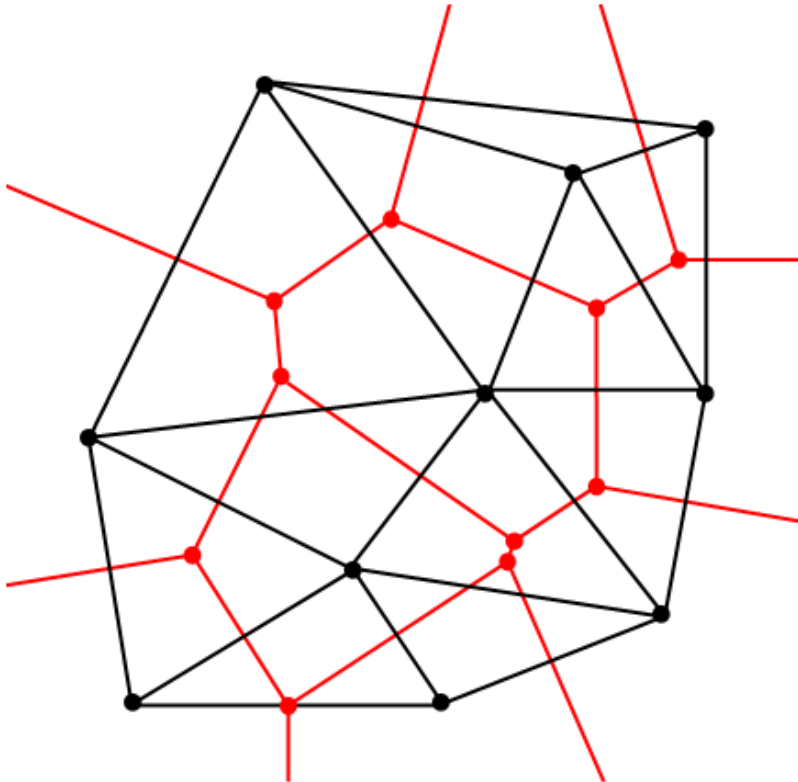
The triangles (black) shown in Figure 3-5 are made by using the Delaunay triangulation technique (http://en.wikipedia.org/wiki/Delaunay_triangulation). The cells (red) are then made by bisecting all of the triangle edges (black edges), and then connecting the intersection of the red lines (Voronoi diagram). This is analogous to the Thiessen Polygon method for attributing basin area to a specific rain gage.

The computational mesh can be edited/modified with the following tools: break lines; refinement regions; moving points; adding points, and deleting points.

Break Lines

Either before or after the computational mesh is created the user may want to add break lines to force the mesh to align the computational cell faces along the break lines. In general, break lines should be added to any location that is a barrier to flow, or controls flow/direction. The user should align the faces of the 2D mesh for areas that are barriers to flow in order to accurately capture the

high ground with cell faces. Examples where this should always be done are levees, roads, and natural berms in the terrain.

The user can add new break lines at any time. 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. Break lines can be drawn by hand; imported from Shapefiles; or detailed coordinates for an existing break line can be pasted into the break line coordinates table.

To add break lines by hand into a 2D flow area (while in the geometry editing mode), select the **Break Lines** layer (it should then be highlighted in magenta), then left click on the location within the 2D flow area that you want to start a break line. Left click to add additional points, and right click to re-center the view within the window. Double click to end a break line. Once a break line is drawn the software will ask you to enter a name for the break line. After the break line is entered, the mesh generation tools will automatically try to "snap" the cell faces to the break lines. The cells formed around break lines may not always have cell faces that are aligned perfectly with the break lines. The user can draw a new break line, then right click on the break line and select the option **Enforce Break line**. Once this option is selected, new cells will be generated around the break line with cell faces that are aligned along the break line. Any existing cell centers that were already in the mesh in the area of the break line are remove first (within a buffer zone around the break line, based on the cell size used around the break line). By default, the cell size used along the break line will be equal to the nominal cell size entered for the 2D flow area.

Additionally, the user can control the size/spacing of cells along the break line. 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. To control the cell spacing along a break line, right click on the **Break Lines** layer and select the option **Open Attribute Table (**Figure 3-6). A window will appear allowing the user to enter: a **Near Spacing**; **Near Repeats**; and a **Far Spacing**. There is also an option to "**Enforce a 1 Cell Protection Radius**" around the break line. This option protects the cells immediately around the break line from being deleted or moved due to other break lines that may be very close. The **Near Spacing** field is used to enter the cell size you want right along the break line. The **Near Repeats** field is an optional field that allows you to repeat the cell size define in the Near Spacing filed multiple times. For example, if the user entered a Near Spacing of 50 ft, then the cells on both sides of the break line would be 50 ft cells. If the user also entered a Near Repeats of 2, then two additional rows of 50 ft cells would be placed on both sides of the break line. The **Far Spacing** option allows the user to control how far the software will increase the cell size as it gradually transitions from the Near spacing to the user entered Far Spacing. If a Far Spacing is not entered, it is automatically set to the nominal cell size of the 2D flow area. The software will then increase the cell size around the break line, in order to provide a gradual cell size transition from the break line to the Far Spacing cell size being used for the mesh.

Figure 3-6. Break Line Attributes Table.

To import Break lines from a shapefile, while editing the break lines, right click on the **Break Lines** layer and select **Open Attribute Table**. At the lower right hand corner of this editor is a button labeled **Import Features** (Figure 3-6)**.** Select the **Import Features** button and a file browser will come up. Find the Shapefile that contains the lines that you want to use as break lines and select that file. Then press the **Open** button.

An example of using break lines within a 2D flow area for modeling levees and roads is shown in Figure 3-7.
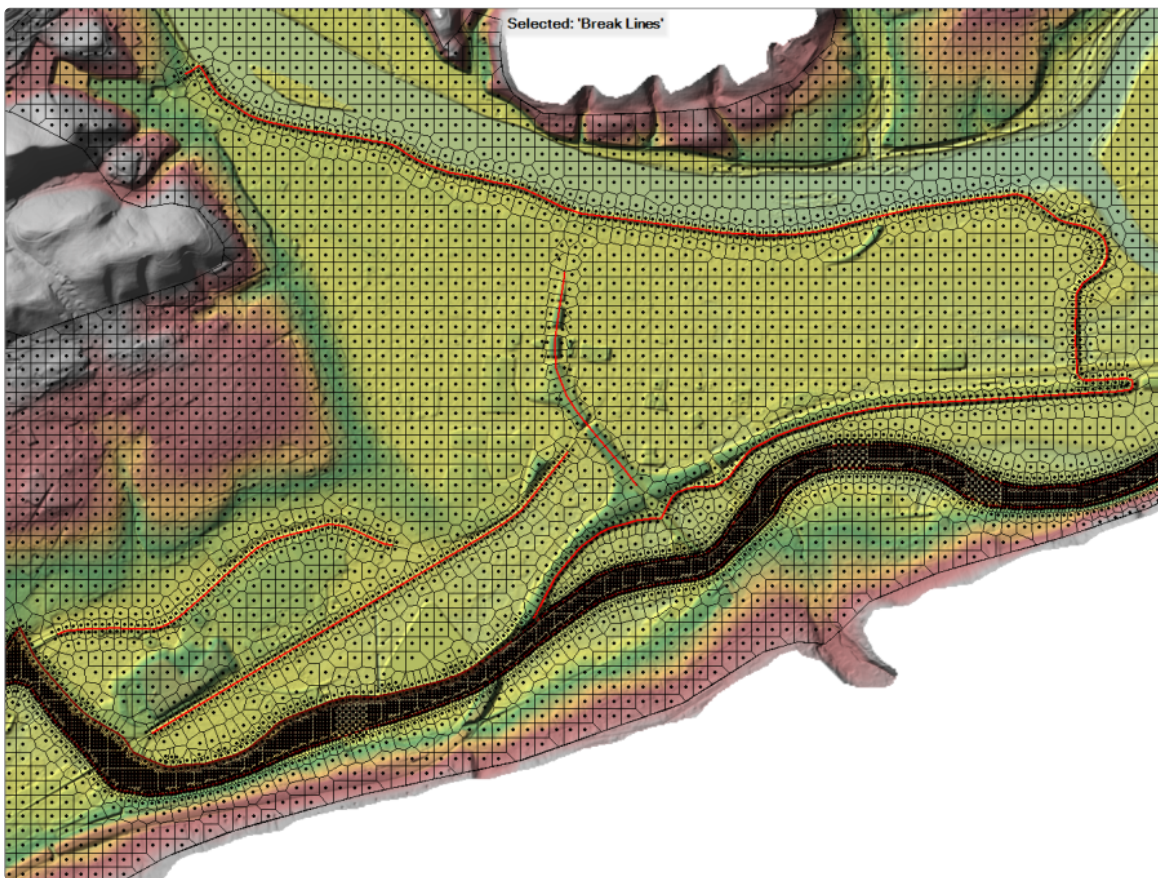
Figure 3-7. Example Break lines for Levees and roads

Mesh Refinement Regions

Refinement regions are a mesh editing tool that allows the user to refine or coarsen an area of the mesh. A polygon is created to define the boundary of the refinement area. The interior of the area is given a cell spacing (just like the Perimeter layer) and the bounding polyline is given a point spacing (just like a break line). Refinement regions can be used to densify an area where more detailed results are desired due to rapid changes in terrain or water surface elevation, or to simplify an area where the water surface elevation will not vary much and users want to reduce the number of computation points in the 2D Flow Area.

Additionally, refinement regions can also be used to create a good mesh in the main channel regions of the model. To add a refinement region, do the following:

1. While editing the geometry in HEC-RAS Mapper, select the refinement region layer. It should turn to a magenta color if it is selected.
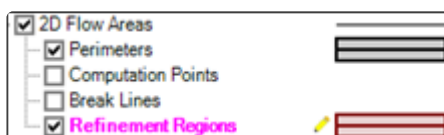
2. Select the **Add New Feature** editing tool, then left click to start drawing the refinement region polygon. Continue to left click to add additional vertices to the polygon. As you are drawing the polygon, users can right click to re-center the drawing window. Double click to end the refinement region polygon. A window will pop up asking the user to enter a name for the refinement region.

Additional properties for controlling how the refinement regions affect the 2D Flow Areas are accessed through the **Refinement Region Editor**. This editor is available by right clicking on the feature or the **Refinement Region** layer and selecting the **Edit Refinement Region Properties** shortcut menu item. The **Refinement Region Editor** allows users to modify the properties of each region.

When a refinement polygon is enforced, the boundary is treated much like a break line, where the point spacing along the break line grows larger farther away from the line. This transition of cell sizes happens both outside of the boundary and on the inside of the polygon. As shown in **Figure 3-8**, the properties for each refinement area include the Name, Cell Spacing X, Cell Spacing Y, Perimeter Spacing, Near Repeats, and Far Spacing. These properties (described below) control how the refinement region will be used to modify the mesh, when enforced (e.g., Figure 3-8).
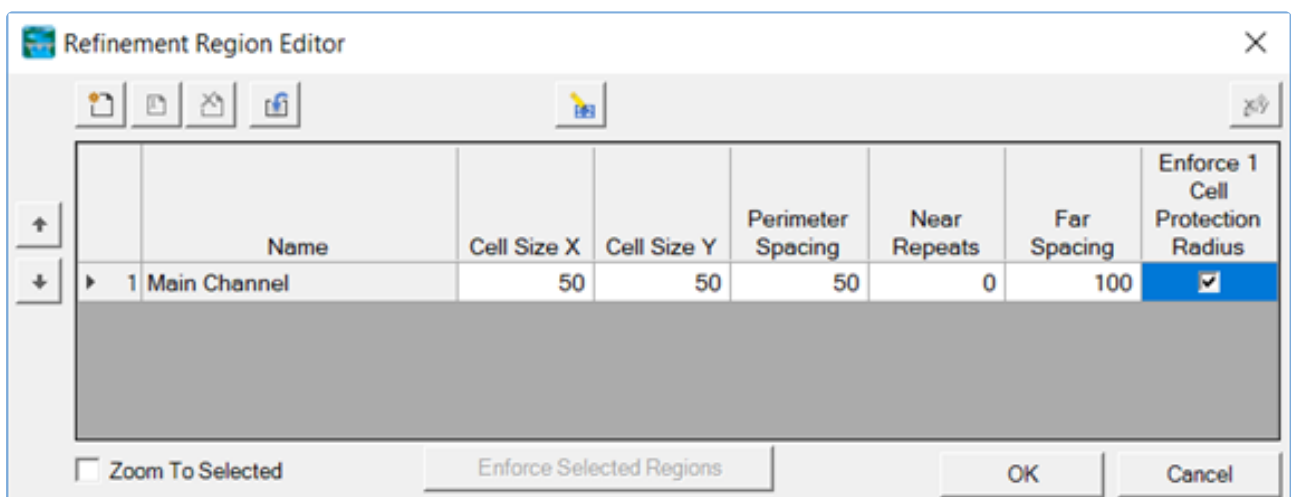
Figure 3-8. Refinement Region Editor

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- **Name** – Each region must have a unique name and the editor.
- **Cell Spacing X** – The spacing distance in the X-direction for adding computation points inside of the refinement region.
- **Cell Spacing Y** – [NOT IMPLEMENTED YET] The spacing distance in the Y-direction for adding computation points inside of the refinement region.
- **Perimeter Spacing** – The distance to add computation points along the region boundary (i.e., how often points are added) just as done with the Near Spacing on the Breakline layer. The points are generally placed along the line offset by ½ of the spacing value. If not specified, the default value is the Cell Spacing X value.
- **Near Repeats** – The number of times to duplicate the Perimeter Spacing on both sides of the perimeter before transitioning to the Far Spacing. If not specified, the default value is zero.
- **Far Spacing** – How large a distance to go when adding points away from the line. Computation points will be added sequentially starting with the Near Spacing and doubling the previous spacing until the Far

Spacing values is achieved (approximately). If not specified, the default value is the point spacing on the 2D Flow Area.

- **Enforce 1 Cell Protection Radius** – A protective region buffered around the perimeter that extends by the Perimeter Spacing distance on each side. Within this protection region, cells can neither be added nor removed by the cell generation routines. This means that any previous hand-edits to those cells will remain, and any nearby break lines cannot interfere with this already-enforced region.

A simple example of using two refinement regions to simplify and densify a mesh are shown in Figure 3-9.
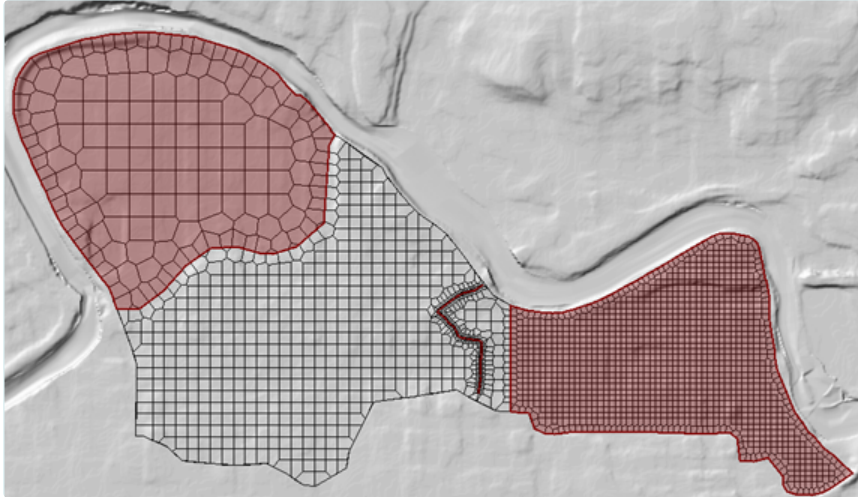
Figure 3-9. Example 2D Area with Refinement Regions

Making a Channel Mesh

Another use for the refinement region is around the main channel of a stream. Shown in Figure 3-10 is an example where a single refinement region was created for the entire main channel. By doing this, the user can control the cell size inside of the channel and ensure that cell faces are aligned with the high ground at the main channel banks. This approach ensure that flow does not spill out of the channel until the water is high enough to cross over the outer cell faces representing the high ground of the main channel bank lines. In addition to the refinement region, a break line was placed right down the center of the refinement region, following the path of the flow. The break line is used to align the cells in the middle of the channel with the direction of the flow. For the breakline in the example below, the number of near repeats was set to 4. For the refinement region, the near repeats was set to zero. Additionally, the option to "Enforce a 1 cell protection radius" was turned on for both the refinement region and the break line. Also, the break line was enforced after the refinement region. This combination of a refinement region and a break line down the center of the channel makes for a very nice channel mesh (Figure 3-10).
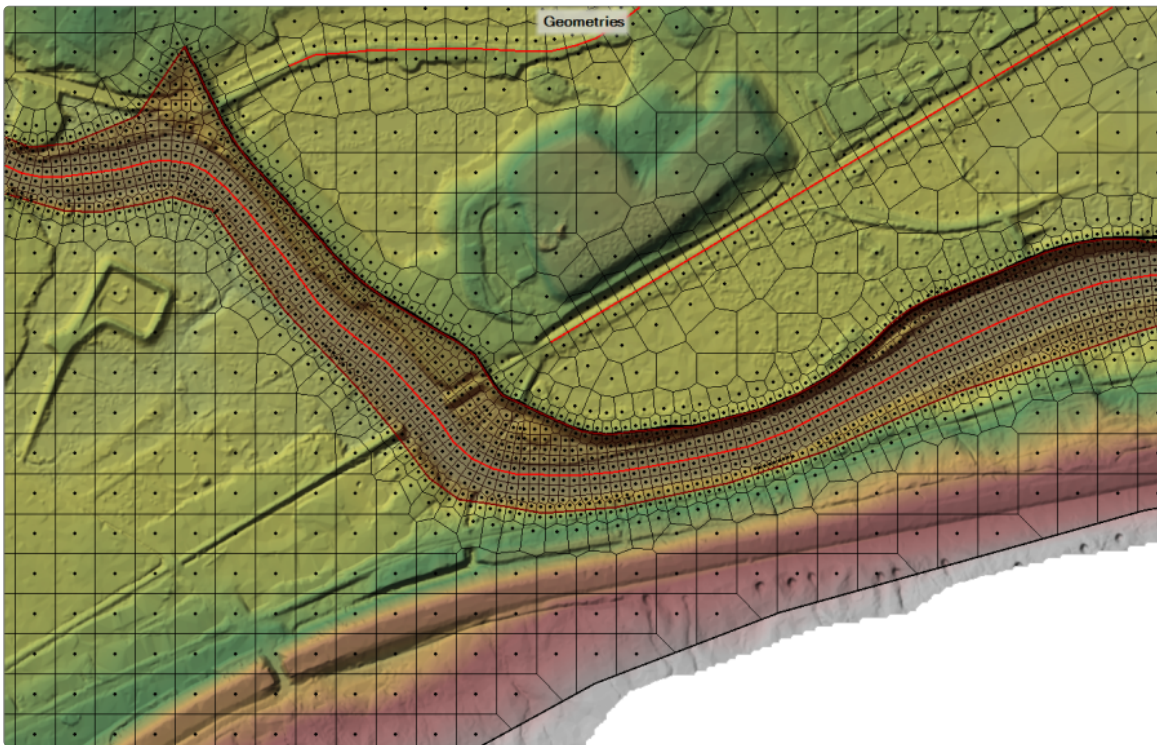
Figure 3-10. Example Refinement Region and Break Line Combination to form a Channel Mesh.

Hand Based Mesh Editing Tools

The hand editing mesh manipulation tools are available under the **Edit** menu of the HEC-RAS Geometric Data editor and are also available in HEC-RAS Mapper. From the Geometric editor, if the user selects **Edit** then **Move Points/Object**, the user can select and move any cell center or points in the bounding polygon. If a cell center is moved, all of the neighboring cells will automatically change due to this movement. If the user selects **Edit** then **Add Points**, then wherever the user left clicks within the 2D flow area, a new cell center is added, and the neighboring cells are changed (once the mesh is updated). The software creates a local mesh (Just the area visible on the screen, plus a buffer zone), such that while you are editing, just the local mesh will get updated. The entire mesh only updates once the user has turned off the editing feature, which saves computational time in creating the new mesh. If the user selects **Edit** then **Remove Points**, then any click near a cell center will remove that cell's point, and all the neighboring cells will become larger to account for the removed cell.

From HEC-RAS Mapper, the user can also hand edit the 2D Flow Area boundary and computation points. Start editing the Geometry in HEC-RAS Mapper, then select the **Perimeter** to edit the boundary, or select **Computational Points** to edit the cell computational points. To add new cell points, use the **Add New Feature** editing tool. To move or delete points use the **Edit Feature** tool.

The user may want to add points and move points in areas where more detail is needed. The user may also want to remove points in areas where less detail is needed. Because cells and cell faces are

preprocessed into detailed hydraulic property tables, they represent the full details of the underlying terrain. In general, the user should be able to use larger grid cell sizes than what would be possible with a model that does not preprocess the cells and the cell faces using the underlying terrain. Many 2D models simply use a single flat elevation for the entire cell, and a single flat elevation for each cell face. These types of 2D models generally require very small computational cell sizes in order to model the details of the terrain.

Potential Mesh Generation Problems

The automated mesh generation tool in HEC-RAS works well, however, nothing is perfect. On occasion a bad cell will be created due to the combination of the user defined polygon boundary and the selected nominal cell size, or when the user is adding/modifying points inside of the polygon. After the mesh is made, the software automatically evaluates the mesh to find problem cells. If a problem cell is found, that cell's center is highlighted in a red color, and a red message will show up on the lower left corner of the geometric data window. Here is a list of some problems that are possible, and how to fix them with the mesh editing tools described above:

- **Mesh Boundary Issues:** 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 this location (Figure 3-11). To fix this problem, the user can either add more cell centers around the concave portion of the boundary, or they can smooth out the boundary by adding more points to the boundary line, or both.

Sharp Concave Boundary
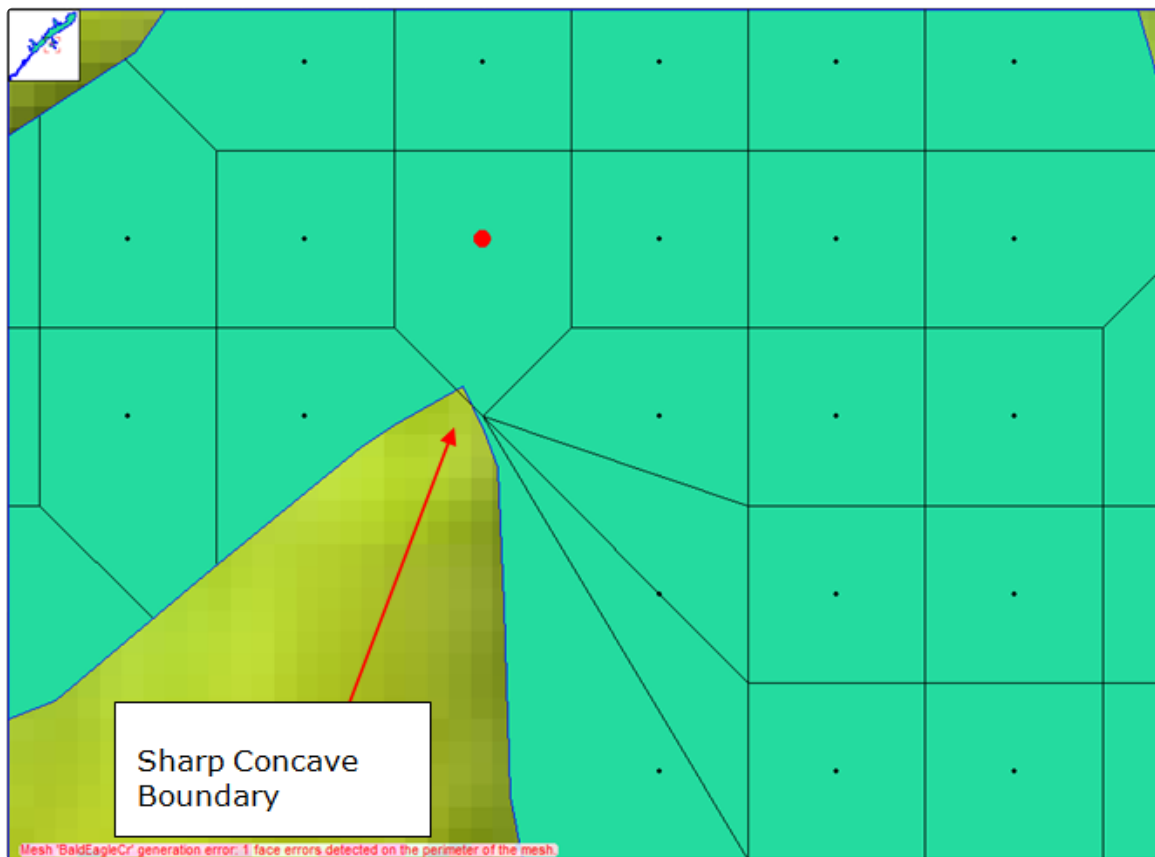
Shown in Figure 3-12 is the fixed mesh. The mesh was fixed by smoothing out the sharp concave boundary and adding some additional cell centers around the sharp portion of the boundary.
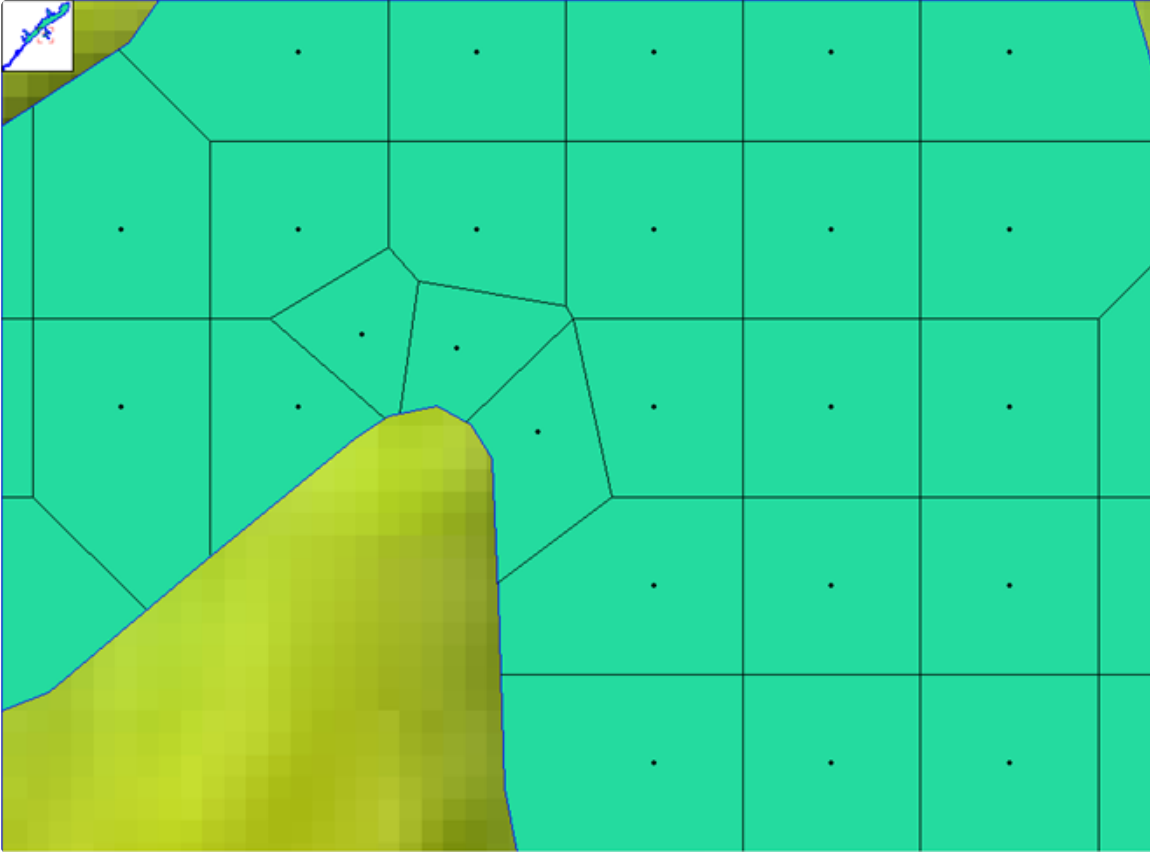
Figure 3-12. Corrected Mesh with Smoothed Boundary and Additional Cell Centers.

- **Too Many Faces (sides) on a Cell:** Each cell is limited to having 8 faces (sides). The HEC-RAS mesh development routines check for cells with more than 8 sides. If a cell exists with more than 8 sides it will be highlighted in red and a message will appear in the lower left portion of the geometric data window. An example of a cell with more than 8 sides is shown in Figure 3-13. If you have a cell with more than 8 sides you will need to edit that cell and/or the cells that bound it. Use the tools found in the Geometric editor under the "**Edit**" Menu. Available tools are (1). **Add Points**: to add points to the cell boundary polygon, or additional cells; (2). **Remove Points**: to delete points in the boundary polygon or delete cells; and (3). **Move Points/Objects**: to move the boundary points or the cell centers.
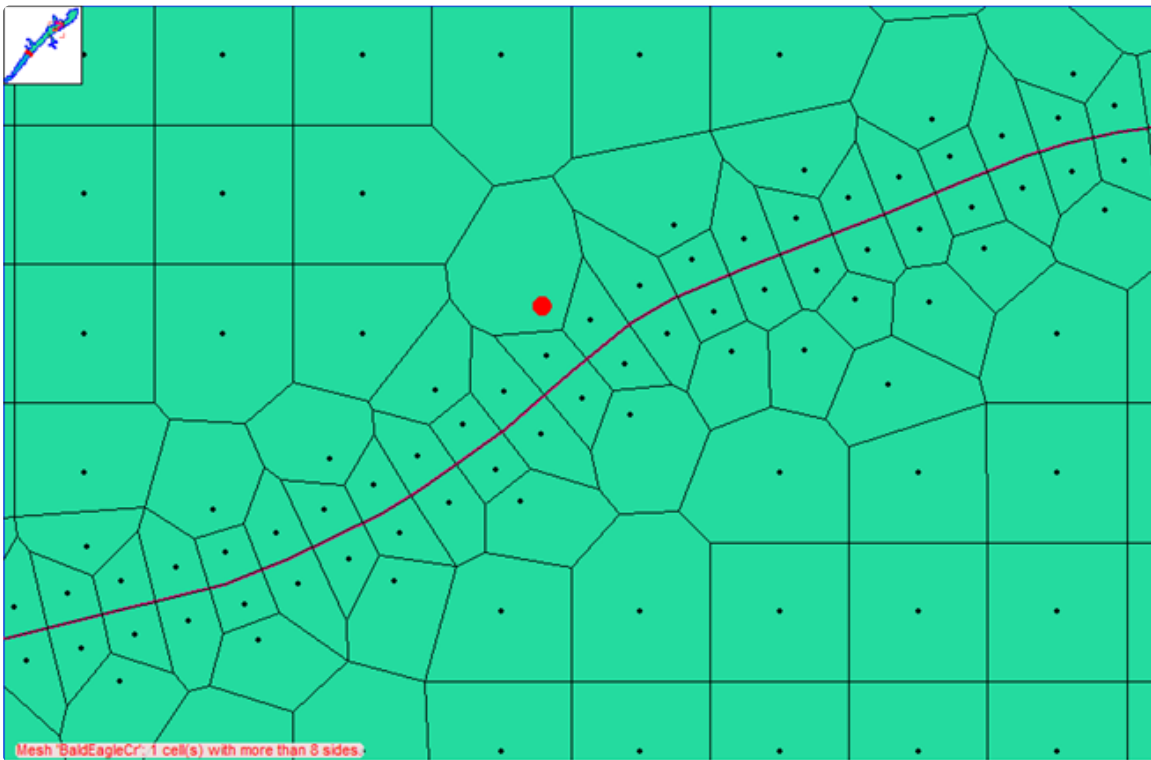
Figure 3-13. Example Mesh with a Cell that has more than 8 sides.

The mesh problem shown in Figure 3-13 (cell with more than 8 sides) was fixed by adding additional cell centers in the area of this cell, which made the cell size smaller and reduced the number of sides of the cells. The fixed mesh is shown in Figure 3-14.
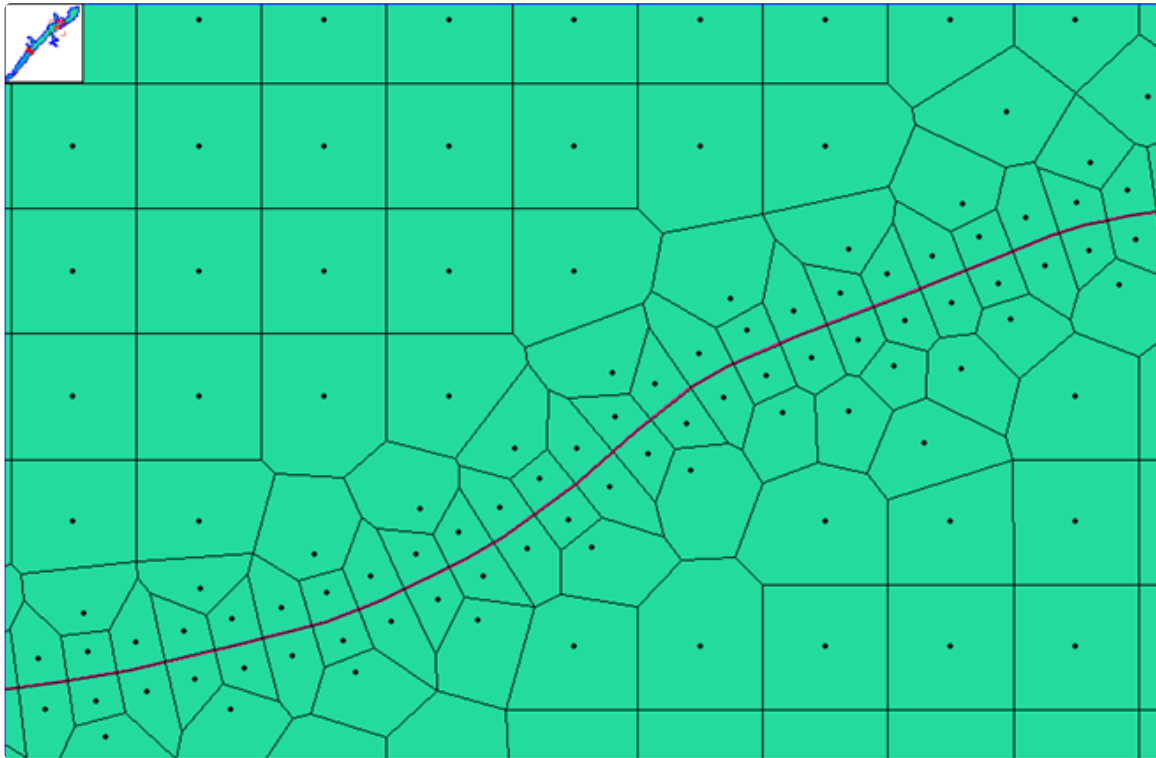
- **Duplicate Cell Centers:** If a user accidentally puts a point right on top of, or very close to an existing cell center, this will cause a mesh generation problem. The mesh generation tools search for this issue and will identify any cell with duplicate cell centers. The solution to this problem is to delete one of the cell centers.
- **Cell Centers Outside of the 2D flow area Polygon.** If a user accidentally drops a point outside of the 2D flow area polygon, or they move the polygon boundary to the point in which cell centers are outside the polygon, this will generate a mesh error. The mesh routines will identify any points that are outside the current boundary. To fix the mesh, simply delete the points that are outside of the 2D flow area boundary.
- **Cells with Collinear Faces (Break Lines too close together).** Computational cells used within the HEC-RAS 2D code cannot have two faces that are collinear (i.e., they cannot form a straight line). Where two cells meet (at a face point), the outside angle formed by the two faces must be greater than 180 degrees. This is called "Strict Convex" in mathematical terms. Meaning all cells are require to be strictly convex, and therefore no two faces within the same cell can be collinear (Form a straight line). If cells end up like this, the software will run, but the computation across cell faces that are like this will not be correct.

This problem is 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. Cells are created along break lines one at a time. Additionally, the user can specify a cell min and max size to form the cells around a break line. The min cell size gets used right along the break line, then it transitions out the max cell size by doubling the cell size as it goes outward from the break line. If the user does not put in a max cell size, the software assumes that they want to transition out to the nominal cell size that was entered in the 2D Flow Area editor.

If the break lines are close together, this transitioning out can "Bleed" over into the cell space along a neighboring break line. This can have the effect of forming cells that no longer follow the first break

line, but even worse, cells could be formed that are not correct/consistent with the HEC-RAS 2D solution scheme. Below (Figure 3-15) is an example in which break lines were used for the channel bank lines and the channel centerline. In this case, all break lines were being transition out to the maximum cell size, which caused this bleed over effect. In this example the channel centerline break line was enforced first, then the channel bank lines. The cells around the channel bank lines were formed correctly, but the cells along the channel centerline were not, due to the fact that the cells formed from the channel bank line break lines override the previously formed cells along the channel centerline (Simply because the order in which they were enforced).

To fix this issue, you can either enter a max cell size that prevents that break lines cells from bleeding over into the neighboring break line cells, or you can enforce the break lines by hand, thus controlling the order in which cells get formed. This specific example was fixed by enforcing the Channel centerline by hand as the last break line to be enforced. See the fixed mesh in Figure 3-16.
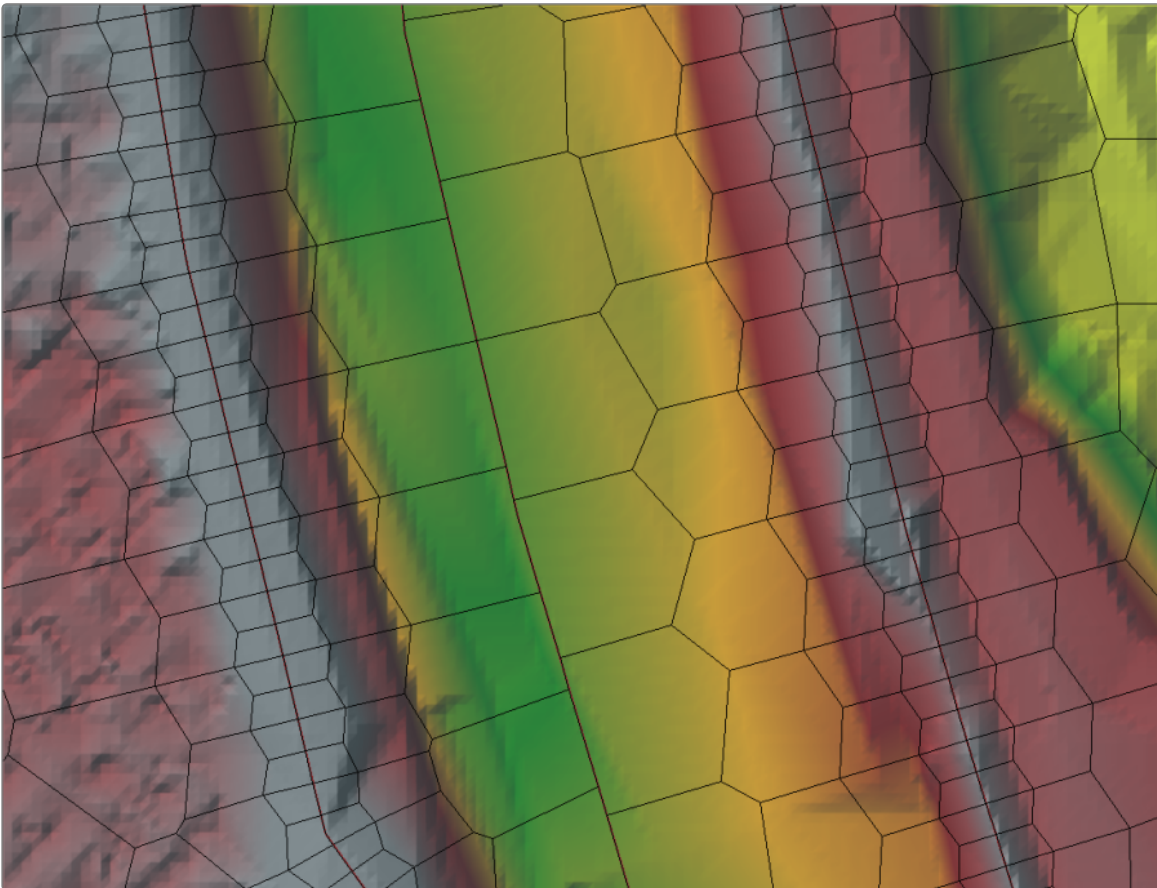
Figure 3-15. Example of bad cells with two or more faces that are collinear.
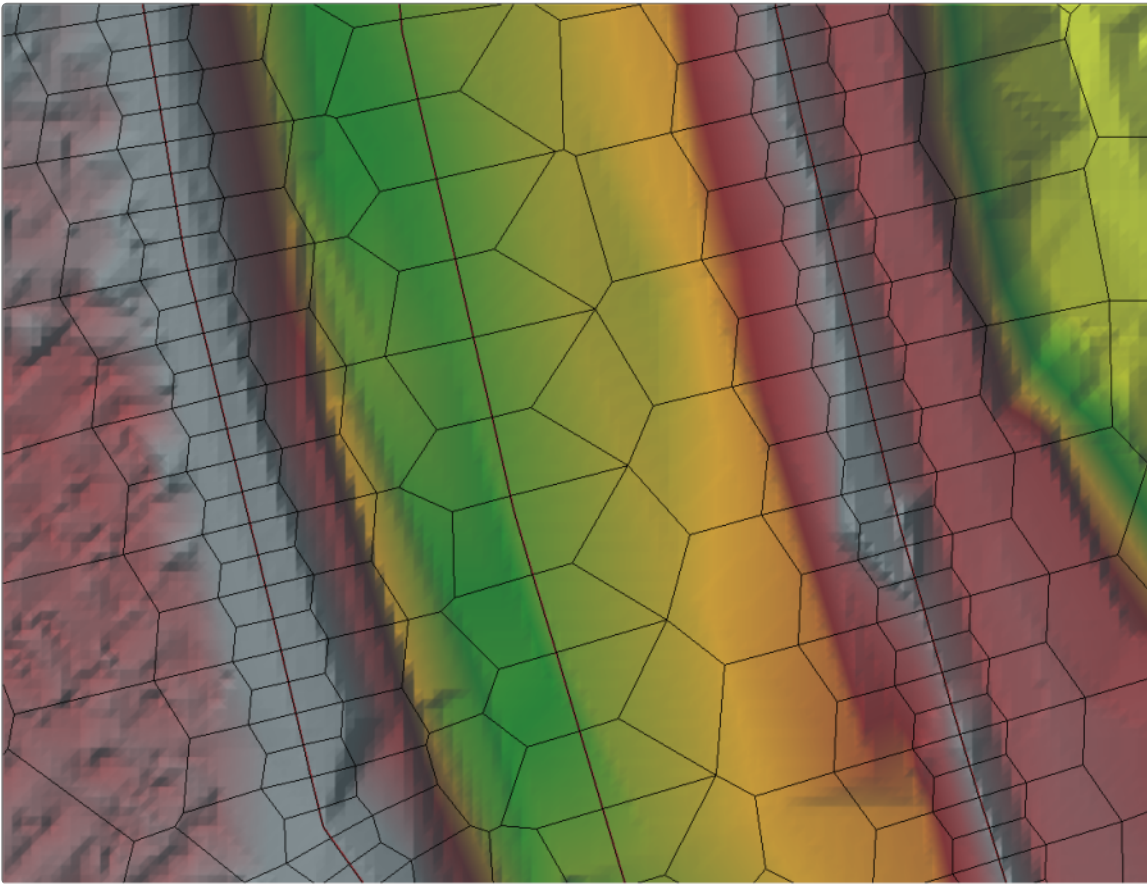
Figure 3-16. Example of properly formed cells along the centerline break line.

Creating Hydraulic Property Tables for 2D Flow Areas

As previously mentioned, the 2D Computation Mesh is preprocessed into an elevation – volume curve for each cell, and a series of hydraulic property curves for each cell face (elevation vs. wetted perimeter, area, and roughness). This pre-processing is accomplished in RAS Mapper. The hydraulic property tables are derived from the details of the underlying terrain used for the model, as well as any user defined Manning's n by land cover relationships set in the geometry file. A terrain model is required to use 2D modeling within HEC-RAS. The terrain data is also required in order to do any mapping of the computed results, for both the 1D and the 2D areas of the model. Please review Chapter 2 of this manual for instructions on creating a Terrain model for use in 2D modeling and results visualization.

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 and Manning's Layer with a Geometry

After a new terrain layer and Manning's n layer are added, the user **must** associate the terrain and Manning's layers with any or all of the geometry files within the HEC-RAS project. This is accomplished in RAS Mapper by right clicking on the **Geometries** layer at the top of the layer list (on the left hand side of the RAS Mapper window), then selecting the **Manage Geometry Associations** option from the popup menu. When this is done a window will appear, as shown in Figure 3-17, in which the user can select a terrain layer for each geometry file.

> (i) **Note:** RAS Mapper will attempt to associate a terrain model with the RAS Geometry when the Terrain Layer is first created. However, the user should verify the correct Terrain has been associated. The user will also be required to associate the terrain with a geometry, if there are multiple terrains.
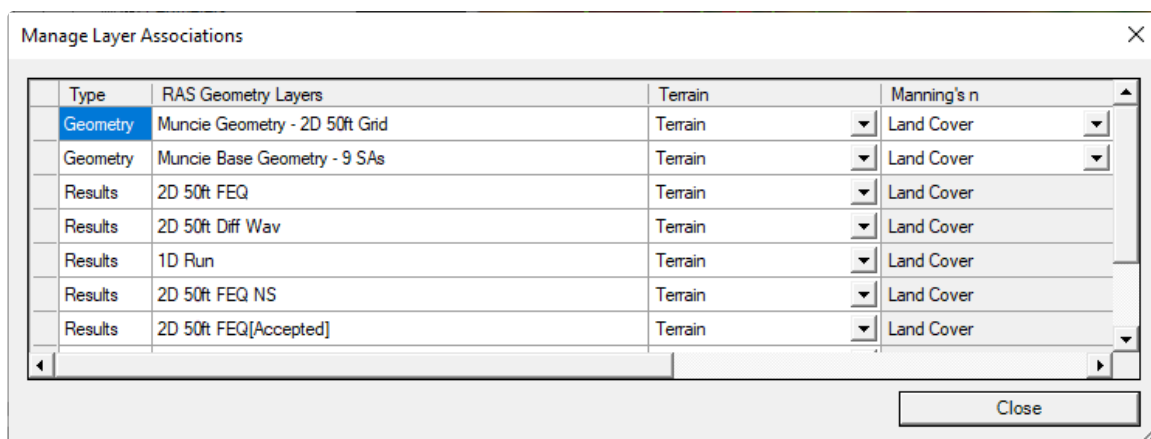

After associating all of the geometry files with the terrain and Manning's n layer(s), select the **Close** button. This will ensure that these associations are saved.

2D Geometric Preprocessor

Overview of Cell and Face Properties

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 (Casulli, 2008). The 2D mesh pre-processor computes a detailed elevation-volume relationship for each cell. Each cell face of a computational cell is pre-processed into detailed hydraulic property tables (elevation versus wetted perimeter, area, roughness, etc…). This allows the user to use larger computational cells, while keeping the details of the underlying terrain. The net effect is that larger cells results in fewer computations, which means much faster run times. Additionally, HEC-RAS will produce more detailed results for a given cell size than other models that use a single bed elevation for each cell and cell face.

An example of how HEC-RAS pre-processes cells and faces into detailed property tables is shown in Figures 3-18 through 3-21. Shown in Figure 3-18 are the details of the underlying terrain within a single computational cell.
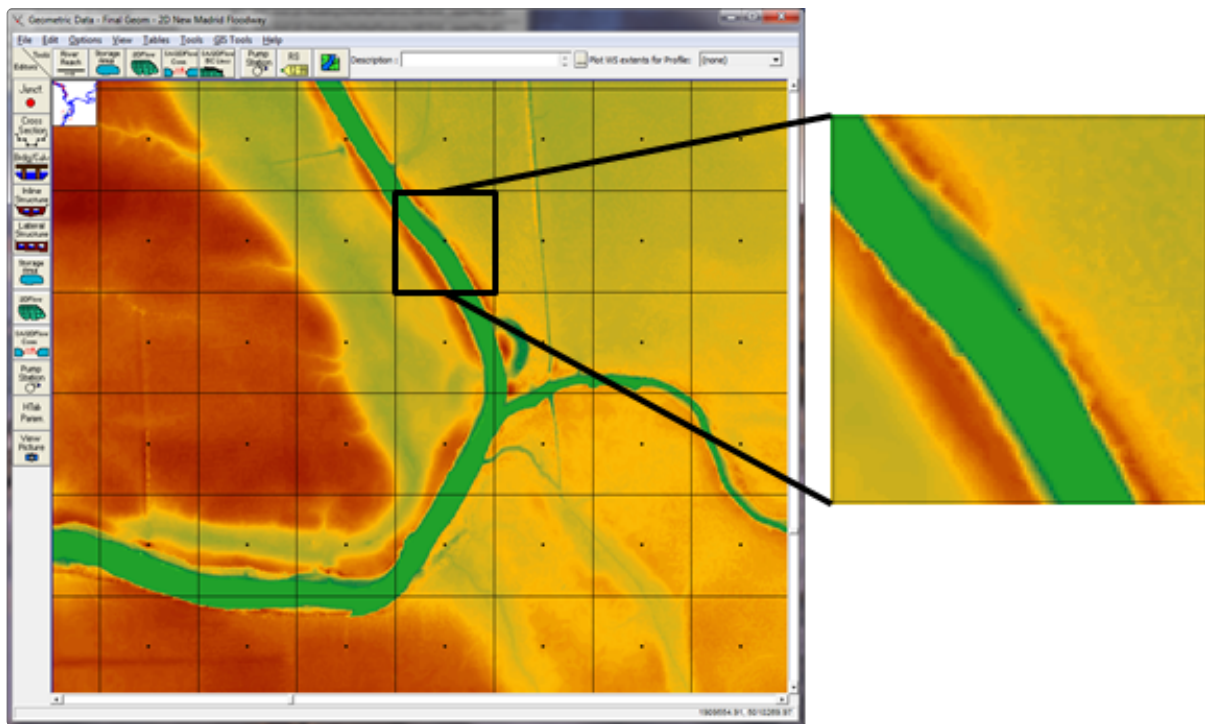
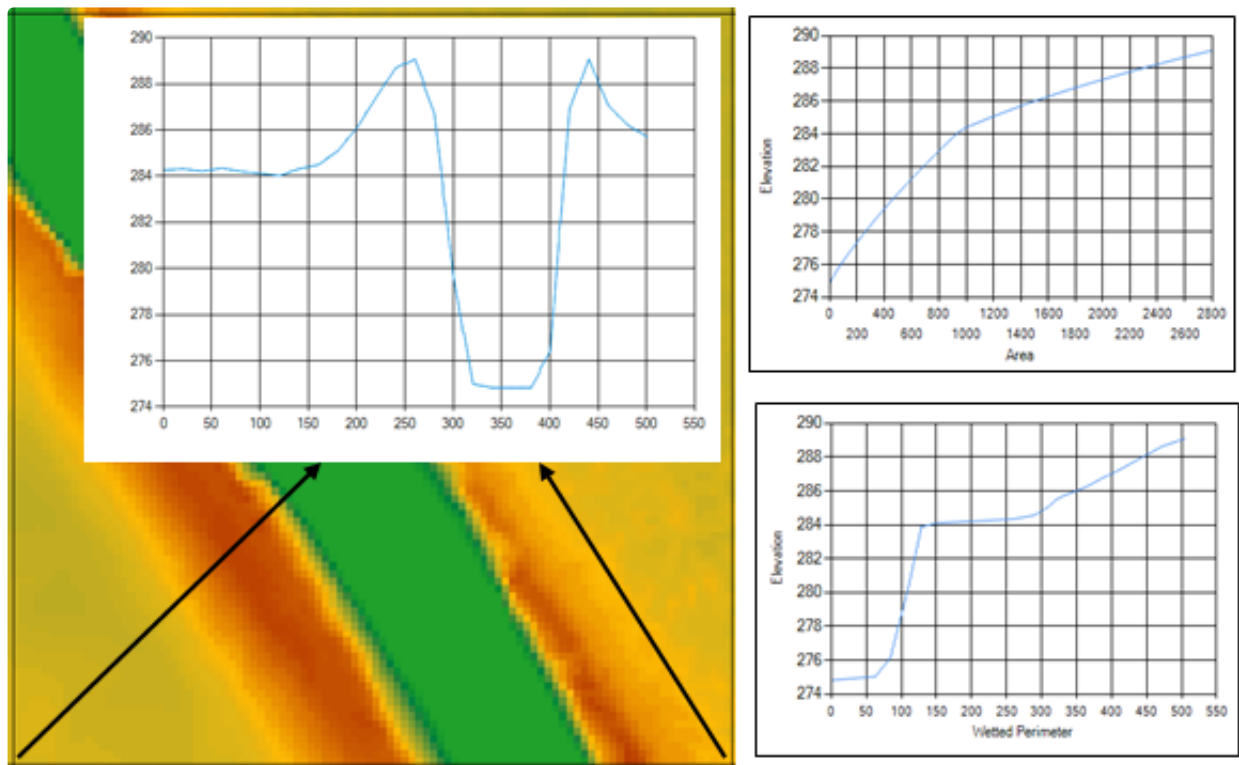When the 2D Geometric Pre-processor runs a detailed elevation-volume relationship is developed for each cell. See an example of this in Figure 3-19 below.
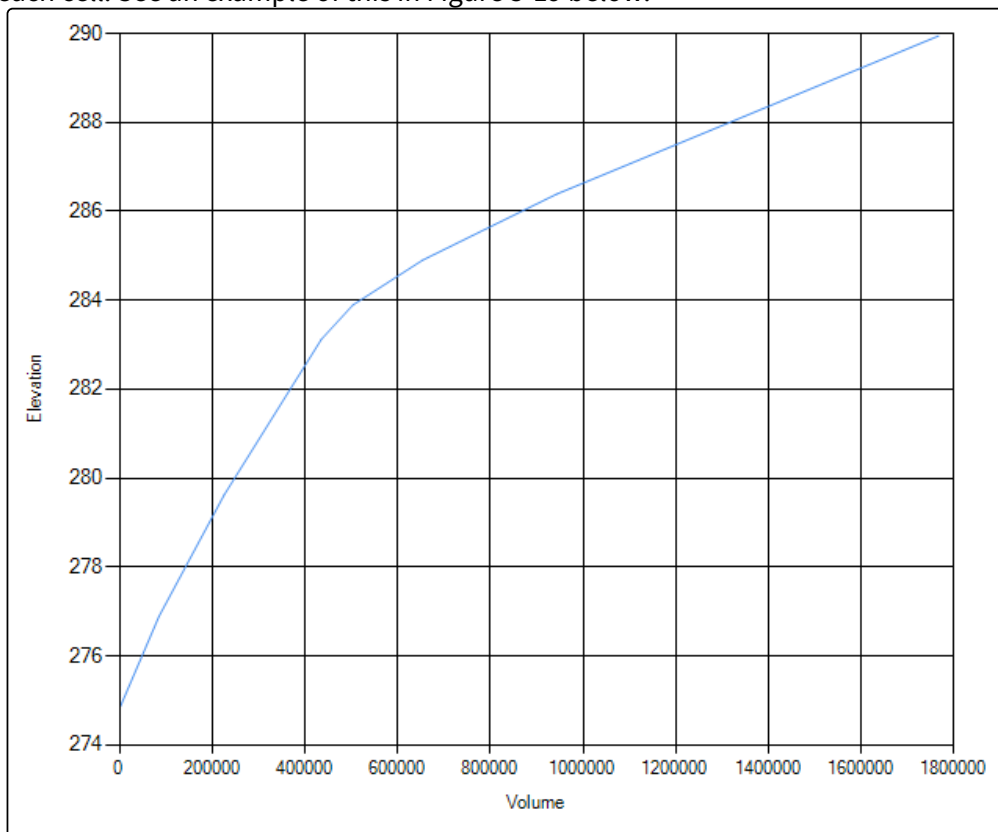
In addition to the processing of the cells, the faces of the cells are preprocessed into tables of elevation versus area, wetted perimeter, and roughness. See Figure 3-20 below:

As shown in Figure 3-20, each cell face is like a detailed cross section. So the flow of water into, through, and out of a cell is controlled by the details of these face properties, and the cell elevation-volume relationship. The benefit of this is much greater hydraulic details at the cell level over other models that use a single elevation for each cell and face. With HEC-RAS, users can have much larger cells, but still retain great hydraulic detail within a cell. Additionally, HEC-RAS cells can be partially wet (i.e., water does not have to cover the entire cell, and can move through a portion of the cell). An example of this is shown in Figure 3-21.

> ⓘ NOTE: The examples shown in Figures 3-18 through 3-21 are not a detailed model. The example of using large cell sizes is just to demonstrate how subgrid technology works, and the power of subgrid technology. A detailed model would align faces along the channel and use smaller cell sizes in the channel.

Shown in Figure 3-21 is an example of how the computational cells in HEC-RAS contain enough hydraulic detail such that flow can move through a channel, even though the channel is smaller than the cell size. In the above example, the 2D cells are 500 x 500 ft (the underlying terrain is 2 x 2 ft grids). Water will move through the channel portion of the cells, because the details of the channel cross sections are contained within the cell faces. Additionally, the details of the elevation-volume relationship in the channel are contained within the cell hydraulic properties table. In this type of example, flow can move through a channel in a 1D-type of mode, while flow in the overbank areas will be 2D from cell to cell. If the user wants more detail within the channel, such as two-dimensional flow velocities and varying water surface elevations, then a cell size in that would allow 5 to 7 (or more) cells across the channel is needed. The smaller cell size will allow the model to capture the two dimensional flow effects within the channel itself. However, if the user only needs to capture the two-dimensional flow effects on the floodplain, then the approach shown in Figure 3-21 is a viable option. This type of model is not a detailed channel model, but it does allow water to move through the channels in a 1D fashion, with a reasonable amount of conveyance computed for the channel, based on the terrain at the cell faces.

The 2D flow capabilities in HEC-RAS can be used in many ways. The user can develop a mesh with very small cell sizes that can be used to model both channels and floodplains in great detail. Or the user can use larger cell sizes, which will give you less detail in the channel, but still 2D flow hydraulics in the floodplain. The level of detail the user chooses depends on what is being modeled, and the purpose of the study. HEC-RAS provides the user with the maximum amount of flexibility in modeling the details of a channel and the floodplain in 2D. Preprocessing the cells and cell faces into detailed hydraulic property tables is an advantage over 2D models that use a single elevation for each cell (flat cells), and a single line for each face (flat or linear sloping faces).

Manning's Roughness Coefficient

There are several options for specifying the Manning's roughness coefficient in HEC-RAS 2D. The first and simplest option is to a constant value for each **2D Flow Area**. This can be accomplished by using the **Default Manning's n value** in the 2D Flow Area editors in **RAS Mapper** or the **Geometric Data Editor** (see figures below), and not providing any other Manning's n information.

If in addition to the default Manning's n value, the user specifies a **Land Cover** layer in RAS Mapper and/or **Calibration Regions**, then the Manning's n value is extracted from those layers. **Calibration Regions** can be used to override any Manning's n values in the **Land Cover** layer. For example, the figure below shows how a Calibration Region can be effective used to specify the Manning's n value for a polygon corresponding to a main channel.
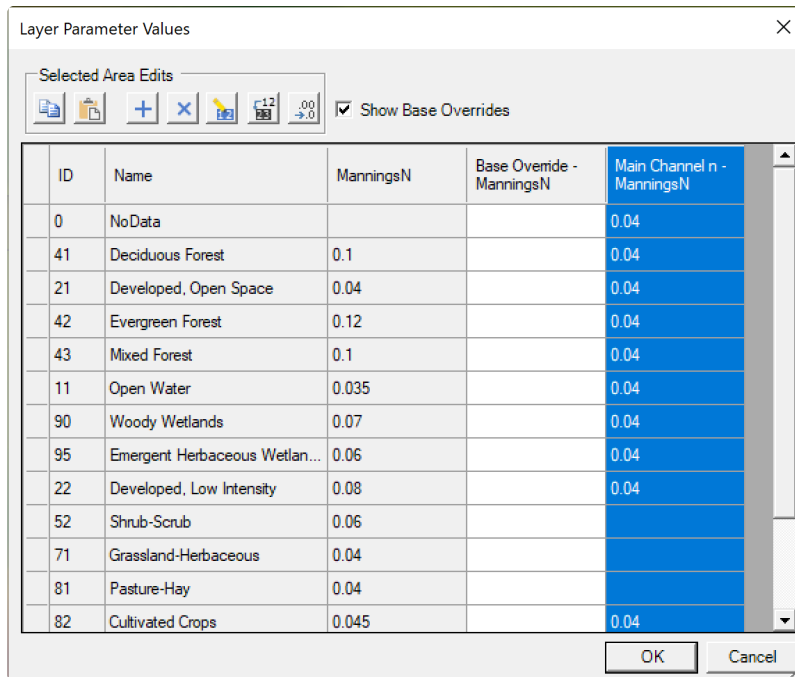
Any areas not covered by the Manning' n layer or a **Calibration Region** are assigned the **Default Manning's n value**. There are two methods for computing the face Manning's n table as a function of elevation. The first and default method extracts a value from the **Land Cover** and **Calibration Region** at the centroid of every face. The second option, available in HEC-RAS Versions 6.4 and later computes a composite Manning's n values as a function of elevation. The composite Manning's n values are computed in the same manner as for 1D channels using the formula:

$$n_c = \left(\frac{1}{P} \sum_{i=1}^{N} P_i\, n_i^{3/2} \right)^{2/3}$$

where

n_c : composite Manning's roughness coefficient [s/m$^{1/3}$]

$P = \sum_{i=1}^{N} P_i$: total wetted perimeter [L]

P_i : local wetted perimeter corresponding to each segment along a face [L]

n_i : local Manning's roughness coefficient corresponding to each segment along a face [L]

> (i) The Manning's n value compositing formula shown above was developed for channels (using an average channel velocity) for a range of "reasonable" n values (range 0.01 - 0.1). If using high n value to represent a total loss of conveyance (such as for buildings), the large n value will dominate the equation resulting in a very high n value for the entire cell face. Manning's n values of 0.25-0.5 are suggested for modeling buildings.

The spatially varied Manning's on faces option is turned either in **RAS Mapper** or the **Geometric Data Editor** as shown in the figures below.
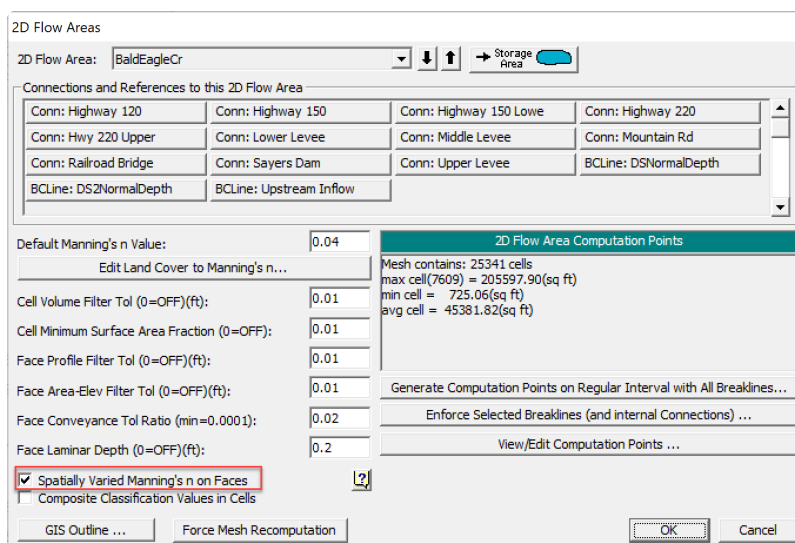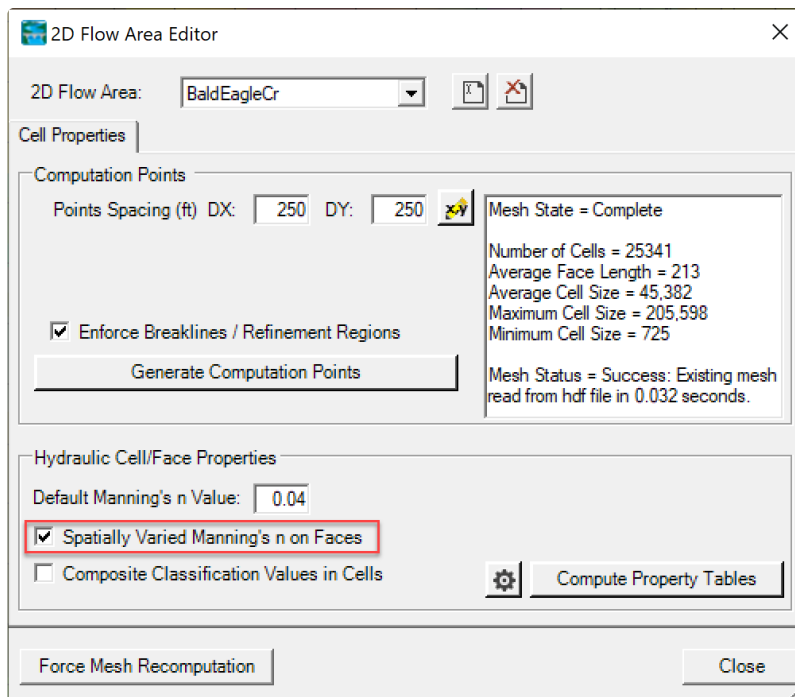
Therefore, the face Manning's n value remains constant above the elevation when the face becomes completely wet and the wetted perimeter does not change. When the spatially varied Manning's roughness is selected, the Manning's n tables will vary as a function of elevation. The section below explains how to run the 2D Geometric Preprocessor which computes the among other things the composite Manning's roughness coefficient as a function of elevation.

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 step does not have to be done in RAS Mapper. If the user does not run the 2D Geometric preprocessor in RAS Mapper, it will automatically be done

as a separate process during the unsteady flow computations.

In the Geometry group there will be a sub layer called **2D flow area**. Checking the box for this layer will turn on the mesh for all of the 2D flow areas contained within that geometry file. In this example, there is only one 2D flow area. Right click on the sub layer called **2D flow area**, then select the option labeled **Compute 2D Flow Areas Hydraulic Tables** (see Figure 3-22). This is the option to pre-process the 2D flow area computational cells and faces into detailed tables based on the underlying terrain data. If the user does not do this step here, the HEC-RAS user interface will detect that the pre-processing step has not been done, and it will do it during the unsteady flow computational process (right before it performs the existing 1D pre-processing of the cross sections and hydraulic structures). Also, if the user later changes anything about the 2D area (adds, moves, deletes cells, changes Manning's n-values, etc…), then the 2D pre-processor step will automatically be rerun during the unsteady flow computational process.
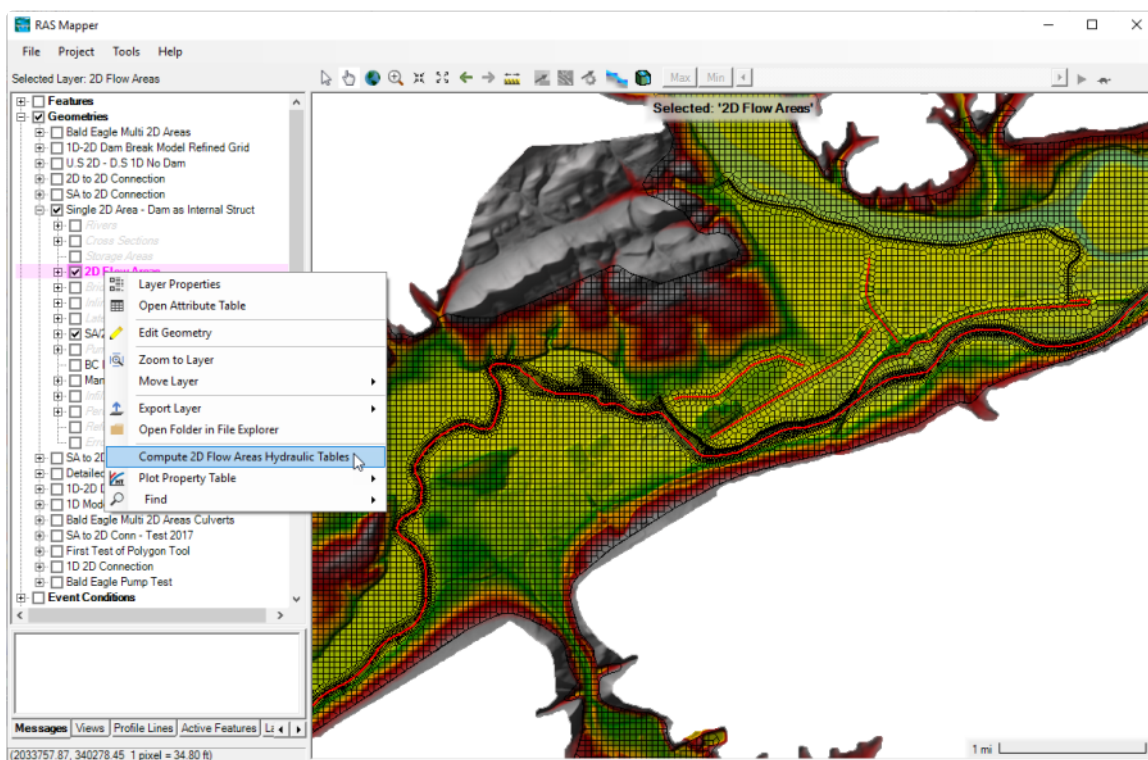
Connecting 2D Flow Areas to 1D Hydraulic Elements

The 2D flow area elements can be connected to 1D elements in several ways: directly to the downstream end or the upstream end of a river reach; laterally to 1D river reaches using a Lateral Structure(s); and/or directly to another 2D area or storage area using the SA/2D Area Connection. The process for connecting a 2D flow area to other hydraulic elements can be accomplished in HEC-RAS Mapper or in the HEC-RAS Geometric Data editor. This example shows how to develop and connect a Lateral Structure from a 1D reach to a 2D Flow Area in the HEC-RAS Geometry Editor. To learn how to do this in HEC-RAS Mapper, please review the HEC-RAS Mapper User's manual.

Connecting a 2D Flow Area to a 1D River Reach with a Lateral Structure.

2D flow areas can be used to model areas behind levees or overbank flow by connecting a 1D river reach to the 2D area using a Lateral Structure (see Figure 3-23).
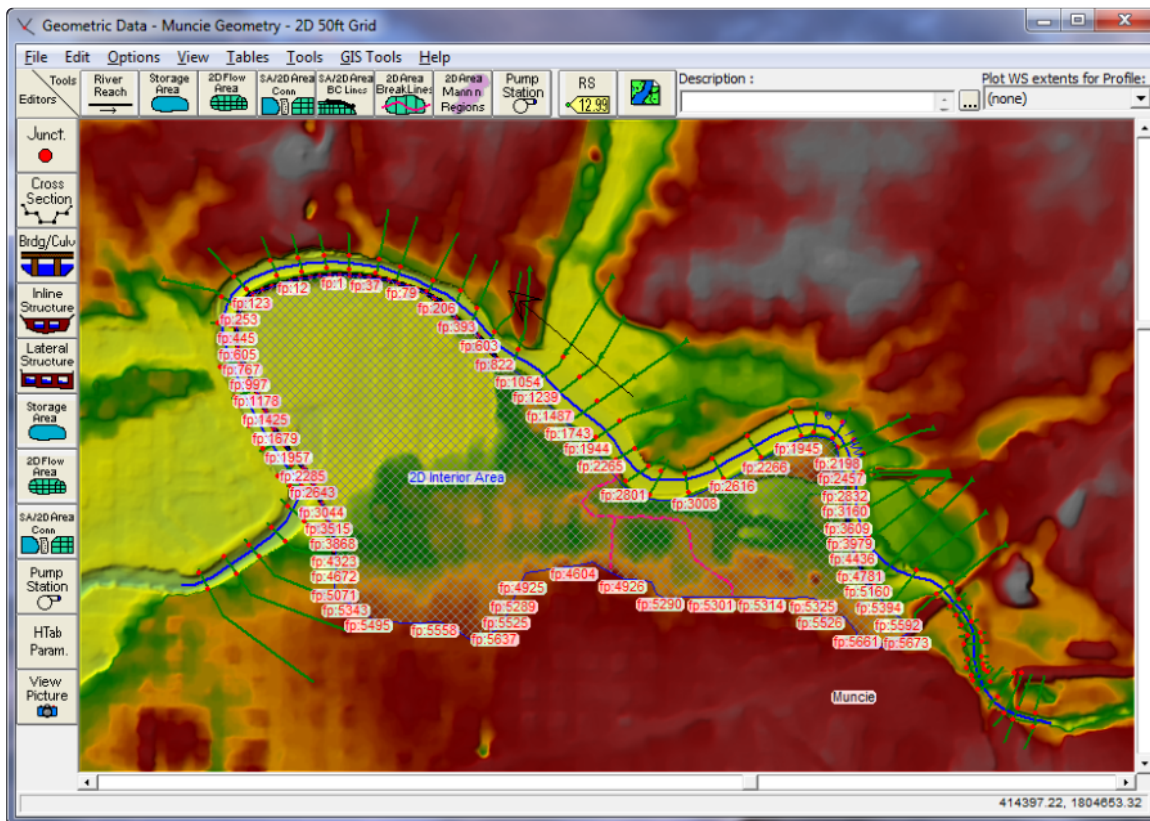
Figure 3-23. HEC-RAS Geometric Editor with the 2D flow area boundary Face Points displayed.

For this example, zoom into the upstream end of the river, which is on the right hand side of the schematic. At this location add a Lateral Structure that represents the levee in that region. When a Lateral Structure is added to the 1D River Reach, the user can select to link it to another 1D River Reach, a Storage Area, or a 2D flow area. If the user selects to link the Lateral Structure to a 2D flow area, then the stationing of the Lateral Structure will be linked to the 2D Area's face points automatically (this is analogous to the Lateral Structure automatically determining the location and intersection of the 1D cross sections). The connected levee is shown in Figure 3-24.
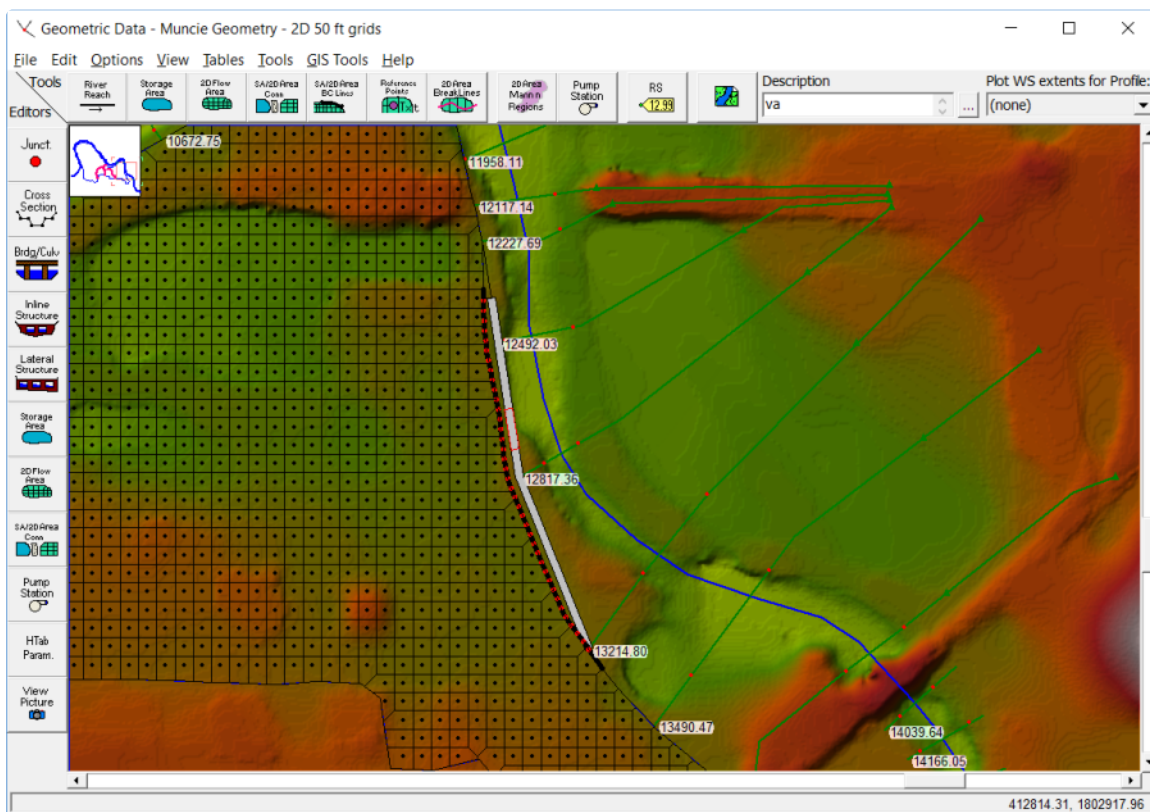
Figure 3-24. Example of a Lateral Structure (levee) hooked up to a 2D flow area.

In this example, this Lateral Structure (levee) will be used to model flow going over the levee, as well as a levee breach that will be added later.

HEC-RAS has the option to have georeferenced lateral structures. Under the menu item labeled **GIS Tools**, there is now a table option called **Lateral Structure Centerlines Table**. User can use the **Measure Tool** to draw a line that would represent the lateral structure geospatial X and Y coordinates, then paste those coordinates into the Lateral Structure Centerline Table (This is optional). If a user inserts geospatial coordinates for a lateral structure, not only will it be drawn geospatially correct, but HEC-RAS will figure out how elements (1D cross sections and 2D Face Points) are connected to the lateral structure based on its spatial location. User's can also layout Lateral structures in HEC-RAS Mapper by editing the geometry layer, then the Lateral structure layer.

Note: if you put in a Geospatial centerline for a lateral structure, the length of the lateral structure weir/embankment stationing must be within 0.5% of the length of the centerline put in (i.e., they need to be consistent with each other in terms of length).
Users can use the Geometry Editor measuring tool option to draw the geospatial line that will represent the Lateral Structure, or they can import the geospatial information from an ESRI shapefile. Shown in Figure 3-25 is the **Lateral Structure Centerlines Table**.

Figure 3-25. Example Lateral Structure Centerlines Table with Geospatial coordinate data for a levee.

To draw a geospatial line from within the Geometric Data editor, use the measuring tool option. This is accomplished by holding down the **Cntrl key**, then using the mouse pointer and the left mouse button to draw the line. Click the left mouse button to start the line, then move the mouse and continue to left click to add additional points in the line. As you are drawing the line, you can also right click the mouse to re-center the drawing within the Geometric Data editor. This is very helpful when you are zoomed in and need to continue the line to an area off of the screen. To finish the line, left click on the last point then release the Cntrl key. Once you release the Cntrl key, a window will appear as shown in Figure 3-26.

Figure 3-26. Example Measuring Tool line data window.

As shown in Figure 3-26, the measuring tool will show you the geospatial X and Y coordinates of the line in a table. To send these coordinates to the Windows Clipboard (so you can then paste them into the Lateral Structure Centerlines Table), simply press the button labeled: **Copy GIS to Clipboard**. These coordinates can be pasted into the Lateral Structure Centerline Table to georeferenced a lateral structure. The measuring tool window also shows you the length of the line; the area of a polygon if the first and last point were connected; Delta X; Delta Y; and dy/dx. Additionally you can plot the terrain data underneath that line by pressing the button labeled: **Cut Profile from Terrain and Plot** (This only works if you have a terrain data set in RAS Mapper and you have it associated with the currently opened Geometry file). This line can be used as a first cut for the user entered Weir Station and Elevation data for the Lateral Structure Weir profile. This is especially useful if the Lateral Structure is being used to represent the high ground barrier between the main channel (1D river reach) and overbank area (2D Flow Area).

The process of connecting a Lateral Structure to a 2D flow area is described below:

1. Add the Lateral Structure as would normally be done in HEC-RAS (i.e., create the Lateral Structure; define the upstream River Station of the structure; enter the station/elevation points that represent the weir/ embankment of the top of the structure; and add geospatial data for the lateral structure as described above).
2. For the **Tailwater Connection** option on the **Lateral Structure** editor, select the **Type** as **Storage Area/2D Flow Area**. Then from the **SA/2D FA** field, select the name of the 2D flow area to be connected to the lateral structure by pressing the **Set SA/2DFA** button and selecting the 2D flow area name. In this example the name of the 2D flow area is "2D Interior Area" (see Figure 3-27).
3. Next, select the **Weir/Embankment** button on the left side of the graphic window. This will bring up the editor that will allow the user to define the top profile of the embankment, as well as determine how the lateral structure is connected to the 1D river cross sections (the headwater side of the structure), and to the 2D area face points (the tailwater side of the structure), as shown in Figure 3-28.
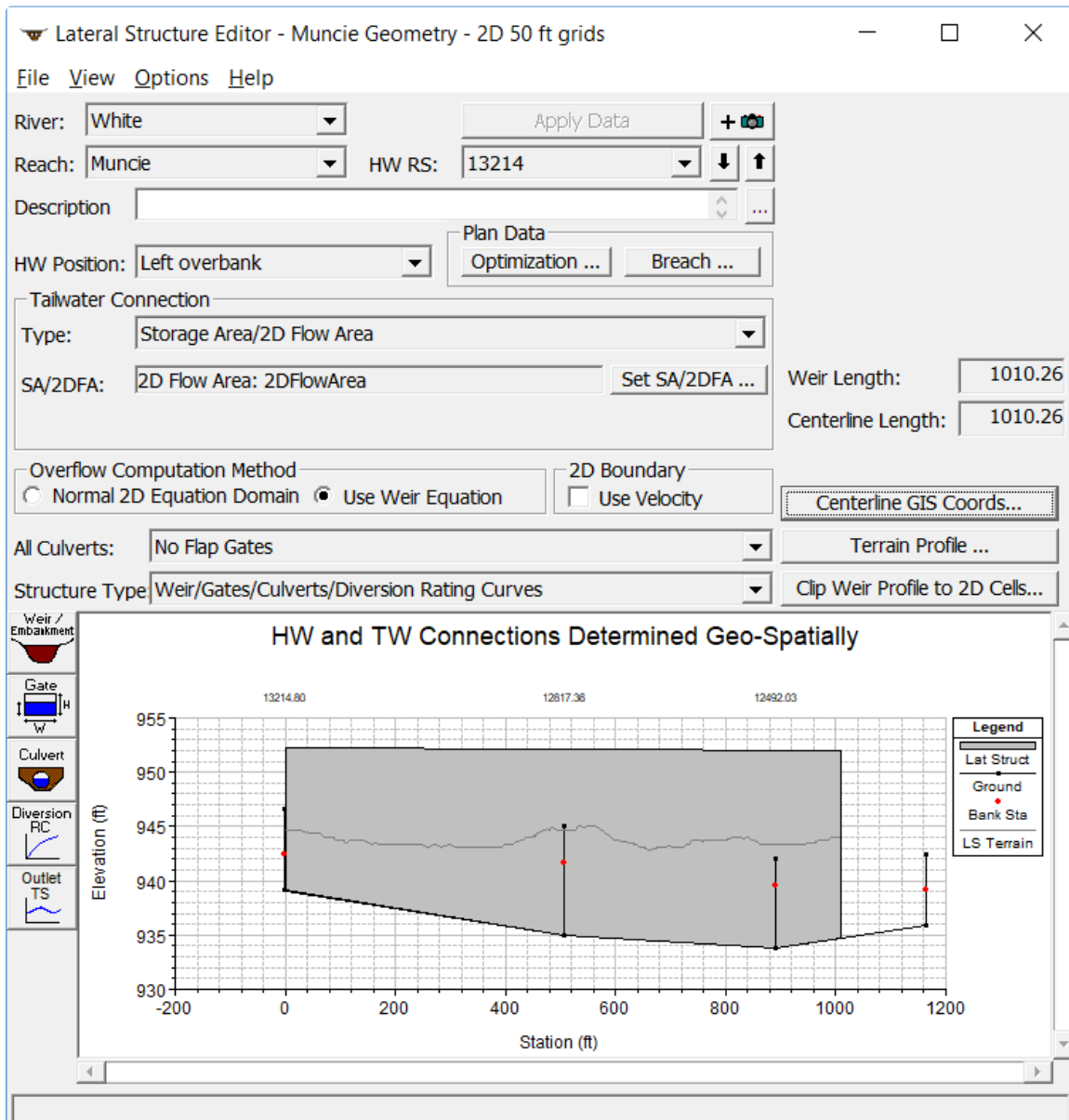
Figure 3-27. Lateral Structure Editor with tailwater connection to a 2D flow area.

As shown in Figure 3-28, the user goes about the normal process of entering a Lateral Structure in HEC-RAS by entering the: weir width, weir coefficient, HW (Headwater) Distance to Upstream XS, and the Weir Station and Elevation points. This will define the top of the lateral structure (levee) profile.

Lateral Weir Embankment

Weir Data

Weir Width   20.

Weir Computations: Standard Weir Eqn ▼

Standard Weir Equation Parameters

Weir flow reference: Water Surface ▼

Weir Coefficient (Cd)   2.

Weir Crest Shape: Broad Crested ▼

Weir Stationing Reference

HW - Distance to Upstream XS: 1.

HW Connections ...   TW Connections ...

Embankment Station/Elevation Table

Insert Row   Delete Row   Filter...

	Station	Elevation
1	0	952.2
2	1010.26	952
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		

OK   Cancel

Figure 3-28. Lateral Structure Editor with structure Station/Elevation data,

.

For the HW Connection to the 1D cross sections, the user can use the default, which is to have HEC-RAS compute the intersection of the 1D cross sections with the Lateral Structure based on the cross section overbank reach lengths (or based on the lateral structures geospatial data, if the user enters geospatial coordinates for the lateral structure) and the Lateral Structure weir profile stationing (see Chapter 6 of the HEC-RAS User's Manual, "Entering and Editing Lateral Structure Data" section, for more detailed discussion). Or the user can choose the option called **User Defined Weir Stationing** to enter their own intersection locations between the 1D cross sections and the Lateral Structure Weir Stationing. To view and/or edit the Headwater connection data, press the button labeled **HW Connections** from the Lateral Weir Embankment editor. When you do a window will appear as shown in Figure 3-29. In this example, the 1D river cross sections are being lined up with the Lateral Structure Weir Station automatically by HEC-RAS. This example also shows that geospatial data was entered for the Lateral Structure Centerline, so the option for the user to enter their own connections from the 1D cross sections to the Lateral Structure is not available.

Figure 3-29. Head Water Connection Table for a Lateral Structure.

For the Tailwater Connection to the 2D Flow Area, the user can select either the default (HEC-RAS will compute the connection between the Lateral Structure Weir stationing and the 2D Flow Area Face Points), or they can define their own connection between the Lateral Structure Weir station and the 2D Flow Area Face Points. To view and/or edit the Tailwater connection data, press the button labeled **TW Connections** from the Lateral Weir Embankment editor. When you do a window will appear as shown in Figure 3-30. In this example, the Lateral Structure Weir Station is automatically connected to the 2D Flow Area Face Points by HEC-RAS. This example also shows that geospatial data was entered for the Lateral Structure Centerline, so the option for the user to enter their own connections from the 2D Flow Area Face Points to the Lateral Structure Weir stationing is not available.

TW Lateral Structure Connections

○ Computed Default Weir Stationing   ○ User Defined Weir Stationing

	Default Computed Weir Stationing				User Defined Weir Stationing	
	2D Face Points	Weir Station			2D Face Points	Weir Station
1	5389	-64.28		1		
2	5296	7.41		2		
3	5204	79.26		3		
4	5115	99.22		4		
5	5022	190.61		5		
6	4921	209.18		6		
7	4819	263.43		7	User Specified Connections	
8	4710	343.4		8	Option will not be used	
9	4589	371.88		9	because the lateral structure	
10	4471	457.92		10	has a geo-referenced	
11	4354	480.28		11	centerline.	
12	4238	531.71		12		
13	4123	582.06		13		
14	4005	632.42		14		
15	3889	714.83		15		
16	3771	733.78		16		
17	3635	784.81		17		
18	3518	835.8		18		
19	3400	886.12		19		

OK   Cancel

The last step is to make sure that the 2D flow area Face Points are correctly linked to the stationing of the Lateral Structure. The Tailwater linking is done automatically by HEC-RAS, but the user can override what it does (as described above). By default, the software will come up with the Tailwater Connection table set to **Computed Default Weir Stationing.** In this mode, HEC-RAS will automatically determine the connections between the lateral structure and the 2D flow area. This means HEC-RAS will find the 2D flow area face points that start at the upstream end of the structure and go along the structure to the downstream end. Generally, a lateral structure will not start exactly at a 2D flow area face point. So, HEC-RAS will pick the face point just upstream of the lateral structure to start the connection. This point will normally be given a negative weir stationing, meaning that it is actually upstream of the lateral structure by that distance. So the zero weir stationing is actually in between two face points. The second face point in the table will be the next point downstream and it will have a positive weir stationing. This stationing will represent how far the upstream end of the lateral weir is from that Face Point, along the length/stationing of the lateral weir.

If Geospatial coordinates are not entered for the Lateral Structure, the user has the option to enter the face points and Lateral Structure weir stationing by hand. This is done by selecting **User Defined Weir Stationing** from the Tailwater Connection window. Once the user has selected **User Defined Weir Stationing** they can enter/change/modify the table as they see fit. However, the user must remember not to skip any face points as previously discussed. To connect an HEC-RAS Lateral Structure to a 2D flow area by hand, the user enters face point numbers, from upstream to downstream, that will be linked to the Lateral Structures weir profile stationing. If the Lateral Structure does not begin at a face point, start with the face point that is just upstream of the beginning of the Lateral Structure. Also, continue entering Face Points until you have just gone past the end of the lateral structure. The Face Point numbers must be in the order that they are labeled on the 2D flow area boundary, starting upstream and going downstream**.**

> ⓘ **Note:** The user cannot skip over (exclude) any of the face point numbers. If any face points along the boundary are skipped the model will not run, and it will give an error message saying the connection to the 2D flow area is incorrect.

> ⓘ **Note:** If the user makes any changes (such as adding, moving, or deleting cell centers) that cause the cell mesh to be regenerated, the face point numbers and locations may change causing the user entered face point intersections to no longer be valid.

Sometimes, the graphical length of the weir is shown longer or shorter than the true length. This occurs when the lateral structure is on the outside or inside of a bend, and the user has not entered any geospatial information for the Lateral Structure Centerline Table. When this occurs, the HEC-RAS automated Face Point connections will be adjusted such that the Lateral Structure weir stationing lines up with the correct Face Points. This is done by figuring out the total length along the 2D flow area, from Face Point to Face Point, then proportioning those lengths based on the total Length of the Lateral Structure divided by the total length along the 2D flow area Face Points. If the user chooses to enter the Tailwater connection using **User Defined Weir Stationing**, then the user has to determine the intersections on their own. One way to do this is to measure the lengths along the face points, and then use Excel to reduce the lengths to equal the true structure length, by multiplying the computed face point lengths by the ratio of the true structure length divided by the graphical length of the structure.

Once the user has entered all of the data for the Lateral structure, including the links to the 2D flow area, press the **OK** button to close the Lateral Weir Embankment editor, then close the Lateral Structure editor (unless the user needs/want to add gates, culverts, rating curves, etc… to further define the details of the lateral structure). The HEC-RAS Geometric editor will now show a thick black line along the 2D Area Face Points, to show you where the Lateral Structure is connected to the 2D flow area (see Figure 3-35). If this black line does not follow all of the appropriate Face Points from the 2D flow area, then there is a mistake in the 2D flow area connection table. So the thick black line can be used as a guide to help identify if the Lateral Structure is connected correctly to the 2D flow area. The **Black line** represents the 2D Faces that are connected to the lateral structure. The Black line will always start and stop at the beginning or end of a 2D Face (Face Point). On top of the black

line is a **Red dashed line**, the Red line represents where HEC-RAS has linked the lateral structure to the 2D Flow Area boundary. The Red line can start and stop in the middle of a 2D Face. The Red Line shows the user the exact location of how the 2D area is connected to the Lateral Structure.

Shown in Figure 3-31 is how the Lateral structure will look when geospatial data has been entered for the centerline of the structure.
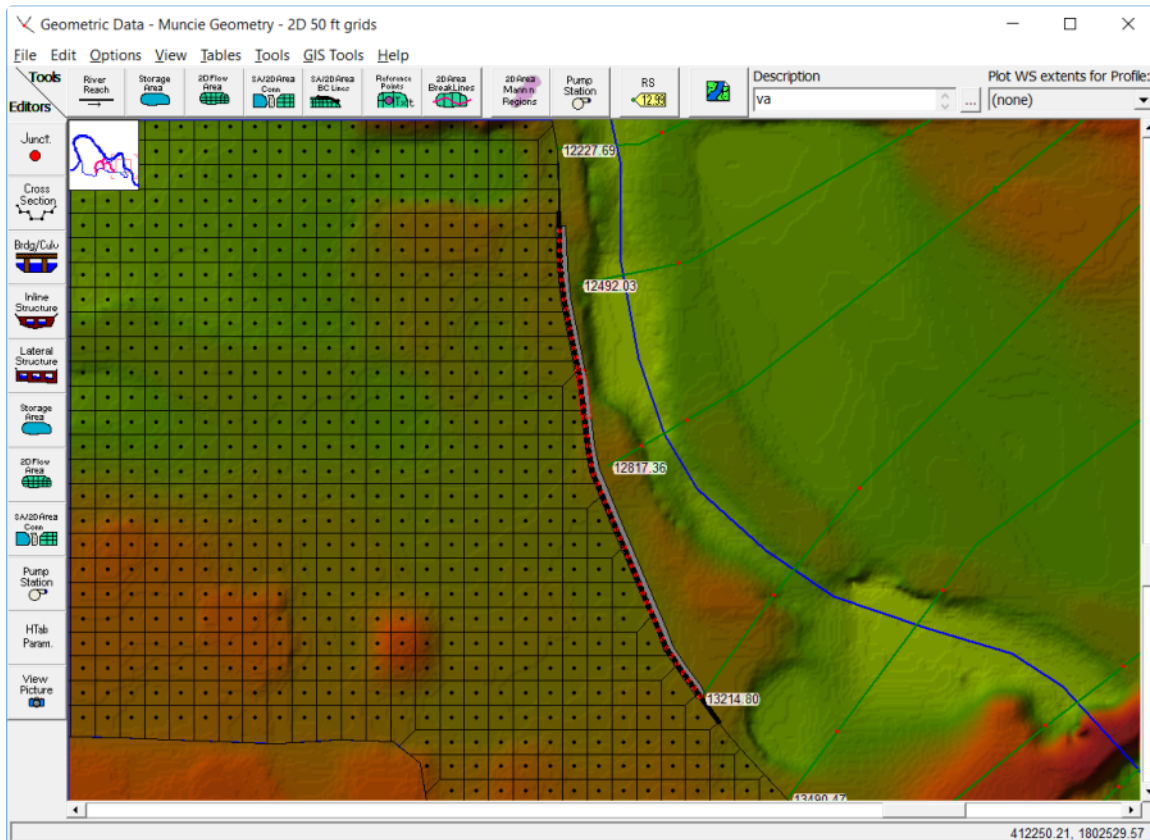
Figure 3-31. HEC-RAS Geometric Editor showing a thick black line for the connection of a Lateral Structure to the 2D flow area Face Points.

For this example a breach location/data has also been added for the analysis of this upper levee. Shown in Figure 3-32 is the Levee (Lateral Structure) Breach Data editor with the data for this levee.
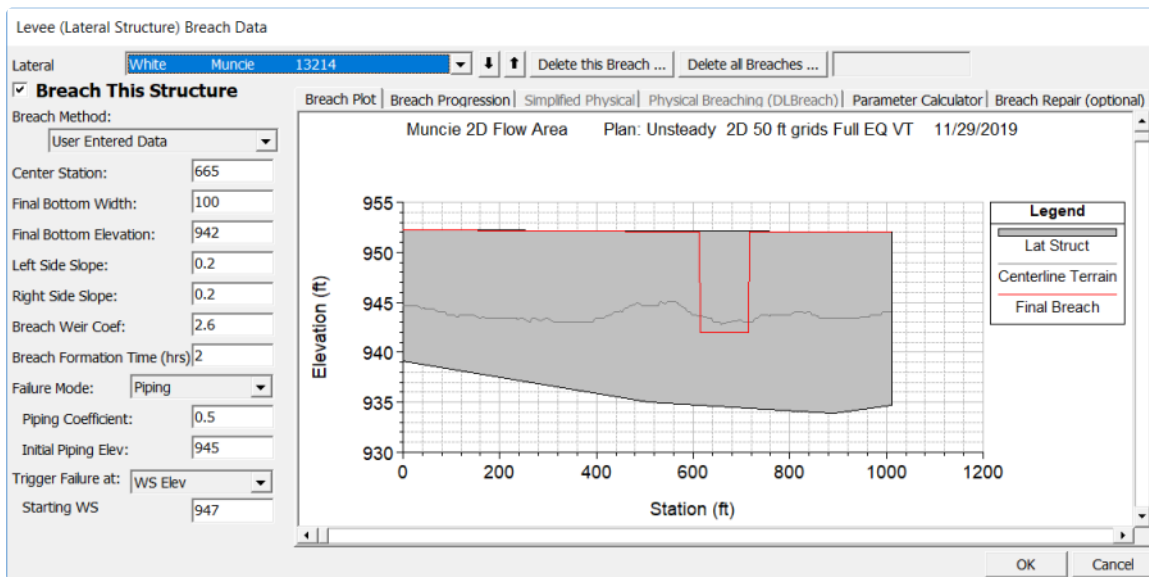
Figure 3-32. Levee (Lateral Structure) Breach Data editor, with breach data for the upstream levee.

For this specific example, a second additional lateral structure at the lower end of the 2D flow area will be added. This Lateral Structure will be used to model flow that ponds on the inside of the protected area, then flows back over the top of the Levee (Lateral Structure) into the 1D river system. See Figure 3-33 for the extents of this downstream Levee.
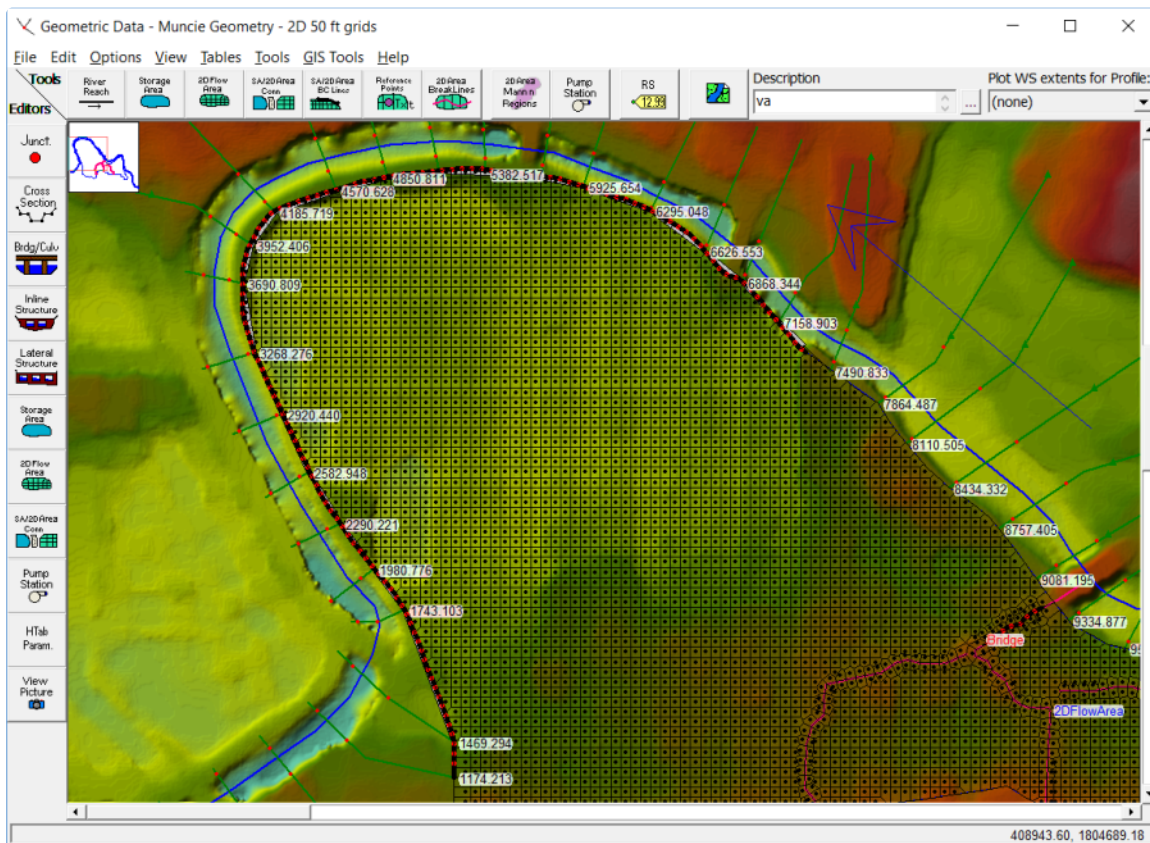
Figure 3-33. HEC-RAS Geometric Editor with downstream Levee (Lateral Structure) highlighted in red.

The downstream Lateral Structure in this example starts at River Station 7300, and goes along the entire downstream boundary of the protected area, tying back into high ground at the downstream end. The Lateral Structure editor for this Levee is shown in Figure 3-34.
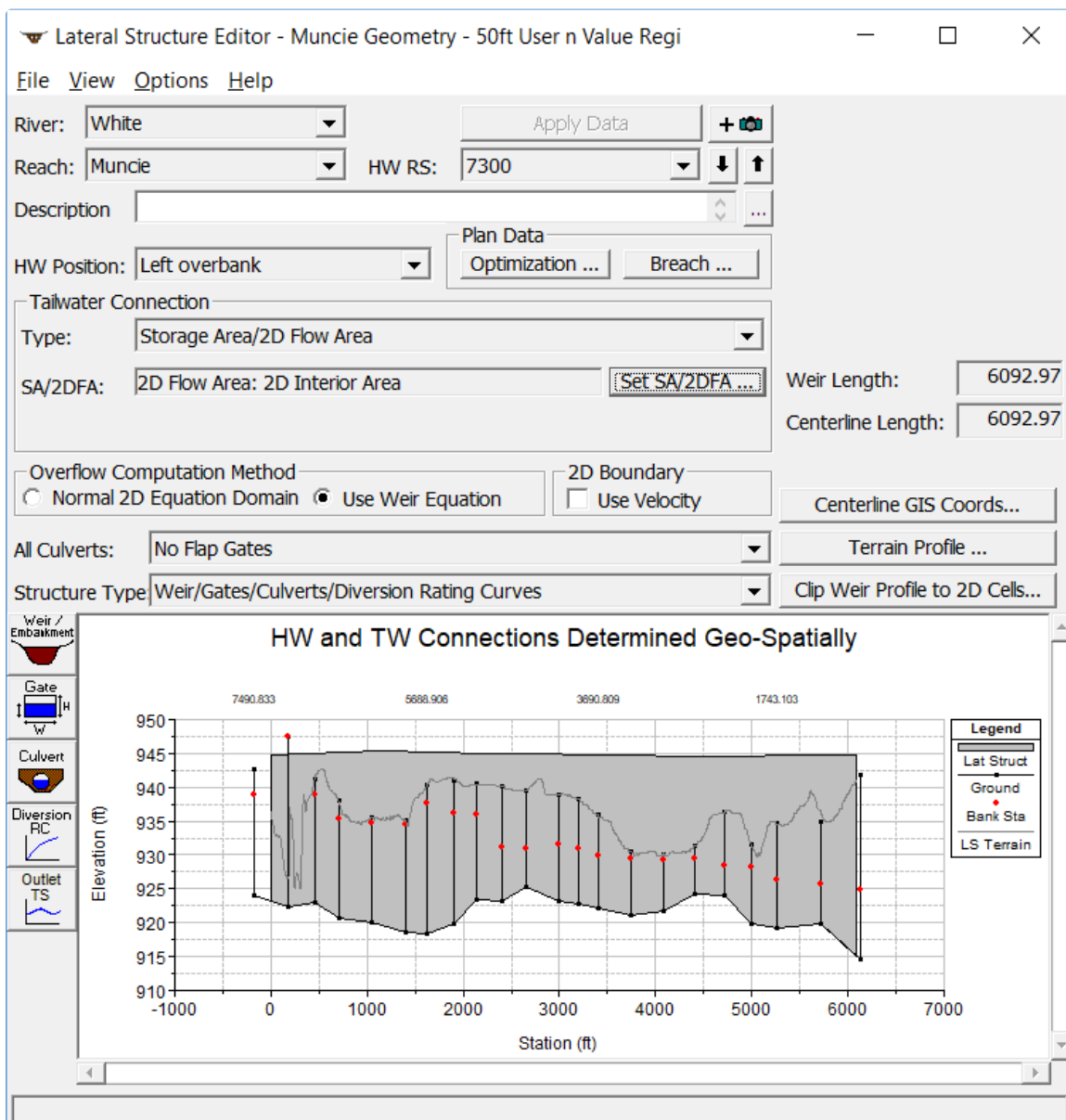
Figure 3-34. Downstream Levee (Lateral Structure) with a tailwater connection to the 2D flow area

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Shown in Figure 3-35, is the Weir Embankment editor, with the data for the Lateral Structure stationing and elevations, as well as access to the Lateral Structure linking to the 1D cross sections (HW Connections) and the 2D flow area Face Points (TW Connections).

Figure 3-35. Lateral Weir Embankment editor with data for the downstream levee and linked to the 2D flow area Face Points.

Lateral Structure Weir Coefficients

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

Table 3-1. Lateral Weir Coefficients

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

Note: The biggest problem HEC-RAS users have when interfacing 1D river reaches with 2D flow areas is using a weir coefficient that is too high for the situation being modeled. If the lateral structure is really just an overland flow interface between the 1D river and the 2D floodplain, then a weir coefficient in the range of 0.2 to 1.0 should be used to get the right flow transfer and keep the model stable. However, weir coefficients should be calibrated to produce reasonable results whenever possible.

Note: A second issue is weir submergence. When a lateral structure gets highly submerged, HEC-RAS uses a weir submergence curve to compute the flow reduction over the weir. The curve is very steep (i.e., the flow reduction changes dramatically) between 95% and 100% submergence. This can cause oscillations and possible model stability issues. To reduce these oscillations, user can have HEC-RAS use a milder loping submergence curve by going to the 1D "Computational Options and Tolerances" and setting the field labeled "**Weir flow submergence decay exponent"** to 3.0.

Directly Connecting an Upstream River Reach to a Downstream 2D flow area

Users can connect a 1D River Reach directly to a 2D flow area. When this type of boundary condition is used, the last cross section of the 1D River Reach must be lined up with the upstream boundary of the 2D flow area (i.e., the last cross section of the 1D reach is directly linked to the boundary of the 2D area, so they need to be at the same exact location). See the example shown in Figure 3-36.
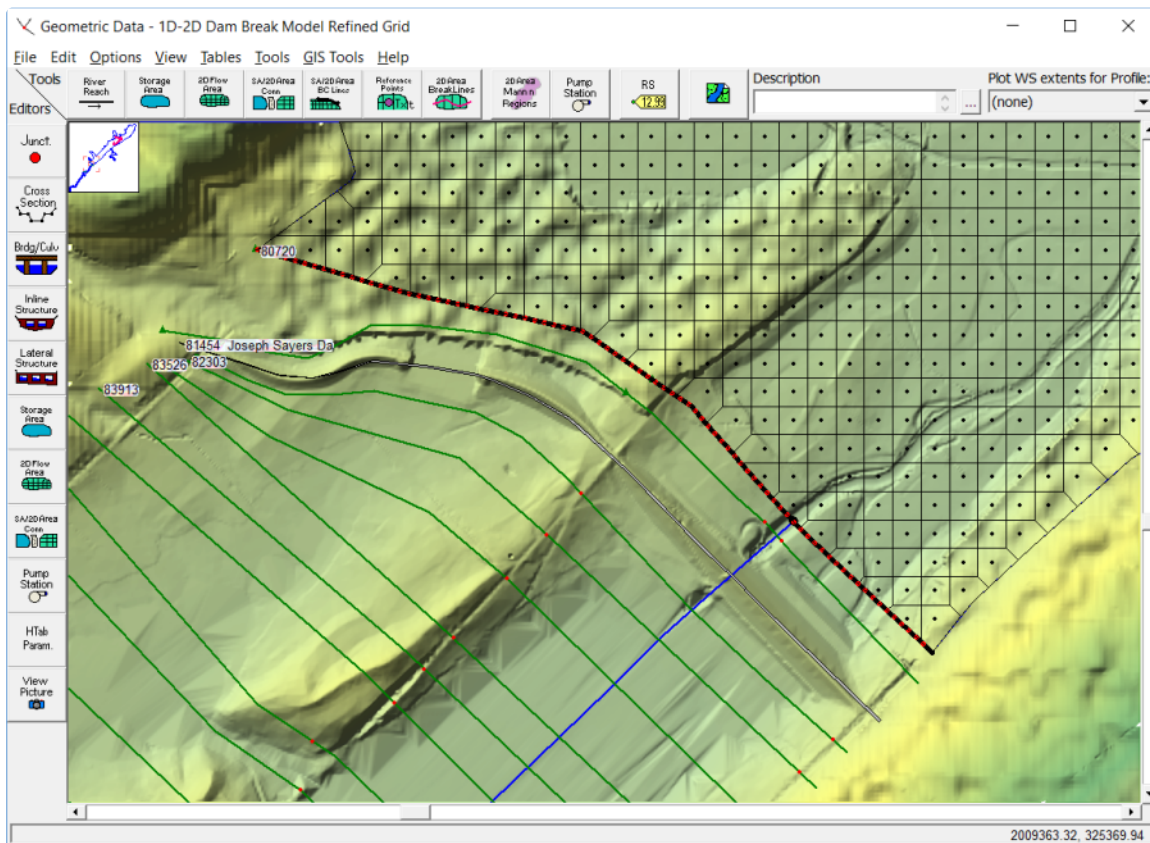
Figure 3-36. Example of an upstream 1D River Reach connected to a downstream 2D flow area.

For this type of boundary condition, the 1D River Reach passes flow each time step to the 2D flow area, while the stage in the cross section is based on the water surface elevation in the 2D cells that it is connected to. Flow is distributed to the 2D cells based on the conveyance distribution in the cross section, and the stationing of the cells linked to the cross section. The computed stage for the 1D cross section is based on computing a conveyance weighted stage from the connected boundary cells in the 2D flow area, and then forcing that stage on the 1D cross section each time step.

This type of boundary condition should only be placed in areas where the flow and stage are **highly one-dimensional in nature**. If the flow is not highly one-dimensional, you may run in to model stability issues with this type of boundary condition. User's can try turning on the option to allow the program to iterate back and forth between the 1D and the 2D computations during each time step, until the computed flow and stage at the boundary connection converges within a user specified tolerance. This may not solve the issue for areas that are highly two-dimensional (i.e., the water surface varies significantly). If the flow is highly one dimensional, 1D to 2D iterations are generally not necessary for this type of boundary condition.

To connect a 1D river reach to a 2D flow area, do the following:

- 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.

- Go to the **Edit** menu of the **Geometric Data editor**, and turn on the Option to **Move Points/Objects**.
- Move the last point of the stream centerline inside of the 2D flow area. The software will ask you if you want to connect the 1D River Reach to the 2D flow area. Select **Yes**.

This type of connection between a 1D cross section and a 2D area requires the following to be true:

- The location for this type of connection should be placed where the flow is highly one-dimensional (water surface is relatively horizontal and flow lines are perpendicular to the 1D cross section.
- The 1D cross section is exactly on top of the boundary of the 2D area that it is connected too.
- The terrain defining the 1D cross section must be exactly the same as the terrain along the boundary of the 2D flow area where it is connected to the 1D cross section.
- The Manning's roughness coefficients must be exactly the same spatially along the cross section and the 2D flow area boundary that it is connected too.

Once the 2D flow 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 the user how it is connected. The Black line represents the 2D cell Faces that the 1D cross section is connected to. A red line is drawn on top of the black line. The red line represents what HEC-RAS thinks is the exact location of where the 1D cross section starts and stops along the 2D Flow Area boundary. The red line is what HEC-RAS is using to figure out what portion of the 1D cross section corresponds to the 2D Flow Area Faces. That is all that needs to be done for the connection.

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: 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.

> ⓘ **NOTE:** when a 1D reach is connected to a 2D area, the 2D area must have water in it at the connection zone. If it does not the model will go unstable right away.

The 2D unsteady flow solver can handle "wetting" and "drying" of cells. However, the original finite difference 1D unsteady flow solver cannot handle "dry" cross sections. Therefore, a "wet" water surface at the 1D/2D boundary must be established at the beginning of the run and maintained during the simulation. If a restart file is not used, then HEC-RAS will compute the starting water surfaces in two distinct parts. The first part is the "initial condition" phase.

For the initial condition phase, water surfaces are determined for any 2D areas that start wet and the initial backwater is determined for all 1D reaches. Every 2D area that has a direct connection to a 1D reach must have enough water in it to provide a water surface at any and all of the 1D boundary connections. The user can specify a starting 2D water surface and/or use the 2D Initial Conditions Ramp Up option (This is highly recommended). To set the 2D Initial Conditions Ramp Up option, go to the **Unsteady Flow Analysis** window, then Select **Calculation Options and Tolerances** from the **Options** menu. Select the **2D Flow Options** Tab. Enter a time in hours for each of the 2D flow areas in the filed labeled **Initial Conditions Time (hrs)**. This is the time each 2D flow area will run on

its own at the beginning in order to establish a good initial conditions within that 2D Flow Area.

During this phase, the program may cycle between 2D areas and 1D reaches in order to determine the flows and water surfaces at the boundaries. If the upstream end of a 1D reach is connected directly to a 2D area and the user has specified an initial flow for this reach, then the program will use that flow during the initial conditions. If an initial flow is not specified, then the program will attempt to determine this flow automatically. If the downstream end of a 1D reach is connected, then there is nothing for the user to specify. The program will try to determine the water surface in the 2D area first which will allow for a stage boundary for the 1D reach. If this is not possible, a critical depth boundary may be initially used.

The second part of determining the starting water surfaces is the optional warm-up period. This is the same warm-up period that 1D has always had except that it now also includes the 2D areas. As explained above, there must be a valid water surface at the 1D/2D boundaries before the warm-up period and/or the main simulation starts.

Directly Connecting an Upstream 2D Flow Area to a Downstream River Reach

Users can directly connect an upstream 2D flow area to a downstream 1D River Reach. When this type of boundary condition is used, the first cross section of the 1D River Reach must be lined up with the downstream boundary of the 2D flow area (i.e., the first cross section of the 1D reach is directly linked to the downstream boundary of the 2D area, so they need to be at the same exact location). See the example shown in Figure 3-37.
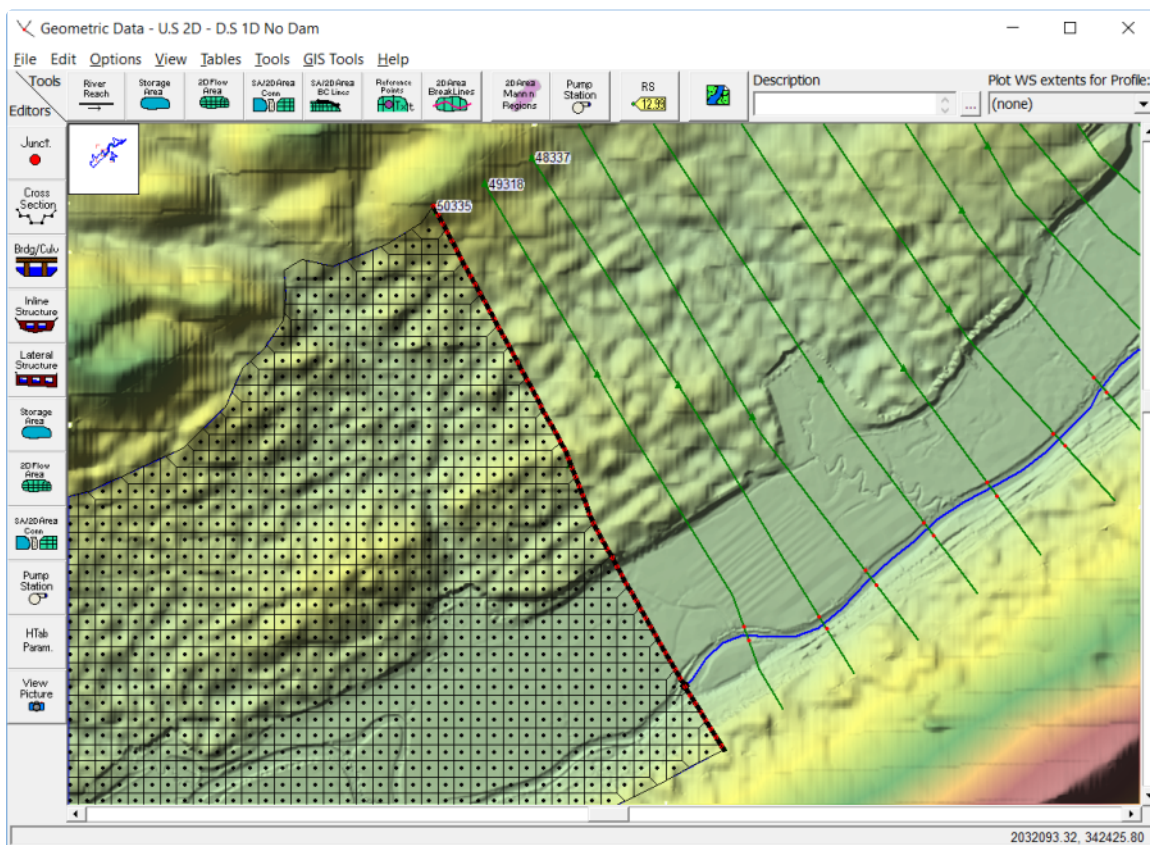
Figure 3-37. Example of an upstream 2D flow area connected to a downstream 1D River Reach.

For this type of boundary condition, the 2D flow area passes flow each time step to the 1D river reach, while the stage in the 2D flow area is based on the stage in the 1D cross section that it is connected too. Flow is passed to the 1D section by adding all of the flows leaving the 2D cells at the boundary for each time step. The stage for the 2D flow area downstream boundary is set to the computed stage of the 1D cross section each time step.

This type of boundary condition should only be placed in areas where the flow and stage are highly one-dimensional in nature. If the flow is not highly one-dimensional, the user will need to turn on the option to allow the program to iterate back and forth between the 1D and the 2D computations during each time step, until the computed flow and stage at the boundary connection does not change within a user specified tolerance. Even if the flow is highly one-dimensional, 1D to 2D iterations may be necessary for this type of boundary condition, depending on how quickly the flow and stage are changing, compared to the user selected computation interval.

To connect an upstream 2D flow area directly to a downstream 1D River Reach, do the following:

- Draw the 2D flow area polygon such that the outer boundary at the downstream end is right on top of the first cross section of the 1D river reach.
- Go to the **Edit** menu of the **Geometric Data editor**, and turn on the Option to **Move Points/Objects**.

- Move the first point of the stream centerline inside of the 2D flow area. The software will ask you if you want to connect the 1D River Reach to the 2D flow area. Select **Yes**.

This type of connection between a 2D area and a 1D cross section requires the following to be true:

- The location for this type of connection should be placed where the flow is highly one-dimensional (water surface is relatively horizontal and flow lines are perpendicular to the 1D cross section.
- The 1D cross section is exactly on top of the boundary of the 2D area that it is connected too.
- The terrain defining the 1D cross section must be exactly the same as the terrain along the boundary of the 2D flow area where it is connected to the 1D cross section.
- The Manning's roughness coefficients must be exactly the same spatially along the cross section and the 2D flow area boundary that it is connected too.

Once the 2D flow 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 the user how it is connected. The Black line represents the 2D cell Faces that the 1D cross section is connected to. A red line is drawn on top of the black line. The red line represents what HEC-RAS thinks is the exact location of where the 1D cross section starts and stops along the 2D Flow Area boundary. The red line is what HEC-RAS is using to figure out what portion of the 1D cross section corresponds to the 2D Flow Area Faces. That is all that needs to be done for the connection.

> ⓘ **Note:** When a 2D area is connected to a 1D River Reach, the user will need to define the initial conditions of the 1D Reach and 2D area. Initial conditions for an upstream 2D flow area cannot be dry. The initial conditions for an upstream 2D area can be: set to a single water elevation; set with 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.

For the initial condition phase, water surfaces are determined for any 2D areas that start wet and the initial backwater is determined for all 1D reaches. Every 2D area that has a direct connection to a 1D reach must have enough water in it to provide a water surface at any and all of the 1D boundary connections. The user can specify a starting 2D water surface and/or use the 2D Initial Conditions Ramp Up option (This is highly recommended). To set the 2D Initial Conditions Ramp Up option, go to the **Unsteady Flow Analysis** window, then Select **Calculation Options and Tolerances** from the **Options** menu. Select the **2D Flow Options** Tab. Enter a time in hours for each of the 2D flow areas in the filed labeled **Initial Conditions Time (hrs)**. This is the time each 2D flow area will run on its own at the beginning in order to establish a good initial conditions within that 2D Flow Area.

Connecting a 2D Flow Area to a Storage Area using a Hydraulic Structure

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**)**.** See the example in Figure 3-38 below.
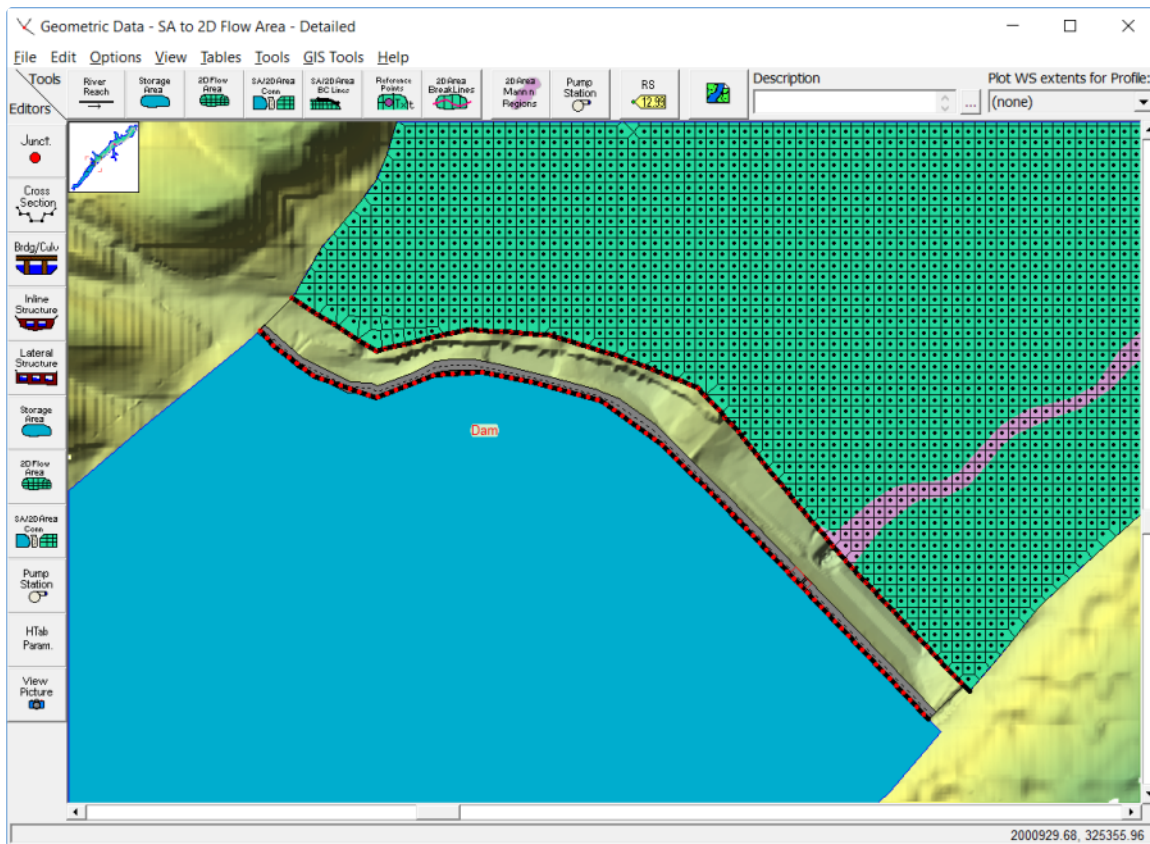
Figure 3-38. Example of a Storage Area connected to a 2D flow area

- Draw the storage area polygon right up to the edge of the hydraulic structure. This can be as close to the hydraulic structure as desired 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 the user wants 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.
- Select the drawing tool at the top of the Geometric Data 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 for a label to define the hydraulic structure. See the red line shown in Figure 3-38.

- 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 Figure 3-39.
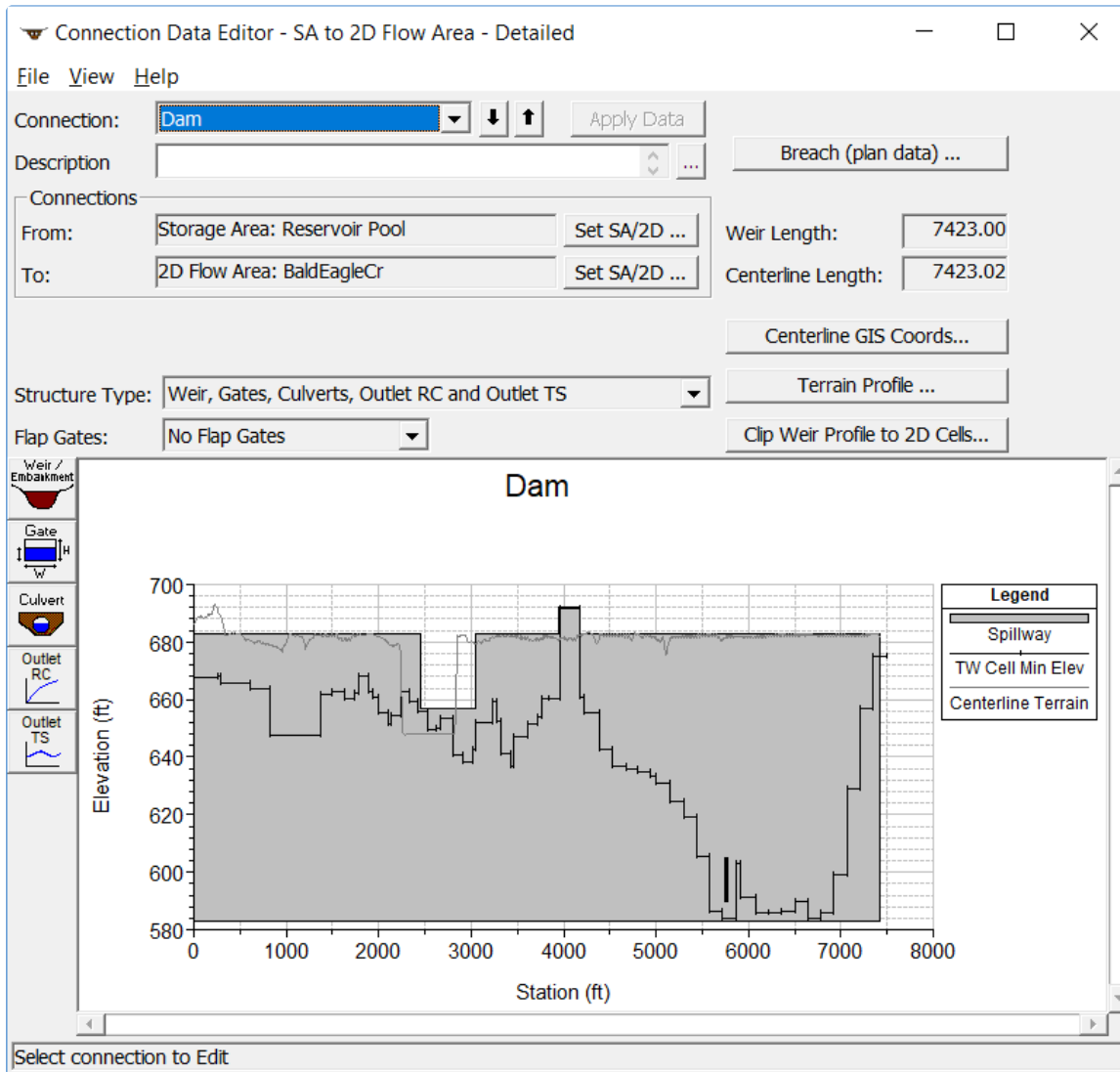
Figure 3-39. SA/2D Area Hydraulic Connection editor.

- 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 Figure 3-39, there is an embankment with an emergency spillway defined, and there are also two low flow gates defined.

Geospatial coordinates can be entered can be entered for any of the outlet types avasilable in the SA/2D Area Connection editor (ie. Culvert, gates, rating curves, and time series outlet). This will allow the user to specify a location within the 2D area that you want that specific outlet to connect to, such as an interior cell instead of one of the boundary cells.

This is all that is needed for this type of hydraulic connection. HEC-RAS automatically computes the stationing along the centerline drawn for the hydraulic structure, and then lines it up with the outer boundary of the 2D flow area based on their spatial location. The connection to the Storage Area is very simple, since it can only have a single water surface elevation inside the storage area each time step.

In the example shown in Figure 3-38, 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 in Figure 3-38, 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.To hydraulically connect a Storage Area to a 2D flow area, do the following:

Connecting a 2D Flow Area to another 2D Flow Area using a Hydraulic Structure

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**)**.** See the example below in Figure 3-40.
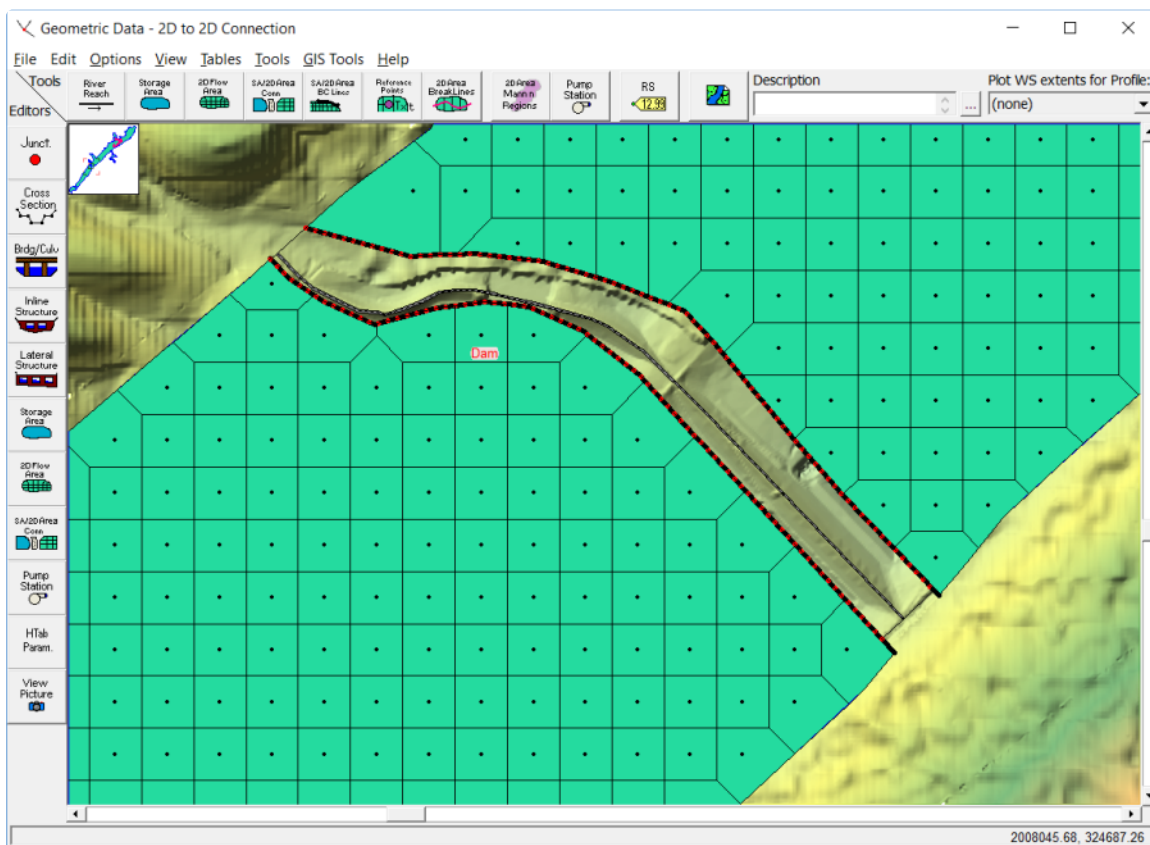
Figure 3-40. Example of connecting one 2D flow area to another 2D flow area with a Hydraulic Structure.

- 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 the user wants to be used in the hydraulic calculations of flow over and through the hydraulic structure.
- Select the drawing tool at the top of the Geometric Data 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 the user for a label to define the hydraulic structure. See the red line shown in Figure 3-40.
- 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 Figure 3-41.
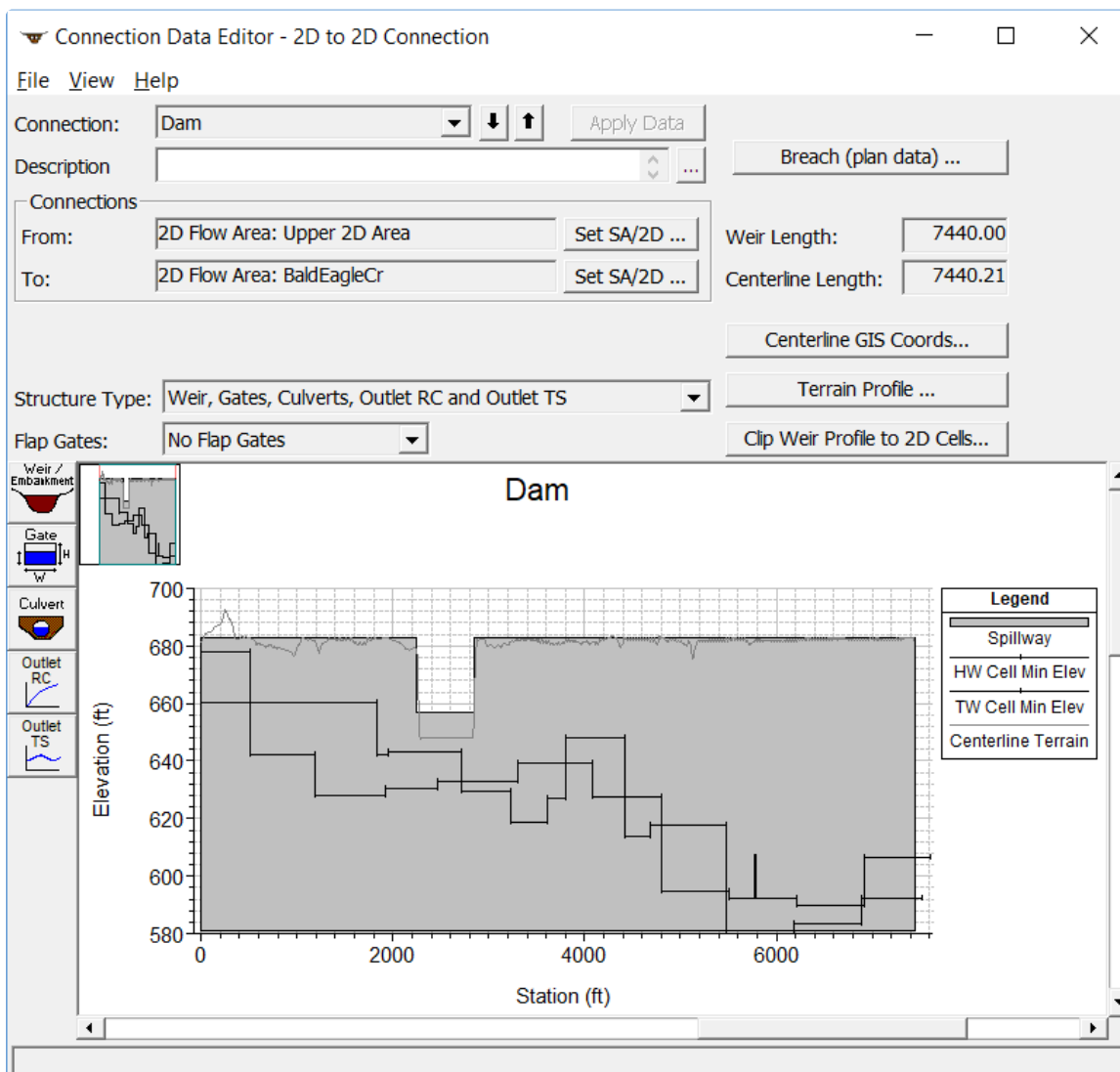
Figure 3-41. SA/2D Area Hydraulic Connection editor.

- On the **SA/2D Area Conn** editor set the **From** and **To** by selecting the buttons labeled **Set SA/2D Area**. In this example the upstream 2D flow area labeled "Upper 2D Area" 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 Figure 3-45, there is an embankment with an emergency spillway defined, and there are also two low flow gates defined.

This is all that is needed for this type of hydraulic connection. HEC-RAS automatically figures out the stationing along the centerline drawn for the hydraulic structure, and then lines it up with the outer boundary of the upstream and downstream 2D flow areas based on their spatial location.

In the example shown in Figure 3-40, 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. The hydraulic connection between the two 2D flow areas is a dam in this example. The downstream 2D flow area is being used to model the hydraulics of the flow downstream of the dam.To hydraulically connect one 2D flow area to another 2D flow area, do the following:

Multiple 2D Flow Areas in a Single Geometry File

HEC-RAS has the ability to have any number (within the computer's memory limitations) of separate 2D flow areas within the same geometry file. Multiple 2D flow areas can be added in the same way as storage areas. Hydraulic connections can be made from 2D flow areas to 1D Elements, as well as between 2D flow areas. See the example in Figure 3-42.
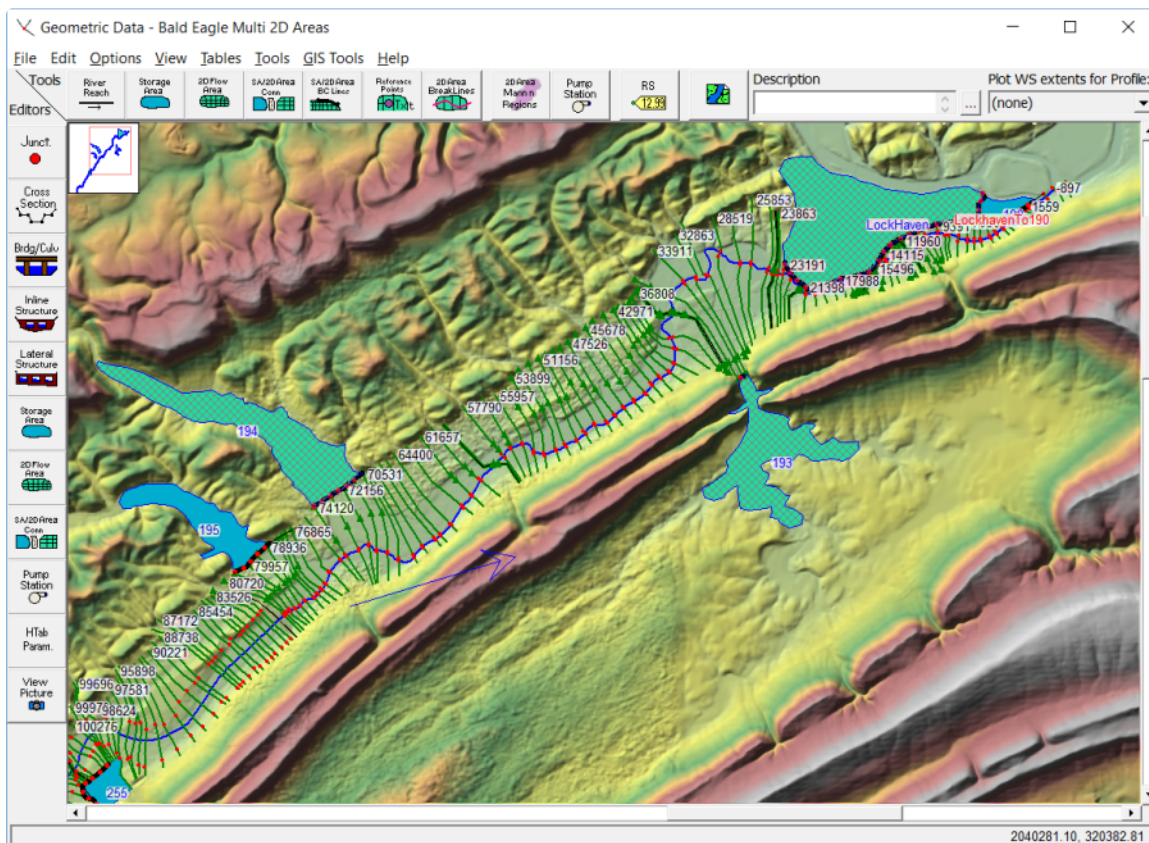

**Figure 3-42. Multiple 2D flow areas in a single geometry file.**

Hydraulic Structures Inside of 2D Flow Areas

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 acts just like a breakline, in that users can align the cells along the structure, as well as control the cell size along the structure as shown in the figure below. 2D Area Connections can be used to model a **Weir** with Gates and Culverts or as a **Bridge**.

Weir, Gates, Culverts, Outlet RC and Outlet TS
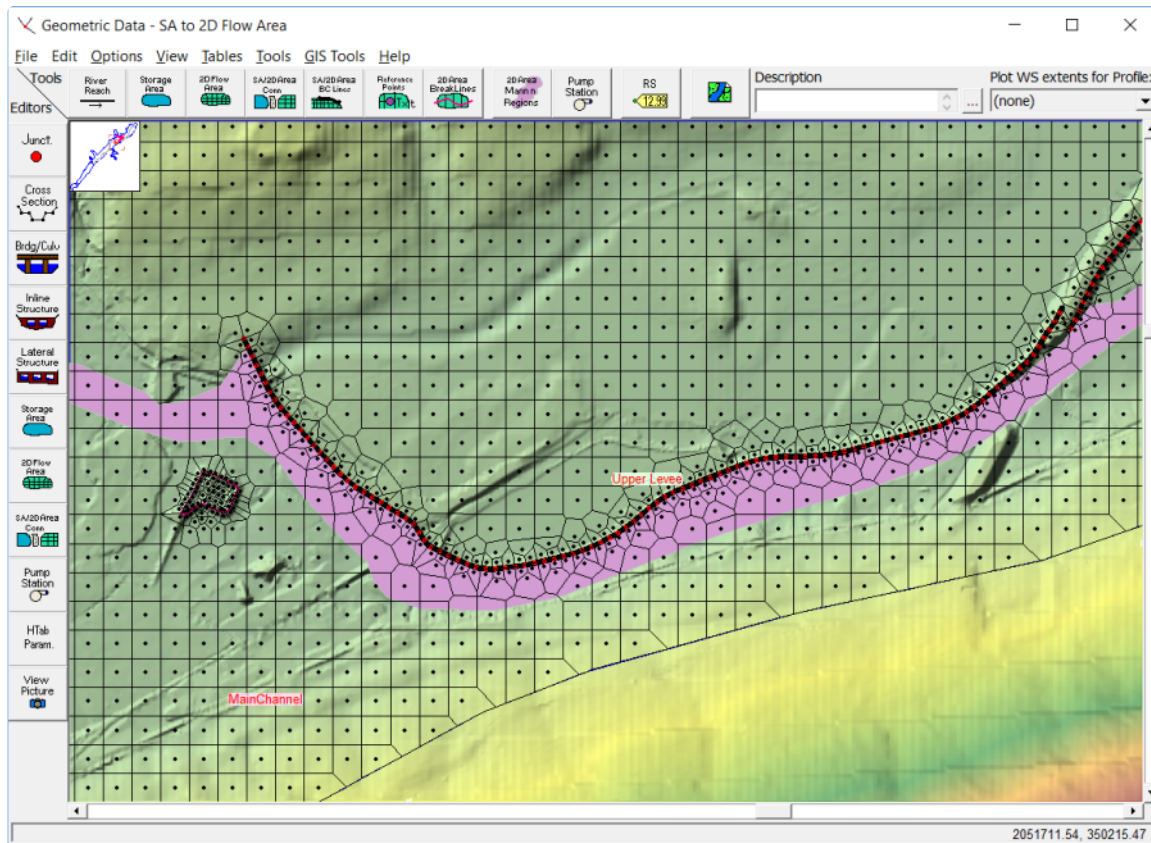
The SA/2D Hydraulic Connection can be used to model all kinds of structures inside of a 2D Flow Area. Flow going over top of the structure can be modeled with either a weir equation, or the full 2D equations. Additionally there are options to add gates, culverts, rating curves, and time series of flows for independent outlets. Any combination of these outlet types can be used. Additionally, users can now specify an X and Y geospatial coordinates for the upstream and downstream ends of each hydraulic outlet (culverts, gates, rating curves, and time series outlets).

To add a hydraulic structure inside of a 2D flow area, do the following:

- First, select the Drawing tool at the top of the Geometric Data editor labeled **SA/2D Area Conn**. Then draw a line directly down the center of the hydraulic 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 represent 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 for a label to define the name of the hydraulic structure. This structure centerline can also be drawn from HEC-RAS Mapper.
- Next, modify the 2D flow area mesh so that the faces of the cells go along the centerline of the top of the hydraulic structure. To do this, Left Click on the Hydraulic structure centerline and select the option called **Edit Internal Connection (Break Line) Cell Spacing**. A window will appear in which it will allow the user to

enter a Minimum and Maximum cell spacing to be used for creating cells along the centerline of the hydraulic structure. By default it will use the nominal cell size for spacing cells along the hydraulic structure centerline, however, the user can change the cell spacing along the structure to get more detail along the hydraulic structure. This step is option, but generally a good idea to establish cells along the structure with an appropriate size. Next, left click on the hydraulic structure centerline and select the option called **Enforce Internal Connection as Break Line in 2D Flow Area**. When this option is selected, the software will use the structure centerline and the cell spacing information to create cells along the centerline of the structure that have faces exactly along the centerline. This is a necessary step in order to get the 2D mesh correctly developed for incorporating the hydraulic structure data (Station-elevation data; culverts, gates, breaches, etc…)

> ⓘ The 2D Connection must span at least 1 cell face. A runtime error message will be listed with the structure name and the computations will stop, if the structure is not at least 1 cell wide.

For example, as shown in the figure above, a levee is being modeled inside of a single 2D flow area as a hydraulic structure. The 2D flow area mesh was modified to have cells on both sides of the levee lined up on top of the levee. This requires adding small enough cell spacing along the hydraulic structure centerline to get the correct detail. However, you do not want the cells to be so small that you have cells going down the levee embankment, such that these cells would be very steep. Steep cells on the back side of a levee could cause the model to have stability issues when flow overtops the levee (i.e., the flow may appear to be going over a water fall). So make the cells large enough to encompass the levee embankment slope and a little of the area away from the toe of the levee.

- 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 2D Connection editor shown in the figure below.
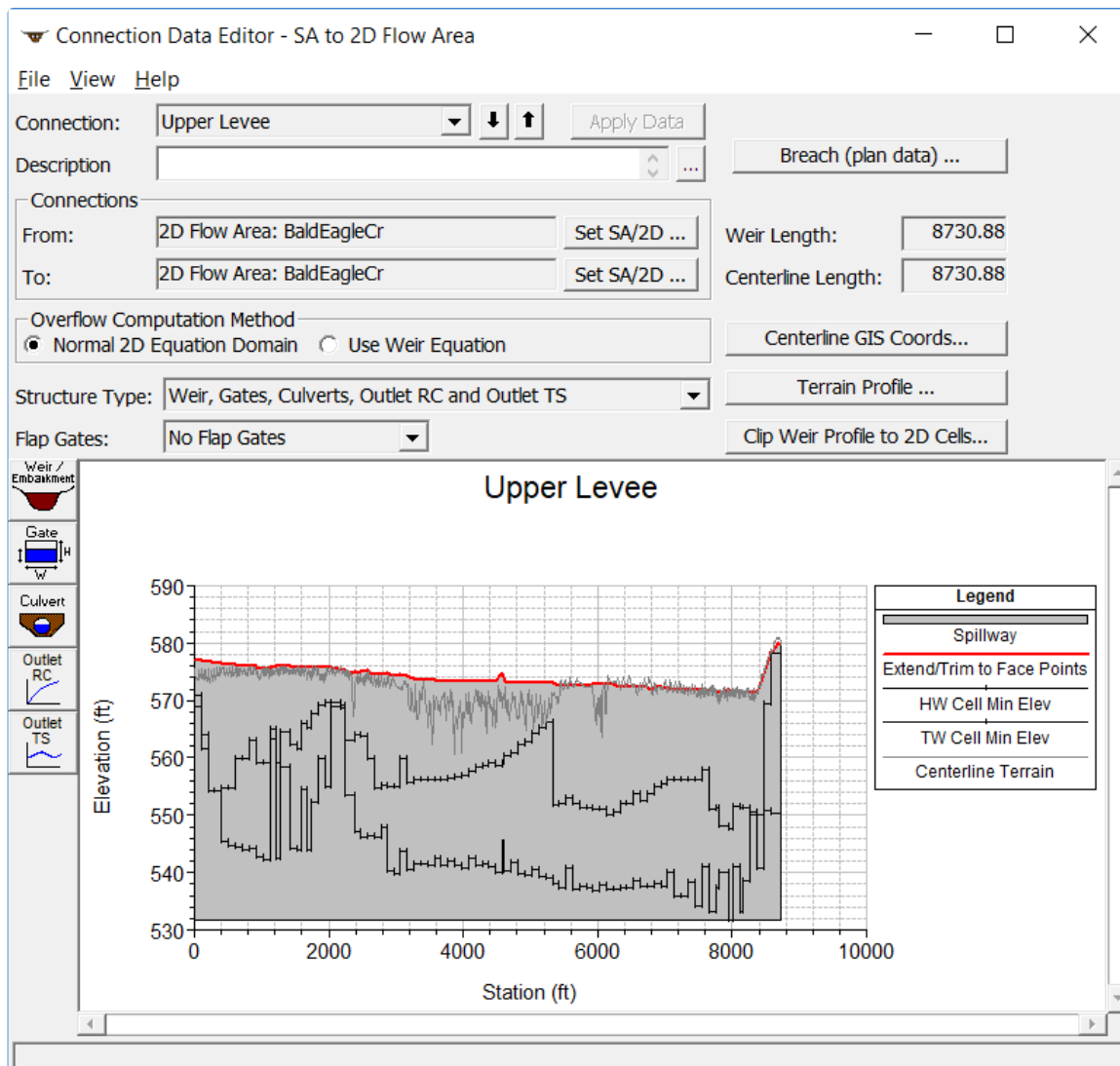
If the structure being modeled is high ground (as shown in the layout above), choose the **Weir, Gates, Culverts, Outlet RC and Outlet TS** structure type. The user can define station elevation data for the structure that is the same or higher than the natural ground using the **Weir/Embankment Editor**. Additionally, culverts, gated openings, rating curves, and time series outlets can be added into the hydraulic structure. The user entered weir line (station/elevation data), culverts, and gate openings, are not allowed to be lower than the minimum elevation of the cells they are connected to. However, a breach minimum elevation can go lower than the cells it is connected too (you will get a warning about this when you do it though). If a breach goes lower than the cells it is connected too, HEC-RAS will automatically lower the cell elevations (both upstream and downstream) dynamically as the breach is eroding down below the ground elevations. However, it will only lower the cells immediately next to the structure centerline on both sides.

The editor shows to black lines that represent the minimum elevations of the cells on each side of the internal hydraulic structure. These lines show the user both the elevation and stationing of how the hydraulic structure is connected to the 2D cells on each side of the structure. Users can click on any of these lines and get the cell number of the connection, as well as the stationing (stationing along the hydraulic structure) and elevation of the cell. Additionally the cell will be highlighted on

the geometric data editor, so you can see where that cell lives spatially.

The user has the option for flow going over the top of the structure (Overflow Computation Method) to be computed by either the **Weir Equation** or the **Normal 2D Equation Domain**. If **Weir Equation** is chosen, all flow over the top of the hydraulic structure is computed with the weir equation. If **Normal 2D Equation Domain** is selected, the flow over the top of the structure is computed as normal 2D Flow between cells. In either case, the flow through the culverts and gates is computed separately and linked between the cells on each side of the culvert or gate. For a highly submerged structure, where the flow is not behaving like weir flow, the 2D equation will generally give better results, but the 2D equation is not as appropriate for traditional weir flow.

> ⚠ Warning: The "Normal 2D Equation Domain" option should NOT be used if the height of the structure is high, such that the water flowing over the structure will go into free fall (like a waterfall). The 2D equations cannot be solved in a stable solution through a waterfall. For this situation the user will need to use the "Weir Equation" option. We plan to investigate having the program automatically switch between the weir equation and the 2D equation based on the flow condition.

To enter the structure embankment data, select the **Weir/Embankment** button. The embankment editor will come up, and the user can enter station elevation data that is either the same as the ground profile, or they can enter elevations that are higher than the ground profile in order to represent a structure that is not accurately represented by the terrain data.

Geospatial Coordinates for Hydraulic Outlets Connected to 2D Flow Areas

Users can enter geospatial coordinates for any of the hydraulic outlets that are connected to a 2D flow area (Lateral Structures and SA/2D Hydraulic Connections) or for hydraulic structures inside of a 2D Flow Area. The example SA/2D Area Connection displayed in Figure 3-45 shows a levee with two culverts going through the levee. Note that the culverts cross over multiple cells on the inside of the levee. This is accomplished by the fact that users can now enter X and Y coordinates for the centerlines of the culverts, as well as gates, rating curves, and flow time series outlets.
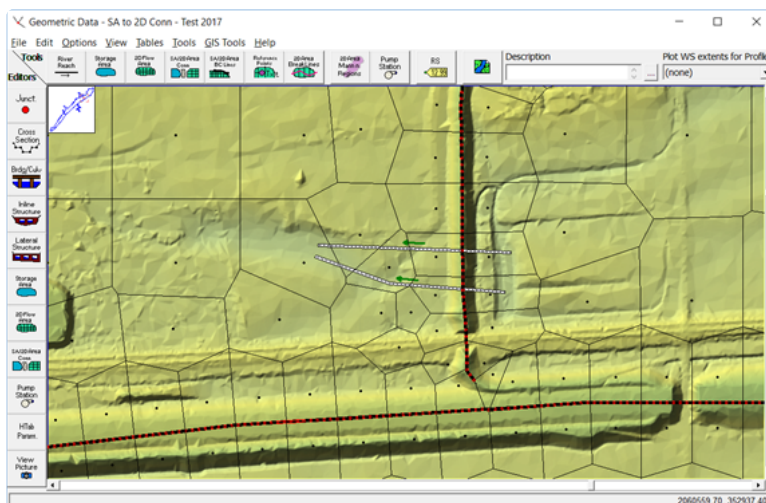
From the **Geometric Data** editor, click the [ ] **SA/2D Area Conn** button and the updated SA/2D Area **Connection Data Editor** will open, as shown in Figure 3 46.
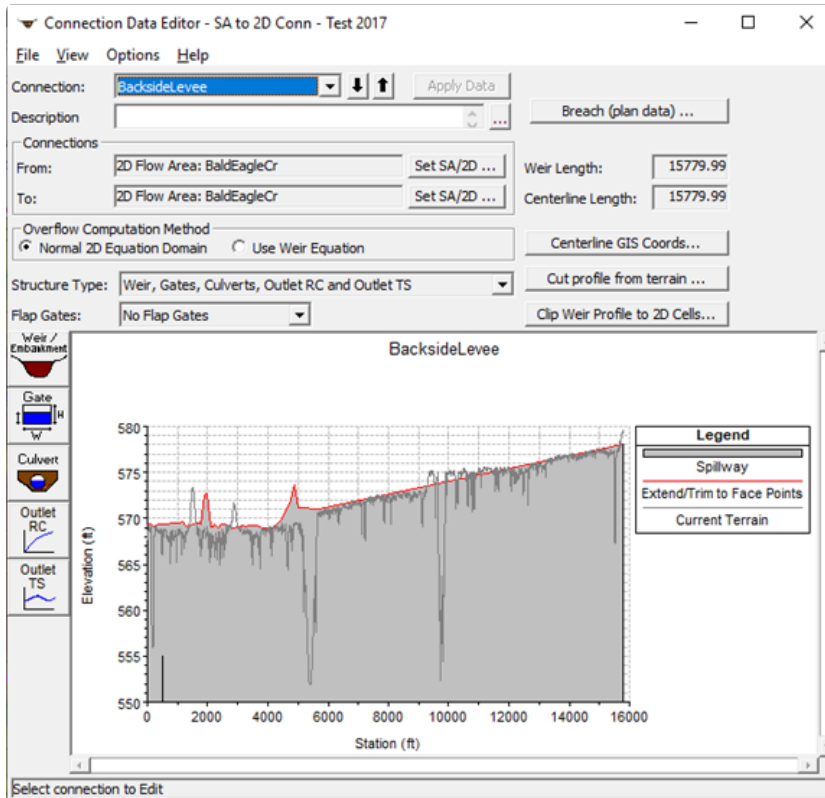
Figure 3-46. SA/2D Area Connection editor with Levee and Culverts

As shown in Figure 3 46, users can define several hydraulic opening types (spillways/weirs, gates, culverts, rating curves, and time series outlets) utilizing the buttons on the left side of the window and all within the same structure. The water going over the structure can be modeled with a weir equation or with the solution of the normal 2D Flow equations (Full St. Venant or Diffusion wave). Culverts can have flap gates on either side, or no flap gates. In the example shown in Figure 3-45 and

Figure 3 46, there is a culvert group with two culvert barrels. If the user selects the [ ] **Culvert** button on the left, the **Culvert Data Editor** will open (Figure 3 47).

Figure 3-47. Culvert Data Editor for the SA/2D Area Connection.

To enter spatial coordinates for a culvert, press the button on the lower left portion of the editor labeled "**Individual Barrel Centerlines**" (*red box* in Figure 3 47). This button opens the **Edit GIS Data Table** editor (Figure 3 48), for entering the X and Y coordinates for the centerline of each culvert barrel added to the model, which allow users to view the barrels spatially. **[Note:** Separate centerlines must be added even for identical barrels within the same culvert group, and the barrels may also be connected to different cells.**]**

All Culvert centerlines (as well as gates, rating curves, and flow time series outlets), must be drawn from upstream to downstream. Keep in mind that is how the original centerline of the SA/2D Area Connection is drawn which defines upstream and downstream. Therefore, when users draw the centerline for the SA/2D Area Connection, it is drawn from left to right looking in the downstream direction. Based on that convention, when the centerlines for the hydraulic outlets (culverts, gates, rating curves, etc.) are drawn, yet again the centerlines must be drawn from the upstream side of the structure to the downstream side of the structure. For the example provided in Figure 3 46, the structure being used to model the levee was drawn from the south end of the levee to the north end of the levee. Therefore, the culverts were drawn from the right hand side of the structure (head water) to the left hand side of the structure (tailwater).

If the user presses the button labeled "**Individual Barrel Centerlines**" from the **Culvert Data Editor**, the **Edit GIS Data Table** centerline coordinate editor opens (Figure 3 48).
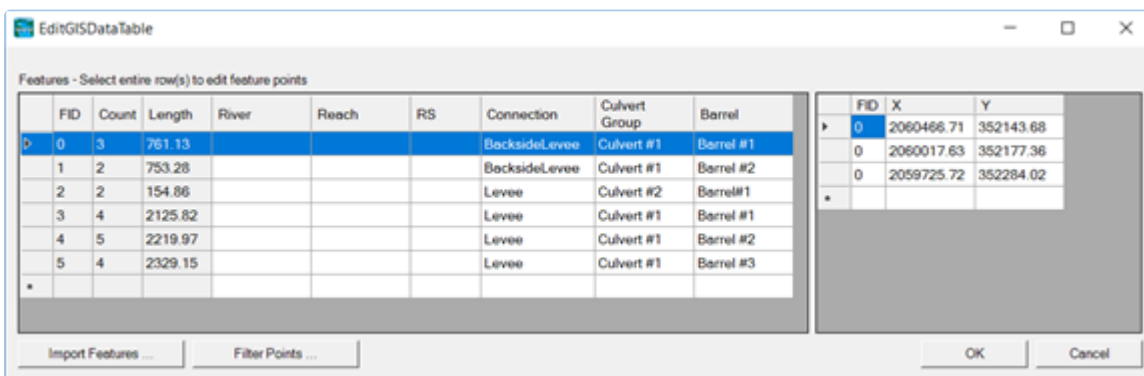
Figure 3-48. Hydraulic Structure Centerline Data Table

As shown in Figure 3 48, the feature centerline table contains the centerline X and Y coordinate data for all of the structures in the model. When the **Edit GIS Data Table** editor is opened, it will highlight the culvert that was open and selected in the **Culvert Data Editor**. To use this editor, from the Features table (located on the left of the editor), select a single culvert barrel (highlight it), and then past in the X and Y coordinates for the barrel into the data table (on the right hand side of the editor). **Hint:** The easiest way to define the culvert barrel X and Y centerline coordinates is to go back to the **Geometric Data** editor, hold down the **Ctrl** key, and digitize the culvert barrel centerline from the headwater side of the structure to the tailwater side of the structure. This digitized line can be copied to the clipboard from the **Measure Line** editor that pops up once digitizing the line is complete. Once all of the barrel coordinates have been entered, close all of the SA/2D Area Connection windows, and the digitized culvert(s) will appear in the **Geometric Data** editor window, similar to what is shown in Figure 3-45. Additionally, there is an option to import the culvert X and Y centerline coordinates at the bottom of the editor.

> ⓘ **Note:** In HEC-RAS, the process for adding centerline X and Y coordinates for individual hydraulic outlets (gates, rating curves and flow time series, etc.) is exactly the same as described above for culverts.

Modeling Bridges Inside 2D Flow Areas

Users can model bridges directly inside of 2D flow areas. Bridges inside of 2D flow areas can handle the full range of flow regimes, from low flow to pressure flow, and combined pressure flow and flow going over top of the bridge deck or roadway. Users enter bridge data inside of 2D Flow Areas similarly to the modeling of bridges in a 1D model. Additionally, users have the same low flow (energy, momentum, and Yarnell) and high flow (energy and pressure/weir) bridge modeling approaches available for 1D bridge modeling (except the WSPRO low flow method is not available for 2D modeling).

The HEC-RAS software takes the user input bridge data and modeling approaches, then develops a family of rating curves for the bridge, just as is does for 1D modeling. However, for 2D modeling, the bridge's curves are used to obtain a water surface difference through the bridge for each set of cells

being used to model the bridge. This water surface difference is then equated to a force. That force is distributed and put into a special version of the momentum equation for each set of cells spanning the bridge centerline. So instead of calculating friction forces, pressure forces, and spatial acceleration forces, these forces are obtained from the bridge curves. Then the 2D equations are solved as they are normally solved at any cell/face in the model. This approach used for 2D modeling allows for equivalent forces to be computed for low flow, pressure flow, and combined pressure flow/weir flow, or even low flow/weir flow.

The amount of force given to each cell is based on the percentage of the total flow passing through that particular set of cells. This 2D modeling approach allows for varying flow, water surface, and velocity at each of the cells around the centerline of the bridge opening. Therefore, the flow is still computed as two-dimensional flow through and over top of the bridge. Flow can pass at any angle through the bridge opening based on the hydraulics of the flow and the number of cells being used to represent the bridge opening.

To model a bridge inside of a 2D Flow Area, the **SA/2D Area Conn** geometry drawing tool is used. The basic steps for adding a bridge to a 2D model are the following:

1. Draw a centerline for the bridge opening/embankment using the **SA/2D Area Conn** drawing tool in the Geometric Data editor, or by using the editing tools in RAS Mapper. **The bridge centerline must be drawn from left to right looking downstream.**
2. Develop an appropriate mesh (cell size and orientation) for the bridge, using the structure mesh controls. Some hand editing may be required depending on the bridge and what else is near the bridge (i.e., levee, another bridge, railroad tracks, road, etc…)
3. Enter the bridge data (deck and roadway; distance from upstream bridge deck to outside cross section's piers; abutments; bridge modeling approach; Manning's n values for the 1D bridge cross sections; and hydraulic tables controls (HTAB) into the **SA/2D Area Conn** editor.
4. Pre-process the geometry to create the bridge curves. Review the bridge family of rating curves for hydraulic accuracy.

Run the model and review the results. Make any necessary changes to the data to improve the results.
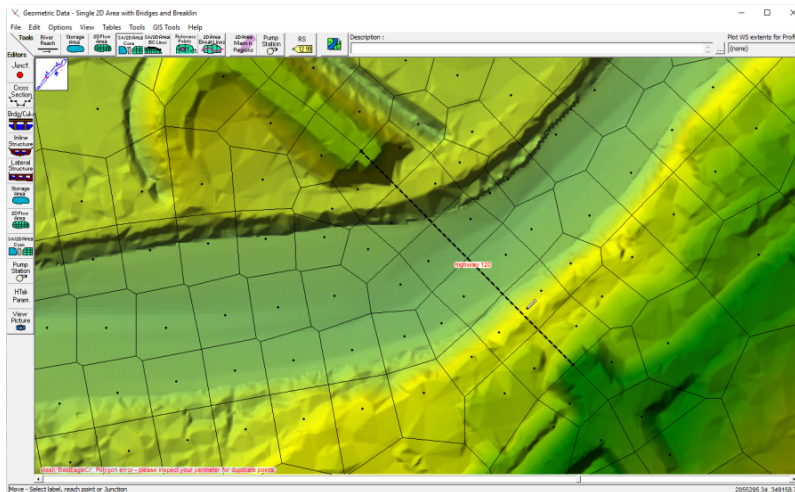
Draw the Bridge Centerline

To add a bridge inside of a 2D flow area, open the **Geometric Data** editor (accessed from the HEC-RAS main window by clicking the **Edit | Geometric Data** menu command) and select the **SA/2D Area Conn** drawing tool, from the tool bar across the top of the editor. Draw the centerline of the bridge from left to right looking downstream. In the example shown in Figure 1, the bridge centerline is only laid out for the bridge opening.

The user has the choice of just modeling the main bridge opening with this structure (including the bridge abutments), or also including the entire road embankment (left and right of the bridge opening). If the approaches for the entire roadway are included in the structure, then the family of rating curves will include flow over the left and right roadway approaches, as well as flow through and over the bridge. However, if the user chooses to model just the main bridge opening with the structure, then the family of bridge rating curves will only include flow going through and over the main bridge opening.

The left and right embankments can be modelled as either normal 2D flow cells and faces (solving the general 2D equations), or separate hydraulic structures can be laid out for the left and right roadway approaches. Using separate hydraulic structures for the roadway approaches allows the

user to change the elevation of the roadway, instead of using the raw terrain elevations; furthermore, using separate hydraulic structures allows the weir equation to compute the overflow (if desired) and breaching of the embankments. Additionally, these separate SA/2D hydraulic connections can be used to breach the roadway embankments, if desired.

Example layout of a 2D bridge centerline shown as the dark dashed line.

Entering the Bridge Data

To enter the bridge data, either left click on the bridge centerline and choose **Edit Connection**, or open the **SA/2D Area Conn** editor and select the correct structure. The figure below provides an example view of the first time the **SA/2D Connection Data Editor** is opened for a new **SA/2D Area Conn**.
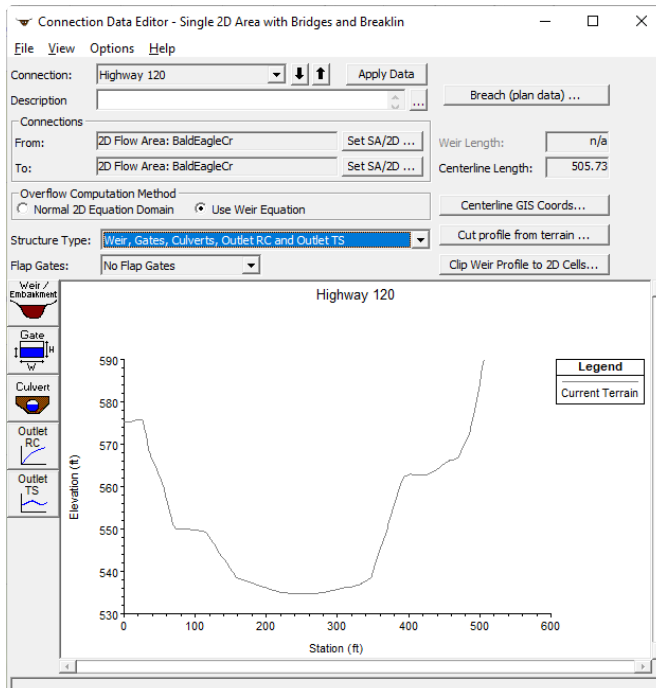
Example view of the Connection Data Editor for an internal structure of type Weir, Gates, Culverts, Outlet RC and Outlet TS.

From the **SA/2D Connection Data Editor**, the first step is to change the **Structure Type** from the default selection (Weir, Gates, Culverts, Outlet RC and Outlet TS) to a **Bridge (Internal to 2D Flow Area)**. The **SA/2D Connection Data Editor** updates as displayed below.
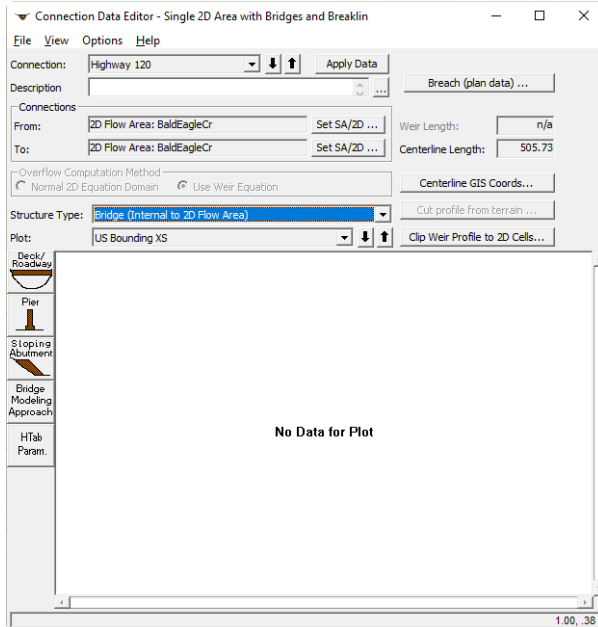
Example view of the SA/2D Connection Data Editor with the structure type as Bridge (Internal to 2D flow Area) before entering the bridge deck and pier geometry.

The **SA/2D Connection Data Editor** with the **Bridge (Internal to 2D Flow Area)** Structure Type selected, contains data editor icons (located left of the Plot window) for entering a **Deck/Roadway**, **Pier**, **Sloping Abutment**, the **Bridge Modeling Approach** and the **HTab Param.** (parameters).

The first step is to enter the Bridge **Deck/Roadway** data. Click the **Deck/Roadway** icon to open the **Deck/Roadway Data Editor**.

Example Deck/Roadway Data editor showing the bridge geometry.

As shown in figure above, the user must enter the **Distance** (this is the distance from the upstream side of the bridge deck to the cross section upstream outside of the bridge; the **Width** of the bridge deck in the direction of flow; a **Weir Coefficient** for flow going over the road way; and the **Station** (distance from left to right along the bridge deck/roadway)**, High Chord,** and **Low Chord** elevations for the upstream and downstream side of the bridge deck.

The **U.S Embankment SS** (upstream embankment side slope) and **D.S Embankment SS** (downstream embankment side slope) are optional, as the values entered are only used for plots. By default, the **Weir Crest Shape** is set to "Broad Crested," which is appropriate for a bridge deck/ roadway. The **Max Submergence** value is the submergence percentage at which HEC-RAS will stop using the weir equation and will transition to the energy balance method for developing the bridge curves under high submergence. Click **OK** to save the deck or roadway data and return to the **Connection Data Editor**.

The next step is to enter any piers or abutments that are inside of the bridge opening. From **SA/2D Connection Data Editor**, click the Pier icon and the Pier Data Editor opens.
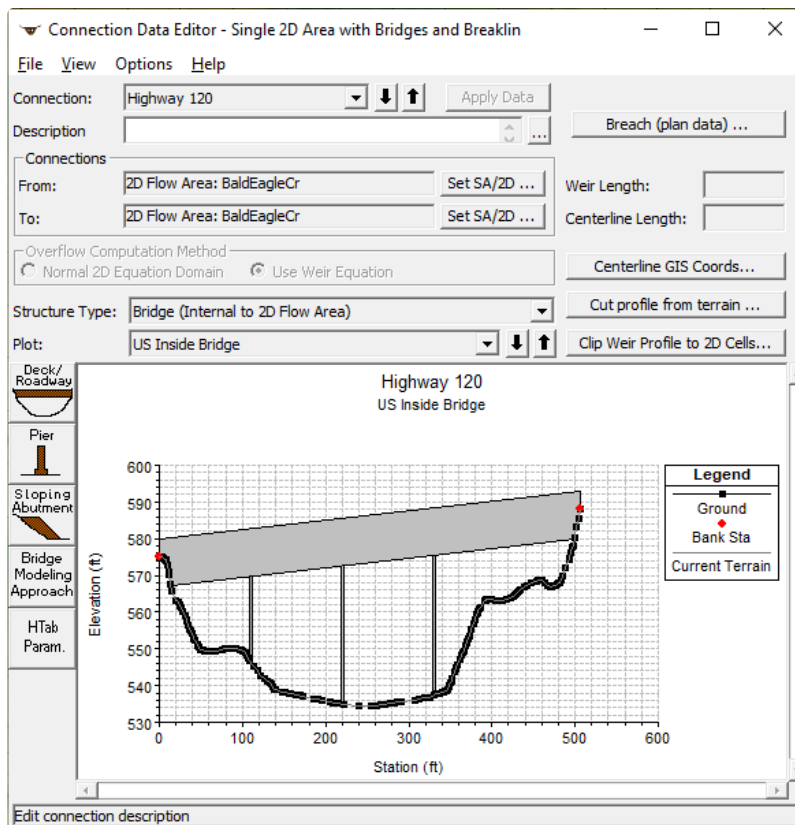
Example view of the Pier Data Editor.

As shown in the figure above, the user enters pier data in the same exact manner as required for a 1D bridge. A **Centerline Station** is required for both the upstream and downstream side of the bridge pier. The pier is formed by entering pairs of elevations versus pier widths, starting below ground and continuing up past the low chord of the bridge deck. The paired elevation and pier width values must be completed for both the upstream side and downstream side of the bridge. However, if the upstream and downstream sides are the same, then fill in the upstream side and use the **Copy Up to Down** button to copy the data to the downstream side. Click **OK** to add the pier and return to the **Connection Data Editor**.

The abutment editor (accessed from the **Connection Data Editor** by clicking the **Sloping Abutment** icon) allows users to add abutments inside of the bridge opening that are different than the natural ground. For example, "Spill through Abutments" are abutments that have a slope and often a rounded or angled approach to guide the flow through the opening. The abutment editor is the same as for 1D bridges, and works the same way. The user enters station and elevation data going from left to right, for each abutment in order to modify the terrain through the bridge opening.

After the bridge deck/roadway, piers, and any abutments are entered, the editor will show the bridge information graphically.

Example view of the SA/2D Connection Data Editor showing the bridge deck and pier geometry.

The next step is to enter Manning's n values for all of the 1D cross sections that are automatically formed by the user entered bridge data. To enter Manning's n values for the 1D cross sections, select the **Options | External and Internal Bridge Cross Sections** menu option to open **Bridge Cross Sections** editor, shown below.

As shown in in the figure above, the user must enter Manning's n values for each of the four bridge cross sections (**Upstream Outside**, **Upstream Inside** the bridge deck, **Downstream Inside** the bridge deck, and **Downstream Outside** the bridge). Manning's n values are entered as horizontally varying values, starting with the very first station within the cross section. At least one n value must

be entered for each cross section. Users can also modify the cross-section station elevation data from the **Bridge Cross Sections** editor. However, the length of the cross section must stay the same as what is spatially laid out form the bridge centerline data and other bridge information. The left and right main channel bank stations can also be changed; by default, they are set to the first and last point of each cross section. When the cross section data has been entered, click **OK** to return to the **Connection Data Editor**.

The next step for entering the bridge data is to define the bridge modeling approach. From the **Connection Data Editor** select the **Bridge Modeling Approach** button to open the **Connection Bridge Modeling Approach Editor.**

Example view of the Connection Bridge Modeling Approach Editor.

The **Connection Bridge Modeling Approach Editor** is very similar to the bridge modeling approach editor for 1D bridges. The user can select one or more low flow bridge hydraulic methods (water stays below the low chord of the bridge deck and does not pressurize the bridge opening) and take the **Highest Energy Answer** as the selected answer. Available **Low Flow Methods** are: Energy, Momentum, and Yarnell. The WSPRO low flow bridge modeling method was removed, from this editor in HEC-RAS Version 6.0, as it requires approach and exit cross sections which are not available inside of a 2D flow area.

The **High Flow Methods** are: Energy Only and Pressure and/or Weir flow. The Pressure and/or Weir high flow method should be used when the bridge deck blocks a significant amount of the flow area, and the resulting upstream water surface will be significantly higher than the downstream water surface. This situation will cause the flow going over the roadway to pass through critical depth, much like a normal weir. In general, the Energy high flow method should be used if the bridge deck is a smaller portion of the flow area, and the resulting upstream and downstream water surface will not be significantly different. Click **OK** to save the selected bridge modeling approach and return to the **Connection Data Editor**.

The last step for entering the bridge data is to define the **HTAB Parameters**. From the **Connection Data Editor**, click the **HTab Param** button to open the **Connection Hydraulic Property Table Parameters** editor.

Example view of the Connection Hydraulic Property Tables Parameters editor.

As show in in the figure above, the user must enter the following information: **Number of points on free flow curve** (maximum is 100), **Number of submerged curves** (maximum is 60), **Number of points on each submerged curve** (maximum is 60), and **Head water maximum elevation**. The **Tail water maximum elevation** is optional, as is the **Maximum Flow**. However, the maximum flow is recommended as it will help control the limits of the connection hydraulic property table. Click **OK** to close the editor and return to the **Connection Data Editor**.

After adding all of the necessary bridge data, close the editor by clicking the **File** | **Exit** menu command. The entered bridge data will be added to the **Geometric Data** window similar to the bridge shown in Figure 8. As displayed in Figure 8, the grey area is the bridge deck/roadway. The black and red dotted line is the bridge centerline. There are also four red dotted lines, which represent the four cross sections that will be extracted and used by the geometric pre-processor to perform the bridge hydraulic computations in order to develop the family of rating curves for the bridge. The user can view the four cross sections from the SA/2D Area **Connection Data Editor**.

For modeling bridges inside of a 2D flow area, HEC-RAS will automatically create the four needed cross sections for pre-processing the bridge hydraulics into a family of curves. These four cross section locations are:

1. Upstream just outside the bridge deck, normally at the toe of the upstream embankment. This cross section is automatically generated upstream of the bridge deck based on the user entered **Distance** field (entered in the bridge **Deck/Roadway Data Editor**).
2. Upstream just inside the bridge deck and/or roadway.
3. Downstream just inside the bridge deck and/or roadway.
4. Downstream outside of the bridge deck and/or roadway, normally at the toe of the downstream embankment. This cross section is automatically generated downstream of the bridge deck a distance equal to what the user entered for the upstream **Distance** field.

For the two cross sections inside the bridge, they follow the edges of the deck/roadway. However, for the outside cross sections, HEC-RAS automatically generates their locations by simply creating cross sections that are parallel to the inside cross sections. The distance upstream and downstream from the bridge deck is based on the user-entered **Distance** value (entered within the **Deck/Roadway Data Editor**). If the user changes the deck and/or roadway data entered in the **Deck/Roadway Data Editor** (i.e., Bridge Width or Distance), then the locations of the 1D cross sections

outside the bridge and/or roadway will change. The user can view each of the four cross sections, as well as the centerline data (the centerline terrain data is applied to the 2D cell faces inside of the bridge). If the bridge data changes, the user will see that the terrain under the current 1D cross section line does not match the updated 1D cross section locations. However, to fix the out-of-date cross sections, the user can recut any of the 1D cross sections by simply pressing the **Cut Profile from Terrain** button (selected from the **Connection Data Editor**, from the **Options** menu) while viewing a specific cross section.

The user entered bridge deck/roadway, piers and abutments are applied to the inside 1D cross sections. However, this data is averaged (interpolated between the two inside cross sections) in order to modify the terrain data of the 2D cell faces that are at the centerline of the bridge. The bridge centerline ground is interpolated, from the two cross sections inside the bridge, at the upstream and downstream end. The bridge centerline is interpolated in this manner because the bridge curves are based on those cross sections, and the terrain at the centerline was not used to develop the bridge curves. Additionally, the user can edit the internal bridge curves, say for example to better represent the terrain inside the bridge. Therefore, interpolating the centerline from the two cross sections inside the bridge is necessary to be consistent with the cross sections used to make the bridge curves, and to maintain model stability. In other words, check that the bridge centerline profile is appropriate because that is the profile being used for the terrain data of the bridge centerline faces for the 2D cells.
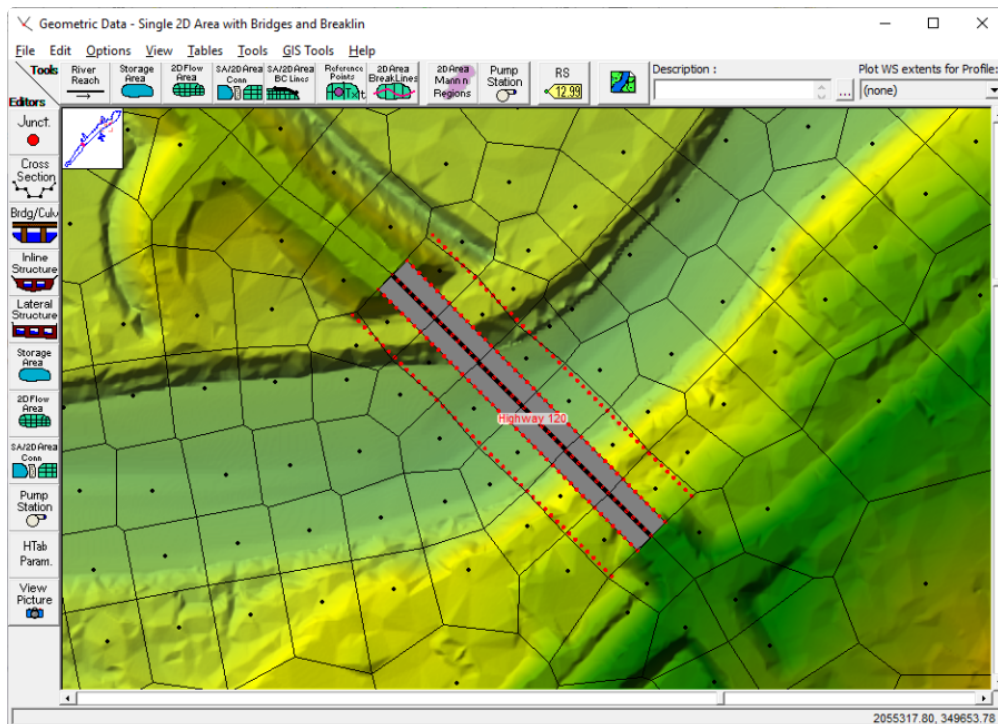
Example view of a 2D bridge showing the deck extent in grey, the bridge centerline in dark black, and the four 1D cross-sections as dashed red lines.

As shown in figure aboce, this bridge was laid out to only represent the bridge opening and abutments. The road approaches are being modelled with cell faces aligned with the high ground of the roadway. Note, the example provided for modeling the road approaches is just one of the options available in HEC-RAS. The roadway approaches could have been included as part of the

bridge, and the deck/roadway could have been used to refine the elevations of those roadway approaches. If the roadway approaches were included as part of the bridge model, then **Ineffective Flow Areas** would need to be entered for the two cross sections outside of the bridge. There is an option to add Ineffective Flow Areas for these cross sections under the **Options** menu of the SA/2D Area Conn editor.

For the bridge modeling approach shown in Figure 3-58, there are six cells going across the bridge. The SA/2D Area Conn (Bridge in this case) allows the user to define a cell spacing along the centerline, then enforce that cell spacing such that the cells start and end exactly at the beginning and end of the bridge deck/roadway (this is a requirement for all structures modelled with the SA/2D Area Conn). When forming the cells around the bridge, it is a good idea to use the mesh/cell option for "Near repeats." The "Near repeats" option means that not only will HEC-RAS form the cells around the bridge centerline, but it will repeat those same exact cells outside of the initial cells. This option allows the cells around the bridge centerline to be square. Keep in mind, these four bridge cross sections are only used to develop the bridge curves, but the flow through and over the bridge is still being solved using the 2D flow equations.

There are several **Options** available for Bridges inside of 2D Flow Areas. From the **Options** menu at the top of the SA/2D Area **Connection Data Editor**, the following options are available.

1. **External and Internal Bridge Cross Sections** -This option allows the user to edit the four cross sections that will be used for the bridge in computing the bridge curves. The user can change the station/elevation data, Manning's n values, and the main channel bank station locations. Also, if the bridge deck/roadway data is changed, the location of the four cross sections will change. The user also has the option to re-cut the cross sections from the terrain using the button labeled "**Cut Profile from Terrain**". This button will re-cut the current cross section being viewed in the editor.
2. **Bridge Ineffective Regions** - This option allows the user to define ineffective flow areas for the upstream and downstream cross sections outside of the bridge. If the user has included the left and right roadway approaches as part of the bridge, then it may be necessary to define ineffective flow areas for the outside cross sections in order to compute accurate headwater and tailwater elevations for the bridge curves.
3. **Momentum Equation** - This option allows the user to control which components of the low flow Momentum bridge hydraulic method are turned on or off. For more details on this review the chapter on 2D Bridge Hydraulics in the HEC-RAS Version 6.0 Hydraulic Reference Manual.
4. **Class B Defaults** - This option allows the user to control where critical depth will be calculated/used for Class B low flow. For more details on this review the chapter on 2D Bridge Hydraulics in the HEC-RAS Version 6.0 Hydraulic Reference Manual.
5. **Pressure Flow Criteria** - This option is used to define when the software will start checking for the flow to transition from low flow to pressure flow. By default, HEC-RAS uses the energy gradeline of the upstream outside cross section. This default method is conservative and can often lead to the software jumping to pressure flow for bridges that have high velocities. The user can change this criterion to the "water surface elevation" if the bridge hydraulics are jumping to pressure flow too soon.
6. **Skew Bridge Data** - This option allows the user to specify a skew angle. The angle will be used to reduced the effective length of the bridge opening by projecting the internal and external bridge cross sections. This is done by multiplying the stationing data by the cosine of the skew angle. An example plan view for a bridge with skeww is shown below.
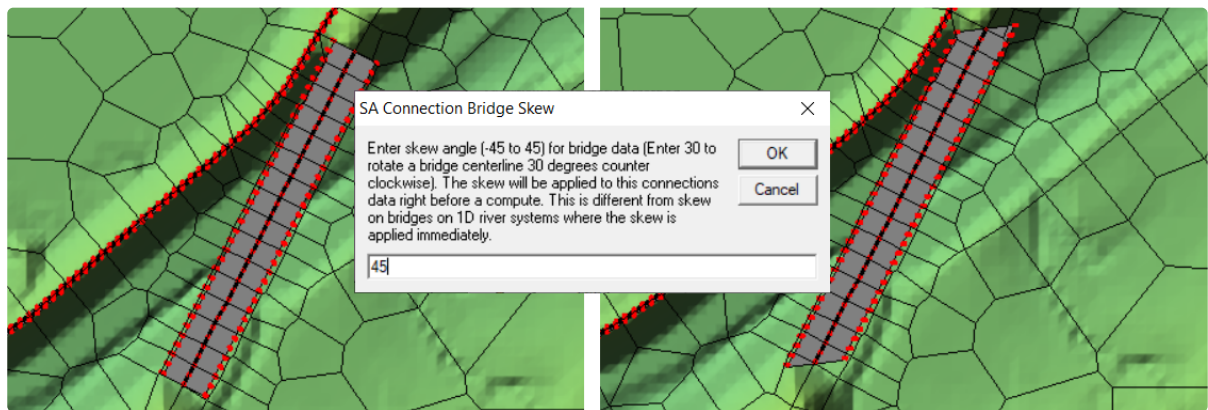
Below is an example plot for the the original bridge data with the adjusted (skewed) data.
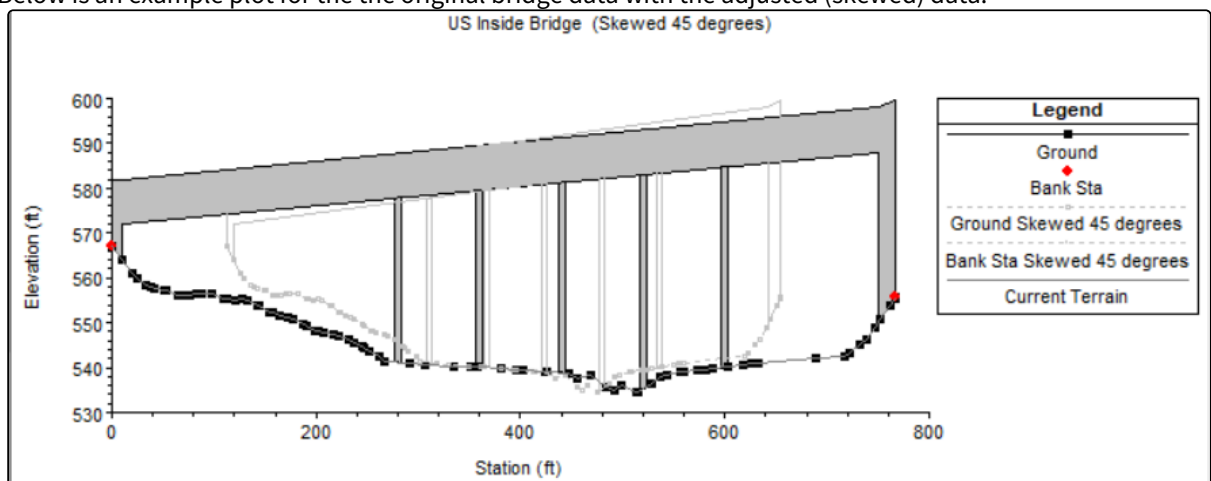
> ⓘ Pier data sent to the computation engine is NOT adjusted (even though the simple plot above shows a reduction.)

When skew is applied, the internal and external cross sections locations will also be shifted to attempt account for the bridge realignment. Therefore, if the realignment of the cross sections results in a significant change in the cross section profile, you may need to re-cut the profile from the terrain. This can be done using the "Cut Profile from Terrain" button (but must be done on all four bounding sections). In the figure below, you can see a cross section with the (1) original Ground line, (2) Skewed Ground line, and (3) Current

Terrain profile that would result if the profile was re-cut.
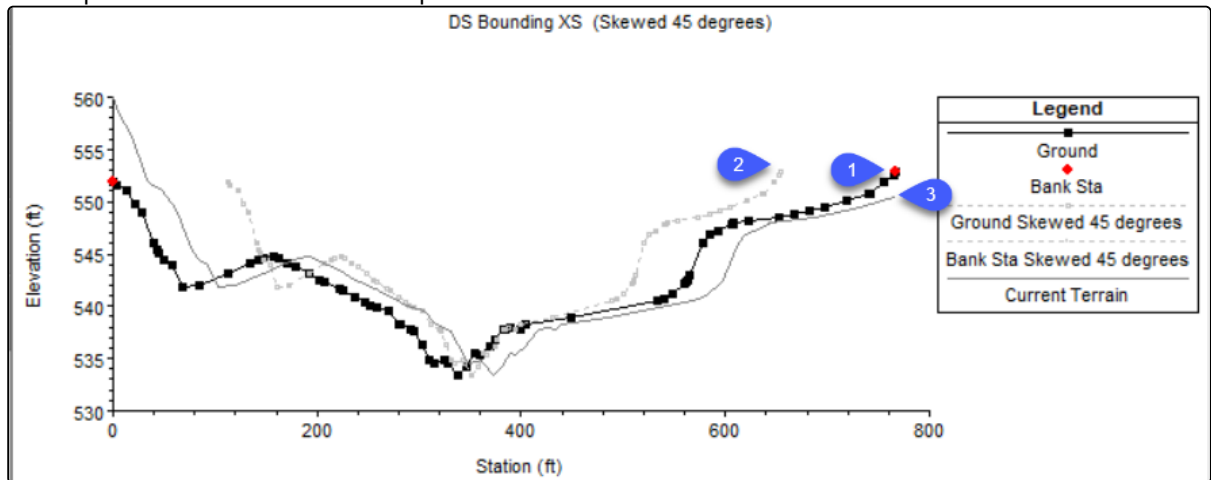
Pre-Processing the 2D Bridge into Curves

After the user has entered the bridge data and has ensured that the mess/cells and the 1D cross sections are well formed around the bridge, then the user must run the 2D **Geometric Preprocessor** to generate the bridge family of curves (which is computed for each bridge in the model). If HEC-RAS detects that the Geometric Preprocessor needs to be computed, then the software automatically runs the preprocessor before an unsteady flow simulation. However, the user can just run the Geometric Preprocessor, without performing the full Unsteady Flow computations, to view the bridge curves before the unsteady flow computations are performed. Either way, once the geometric preprocessor is run, the user can view the family of curves for each of the bridges in the model.

To view the bridge curves, press the **Hydraulic Tables** button on the main HEC-RAS window. Then from the **View Hydraulic Properties Tables** window, from the **Type** menu, select **SA/2D Area Connections**. Shown in figure below are example bridge curves.
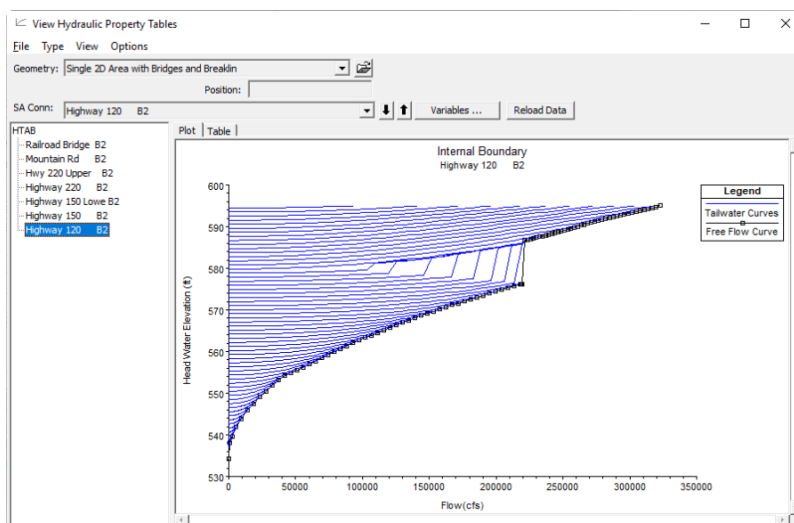

Example Bridge Hydraulic Property Tables

Performing the Computations and Viewing the Results

Once the model has finished running the user can begin to view the output related to the 2D bridge hydraulics. There are several ways to view output for 2D bridges within HEC-RAS. These viewing options include:

• Inundation maps in RAS Mapper, including water surface, velocity, etc.
• Profile line plots viewed in RAS Mapper.
• Stage and Flow Hydrograph plots opened from the HEC-RAS main window by clicking the Plot Stage and Flow Hydrographs button, or by left clicking on the structure in the Geometric Data editor and selecting "Stage and Flow Hydrograph."
• Cross section plot of the SA/2D Area Connection. From the Cross-Section plot window, select "SA/2D Area Conn" from the Type menu.
• Tabular Output from the detailed output tables for the SA/2D Hydraulic Connection that represents the bridge.

Output from RAS Mapper is available in many forms. The most common output is maps of water surface elevation and velocity. Shown in the figure below is a colored water surface elevation plot though the bridge area. The water surface elevation plot also has water surface contours turned for 0.2ft elevation, which provides more context into how and where the water surface is changing.
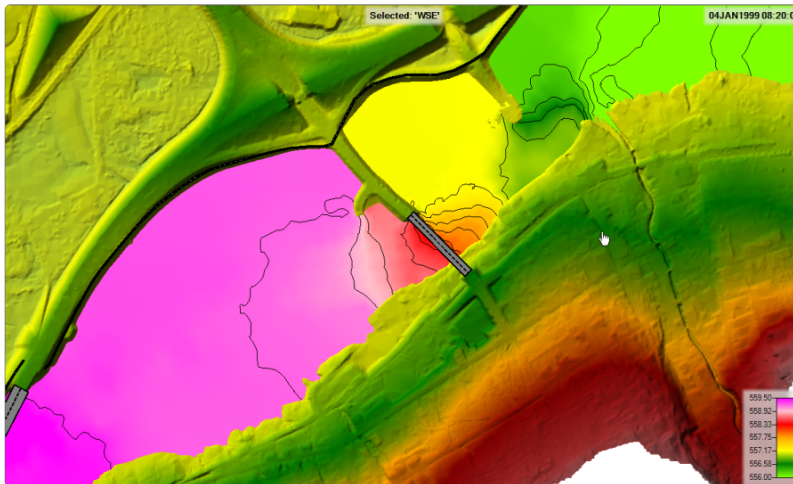
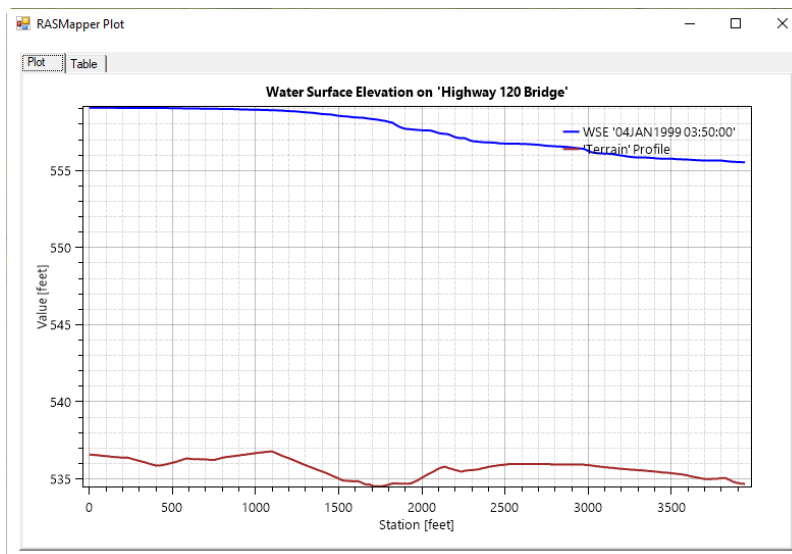Example water surface map for a 2D bridge.

Another very useful plot, especially in the area of the bridge, is one of colored velocity with particle tracers enabled. Shown in the figure below is a velocity plot with particle tracers enabled.
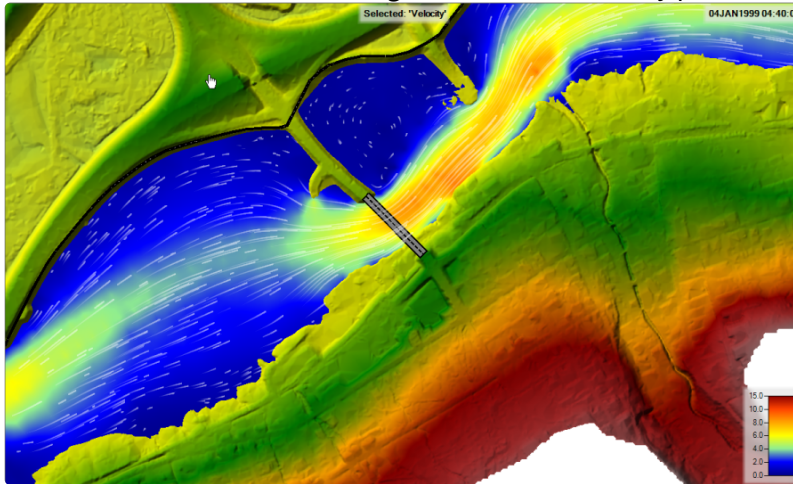
Example velocity magnitude and flow trace map for a 2D bridge.

One thing to make note of from both figure above: the flow is computed as "true" 2D flow through the bridge, even if it overtops the bridge. The 1D cross sections and bridge information are used to compute the family of rating curves, but the curves are only used to obtain the momentum force loss through the bridge opening. This approach does not force a 1D bridge water surface or velocity. As shown in the Figures 12 and 14, the water surface varies across the channel upstream of the bridge, through the bridge, and downstream of the bridge. The velocity also varies, from cell to cell, based on the terrain, degree of constriction, and roughness coefficients.

Another useful output from RAS Mapper are Profile Line Plots. A common use of profile lines is to draw a line down the centerline of the channel and then request a plot of the terrain and the computed water surface elevation. Shown in Figure 14 is an example of a terrain and water surface elevation plot through the area of the bridge.

Example water surface profile through a 2D bridge along the channel centerline.

Another example of a Profile Line Plot for the bridge is displayed in the figure below, showing a plot of a cross section view just upstream of the bridge.
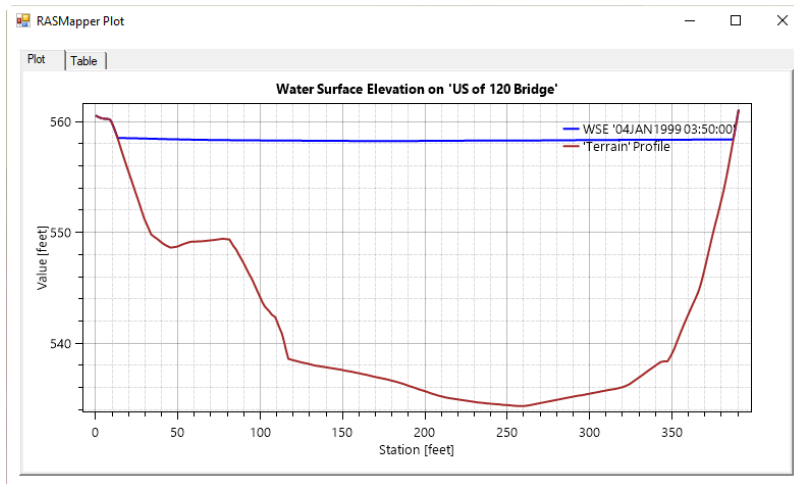
Example water surface profile along a 2D bridge centerline.

In addition to the 2D hydraulic results of water surface, velocities, etc., there are several time-series output that can be plotted by the user from the **Stage and Flow Hydrograph** plotter . The 2D bridge time-series plots can be accessed by clicking on the menu **Type | SA/2D Connections** as shown in the figure below.
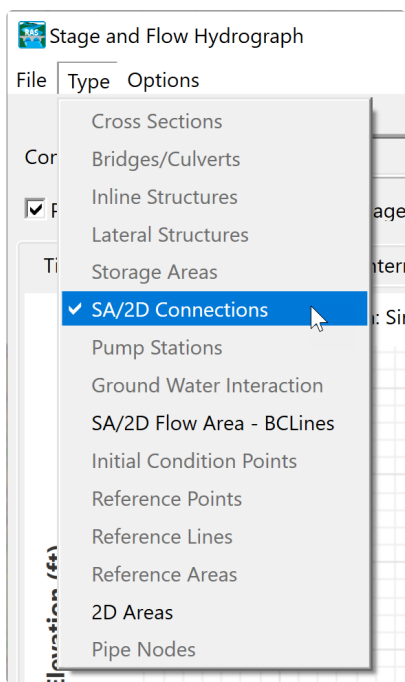
Changing the plot type to SA/2D Connections in the Stage and Flow Hydrograph plotter.
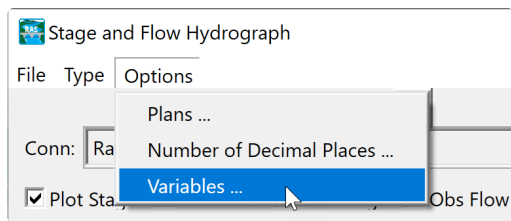
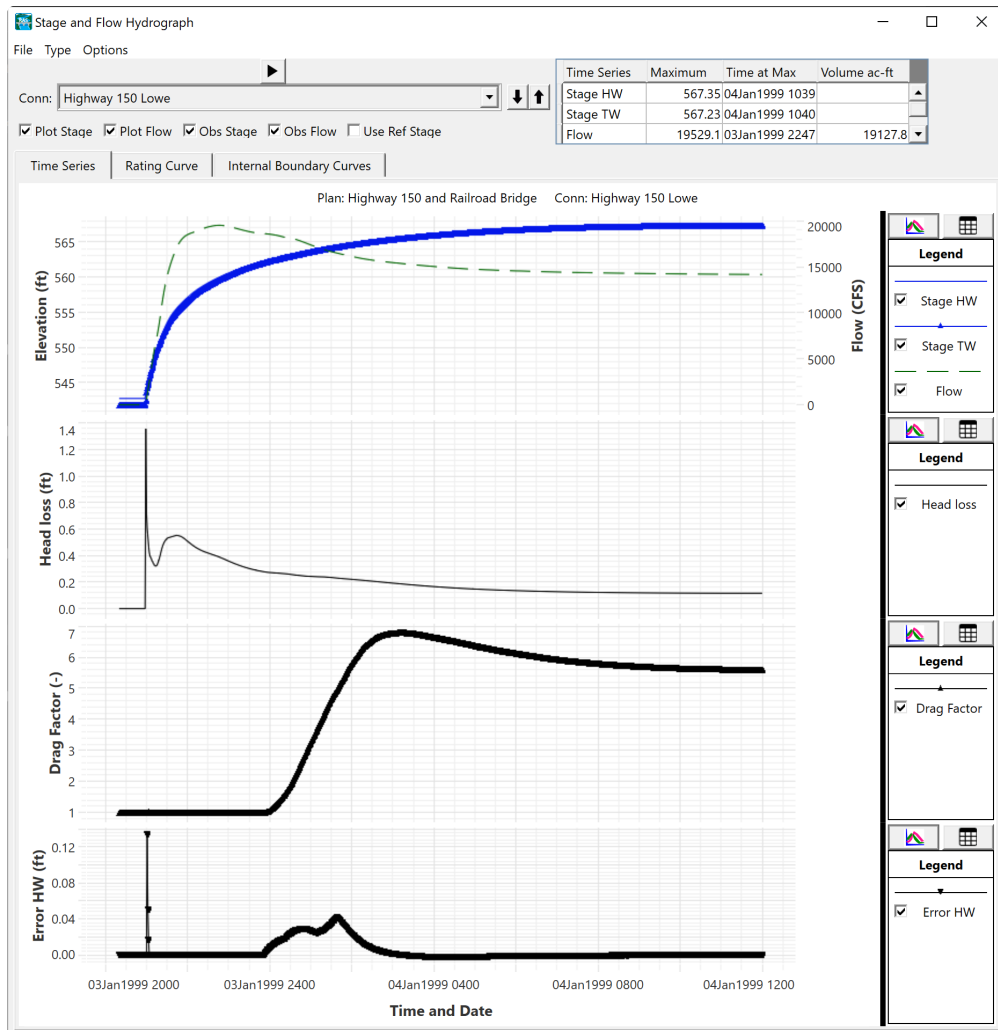Selecting the bridge plotting variables in the Stage and Flow Hydrograph plotter.

Example timer-series plot for a simplified 1D/2D bridge.

Modeling Pump Stations inside 2D Flow Areas

A pump station can be used to pump water between two storage areas, a storage area and a river reach, between two river reaches, a river reach and a 2D Flow Area, a Storage Area and a 2D Flow Area, between two 2D Flow Areas, or from one cell to another cell within the same 2D Flow Area. Each pump station can have up to ten different pump groups, and each pump group can have up to twenty identical pumps.

To add a pump station to the system, select the **Pump Station** drawing tool at the top of the Geometric Data editor. When this button is pressed, move the mouse to the location that represents where the pump station will be located, and click the left mouse button. An HEC-RAS editor will open asking users to enter a name for the Pump Station. This will establish a pump station location and Icon. Shown in Figure 3-64 is an example of connecting a 2D flow area to a 1D cross section (TestPump) and a 2D flow area to a storage area (SAPump).
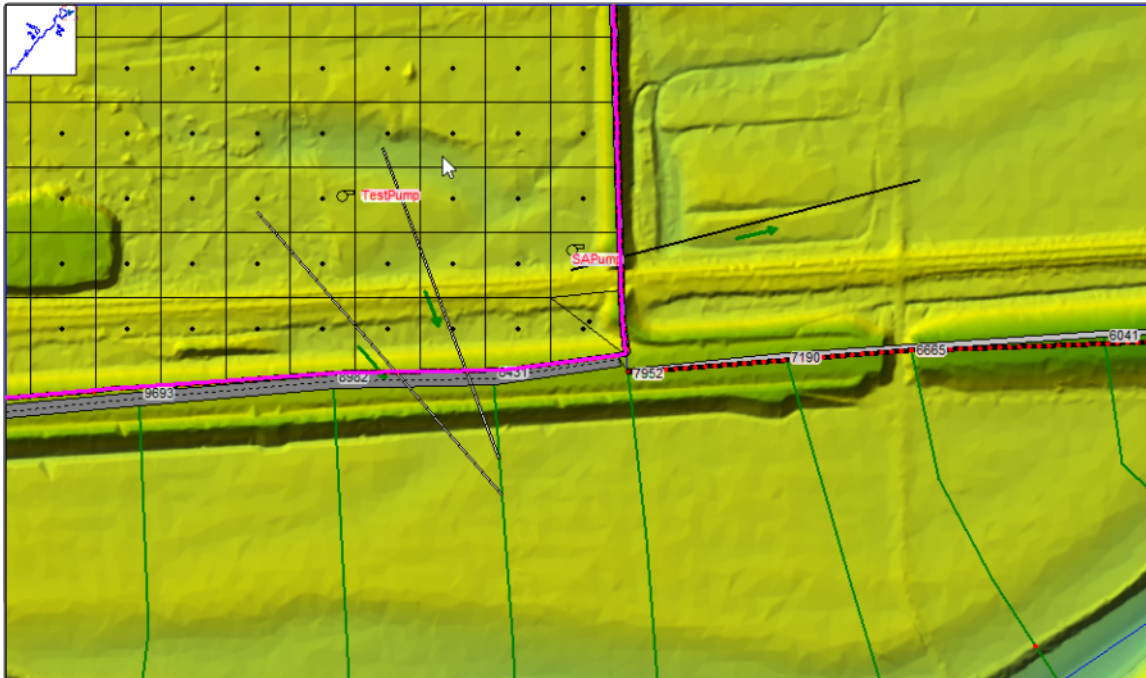
Figure 3-64. Two example pump station connections.

Once a pump station is added to the system, the user must edit the pump station and fill in the required data. To open the pump station editor, select the **Pump Station** editor button on the left hand side of the Geometric Data editor. Alternatively, move the mouse over the pump station icon on the schematic, left click the pump station, and select **Edit Pump Station** from the shortcut menu. The **Pump Station Data Editor** opens (Figure 3-65).

Figure 3-65. Pump Station Editor with Pump Connection Data

As shown in Figure 3-65, the **Pump Station Editor** has the following three tabs: the **Pump Connection Data**, the **Pump Group Data**, and the **Advanced Control Rules** (for applying advanced rule controls over the pump station).

The **Pump Connection Data** tab contains the following data:

Rename Pump Station button: This option allows the user to rename the pump station to something other than the default.

Pump Inlet: This is the location of where the pump station is pumping from. This location can be either a storage area, 2D Flow Area, or a river station from a river reach. The **Set RS** button allows the user to connect a pump from a river station of a reach, the **Set SA/2D** button allows the pump to be connected from a Storage Area or a 2D Flow Area.

Pump Outlet: This is the location of where the pump station is pumping to. This location can be either a storage area or 2D Flow Area (use **Set SA/2D** button) or a river station from a river reach (use **Set RS** button).

Optional On-Off Monitor Reference: By default, the program uses the "Pump Inlet" location to determine when the pump should turn on or off. However, the user has the option to set a different location to be used as the monitor point for determining whether the pump should be turned on or off. This optional monitor location can be a storage area, a 2D Flow Area (when using a 2D Flow Area, the user must add a reference point into the geometry data within that 2D flow Area), or a river station within a river reach.

Highest elevation in pump line: This option allows the user to enter an elevation to be used as the highest elevation in the pump line. One example of where this may be useful is if a pump station was being used to pump water over top of a levee. In this situation, the required head to pump the water over the levee is not completely quantified by the too and from water surface elevations; therefore, it is necessary to enter the elevation of the highest point in the pump line (top of the levee) in order to accurately compute the flow going through the pump.

Steady Flow Optimization: This option is for steady flow modeling only. If water is being pumped from or to a river reach, the amount of flow going into or out of the reach should be accounted for when computing the water surface profiles. However, the water surface profiles will affect the computation of the amount of flow through the pumps. Therefore, to calculate this accurately, the pump flow and water surface profiles must be calculated iteratively until a balance is found between the river flows and the pump flows. This optimization feature is not done automatically by the steady flow program; however, the user can have HEC-RAS include the optimization feature by selecting **Steady flow optimization**. When this option is selected, a window opens which allows the user to turn on the pump flow optimization feature.

In addition to the pump connection data, the user must fill out the pump group data. Select the **Pump Group Data** tab and the editor updates (Figure 3-66).

Figure 3-66. Pump Station Editor with Pump Group Data

As shown in Figure 3-66, the **Pump Group Data** tab consists of the following:

Pump Group Name: By default, the first pump group is called "Group #1," and the second would be "Pump Group #2," etc. The user has the option to rename pump groups, by clicking the **Rename Group** button.

Add Group: This button is used to add another pump group. If the model requires pumps that have different flow capacities and use different pump efficiency curves, then the pumps must be entered as a separate pump group.

Rename Group: This allows the user to rename a pump group.

Delete Group: This button is used to delete the currently selected pump group.

Bias group operations to On (Steady Flow Only): This option is only relevant for a steady flow run. When this option is selected, and a particular water surface profile is between the on and off

elevation for a pump, HEC-RAS will assume the pump is turned on. If this option is not checked, then the software will assume the pump is off when the water surface is between the on and off elevations.

Startup (min): This option is used for unsteady flow only. When a pump is triggered to turn on, the default operation is that the pump turns on instantly and starts pumping to full capacity the very next time step. This option allows the user to enter a startup time in which the pumps will transition from zero flow to full capacity over the user entered time step (in minutes). This option is very useful to prevent the unsteady flow computations from going unstable when too large of a flow change is experienced from a pump turning on.

Shutdown (min): This option is used for unsteady flow only. When a pump is triggered to turn off, the default operation is that the pump turns off instantly and stops pumping the very next time step. This option allows the user to enter a shut down time in which the pumps will transition from full capacity to zero flow over the user entered time step, in minutes. This option is very useful to prevent the unsteady flow computations from going unstable when too large of a flow change is experienced from a pump turning off so abruptly.

Pump Width: This field is only used for drawing the width of the pump line onto the geometric data window.

Number of Pumps in Group: This field is used to enter the number of identical pumps in the current pump group. Identical pumps must use the same pump efficiency curve but can have different on and off trigger elevations.

Pump Efficiency Curve: This table is used to enter the pump efficiency curve, which is a table of static heads versus flow rates. The head represents the total head in the system, which is normally the difference in the water surface elevations between the from and to locations.

> (i) **Note:** The entered flow is the pump rate capacity at that particular head. In HEC-RAS, the flows entered for a given head difference must already account for all energy losses in the pump line (friction, bends, junctions, etc.).

Do not enter the rated pump curve from the manufacturer, that curve does not account for losses in the pump line. An example of how to compute a pump efficiency curve is shown in Figure 3-67. As shown in Figure 3-67, the user must compute all energy losses in the system between the two static pools. The energy losses in the line are subtracted from the manufacturer pump efficiency curve to get the curve for use in HEC-RAS. The pump efficiency curve can be plotted for visual inspection by pressing the **Plot Pump Curves** button at the bottom of the window.
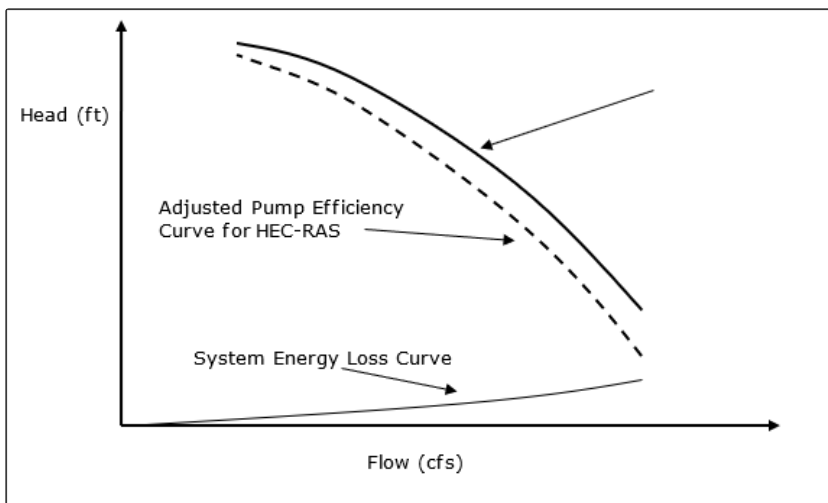
Figure 3-67. Pump Efficiency Curve for HEC-RAS

By default, the monitoring location for triggering a pump on or off is the inlet location, unless otherwise specified in the Optional On-Off Reference field. In general, the pump on elevation must be higher than the pump off elevation. Also, trigger elevations must be specified for all of the pumps. If the user enters a pump off elevation that is higher than the pump on elevation, then the pump turns on when the water surface goes below the on elevation and the pump remains on until the water surface gets higher than the pump off elevation. For example, this situation would be used for pumping water up to a storage tank. On the other hand, when the pump off elevation is lower than the pump on elevation (typical way of using it), then the pump turns on when the water surface gets higher than the pump on elevation, and the pump turns off when it goes below the off elevation. This is the typical use of the pumps for interior ponding areas.

The bottom half of the **Pump Group Data** tab contains a table with all the individual pumps in the group. The table contains the following:

Pump Name: This field contains the name of each of the individual pumps. Pumps are automatically names "Pump #1", then "Pump #2", etc. The user can double click in the Pump Name field and change pump names to be more specific (i.e., identifying a location).

WS Elev On: This is the elevation at which the pump will be turned on. This is based on the elevation of the water surface at the "Inlet" location connected to the pump.

WS Elev Off: This is the elevation at which the pump will be turned off. This is based on the elevation of the water surface at the "Inlet" location connected to the pump.

Pump GIS Data: Another table directly to the right of the individual Pump Name table, is a table containing the GIS coordinates of the individual pumps. If the user clicks on a pump row in the Pump Names table (e.g., if Pump #1 was selected), then the X, Y coordinates in the Pump Coordinates table are for Pump #1. If another Pump is selected, then the X, Y coordinates will be for that pump. Entering X, Y coordinates for a pump is only need when connecting pumps to 2D Flow Areas. The location is required to identify which cell(s) the pump is connected to in the 2D Flow Area. Users must draw a spatial line that goes from the Pump Inlet to the Pump Outlet. This line will be used to show the Pump connection spatially in the Geometric Data editor, as well as establish

which cell is connected to the pump. The X, Y coordinates are not required if pumps are not being connected to a 2D Flow Area. However, if even one end of the pump is connected to a 2D Flow Area, then the X, Y coordinates are required.

The final tab, labeled **Advanced Control Rules**, is an optional tab used to specify rules that will override the physical pump data. Figure 3-68 displays the layout of the **Advanced Control Rules** tab in the **Pump Station Data Editor**.
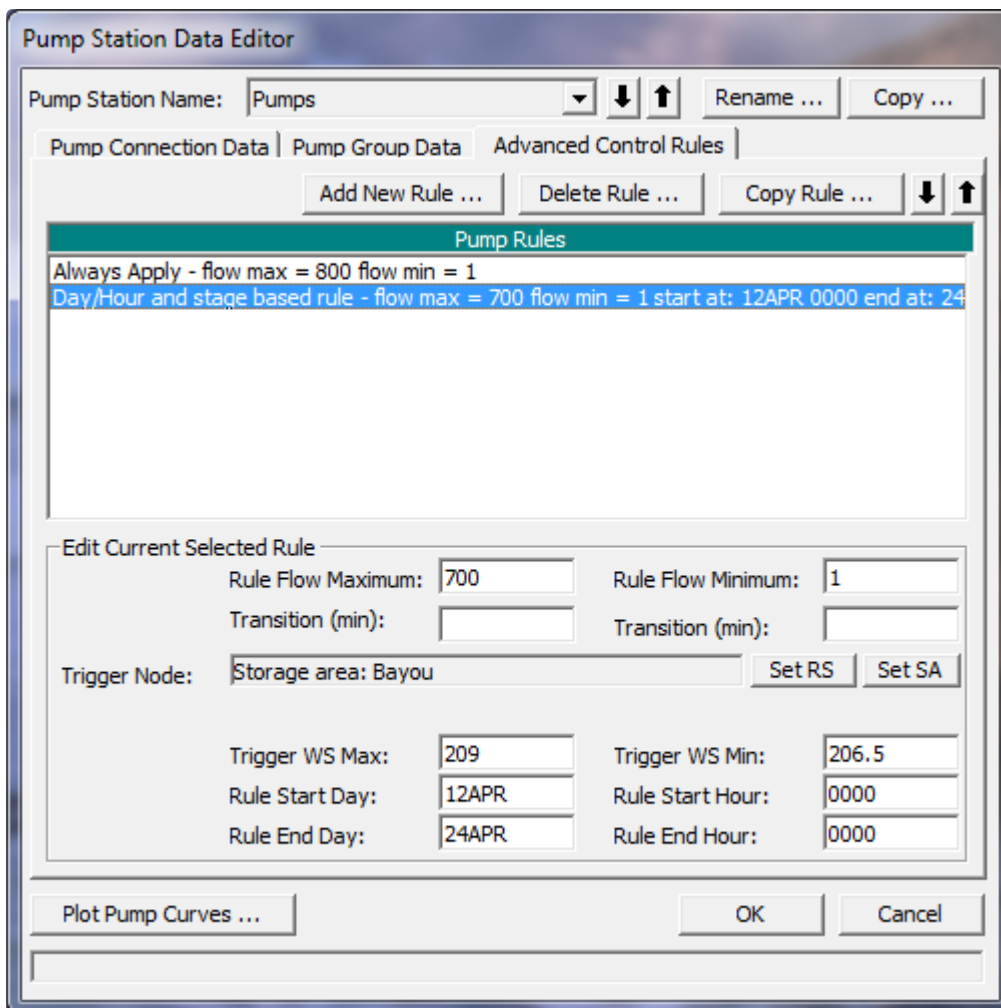
Figure 3-68. Pump Editor with Advanced Control Rules Tab Selected.

As shown in the Figure 3-68 the **Advanced Control Rules** tab has three buttons at the top of the editor: **Add New Rule, Delete Rule** and **Copy Rule**. The **Delete Rule** button will delete the currently selected rule from the list of pump rules shown in the text box labeled **Pump Rules**. The **Copy Rule**

button makes a copy of the currently opened rule. The **Add New Rule** button opens the **HEC-RAS** rule types editor (Figure 3-69), which allows the user to select a new rule from the **Rule Types** list.
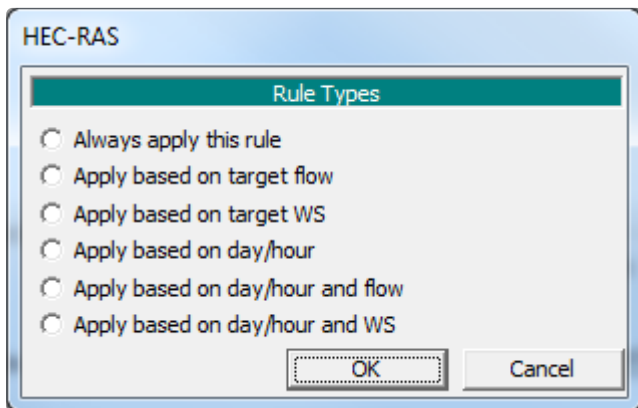
Figure 3-69. Rule Types Editor.

As shown in Figure 3-69, there are six types of rules that can be applied to a pump station. Each of the six rule types allow the user to specify a minimum and maximum flow for the entire pump station. This minimum and maximum flow will narrow the range of possible flows that have been computed for the pump station based on the physical pump data. The rule types only differ in how and when the minimum and maximum flow range gets applied.

The first rule type, **Always apply this rule**, is applied at for all time steps in the solution. The second rule type, **Apply Based on Target Flow**, is applied only when a target minimum and/or maximum flow is exceeded (flow is greater than specified maximum or less than specified minimum) at a user specified flow monitoring location. The flow monitoring location can be a cross section within a river reach, or a storage area. The third rule type, **Apply based on target WS**, is applied only when a target minimum and/or maximum water surface elevation is exceeded (stage is greater than specified maximum or less than specified minimum) at a user specified stage monitoring location. The fourth rule type, **Apply based on Day/Hour**, is only applied only during a user specified time window. The user enters a starting day and time, and an ending day and time. The specified maximum and minimum flows are then applied to the pump station only during the user specified time window. The fifth rule type, **Apply based on day/hour and flow**, is a combination of a user specified time window, and a maximum and/or minimum flow target at a user specified flow monitoring location. The last rule type, **Apply based on day/hour and WS**, is a combination of a user specified time window, and a maximum and/or minimum stage target at a user specified stage monitoring location.

The user can also apply a transition time in minutes to the maximum and minimum flow for each of the rules. Therefore, if a rule will change the flow from the currently computed value to a user entered maximum, the transition time is used to allow for the flow change to occur over a user specified time. This same concept is used for the minimum flow rate also.

The user can specify as many rules as they want for each pump station. The rules will be applied to the pump station in the order that they have been entered (which is also the order in which they appear in the editor). The user can move a rule up or down in the list by highlighting a rule, then using the up and down arrow buttons to move the rule.

After all the pump data are entered, press the **OK** button to have the data excepted by the program. This does not save the data to the hard disk; it only allows it to be used in the current execution of the program. To save the data permanently, the user must save the Geometry data, from the **File** menu of the Geometric Data editor.
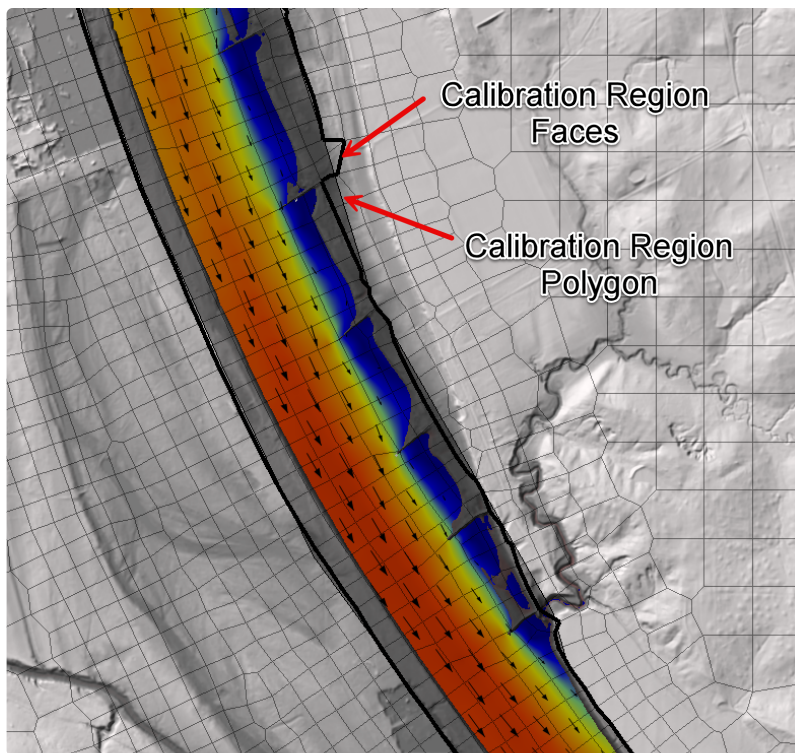
Flow Roughness Factor Curves in Calibration Regions

The total roughness of a mobile bed river is the sum of the grain related roughness and the bedform roughness. Since both of these can vary with flow, the total roughness will also vary with flow. HEC-RAS Version 6.6 has the ability to vary the bottom roughness (i.e. Manning's n) as a function of flow by specifying a curve of roughness factors as a function of flows. This 2D feature works similar to 1D, but instead of using the flows at cross-sections, the flows are calculated as the outflows from **Calibration Region** polygons.

The first step in entering **Flow Roughness Factor**s is to create one or more **Calibration Regions**. This step can be done in the **Geometric Data Editor** or **RAS Mapper**. In the **Geometric Data Editor**, **Calibration Regions** are created by selecting the tool , drawing a polygon, and then providing a name for the region. In **RAS Mapper**, **Calibration Regions** are created by editing a geometry, selecting the **Calibration Regions** node under the **Manning's n** node, drawing a polygon and providing a name.

Calibration Regions can be used to to override Manning's roughness coefficient and/or to specify **Flow Roughness Factors**. As mentioned above, the roughness factors are specified as a function of the **Calibration Region** outflows. Depending on the shape of the polygon, these flows may not be the same as the river flows. For example, the Calibration may not extend over the entire width of the river leading to a smaller flow compared to the river flow, or the polygon may include outflows which are not directed downstream which will lead to a larger outflow compared to the river flow. For this reason, it is often useful to draw the Calibration Region in such a way that these effects are minimized and the outflow is more comparable to the river flow. This can be done by extending the polygon in the transverse direction past the wet/dry boundary, thus capturing the entire river flow in the longitudinal direction and eliminating the effects from polygon outflows in the transverse direction (see example below).

If the **Calibration Region** polygon outflows do not correspond well to the river flows, then it is recommended to do a preliminary run without the **Flow Roughness Factor** factor to compute the range in outflows which can be used to estimate the flows in the **Flow Roughness Factor** curve.

To specify a **Flow Roughness Factor** for a **Calibration Region,** open the **Geometric Data Editor**, and click on **Tools | Flow Roughness Factors …** as shown in the image below.
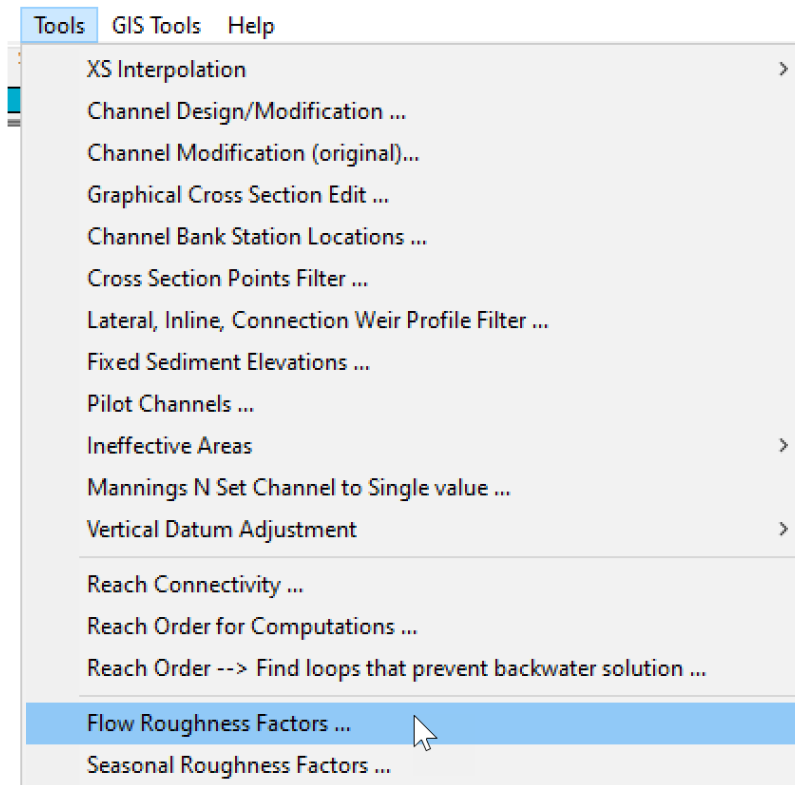
Next, click on the button labeled **+Calib Region** near the top right of the **Geometry - Roughness Change Factors** editor.

Then enter a flow-roughness factor curve for the calibration region.

Geometry - Roughness Change Factors

Set: [Calib Region: Dardanelle_241-256 ▼] ↓ ↑ [+ RS] [+ Calib Region] [X]

Roughness Factor Data

Auto-Generate Flow Column

[Uniform Spacing ...] [Exponentially Increasing ...]

	Flow	Roughness Factor	
1	0	1	
2	100000	1	
3	150000	0.9	
4	200000	0.8	
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			

[Import Calibration Factors ...]   [OK] [Cancel]

It is important to note that if the computed outflows go beyond the extends of the values in the **Flow Roughness Factor** curve, the roughness factors are not extrapolated.

To help with model calibration, time-series of **Calibration Regions** outflows and flow roughness factors and other variables can be plotted in the **Hydrograph Plotter**. To plot **Calibration Region** time-series, open the **Hydrograph Plotter** and select the menu **Type | Calibration Regions.** The figure below shows an example of the Flow Roughness Factor, average water surface elevation (WSE Avg), and polygon outflow (Outflow - Perimeter).
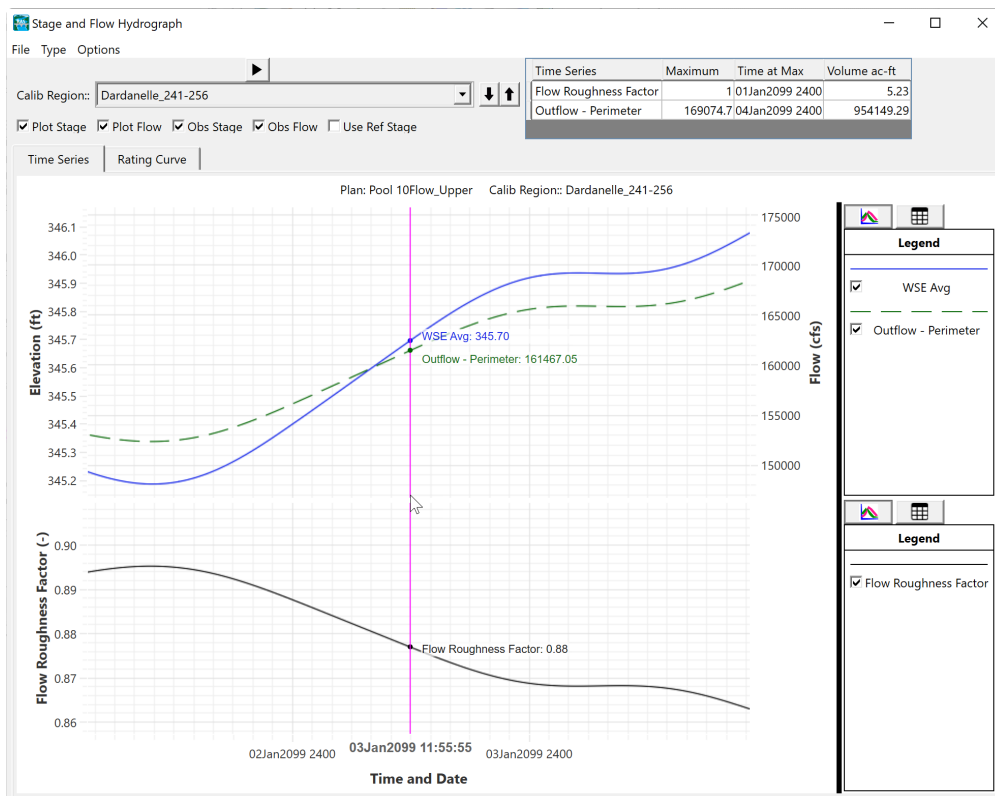
Spatial maps and time-series can be computed by turning on the **Face Manning's n** dataset by going to the **Unsteady Flow Analysis** editor and selecting **Options | Output Options ...** and selecting **Face Manning's n** dataset from the **HDF5 Write Parameters** tab.

An important detail about the roughness factor is that it is not applied to any Manning's n values larger than 0.09 s/m$^{1/3}$. The reasoning behind this is that large roughness values will typically represent non-mobile bed materials, such a rubble mound structures or mixed forest and therefore the bottom roughness does not vary with flow.

5 BOUNDARY AND INITIAL CONDITIONS FOR 2D FLOW AREAS

Overview

HEC-RAS has a wide range of boundary and initial conditions that can be applied to a model. Boundary conditions consist of **external boundary conditions** along the perimeter of the 2D area, **internal boundary conditions**, and **global boundary conditions (**Meteorological Data**)** that are applied to the entire model (i.e., precipitation, wind, etc.).

There are four types of external boundary conditions that can be linked directly to the boundary of 2D Flow Areas, these are:

- **Flow Hydrograph**
- **Stage Hydrograph**
- **Normal Depth**
- **Rating Curve**

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 or 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 flow will not transfer.

There are two types of internal boundary conditions that can be used in HEC-RAS:

- **Flow Hydrograph**
- **Precipitation**

The **Precipitation** boundary condition can be applied directly to any 2D flow area as a time series of rainfall excesses. This method is limiting in that it applies the same precipitation spatially to the entire 2D Flow Area. A newer way of applying precipitation has been added to HEC-RAS Version 6.0.

Global boundary conditions are boundary conditions that get applied to the entire model. The current global boundary condition types in HEC-RAS Version 6.0 are:

- **Precipitation**
- **Evapotranspiration**
- **Wind**

The new methods for entering global precipitation and wind boundary conditions can be in the form of gridded data or point gage data. If point gage data are used, then the information is interpolated between the gages using various optional methods.

External Boundary Conditions

As mentioned previously, there are four types of external boundary conditions that can be applied to the outer boundary of 2D Flow Areas. These boundary condition types are: flow hydrograph, stage hydrograph, normal depth, and rating curve. External boundary condition locations can be added to the geometry either in **RAS Mapper**, or in the **Geometric Data** editor. The following explains how to

do this from the **Geometric Data** editor. To use **RAS Mapper** to do this, please review the HEC-RAS Mapper User's Manual.

To add external boundary conditions to a 2D flow area, open the **Geometry Data** editor and select the tool (button) called **SA/2D Area BC Lines** (Figure 4-1). Once the **SA/2D Area BC Lines** tool has been selected, the user can draw a line along the outer boundary of the 2D Area to establish the location of the boundary condition. To create the external boundary condition, click the left mouse button one time at the location along the outside perimeter of the 2D Area where the boundary condition should start. Next, add points by single clicking along the perimeter, then double click to end the boundary condition line at the location where it should end. Once the user double clicks to end the boundary condition line, an HEC-RAS window will open and ask the user to enter a name for the new boundary condition. In the example shown in Figure 4-1, two 2D flow area boundary condition lines were entered at the right hand side of the 2D flow area. These boundary condition locations were given the name "DSNormalDepth1" and "DSNormalDepth2"; however, the user can enter any name desired.

The user can add any number of external boundary conditions to a 2D flow area. For example, HEC-RAS allows one or more locations where a **Flow Hydrograph** boundary condition (or other types) can be connected to a single 2D flow area. The user can also have one or more **Stage Hydrographs** linked to the same 2D flow area. The user can have **Rating Curves** and **Normal Depth** boundary conditions at multiple locations to allow flow to leave the 2D area.

> **⬥ Warning**
>
> Two different external boundary conditions cannot be attached to the same cell face. The user must start or end at the adjacent cell face**.**
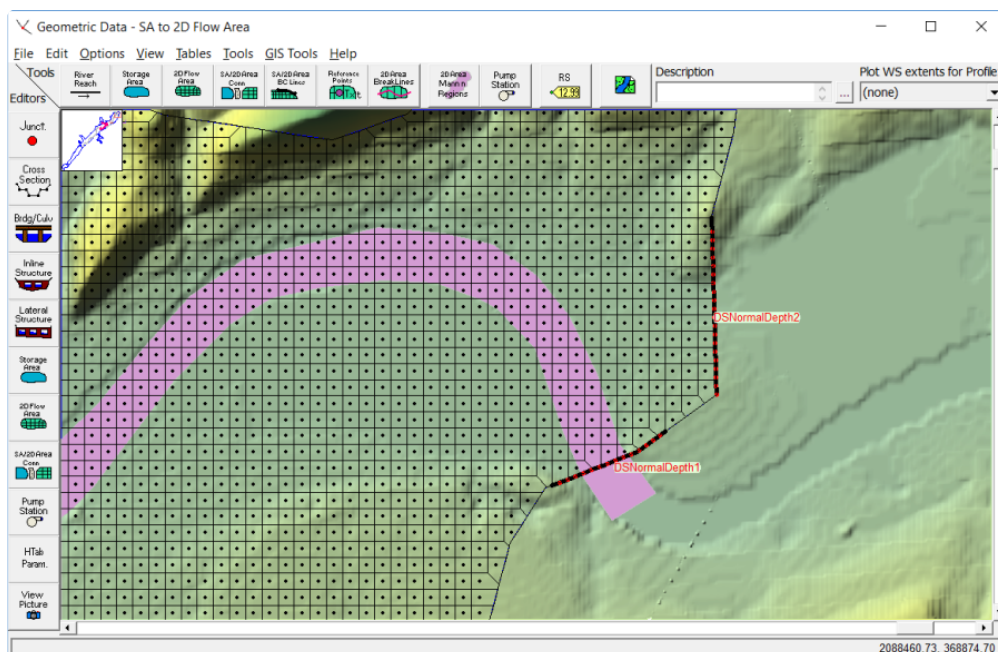
Once all of the 2D flow area boundary conditions have been identified (drawn with the **SA/2D Area BC Lines** tool), the boundary condition type and the boundary condition data must be entered (from

the **Unsteady Flow Data** editor). The **Unsteady Flow Data** editor is where the user selects the boundary condition type and enters the data for the created boundary condition (Figure 4-2).

 As shown in Figure 4-2, the **Select Location in table then select Boundary Condition Type** lower table on the **Boundary Conditions** tab will contain all of the 2D flow area Boundary Condition locations that were entered in the **Geometric Data** editor (Figure 4-1). To enter a 2D flow area boundary condition, select the appropriate field in the **Boundary Condition** column (Figure 4-2) for a particular location, then select the boundary condition type from the active **Boundary Conditions Types** (Figure 4-2) at the top of the window. For example, when a 2D flow area is selected, there are only four types of boundary conditions available: Stage Hydrograph, Flow Hydrograph, Rating Curve, and Normal Depth. For the example shown in Figure 4-1, two boundary condition lines were established for the 2D flow area. These two boundary conditions lines were added to allow flow to leave the 2D flow area using the **Normal Depth** (Manning's equation) boundary condition method. Boundary condition lines can also be placed along other parts of the 2D flow area to allow flow to enter. In this case, the **Flow Hydrograph** (to bring flow directly into the 2D Area), or the **Stage Hydrograph** boundary condition type can be used.

The following four sections (Flow Hydrograph, Stage Hydrograph, Normal Depth, and Rating Curve) describes the information that is required for each boundary condition type connected directly to a 2D flow area.

Flow Hydrograph

A flow hydrograph is generally used to bring flow into a 2D flow area; however, it can also be used to take flow out (negative flow values). The required data for this boundary condition type is:

1. Flow hydrograph (discharge, Q, versus time)
2. Energy Slope (for computing Normal Depth)

The Energy Slope is used to compute a Normal Depth from the given flow rate and the cross-section data (underlying terrain data) along the **Boundary Condition Line** for each computational time step.   A flow distribution in the cross section is then computed (based on the normal depth water surface and the conveyance in the cross section underneath the 2D Boundary Condition line) and this flow distribution is used to appropriately distribute the flow to the cells along the boundary condition line that are wet. At any given time step, only a portion of the boundary condition line may be wet, thus only the cells in which the water surface elevation is higher than their outer boundary face terrain will receive water. However, if the computed Normal Depth water surface is higher than all the boundary face elevation data along the **Boundary Condition Line**, then all the cells will receive water based on a conveyance weighting approach.

Stage Hydrograph

A Stage Hydrograph can be used to bring flow into or take flow out of a 2D flow area. If the water surface elevation in the Stage Hydrograph is higher than the cell water surface elevation (or dry elevation), flow will go into the 2D cells. When the water surface elevation of the Stage Hydrograph is lower than the water surface in the 2D flow area, flow will go out of the 2D area. If a cell is dry and the stage boundary condition is lower than the 2D flow area cell minimum elevation, then flow will not transfer. The flow is computed on a per cell basis. For instance, if the Stage Hydrograph water surface is higher than the water surface of some of the 2D boundary cells and lower than the water surface of other 2D boundary cells, then water will simultaneously enter and exit the Stage Hydrograph boundary. The Stage Hydrograph boundary condition also has an option called "**Use Initial Stage**." When this option is turned on, the first stage in the hydrograph will be used to fill the 2D area as an initial condition. Specifically, the filling starts at the boundary condition and then progressively fills any cell to that water surface if the cell is hydraulically connected. Then the filling stops when the water surface elevation of the first stage hydrograph is lower than the water surface of the cell.

In HEC-RAS Version 6.3 the option is available to specify spatially variable stage hydrographs along boundary condition lines. This new feature is useful for nesting HEC-RAS within other models. This feature is described in detail here.

Normal Depth

The **Normal Depth** boundary condition can only be used to take flow out of a 2D flow area. When using the **Normal Depth** boundary condition, the user is required to enter a friction slope for that area, which is also required for a 1D cross section location. The friction slope can be based on the

land slope in the vicinity of the 2D flow area boundary condition line. The Friction Slope is used within Manning's equation to compute a **Normal Depth** water surface elevation for each given flow, based on the cross section underneath the 2D Boundary Condition line. Just like the **Stage Hydrograph** boundary, the **Normal Depth** boundary is computed on a per cell basis.

Rating Curve

The **Rating Curve** option can only be used to take flow out of a 2D flow area. The user is required to enter a stage (water surface elevation) versus flow relationship (rating curve) for this option. The rating curve is also applied on a per cell basis.

Spatially Variable Water Level Boundary Condition

Introduction

In HEC-RAS Versions 6.2 and earlier, the water level (i.e. stage) boundary condition can only be specified as single time-series per boundary condition line. In other words, the water level is spatially constant along the boundary condition line. In HEC-RAS 6.3, the option was added to specify a spatially variable water level boundary condition. This option is especially useful for nesting HEC-RAS within other models, such as ADCIRC. In this new feature, the user can specify any number of time series along a boundary condition line. The location of each water level time series is specified as a fractional distance along the boundary condition line. Open-source and prebuilt binary utilities have been developed which make it easier for users to extract water level time series along HEC-RAS boundaries. These utilities are described in subsequent sections and are provided to users so that they can be run on different platforms and operating systems. The utilities for interpolating water levels are specific to the ADCIRC model but the other models can be used if their output is converted to the ADCIRC format. The method for specifying the water levels along boundary condition lines is quite general and is not model specific.

Interpolating Water Level Time-Series from ADCIRC Solutions

For most practical applications, ADCIRC is run on very large computational domains for many events producing large computational meshes and solution files. In addition, ADCIRC is typically run on High-Performance Computers (HPC) which utilize a Linux type operating system while HEC-RAS is always run on desktop Windows computers. These factors complicate the extraction of HEC-RAS water level boundary conditions. With the utilities provided, it is possible to extract water level time series directly from the full domain ADCIRC simulations and then transfer the water level time series files from the HPC onto the computers running HEC-RAS. The disadvantage of this approach is that if the HEC-RAS boundary condition line or mesh are modified the user may need to repeat this step and transfer the water level time series files again from the HPC. An alternative approach is to extract water levels on an ADCIRC subdomain encompassing the HEC-RAS boundaries, transfer these files from the HPC, and then extract boundary water levels on the Windows desktop from the subdomain water level solution files.

Creating a Boundary Coordinates File

The Boundary Coordinates File is a simple Comma Separated File (CSV) which contains the WGS84 coordinates of the boundary faces. The coordinates are used to interpolate water levels from ADCIRC

simulation results. ADCIRC meshes are typically in Geospatial Coordinates while HEC-RAS projects are always in Projected Coordinates such as State Plane or UTM. The coordinates of the boundary faces can be viewed in the Geospatial Coordinate system WGS84 by right-clicking on the boundary and selecting **View WGS84 Coordinates of Faces ...** from the menu as shown in the figure below.
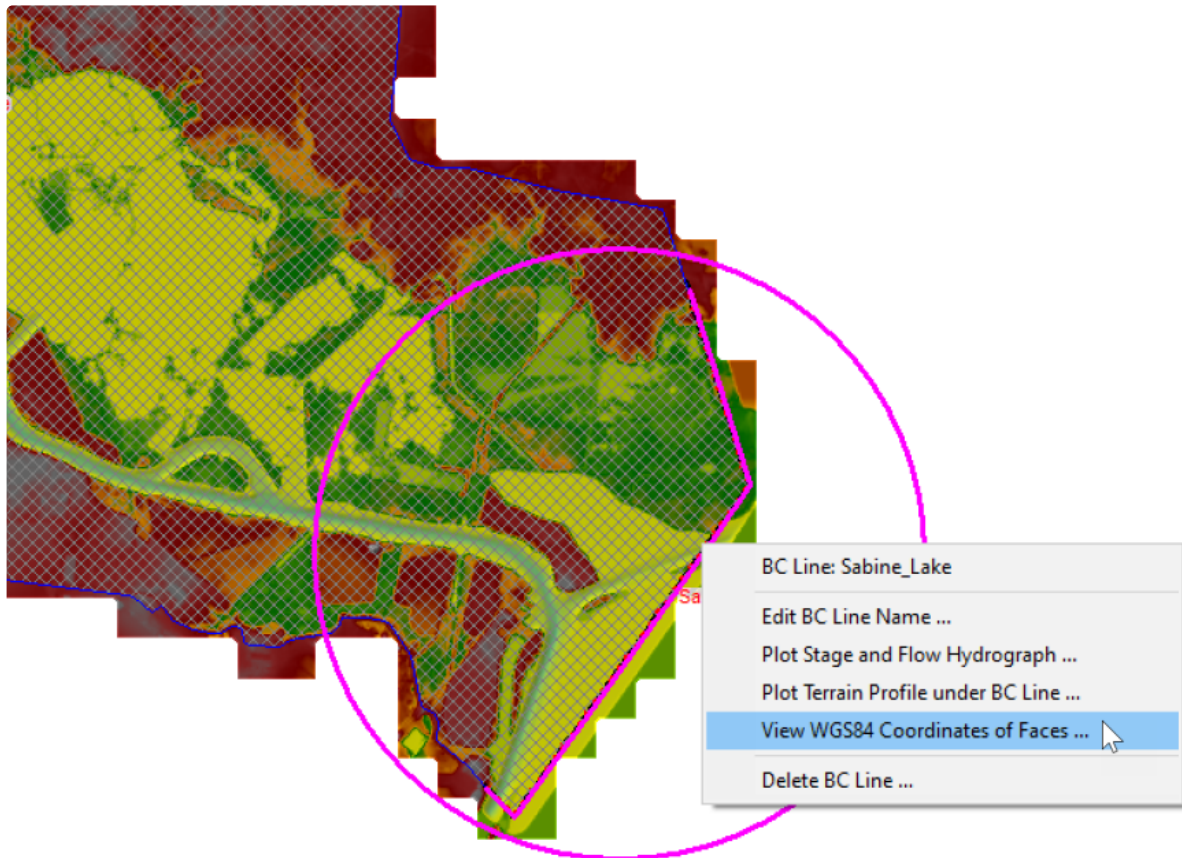

Figure 1. Menu to View WGS84 Coordinates of Faces.

HEC-RAS displays both the Projected and Geospatial (i.e. Longitude and Latitude) coordinates of the boundary face centers as shown in the figure below.

Face Centers for BC Line:Sabine_Lake

	Projected X(ft)	Projected Y(ft)	Longitude	Latitude
1	674526.129973785	2510384.43382045	-93.86822	29.9413
2	674863.873719196	2510012.04968899	-93.86718	29.94025
3	675267.737953915	2509566.76347921	-93.86593	29.939
4	675762.674283241	2509021.06444665	-93.86441	29.93748
5	676311.767669619	2509144.92891932	-93.86266	29.93778
6	676681.254802886	2509663.9208936	-93.86146	29.93918
7	676896.110980639	2509965.71389757	-93.86076	29.94
8	677228.80277283	2510433.02210538	-93.85968	29.94126
9	677583.492409394	2510931.22910141	-93.85852	29.94261
10	677833.011253537	2511281.71025726	-93.85771	29.94356
11	678060.532253309	2511601.2926249	-93.85696	29.94442
12	678426.516510371	2512115.36436117	-93.85577	29.94581
13	678676.035354514	2512465.84551702	-93.85496	29.94676
14	678892.261733788	2512769.56314442	-93.85425	29.94758
15	679224.953525979	2513236.87135223	-93.85317	29.94884
16	679578.272961022	2513733.15372483	-93.85202	29.95018
17	679827.791805166	2514083.63488069	-93.8512	29.95113
18	680056.683006458	2514405.14187175	-93.85046	29.952
19	680421.297061999	2514917.28898459	-93.84927	29.95338
20	680670.815906143	2515267.77014045	-93.84845	29.95433
21	680888.412486936	2515573.41239127	-93.84775	29.95515
22	681221.104279128	2516040.72059908	-93.84666	29.95641
23	681573.053512651	2516535.07834826	-93.84551	29.95775
24	681822.572356794	2516885.55950412	-93.8447	29.9587

Clipboard | Print ... | File ... | Close

Figure 2. HEC-RAS boundary condition face coordinates in both Projected and WGS84.

The columns for the Longitude and Latitude can be copy-pasted into a Boundary Coordinates File CSV file like the example shown in the figure below. The columns correspond to the Longitude and Latitude, respectively, of the boundary face center coordinates.

Figure 3. Boundary Coordinates CSV File.

Interpolating Water Level Time-Series at Boundary Condition Points from a Full ADCIRC Domain

The most direct way of obtaining water level time-series for a HEC-RAS boundary condition, is to directly interpolate the water-levels from a full ADCIRC domain. This can be done by either calling the **Nesting.exe** utility or by calling the Fortran library. Below are two examples of interpolating water levels from a full ADCIRC domain using the Nesting.exe utility.

```
>Nesting.exe -interpwse "fort.grd" "coordBoundary.csv" "Run1.63" "Run1.csv"
>Nesting.exe -interpwse "fort.grd" "coordBoundary.csv" "Run1.63" "Run1.csv" "Run2.63"
"Run2.csv" > log.txt
```

In the second example two ADCIRC runs are processed at the same time. Any number of ADCIRC simulations can be processes at the same time this way. It is noted that the output from the Nesting.exe command can be redirected to a log file using the ">" operator followed by the name of the output file. The second example above also shows how to redirect the command standard output to a log file called log.txt. When utilizing the Nesting.exe utility it is important that every file (including the executable) have correct paths if not in the local directly.
The code below shows an example Fortran code to extract point water level time series from a full ADCIRC domain. The ADCIRC water levels are stored in the ASCII

```
numWSEFiles = 3
gridFile = "fort.grd"
pointsCoordFile = " coordBoundary.csv"
solWSEFiles(1) = "Run1.63"
solWSEFiles(2) = "Run2.63"
solWSEFiles(3) = "Run3.63"
solWSEFiles(1) = "Run1.csv"
pointsWSEFiles(2) = "Run2.csv"
pointsWSEFiles(3) = "Run3.csv"
call
nesting_interpwse(childGridFile,pointsCoordFile,numWSEFiles,solWSEFiles,pointsWSEFiles,status,msg)
```

Creating an ADCIRC Subdomain

An ADCIRC subdomain is portion of an ADCIRC domain and is utilized here to extract ADCIRC water levels for a smaller region of the full ADCIRC domain. Subdomains have their own node and element indexes but include index maps to the full ADCIRC domain. In this way, every node of the subdomain can be easily mapped back to the full domain.

Creating a Subdomain Bounding Polygon

The spatial extent of the subdomain is specified with a bounding polygon. The coordinates of the bounding polygon are specified in a CSV file as shown in the figure below. The first and second columns correspond to the longitude and latitude of each polygon point. The polygon can have any number of points and the points can be in any direction (clockwise vs counter-clockwise). However, the points do need to be contiguous.

Figure 3. Subdomain Bounding Polygon CSV File.

Creating Subdomain Mesh

The main advantage of using ADCIRC subdomains is that it provides the user the flexibility to change the HEC-RAS boundary condition line and re-interpolate water level time series from the subdomain without having to go back to the full domain. In the example, below, the full domain ADCIRC mesh has about 9 million nodes while the subdomain has about 12 thousand.
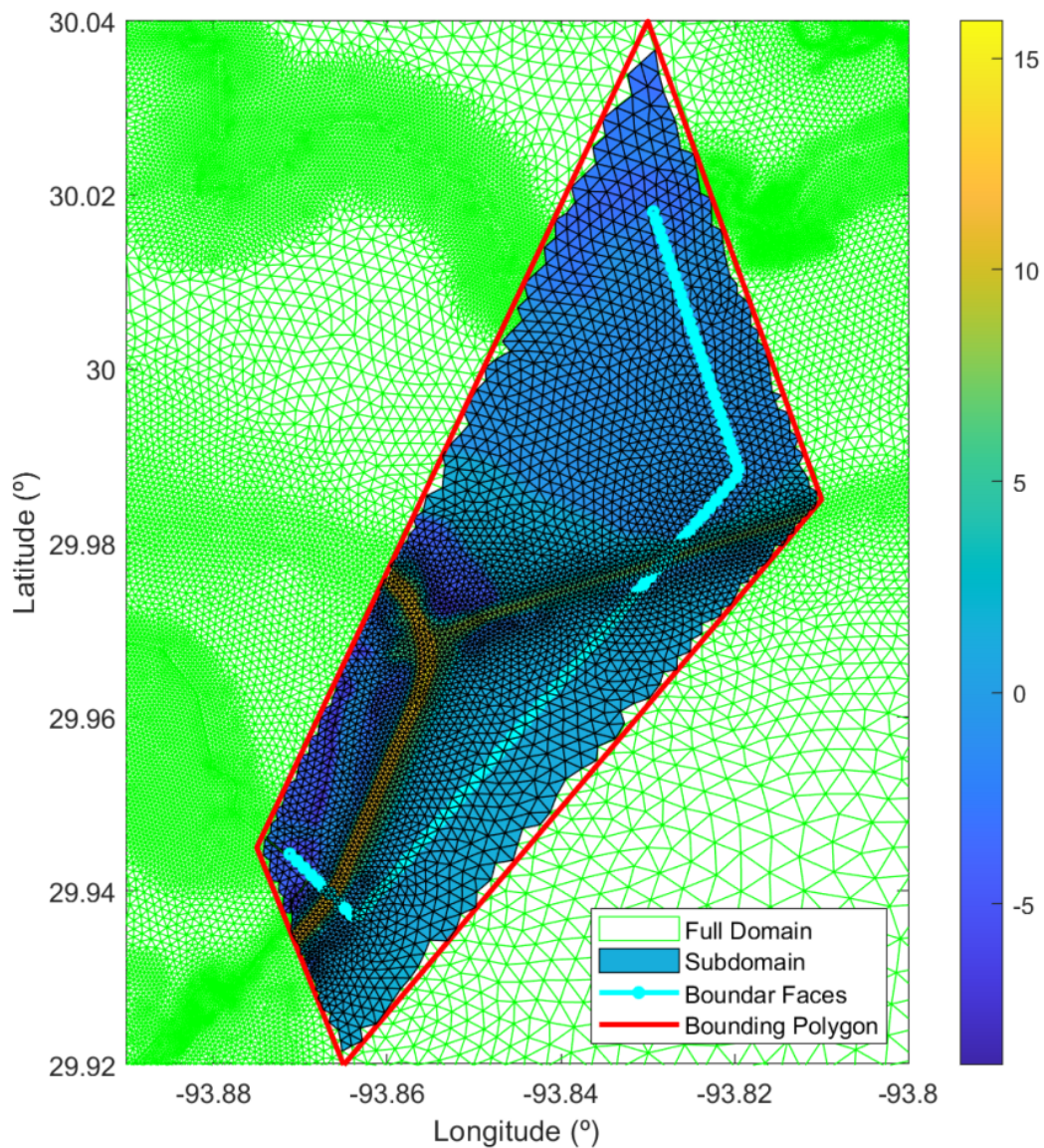
Figure 4. Example ADCIRC Full Mesh Nodes, Subdomain Nodes, Boundary Faces, and Subdomain Polygon.

The HEC-RAS nesting utility can be run from a Windows Command Prompt using the prebuilt executable, called as a library or batch script.

The example below shows how to run the Nesting.exe from the Command Prompt to create an ADCIRC Subdomain (Child Mesh) from a full Mesh (Parent Mesh) and a user-specified subdomain bounding polygon contained in a simple CSV file (Comma Separated Variables).

```
>Nesting.exe -gensub "Parent.grd" "polygonBoundary.csv" "Child.grd"
```

Similarly, the example below shows how to call the Fortran method to extract a subdomain.

```
parentGridFile = "Parent.grd"
polyFile = "polygonBoundary.csv"
childGridFile = "Child.grd"
call nesting_gensub(parentGridFile,polyFile,childGridFile,status,msg)
```

The format of the subdomain mesh file is similar to a regular ADCIRC mesh file except there is an additional column with the corresponding full mesh node indexes of each node subdomain node. An example subdomain file is shown below. The first line contains a header line. The second line contains the number of elements and nodes. The next section contains the columns, node index, node x-, y-, and z-coordinates, and corresponding full domain index number. The next section contains the 5 columns contains the element index, the number of nodes per element (always 3 in the case of ADCIRC), and the node indexes for each element. The subdomain utilized here does not contain any boundary strings since the file is not intended for model simulations.
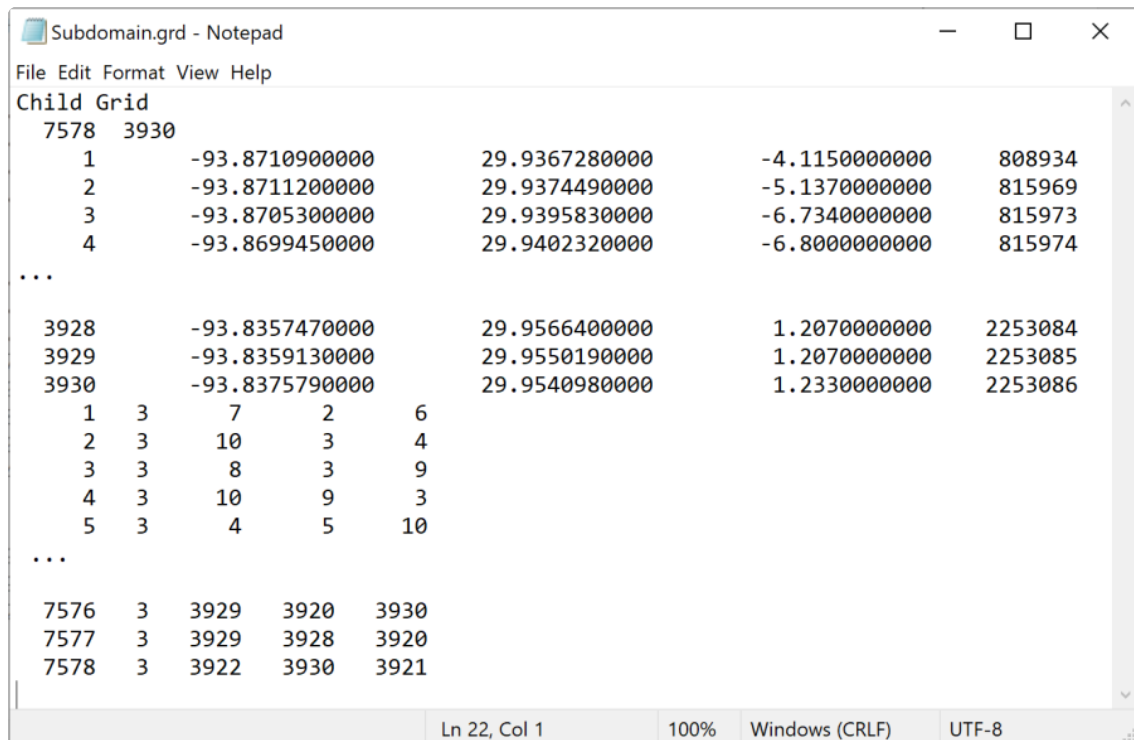
Figure 5. Example subdomain mesh file.

Extracting Water Levels on the ADCIRC Subdomain

Water levels can extracted from the full domain onto the subdomain by either running the Nesting.exe utility or calling the Fortran library. Below is an example of using the Nesting.exe utility.

```
>Nesting.exe -extractwse "Child.grd" "Parent_Run1.63" "Child_Run1.63"
>Nesting.exe -extractwse "Child.grd" "Parent_Run1.63" "Child_Run1.63" "Parent_Run2.63" "Child_Run2.63"
```

It is noted that any number of runs can be processes with a single argument

```
numWSEFiles = 3
childGridFile = "Child.grd"
parentWSEFiles(1) = "Parent_Run1.63"
parentWSEFiles(2) = "Parent_Run2.63"
parentWSEFiles(3) = "Parent_Run3.63"
childWSEFiles(1) = "Child_Run1.63"
childWSEFiles(2) = "Child_Run2.63"
childWSEFiles(3) = "Child_Run3.63"
call nesting_extractwse(childGridFile,numWSEFiles,&
parentWSEFiles,childWSEFiles,status,msg)
```

Interpolating Water Level Time Series at Boundary Condition Points from Subdomain

Water levels are interpolated from the subdomain at user-specified points. Generally, the points will correspond to the face centers of a boundary. However, the points can be any points along the boundary as long as the fraction distances along the boundary are specified appropriately. An example is provided below on using the Nesting.exe utility to interpolate points from two ADCIRC runs which have been extracted onto the same subdomain.

```
>Nesting.exe -interpwse "Child.grd" "coordBoundary.csv" "Child_Run1.63"
"wseBoundary_Run1.63" "Child_Run2.63" "wseBoundary_Run3.63" 3.280839895
```

If multiple runs are extracting within the same command, the runs must share the same grid. The last argument is a units conversion factor for the water levels between ADCIRC and HEC-RAS. Generally, ADCIRC water levels will have units of meters while HEC-RAS will have units of feet.

The same task can be done by calling the Fortran library.

```
childGridFile = "Child.grd"
pointsCoordFile = "coordBoundary.csv"
childWSEFiles(1) = "Child_Run1.63"
childWSEFiles(2) = "Child_Run2.63"
childWSEFiles(3) = "Child_Run3.63"
pointsWSEFiles(1) = "wseBoundary_Run1.csv"
pointsWSEFiles(2) = "wseBoundary_Run2.csv"
pointsWSEFiles(3) = "wseBoundary_Run3.csv"
factor = 3.280839895D0
call
nesting_interpwse(childGridFile,pointsCoordFile,numWSEFiles,childWSEFiles,pointsWSEFiles,factor,status,msg)
```

Interpolating Water Level Time-Series from ADCIRC Save Points

Save Points are user-specified locations where various output time-series are output. Usually, the output time interval for Save Points is finer than for global output results. In some cases, it may be desirable to interpolate water levels from ADCIRC Save Points.

Triangulating Save Points

Save points are triangulated within a bounding polygon. This saves memory and time. As similar approach is adopted as in creating a subdomain in which the Save Point triangulation is stored in *.grd file with the subdomain format. Below is an example of triangulating water levels from ADCIRC Save Points using the Nesting.exe utility.

>Nesting.exe -trisp "elev_stat.151" "polygon.csv" "SavePointTriangulation.grd"

The first argument "-trisp" is the command for Save Point Triangulation. The file "elev_stat.151" contains the coordinates of the save points. The third argument "polygon.csv" is a CSV file containing a bounding polygon for the points which will be triangulated.

The same task can be done by calling the Fortran library as in the example below.

savePointFile= "elev_stat.151"
polyFile= "polygon.csv"
childGridFile= "SavePointTriangulation.grd"
call nesting_trisp(savePointFile,polyFile,childGridFile,status,msg)

The triangulation is computed with Delaunay triangulation. An example Save Point triangulation is shown in the figure below. It is noted that the bounding polygon for the Save Point triangulation is larger than the bounding polygon for the boundary condition faces.
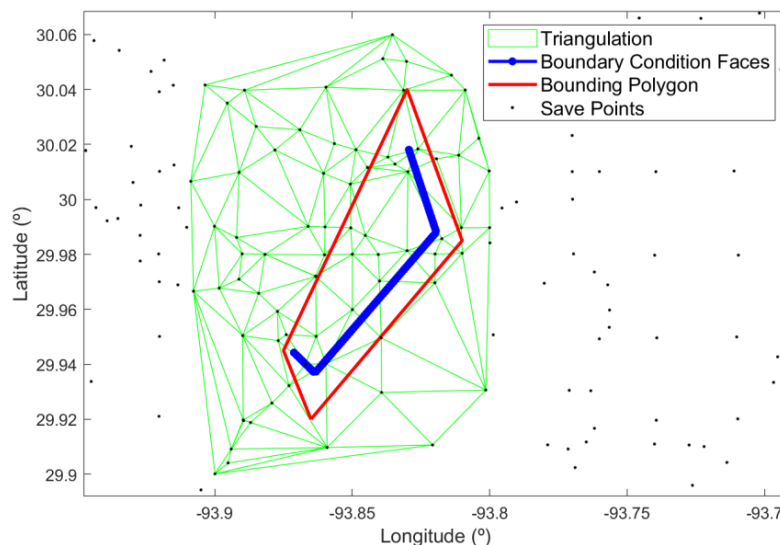
Figure 6. Example Triangulation of ADCIRC Save Points around an HEC-RAS Boundary Condition, and bounding polygon.

Extracting Water Levels on Triangulated Save Points

Water levels on the Triangulated Save Points can be extracted from the larger set of Save Points using the Nesting.exe utility with the following command:

>Nesting.exe -extractwse "SavePointTriangulation.grd" "fort.61" "TriangulationWaterLevels.61"

The second argument is the same as when extracting water levels on a subdomain from a full domain. This is possible because the Save Point triangulation is stored as a triangular unstructured mesh in the same format as the ADCIRC subdomain.

The same task can be done by calling the Fortran library as in the example below.

```
numWSEFiles = 1
childGridFile= "SavePointTriangulation.grd"
parentWSEFiles(1) = "fort.61"
childWSEFiles(1) = "SavePointWaterLevels.61"
call nesting_extractwse(childGridFile,numWSEFiles,parentWSEFiles,childWSEFiles,status,msg)
```

Interpolating Water Levels from Triangulated Save Points

Save Points are user-specified output locations which are generally output at a higher output interval than the global output variables.

>Nesting.exe -interpwse "Child.grd" "coordBoundary.csv" "SavePointWaterLevels.61" "wseBoundarySavePoint.61" 3.280839895

The same task can be done by calling the Fortran library.

```
numWSEFiles = 1
childGridFile= "SavePointTriangulation.grd"
pointsCoordFile = "coordBoundary.csv"
childWSEFiles(1) = "SavePointWaterLevels.61"
pointsWSEFiles(1) = "wseBoundarySavePoint.csv"
factor = 3.280839895D0
call
nesting_interpwse(childGridFile,pointsCoordFile,numWSEFiles,childWSEFiles,pointsWSEFiles,factor,status,msg)
```

Specifying Spatially Variable Water Level Time Series in the HEC-RAS DSS Viewer

Spatially variable water level time series are specified using a similar approach to the stage hydrograph boundary condition from a DSS file. Spatially variable water levels can only be specified from a DSS file. Data in a different format can be imported into a DSS file using the HEC-RAS DSS viewer as discussed below. The main difference is that the spatially constant and spatially variable water level boundary condition DSS file will have multiple columns each corresponding to a different point along a boundary condition. It is important to recognize that the number of columns or water level time series does not have to match the number of faces along a boundary condition. The location of each water level time series is specified as a fractional distance from 0 to 1 along the boundary condition line. This approach allows for more flexibility in the specifying the boundary water levels.

The first step in specifying a spatially variable water level time series is to open the HEC-RAS Unsteady Flow Data editor, select the **2D Flow Area Boundary Condition Location**, and then select the **Stage Hydrograph Boundary Condition Type**, as shown in the figure below.
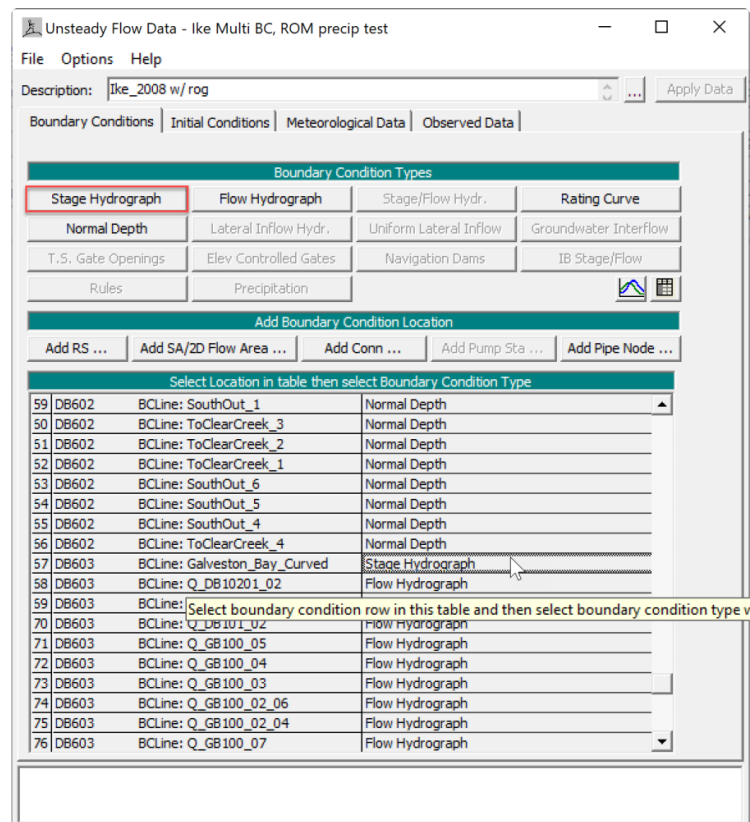
Figure 7. Selecting the Stage Hydrograph Boundary Condition in the Unsteady Flow Data Editor.

Within the **Stage Hydrograph** editor, select **Read from DSS before simulation**, and then click on the button which reads **Select DSS file and Path**, as shown in the figure below. This will open the HEC-RAS DSS viewer.

Figure 8. Selecting the DSS option for the Stage Hydrograph boundary condition.

Within the HEC-RAS DSS viewer, select the menu **Utilities | Time Series Import ...** as shown in the figure below.

Figure 9. Selecting the option to import Time-Series in the HEC-RAS DSS Viewer.

Within the **Write Time Series Data to DSS** editor, specify the path and name of the DSS file which will be used to store the water level time series (see figure below). It is recommended to use a separate file from other existing DSS file. The DSS parts A, B, C, and F are not utilized in this case but must have a value specified. For simplicity the example below uses the lower case names of the DSS path parts. The Date must be specified with the format DDMMMYYYY and the time as HHMM. A constant time interval can be selected from a drop down. The units for water levels are typically feet or meters and the data type must be INST-VAL indicating instantaneous values.

Figure 10. Example general input parameters for importing water level time series in the HEC-RAS DSS viewer.

The next step is to select the number of columns by clicking on the button as shown in the figure below. After clicking **OK**, another window will appear where the time series locations specified as fractional distances along the boundary condition line are specified. These are referred to as profile numbers in DSS. The easiest way to do this is to copy-paste the values from an Excel spreadsheet. The nesting utility produces a CSV file where the first row is the fractional distances of each column. The row values cannot be copy-pasted into the HEC-RAS table, and need to be transposed first. This can easily be done in Excel.

Figure 11. Entering the number of columns and face fractions as profile numbers.

Once the number of columns and column profile numbers have been specified, the next step is to specify the time series data. This is done by selecting the top-left cell in the table and copy-pasting all of the data from a spreadsheet. Then the data can be exported into the DSS file by selecting the **Export Time Series to DSS file** button. Click **OK** in the window with the message **Successfully exported time series to DSS file**. Then close the **Write Time Series Data to DSS** editor (see figure below).

Figure 12. Copying the water level time series in the HEC-RAS DSS viewer and exporting the data to a DSS file.

Once the water level data is exported to the DSS file, the file needs to be dataset file and path need to be selected in the HEC-RAS DSS viewer (see figure below).
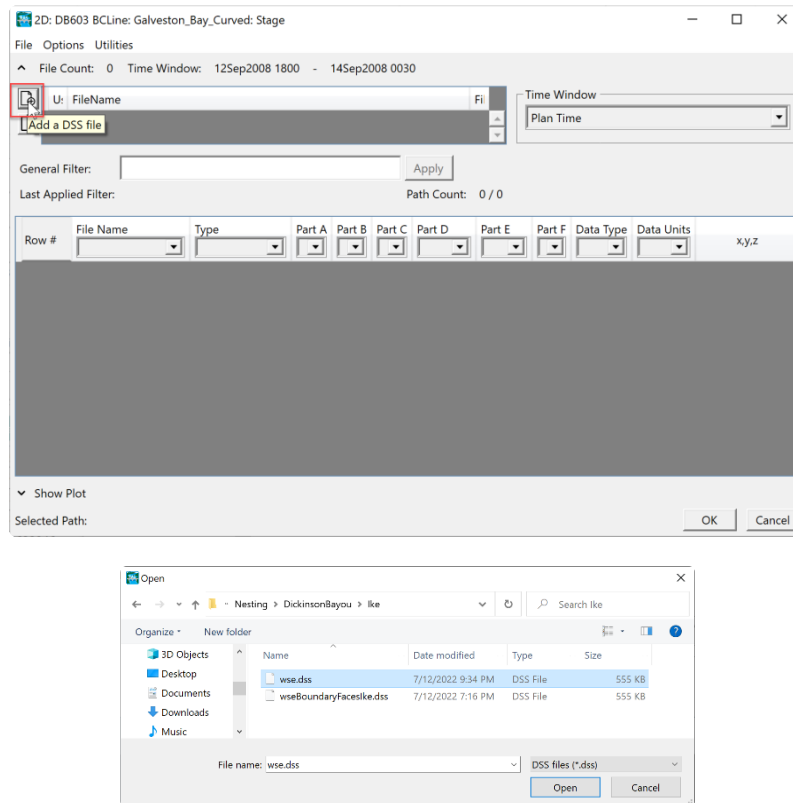
Figure 13. Selecting the DSS file with the spatially variable water level time series.

Then the DSS record path is selected as shown in the figure below. While highlighting the appropriate DSS file, select the DSS record by double clicking on the appropriate row. If the HEC-RAS project has many DSS files, it can be easier to remove the used DSS files or unselect them to reduce the number of records to choose from. Once the DSS record is selected, click on the **OK** button to exit the HEC-RAS DSS viewer.
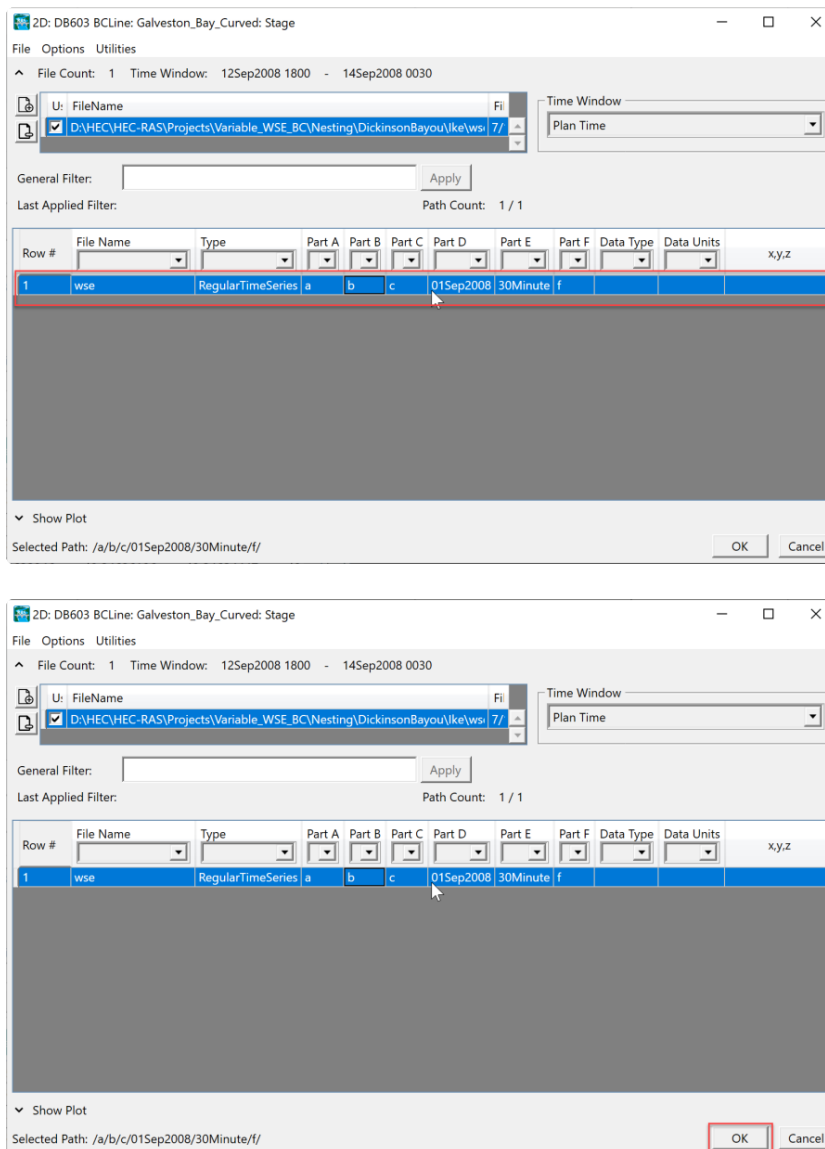
Figure 14. Selecting the DSS file and path.

Once in the **Stage Hydrograph** editor, check the DSS data by clicking the **Plot Data** button as shown in the figure below.

Figure 15. Plotting the DSS time series.

It is noted, that dry water surface values in ADCIRC are stored as -99999. These values will not plot well and may require the user to zoom in to viewer the data correctly. The dry values are handled inside the unsteady computational engine.

Internal Boundary Conditions

Internal Flow Hydrograph

The user has the option to add a flow hydrograph as an internal boundary condition. To add an internal boundary condition line, from the **Geometric Data** editor, select the **SA/2D Area BC Lines** tool, then draw an internal line inside of the 2D Flow Area (shown below). The internal boundary condition (BC) line can encompass one or more 2D cells. Once the line is drawn, a name for the BC line must be entered. An example of a created internal BC line named "*Internal BC*," as well as an example of an external BC line (labeled "*edge BC*") is shown in the figure below.
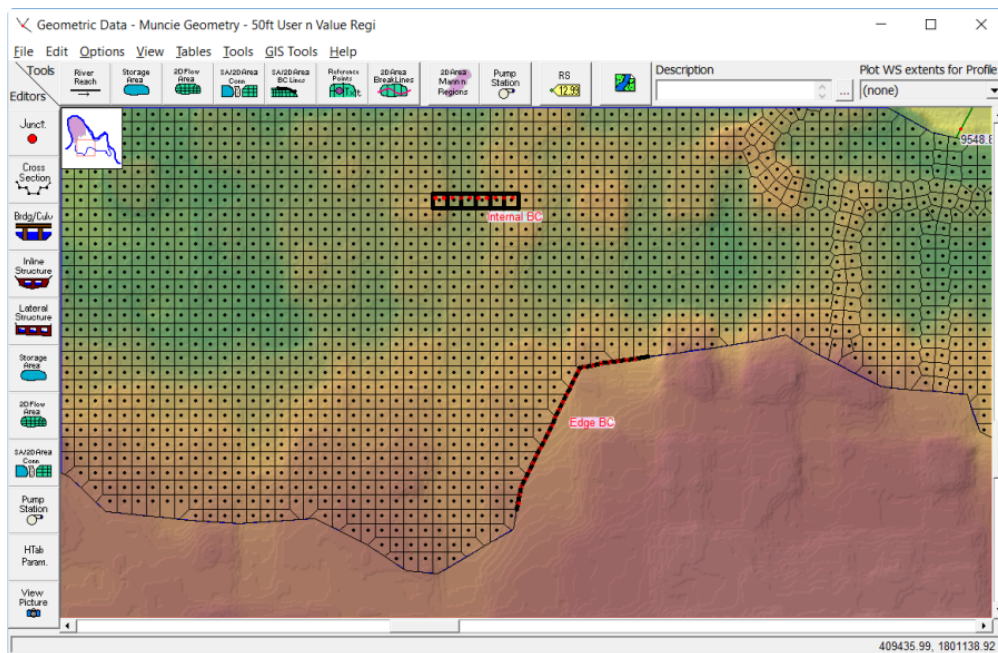
After an internal BC line is drawn in the **Geometric Data** editor, the user can open the **Unsteady Flow Data** editor (opened from the HEC-RAS main window by clicking the [ ] button) to attach flow hydrographs to the internal BC lines. Once the **Unsteady Flow Data** editor is open (shown in the figure below), select the **Boundary Conditions** tab, and view in the "Storage/2D Flow Areas" table that there is a row for the newly created internal boundary condition line(s) (e.g., *2D Interior Area BCLine: Internal BC* in Figure 4-4) that were created in the **Geometric Data** editor.

Figure 4-4. Unsteady Flow Data Editor with Example Internal BC Line.

As shown in the figure above, the created internal BC lines will be listed in the boundary conditions table, and will allow the user to attach a flow hydrograph to a selected BC line. If the BC line crosses more than one cell, flow is distributed across the cells based on the percentage of the line length that crosses that cell. For example, if a cell contains 20% of the BC line length, then the cell will receive 20% of the flow each time step.

Use with HEC-HMS Results

When using results supplied by HEC-HMS within a 2D Flow Area as internal boundary conditions, special care needs to be taken to avoid double routing. Specifically, when using unit hydrograph transform methods (e.g., ModClark) within HEC-HMS to compute subbasin outflow hydrographs, the computed results represent discharges AT THE OUTLET and SHOULD NOT be distributed over a significant longitudinal length (e.g., greater than 1 mile) or area.

In general, HEC-RAS boundary condition lines should be drawn perpendicular to expected flow paths at the location of interest. If an internal boundary condition line is drawn along the watercourse a significant distance upstream of the outlet of the subbasin, the peak flow and resulting elevation

from HEC-RAS will be underestimated due to double routing of the hydrograph from HEC-HMS. If there are additional locations upstream of the subbasin outlet where flow estimates and stages are important, additional subbasin delineations will be required rather than applying the hydrograph over a long longitudinal distance.

Precipitation

This **Precipitation** option can be used to apply rainfall excess (rainfall minus losses due to interception and/or infiltration) directly to a 2D flow area. To apply a precipitation boundary condition to a 2D flow area (or storage area), open the **Unsteady Flow Data** editor and select the button that is labeled **Add Storage Area** from the **Add Boundary Condition Location** table. Select the 2D flow area of interest to add to the table. Once the 2D flow area is in the **Select Location in table then select Boundary Condition Type** lower table, select the blank field under the **Boundary Condition** column (shown in the figure above), then select the **Precipitation** boundary condition type. The Precipitation boundary condition type selection opens an editor that will allow users to either read the precipitation data from HEC-DSS or enter the data as a time series into a table directly. Precipitation is applied equally to all cells within the 2D flow area.

> (i) **NOTE:** This is the older method for adding precipitation data into HEC-RAS. Newer capabilities have been added to HEC-RAS Version 6.0 that allow for spatially distributed rainfall. See the section below on "Global Boundary Conditions for further information."

Global Boundary Conditions

HEC-RAS now has the capability to have spatially varying precipitation, evapotranspiration, and wind. Spatial precipitation, evapotranspiration, and wind data are added into the Unsteady Flow Boundary Conditions editor from the **Meteorological Data** Tab.

Precipitation Data

Spatial precipitation and evapotranspiration can be entered into HEC-RAS as either gridded data, point gage data, or a constant rate. The spatial precipitation and evapotranspiration data are added into HEC-RAS through the **Unsteady Flow Boundary Conditions** editor. From the **Unsteady Flow Boundary Conditions** editor, select the **Meteorological Data** tab and the editor will update (Figure 1). As shown in Figure 1, the user can enter precipitation data in either gridded or point gage formats.

Gridded Precipitation

To enter gridded precipitation data, first the user must select "**Enable**" from the "**Precipitation/ Evapotranspiration:**" selection box, located at the upper left of the tab. Next the user must then select **"Gridded"** from the **Mode** selection box in the **Meteorological Variables** section of the editor. Next, click the **Edit** button (located to the right of the Mode selection box) (Figure 1).
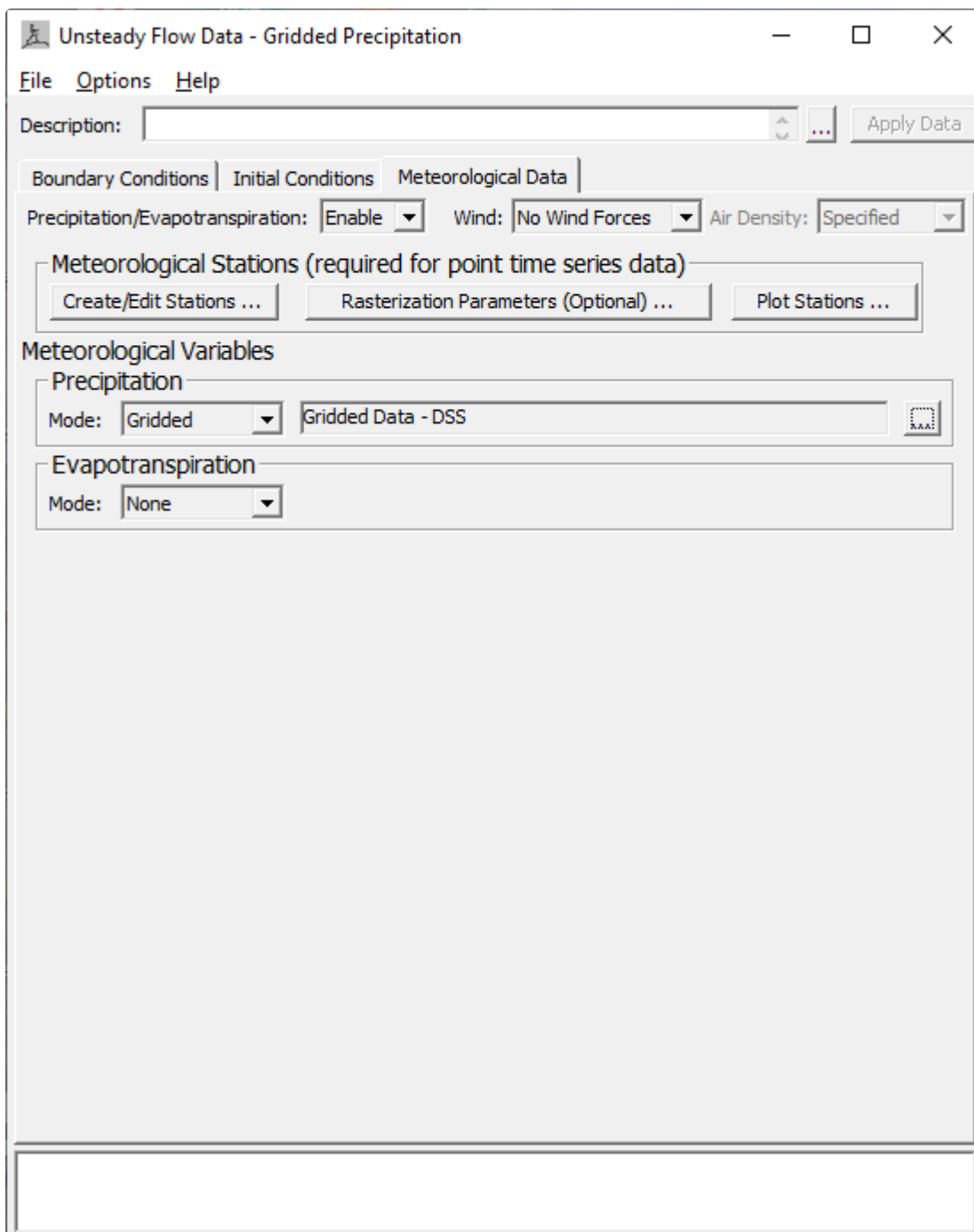
Figure 4-5. Example Unsteady Flow Boundary Condition editor with Meteorological Data tab open.

Figure 1. Meteorological Data tab with Gridded DSS precipitation data.

Selecting the **Edit** button updates the **Unsteady Flow Data** editor, **Meteorological Data** tab to include the sections displayed in Figure 2.
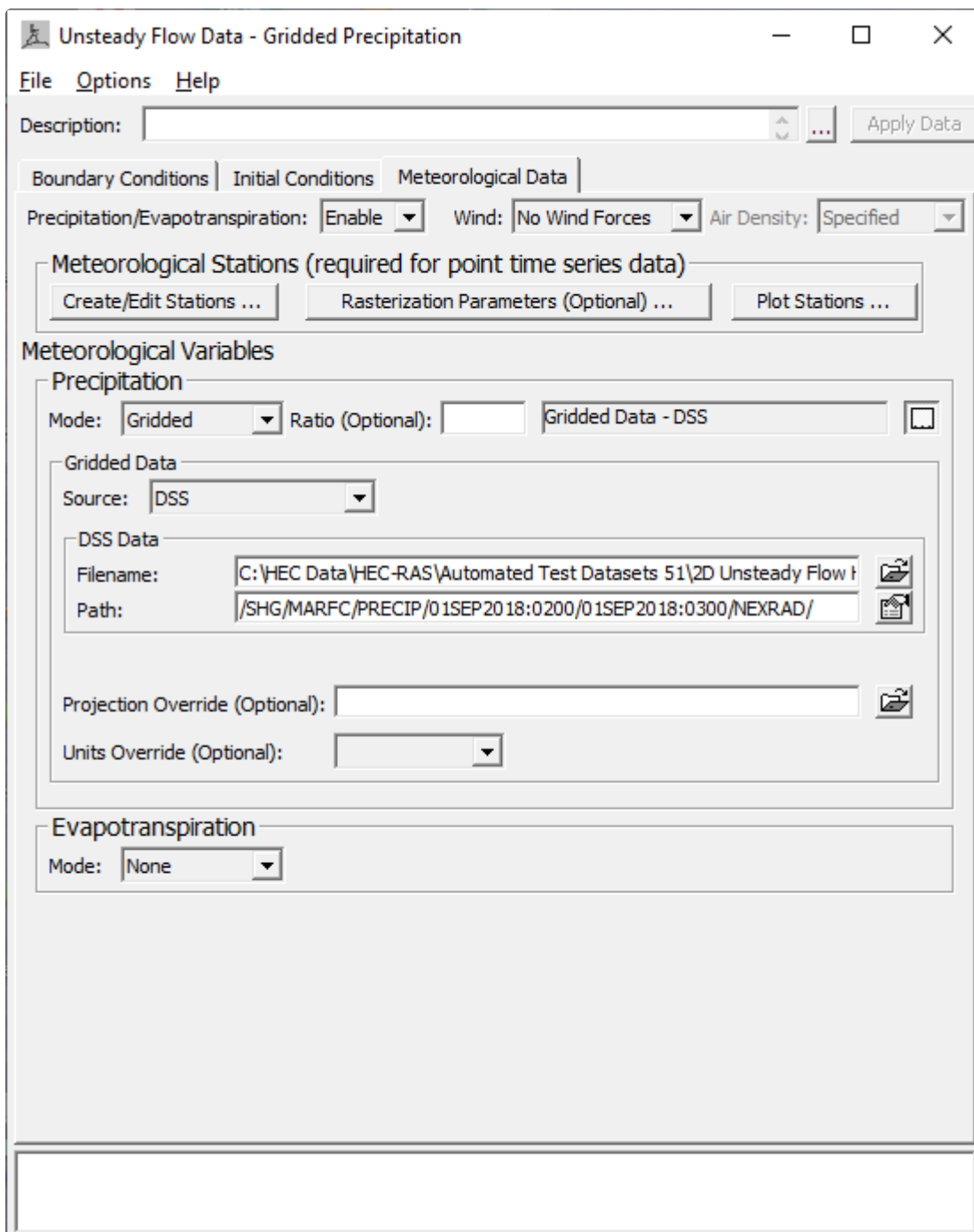
Figure 4-6. Unsteady Flow Data Window with Gridded Precipitation Data from HEC-DSS.

Figure 2. *Meteorological Data tab with Gridded DSS precipitation data and input options.*

As shown in Figure 2, the user must select a data **Source** for the gridded data from the following options:: HEC-DSS and GDAL Raster Files (Single Raster File or Multiple Raster Files). If the "GDAL Raster Files" option is selected, that data must be in either the **NetCDF** or the **GRIB** file formats. These are National Weather Service (NWS) file formats for NWS gridded data. Once the user selects a data source, then the user should use the **Open File** 📂 icon next to the filename field to select the

source file. If a **DSS** file type is selected, a DSS Pathname chooser will open once the DSS file is selected. The user must choose the DSS pathname that want to use for reading the gridded precipitation data from DSS. If the data is being read from either the **NetCDF** or **GRIB** file formats, the user must go through an import process to bring the data in before it can be used. This import process is explained in the **Wind** data section of this manual (both meteorological variables use is the same process for GDAL gridded data sources).

Additional options for the selected source gridded data are: Ratio, Projection Override, and Units Override. The **Ratio** option allows the user to multiple all of the precipitation by a user specified ratio. For example, if the user enters "5" in the ratio field, then all the precipitation values will be multiplied by 5 before being used. The **Projection Override** option allows the user to override the horizontal projection found in the file being read. This override option is generally only needed if the software is unable to understand the projection information stored in the gridded data file. The **Units Override** option allows the user to override the units of the data. This option is also only needed if the software has trouble detecting the units of the data from the meta data contained within the gridded data file.

Once the gridded precipitation is defined in the **Unsteady Flow Data** editor (Figure 2), and saved, the user can visualize the precipitation data in HEC-RAS Mapper. Gridded precipitation can be viewed as spatial maps in both an incremental (e.g., hourly) and a accumulated form. This precipitation data is available from the RAS Mapper, Layers tree, under **Event Conditions** (Figure 3). Shown in Figure 3 is an example incremental precipitation map. These incremental maps can be animated over time by pressing the green **Play** button at the upper left of the RAS Mapper window.
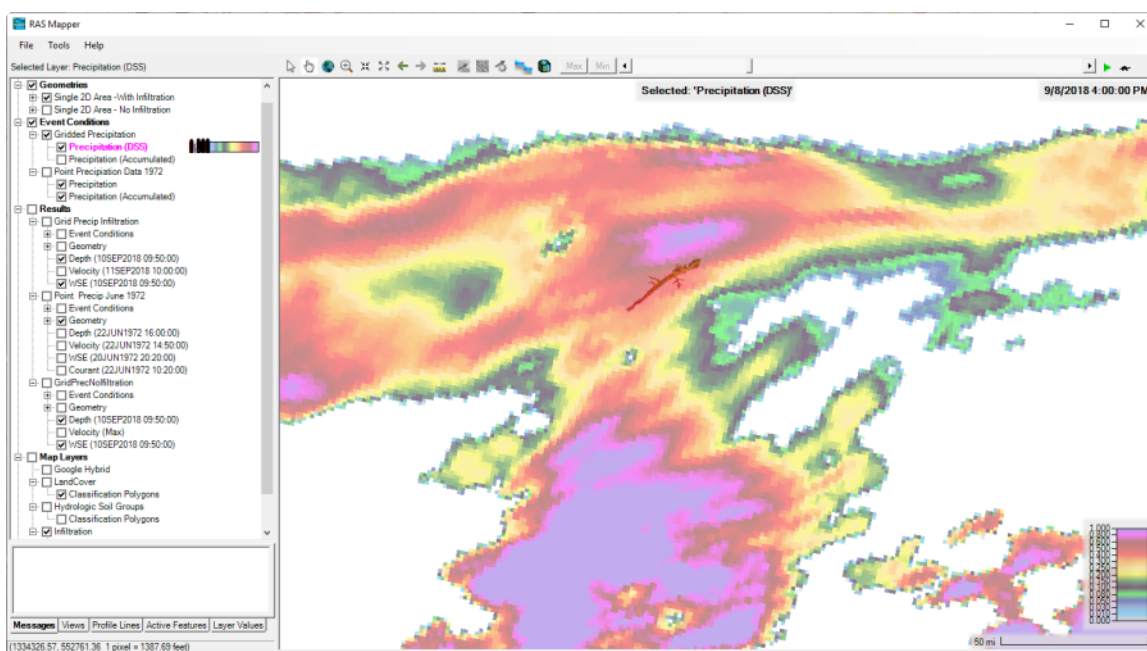
Figure 4-7. Example Incremental Precipitation Map

Figure 3. Example gridded precipitation rates in the RAS Mapper Event Conditions.

The example provided in Figure 4-8 displays an accumulated precipitation map.
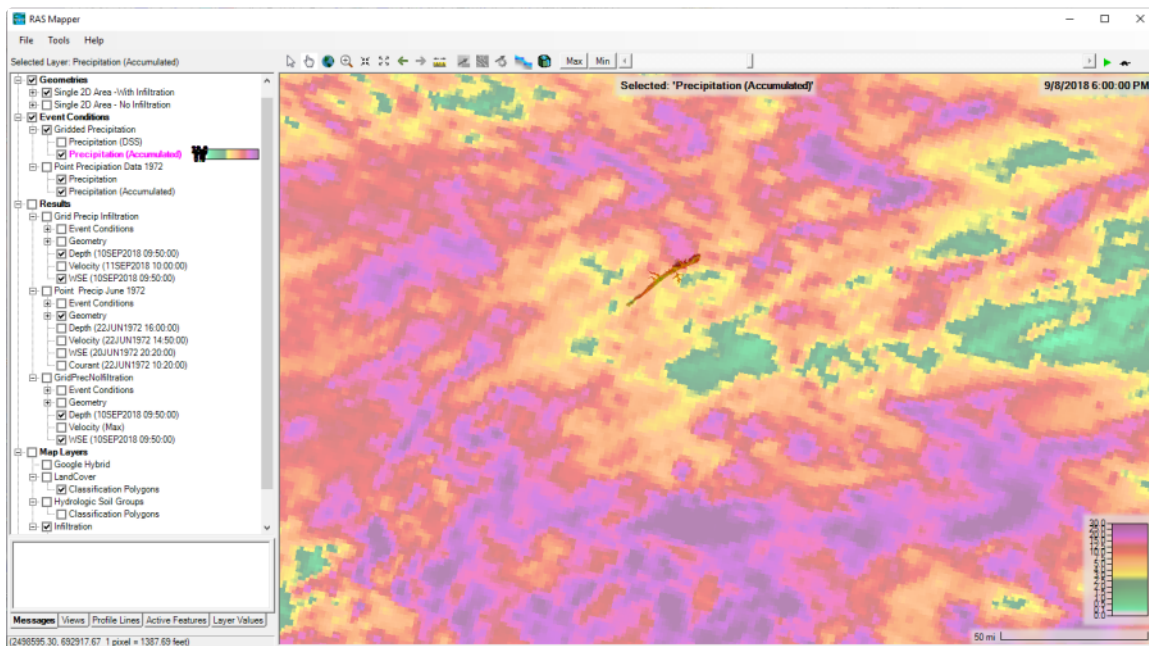
Figure 4-8. Example Accumulated Precipitation Map.

Figure 4. Example accumulated precipitation map in the RAS Mapper Event Conditions.

In addition to spatial maps, precipitation can be plotted at a point location for both incremental and accumulated precipitation data. With the two map types turned on (by checking ☑ the checkbox for the layer), from the map window right click at any location and from the shortcut menu select either: **Plot Precipitation** or **Plot Accumulated Precipitation** to open a RAS Mapper Plot of the data at the selected location. An example of a plot of incremental precipitation at a point location is shown in Figure 5.
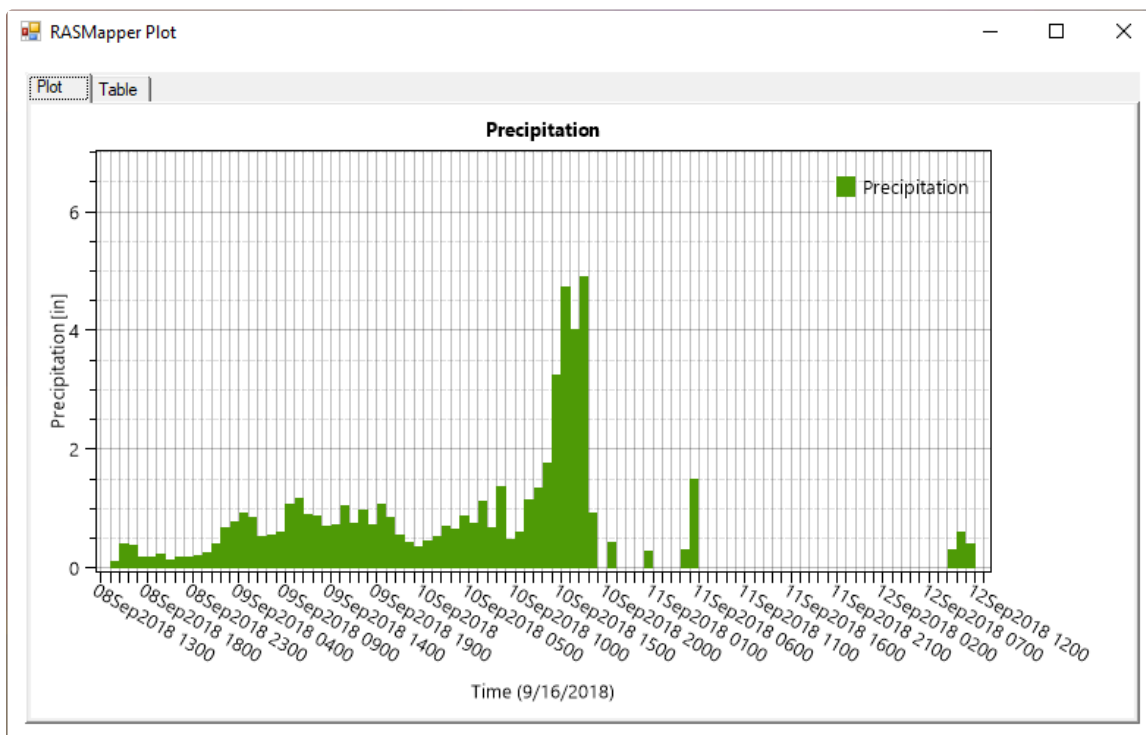
Figure 4-9. Example incremental precipitation plot at a point location.

Figure 5. Example time series of incremental precipitation rates.

An example of an accumulated precipitation plot from a point location is shown in Figure 6.
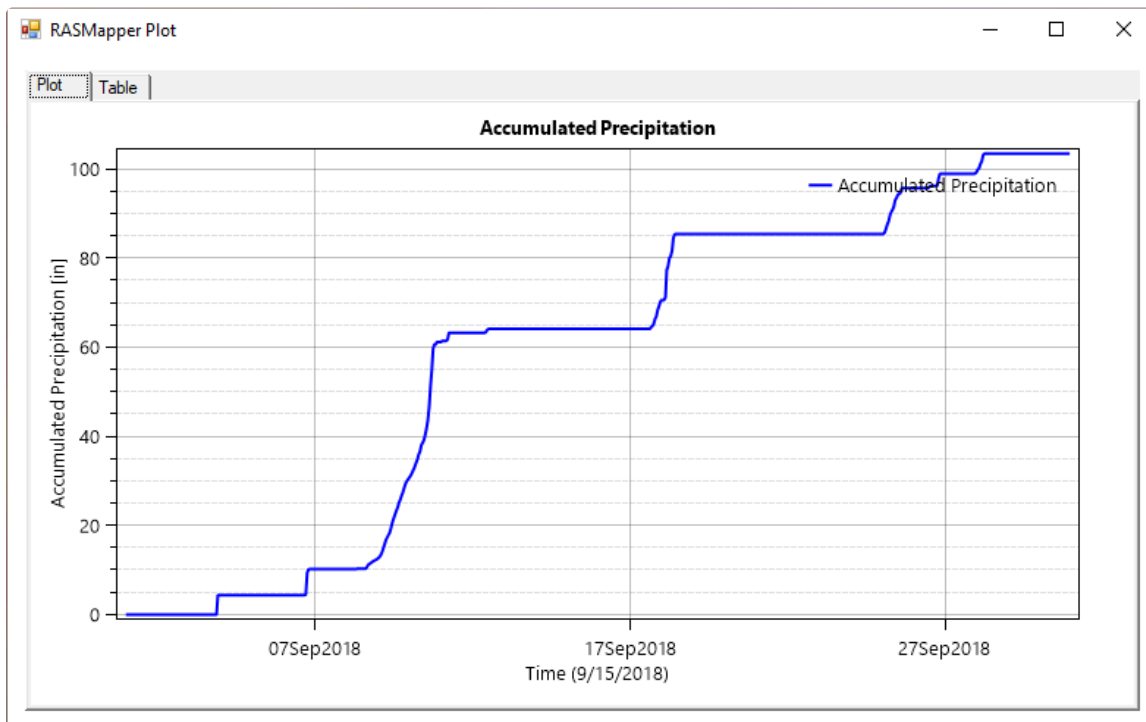
Figure 4-10. Example of an Accumulated Precipitation Plot from a Point Location.

Figure 6. Example time series of Accumulated Precipitation at a point.

Once the user makes a model run, this same type of information and plotting capability is available from the **Results | Event Conditions** shortcut menu for a specific Plan.

Point Gage Precipitation

Users can also enter precipitation data as point gage data in HEC-RAS. This data is then interpolated in order to convert it to a gridded data form, which is how the computational engines use the data.

To enter point gage data into HEC-RAS, open up the **Unsteady Flow Data** editor, then select the **Meteorological Data** tab. The editor will update as shown in Figure 7.
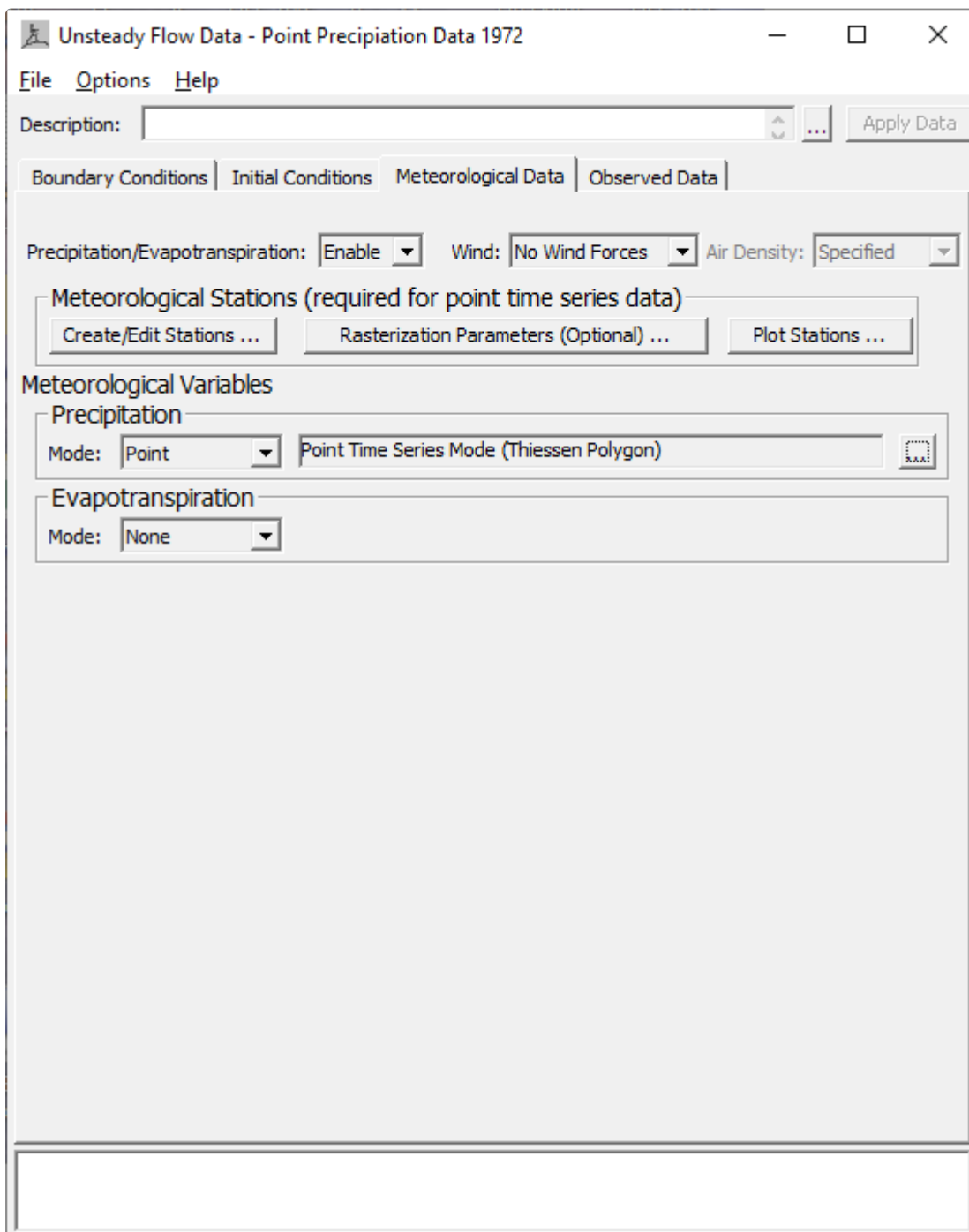
Figure 4-11. Meteorological Data tab with point gage data being used.

Figure 7. Example Meteorological tab showing point precipitation data specified at Meteorological Stations.

To enter or edit gaged precipitation data, the user must press the **Create/Edit Stations** button first (Figure 7). This button will open the **Meteorological Stations** window, select the **Table** tab (Figure 8) to view the point gage Meteorological Station table. The Meteorological Stations table is used to enter the **Name** of the gage, and the **X, Y coordinates** of the gage location. Users can enter the gage

location in either Latitude/Longitude, or in the project X, Y coordinate system (this is based on the horizontal coordinate system setup for the RAS Mapper project). Users must first fill out all of the gage Point Names (or gage locations). The tab labelled "**Detailed**," allows the user to create one gage at a time, rename a gage, and delete a gage.

Figure 4-12. Point gage Meteorological Station Table for entering Gage Names and locations.

Figure 8. Meteorological Stations editor showing the Geographic and Projected station coordinates.

Then, under the **Meteorological Variables** section of the editor, the user should select the **Point** method from the **Precipitation Mode** dropdown. Next press the **Expand/Edit** button to view the additional point data information. The **Point Time Series Data** will open, allowing the user to select one of the **Interpolation Methods** and for each individual point gage in the **Point Time Series Data** table (Figure 9), click the **Edit** ⌨ button to edit or enter data for each of the individual point gages. See Figure 4-13 below.

Figure 9. Example precipitation data specified at Meteorological Stations.

For each of the gages that the user would like to use for the event being modelled, the user must **Edit** each of the individual point gages in order to define the precipitation and turn that gage on for use. Click the **Edit** 🖱 button to open the **Point Meteorological Time Series** window for the selected gage (Figure 10).
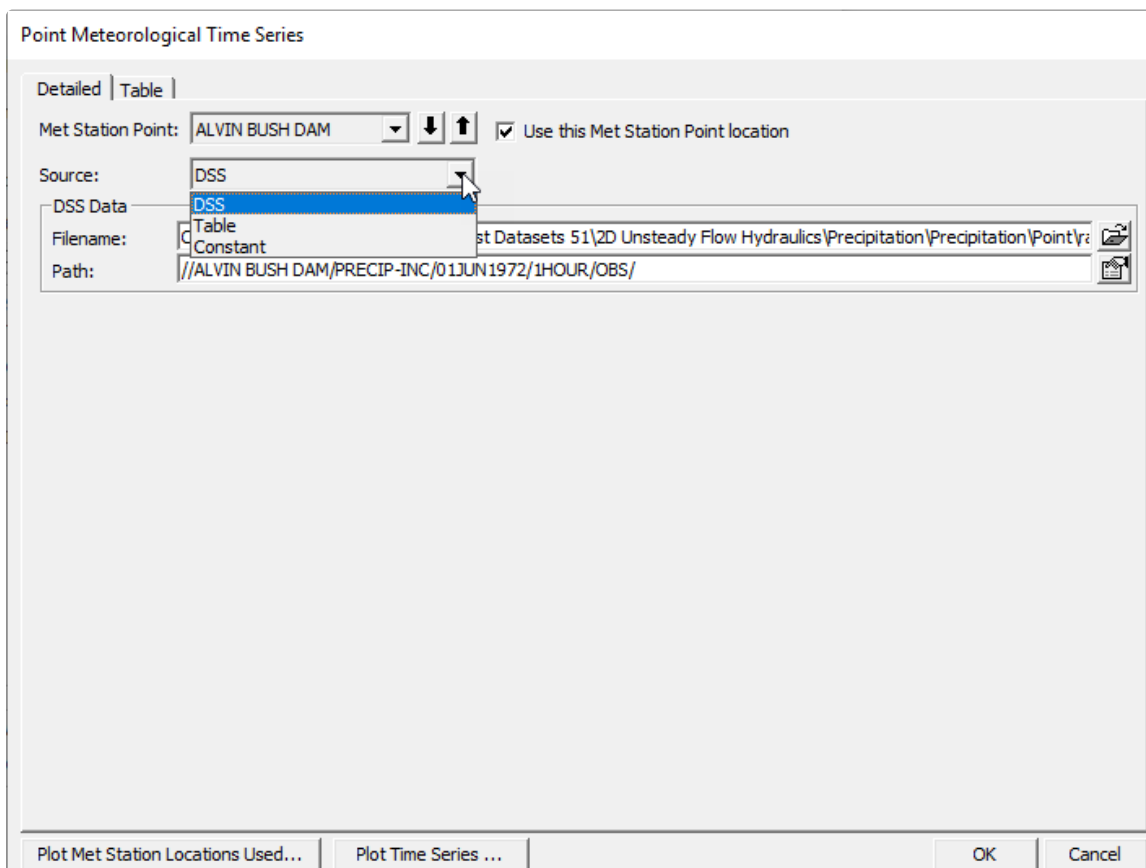
Figure 4-14. Point Precipitation Gage editor.

Figure 10. Example DSS time series of hourly precipitation data.

As shown in Figure 10, the user must also select the **Source** for the data. The data **Source** can be: DSS (HEC-DSS), Table, or a Constant value (e.g., 1.5 in/hr). If DSS is selected, then the user must select the appropriate HEC-DSS file and also the specific HEC-DSS pathname that contains the correct data for the specific gage and the event being modelled.

For the point gage data to be used in the analysis, the user MUST check the **Use this Met Station Point location** ☑ checkbox. If this box is not checked, then the selected gage (e.g., *ALVIN BUSH DAM* in Figure 4-14) will not be used in the analysis. This option allows user to turn on or off various gages in order to experiment with the effect of different gages being included or not. The user must check this checkbox for all the desired gages to be used in the analysis. From the Point Meteorological Time Series window, click **OK** to return to the **Unsteady Flow Data** editor, **Meteorological Data** tab, and continue editing or entering data for each of the individual point gages (Figure 10).

Once all of the desired point gages data has been entered, and the checkboxes have been checked to use those gages, the last steps are to set the **Rasterization Parameters** and to select the **Interpolation Method**. To set the rasterization parameters, press the button labeled **Rasterization Parameters (Optional)** from the **Meteorological Data** tab. The **Raster Parameters** editor opens (Figure 11).

Figure 4-15. Editor for controlling Rasterization of point gage data.

Figure 11. Raster Parameters editor.

As shown in Figure 4-15, the user can define the coordinate extents for how the point gage data will be rasterized. There are several options for defining the raster coordinate extents. The first option is to completely define the extents and the cell size to use. This first option is accomplished by entering a **Left** and **Top** coordinate (in the coordinate system established for the model in RAS Mapper), entering the number of **Rows**, **Cols** (columns), and the **Cell Size**. Note, the **Cell Size** is entered in feet when working in English units, and in meters when working in metric units. The second approach is to use one of the three buttons on the right-hand side of the window. These three options are: **Fix Raster Parameters based on the current Met Station Extent**, **Fix Raster Parameters based on the current Met Stations and Current Geometry Extent**, and **Clear (use Met Stations Extent at runtime)**. The last option is often used for real time forecasting, in which the number of available gages that are recording may change.

To understand exactly what is produced by the rasterization of the point gage data, press the button labeled **Plot Raster Extents.** The **Meteorological Stations** window opens (Figure 12), which provides a plot for visualizing what the extents would be for each of the possible options. See an example below in Figure 12. Click **OK** to save the selected rasterization of point gage data and return to the **Unsteady Flow Data** editor, **Meteorological Data** tab (Figure 11).
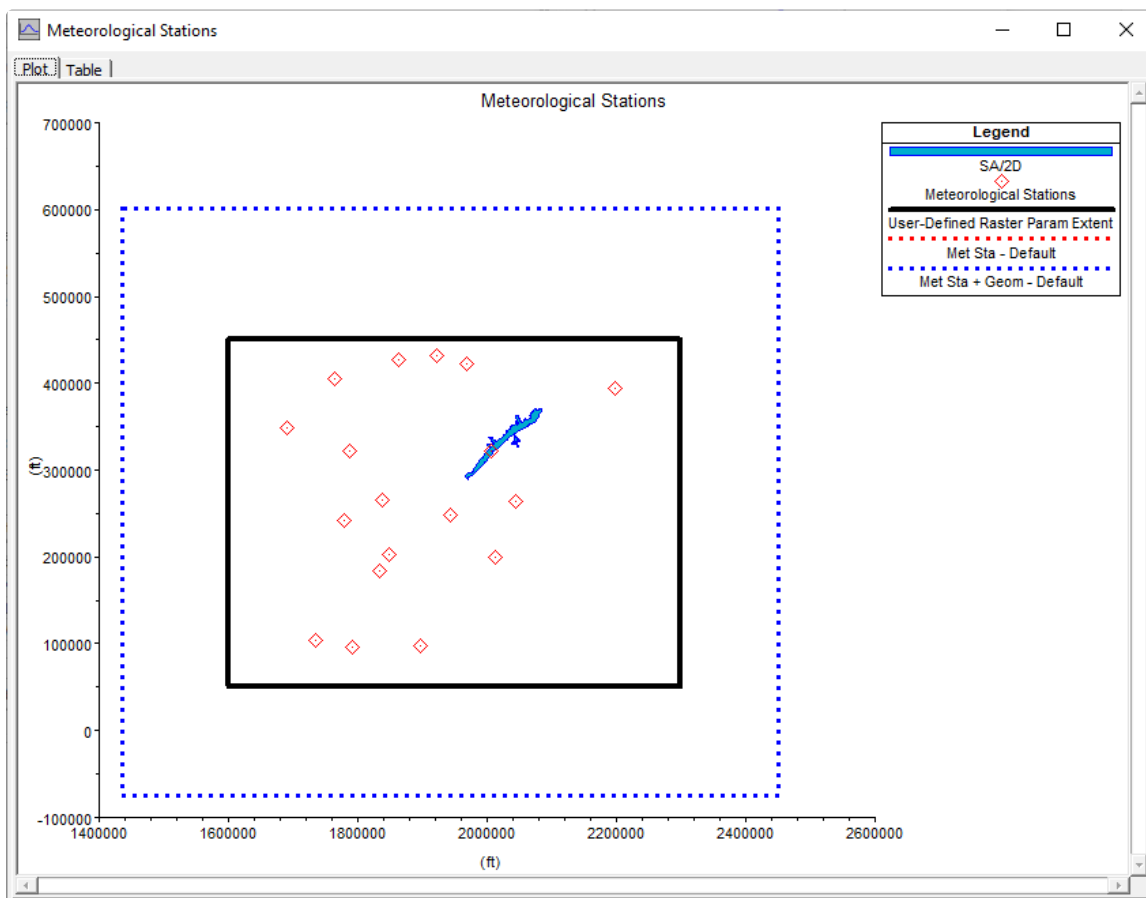
Figure 4-16. Plot showing all the possible options for rasterizing the point gage data.

Figure 12. Example Meteorological stations plot.

In order to complete the point gage precipitation method, from the **Unsteady Flow Data** editor, **Meteorological Data** tab, the user must select the **Interpolation Method** (Figure 9). The four point gage Interpolation Methods available to the user are: **Thiessen Polygon**, **Inverse Distance Squared**, **Inverse Distance Squared (Restricted)**, and **Peak Preservation**.

The **Thiessen Polygon** method is the traditional method often used in hydrologic modeling. This method draws a line between two point gages and finds half the distance between each gage. This distance calculation is done for all of the gages and then polygons are formed by the linear bisection lines between the gages. HEC-RAS only does this in order to figure out which gage should be used for the pattern of the rainfall event. If a 2D cell is closet to a specific gage (inside that gages' polygon), then that gage will be used for the pattern (intensity versus time) for the rainfall event. However, for the storm total rainfall at each cell, the Inverse Square of the Distance method is used in order to get a weighted storm total rainfall for each cell. That storm total is then applied to the nearest gages' pattern in order to define the rainfall for that specific cell.

The **Inverse Square of the Distance** method computes a weighted depth of rainfall for each time period individually by using the inverse square of the distance weighting method for all of the gages near a specific cell. If the rainfall data is hourly, then the inverse square of the distance weighting method is done individually for each one hour time step.

The **Inverse Distance Squared (Restricted)** method does the same thing as the Inverse Square of the Distance method, except it first triangulates all of the gages. Then, if a cell lies inside of a specific triangle, then only the three gages that form the triangle are used in the storm weighting process. This method prevents gages that are far away from being used and limits the interpolation to the three closest gages to the cell.

The **Peak Preservation** method is an attempt to retain the intensities within a storm as it moves across a watershed. The Inverse Square of the Distance and Inverse Distance Squared (Restricted) methods have the problem of diminishing the rainfall intensities when the timing of the rainfall is different at each of the gages being used for the interpolation. The Peak Preservation method takes all the gages being used for a particular cell and finds the center of mass of the precipitation for each of the gages. Next all the gaged data is lined up by the center of mass. Then the data is interpolated on a time step by time step basis. Finally, the interpolated data is shifted back to the correct time to account for the location of the cell between the gages.

In order to test the different interpolation methods, the HEC-RAS team has added the ability to visualize the interpolation of the precipitation data inside of RAS Mapper. RAS Mapper (in HEC-RAS Version 6.0) now contains a layer in the Layers window, called **Event Conditions**. This new layer will allow the user to view and/or animate precipitation data (gridded and point data) and wind data. To view the Point Precipitation data and its resulting interpolated values, save the precipitation data (by selecting the **File | Save Unsteady Flow Data** menu option), open RAS Mapper, and from the Layers window, turn on the precipitation layer that corresponds to the data entered into the **Unsteady Flow Data** editor. An example of this for Point Precipitation, using the Thiessen Polygon interpolation method is shown in Figure 13.
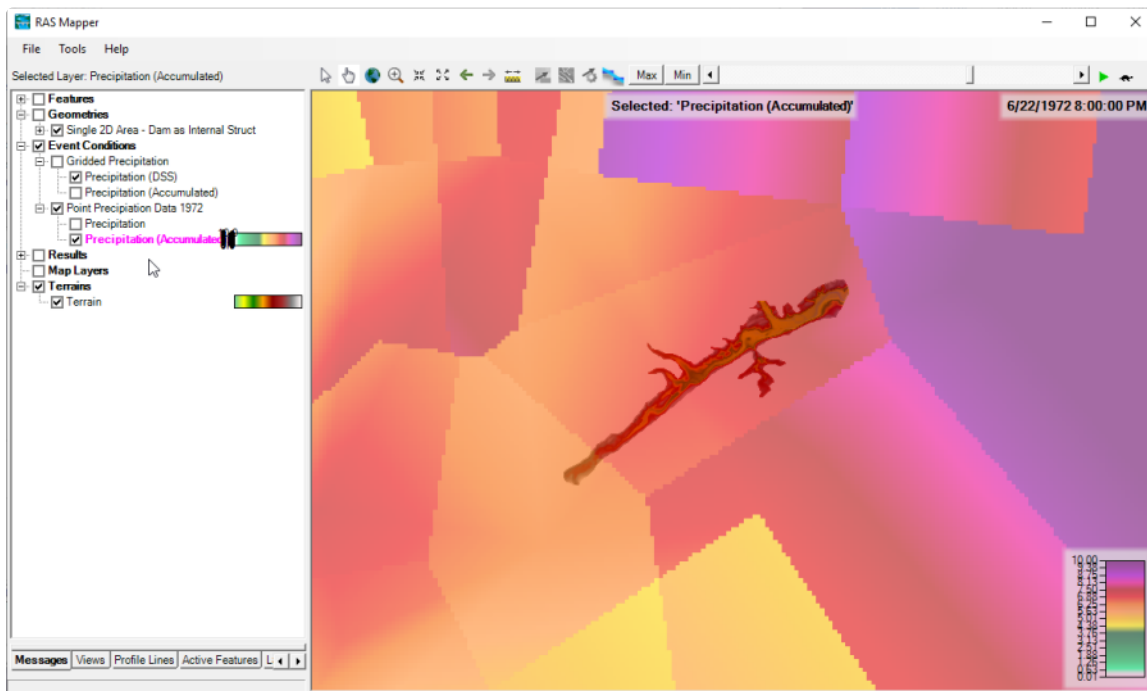
Figure 4- 17. Point Precipitation with the Thiessen Polygon Interpolation Method.

Figure 13. Example map of precipitation rates interpolated with the Thiessen Polygon method.

HEC-RAS Mapper has a layer for the incremental precipitation, called **Precipitation**. There is also a layer for the cumulative precipitation, called **Precipitation (Accumulated)**. User can turn on ether of the precipitation layers. These layers can be animated or a specific point in time can be selected. Additionally, the user can right click on the map and request one of three different time series plots. The time series plotting options are: **Plot Precipitation** (this is the incremental precipitation versus time plot), **Plot Accumulated Precipitation** (accumulated precipitation versus time), and **Compare Precipitation Methods (accum)** (this option plots all four of the point precipitation methods for the accumulated rainfall versus time). Shown in Figure 14 is an example of an Incremental Precipitation time series plot.
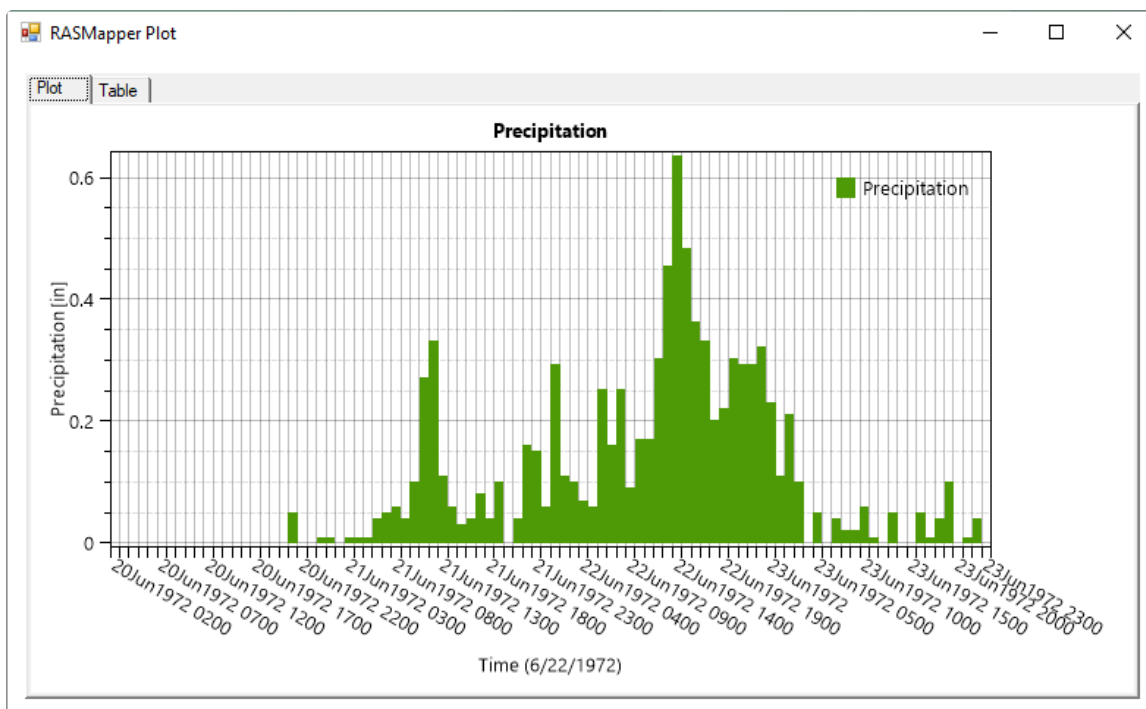
Figure 4-18. Example Incremental Precipitation Time Series Plot.

Figure 14. Example time-series plot of incremental precipitation rates.

Shown in Figure 15 is an example Accumulated Precipitation versus Time plot.
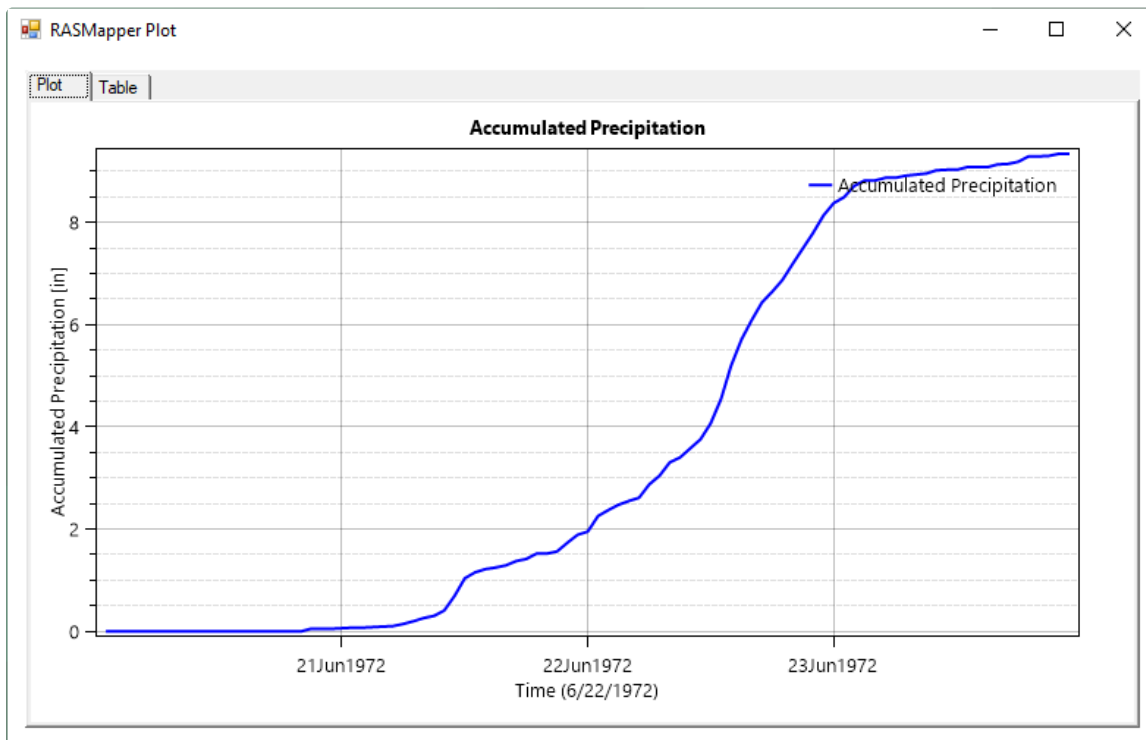
Figure 4-19. Example of Accumulated Precipitation versus Time Plot.

Figure 15. Example time-series plot of Accumulated Precipitation.

Shown in Figure 16 is an example of Accumulated Precipitation versus Time for all four available precipitation interpolation methods.
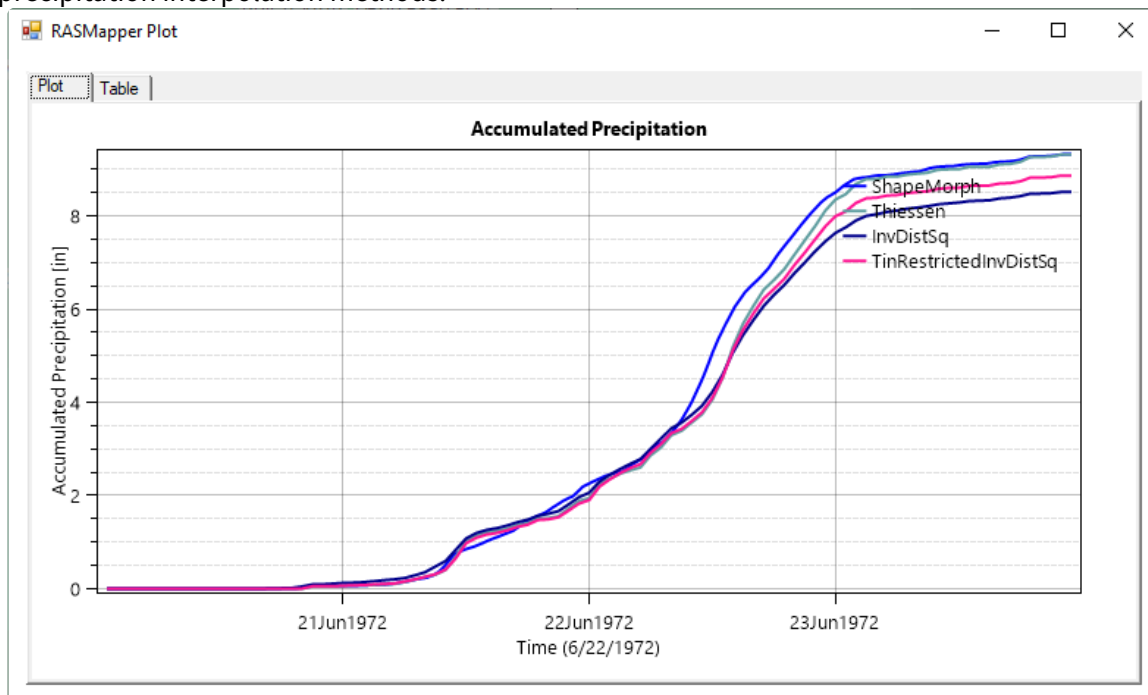
Figure 16. Compared of Accumulated Precipitation time-series for different interpolation methods.

Additionally, users can right click on the **Precipitation** layer and select the menu option called: **Rasterization Parameters**. This menu option will bring up a submenu allowing the user to select one of the four point precipitation interpolation methods, define how the program extrapolates outside of the point gage data, select a resampling technique, and also select the cell size to use when rasterizing the precipitation data (default is a cell size of 2 kilometers). Users can select a smaller cell size for rasterizing the precipitation data; however, there must be enough point gages close enough together in order to justify using a smaller precipitation cell size.

> (i) **NOTE:** HEC-RAS Mapper allows the user to select different interpolation methods and then visualize the result of using those interpolation methods; therefore, the user is allowed to experiment with the different methods. However, once the user decides on a final interpolation method to use in a simulation, then that method must be selected in the **Unsteady Flow Data** editor, on the **Meteorological Data** tab. The method selected in the **Unsteady Flow Data** editor is the actual method that will be used in the simulation.

Evapotranspiration Data

Evapotranspiration data represents the potential evapotranspiration (PET) and is applied first to the surface water (storage areas, 1D XS's, and 2D cells) and then the soil moisture in the Deficit and Constant or Green and Ampt infiltration methods. The PET is not utilized in the SCS Curve Number method. Additionally, PET is an option, not a requirement, for these two methods. Evapotranspiration data can be entered as gridded data, point gage data, or just a constant rate. The methods of entering the evapotranspiration data into the **Unsteady Flow Data** editor is similar to precipitation, as described above.

Wind Forces

Wind forces can be incorporated in both 1D and 2D unsteady flow modeling. Wind data (speed and direction) can be entered as either gridded data or point gage data, just like precipitation data described above. If the user enters wind data into the **Unsteady Flow Data** editor, that data will be used and wind forcing will be applied to all 1D river reaches and 2D flow areas that are using any of the 2D flow solvers. However, it is recommended to use the Shallow Water Equation solvers in combination with wind forcing.

Gridded Wind Data

To enter gridded wind data (speed and direction), open the **Unsteady Flow Data** editor and select the **Meteorological Data** tab (Figure 4-21). From the **Wind Forces** dropdown select from one of the three options: No Wind Forces, Speed/Direction, and Velocity X/Y. If **No Wind Forces** (Default) is selected, then no wind forces are applied to the data set. If **Speed/Direction** is selected, then the user must enter the wind data as separate speed data and separate direction data, based on degrees from north (North is zero degrees, East is 90 degrees, etc.). If the user selects **Velocity X**, **Y**, then the wind data is entered as a velocity X component and a velocity Y component for each grid. The **Velocity X, Y** approach will define the magnitude and direction. An example with wind defined by Speed/Direction is shown below in Figure 17.

Figure 4-21. Example of Wind data entered as Speed/Direction.

Figure 17. Example Meteorological tab with wind defined as Speed and Direction.

As shown in Figure 17, the user must first define the **Mode** for entering the data, such as: **Point**, **Gridded**, or **Constant**. In the example shown in Figure 17, the wind data is being entered as Gridded data. Gridded data requires a separate grid for the Wind Speed and the Wind Direction. The options for the **Source** of the wind data are: **DSS**, **Single Raster File**, and **Multiple Raster Files**.

If **DSS** is selected the user must specify the HEC-DSS file containing the data, and the DSS pathname pointing to the gridded information. If a **Single Raster File** is selected, that means a single Raster file contains all of the spatial data for the entire time window of the event being modelled. The Raster files can be either a NetCDF file or a GRIB file (National Weather Service formats). If the **Multiple Raster Files Source** is selected, that means that more than one file contains the data for the entire time window being modelled. NetCDF and GRIB file formats are also available for this data source.

For the **Raster** file data source, the user must specify the location and name of the file(s), as well as which group within the file contains the specific data (speed or direction, velocity X and velocity Y). As shown in Figure 17, once the user has specified "Gridded" data and the source as "GDAL Raster Files," then the user must press the **Import Raster Data** button to go through the import process. When the **Import Raster Data** button is pressed, then an **Import Gridded Data** window will open, as shown in Figure 18.
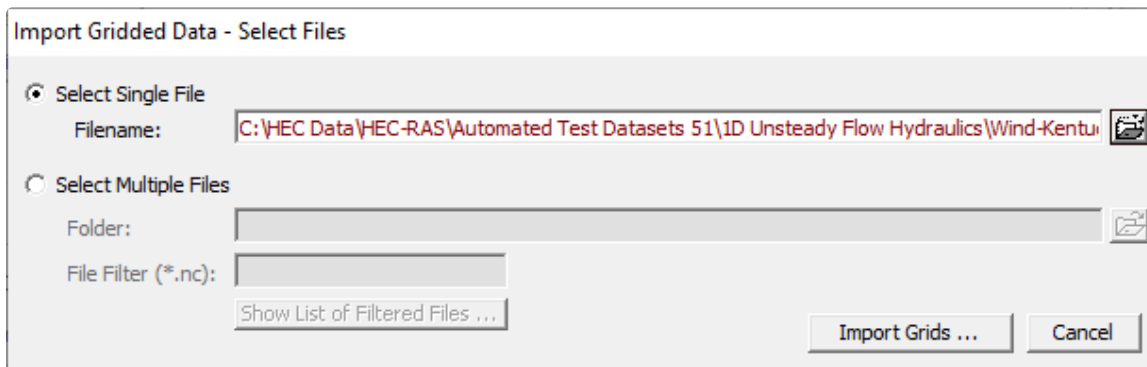
Figure 4-22. Gridded Rastewr Data Importer.

Figure 18. Import Gridded Data editor.

As shown in Figure 18, the user selects from importing either a **Single Raster File** that contains all the data or **Multiple Raster Files**. Once either the Single or Multiple Raster files are selected, the user presses the **Import Grids** button to import the data. If the data is from a NetCDF file, a new window will appear, asking the user to select which individual data set should be imported from the discovered data sets in the file. For example, if the user is trying to import the Wind Speed data, then the header or data set that contains the wind speed data (usually labeled "US" should be selected. If the user is trying to import the wind direction data, then the header or data set that contains the wind direction data (usually labeled "UD" should be selected.

Because the NetCDF and GRIB file formats can contain meta data in different formats, from the **Unsteady Flow Data** editor, **Meteorological Data** tab (Figure 4-21) there are two options to override certain pieces of needed information. These options are: **Projection Override** and **Units Override**. These fields are optional and should only be used to override the projection and/or units of the data.

Once the gridded data is entered into the **Unsteady Flow Data** editor and saved, the user can open HEC-RAS Mapper and visualize the gridded wind data from the **Event Conditions** layer. This data can be animated in time. Users can also right click on the map and ask for a time series of the wind speed and direction at that location (this will bring up two separate plots, one for speed and one for direction). An example plot of a gridded wind field is shown in Figure 19 below.
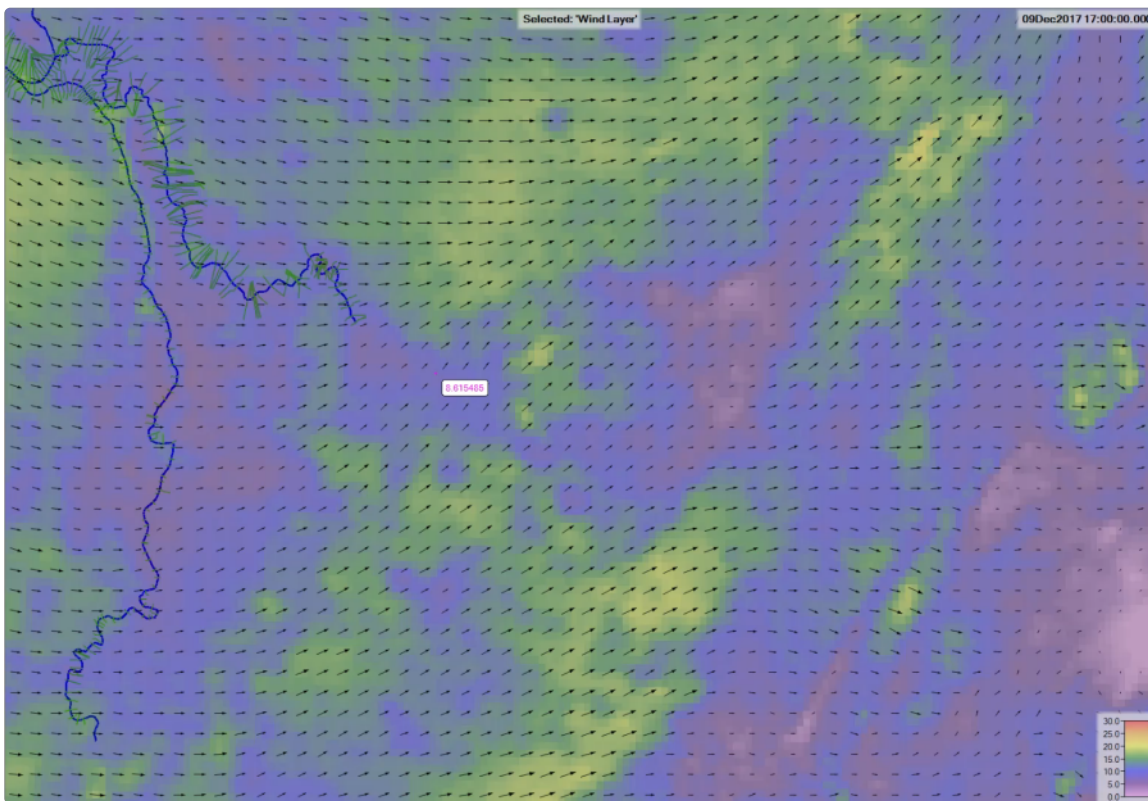
Figure 4-23. Example gridded wind field for 1D and 2D modeling.

Figure 19. Example map in RAS Mapper of gridded winds.

Gridded wind data can be created from ADCIRC wind files using the HEC-RAS nesting utility (https://github.com/HydrologicEngineeringCenter/ras-nesting-util). The utility is available as binaries or can be compiled and run directly from the source code. The nesting utility allows the user to extract winds from an ADCIRC model for a smaller subdomain of the whole mesh. The subdomain wind data can then be interpolated using external utilities and converted to the GDAL NetCDF format to import into HEC-RAS.

Point Gage Wind Data

Users can also enter wind data as point gage data in HEC-RAS. This data is then interpolated in order to convert it to a gridded data form, which is how the computational engines use it. Point gage data for wind is entered in the same manner as point gage precipitation data, which is documented above. Please refer to the Point Gage Precipitation Data section of this manual to understand how to enter point gage data for wind gages.

Atmospheric Pressure Data

Gradients in atmospheric pressure act as a driving force for 2D flow models. Atmospheric pressure forcing is important when simulating coastal storms, hurricanes/cyclones when the gradients of atmospheric pressure can be significant. It is not recommended to use HEC-RAS as a coastal model since it does not have wave forcing and other processes. HEC-RAS should only be used for in areas where waves are not significant. Atmospheric pressure data can be entered in the **Meteorological**

Data tab of the **Unsteady Flow Data** editor (see figure below). Atmospheric forcing can be applied to any of the hydraulic flow models. However, it is recommended that the shallow water models be used in combination with atmospheric pressure. The methods for specifying atmospheric pressure data in HEC-RAS are very similar to the other meteorological data described in the sections above. The data entry modes for Atmospheric pressure are **Constant**, **Point**, and **Gridded**. If default mode is constant in which the user may enter a single constant value. It is noted that in this mode the atmospheric pressure does not provide any forcing. The **Constant** mode option is provided for completeness and to support future features in HEC-RAS. The **Point** and **Gridded** modes work essentially the same for atmospheric pressure as they do for the other meteorological variables.

As with the other Meteorological Variables, Atmospheric Pressure is first interpolated onto a meteorological grid, and then interpolated on to cell centers. The gradients of atmospheric pressure are then computed at each face using the cell values.

Similar to wind data, gridded atmospheric pressure data can be created from ADCIRC files using the HEC-RAS nesting utility (https://github.com/HydrologicEngineeringCenter/ras-nesting-util). The utility can be used to extract atmospheric pressure from the whole ADCIRC domain to a smaller subdomain covering the HEC-RAS geometry. The subdomain atmospheric pressure data can then be interpolated using external utilities and converted to the GDAL NetCDF format to import into HEC-RAS.

Initial Conditions

Initial conditions for 2D flow areas can be accomplished in several ways. Two-dimensional (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; set by **interpolating** results from an existing HEC-RAS **Results File** for a specific Plan, date, and time; 2D flow areas can be established using the **2D Initial Conditions Ramp up Time** option at the beginning of the run; or by using Initial Conditions Points with a specified water surface.

Dry Initial Condition

Nothing needs to be done to start a 2D flow area in a dry condition as this is the default option. The name of the 2D flow area will show up under the **Initial Conditions** tab of the **Unsteady Flow Data** editor (see figure below). If the initial condition elevation column is left blank, this tells the software to start the 2D flow area dry. **Note: A 2D area connected directly to the upstream end or the downstream end of 1D reach cannot start dry (see previous discussion).**

Single Water Surface Elevation

When the single water surface elevation option is used, every cell that has a lower terrain elevation than the user established water surface will be wet (with a water surface at that elevation), and cells with a terrain elevation that is higher than that water surface will be dry. To use this option, enter the water surface elevation desired in the **Initial Elevation** column of the **Unsteady Flow Data** editor, **Initial Conditions** tab and in the row for the 2D flow area (see figure below).

Restart File

A **Restart File** can be used to establish initial conditions for an entire simulation. Refer to the **Unsteady Flow Data Editor** section of the HEC-RAS User's Manual for more information regarding the **Restart File** option. 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. The **Restart File** option has been modified in HEC-RAS Version 6.0 to allow for restarting 2D flow areas in addition to all of the 1D flow elements in HEC-RAS. For 2D modeling, the **Restart File** will contain a water surface elevation for every cell in the model. Additionally, 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 (i.e., the user can run the original run with the Diffusion Wave option and create a **Restart File**, then start up a model that uses the Full Saint Venant equations from that restart file). See the section on **Initial Conditions** in Chapter 8 of the HEC-RAS Version 6.0 User's Manual for more information on how to use the **Restart File** option.

Figure 4-24. Unsteady Flow Data Editor with 2D flow area initial conditions.

Interpolation from Previously Computed Results

Another way to establish the initial conditions of a model (1D, 2D, or combined 1D/2D), is to use the interpolated results from a previously run Plan. This option is extremely flexible in that it does not have to be from the Plan being run and the model geometry being used for the plan can be edited and the compute will still work without modification. The user selects a previously computed Plan, Date, and time of an existing results file. At run time, HEC-RAS will interpolate water surface elevations, velocities, and flows, as needed from the HEC-RAS Mapper output data for the Plan. For example, 2D cells get an interpolated water surface elevation at the cell computation point if the cell is wet. 2D faces get an interpolated normal velocity at the center of the face for each face that is wet. 1D cross sections get an interpolated water surface at the location where the river line crosses the cross section. 1D cross sections get an interpolated flow for that cross section. And 1D Storage Areas get and average water surface computed from all the water surfaces contained within the storage area polygon.

To use the option to "**Interpolate from Previously Computed Results File**," go to the **Initial Conditions** tab on the **Unsteady Flow Data** editor (see figure below).
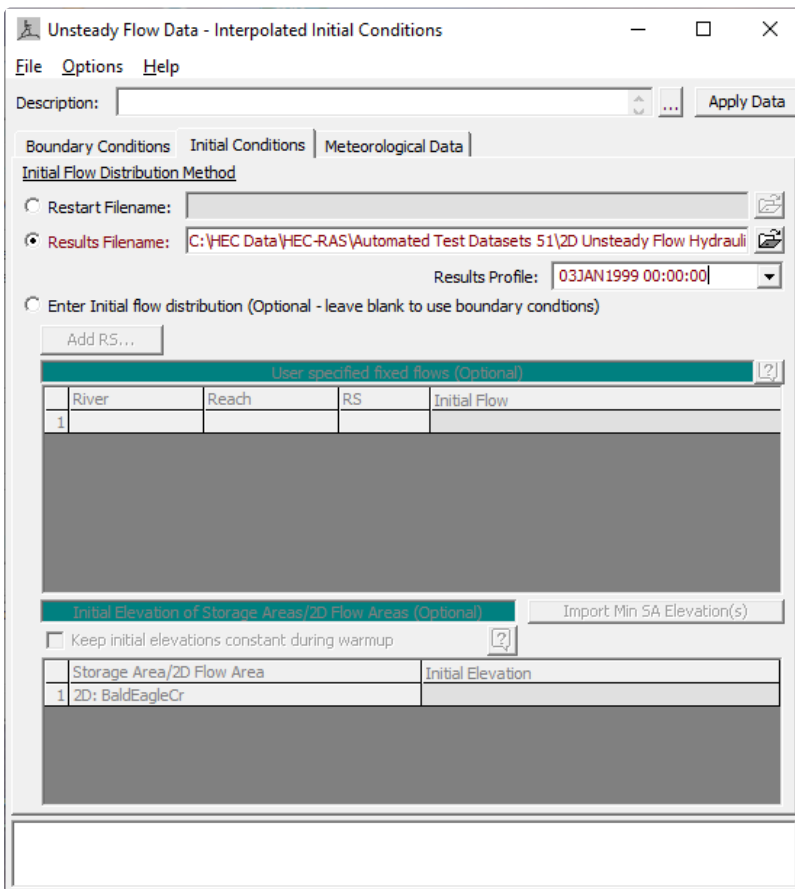
Figure 4-25. Example of Interpolating Initial Conditions from a Previously Run Plan/Date/Time.

As shown in the figure above, to use this method for initial conditions select the **Results Filename** option. Once this option is selected the user must first pick the HDF output file from the previously run Plan that they want to interpolate an initial condition from. The HDF output files will follow this convention: "*projectname.p##.hdf*". This is the output file that HEC-RAS Mapper uses to create all of the results maps. The next step is to pick an available **Results Profile** (Date and Time) from the selected output file.

As stated previously, at run time HEC-RAS will interpolate results from the computed results of the selected plan/date/time and set those results for the currently run Plan. This method will work even if the 2D mesh, 1D cross sections, or storage areas are modified. This makes the **Interpolation from Previously Computed Results** option the most flexible way to establish an initial condition when the model contains 2D flow areas.

2D Flow Area Initial Conditions Ramp Up Option

The unsteady flow capability in HEC-RAS has always had an option to run a model warm-up period. The model starts with the initial conditions and holds all of the boundary conditions constant, based on their value at the beginning of the simulation, and then runs a series of time steps with the constant inflow. This warm-up period allows the model to establish water surface elevations and flows that are consistent with the unsteady flow equations being applied. If there are any lateral structures that have flow (based on the initial conditions) going across the structure, this flow will

transition from a very small flow to the full computed flow over the duration of the warm-up period. This unsteady flow capability can reduce shocks to the system, especially in 1D river reaches.

Two-dimensional (2D) flow areas have an additional option called **Initial Condition Ramp Up Time**. If a 2D area has external boundary conditions (flow hydrographs or stage hydrographs) or links to 1D elements, in which flow will be going into or out of the 2D area right from the start of the simulation; 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). The 2D flow area **Initial Condition Ramp Up Time** is a separate option for the 2D flow areas (separate from the overall model warm-up option). To use this option, select the **Options** menu from the **Unsteady Flow Analysis** window, then select **Calculation Options and Tolerances**. The HEC-RAS Unsteady **Computation Options and Tolerances** (Figure 4-26) window opens. Select the **2D Flow Options** tab (Figure 4-26). The user enters a total ramp up time in the **Initial Conditions Ramp Up Time** (in hours) field. 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 entering the 2D Area). This is accomplished by entering the fraction in the **Boundary Condition Ramp Up Fraction (0 to 1)** field. The default value for the ramp up fraction is 0.1 (10 % of the ramp up time).
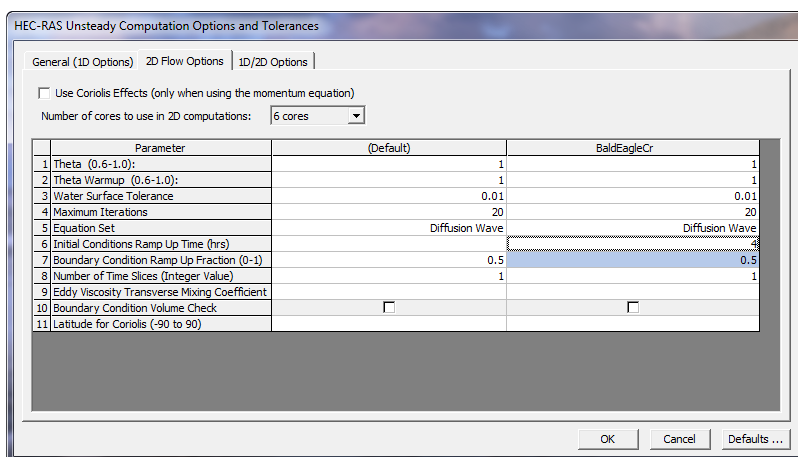
Figure 4-26. 2D flow area Computational Options.

Say, for instance, that a 2D area has an upstream flow boundary and a downstream stage boundary and the user has entered a two hour **Initial Conditions Ramp Up Time** with the **Boundary Fraction** at 0.5 (50%). Assume for this example that the first flow on the flow boundary is 1,000cfs and the first stage of the downstream boundary has an elevation that corresponds to 10ft of depth above the invert of the stage boundary (the invert is the lowest point along any part of the faces that make up the boundary). For the first hour of the initial conditions, the flow will increase linearly from 0cfs up to 1,000cfs. Then for this example, the downstream stage boundary will transition from a depth of 0ft up to a depth of 10ft (and even though this is a "downstream" boundary, if the 2D area started out dry, then flow will initially come into the 2D area). For the second hour, the flow will held at 1,000cfs upstream and the depth at 10ft downstream.

The initial conditions, if any, are computed separately for each 2D area (in a "standalone" mode). The flow and stages from any boundary conditions directly connected to the 2D area are taken into account. The flow and/or stage from any 1D river reach (that is directly connected) is taken into account to the extent possible. However, flow from any lateral structure or storage area connections

is not taken into account during this part of the computations. Flow crossing a hydraulic structure that is internal to the 2D area is computed. If the user has entered a starting water surface for the given 2D area, that water surface is used before applying the 2D initial conditions ramp up time. Otherwise the 2D area starts out dry.

> ⬤ **Warning:** When 2D flow areas are directly connected to 1D river reaches, then users must use the 2D Initial Conditions Ramp Up option to get water all the way through the 2D flow area, such that the 1D/2D connection will be wet when the model starts up. If the user do not do this, the 1D connection may go unstable at the beginning of the simulation because there is no water in the 2D area that it is connected.

In addition to establishing the initial conditions within 1D river reaches and 2D flow areas, it is a good idea to turn on the overall model warm up option. By enabling this option, the program will hold all inflows constant, then solve the entire unsteady flow model together (1D and 2D) to get the unsteady flow equations and hydraulic connections to settle to a stable initial condition before proceeding with the event simulation. The overall model warm up is turned on under the **General (1D Options)** tab from the Unsteady Flow Analysis window, **Options** menu, **Calculation Options and Tolerances**. The user turns this option on by entering a value into the field labeled **Number of warm up time steps (0 – 100,000)**. This entered value is for the number of time steps the user wants the model to run for the warm up period. From the **General (1D Options)** tab, there is also an option to put in a computation interval to use during the model warm up period (**Time step during warm up period (hrs)**). If this field is not set, then the program uses the default computation interval set by the user from the **Unsteady Flow Analysis** window. However, sometimes it can be very useful to use a smaller time step during the model warm up period in order to get the initial conditions established without going unstable.

Initial Conditions Points

Initial Conditions Points (IC Points) are used in HEC-RAS to establish an initial water surface. To use the IC Points option, you create IC Points in RAS Mapper and then provide the water surface elevation for each point in the Unsteady Flow Editor.

The **Initial Conditions Points** layer for each geometry is available for editing using the tools in RAS Mapper (or the Geometric Data Editor). To create a IC Points in RAS Mapper, **Start Editing** the **Initial Conditions Points** layer and then use the **Add New Feature** tool to add a point. Once a point is created, you will be asked to provide a **Name**, as shown below.
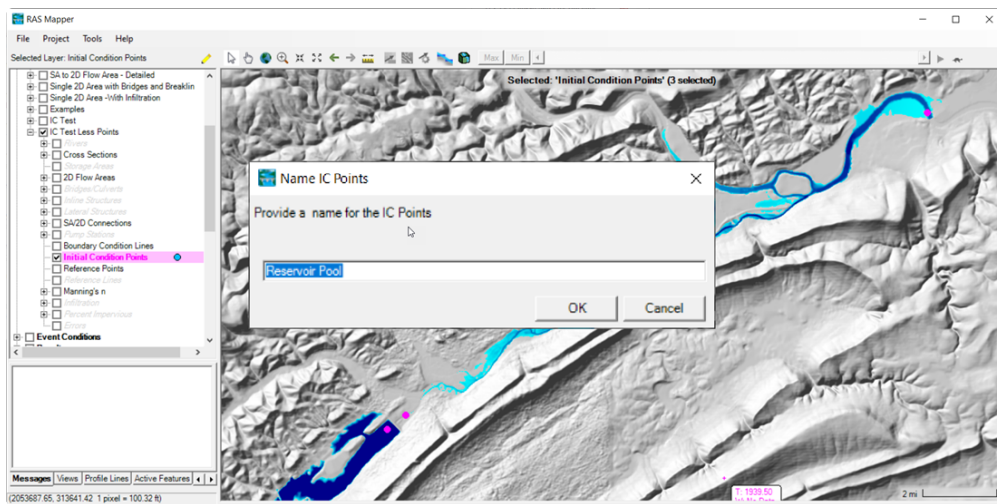
After creating IC Points, open the **Unsteady Flow Data Editor**, shown below. Navigate to the **Initial Conditions** tab, and enter an **Initial** (water surface) **Elevation** for each point.
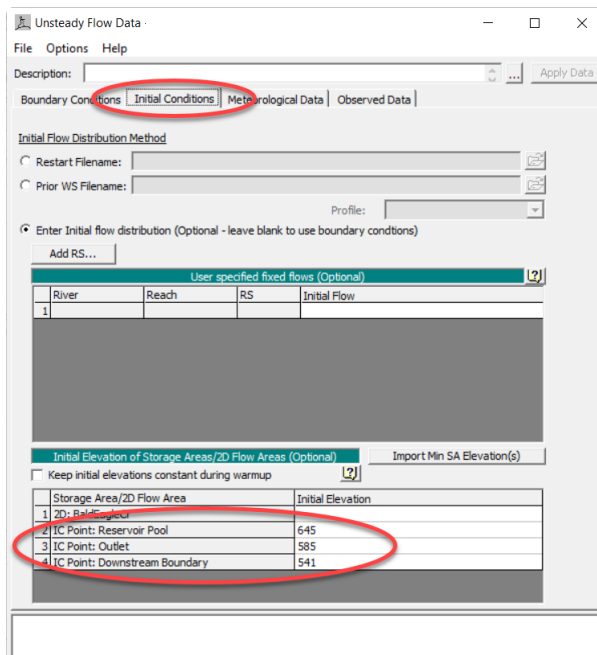
Plotting the Initial Elevations in RAS Mapper is shown in the figure below.
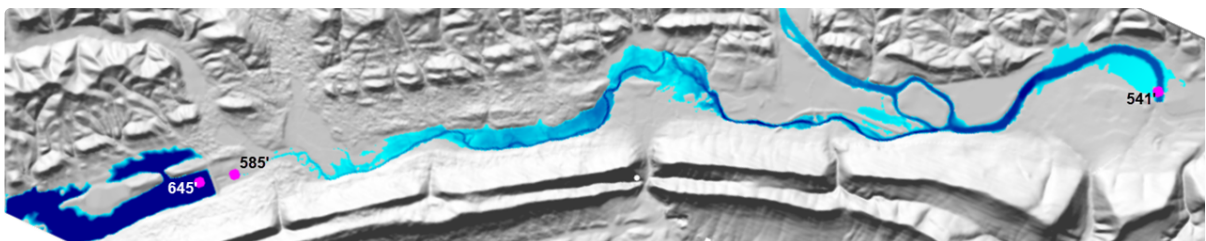
Prior to running the simulation, the specified Initial Elevations will be used to compute the initial conditions water surface. How the initial water surface is computed, depends on the layout of the IC Points - whether the points are considered Upstream Points or the most Downstream Point. There is only 1 Downstream Point and it is selected by having the lowest elevation based on the underlying terrain.

- Upstream Points - there are no IC Points hydraulically upstream from Upstream Points. The water surface elevation at these points are projected horizontally upstream until they intersect with high ground or reach the booundary.
    - These points will fill a pool with a horizontal water surface and are appropriate upstream of hydraulic structures like dams.
    - The water surface is computed assuming normal depth is achieved, using a constant flow per unit width (q) approach to Manning's equation to connect with the most Downstream Point. This flow per unit width computation procedure is described in more detail below.
    - If the computed water surface profile would create a backwater on another tributary, the higher water surface is projected horizontally until it intersects the tributary water surface.
- Downstream Point - there are no IC Points hydraulically downstream from the Downstream Point. The water surface elevation at this point is projected horizontally downstream to the boundary or until it intersects with high ground. Therefore, you should *always* specify a IC Point *at* the downstream boundary.

Once the initial water surface is computed for the main river network, it is used to seed a wave fill algorithm to propagate the computed water surface out into the floodplain. The wave fill is similar to a flood fill in that the seeded water surface elevation attempt only fill connected areas, however, the wave continues to interpolate water surface elevations based on neighboring cell values to allow for a sloped water surface.

The initial conditions water surface will be computed and used at the starting water surface for the unsteady flow simulation. An example initial conditions water surface is shown below.

> ⓘ Note that if the initial conditions water surface is jagged or does not look appropriate, you can set the **Number of Warm Up Time Steps** >0 to run the the model holding all flows constant but using the initial water surface to set the elevations throughout the model.
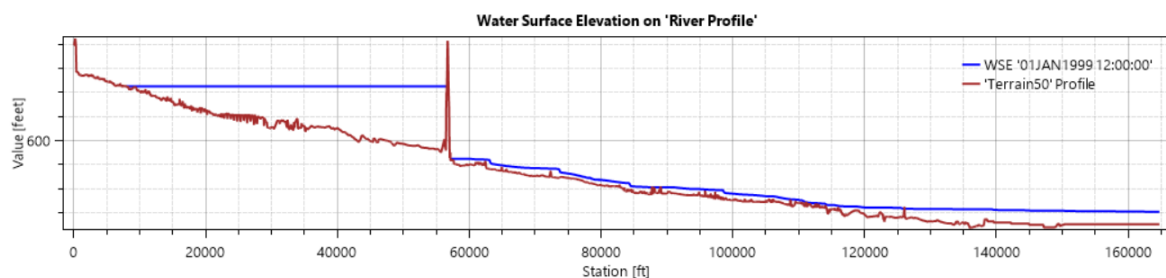
Flow Per Unit Width Computation Procedure

The Flow per Unit Width Computation Procedure used in RAS Mapper to establish initial conditions has several assumptions built into the method. First, is that that normal depth is achievable given the prescribed geometry such that Manning's equation (show below) is appropriate.

$$Q = \frac{1}{n} A R^{2/3} S_f^{1/2}$$

Writing Manning's equation out with more terms (d, depth and w, width), we have the following equation.

$$Q = \frac{1}{n}dw * [\frac{dw}{w + 2d}]^{2/3} S_f^{1/2}$$

Further, using the wide-channel assumption (w >> d), we can rewrite Manning's equation as a flow per unit width (q), as shown below.

$$q = \frac{1}{n}d^{5/3} S_f^{1/2}$$

Using the unit flow width equation, HEC-RAS iteratively solves for a flow that meets the water surface (d, depth) at the upstream initial conditions point using the specified downstream boundary water surface elevation (downstream initial conditions point). For all locations between an IC Point and the Downstream IC Point, we solve for a water surface (assuming normal depth) based on the computed flow per unit width. Wherever a higher water surface is computed throughout the domain, the higher water surface is used. This will result in reasonable starting water surface for the 2D domain. If the initial water surface is not satisfactory, the warm up time step option can be used to settle down the water surface. An illustration of the computational procedure is shown below for a simple river system comprised of a river (a-b) with a tributary (j-c).
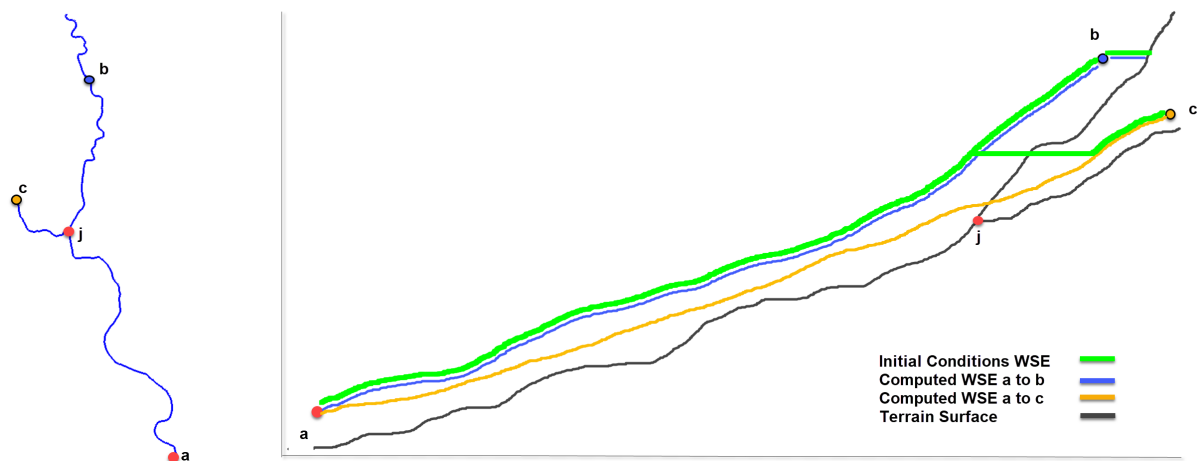
An example initial conditions for a planar surface 1000m long, set at a slope of 0.0004, with Manning's n value of 0.02 is shown in the figures below to illustrate the the computational process. The IC Points for the downstream water surface is computed to 1m depth.

Using a single IC Point at the downstream boundary results in a horizontal backwater.
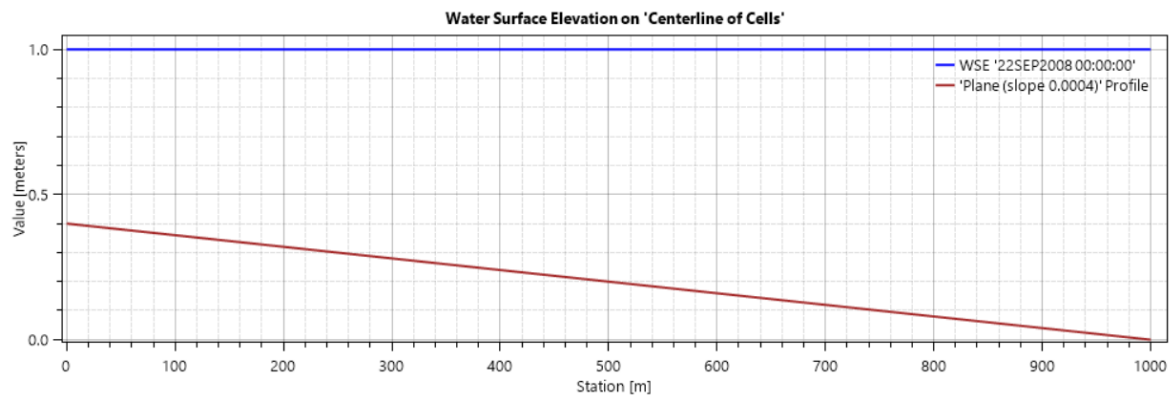
Setting the **Number of Warm Up Time Steps**, holds flow constant, and results in the normal depth solution for the model domain where the water slope is equal to the bed slope.
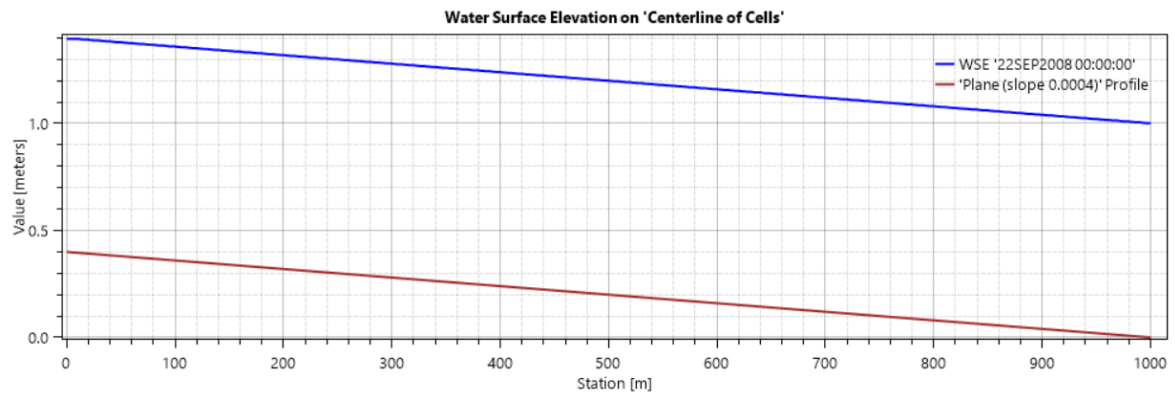
6 RUNNING A MODEL WITH 2D FLOW AREAS

Running a 2D or combined 1D/2D unsteady flow model in HEC-RAS is no different than running a standalone 1D unsteady flow model. The 2D unsteady computational module is built directly into the HEC-RAS unsteady flow computational engine - it is not a separate program. The 1D and the 2D computations are directly coupled on a time step by time step basis (there is also an iteration option for connections between 1D and 2D elements). This allows direct feedback from 1D to 2D elements and from 2D to 1D elements for each time step. This makes the linking of the 1D and 2D very accurate when it comes to sending flow through a breach (using a lateral structure), or any other type of hydraulic link between 1D and 2D elements. This direct feedback allows the software to more accurately calculate headwater, tailwater, flow, and any submergence that is occurring at a hydraulic structure on a time step by time step basis.

Shallow Water or Diffusion Wave Equations

As mentioned previously, HEC-RAS has the ability to perform two-dimensional unsteady flow routing with either the Shallow Water Equations (SWE) or the Diffusion Wave equations (DWE). HEC-RAS has three equation sets that can be used to solve for the flow moving over the computational mesh, the Diffusion Wave equations; the original Shallow Water equations (SWE-ELM, which stands for Shallow Water Equations, Eulerian-Lagrangian Method); and a new Shallow Water equations solution that is more momentum conservative (SWE-EM, which stands for Shallow Water Equations, Eulerian Method). The SWE also have options for modeling turbulence and Coriolis effects. See Chapter 2 of the Hydraulic reference manual for the theory on the development of these equations for use in HEC-RAS.

Within HEC-RAS the Diffusion Wave equations are set as the default, however, the user should always test if the Shallow Water equations are need for their specific application. A general approach is to use the Diffusion wave equations while developing the model and getting all the problems worked out (unless it is already known that the Full Saint Venant equations are required for the data set being modeled). Once the model is in good working order, then make a second HEC-RAS Plan and switch the equation set to the **SWE** option (SWE will generally require a smaller computation interval than the Diffusion wave method to run in a stable manner). Run this second plan and compare the two answers throughout the system. If there are significant differences between the two runs, the user should assume the SWE (Saint Venant equations) answer is more accurate, and proceed with that equation set for model calibration and other event simulations.

There are some obvious situations that the SWE should always be used. The following is a list of examples of situations in which the user should generally use the SWE based equations:

1. **Highly Dynamic Flood Waves**: If the modeler is performing a Dam breaching or flash flood analysis, the flood wave will rise and fall extremely quickly. The change in velocity (acceleration) both spatially and over time will be dramatic. The Diffusion wave equations do not include the local acceleration (changes in velocity with respect to time) and convective acceleration (changes in velocity with respect to distance) terms. These two terms are extremely important in order to model rapidly rising flood waves accurately.

2. **Abrupt Contractions and Expansions:** In areas where there are very abrupt contractions and

expansions, the Full Momentum based equation set will more accurately capture the associated forces through the contraction and expansion of the fluid. This is also due to the inclusion of the convective acceleration term (Which is not included in the Diffusion Wave equations). In general the Full Momentum equation set will compute a higher water surface upstream of the contraction zone.

3. **Flat Sloping River Systems:** For rivers with very flat slopes (less than 1 ft/mi), gravity and friction may not be the dominant forces acting on a body of water as it travels from one point to another. The forces associated with changes in velocity with respect to time and distance, will play a much more significant role in how a floodwave moves and changes shape in a flat system. Because of this, users should use the Full Momentum equation set instead of then Diffusion Wave equations. As Diffusion wave does not include the acceleration terms with respect to time and space.

4. **Tidally Influenced Conditions:** If you are modeling a bay, estuary, or a river that is tidally influenced, then you have to use the full momentum based equation set. The propagation of waves (tide cycle) cannot be modeled with the diffusion wave equations. The ocean tides are dynamic waves that can propagate way up into a river system. There are many examples of where you can see this in gaged river stage data that is very far from the ocean, but still showing a tidal cycle in the stage hydrographs during low flow. Shown below in Figure 4-1 is the Stage data at Vancouver Washington and at the mouth of the Columbia River. As you can see, the tide cycle is evident in the stage data at Vancouver, even though this gage is 106 miles upstream from the mouth of Columbia bay.

5. **General Wave Propagation Modeling:** If the user needs to model wave propagation due to rapidly opening or closing of gated structures, or wave run-up on a wall or around an object (e.g. bridge piers, buildings, etc…), then the Full Momentum equation set is necessary for this type of modeling.

6. **Super Elevation around Bends:** If you have 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, this required the Full Momentum based equation set.

7. **Detailed Velocities and Water Surface Elevations at Structures:** If you are trying to compute a detailed velocity distribution at or near a hydraulic structure, The full momentum based equation set is more accurate. Some examples are, detailed water surface and velocity through a bridges and around the abutments and piers; Open channel flow through a gate or culvert; detailed velocities though and around a levee breach; detailed water surface and velocities around a building. Note: this type of modeling also requires very small grid cells and small computational time steps.

8. **Mixed Flow Regime:** In order to accurately model transitions from subcritical to supercritical flow, and from supercritical to subcritical flow (hydraulic jumps), the Full Momentum equation is more accurate.
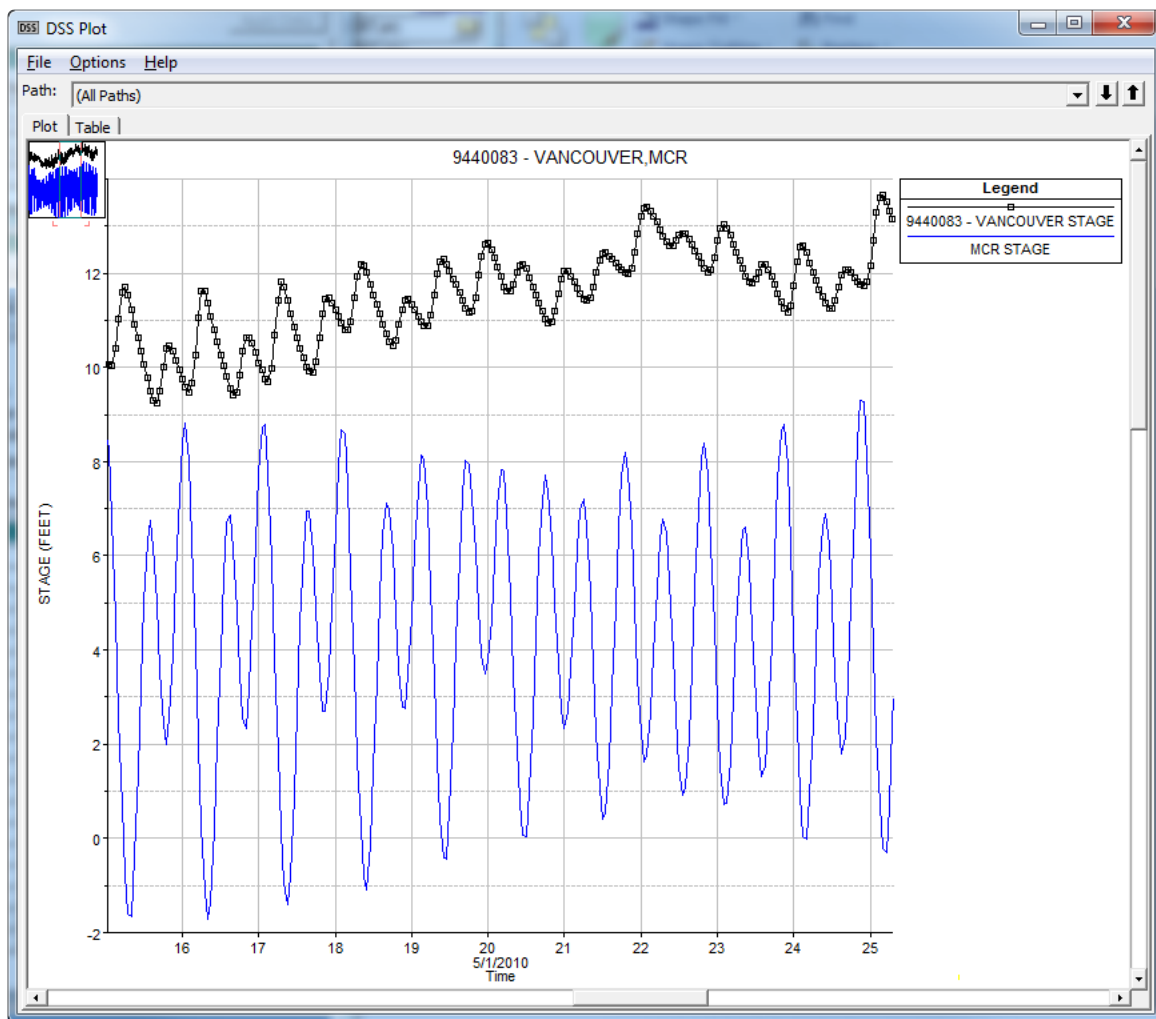
Selecting an Appropriate Grid Size and Time Step

Assigning an appropriate mesh cell size (or sizes) and computational time step (ΔT) is very important to getting accurate answers with 2D flow areas. The first step is to develop a computational mesh that has cell sizes that are appropriate for modeling both the terrain as well as the water flowing over the terrain. Many 2D flow models use a single elevation for each cell and cell face (grid-based models). Finite Element models commonly (not always) use triangles (three elevations and a planar surface to represent each triangle) to represent the land surface, while each face has two elevations and a straight line between them. 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.

HEC-RAS takes a very different approach than the two previously mentioned modeling techniques. Cells in HEC-RAS can have three, four, five… up to eight sides. Each cell is not a single elevation, but a detailed elevation volume/area relationship that represents the details of the underlying terrain. The HEC-RAS cell faces are detailed cross sections, which get processed into detailed elevation versus area, wetted perimeter, and roughness relationships. This approach allows the modeler to

use larger cell sizes with HEC-RAS, and still accurately represent the underlying terrain. 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. Additionally, one must consider changes in the water surface slope and changes in velocity. 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). This is acceptable for some areas, but not appropriate for others. If the water surface slope and velocity vary rapidly, smaller cell sizes must be used in that area to capture the changing water surface and velocity. HEC-RAS allows the user to vary the cell size and shape at all locations in the model. So computational meshes can be developed with smaller cells where they need to be and larger cells where the terrain and water surface and velocity are not changing rapidly.

Some key factors for developing a good computational mesh with HEC-RAS are:

1.Make sure the cell sizes, shapes, and orientations adequately describe the terrain. Specifically, since the cell faces control the movement of water, there must be enough of them, oriented correctly to describe the key features of the terrain that will control water movement. This includes barriers to flow, such as roads, levees, floodwalls, and natural high ground areas, that will prevent flow from going from one area to another, until the water surface elevation is higher than the barrier. Additionally, the user may want to use a refinement region along the banks of the main channel. By using a refinement region along the bank of the main channel, the computational faces will be aligned along the high ground that separates the main channel flow from the overbank flow. This will ensure that no water leaves the main channel until it has reached an elevation higher than the cell faces that are aligned with the channel banks. Additionally, the use of a refinement region allows the modeler to easily control the cell size within the main channel. Adding a breakline down the middle of the channel, on top of the refinement region, and using the near repeats option, will allow the user to align the cells with the direction of the flow.

2.The cell size must be adequate to describe changes in the water surface slope and changes in velocity. If the water surface slope and velocity does not change rapidly, larger cell sizes can be used to accurately compute the water surface elevation and slope. If the water surface slope and/or velocity changes rapidly, then smaller cell sizes need to be used to have enough computation points to describe the changing water surface and velocity, as well as compute the force/energy losses that are occurring in that area. While cell sizes (and shapes) can vary, transitioning from larger to smaller cell sizes should be done gradually to improve computational accuracy.

Once a good computational mesh is developed, then the user must pick an appropriate computational time step that works well with the mesh and the event being modeled. Picking an adequate time step is a function of the cell size and the velocity of the flow moving though those cells. HEC-RAS has three equation sets that can be used to solve for the flow moving over the computational mesh, the Diffusion Wave equations; the original Shallow Water equations (**SWE-ELM**, which stands for **Shallow Water Equations, Eulerian-Lagrangian Method**); and a new Shallow Water equations solution that is more momentum conservative (**SWE-EM**, which stands for **Shallow Water Equations, Eulerian Method**). The new Shallow Water equation solution methodology (SWE-EM) uses an explicit solution scheme for solving the equations. While this method is more momentum conservative, it requires smaller computational time steps (i.e. in general, the time step must be selected to ensure the Courant number is less than 1.0).

In general, the Diffusion Wave equations are more forgiving numerically than the SWE. This means that larger time steps can be used with the Diffusion Wave equations (than can be with the SWE), and still get numerically stable and accurate solutions. The following are guidelines for picking a computation interval for the Shallow Water equations and the Diffusion Wave equations:

Shallow Water (SWE-ELM):

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

Or

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

Where:

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

Shallow Water (SWE-EM):

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

Or

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

Diffusion Wave Equations:

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

Or

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

> ⓘ **Note:** There are times when the diffusion wave method will need to be run with a time step that would produce a Courant number of 1.0 or less. Some examples are: very rapidly rising hydrographs and routing rapidly changing hydrographs over a completely dry channel.

Practical Time Step Selection: The way to use these equations is to find the area(s) with high velocities and rapid changes in water surface and velocity (with respect to space and time). Take the average cell size in that area for ΔX. Put in the maximum velocity in that area for V. User's will need to estimate a max velocity as a first guess for this calculation before running the model, then plot the max velocities from the run to make a better estimate. Users can also plot Courant Number directly from within HEC-RAS Mapper. Select a ΔT, such that the Courant Number (C) is equal to the suggested value (i.e. 1.0 for SWE). However, you may be able to get away with a Courant number as high as 3.0 for the SWE's and 5.0 for the Diffusion Wave equations, and still get stable and accurate results. If the event being modeled changes gradually with time and space, larger time steps can be used (i.e. Courant numbers approaching the maximum listed values). If the flood wave being modeled changes rapidly with respect to time and space, then you will need to use a time step closer to a Courant number of 1.0 (i.e. C = 1.0) for the high velocity zones. Also, if you have started the 2D area completely dry, then you will need to use a time step based on a Courant number of 1.0, in order to get a more accurate and stable wetting front.

> ⓘ **Note:** 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. If the grid is refined and the time-step is reduced simultaneously, the method will achieve convergence. The user should always test different cell sizes (ΔX) for the computational mesh, and also different computational time steps (ΔT) for each computational mesh. This will allow the user to see and understand how the cell size and computational time step will affect the results of your model. The selection of ΔX and ΔT is a balance between achieving good numerical accuracy while minimizing computational time.

Variable Time Step Capabilities

Variable time step capabilities have been added to the unsteady flow engine for both one-dimensional (1D) and two-dimensional (2D) unsteady flow modeling. In HEC-RAS Version 6.0, two new options are available. The first option is a variable time step based on monitoring Courant numbers (or residence time within a cell). The second variable time step option is a method that allows users to define a table of dates and time step divisors. The variable time step option can be used to improve model stability, as well as reduce computational time (however, not all models will be faster with the use of the variable time step).

These new Variable Time Step options are accessed from the **Unsteady Flow Analysis** window (and also by going to the Computational Options and Tolerances window). From the **Unsteady Flow Analysis** window (Figure 5-2), from the **Computation Settings** section, there is a new ellipse button located to the right of the **Computation Interval** dropdown menu. The ellipse button (Figure 5-2) provides users access to these new Variable Time Step options.

From the **Unsteady Flow Analysis** window (Figure 5-2), from the **Computation Settings** section, click the new Variable Time Step control editor ellipsis button. The modified HEC-RAS **Unsteady Computation Options and Tolerances** window opens to the new **Advanced Time Step Control** tab (Figure 5-3). Alternatively, users can open the window and navigate to the new tab from the **Options | Computation Options and Tolerances** menu command.

As shown in Figure 5-3, the new Advanced Time Step Control tab now has three different methods for selecting and controlling the computational time step: (i) Fixed Time Step (default); (ii) Adjust Time Step Based on Courant, which is a variable time step based on the Courant number; and (iii) Adjust Time Step Based on Time Series of Divisors, which is a variable time step based on a user entered table of dates, times, and time step divisors. The two new variable time step options (Courant number and Time Step Divisor) are discussed in the following sections.

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Figure 5-3. Variable Time Step Editor within the Computational Options and Tolerances.

Courant Number Method

The first new variable time step option is to use the Courant number method, from the new **Advanced Time Step Control** tab. In the example shown in Figure 5-2 and Figure 5-3, the Courant number is being used for the variable time step. To use this method, select the **Adjust Time Step Based on Courant** option and provide the following information:

- **Maximum Courant**: This is the maximum Courant number allowed at any 2D cell or 1D cross section. If the maximum Courant number is exceeded, then the time step is cut in half for the very next time interval. Because HEC-RAS uses an implicit solution scheme, Courant numbers can be greater than one and still maintain a stable and accurate solution. In general, if the flood wave is rising and falling slowly (depth and velocity are changing slowly), the model can handle extremely high Courant numbers. For these types of cases, users may be able to enter a Maximum Courant number as high as 5.0 or more. However, if the flood wave changes very rapidly (depth and velocity are changing very quickly over time), then the Maximum Courant number will need to be set closer to 1.0. The example shown in Figure 5-3 was for a Dam break type of flood wave, and in this type of scenario depth and velocity change extremely rapidly. In this example, because of the rapid changes in depth and velocity, the Maximum Courant number was set to 1.0.

- **Minimum Courant**: This is the minimum Courant number threshold for 2D cells and 1D cross sections. If the Courant number at **all** locations falls below the Minimum Courant number, then the time step will be doubled. However, the time step will only be doubled if the current time step has been used for enough time steps in a row to satisfy the user entered criteria called "Number of steps below Minimum before doubling" (see below for an explanation of this field). The "Minimum Courant" value should always be less than half of the "Maximum Courant" value. If the Minimum Courant value is equal to or larger than half the Maximum Courant value, the software will flip back and forth between halving and doubling the time steps. In the example shown in Figure 5-3, since the Maximum Courant number was set to 1.0, the Minimum

Courant was set to 0.45 (less than half of the maximum), which allowed the model to stay stable, but also run faster.

- **Number of steps below Minimum before doubling**: This field is used to enter the integer number of time steps in which the Courant number must be below the user specified minimum before the time step can be increased. This can prevent the model from increasing the time step too quickly and/or from flipping back and forth between time steps. Typical values for this field may be in the range of 5 to 10.
- **Maximum number of doubling base time step**: This field is used to enter the maximum number of times the base time step can be doubled. For example, if the base computation interval is 10 seconds, and the user wants to allow it to go up to 40 seconds, then the value for this field would be 2 (i.e., the time step can be doubled twice: 10 to 20 to 40 seconds). The value displayed in the box to the right of the user entered value is what the entered maximum time step will end up being.

ⓘ **NOTE**: The HEC-RAS software requires that all time steps end up exactly hitting the Mapping Output Interval. This requirement is because output for HEC-RAS Mapper must be written to the output file for all cross sections, storage areas, and 2D cells at the mapping interval. Because of this fact, if users enter a **Maximum number of doubling base time step** that results in a computation interval that does not exactly land on the mapping output interval, then the unsteady flow computational program will compute its own time steps that work with the parameters entered in the **Adjust Time Step Based on Courant** section. Furthermore, the base time step will be changed to something close to what was entered, but when doubling it, all values will still line up with the mapping output interval. Therefore, when the model runs it will list what time step it is currently using in the message window of the computational output window.

- **Maximum number of halving base time step**: This field is used to enter the maximum number of times that the base computation interval can be cut in half. For example, if the base computation interval is 10 seconds, and the user wants to allow it to go down to 2.5 seconds, then the maximum number of halving value would need to be set to 2 (i.e., the time step can be cut in half twice: 10 to 5 to 2.5 seconds). The value displayed in the box to the right of the user entered value is what the entered maximum time step will end up being.
- **Select the Courant Methodology**: For the **Courant** number method, the default approach for computing the Courant number is to take the velocity times the time step divided by the length (between 1D cross sections, or between two 2D cells). For 2D, the velocity is taken from each face and the length is the distance between the two cell centers across that face. For 1D, the velocity is taken as the average velocity from the main channel at the cross section, and the length is the distance between that cross section and the next cross section downstream.

User Defined Dates/Time versus Time Step Divisor

Another option available from the **Advanced Time Step Control** tab is to set the variable time step control based on a user defined table of dates and times verses a time step divisor (Figure 5-4).

Figure 5-4. User Defined Variable Time Step Table.

As shown in Figure 5-4, the user can select the "Adjust Time Step Based on Time Series of Divisors" option from the **Advanced Time Step Control** tab. When this option is selected the user must enter a table of Dates and Times verses time step Divisors. The first date/time in the table must be equal to the starting date/time of the simulation period. To use this method, enter a base time step equal to the maximum time step desired during the run. Then in the table, under the Divisor column, enter the integer number to divide that time step by for the current date/time in the table. Once a time step is set for a date/time, the Unsteady Flow Analysis compute will use that time step until the user sets a new one.

In the example shown in Figure 5-4, the base computational interval was set at 1 minute. Based on the table of dates/times and Divisors entered, the actual time steps that will be used are displayed in the first column labelled "Time Step".

The Time Step Divisor method for controlling the time step requires much more knowledge by the user about the events being modelled, the system being routed through, as well as knowledge of velocities, cross section spacing, and 2D cell sizes. However, if done correctly, this method can be a very powerful tool for decreasing model run times and improving accuracy.

Performing the Computations

To run the model, open the **Unsteady Flow Analysis** window. Make a Plan by selecting the geometry that contains the combined 1D and 2D data, select an unsteady-flow file for the event to run, and give the Plan a Title and a Short ID. Set the following items: which Programs to Run; the Simulation Time Window; and all of the Computational Settings. Then press the **Compute** button to begin the run. (The window should look similar to Figure 5-5). If the 2D flow area pre-processor has

not been previously computed (from RAS Mapper) then the pre-processor will compute automatically at the beginning of the unsteady flow process.

Under the **Programs to Run** area, there is a check box for **Floodplain Mapping.** If a terrain data set has been imported using RAS Mapper, associated with the relevant geometry files, and stored maps staged for generation, this option will automatically create those stored maps following a successful compute. **This option is not required for flood mapping**. The **Floodplain Mapping** option is off by default because the user can perform Dynamic Flood Mapping and create Static Flood Maps (e.g., stored Depth grids) from RAS Mapper after the computations have been completed (this is the suggested workflow). The main purpose of this option is to automate the process of computing an inundation map (e.g., Depth grid) for use in CWMS or HEC-WAT. In general, this option will most likely not be used when running HEC-RAS in a standalone mode.

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. The 2D output is generated during the unsteady flow run.

Under the **Computational Settings** area, there is a feature called **Mapping Output Interval**. This feature allows users to set a mapping interval that will be used in RAS Mapper for creating Dynamic Maps (computed on-the-fly in memory, and not stored to disk), as well as for performing animations of the flood maps. When the user selects a specific interval (e.g., 1-hr), a limited set of hydraulic output variables are written to a binary (HDF5) output file for all Cross Sections, Storage Areas, and 2D Flow areas. Additionally, the maximum and minimum values that were computed at all locations during the run are also written to this file. This file is then used by RAS Mapper to perform dynamic mapping of the results. There are some additional Mapping Output/HDF5 options under the **Options** menu. From the **Option** menu, point to **Output Options** and select **HDF5 Write Parameters** from the submenu.
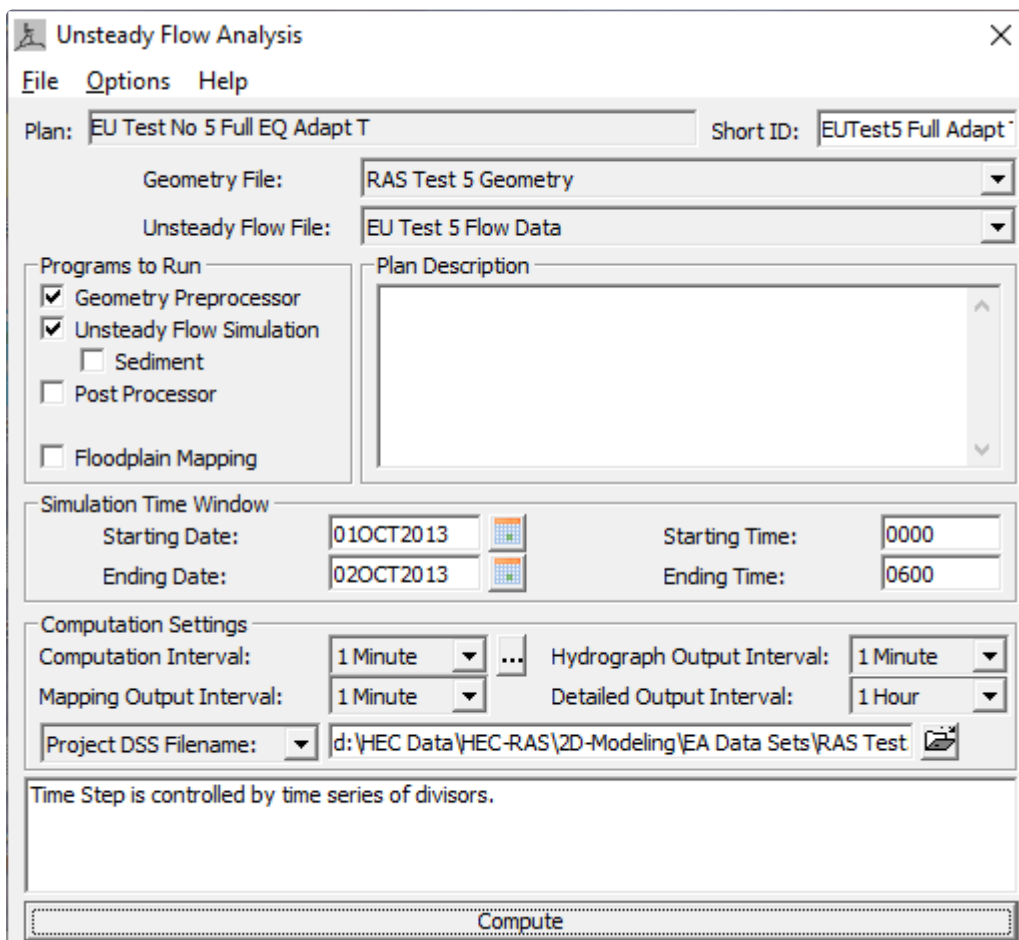
Figure 5-5. Unsteady flow Analysis Window with the new Floodplain Mapping feature.

Once the user presses the **Compute** button, the unsteady-flow computational engines will begin to run. This process consists of running the: 2D Geometry Pre-Processor (only if necessary), 1D Geometry Pre-Processor, Unsteady-Flow computations (combined 1D/2D), the 1D Post-Processor, and finally the Floodplain Mapping process (if it was turned on).

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Computation Progress, Numerical Stability, and Volume Accounting

As the unsteady flow simulation runs, information pertaining 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 will be 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 **Computational Messages** window. This message will provide information as to which cross section, storage area, or 2D cell had the greatest numerical error for that time step. This information can be very useful for detecting numerical problems in the model. For example, if the model goes to the maximum number of iterations for

several time steps in a row, and the numerical errors are significant, then the user should investigate that area of the model during the time that the model encountered problems.

In addition to messages that come up in the **Computation Messages** window, a Computational Log file is written to disk during the run. At a minimum, the Computational Log file will always contain a volume accounting check for the simulation. The volume accounting is done for the entire 1D/2D model and all its elements. There is also a separate volume accounting done for each 2D flow area. To view the Computational Log file, go to the **Options** menu on the **Unsteady Flow Analysis** window and select **View Computation Log File**. When this option is selected, the text file will appear in a Microsoft Notepad® window as shown in Figure 5-6.

As shown in Figure 5-6, the volume accounting is shown for the entire model first, then for each individual 2D Flow Area. Volumes are shown in Acre-Feet for all elements. The example in Figure 5-6 shows that the overall model gained 123.5 acre-feet of water, which equated to a 0.02017% volume error (very low). The separate 2D Flow Areas had flow gains ranging from 0.033 to 0.7646 acre-feet, which equated to volume errors ranging from 0.00003 to 0.001063% volume error (extremely low).

2D Computation Options and Tolerances

2D Flow Options

Options for controlling the 2D computations during the run are available from the same editor that contains the 1D Computational Options and Settings. From the **Unsteady Flow Analysis** window, select the **Options | Calculation Options and Tolerances** menu item to invoke the window shown in Figure 5-7. The HEC-RAS Unsteady Computation Options and Tolerances editor now contains five tabs. The **General** tab is the original 1D Unsteady-flow calculation options. The **2D Flow Options** tab, contains the calculation options and tolerances for the 2D computational module; this tab contains new 2D flow options which were added in HEC-RAS Version X.X which is the focus of this section. The **1D/2D Options** tab, contains options for controlling iterations between 1D and 2D hydraulic connections. The **Advanced Time Step Control** tab contains options for using the variable time step capability. The **1D Mixed Flow Options** tab, is for controlling the mixed flow regime capabilities used with the original 1D Finite Difference solution scheme; however, the 1D mixed flow options are not needed for the new 1D Finite Volume solution scheme.

HEC-RAS Unsteady Computation Options and Tolerances

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

☐ Use Coriolis Effects (not used with Diffusion Wave equation)

	Parameter	(Default)	2DBound
1	Theta (0.5-1.0)	1	0.8
2	Theta Warmup (0.5-1.0)	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	Advanced Convergence	☐	☐
7	Water Surface Max Tolerance (ft)	0.15	0.15
8	Water Surface RMS Toleance (ft)	0.002	0.002
9	Water Surface Stalling Tolerance (%)	1	1
10	Equation Set	Diffusion Wave	SWE-ELM (original/faster)
11	Initial Conditions Time (hrs)		10
12	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.8
13	Number of Time Slices (Integer Value)	1	2
14	Turbulence Model	None	Conservative
15	Longitudinal Mixing Coefficient	0.3	0.3
16	Transverse Mixing Coefficient	0.1	0.1
17	Smagorinsky Coefficient	0.05	0.05
18	Boundary Condition Volume Check	☐	☐
19	Latitude for Coriolis (-90 to 90)		
20	Solver Cores	All Available	4 Cores
21	Matrix Solver	PARDISO (Direct)	PARDISO (Direct)
22	Convergence Tolerance	0.00001	0.001
23	Minimum Iterations	3	3
24	Maximum Iterations	30	30
25	Restart Iteration	10	10
26	Relaxation Factor	1.3	1.3
27	SOR Preconditioner Iterations	10	10
28	ILUT Maximum Fill	8	0
29	ILUT Fill Tolerance	1E-06	0

OK   Cancel   Defaults ...

2D Flow Area Calculation Options and Tolerances

The 2D Flow Options tab (Figure 5-7), contains several new computational options and tolerances added in HEC-RAS Version 6.0 that can be set for the 2D module. These options are discussed below.

Use Coriolis Effects: Only used if the Shallow Water Equations (SWE) are turned on (Full Momentum)

This option allows the user to turn on the effects of the Earth's rotation on the solution (Coriolis Effect). When this option is turned on, the user must enter the latitude of the center of the 2D flow area in degrees (this is the field labeled **Latitude for Coriolis (-90 to 90)** in the table). A latitude with a value greater than zero is considered to be in the northern hemisphere and a value less than zero is considered in the southern hemisphere.

Theta (0.6 – 1.0):   1.0 (default)

This is the implicit weighting factor that is used to weight spatial derivatives between the current solution time and the previously computed time. Theta of 1.0 (default), uses only the currently solved time for the spatial derivatives. This default setting provides for the most stable solution, but possibly at the loss of some accuracy. Theta of 0.6, provides for the most accurate solution of the equations, but tends to be less stable. In general, it has been found that in most applications of real-world flood runoff events in rivers, a Theta of 1.0 will give about the same answers as a Theta of 0.6. However, this should be tested for each model due to site specific geometry and flood propagation, which may make a difference in the results.

Theta Warmup (0.6 – 1.0):   1.0 (default)

This is the value of Theta (see description above) that is used during the model warm up and ramp up periods. The Theta warm up is only used if the user has turned on the unsteady flow warm up option or the Boundary Condition Ramp up option for 2D areas.

Water Surface Tolerance [max=0.2] (ft): 0.01 (default)

This is the 2D water surface solution tolerance for the iteration scheme. If the solution of the equations gives a numerical answer that has less numerical error than the set tolerance, then the solver moves to the next time step. If the maximum error is greater than the set tolerance, then the program will iterate to get a better answer. The program will only iterate up to the maximum number of iterations set by the user. The default is set to 0.01 ft based on experience in using the model for a range of applications.

Volume Tolerance (ft):   0.01 (default)

This is the 2D water volume solution tolerance for the iteration scheme. The volume error is converted to feet (ft) of error by taking the currently solved for water surface elevation into the elevation-volume curve for the cell, then calculating the change in water surface elevation based on the current volume error at that point on the curve. If the solution of the equations gives a numerical answer that has less volume error than the set tolerance (in terms of ft), then the solver is done with that time step. If the maximum error is greater than the set tolerance, then HEC-RAS will iterate to get a better answer. The software will only iterate up to the maximum number of iterations set by the user. The default is set to 0.01 ft based on experience in using the model for a range of applications.

Maximum (Number of) Iterations (0 – 40):   20 (default)

This is the maximum number of iterations that the solver will use while attempting to solve the equations (to get an answer that has a numerical error less than the user specified tolerance at all locations in the 2D computational mesh domain). The default is set to 20 iterations. However, the

user can change the maximum number of iterations to a value from 0 to 40. It is not recommended to change the default value unless the user is certain that changing the value will either improve the chances that the model will converge (i.e., increasing the value) or speed up the computations without causing any significant errors.

Equation Set: Diffusion Wave (default); SWE-ELM (original/faster); and SWE-EM (stricter momentum).

The HEC-RAS two-dimensional computational module has the option of running the following equation sets: 2D Diffusion Wave equations; Shallow Water Equations (SWE-ELM) with a Eulerian-Lagrangian approach to solving for advection; or a new Shallow Water Equation solver (SWE-EM) that uses an Eulerian approach for advection. The new SWE solution method is more momentum conservative but may require smaller time steps and produce longer run times. The default is the 2D Diffusion Wave equation set. In general, many flood applications will work fine with the 2D Diffusion Wave equations. The Diffusion Wave equation set will run faster and is inherently more stable. However, there are applications where the 2D SWE should be used for greater accuracy. Users can try the multiple equation sets and efficiently compare the answers by selecting the equation set to use and running the simulation. It is suggested that users first create a new Plan file and then use a different equation set in order to easily compare the results.

The new SWE solver (SWE-EM) is an explicit solution scheme that is based on a more conservative form of the momentum equation. This solver requires time steps to be selected to ensure the Courant number will be less than 1.0, in general (not always). This solver produces les numerical diffusion than the original SWE solver. However, in general, this new solver is only needed when users are interested in taking a very close look at changes in water surfaces and velocities at and around hydraulic structures, piers/abutments, and tight contractions and expansions. The original SWE solver is more than adequate for most problems requiring the full momentum equation based solution scheme.

Initial Conditions Ramp up Time (hrs): (blank by default, not used)

This option by default is not used but can be used to ramp up the water surface from a dry condition to a wet condition within a 2D area (or from a flat water surface if an initial water surface elevation was entered). When external boundary conditions, such as flow and stage hydrographs (or 1D reaches), are connected to a 2D area the first value of the connected flow or stage may be too high (i.e., a very large flow or a stage that is much higher than the attached cell's elevation). If the model were to start this way, such a high discontinuity could cause model instability. This option allows the user to specify a time (in hours) to run the computations for the 2D flow area while slowly transitioning the flow boundaries from zero to their initial value and the stage boundaries from a dry elevation up to their initial wet elevation. The user specifies the total Initial Conditions Ramp up Time in this field (10 hours, for example). The user must also specify a fraction of this time for Ramping up the boundary conditions. A value of 0.1 means that 10% of the Initial Conditions time will be used to Ramp Up the boundary conditions to their initial values; the remaining time will be used to hold the boundary conditions constant but allow the flow to propagate through the 2D flow area, thus giving it enough time to stabilize to a good initial condition throughout the entire 2D flow area. The Ramp up time for the boundary conditions is entered in the next row, which is labeled **Boundary Condition Ramp up Fraction**.

Boundary Condition Ramp up Fraction (0 to 1.0): 0.1 (default)

This field goes along with the previous **Initial Conditions Ramp up Time (hrs)** field. This field is used to enter the fraction of the Initial Conditions Ramp up Time that will be used to ramp up the 2D flow area boundary conditions from their initial flow or stage. Users can enter a value between 0.0 and 1.0, representing the decimal fraction of the Initial Conditions Ramp up Time.

> **Number of Time Slices (Integer Value):**   1 (default)

This option allows the user to set a computational time step for a 2D flow area that is a fraction of the overall unsteady flow computation interval. For example, if the user has set the unsteady flow overall computation interval to 10 minutes, then setting a value of 5 in this field (for a specific 2D area) means that the computation interval for that 2D area will be 1/5 of the overall computation interval, which for this example would be 2 minutes (e.g., 10/5 = 2). Different values can be set for each 2D flow area. The default is 1, which means the 2D flow area will use the same computational time step as the overall unsteady flow solution (computation interval is entered by the user on the unsteady flow analysis window).

Advanced Convergence Criteria

HEC-RAS 6.6 has the option to specify additional convergence criteria which are aimed at reducing convergence stalling of the 2D hydraulic flow solver. Convergence stalling is the condition where the iteration errors stop decreasing without satisfying the convergence tolerance and thus causing the iterations to reach the maximum number of iterations (see figure below).

Comparison of Converged (left) and Stalled (right) iteration conditions.

Once stalling occurs, continuing iterations does not significantly improve the solution. Convergence stalling causes the solver to slow down due to the excessive iterations. Therefore, detecting stalling and exiting this condition can significantly improve model speed without affecting accuracy. The HEC-RAS 2D flow solver has two nested iteration loops. The outer loop is the loop in which the face hydraulic variables and matrix coefficient are updated while the inner loop iterates on the cell water surface and volumes. Stalling tends to occur within the outer loop in HEC-RAS while the inner loop tends to converge relatively fast within 1 to 3 iterations. Convergence is monitored in the outer loop using the maximum cell water surface elevation iteration difference (i.e. new values minus the previous iteration values) as a proxy for the iteration error. The convergence criterion based on the maximum water surface error is given by

$$\varepsilon_{\max}^{m} = \max(|z_{s,i}^{m} - z_{s,i}^{m-1}|) < \varepsilon_{\max}^{\text{conv}}$$

where

$z_{s,i}^m$: cell water surface elevation for the mth iteration and ith cell [L]

ε_{max}^m : computed water surface elevation maximum error for the mth iteration [L]

ε_{max}^{conv} : user-specified water surface tolerance (default is 0.01 ft) [L]

The convergence criterion is used in both previous versions of HEC-RAS and 6.6 with and without the advanced convergence criteria. The advanced convergence parameters are:

Advanced Convergence: (checkbox to enable, unchecked by default)

Water Surface Max Tolerance (ft): 0.15 (default)

Water Surface RMS Tolerance (ft): 0.002 (default)

Water Surface Stalling Tolerance (%): 1 (default)

The advanced convergence criteria is turned on with the checkbox on row 6 in the **2D Flow Options** tab of the **HEC-RAS Unsteady Computation Options and Tolerances** editor shown below.

Advanced Convergence Parameters

The maximum error is efficient to calculate compared to other statistics. The criterion works well when the maximum error is small so no or few iterations are computed, or the maximum error has a narrow or short-tailed distribution without outliers. The main issue with the above criterion is that the maximum error is often not a representative value of the water surface error for the whole computational domain, because it represents an outlier in the error distribution. If the advanced convergence option is turned on, an additional convergence criterion is applied:

$$\varepsilon_{RMS}^m = \sqrt{\sum |z_{s,i}^m - z_{s,i}^{m-1}|^2} < \varepsilon_{max}^{conv} \text{ and } \varepsilon_{max}^m < \varepsilon_{max}^{max}$$

where

$\varepsilon_{\text{RMS}}^m$: computed water surface elevation Root-Mean Squared Error for the mth iteration [L]

$\varepsilon_{\text{RMS}}^{\text{conv}}$: user-specified water surface RMS tolerance (default is 0.002 ft) [L]

$\varepsilon_{\text{RMS}}^{\text{max}}$: user-specified water surface max tolerance with $\varepsilon_{\text{RMS}}^{\text{max}} > \varepsilon_{\text{RMS}}^{\text{conv}}$ (default is 0.15 ft) [L]

The above convergence criterion utilizes the water surface RMSE and a larger maximum water surface tolerance, $\varepsilon_{\text{RMS}}^{\text{max}}$, compared to the convergence tolerance $\varepsilon_{\text{RMS}}^{\text{conv}}$. The water surface RMSE, $\varepsilon_{\text{RMS}}^m$, is only computed if $\varepsilon_{\text{max}}^m < \varepsilon_{\text{RMS}}^{\text{max}}$. This reduces the computational cost of the more expense RMSE compared to the maximum error. The parameters $\varepsilon_{\text{RMS}}^{\text{conv}}$ and $\varepsilon_{\text{RMS}}^{\text{max}}$ are set on rows 7 and 8 of the **2D Flow Options** tab of the **HEC-RAS Unsteady Computation Options and Tolerances** editor shown above.

If the above convergence criteria are not satisfied, the solver continues to iterate until the maximum number of iterations or if the advanced option is selected, until stalling is detected. Stalling is computed based on both the maximum error and RMSE by comparing the improvement/reduction in the error statistic within the last two iterations normalized by the initial error compared to a user-specified tolerance as a percentage.

$$\frac{\varepsilon_{\text{max}}^m - \varepsilon_{\text{max}}^{m-2}}{\varepsilon_{\text{max}}^0} < \frac{T^{\text{stall}}}{100}$$

$$\frac{\varepsilon_{\text{RMS}}^m - \varepsilon_{\text{RMS}}^{m-2}}{\varepsilon_{\text{RMS}}^0} \frac{\varepsilon_{\text{max}}^m}{\varepsilon_{\text{RMS}}^m} < \frac{T^{\text{stall}}}{100}$$

where

T^{stall} : user-specified water surface stalling tolerance [%].

In the case of the RMSE, the value $\varepsilon_{\text{max}}^0$ is not available and so it is estimated based on the ratio of the RMS and maximum errors. Stalling is computed based on the m and m-2 iterations since the errors often oscillate at this frequency. The parameter T^{stall} is set on 9 of the **2D Flow Options** tab of the **HEC-RAS Unsteady Computation Options and Tolerances** editor shown above.

Turbulent Mixing Coefficients

The modeler has the option to include the effects of turbulent mixing and dispersion in the 2D flow field. HEC-RAS has two different formulations for turbulence modeling: a non-conservative formulation and a fully conservative formulation.

Turbulent mixing is the transfer of momentum due to the chaotic motion of the fluid. Dispersive mixing is the transfer of momentum due to subgrid variations in the time-averaged velocity field, both vertically and horizontally. The sum of horizontal molecular and turbulent mixing and dispersion are referred to simply as mixing here and are simulated as a Fickian diffusive process with a diffusion coefficient represented by the eddy viscosity. The default in HEC-RAS is to have all of the mixing coefficients empty, meaning turbulence is turned off. The numerical scheme in HEC-RAS provides some numerical diffusion. The larger the computational cell size and time step the larger the numerical diffusion. Therefore, when utilizing relatively fine computational cells with small time steps, it may be necessary to turn on mixing in order to obtain accurate results. To turn on horizontal mixing, enter a value for at least one of the mixing coefficients. These are the **Longitudinal Mixing Coefficient**, the **Transverse Mixing Coefficient**, and the **Smagorinsky**

Coefficient. In previous versions of HEC-RAS, the longitudinal and transverse mixing coefficients were assumed to be equal. However, in HEC-RAS Version 6.0 these coefficients can now be specified separately. An additional parameter, the **Smagorinsky Coefficient** has also been added. Simple guidance is provided for initial values for these parameters. Nonetheless, these coefficients should be calibrated using spatially distributed velocity measurements. For the details on the Turbulence modeling approaches in HEC-RAS, please review the 2D modeling section of Chapter 2 in the HEC-RAS Hydraulic Reference Manual.

Turbulence Model: None (default), Conservative, and Non-Conservative (original).

The Turbulence model choices are None (no turbulence modeling will be performed), Conservative (a conservative formulation that ensures little to no momentum loss when turbulence is turned on), and a Non-Conservative formulation (this formulation has some numerical diffusion, however it is very small when the cell size is small and the time step is small).

Longitudinal Mixing Coefficient: (blank by default, not used)

In general, the turbulence intensity and dispersion are not the same in all directions. The **Longitudinal Mixing Coefficient** is utilized to compute the contribution of the eddy viscosity from the turbulence and dispersion in the longitudinal direction (i.e., the direction of flow). In practice, this coefficient can differ by several orders of magnitude, depending on the flow. Table 5-1 lists some values for the **Longitudinal Mixing Coefficient** (D_L) that have been found to be appropriate under certain conditions.

Table 5 1. Longitudinal Coefficients.

DL	Mixing Intensity	Geometry and surface
0.1 to 0.3	Little longitudinal mixing	Straight channel Smooth surface
0.3 to 1	Moderate longitudinal mixing	Gentle meanders Moderate surface irregularities
1 to 3	Strong longitudinal mixing	Strong meanders Rough surface

Transverse Mixing Coefficient: (blank by default, not used)

The **Transverse Mixing Coefficient** is utilized to compute the contribution of the eddy viscosity from the turbulence and dispersion in the transverse direction (i.e., perpendicular to the flow direction). In practice, this coefficient can differ by several orders of magnitude, depending on the flow. Table 5-2 lists some values for the **Transverse Mixing Coefficient** (D_T) that have been found to be appropriate under certain conditions.

Table 5 2. Transverse Mixing Coefficients.

DT	Mixing Intensity	Geometry and surface
0.05 to 0.1	Little transversal mixing	Straight channel Smooth surface
0.1 to 0.3	Moderate transversal mixing	Gentle meanders Moderate surface irregularities
0.3 to 1	Strong transversal mixing	Strong meanders Rough surface

Smagorinsky Coefficient: (blank by default, not used)

The Smagorinksy component of the eddy viscosity represents the turbulence intensity produced by flow shear and assumes that the energy production and dissipation are equal at subgrid scales. The component is expressed as a function of length scale defined by the local grid resolution, the flow strain (magnitude of the depth-averaged current velocity gradients), and the dimensionless **Smagorinsky Coefficient**. The Smagorinksy eddy viscosity component requires computing four current velocity gradients for the flow strain and therefore it is relatively computationally expensive and should only be used (and is only necessary) when simulating high-resolution flows. This Smagorinksy eddy viscosity is important in regions close to solid boundaries or obstacles in the flow. The **Smagorinsky Coefficient** value is typically in the range of **0.05** to **0.2**. However, it is best to calibrate this and other mixing parameters using spatially distributed current velocity measurements. Since the eddy viscosity is computed as the sum of the various components, their values must be calibrated together.

Boundary Condition Volume Check: (checkbox to enable, unchecked by default)

When this option is turned on (by checking the checkbox), the software will check 2D to 1D boundary connections to ensure that there is enough water in a 2D cell over the time step to actually satisfy the computed flow exchange. If there is not, the computed flow exchange will be reduced for the first guess of the flow rate for that time step.

Latitude for Coriolis (-90 to 90):   (blank by default, not used)

If the user checks the checkbox to turn on the "Use Coriolis Effects (not used with Diffusion Wave equation)" option, then a latitude for the centroid of the project should be entered in this field.

Solver Cores: (by default all available CPU cores are used)

The Solver Cores parameter refers to the number of CPU cores that will be used in solving the 2D Flow Area solution. The HEC-RAS 2D computational module was developed with parallel processing in mind. The HEC-RAS 2D computations will use as many CPU cores as there are available on the user's machine (which is the default mode for running). However, HEC-RAS provides the option to set the number of cores to use for the 2D computations. In general, it is recommended to use the default of "All Available". However, the user may want to experiment with this for a specific data set to see if it will either speed up or slow down computations based on a specific number of cores. The ideal number of cores for a given problem is size (i.e., number of cells) and shape dependent (i.e., shape of the 2D Flow Area). As more cores are used, the problem is split into smaller pieces, but there is overhead in the communications between the pieces. So, it is not necessarily true that a

given problem will always run faster with more cores. Smaller data sets (2D areas with fewer cells) may actually run faster with fewer cores. Large data sets (2D Areas with lots of cells, i.e., > 100,000 cells) will almost always run faster with more cores, so use all that is available.

Shown below in Table 5-3 and Figure 5-8 are the results of testing a few data sets by running them with different numbers of Solver Cores. Each model was run several times with the number of solver cores set to: 1, 2, 4, 8, and 16 (Figure 5-8). As Figure 5-8 illustrates, four of the data sets displayed an improvement in computation speed with the number of cores set from 1 up to 8 but ran slower with 16 cores. These four data sets ranged in size from 10,000 to 80,000 cells. However, one data set displayed speed improvements all the way up to 16 cores. This was the largest data set with 250,000 cells. Further runs were done to find the optimal number of cores for each data set, these results are shown in Table 5-3.

> (i) **NOTE:** HEC-RAS uses a parallelization process called OpenMP, within the Intel Fortran compiler. Intel states in their Fortran manual, that exact duplication of math cannot be guaranteed when using multiple cores to solve a problem. In practical application we have seen that if a model iterates a lot, and has some instabilities, the computed results can change a small amount when even running the same model on the same machine. However, if a model is stable, in general we have not seen any significant differences in results, even when running on different machines. If a user uses a single core, results are consistently reproducible, however, the model will take significantly longer to run.

Table 5 3. Optimal No. of CPU Cores versus Number of 2D Cells

Data Set Name	Time Window	Time Step	Number of Cells	Optimal No. of Cores	Computation Time
Saint Paul 1D/2D	16 days	30 sec	2,251	6	48 sec
EU Test No 5 2D	1 day 6 hrs	10 sec	7,460	8	36 sec
Ohio/Miss 1D/2D	49 days	5 min	23,087	8	3 min 37 sec
EU Test No 4 2D	5 hrs	20 sec	80,000	10	41sec
400 sq mi Watershed 2D	2 days	2 min	250,000	16	23 min 23 sec
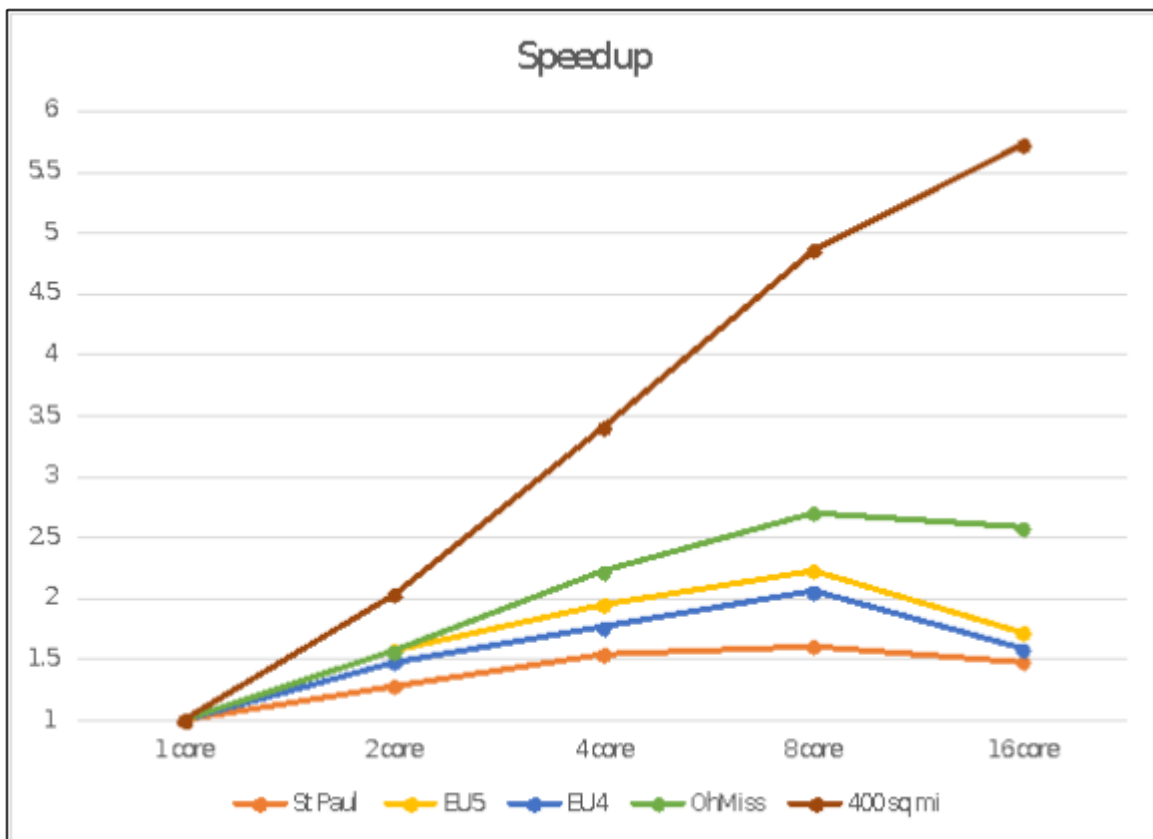
Figure 5-8. Number of processor cores vs. computational speed.

Matrix Solver: PARDISO (default)

This option allows the user to select one of several sparse matrix solvers. There are two types of solvers available: direct and iterative. PARDISO is the only direct solver available. Direct solvers compute the final solution within a finite number of steps and do not require an initial guess. Since direct solvers produce very accurate solutions, they are very robust. For this reason, PARDISO is the default matrix solver in HEC-RAS. One other advantage of the PARDISO solver is that it does not require any user-specified parameters. The second type of matrix solvers in HEC-RAS are iterative solvers. Iterative solvers generally require less memory because, unlike direct solvers, the structure of the matrix does not change during the iteration process. In addition, iterative solvers utilize matrix-vector multiplications which can be efficiently parallelized. The main drawback of iterative solvers is that the rate of convergence depends greatly on the condition number of the coefficient matrix. For poorly conditioned matrices, the iterative solver may not converge at all. Therefore, the efficiency of iterative solvers greatly depends on the size and condition number of the coefficient matrix.

HEC-RAS Version 6.0 and newer also have the option to select one of two iterative solvers. The iterative solvers can be faster under certain conditions. The iterative solvers available are: SOR (Successive Over-Relaxation) and FGMRES-SOR (Flexible Generalized Minimal Residual with SOR preconditioner). The SOR method is used both as an iterative solver and as a preconditioner for FGMRES. The SOR solver works well for small (~5000 to 10000 cells) to medium (~30000 to 50000 cells) size 2D areas. Generally, the larger the mesh, the more iterations are required for convergence.

Convergence Tolerance: (blank by default, this is an optional parameter)

This option allows the user to specify the convergence tolerance for the iterative solver. The tolerance is compared to the root-mean-squared of the normalized residuals. If not specified, the tolerance is set to 1×10^{-4} times the water surface tolerance. Decreasing the tolerance will increase the number of solver iterations and decrease the speed of the simulation and vice-versa. If the tolerance is too small, it is possible the iterative solver will take a large amount of iterations to reach the tolerance or never reach it at all. Conversely, if the tolerance is set too large, the solution errors will produce water volume errors. Therefore, the user must be careful when setting this parameter.

Minimum Number of Iterations: None (Optional)

This option allows the user to specify the minimum number of iterations. The iterative solver will continue to iterate even if the convergence criteria is satisfied until the minimum number of iterations. The minimum number of iterations avoids solution creep or divergence in cases where the solution is changing slowly, or the convergence tolerance is set too high. The default minimum number of iterations is computed internally based on the number of cells and the matrix solver. The SOR solver generally requires fewer iterations than the FGMRES-SOR solver.

Maximum Number of Iterations: None (Optional)

This option allows the user to specify the maximum number of iterations. The maximum number of iterations keeps the solver from iterating too many times past the point of diminishing returns. Generally, iterative solvers will reach a point at which the improvement in the solution for each iteration is relatively small and the computational cost of each iteration does not outweigh the benefit of continuing to iterate. The default maximum number of iterations is computed internally based on the number of cells and the matrix solver. The SOR solver generally requires fewer iterations than the FGMRES-SOR solver.

Relaxation Coefficient: 1.3 (default)

This option allows the user to specify the relaxation coefficient for the SOR solver. The optimal relaxation value of the relaxation coefficient is generally between 1.1 and 1.5. However, if the value is too large the solver may diverge. Therefore, it is best to utilize a conservative value which will be relatively fast and not have divergence problems.

Restart Iterations: 10 (default)

This option allows the user to specify the restart iterations used in the FGMRES solver. Because the amount of storage and computational work required by FGMRES increases with each iteration, the method is typically restarted. The group of iterations between successive restarts is referred to as a cycle. When a cycle is completed the results' approximate solution is used as an initial guess for a new cycle of iterations. Generally, the restart iterations is between 8 and 20.

SOR Preconditioner Iterations: 10 (default)

The SOR method is used both as a solver and as a preconditioner for the FGMRES solver in HEC-RAS. When SOR is used as a preconditioner, the SOR method is applied for a fixed number of iterations which is specified as the **SOR Preconditioner Iterations**. This eliminates the need to specify separate convergence criteria for the auxiliary system of equations for which the SOR method is applied. It also eliminates the need to compute convergence parameters during the SOR iterations. The optimum number of iterations will be problem specific. However, in general, the larger the mesh, the more iterations that will be necessary.

1D/2D Options Tab

From the **HEC-RAS Unsteady Computation Options and Tolerances** editor (Figure 5-7), from the **1D/2D Options** tab. There are also some options for controlling 1D/2D iterations, which can be used to improve the computations of flow passing from a 1D element (reach or storage area) to a 2D Flow Area. By default, this option is turned off, and most 1D to 2D connections will not need iterations. However, when the1D/2D hydraulic conditions become highly submerged, or there are flow reversals or tidally influenced stages or flows, then iterating between the 1D solution and 2D solution may be necessary to get an accurate and stable solution. To turn on the 1D/2D iterations option, from the **HEC-RAS Unsteady Computation Options and Tolerances** editor (Figure 5-7), select the **1D/2D Options** tab. Then set the **Maximum iterations between 1D and 2D**, as well as tolerances for controlling the convergence criteria. The maximum iterations can be set from 0 to 20, with zero meaning that the compute will not perform extra iterations (this is the default). In general, only use this option if there is a stability problem at a 1D/2D hydraulic connection. Set the number of 1D/2D iterations to as low a value as possible in order to get a stable answer between a 1D and 2D connection that is having stability problems. The number of 1D/2D iterations will cause the entire solution to be calculated multiple times for each time step in order to get the desired convergence. **NOTE: Increasing the maximum number of iterations could dramatically lengthen run times**. If the user turns this option on, it is suggested to start with a low value, such as 3 or 4. If the stability problem still exists with that number of iterations, then increase the value until a stable solution is achieved.

The convergence criteria for 1D/2D iterations consists of a **Water Surface Tolerance**, **Flow Tolerance (%)**, and a **Minimum Flow Tolerance**. The water surface tolerance is currently only used when an upstream 1D reach is connected to a downstream 2D Flow Area. In this situation, the 1D region is computed, then the 2D region. The assumed water surface elevation at the boundary is re-evaluated. If the water surface has changed more than the **Water Surface Tolerance**, then the program will iterate. When the water surface elevation at the boundary has changed less than the tolerance, the solution stops iterating and moves on to the next time step.

The **Flow Tolerance (%)** is utilized for the following 1D/2D connections: Lateral Structure; SA/2D Hydraulic Connection (SA to 2D, or 2D to 2D); and 2D Flow Area to 1D Reach connection. The default value for the Flow Tolerance (%) is 0.1. If 1D/2D iterations are turned on, then the flow between these types of 1D/2D connections gets recomputed after each trial to see if it has changed more than the user defined **Flow Tolerance** (%). If it has changed more than the flow tolerance, then the program iterates. A companion tolerance to the **Flow Tolerance** is the **Minimum Flow Tolerance (cfs)**. The purpose of this tolerance is to prevent the program from iterating when the flow passed between a 1D and 2D element is very small and not significant to the solution. For example, there may be a connection from a 1D reach to a 2D Flow Area via a Lateral Structure in which the flow under certain conditions is very low. As such, the actual change in the flow from one iteration to the next could be very small (but the percent error is very high). Such a small flow may not add significance to the solution, so iterating the entire solution to improve this small flow between the 1D and 2D elements is not recommended and may unnecessarily increase the computational time. In general, it can be beneficial to set a minimum flow when turning on 1D/2D iterations. The default value is 1 cfs, however, this parameter is model specific.

New 1D Computational Options

A few new 1D only computational options have been added for version 6.0, and one existing option has been removed. The **General** tab, selected from the **Computational Options and Tolerances** window, contains the following new 1D options:
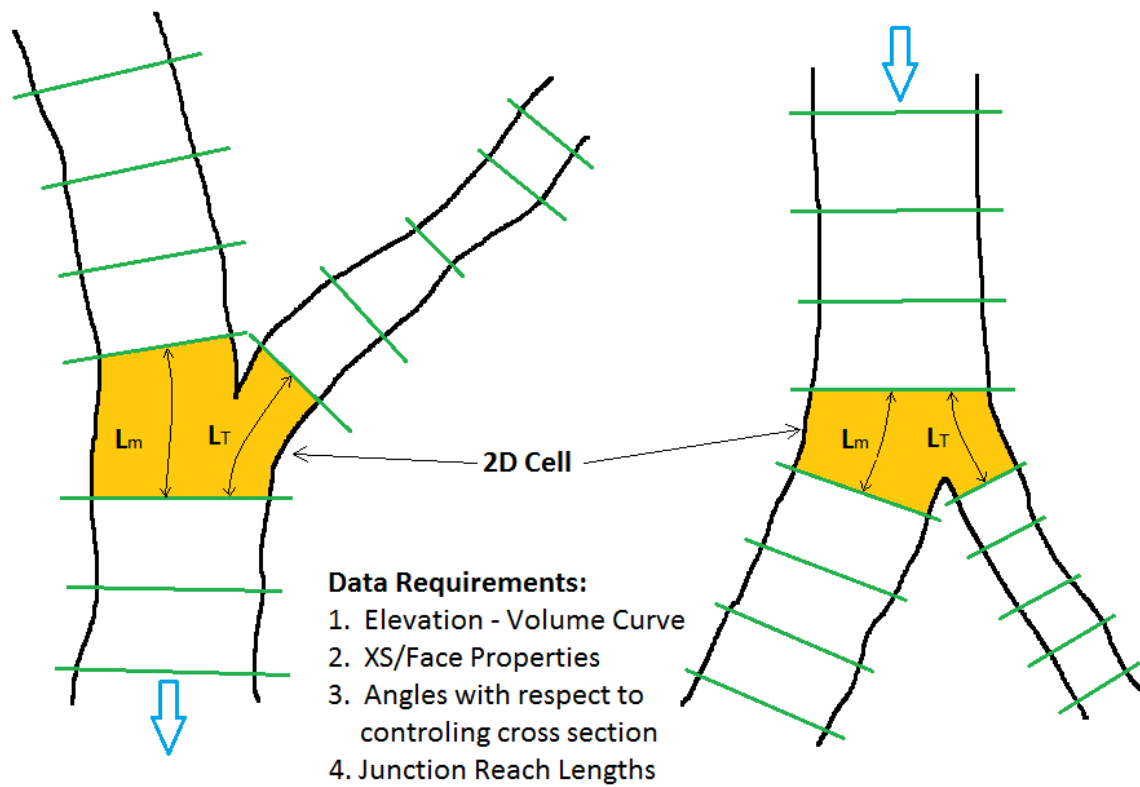
1. **1D Finite Volume Solver**. HEC has developed a new 1D Finite Volume solution algorithm for solving the 1D Shallow Water equations. The current 1D Finite Difference scheme has trouble in the following situations:

- Can't handle starting or going dry in a cross section (XS).
- Low flow model stability issues with irregular XS data.
- Extremely rapidly rising hydrographs.
- Mixed flow regime (i.e., flow transitions).
- Stream junctions do not transfer momentum.

The new 1D Finite Volume algorithm has the following positive attributes:

- Can start with channels completely dry or they can go dry during a simulation (wetting/drying).
- Very stable for low flow modeling.
- Can handle extremely rapidly rising hydrographs without going unstable.
- Handles subcritical to supercritical flow and hydraulic jumps better – No special option to turn on.
- Junction analysis is performed as a single 2D cell when connecting 1D reaches (continuity and momentum is conserved through the junction).

Additionally, the new 1D Finite Volume solution scheme breaks up the cross section into separate cells for the left overbank, main channel, and the right overbank. The current finite difference scheme combines the properties of the left and tight overbank into a single flow area called the floodplain. Additionally, the hydraulic properties of the left and right floodplain are combined and the reach lengths are averaged together.

Stream junctions are also handled very differently in the new 1D Finite Volume scheme. The 1D finite difference scheme had two options. The default option was to assume all cross sections bounding the junction had the same water surface elevation. The second option allowed the user to compute the water surface across the junction using a steady flow energy solution each time step. For the 1D Finite Volume solution, the junction is treated as a single 2D cell and the 2D shallow water equations are solved through the junction. This solution allows for more complex junctions within a 1D framework. Also, this approach allows for the transfer of momentum through the junctions as well as a more detailed calculation of the water surface elevations around the junction. The 1D model must be georeferenced in order for this to work correctly, as that is how the software forms the 2D cell correctly. See the example in Figure 5-9 below.

2D Cell

Data Requirements:
1. Elevation - Volume Curve
2. XS/Face Properties
3. Angles with respect to controling cross section
4. Junction Reach Lengths

To use the new 1D finite volume solution scheme, select **Computational Options and Tolerances** from the **Unsteady Flow Analysis** window. Then from the **HEC-RAS Unsteady Computation Options and Tolerances** editor, select the **General** tab (Figure 5-10).

Figure 5-10. General Tab from the Unsteady Flow Analysis Computational Options and Tolerances.

As shown in Figure 5-10, to turn on the new 1D Finite Volume solution scheme, simply select the **Finite Volume (new approach)** radio button from the **1D Numerical Solution** area in the lower right-hand side of the window. The user can also control the number of cores used to solve the problem. Most of the time, the solution will be solved the fastest with a single core.

An example of a model that was started completely dry, and containing bridges, is shown in Figure 5-11.
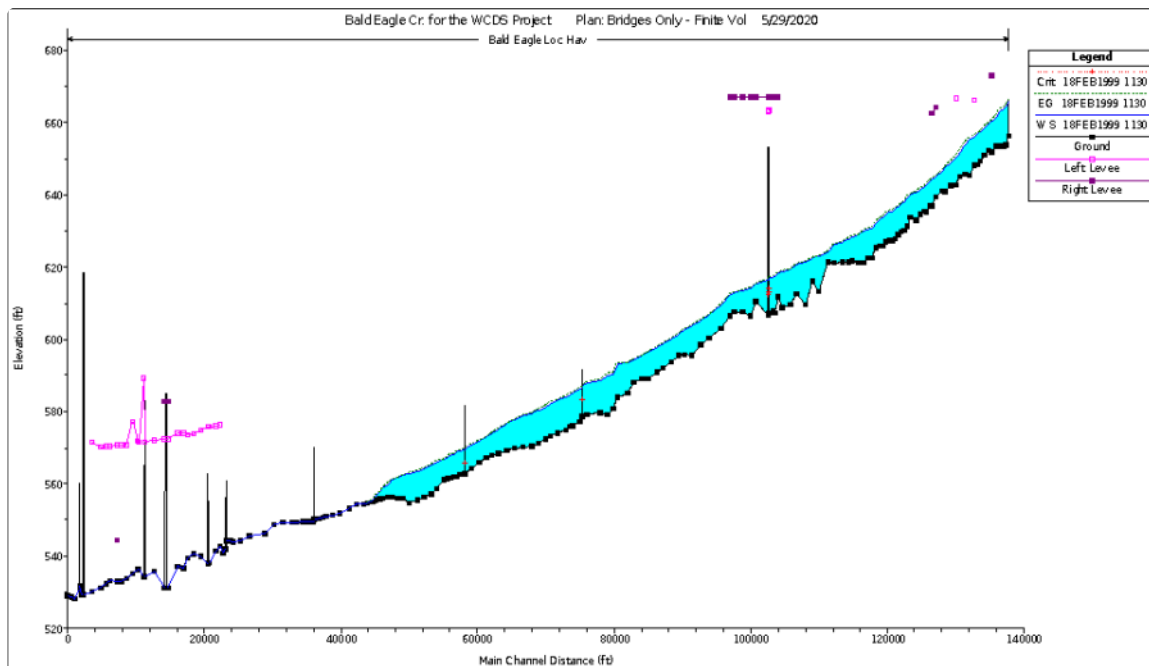
In general, the 1D Finite Volume solution algorithm is more robust (greater model stability) that the existing 1D finite Difference solution scheme. However, there are some draw backs to the new 1D Finite Volume solution scheme. These deficiencies are:

1. **Users cannot use lidded cross sections with the new 1D Finite Volume solution scheme.** This also means that it cannot handle pressurized flow, even with the Priessman slot option turned on. If the model contains lidded cross sections, as soon as the water hits the high point of the lids' low chord it will go unstable.
2. **The 1D Finite Volume solution scheme is sensitive to the volume of water between any two cross sections.** The equations are written from a "volume" perspective. If two cross sections are very close together, then there is very little volume between those two cross sections. The 1D Finite Volume scheme will require smaller time steps in order to handle the change in volume over the time step for this type of situation. The 1D Finite Difference scheme handles this better, because the equations are written in terms of change in water surface and velocity, which may be a small change for cross sections that are closer together. Therefore, for the 1D Finite Volume scheme to work well with larger time steps, users may need to remove cross sections that are very close together.
3. **The 1D Finite Volume scheme is computationally slower than the 1D Finite Difference solution scheme.** This is because the 1D Finite difference scheme combined the properties of the left and right overbank together (area, wetted perimeter, average length between cross sections, etc.) and solved the equations for a main channel and a single floodplain. The new 1D Finite Volume solution scheme keeps the left and right overbank properties completely separate. Thus the equations are written for a separate left overbank, main channel, and right over bank, and then solved. This is more computational work for every time step, but it is computationally more accurate.
4. **The 1D Finite Volume Solver cannot be used with the Modified Puls Routing Option.** The Modified Puls Routing option cannot be used with the 1D Finite Volume solution scheme. This was done on purpose, as it was deemed users would not need the Modified Puls Routing option since the Finite Volume routing method can handle dry channels, extremely low flows, rapidly rising flows, and very steep channels. Modified Puls routing was added to HEC-RAS because the original 1D Finite difference solver has trouble in the areas previously described.

2. **Maximum number of Iterations without improvement.** This option is off by default. If the user turns it on, the maximum numerical error computed during the 1D Iterations will be monitored. If the error does not improve within the specified number of iterations, then the 1D solver stops iterating and goes on to the next time step. For example, let's say the default maximum number of iterations set to 20. If the "Maximum number of iterations without improvement" is set to 5, then during any time step, if the iteration scheme does not continue to improve the numerical solution for 5 iterations in a row it will stop and go to the next time step, using whichever previous iteration was the best solution. In general, 5 is a good number to start with for this option, but the user may want to try lowering it. This option will improve computational speed for data sets that iterate a lot. However, if the user turns this option on and sets the value too low, then the result may be an increase the model instability.

3. **1D Equation Matrix Solver.** HEC-RAS uses a matrix solution solver called "Skyline" which uses Gaussian elimination for reducing the size of the matrix. The 1D Equation Matrix Solver has been optimized for dendritic river systems and is very fast. However, sometimes HEC-RAS models can be very large and have many interconnections (loops in the stream network, or many interconnected storage areas). The HEC-RAS team has added an option to solve the 1D matrix with the "PARDISO" solver, which is used by the 2D solver. This solver has the benefit of being able to use multiple cores. Results from experiments conducted at HEC have found that the Skyline Matrix solver is still faster for dendritic systems. However, large models with lots of lateral structures, storage areas, and loops in the reaches **may** be solved faster using the PARDISO solver. Users can try the Skyline Matrix Solver out to see which one works better on a specific data set. However, the HEC-RAS team do not have a lot of experience in using this solver on the 1D side. So if using the 1D Equation Matrix Solver be aware of the risk. In other words, don't just compare the computational times, also compare the results to make sure they are the same.

Note: The HEC-RAS team removed the option to "**Convert 1D Energy Bridges to Cross Sections with Lids**." This option was not used often, and in some cases caused model stability issues. So now all bridges are pre-processed into a family of curves. If this option was turned on in a model built and computed in an older version of HEC-RAS, then this change may produce different computed results in the vicinity of that bridge.

Wind Force Options

Specifying the wind data in the **Unsteady Flow Data** Editor's **Meteorological Data** tab (Figure 4-21) automatically turns on wind forcing in the computational engine. However, there are some additional computational options available to the user from the **HEC-RAS Unsteady Computation Options and Tolerances** window. This is done by opening the **Unsteady Flow Analysis** window and select the menu option **Options** | **Calculation Options and Tolerances** (Figure 5-12).

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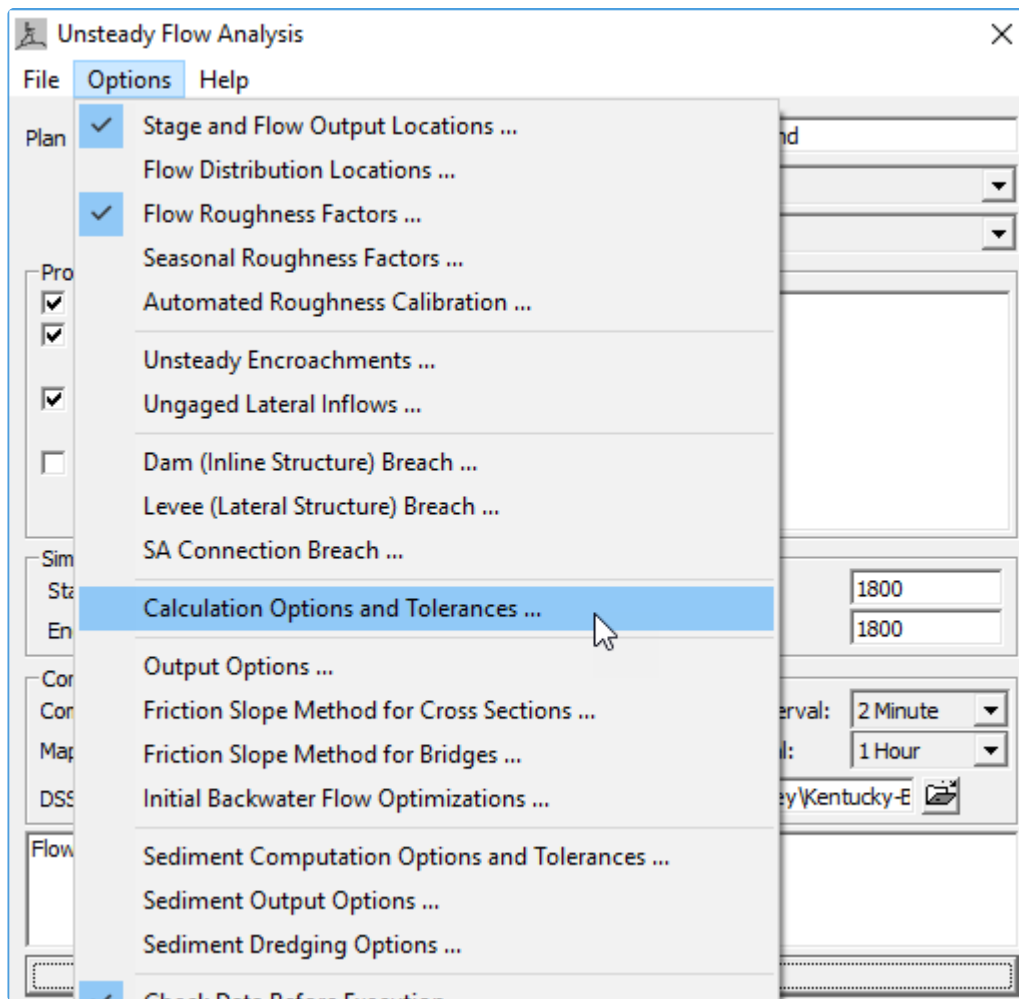
Within the **HEC-RAS Unsteady Computation Options and Tolerances** window (Figure 5-13), the wind **Reference Frame** may be specified as **Eulerian** or **Lagrangian**. An Eulerian reference frame only takes into account the speed of the wind when computing the wind drag forces. The Lagrangian reference frame also takes into account the speed and direction of the water.

The wind **Drag Formulation** may be specified using the drop-down menu. Users can choose from four different equations to compute the drag coefficient (i.e., Hsu (1988), Garratt (1977), Large and Pond (1981), Andreas et al. (2012)), or enter the drag coefficient as a constant value. Please see Chapter 2 of the HEC-RAS Version 6.0 Hydraulic Reference Manual for the details of the different wind drag equations and their applicability.

Figure 5-13. HEC-RAS Unsteady Computation Options and Tolerances dialog shown the Wind Forcing options.

7 VIEWING 2D OR 1D/2D OUTPUT USING HEC-RAS MAPPER

Once the user has completed an unsteady flow run of the model, the user can look at all of the 1D output (plots and tables) in the same manner as before, using the traditional plots and tables. However, the 2D output results can only be viewed within RAS Mapper. Currently, the user can visualize inundation areas (and other types of output) within RAS Mapper for River Reaches, Storage Areas, and 2D flow areas at the same time. To visualize the output, select the **GIS Tools | RAS**

Mapper menu on the main HEC-RAS window (or just select the RAS Mapper button ⬙ on the main HEC-RAS window). The RAS Mapper window shown in Figure 6-1 will appear.

Note: This chapter is an overview of RAS Mapper to assist users with visualizing 1D/2D output. For more details on RAS Mapper, see the separate RAS Mapper User's manual.
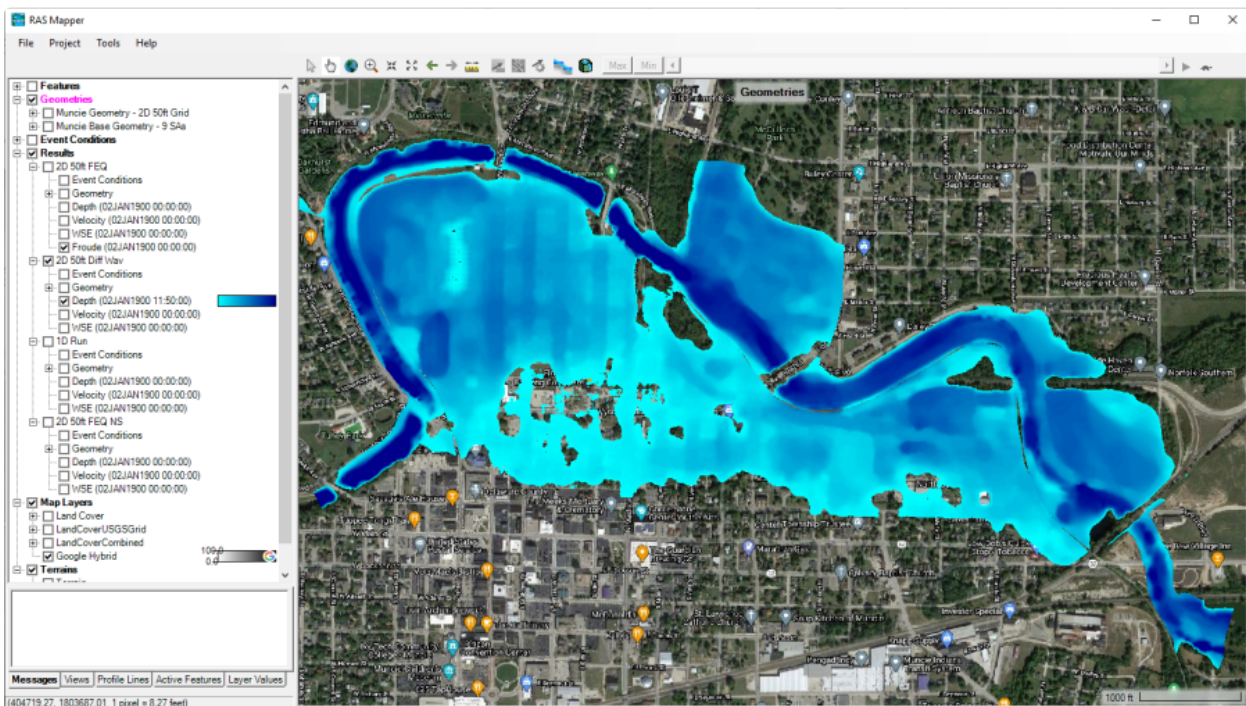
Figure 6-1. RAS Mapper window with combined 1D/2D flood inundation output displayed.

Overview of RAS Mapper Output Capabilities

HEC-RAS Mapper can be used to develop terrain models and visualize HEC-RAS results in a map-based format. For a more detailed description of RAS Mapper, see the RAS Mapper User's Manual. RAS Mapper has the following capabilities:

1.   a. 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.

b. Develop Land Cover Layers (for use in defining Manning's n values and percent impervious); soils layers, and infiltration layers.
c. Various types of map layer results can be generated, such as: depth of water; water surface elevations; velocity; inundation boundary (shapefile); flow (1D only right now); depth times velocity; depth times velocity[2]; Courant number; Froude number; Residence Time; Shear stress; Energy Depth; Energy Elevation; arrival time; Arrival time (max); Recession; flood duration; percent time inundated; Stream power; and wet cells (completely color any cell that gets wet).
d. 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 file.
e. Computed model results can be animated (dynamic mapping) or shown for a specific instance in time. There are also options for plotting maximum (Max) and minimum (Min) values at all locations.
f. 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. Time series plots and tables include: water surface elevation; depth; and velocity (2D node velocities, 2D average face velocities, and 1D velocities), etc….
g. Users can query any active map layers value by simply moving the mouse pointer over the map.
h. Web imagery, shape files, and point layers can be displayed as background layers behind the computed results. Shapefiles and Point layers can also be added to the "Features" layer in order to be plotted on top.
i. The user can make a terrain model from the cross sections (channel only or entire sections), the river and bank lines, and the cross-section interpolation surface. Elevations between the cross sections are interpolated using the interpolation surface and the cross-section elevations. This terrain model can then be combined with other terrain data (overbank/floodplain) to make a new terrain model in which the channel/cross section data is now burned into the overall terrain model.
j. Users can create User Defined Profile Lines, then request various types of output along those profile lines (i.e., WSE and terrain, velocity, depth, flow, etc…)
k. User can zoom into an area of their model then store that location as a User Define View. Then later you can click on any User define view and it will jump to that location and view.

Adding Results Map Layers for Visualization

Once an HEC-RAS model run is completed, and RAS Mapper is opened, there will be a **Results** Layer that has the same name as the HEC-RAS Plan Short ID for that run (see Figure 6-2 below). Beneath the **Results | Plan Short ID** Layer, will be a tree of related results. By default there will be an **Event Conditions** layer, a **Geometry** layer, **Depth** layer, **Velocity** layer, and **WSE (water surface elevation)** layer. The Geometry layer will contain the HEC-RAS Input Geometry layers that were used in that specific run. The Geometry layer includes sub layers of: River; XS (cross sections); Storage Areas; 2D flow areas; Bridges/Culverts, etc… Any or all of these Geometry layers can be turned on for visualization of model elements.
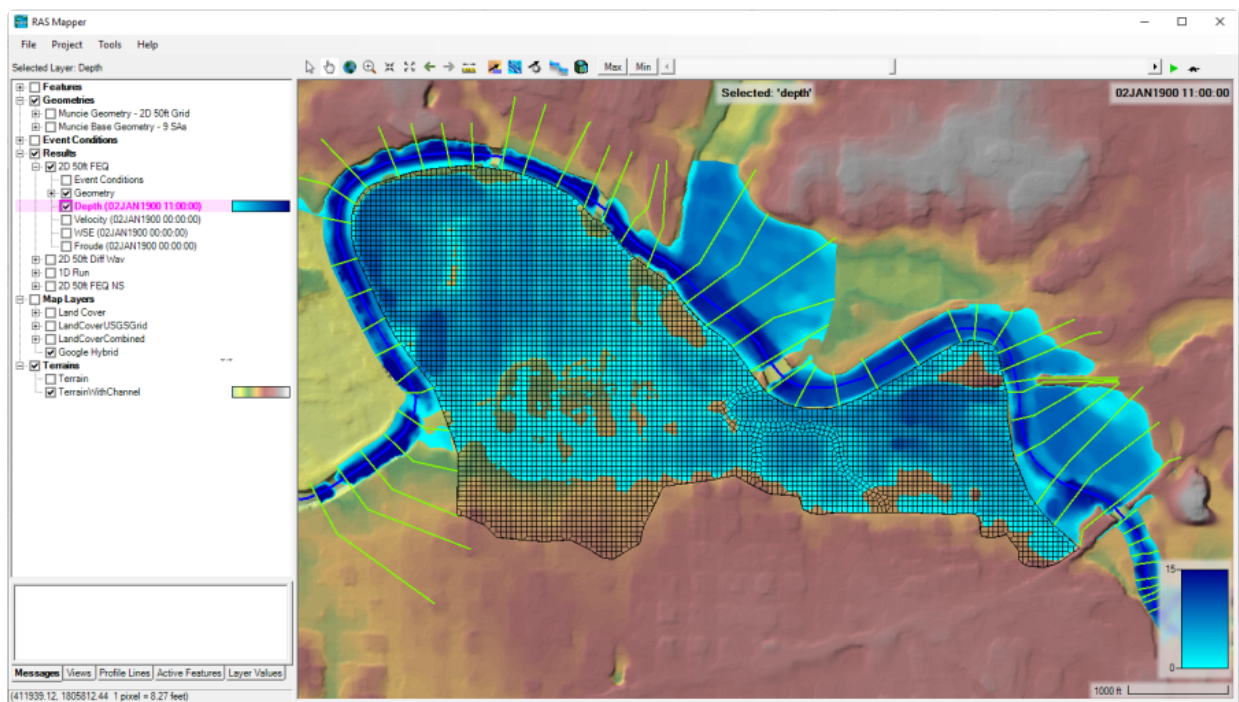
By default, after a successful HEC-RAS model run, there will be three dynamic results layers called **Depth, Velocity, and WSE** (Water Surface Elevation). These layers can be used to visualize the model results in an inundation mapping form (e.g. two-dimensional map of the geometry, with water and other layers on top of it). The layers will be computed and displayed on-the-fly, meaning RAS Mapper reads the computed model result from a file, and then it computes the map in memory and displays it as needed. The underlying terrain used for computing the map layers is based on the view scale of the map. If the user is zoomed in, the base (raw) data will be used for computing the inundation map layers; however, if the user is zoomed out, a re-sampled version of the terrain is used. Therefore, the displayed map layers may change slightly based on the scale at which the user is zoomed. By default, the map layers are not pre-computed grids stored on the hard drive. By computing the map layer on the fly, the mapping is actually faster and takes much less disk space. The user has the option to create a "Stored" map layer (a grid stored to the hard disk) if desired. The "Stored" grids are based on the raw (most detailed) terrain layer for computing the grid.

Other results layers are available for visualization, but the user has to request/create a results layer to display. To create a new results layer, right click on the desired Plan Name (listed in the Results Layer) and select the option called **Add New Results Map Layer**. This option will bring up a window that will allow you to select a new Results Map Type (see Figure 6-3). This window can also be displayed by selecting **Tools | Manage Results Maps**. Then the **Results Map Manager** will appear, and the user can then select **Add New Map** button from any of the Plan names listed in that window to create a new results map layer.
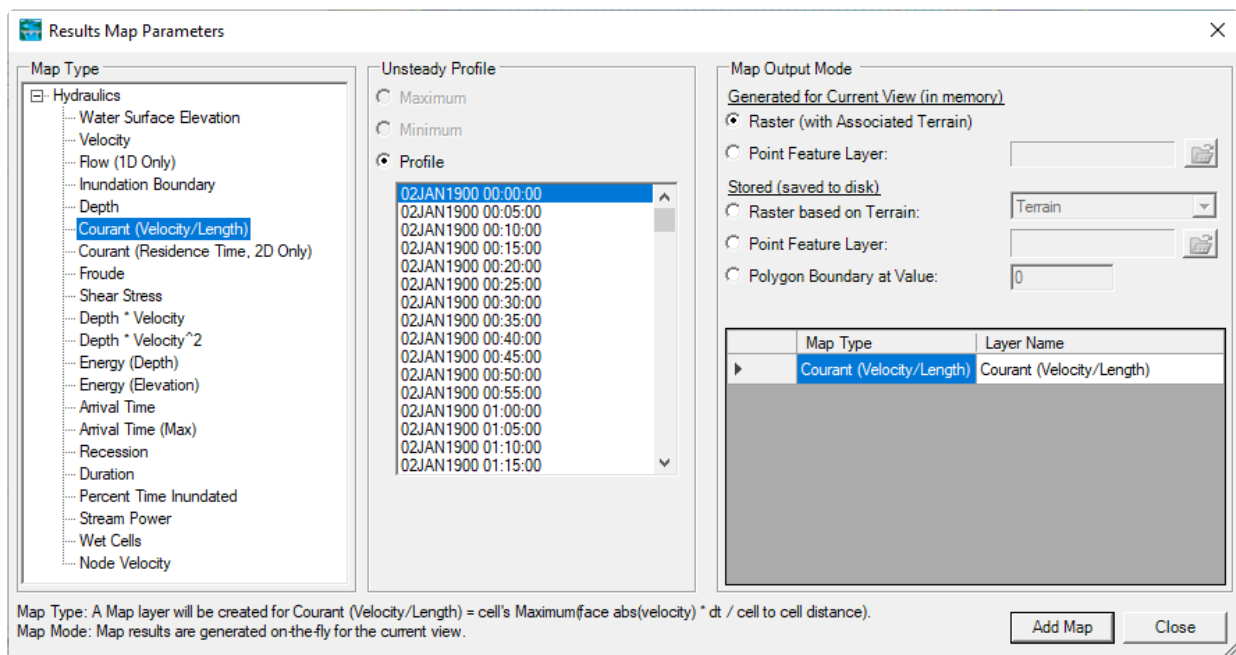
As shown in Figure 6-3, the new **Results Map Parameter** window has three sections to select from. On the left is the **Map Type**, where the user selects the parameter to map (create a layer for). Currently RAS Mapper allows the user to create 20 different Map Types (Table 6-1).

After a Map Type is selected, the middle section of the window (**Unsteady Profile**) is used to pick the profile type: Maximum (Max stage everywhere regardless of time); Minimum (Min stage everywhere regardless of time); or a specific date and time (results at that specific instance in time). If a map is going to be displayed dynamically (computed in memory and displayed on-the-fly), it does not matter what is picked for the profile, the user will be able to dynamically visualize all the profiles. If a map needs to be created as a static map (a results or depth grid written to a file) then the specific profile picked will be used for that static map.

Table 6 1. Current RAS Mapper Map Types.

Map Type	Description
Depth	Water depths computed from the difference in water surface elevation.
Water Surface Elevation	Water surface elevations at all computed locations and spatially interpolated water surface elevations between those locations.
Velocity	Velocity at all computed locations and spatially interpolated velocity between those locations.
Inundation Boundary	Inundation boundary computed from the zero-depth contour of flood depths for the selected water surface profile.
Flow (1D Only)	Computed flow values at the 1D cross sections and Interpolated flow values between cross sections. This option is only available for 1D simulations

Map Type	Description
Shear Stress	Shear stress computed as: (γ R Sf). For 2D cells it is the average shear stress across each face, then interpolated between faces. For 1D cross sections, the cross section is broken into user defined slices, then average values are computed for each slice. Values are interpolated between cross sections using the cross section interpolation surface.
Depth * Velocity	Computed as the hydraulic depth (average depth) multiplied by the average velocity at all computed locations and spatially interpolated between those locations. For 2D cells the hydraulic depth is computed for each Face, then multiplied by the average velocity across that face. For 1D cross sections, the cross section is broken into user defined slices, then average values are computed for each slice. For unsteady-flow runs, the Maximum value is the maximum of depth times velocity based on the user mapping interval, and not the computation interval.
Depth * Velocity^2	Computed as the hydraulic depth (average depth) multiplied by average velocity squared at all computed locations and spatially interpolated between those locations. For 2D cells the hydraulic depth is computed for each Face, then multiplied by the average velocity squared across that face. For 1D cross sections, the cross section is broken into user defined slices, then average values are computed for each slice. The Maximum value is the maximum of depth times velocity squared based on the user mapping interval, and not the computation interval.
Arrival Time	Computed time (in hours or days) from a specified time in the simulation when the water depth reaches a specified inundation depth (threshold). The user may specify the time units, start time, and depth threshold.
Arrival Time (Max)	Arrival time max is the time it takes, from a user specified time and date, to get to the maximum water surface at each location (XS, 2D cell, storage area)
Recession	Computed time (in hours or days) from a specified time in the simulation when the water depth recedes back below a specified inundation depth (threshold). The user may specify the time units, start time, and depth threshold.
Duration	Computed duration (in hours or days) for which water depth exceeds a specified flood depth (threshold). The user may specify the time units, a start time, and depth threshold. (Note: RAS ignores multiple peaked events. Once a depth threshold is reach the duration continues until the depth has completely receded for the event.)
Percent Time Inundated	The amount of time an area is inundated as a percentage of the total simulation time range.
Stream Power	Stream Power is computed as average velocity time's average shear stress. For 2D cells it is the average velocity times average shear stress across each face, then interpolated between faces. For 1D cross sections, the cross section is broken into user defined slices, then average values are computed for each slice. Values are interpolated between cross sections using the cross-section interpolation surface.
Courant Number	The Courant number is value used to assist understanding numerical stability. Review the section in Chapter 5 of this document on picking a computational time step for more details on Courant number.
Froude Number	The Froude number is used to define if the flow regime is subcritical, supercritical, or at critical depth. If Froude number is greater than 1.0, then the flow is supercritical. If the Froude

Map Type	Description
	number is less than 1.0, then the flow is subcritical. If the Froude number is 1.0, then it is at critical depth.
Residence Time (2D only)	Residence time is the time it would take for the volume of water in a cell to leave, given the current velocity of the flow leaving the cell.
Wet Cells	This map simply shows which 2D cells are wet. When using this map layer, if a 2D cell even gets a drop of water it shows the entire cell as wet.
Energy (Depth)	The energy depth is the depth of the water plus the velocity head, mapped as an Energy Depth.
Energy (Elevation)	The energy elevation is computed as the water surface elevation plus the velocity head, and mapped as an Energy Elevation.

Arrival time and duration map layers, require additional information from the user: whether to write the results out in hours or days; a depth threshold (default is zero, but the user may want to enter a higher value, like 0.5 or 1.0 feet); and finally a starting data and time to be used for the evaluation (this may be the start of a warning time, which would then make the arrival time calculation a warning time).

The last thing to select on the window is the **Map Output Mode** (Table 6-2). The **Map Output Mode** is where the user selects whether the map will be a Dynamic layer, **Generated for Current View (in memory)**, or a **Stored (Saved to disk)** map layer. **Dynamic** layers get computed on-the-fly as needed and can be animated through the time steps of the solution. **Dynamic** maps are the most useful for visualizing the results. **Stored** maps only need to be created when the user wants to create a depth grid, or other layer type, that needs to be written to the hard disk. A **Stored** layer can be used by another program (for example by HEC-FIA to compute damages or life loss), or it can displayed in a GIS and used for another purpose.

> ⓘ **Note:** The Dynamic mapping uses a pyramiding scheme to display the maps (Just like Google does). You have to be zoomed way in to see the full flooding in detail. As you zoom out, the software grabs a coarser terrain layer in which 4 of the original terrain cells are averaged into a single cell (average elevation) then an inundation map is made from that. If you zoom out further, then an even coarser terrain layer is grabbed (based on how far out you are zoomed), then it creates an inundation map from that. So the further you zoom out, the more coarse the terrain that gets used (i.e. more averaged). This is done for speed. There would be no way we could produce and display the maps on the fly so fast without doing this. Also, Dynamic mapping is done with a sloping water surface TIN, which is then intersected with a TIN of the Terrain surface, in order to find the zero depth intersection.
>
> Stored maps are made from the most detailed level of terrain (Your base terrain). However, stored maps are grids in which a single water surface elevation (or other data layer value) is stored per cell (cell size is based on the terrain data being used to create the map). Ultimately the

Dynamic maps and Stored maps can show some differences in inundated area, depending on your zoom level and the cell size used in creating your terrain model.

Table 6 2. RAS Mapper Map Output Modes.

Map Output Mode	Description
Dynamic	Map is generated for current view dynamically in memory (RAM). Results may also be animated if there are multiple profiles for the variable.
Raster	Gridded output is computed based on the associated Terrain.
Point Feature Layer	Values are computed a locations specified by a point shapefile. For the Depth map type, elevation values to compare against can come from the Associated Terrain, Z-Values from the points, or using a column for elevation data.
Stored	Computed map is stored to disk for a specific profile. Stored maps cannot be animated.
Raster	Gridded output is computed based on the user-specified Terrain and stored to disk. The Associated Terrain is the default.
Point Feature Layer	Values are computed a locations specified by a point shapefile and stored to disk. For the Depth map type, elevation values to compare against can from the Associated Terrain, Z-Values from the points, or using a column for elevation data.
Polygon Boundary at Value	A boundary is polygon is created at the specified contour value stored to disk. This is the default option for the Inundation Boundary map type using the computed depth at the zero-depth contour.

Once a **Map Type**, **Unsteady Profile**, and a **Map Output Mode** have been selected, the user then selects the **Add Map** button and the map will be added to the Results Layer underneath the selected Plan.

Map Rendering Modes

There can be important differences in the computed values between the dynamic results and the stored raster information. Dynamic maps differ in that they are a surface created through the interpolation of values; therefore, as the user moves the mouse in the display the interpolated value for the corresponding location will be displayed. This is in contrast to viewing a raster in a typical GIS where the reported value will be that for the entire grid cell.

For dynamic depth results, the values reported to the user at a specific map location may change depending on the zoom level. This is because for dynamic mapping, the terrain pyramid level used for evaluating the ground surface elevation is dependent on how far the user has zoomed in or out on the map. Even while zoomed in so that the base data are used for analysis, the map results will not be identical, especially at the floodplain boundary. This is because for the stored depth grid the

cell is considered either wet or dry. For a dynamic map, the flood boundary is determined by interpolating the elevations values and intersecting the interpolated water surface with the interpolated terrain elevations for the boundary. The dynamic map will, therefore, result in a "smooth" floodplain boundary. An example of the differences between the dynamic mapping and stored mapping are shown in Figure 64.

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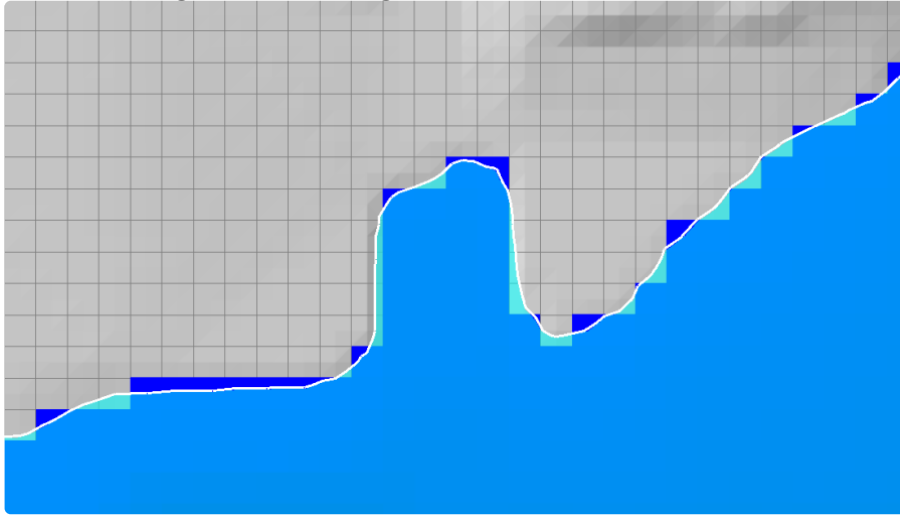
2D Mapping Options

RAS Mapper has three Rendering Mode options for how the water surface is interpolated and displayed for 2D model results. The **Render Mode** options are to plot the water surface as either **Hydrid (Sloping/Horizontal)** (default)**; Sloping;** or as **Horizontal** within a 2D cell. The render mode selection will affect both the dynamic map and the stored map results. To select the Render Mode, select **Tools/Options** to bring up the Options window, then select **Render Mode**, or select the render mode button ![button] on the button layer. Either way the RAS Mapper Options window will appear with the Render Mode settings display in the window.

Hybrid (Sloping/Horizontal – Default) **-** This render mode is a combination of both the Sloping and the Horizontal render modes described below. In general the water surface is plotted using the sloping rendering mode, except for locations where the water surface is not hydraulically connected. For example, two cells that are wet, but have a Face between them that is dry. These two cells are not hydraulically connected, and therefore the sloping rendering model should not be used to plot the water surface across these two cells. Instead, the horizontal rendering mode is used for both cells.

Sloping Water Surface – The Sloping water surface rendering mode plots the computed water surface by interpolating water surface elevations from each 2D cell face. This option of connecting each cell face provides a visualization for a more continuous inundation map. The more continuous inundation map, looks more realistic; however, under some circumstances it can also have the appearance of more water or less water volume in the 2D cells than what was computed in the simulation. This problem generally occurs in steep terrain with large 2D grid cells. This sloping water surface approach is most helpful when displaying shallow inundation depths in areas of steep

terrain. This is the default rendering mode. However, users should plot with both rendering modes and closely inspect the differences.

Horizontal Water Surface – The Horizontal water surface rendering mode plots the computed water surface as horizontal in each 2D Area cell. This option fills each 2D cell to the water surface as computed in the 2D simulation. In areas where the terrain has significant relief between 2D cells this plotting option can produce a "patchwork" of isolated inundated areas when visualizing flood depths. These isolated inundation areas are more visible in areas of steep terrain, using large grids cells, with shallow flood depths.

An illustration of the sloping and horizontal rendering modes is shown in Figure 65 while Figure 66 shows the spatial differences due to the rendering mode.
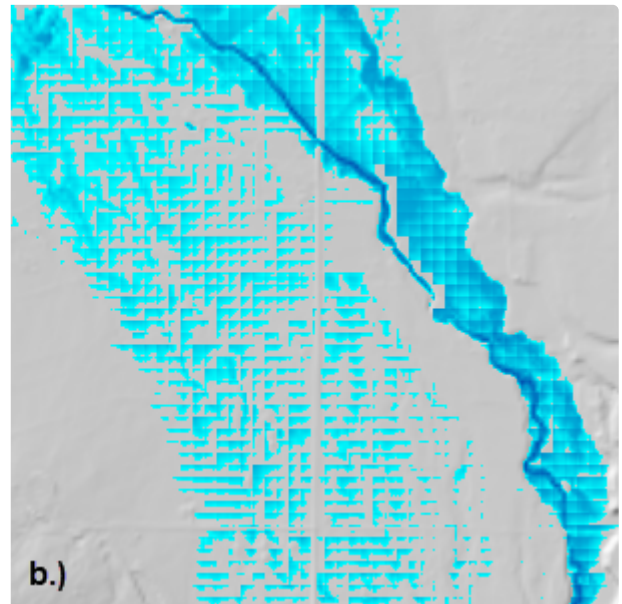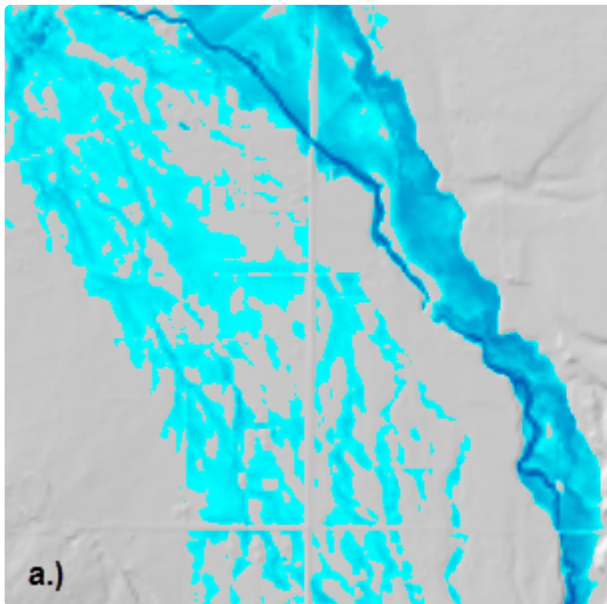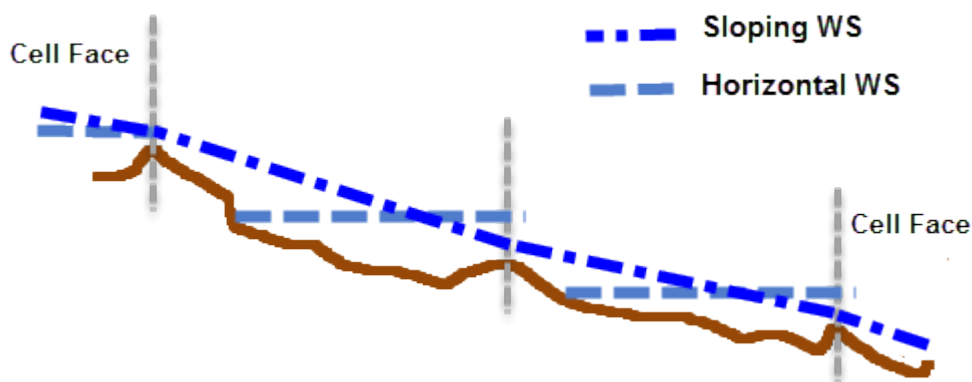
Dynamic Mapping

As shown in Figure 6-7, there will be results layers for each Plan that has been run. For this example, under the **Results** layer in the panel on the left side, there are results for a Plan called "2D 50 ft Grid". Under the "2D 50 ft Grid" layer there are five sub layers: **Event Conditions**, **Geometry**, **Depth**, **Velocity**, and **WSE (water surface elevation)**. The **Event Conditions layer** will contain any spatial meteorological data that has been set up for the boundary conditions file attached to that plan (ex. Precipitation data). The **Geometry Layer** represents the geometry data used in the plan and written to the output file. The other layers (**Depth**, **Velocity**, and **WSE**) are **Dynamic Mapping** output layers. Each layer name is followed by a set of parentheses. The information following in the parentheses describes what current grid is showing in the plot. Inside the parentheses could be a specific date and time, or max, or min.

Right clicking on any of the results layers (for example **Depth**) will show a context sensitive menu that has several options for this output layer. These options are: Layer Properties; Edit Map Parameters; View Map in 3D Viewer; Zoom to Layer; Add Watch to Layer Values; Remove Layer; Move Layer; Export RAS Tiles for Web Mapping (Figure 6-7) and Show Summary Statistics.
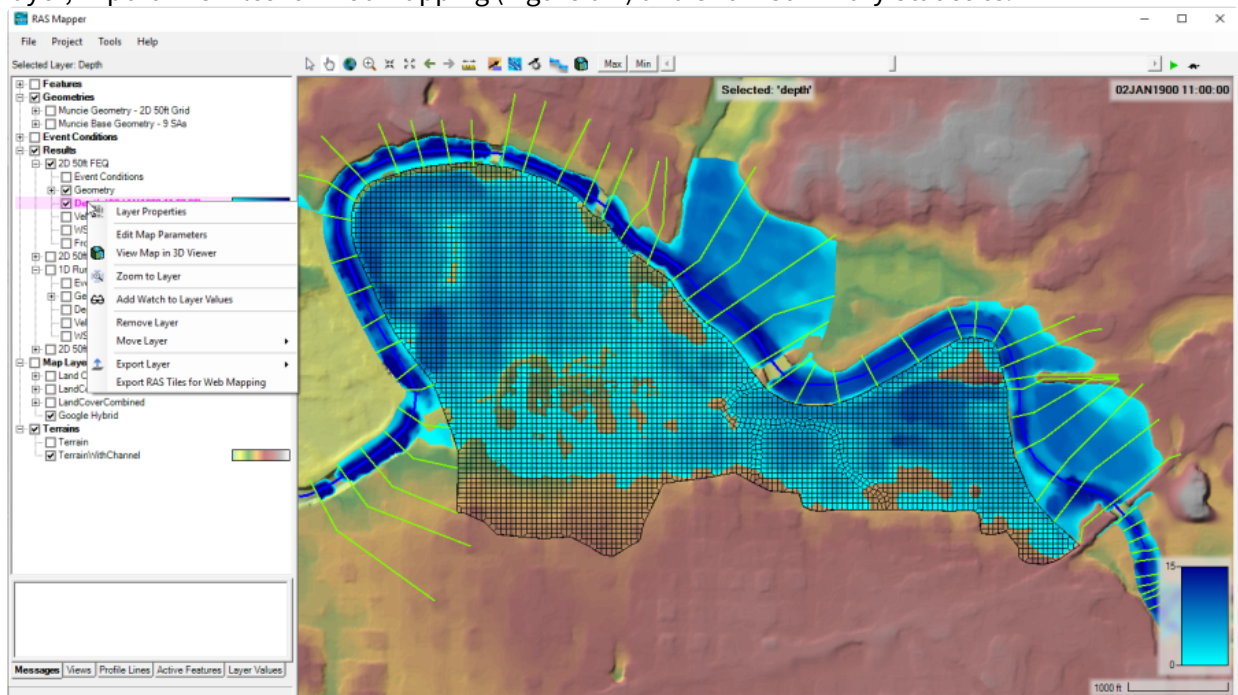
Layer Properties – This option allows the user to control what each layer looks like, such as colors, color ramps, symbol and line colors and types, fill styles, etc… It also contains a tab called "Source" which provides information about the layer, as well as what the file name is, where it is stored, etc…

Edit Map Parameters – This option allows the user to edit or change the parameters of the map layer.

View Map in 3D Viewer – this options opens the currently selected result into the 3D Viewer.

Zoom To Layer – This option zooms in or out, such that the extents of the selected layer are visible.

Add Watch to Layer Values – This option allows the user to add variables to a "Watch" list. When turned on, the variables will show up next to the mouse pointer and also in a table at the bottom left, when the "**Layer Values**" tab is selected. As you move the mouse over top of the wet area on the map, the magnitude of the watch variables is displayed dynamically.

Remove Layer – This option allows the user to delete the layer from the RAS Mapper window.

Move Layer – This option allows the user to move the layer up or down within the RAS Mapper layer list. This is important, since something that is higher in the list (above) will be plotted on top of things that are lower in the list (below), when multiple layers are turned on together for display. When this option is selected, several sub menus will popup that allow the user to move a layer: Top; Up One; Down One; Bottom. The user can also left-click on a layer and drag it up and down within the layers list.

Export Layer – This option allows the user to export the layer as a Raster (*.tif) to a file.

Export RAS Tiles for Web Mapping– This option will export the Depth grid to what is termed a Tile Cache (before doing this the user must set the spatial projection using the **Set Projection for Project** option from the RAS Mapper **Tools** menu). A Tile Cache is a series of files (256 x 256 pixels) with different resolutions, written out using a pyramided and tiled scheme that meets Google's mapping specifications (i.e., there will be several directories, each one representing a different resolution). When this option is selected, the window shown in Figure 6-8 will appear.

The user is required to set the Filename and Folder in which these subfolders will be developed and the tiles will be stored. Additionally the user should select the **Cache Level** that will represent the most detailed tile level (when zoomed in). If the user plans on zooming way in for greater detail in the map, a higher Cache level (smaller cell (pixel) size) should be selected. However, the higher the cache level selected, the longer it will take to generate this Tile Cache, and the larger the file storage space required. Also, this cell (pixel) size will change depending on the latitude of the project.

Show Summary Statistics – When this option is selected for a specific layer (ex. Water Surface Elevation), the software will compute the following summary statistics for that layer based on the currently displayed time step: Mean; Standard Deviation; Minimum; and Maximum.

Animating Map Layers

Any Map Layer that is "Dynamic" can be animated in time. The animation control can be used to animate a single map layer; multiple map layers within the same Plan; or multiple map layers from different plans.

To animate a single map layer, turn that map layer on, then make it the active map layer (Layer will be highlighted in a Magenta color). Once a layer is turned on, and made the active layer, then the animation control at the top of the map window, can be used to animate that layer in time. The animation control has a play button, as well as Max, and Min options.

To animate multiple map layers within the same Plan, turn on all of the desired map layers within the Plan, then select the Plan identifier to make it the Active plan (It should be highlighted in Magenta). Then use the animation control to animate all of that plans layers in time together.

To animate multiple map layers from different plans, turn on all the desired map layers to be animated from separate plans. Next, select the results layer to activate all of the results for animation (The **Results** layer will be highlighted in Magenta). Then use the animation control to animate all of the turned on map layers in time. An example of animating two different Depth layers, from different plans, is shown in Figure 6-9. As long as both plans have output for the same date and time, they will be shown. The software uses the highest layer in the tree for deciding on the time window, and time steps available for animation. If any of the other map layers that are turned on do not have an output at that specific point in time, then it is simply not shown, and the layer will have a label called "No Data" for the date and time portion of the label.
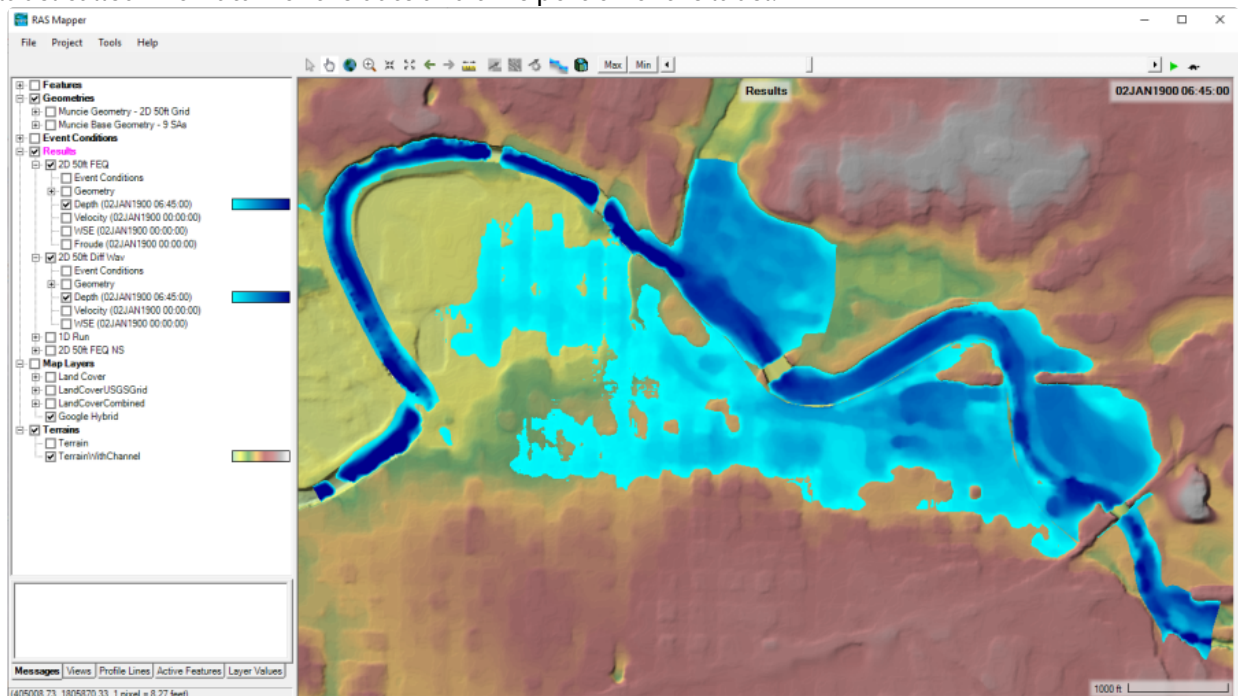
As shown in Figure 6-9, when animating the **Depth** layer for a specific Plan(s), the user will have the option of selecting: **Max**, **Min**, or using the slider bar to move to a specific point in time during the event. If **Max** is selected, then the maximum inundation that occurred at every location in the model (1D cross sections, storage areas, and 2D mesh) will be plotted for the depth grid. If **Min** is selected, then the minimum depth that occurred at every location within the event will be displayed. If the user selects the Play button (far right green arrow), then the map(s) will automatically plot each mapping output interval in sequence (i.e. animate). The animation can be stopped by selecting the **Pause** button. If the user uses the slider bar, they can select a specific date and time, which will result in showing the inundation map for that specific instance in time. The times available are based on the Mapping Output Interval specified in the Unsteady-Flow Simulation window. The user can also hold down the right arrow or left arrow at the ends of the slider bar to have it animate the map, either forwards or backwards in time. Keep in mind these maps are being created on-the-fly in memory. They do not exist in a file on the disk. Because these maps are being created on-the-fly, this is referred to as Dynamic Mapping (Try it out, it's fun!!!). It is also the best way to visualize the results of the model from a mapping perspective.

To create a movie file, one option is to use commercial software, such as Snagit® software (or similar screen capture utility package) to capture the screen while animating the inundation results. Another Option for capturing video is to use the built in video capture tools that are part of Microsoft office. This is available from the PowerPoint software application.

Creating Static (Stored) Maps

The user can create a static map (map stored to the disk) at any time from RAS Mapper by right clicking on **Results | Manage Result Maps** menu item. When this option is selected the window shown in Figure 6-10 will appear.
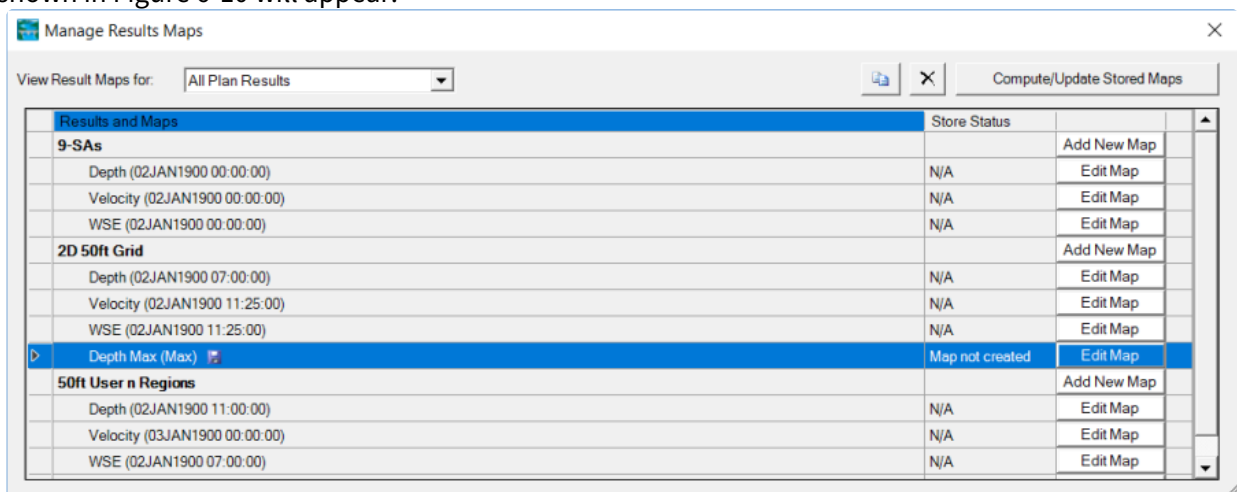
As shown in Figure 6-10, this editor will allow the user to create new map layers (**Add New Map**), as well as generate stored maps to a file (which can be used with HEC-FIA, or in a GIS, etc…). To add a new results map layer, press the button labeled **Add New Map…** for the desired Plan that the user wants to create a map from, this will bring up the window shown in Figure 6-11.
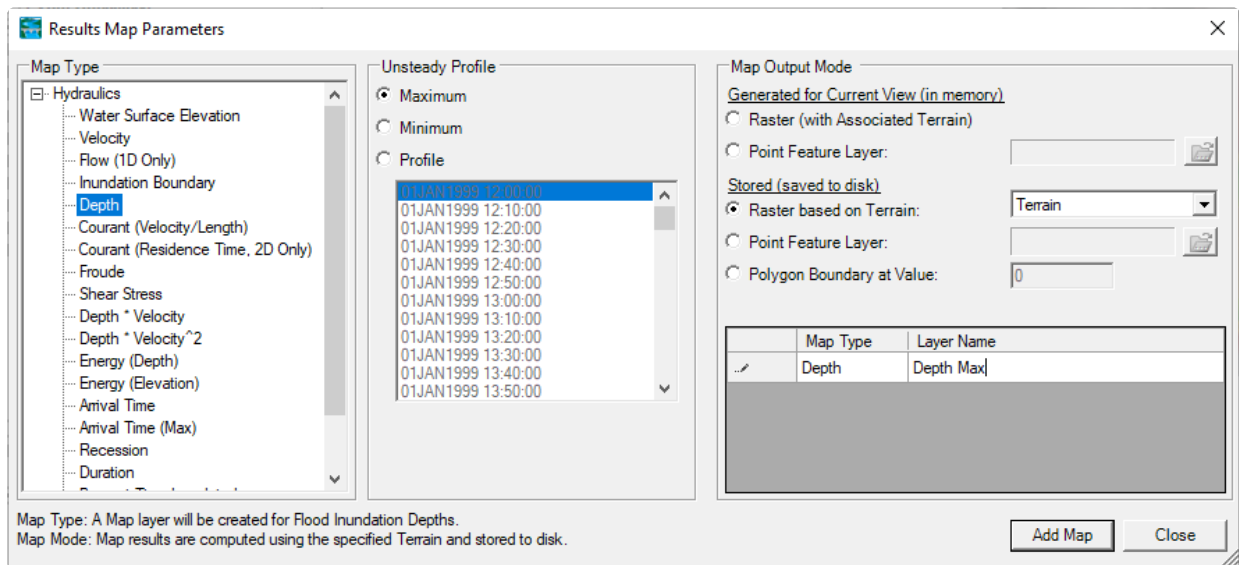
This window was described earlier under the section called **Adding Results Map Layers for Visualization**. This window can be used to create a Dynamic Map Layer, or create a Static Map by checking on one of the options under the **Stored (saved to disk)** section, then pressing the **Add Map** button at the bottom of the window (Figure 6-11). A new Layer will then show up on the **Manage Results Maps** window for the selected Plan, however, the status of that map will be labeled "**Map files are out of date**", which means the stored map has not been created yet.

To create the stored map, first highlight the layer(s) to be created, then press the button labeled **Compute/Update Stored Maps** in the upper right corner (Figure 6-10). This will start the process of creating/updating stored maps for all of the stored map layers that are out of date (only layers that are highlighted will be created/updated). When this process is complete, there will be a subdirectory within the project directory that is labeled the same name as the RAS Plan Short ID. This folder will contain the results in a gridded file format. RAS Mapper creates files in the GeoTIFF (Geospatial Tiff with .tif file extension) file format. The GeoTIFF is a file standard and can be used directly in ArcGIS 10 and higher and other software packages. The user can simply drag and drop the GeoTIFF files onto an ArcGIS project. The latest version of HEC-FIA (version 3.0 and above) also uses the GeoTIFF file format for incorporating HEC-RAS results for the computation of flood damages and potential life loss. Additionally RAS Mapper creates a file with the extension ".hdf" (HDF5 file). The .hdf file contains information for RAS Mapper about the GeoTIFF files. RAS Mapper also creates an XML file with the extension ".vrt". The .vrt file is supported by other GIS software for visualizing raster files. If the user has more than one terrain grid for the Terrain model, then RAS Mapper will also make more than one output depth grid. (i.e. it tiles them). The .vrt file is just a collection file that describes the other files and where they live spatially. If the user drags that file over to a GIS, or import it, then it brings in all the tiles as a single collection in one layer, and the user can have them all attributed the same.
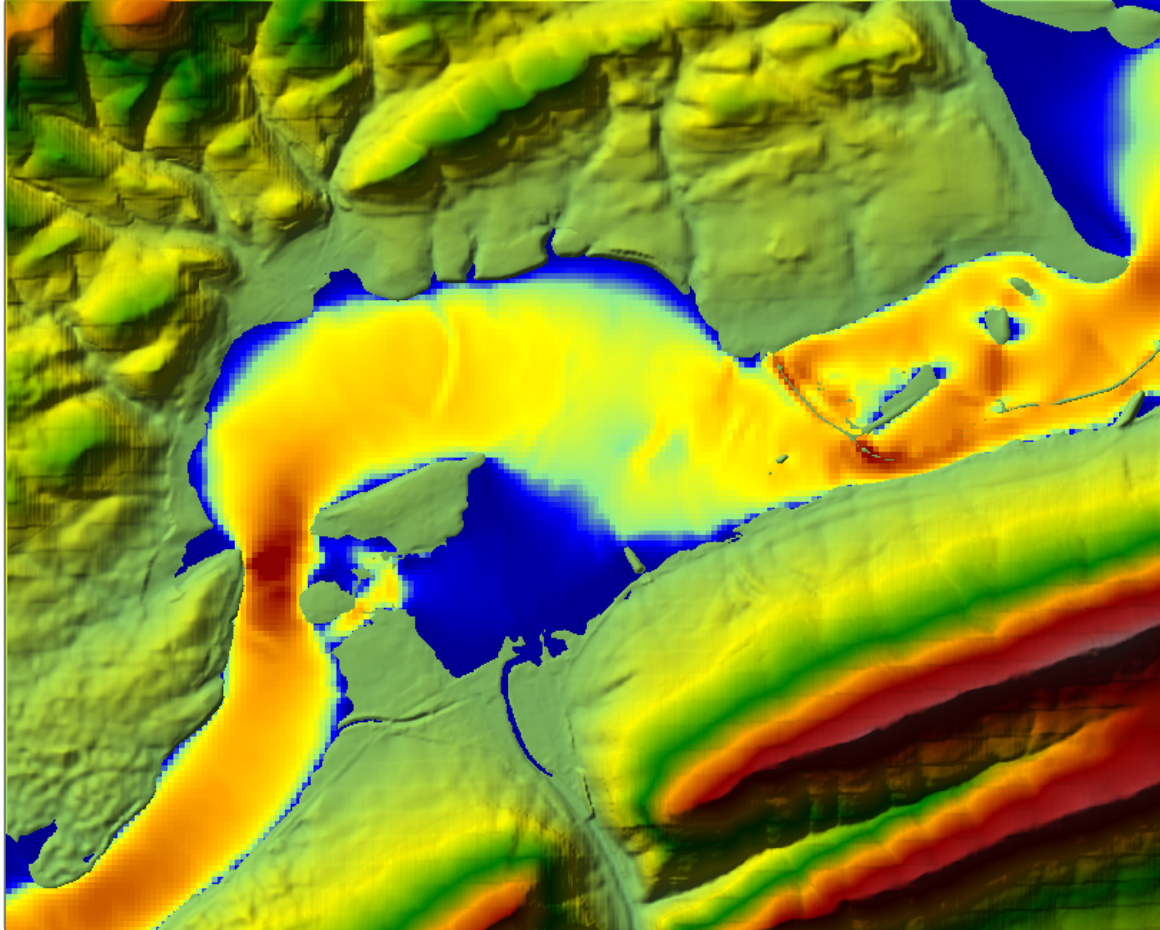
Plotting Velocity

RAS Mapper has the ability to plot velocities spatially for both 1D river reaches and 2D flow areas. Velocity is plotted with a color palette reflecting the magnitude of the velocity. Users can change the color palette, as well as the magnitude range for plotting the colors. Velocity vectors, which reflect

direction and magnitude of the velocity, can be added to the plot. Additionally, there is an option to turn on a particle tracing visualization, which allows for much greater understanding of the velocity flow field, in both magnitude and direction.

Turn on the velocity output layer by checking the box to the left of the layer. From there the user can make the **Velocity** layer the active layer (highlighted in pink) and select the **Animation** tool to animate the entire flood event. See an example 2D model Velocity plot in the Figure 6-12 below.

In addition to color velocity plotting, RAS Mapper has the option to add velocity vectors and show particle traces on top of the map layers. To add velocity vectors, press the **Static Velocity Arrows** button above the map window. This will turn on the velocity direction and magnitude arrows. To control the density of the arrows, select the **Velocity Setting** button above the map window. This button will bring up the window shown in Figure 6-13 below:
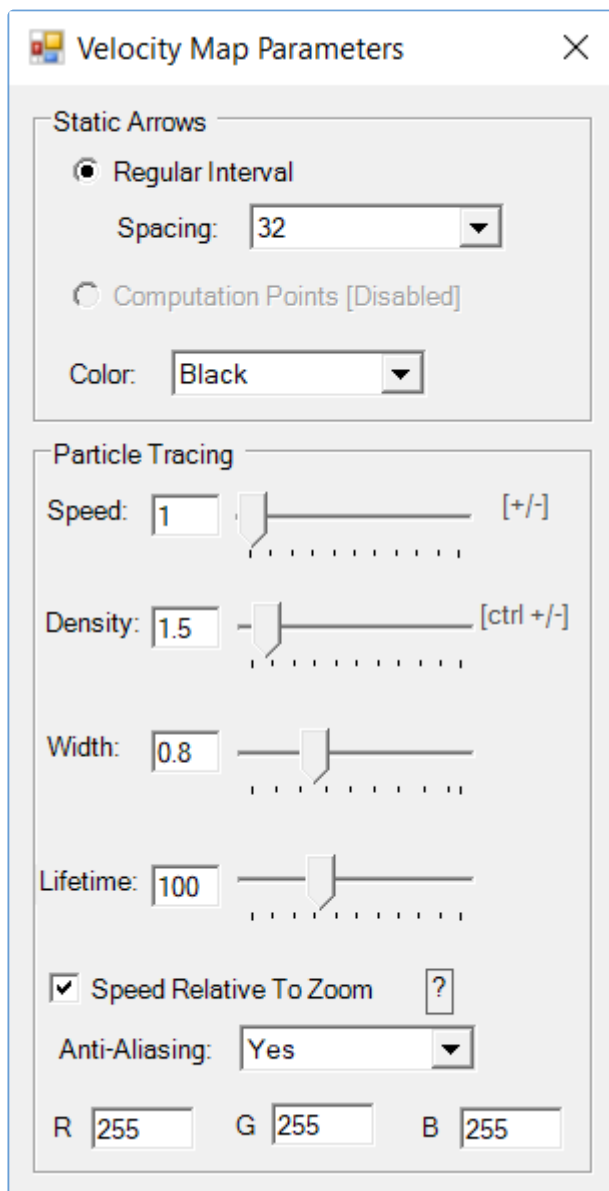
The **Velocity Map Parameters** settings window (see Figure 6=-13) allows the user to control the spacing between arrows by selecting a **Spacing** (pixel width for the spacing between arrows). When the arrows are turned on, they are displayed in the direction of the velocity. The magnitude of the velocity is reflected in the size of the arrows (i.e. larger arrows equates to higher velocity). Show in Figure 6-14 is a velocity plot with magnitude/direction arrows turned on.
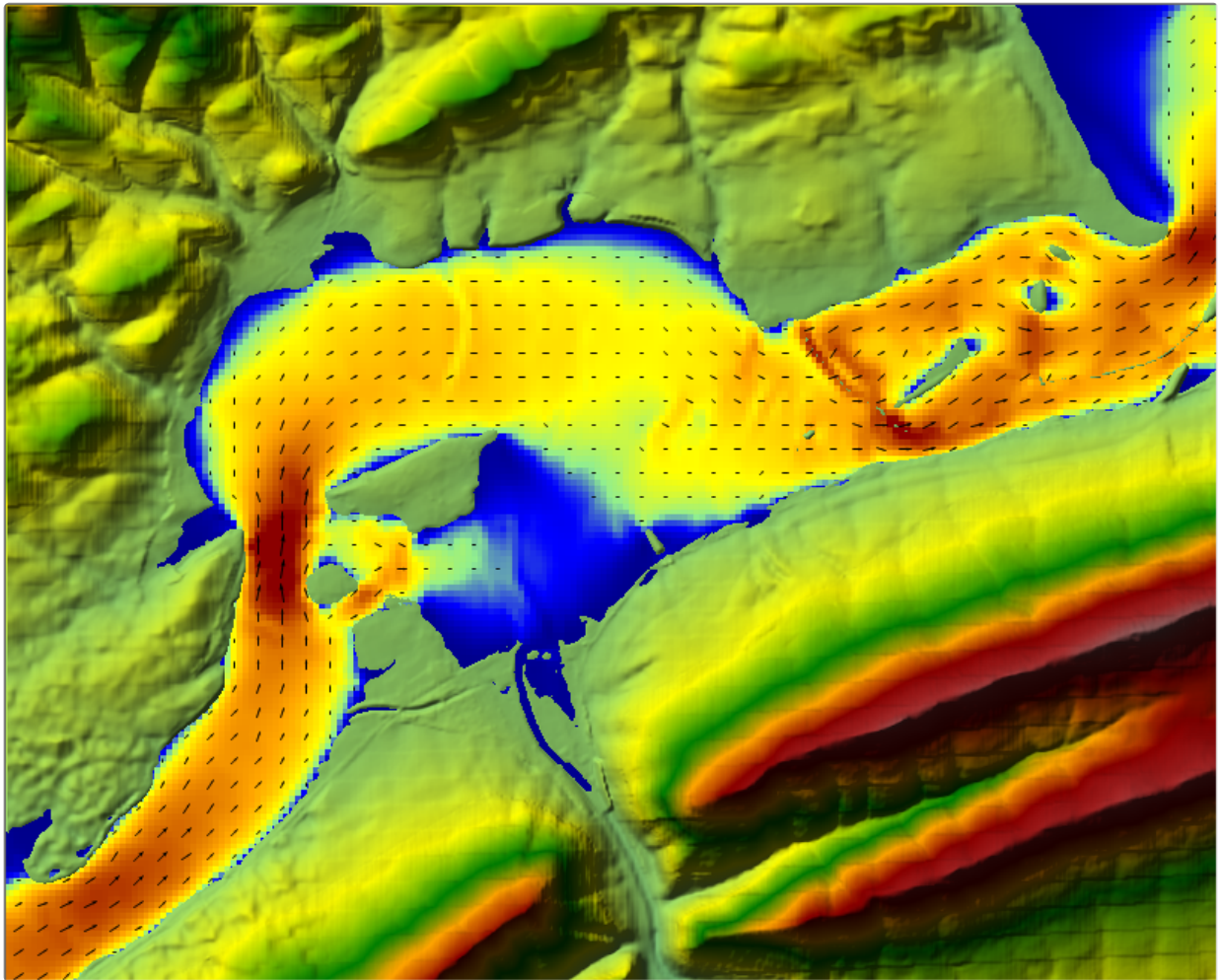
Another extremely cool option for velocity plotting is the option called **Particle Tracing**. When this option is turned on, the user will see what appears to be particles of water moving through the flow field. This is a visualization of water particle movement to improve the understanding of the velocity and the direction of the flow. To turn this option on, press the **Particle Tracing** button above the map window. Once this option is turned on, from the **Velocity Map Parameters** window (Figure 6-13) the user can change the parameters that control the particle tracing visualization. These parameters are: **Speed** (Speed the particles move. The speed is a relative speed, it is not the actual speed of the particles); **Density** (density of the particles); **Width** (how thick they appear); **Lifetime** (how long a particle trace will last); **Speed Relative to Zoom** (this automatically changes the speed with the zoom level); and **Anti-Aliasing** (**Yes** provides smoother lines for the particle traces, but takes more compute power. **No** produces particle lines that are not as smooth, but takes much less compute power) The user can toggle **Particle Tracing** on and off by using the **F5** key (The plot window must be the active window when using the F5 Key to turn particle tracing on and off). Additionally the user can increase or decrease the speed of the particles (to improve the visualization), by using the **+ key** to speed up the particles and the **– key** to slow down the particles. The user can also change the density of the particles. Holding down the **Cntrl key** and then pressing

the **+ key** will increase the density of the particles, while holding down the **Cntrl key** and then the **–key** will reduce the density of the particles.

The particle tracing visualization option can be turned on over the top of the colored velocity plot, or over top of the depth and elevation plots. This option is extremely helpful in visualizing where water is going, and the relative magnitude of the velocity. Try it out; it's really fun and informative!!! Shown in Figure 6-15 is an example plot with the velocity particle tracking option turned on, and being displayed on top of a depth layer plot.
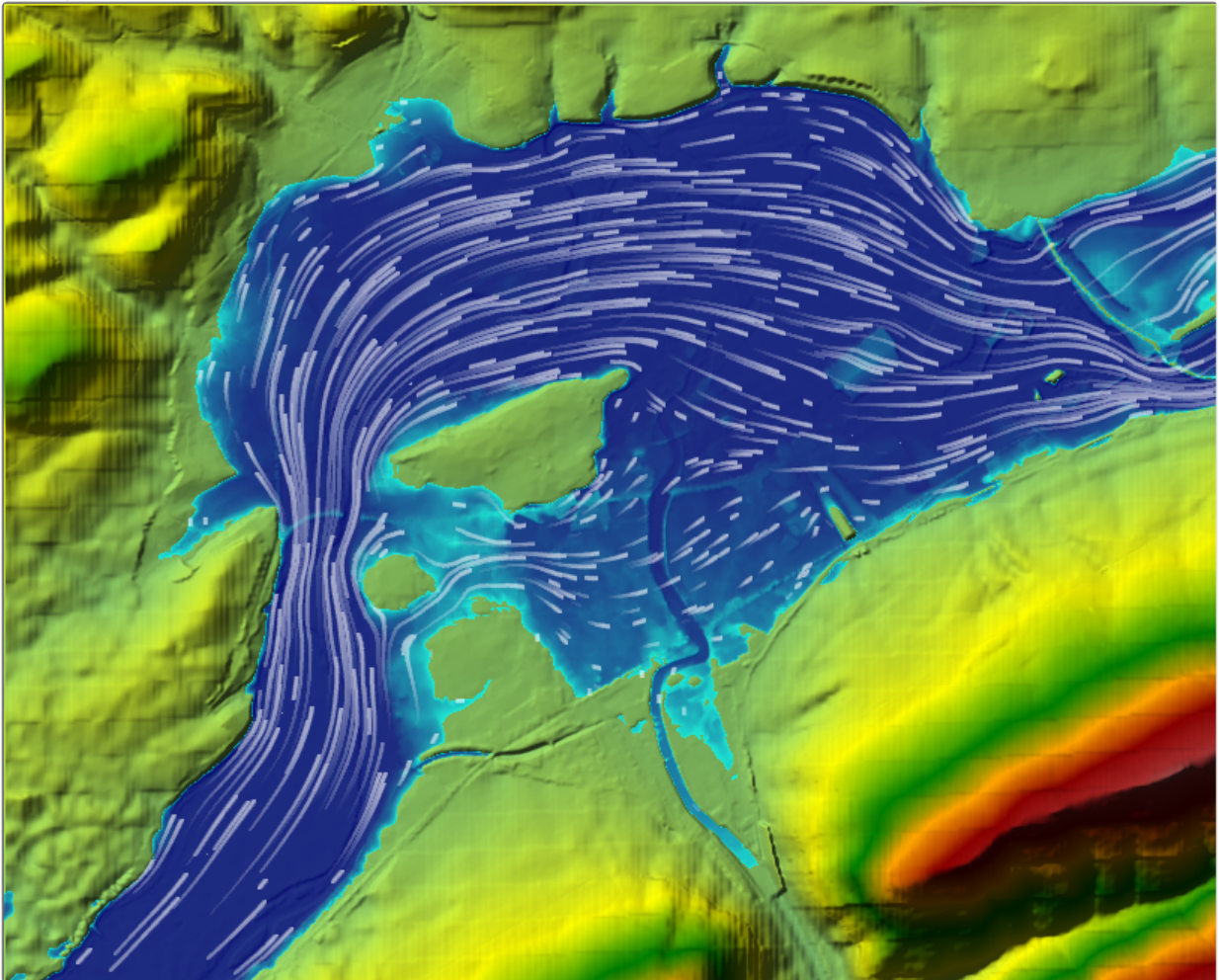
Querying RAS Mapper Results

When a **Map Layer** is being displayed in the map window, the results of that map can be queried to display the point value by simply moving the mouse over the map layer. To do this, first click on the results map layer, to make it the active layer. When a results map layer is being displayed, clicking on that layer will turn the label to magenta in the layer directory tree. Once the desired results layer is turned on, and it is set to the active layer, move the mouse pointer over that layer, and everywhere the user moves the mouse pointer the numerical value of that result will be displayed next to the mouse pointer. See the example below in Figure 6-16.
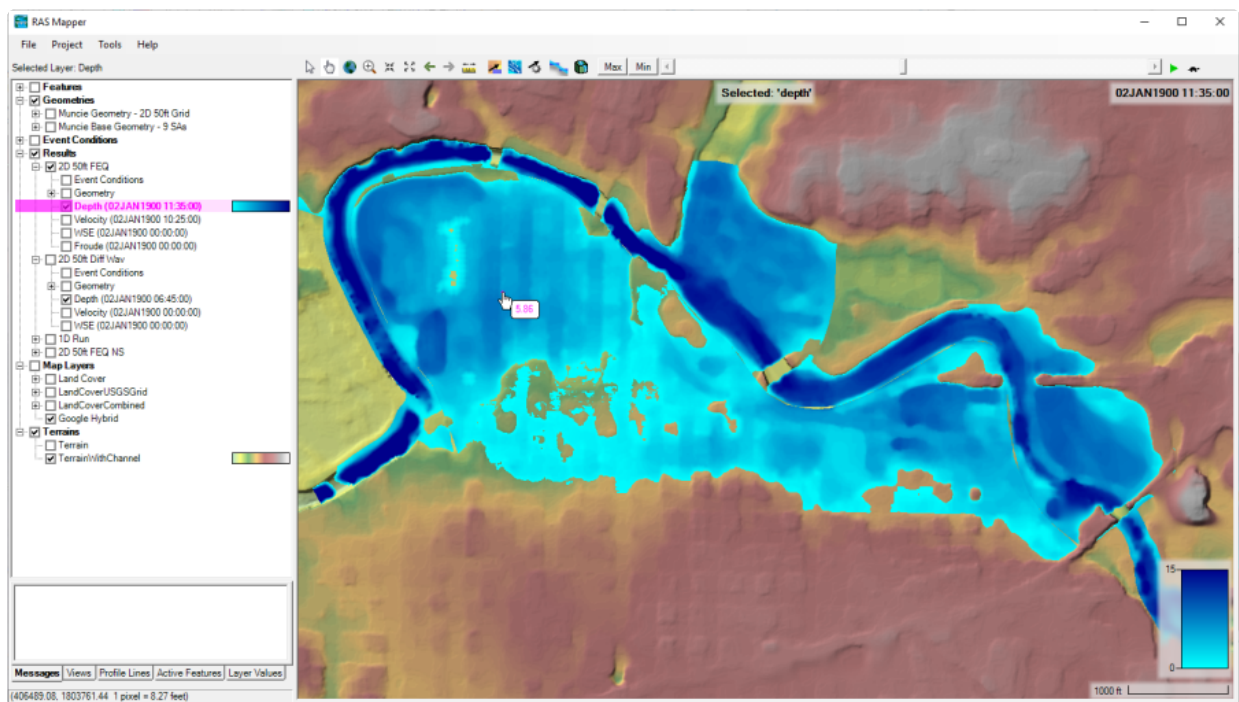
Time Series Output Plots and Tables

When **Results Layer(s)** are turned on for display, the user can also get time series plots and tables for those results layers. If a results map layer is displayed, move the mouse pointer over that graphic layer and then right click the mouse, a pop up window will appear with additional output options for displaying time series plots. For example, if the "Depth" results map layer is turned on, right click on that map window over that layer and an option for plotting a "**Unsteady Time Series**" will be available in the popup window. When this option is selected, there will be a sub menu for selecting the available variable types (i.e. Depth, WSE, and Velocity). Only the map layers that are turned on will be available to plot. Also, if more than one of the same map layer type is turned on for two or more Plans, then all of those map layers will show up on the same time series plot (Figure 6-17).
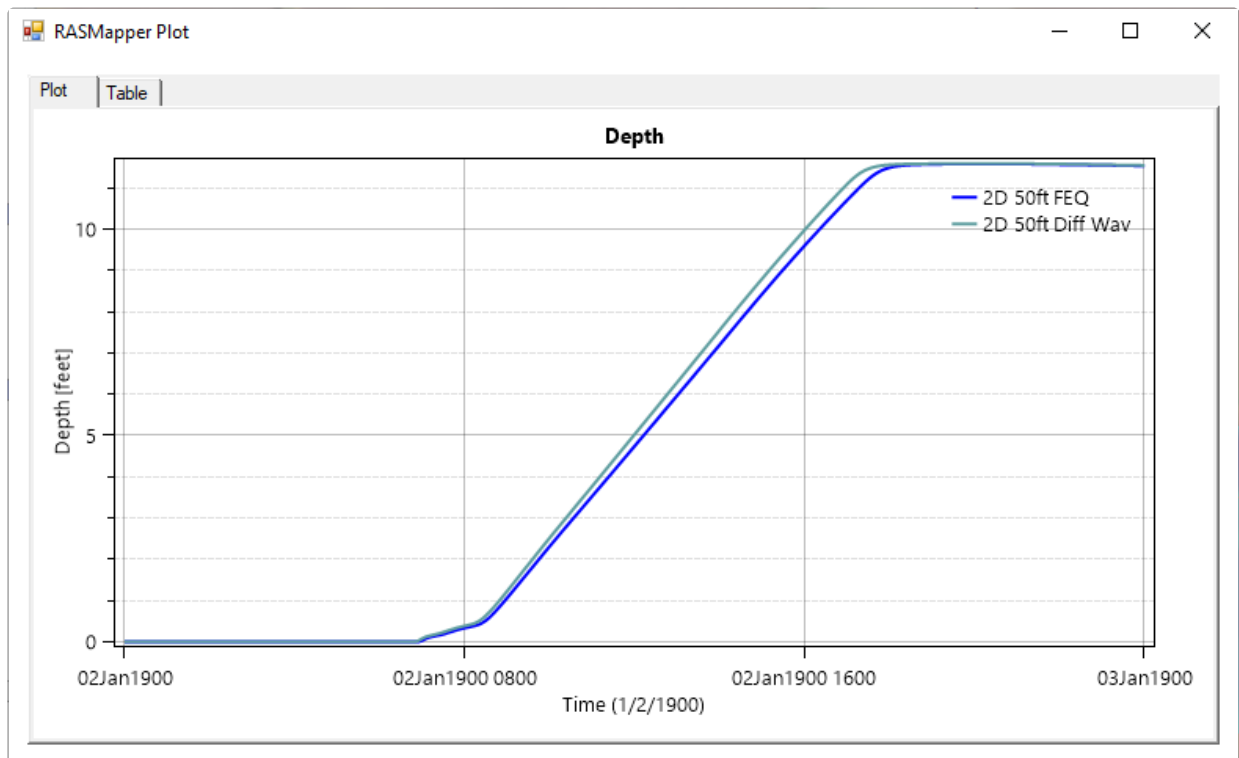
If 2D flow areas are in the model, additional 2D model results in the form of time series plots and tables are available. To get 2D model specific results, first turn on the **2D flow area** grid, from the Geometry layer of the desired plan, listed in the **Results** layer. When the 2D flow area grid is turned on, right click the mouse over top of it, the popup menu will show options for plotting (Figure 6-18) the following results time series: Cell Water Surface Time Series; Face Point Velocity Time series (this is a point velocity of the closest Cell Face Point when selected); Face Perpendicular Velocity Time Series (the component of the velocity that is perpendicular to this face); Face flow (flow across this face in time); Face Shear Stress (the average shear stress across the cell face that is closest to the mouse pointer when selected); and the Property Tables (the pre-computed cell elevation vs volume and face property tables (elevation vs area, wetted perimeter, and roughness) that are used in the solution of the equations). An example 2D cell water surface elevation time series plot from RAS Mapper is shown in Figure 6-19.
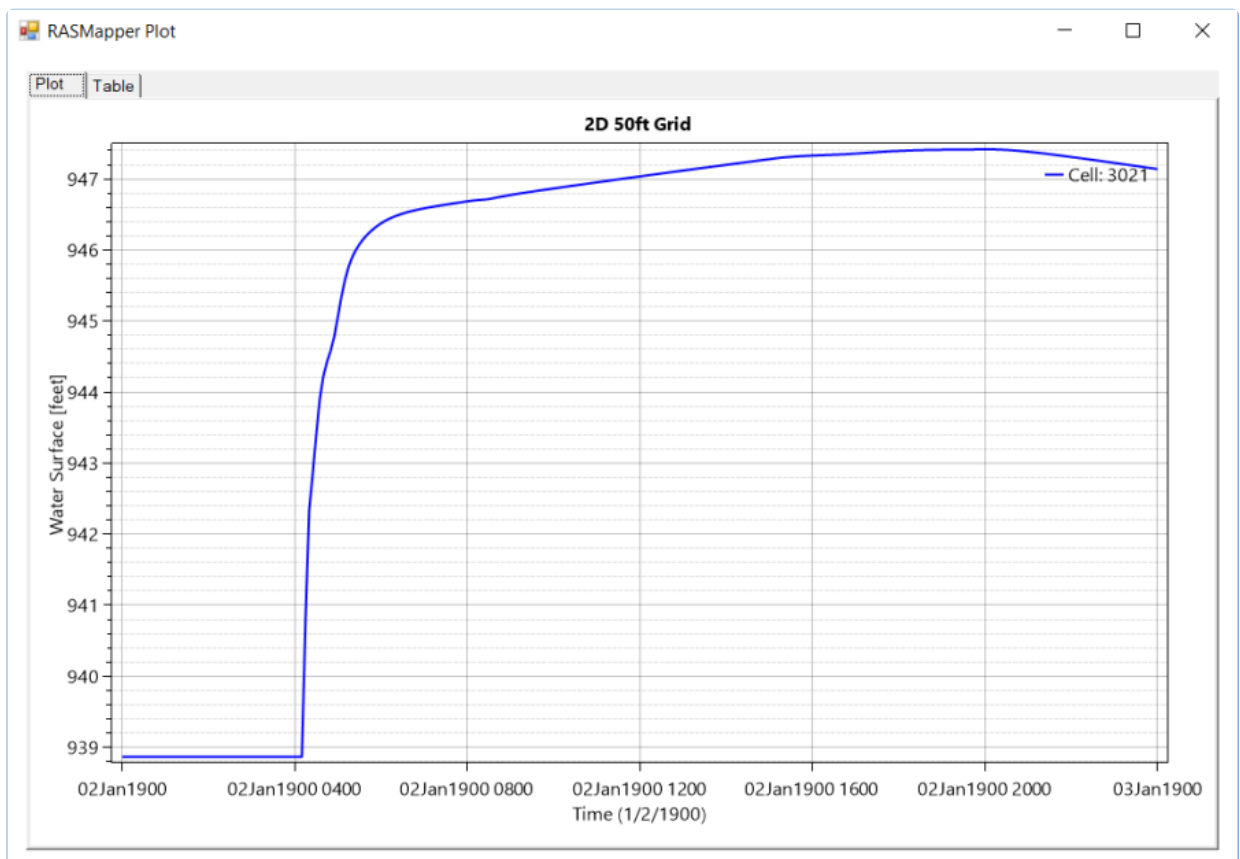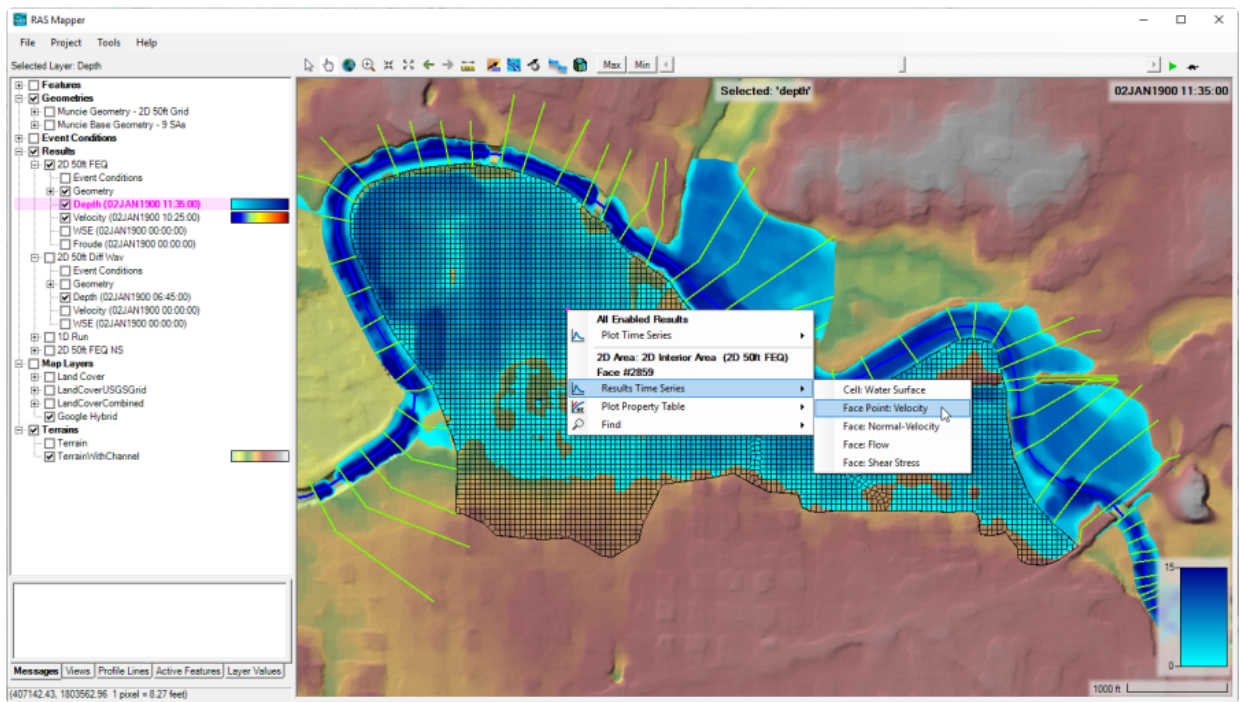
Once a time series is plotted from RAS Mapper, there is also the option to display the results in a table. Tabular results are displayed by selecting the **Table** tab on the time series plot. Users can highlight data in the table and use **Ctrl-C** to copy the highlighted information to the Windows Clipboard. Also, when viewing the plot, right clicking brings up a popup menu with the options to "Copy Values to Clipboard" (which copies all of the data) and to "Zoom to the Full Extent" of the data. Additionally, the mouse wheel can be used to Zoom In and Out on the plot; holding down the **Ctrl** key and using the mouse allows for measuring on the plot; and holding down the "Z**"** key and using the mouse allows the user to draw a Zoom Window; pressing the **Esc** key will zoom to the full extent.

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 are turned on underneath the line. To create or modify Profile Lines, expand the Features Layer at the top of the tree and turn on the **Profile Lines**. Right click on the Profile Lines layer and select **Edit Layer** to begin editing. The HEC-RAS Mapper editing tools will show up allowing you to select the **Add New** or **Edit Feature** tool. If you select "Add New Feature" tool you can draw a new Profile Line. If you select "Edit Feature" tool, you can edit existing Profile Lines. Another way to add new Profile Lines is by selecting the **Profile Lines** tab at the bottom left of the HEC-RAS Mapper window. Once this Tab is selected there is a container for the user defined profile lines, to add a profile line select the **+** (add a profile line) button, and to delete a profile line select the **X** (delete profile line) button. The line can be drawn as a multi-point line anywhere on the map. Once the line is drawn you will be asked to give it a unique name. You can change the name by right clicking on the name and selecting **Rename**.

To plot computed results underneath a user defined profile line, first click on the profile line name in the container box on the lower left hand side of HEC-RAS Mapper (See Figure 6-20). This will activate that line. Next, right click on the line, this will bring up a popup menu, of which one of the options will be labeled "**Profile Line: Profile line 1**". Below that will be an option called "**Unsteady Profile Plots**", then a sub menu of that will contain all of the available data layers that can be plotted as a profile plot. Select the layer you want, for example WSE (Water Surface Elevation). Once a data layer is selected then the profile plot for that data layer will show up in a separate window (Figure 6-21).
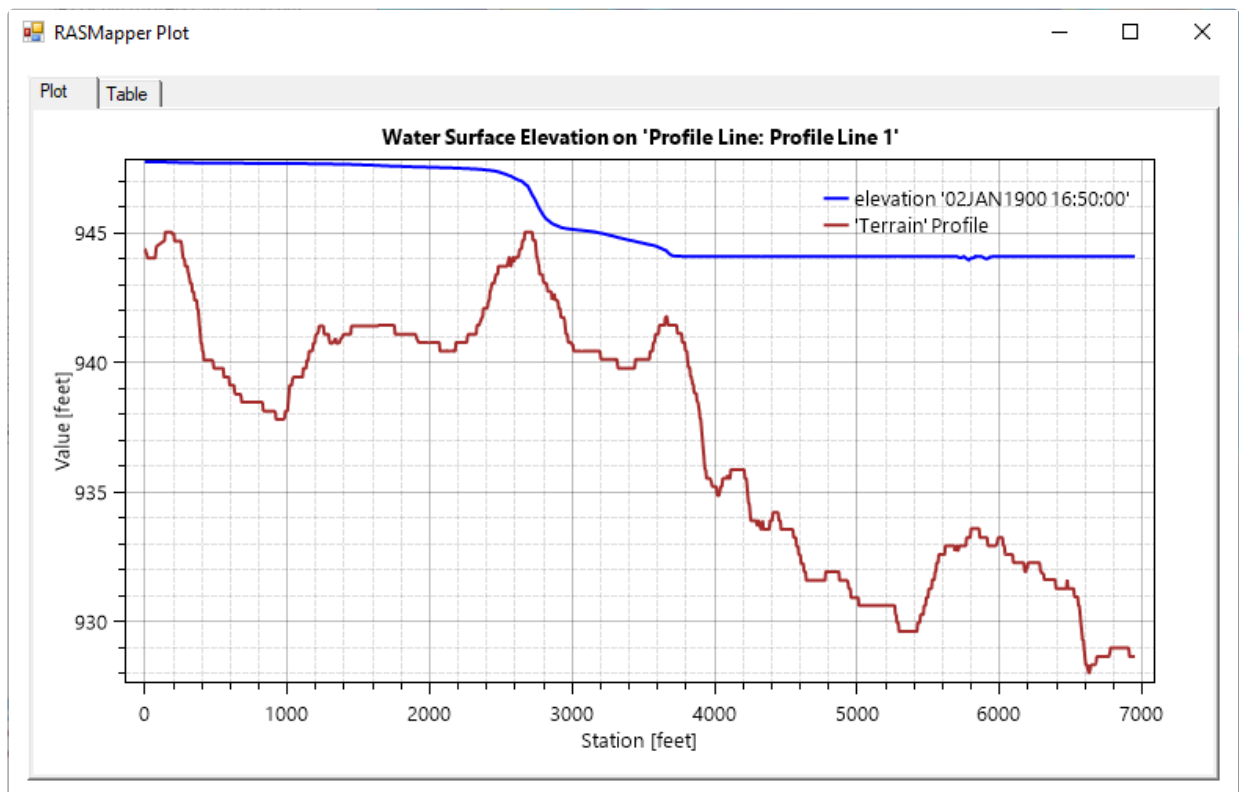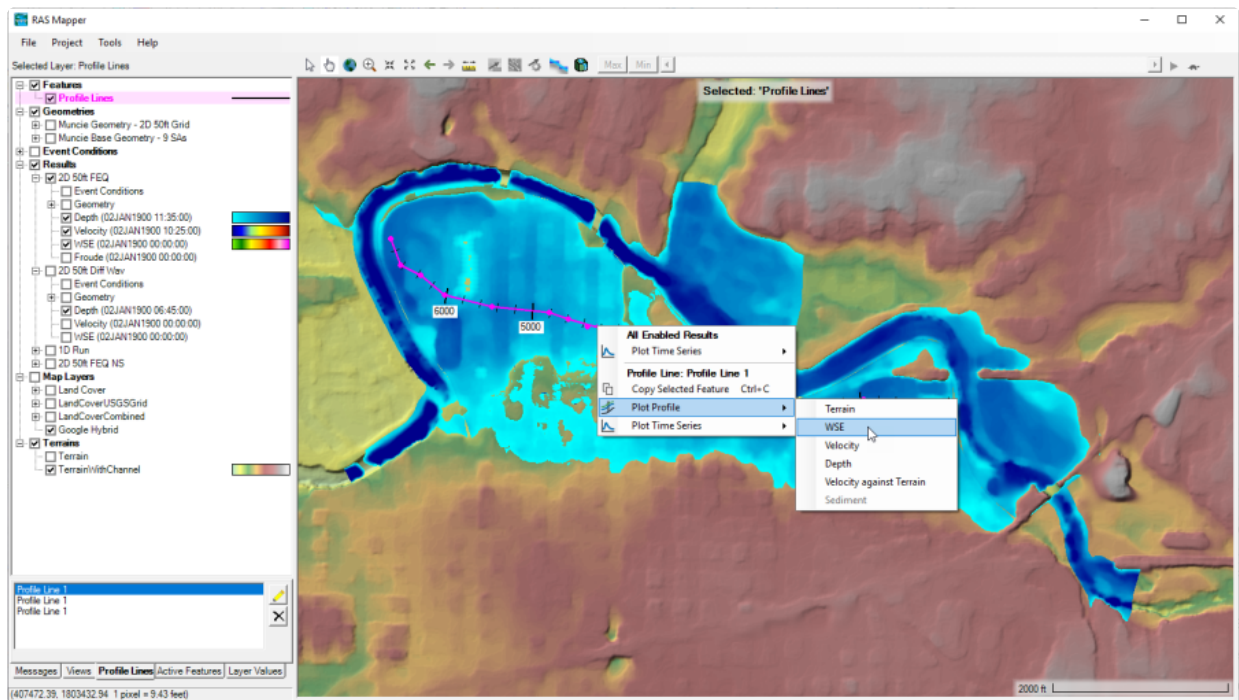
Additionally, Profile Lines can be used to plot **Time Series** Output. For the Example shown in Figure 6-20, there is a second Profile line called "FlowLine1". This line was drawn perpendicular to the direction of flow, for the purpose of plotting time series data for the flow crossing that line. If the user

right clicks on a profile line, there is an option called **Plot Time Series**. Sub menu options of this menu include: Flow; Volume Accumulation; and Rating Curve. An example Flow time series is shown in Figure 6-22.
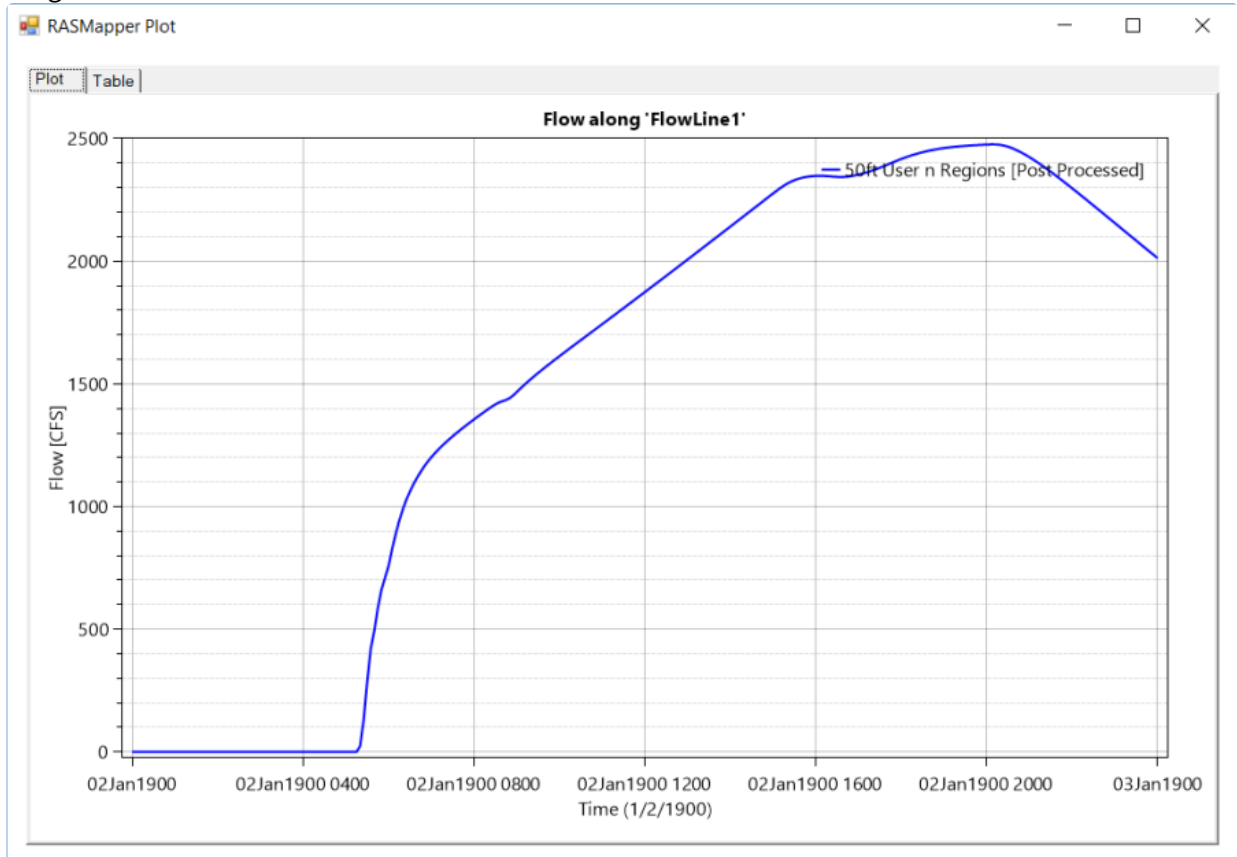
User Defined Views

HEC-RAS Mapper has the option to allow the user to store specific Views. Views are the current extents of the map view window. This can be a very handy feature when you have a large model. The user can zoom in to an area of interest, then store that view with a user defined name. Then go to another area of interest, and store that view, etc…

To use the **Views** option, select the **Views** tab from the lower left portion of the HEC-RAS Mapper window. Zoom into the location of interest, and the exact extents for which you want to save as a view. Press the **+**key to save the view. The user will be asked to give a unique name for each view saved. Once you have saved one or more views, then just click on a particular view name, and the map will automatically transition to that view extents.

Background Map Layers

HEC RAS Mapper has several options for bringing in other data layers/formats to be used as background maps below the computed results. For example, the following file formats are supported: web imagery; ESRI Shapefiles; VRT (Virtual Raster) files; GML (Geospatial Markup

Language) files; and many other file formats (115 file formats are currently supported). The GML file type supported is the "Simple Features version 3" format.

To use the Web imagery capability, first set the spatial reference system for the project. Select the **Project | Set Projection** menu item from the RAS Mapper menu bar. When this option is selected the window shown in Figure 6-23 will appear.
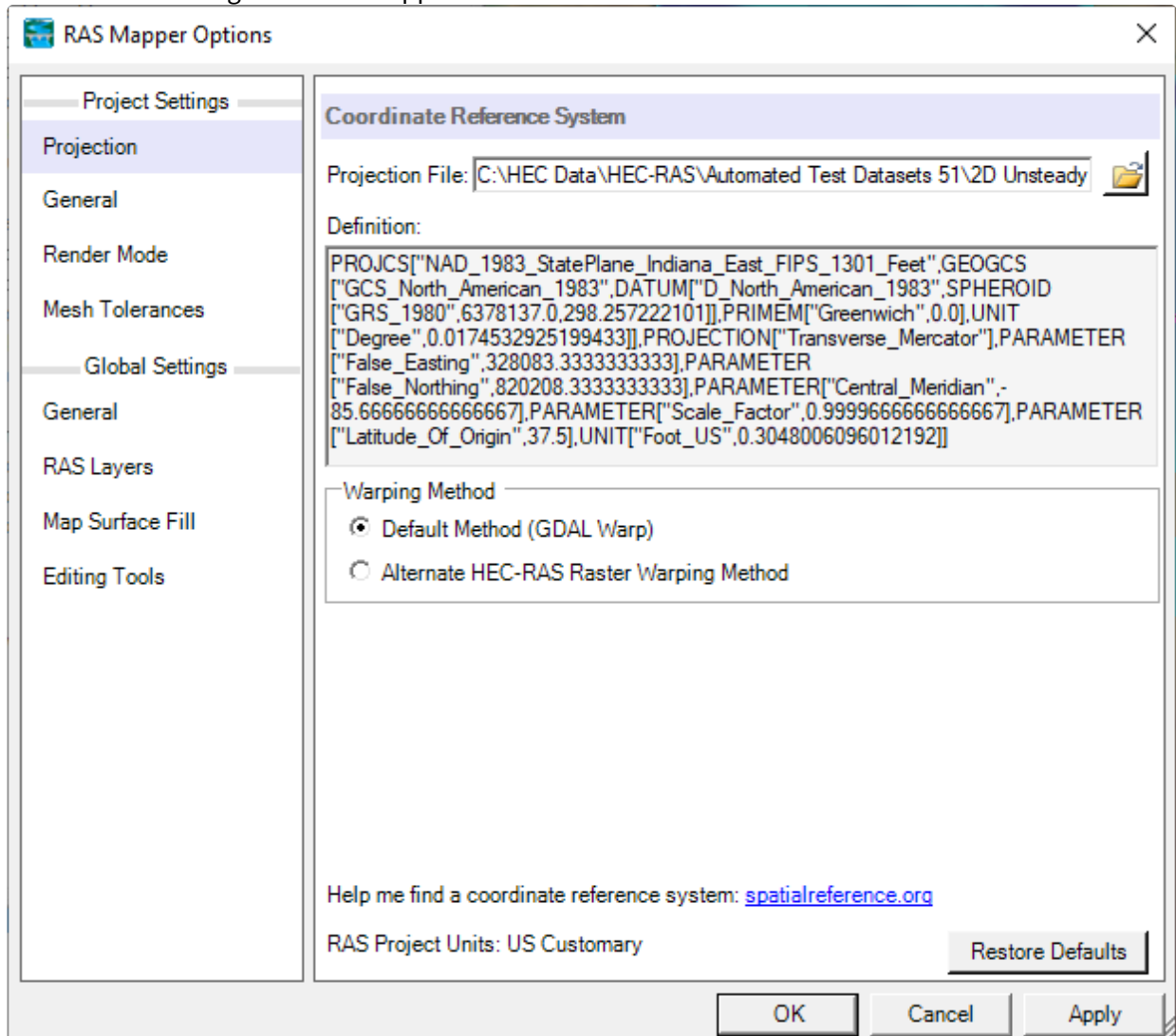
To set the spatial reference system (coordinate system), browse and select an existing ".prj" file (ESRI projection file) that contains the correct coordinate system. If ArcGIS 10 or lower is installed the user can browse to the ArcGIS directory that contains a listing of all the available coordinate systems and select the appropriate one. The default directory path where ArcGIS 10 or earlier stores a listing of all the available coordinate systems is listed in the "Projection File" text box, shown in Figure 6-23. For this example, "NAD 1983 State Plane Indiana East" was selected.

Web Imagery:

Once the correct coordinate system is set in RAS Mapper, the **Web Imagery** option can be used by selecting it from the **Tools** menu (or right click on **Map Layers** and select **Add Web Imagery Layer**). When this option is selected, a window will appear with the list of available web services for downloading web based imagery and map layers (Figure 6-24). Select one of the available options and press the **OK** button. When a web service is selected, RAS Mapper will send the limits of the currently viewed area to that server and request the imagery/map data. Once the data is received it is displayed on the screen. This data is not saved to the hard disk. It is only for real-time display of the imagery and map layers. When using this option, every time the user zooms in or out, or pans, it makes a new request for the data, receives it, and then displays it. See an example of Web imagery used as a background layer in Figure 6-25.
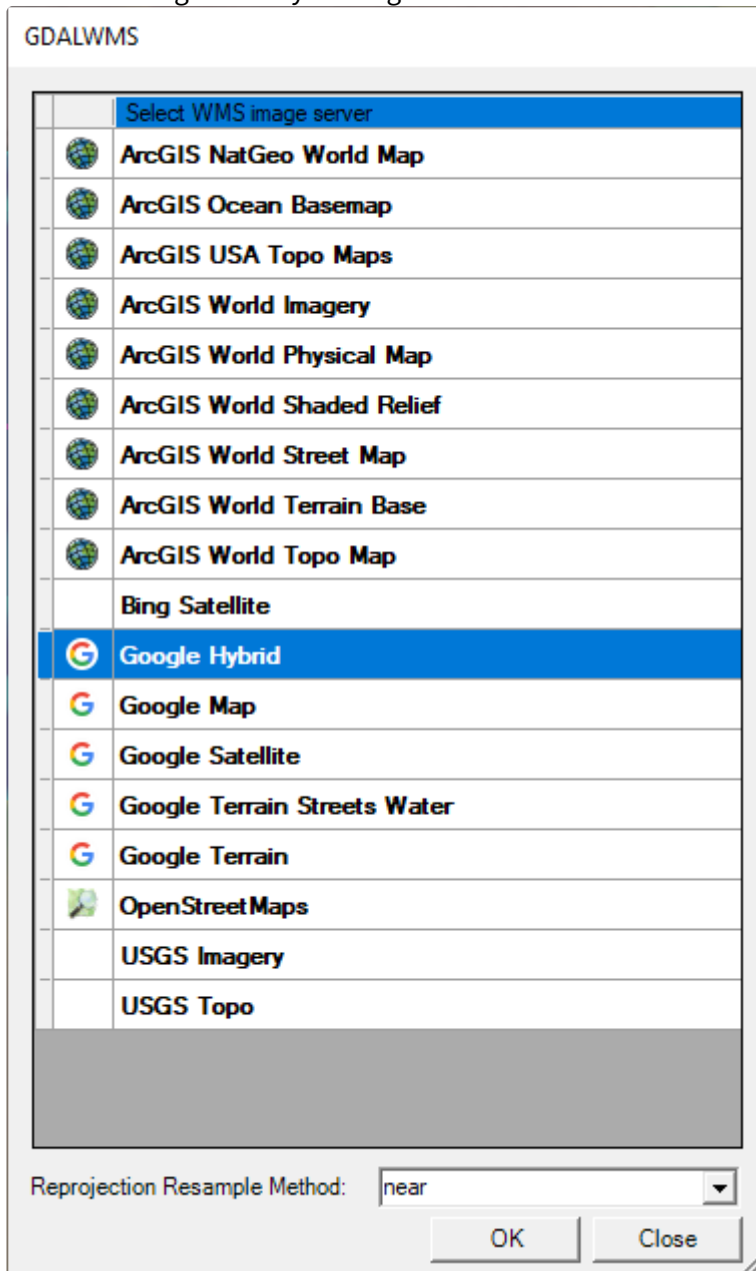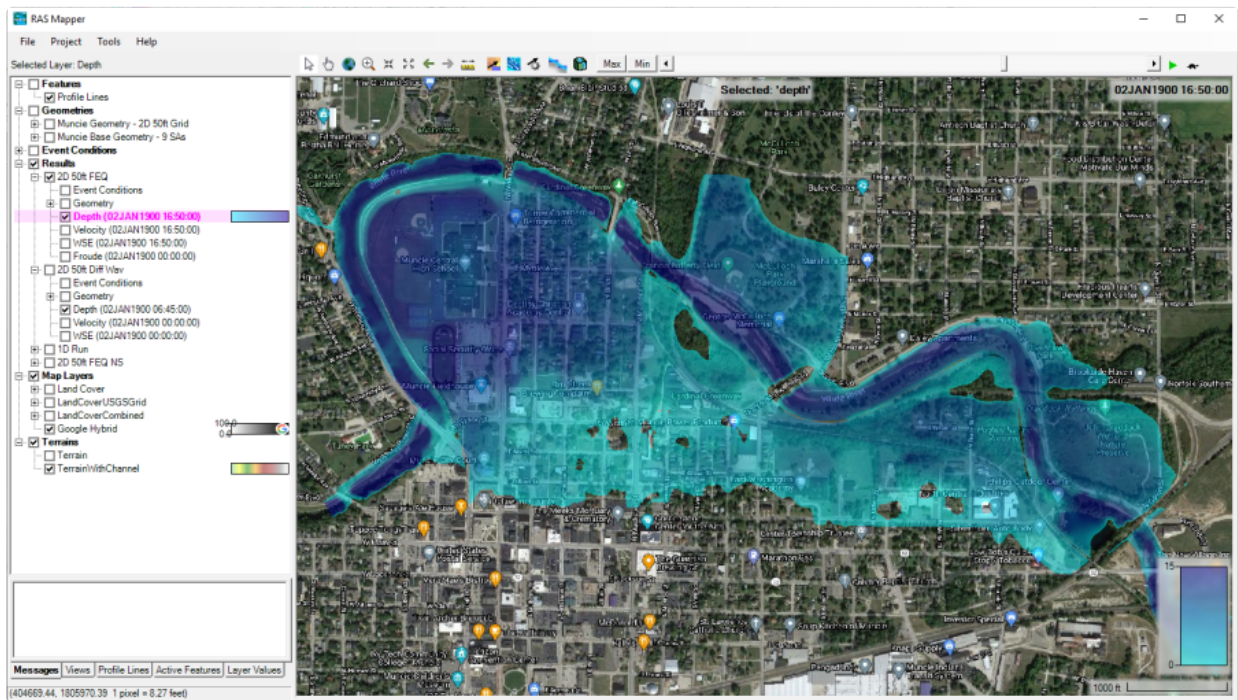
Other Map Layer Formats

As mentioned previously, in addition to web imagery, RAS Mapper supports many different file formats for displaying map layers. Some of the more popular formats are: ESRI Shapefiles; GeoTIFF; MrSID; JPEG; Arc/Info Grids; Bitmaps; NetCDF; USGS ASCII DEM; etc… To use this option, right click on **Map Layers**, then select the **Map Data Layers/Add Existing Layer** option. The file browser window will appear, allowing the user to navigate to the desired file and select it. See Figure 6-26 below:
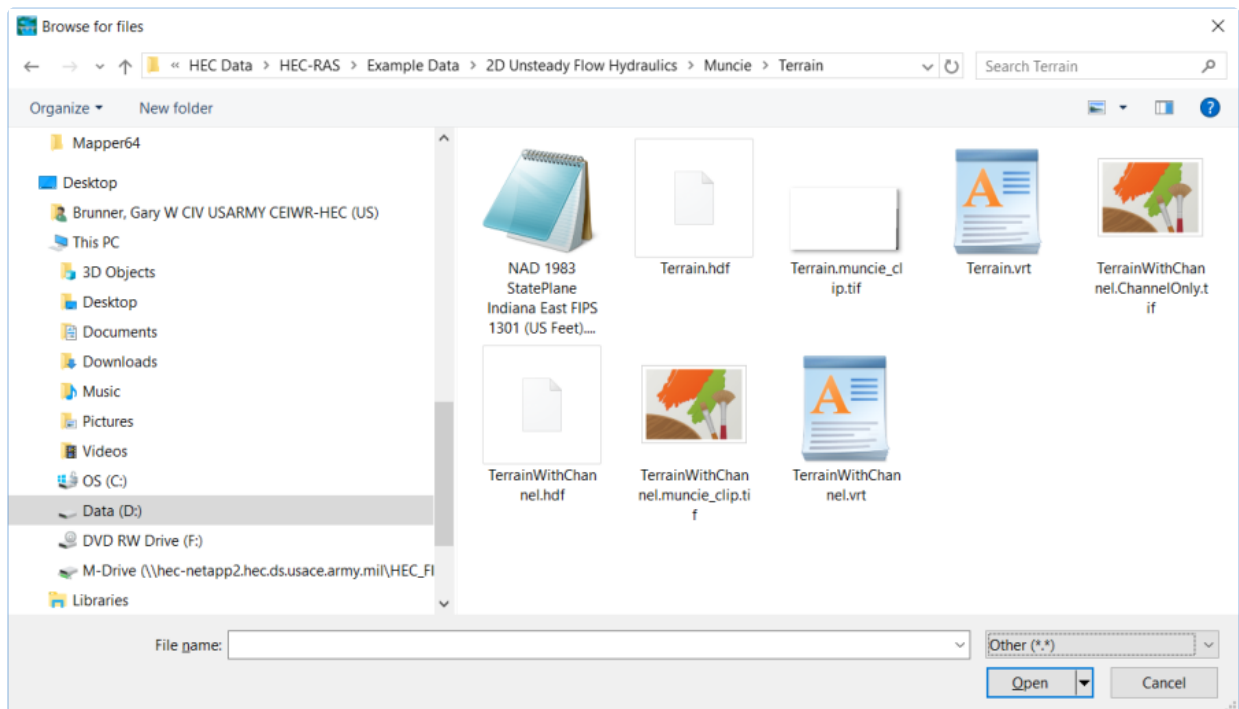
National Levee Database

The last tool to discuss is the link to the National Levee Database (NLD). **Note: This option is only available to U.S. Army Corps of Engineers Employees, using an ACE-IT approved computer.** If the user selects **Import NLD** from the RAS Mapper **Tools** menu, then a window will appear as shown in Figure 6-21. The user can select to query all the levees and floodwalls that are within the current view extents (the area shown on the screen when fully zoomed out), or within the view of selected map layers. Once the **Query** button is pressed, the software calls the NLD for all of its information. The NLD will send a list back to HEC-RAS and a window will appear on the screen with that list of levees/floodwalls (Figure 6-27).
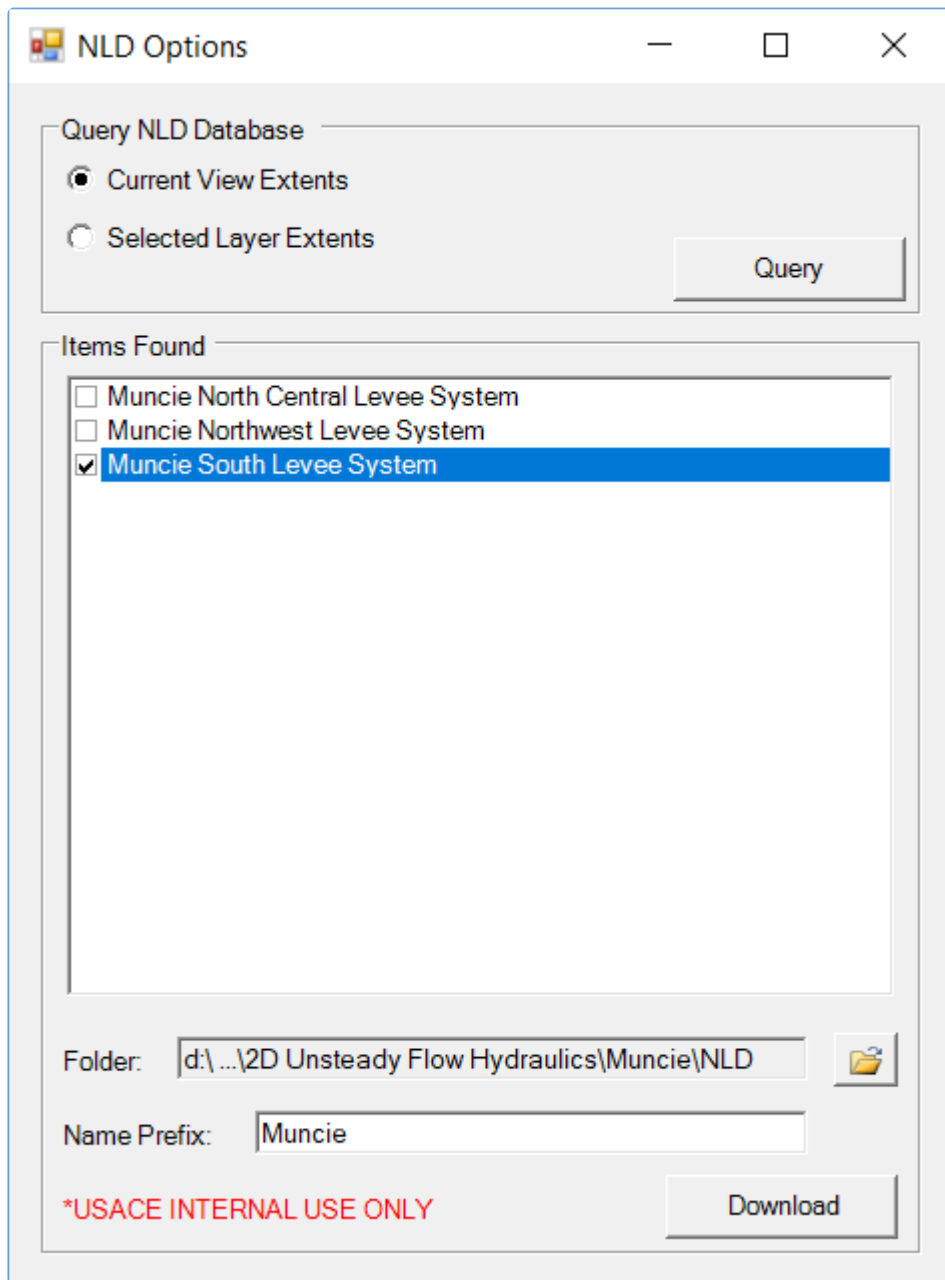
The user then selects what information they want. Finally, the user presses the **Download** button, and then they will be asked to select a directory to store the data in. Once a directory is selected, the software will download a levee 3D centerline, a floodwall 3D centerline, and a polygon of the protected area for each of the levees listed in the window shown in Figure 6-27. Currently the information is stored in a ".gml" file format (Geospatial Markup Language). The next step for HEC-RAS in using this data is to automate the process of converting it into an HEC-RAS Lateral Structure to represent the levees and floodwalls, as well as use the protected area for 2D flow and/or storage area boundaries. This is not available in yet.

2D Output File (HDF5 binary file)

The Output for the 2D flow area computations, as well as most of the 1D output, is contained in a binary file that is written in the HDF (Hierarchical Data Format) file format (The HDF Group, 2014). Similar to an XML document, HDF files are self-describing and allow users to specify complex data relationships and dependencies. However, unlike XML files, HDF files can contain many different types of data and all are stored in an efficient binary form. Furthermore, HDF allows direct access to different parts of the file without first having to parse the entire contents. Specifically, we are using the HDF-5 file format (Version 5 of HDF).

To view and or use some of the output outside of the HEC-RAS interface, the user can access it directly from the HDF files. A Free HDF file viewer can be downloaded from The HDF Group at the following location: https://www.hdfgroup.org/downloads/hdfview/ Download and Install the Windows 64-bit version. Once the HDF file viewer is installed you can open the files, view their contents, display tabular data, and even plot results. Shown in Figure 6-28 is an example HDF file output from an HEC-RAS 1D/2D model run. As shown in Figure 6-28, the user can get to the Unsteady flow output for the 2D areas (as well as 1D objects) by drilling down through the directories… **Results/Unsteady/Output/Output Blocks/Base Output/Unsteady Time Series/2D flow areas/**, then clicking on the folder name of the 2D flow area and the user can see all the output that was computed and stored for that specific 2D flow area. Currently available HDF file time series data that is output for a 2D area is:

1. Water Surface:Water surface elevation for each cell (ft or m)
2. Face Velocity: Normal face velocity (the component of the velocity perpendicular to that face) (ft/s or m/s)
3. Time StepCurrent computational time step at that point in time.

In addition to the Unsteady Time Series output, there is also Summary Output. The Summary Output includes:

1. Maximum Face Velocity: Maximum face velocity in the entire 2D area for each time step (ft/s or m/s)
2. Maximum Water Surface: Maximum water surface in the entire 2D area each time step (ft or m)
3. Minimum Face Velocity:Minimum face velocity in the entire 2D area for each time step (ft/s or m/s)
4. Minimum Water Surface: Minimum water surface in the entire 2D area each time step (ft or m)

NOTE: The node velocities (Node X Vel and Node Y vel) are not automatically written to the HDF output file. HEC-RAS Mapper does not need these velocities to perform any of the mapping (It can compute the node velocities on the fly from the Face Normal velocities). If you want these velocities output to the HDF file you must go to the "**Unsteady Flow Analysis**" window, then select "**Options**", then select "**Output Options**". From here select the Tab labeled "**HDF5 Write Parameters**". Then check on the option labeled "Face Point (Node) Velocities".

There are several optional variables that can be written to the HDF output file. These include: Cell Depth; Cell center velocity; Cell flow balance (inflow minus outflow); Cell and Face Eddy Viscosity values; Face flow; Face WSEL; Face Tangential Velocity (both sides of each face); Face Shear Stress; and Face Point (Node) velocities. As you can see by looking at the file format, there is also time series output in this file for the 1D objects (cross sections, storage areas, lateral structures, inline structures, etc…). Over time all of the HEC-RAS binary output will be switched to HDF file format. For now the traditional ".O##" files are still written to and used for the post processing output, which users can view from the graphics and tables in the HEC-RAS interface. Even after HEC-RAS has switched over to using HDF, HEC-RAS will still fully support DSS (import of data and user selected output of results).
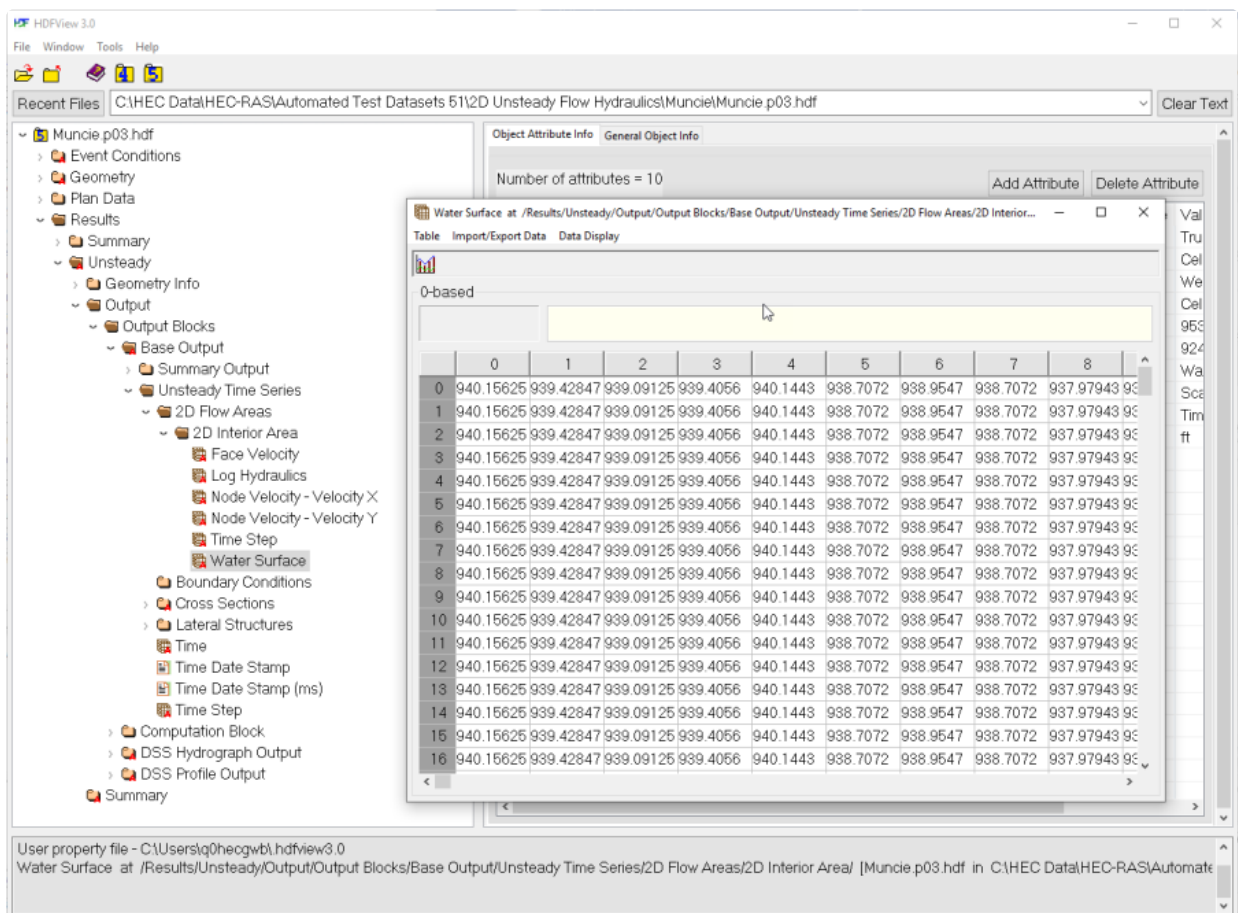
3D Perspective Plots

Another type of graphic available to the user is the 3D Perspective Plot. The 3D plot is a 3-dimensional plot of the terrain on the computed results (Depth, water surface, velocity, etc.).

The HEC-RAS 3D Viewer was developed to help engineers convey hydraulic modeling results to decision-makers. The HEC-RAS 3D Viewer is accessed from either the HEC-RAS program or inside RAS Mapper. The 3D Viewer provides a three-dimensional visualization of HEC-RAS simulation results and terrain data. To access the 3D Viewer through the HEC-RAS program interface, go to **View | 3D View ...** menu item or press the **3D Viewer** button, shown below.
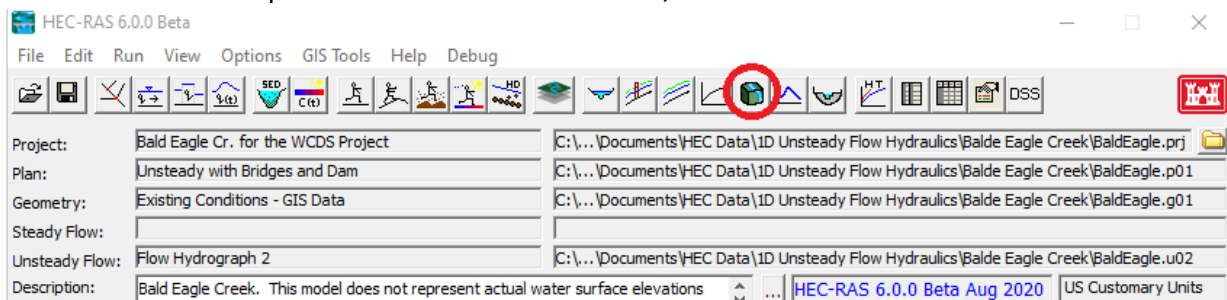
To access the 3D Viewer through RAS Mapper, press the **3D Viewer** button, shown below.
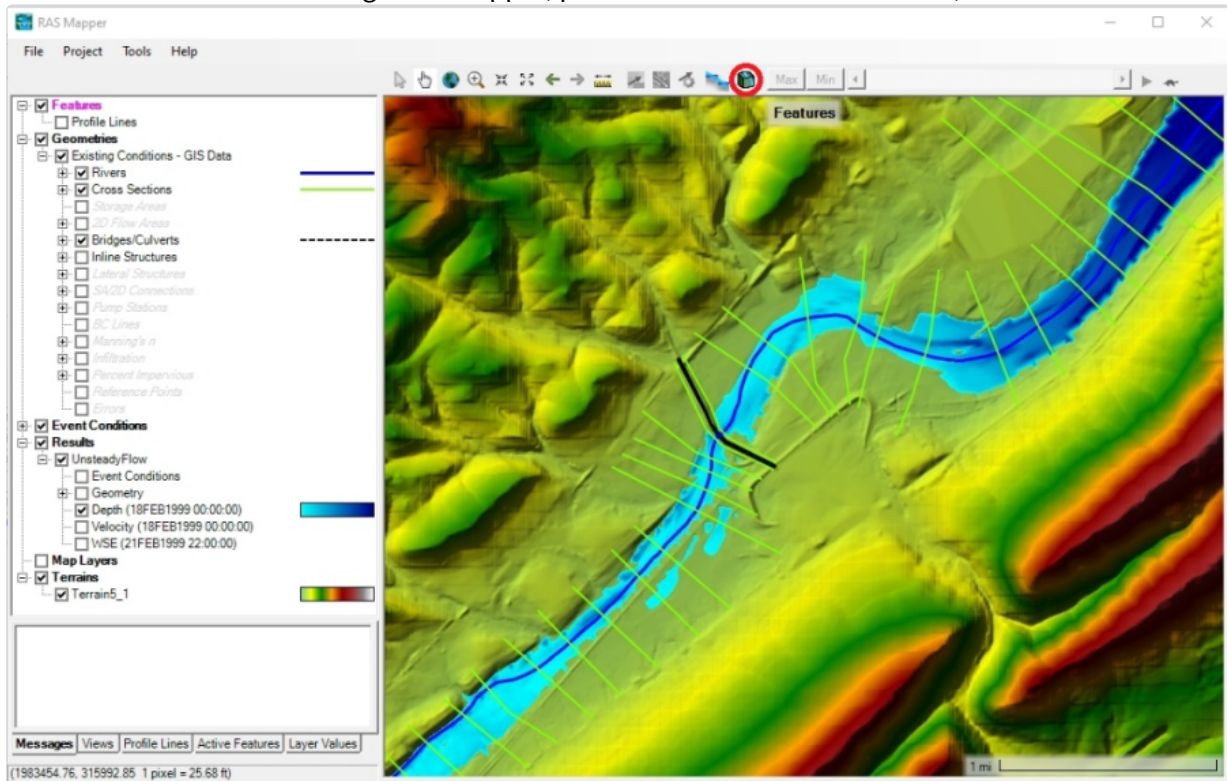
Then select the result to show in the 3D Viewer

Another way to access the 3D Viewer is by right clicking on a particular result and selecting the **View Result in 3D** menu item.
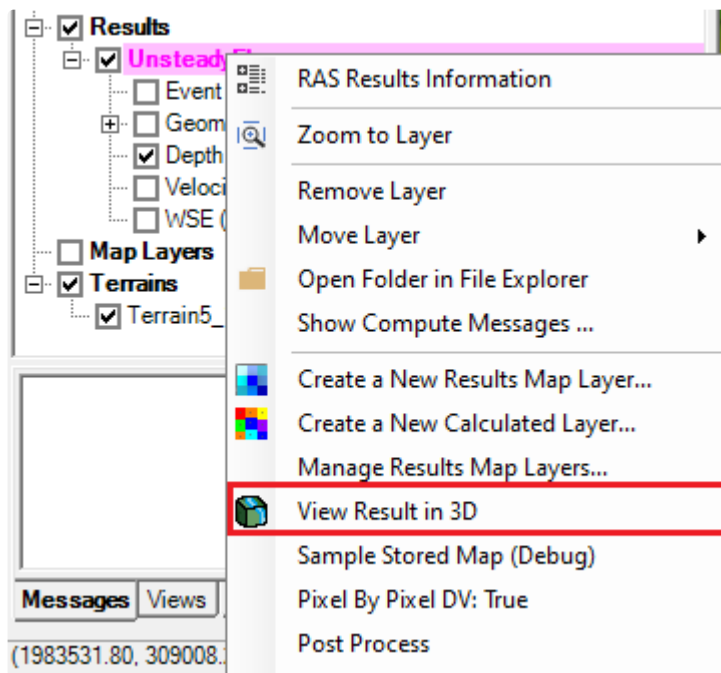
The last way to access the 3D Viewer is by right clicking a particular result map and selecting the **View Map in 3D Viewer** menu item.
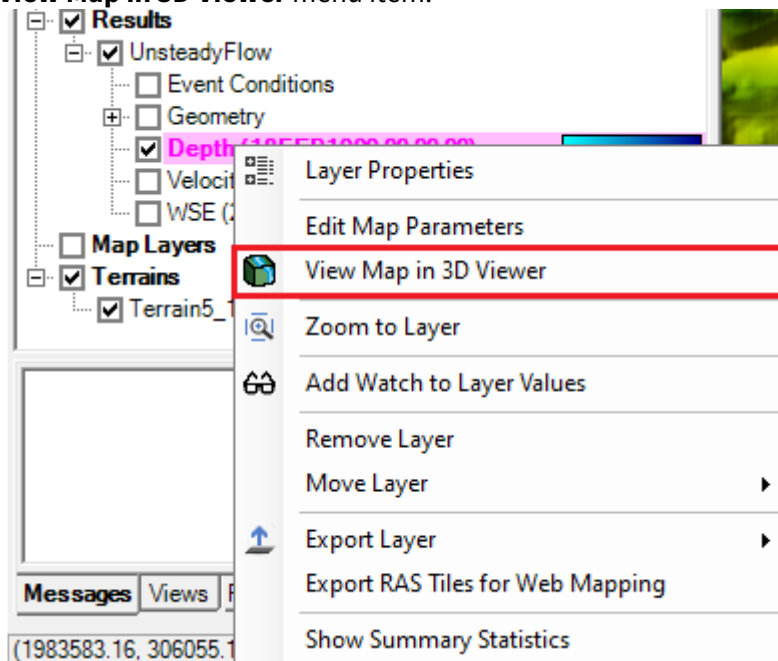
Pre-processing Results for 3D Viewer

Performing any of the various ways to access the 3D Viewer will bring up a pre-processing window if this is the first time you have run the 3D Viewer or if you have cancelled pre-processing the last time you opened this result in the 3D Viewer.
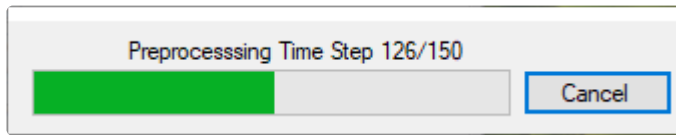
The 3D Viewer has to do much more processing compared to RAS Mapper to show a time step in the simulation. Pre-processing offloads the processing to a file in the same directory as the result file that was selected. It will be named the same except the extension will be sqlite.

BaldEagle.p01.hdf	10/26/2020 6:05 PM	HDF File	5,286 KB
BaldEagle.p01.sqlite	10/28/2020 10:34 AM	SQLITE File	308 KB

Pre-processing will make subsequent loading for this result to be a smoother experience. It will also make playing the results animation smoother. Pre-processing is optional, press the Cancel button if you do not wish to pre-process at this time.

3D Viewer

The 3D Viewer interface, shown below, is comprised of a menu, a toolbar, a mini-map and the view itself.
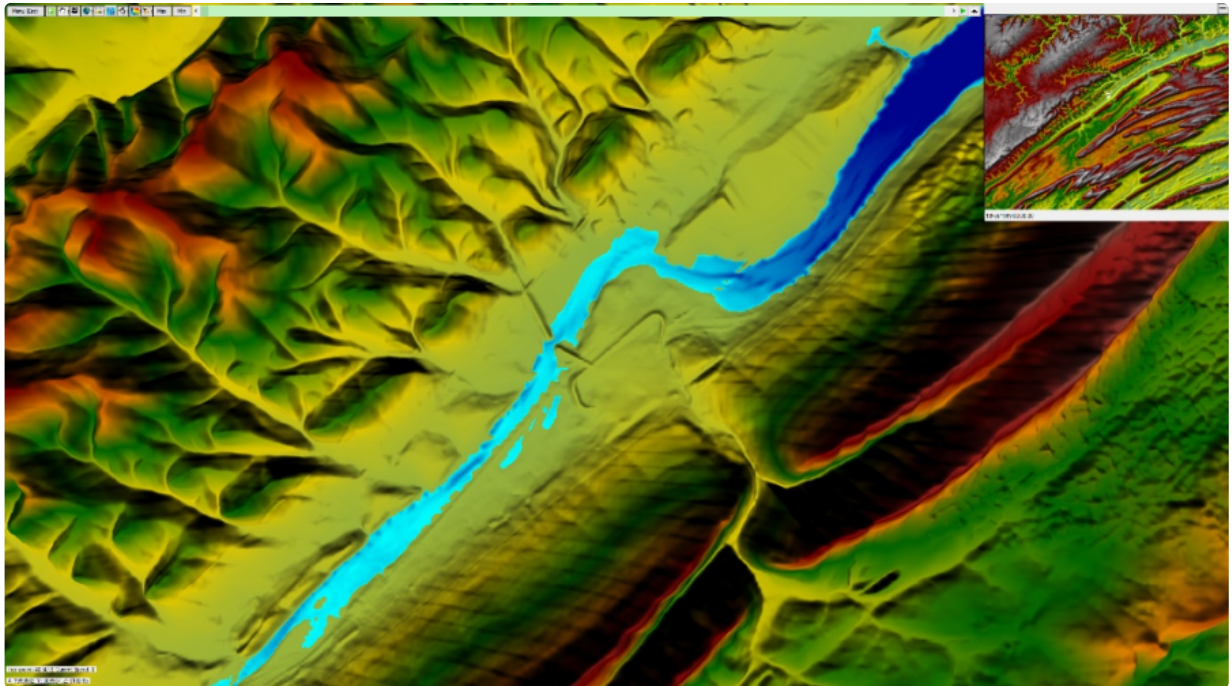
Menu and Options

To access the menu to see options, help, and to quit the application, either click on the menu button on the top left corner or press the escape key.
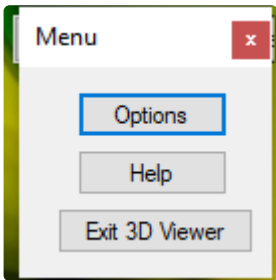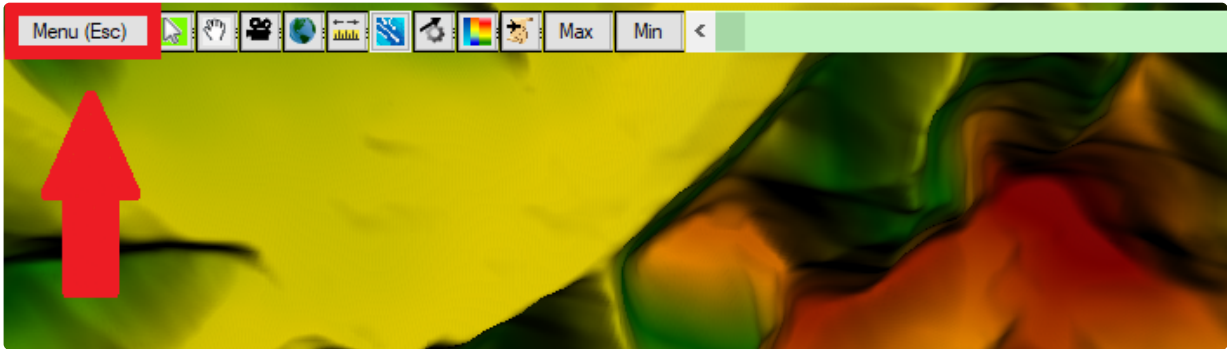
When the Options button is selected a window will appear with four Tabs (General; Graphics; Controls; and Particle Tracing). The following tables describe each of the options on the four Tabs.

General Options

Table 8 1. General Options

Option	Description
Water During Animation	When this option is turned on, the water resolution will be the same resolution as the terrain, based on Level of Detail settings. Animation may play slower than usual with this option turned on
Z Scale	How much the terrain elevation is scaled by. Higher value exaggerates the elevations of the terrain, making it easier to see subtle changes in terrain. **(Not Implemented Yet)**

Controls

There are three ways to control the 3D Viewer, mouse and keyboard, just mouse, and a game controller. These controls options controls certain aspects of using the mouse, keyboard, and game controller.

Table 8 2. Controls for mouse and controller sensitivity.

Option	Description
Mouse Sensitivity	Controls how much the view changes with mouse movement. Higher sensitivity means more view change with mouse movement. Default is 0.1
Controller X Sensitivity	Control how much the view changes with the right stick of the game controller, horizontal axis only. Default is 0.3

Option	Description
Controller Y Sensitivity	Control how much the view changes with the right stick of the game controller, vertical axis only. Default is 0.15
Invert Y Axis	When this is turned on, moving the vertical axis on either the mouse or game controller will change the view in the opposite direction. Default is off

Pressing the **Change Key/Controller bindings** button will bring up a different window where you can change the various bindings for all the controls of the 3D Viewer.

Table 8 3. Controls for Moving around within the 3D Viewer.

Action	Default Key Binding	Default Controller Binding	Description
Move Forward	W	Left Stick up	Moves the viewer forward in space
Move Backward	S	Left Stick down	Moves the viewer backward in space
Strafe Left	A	Left Stick Left	Moves the viewer in a left side-step fashion in space
Strafe Right	D	Left Stick Right	Moves the viewer in a right side-step fashion in space
Increase Elevation	Space	Right Shoulder Button	Moves the viewer up in space
Decrease Elevation	Left Control	Right Trigger Button	Moves the viewer down in space
Change Results Map	M		Changes the results map between 4 different maps, a realistic map, depth map, velocity map, and water surface elevation map
Toggle Particles	P		Turns on or off the particle tracing effect
Flight Path Play/Pause	Return (Enter)		While a flight path is active, will either play the path or pause it.
Go Forward On Flight Path	Up Arrow	Up Directional Arrow	While a flight path is active, will make the viewer go forward on the flight path
Go Backward On Flight Path	Down Arrow	Down Directional Arrow	While a flight path is active, will make the viewer go backward on the flight path
Increase Viewer Speed	Right Arrow	Left Directional Arrow	Makes the viewer travel faster. The viewer can only go so fast however.

Action	Default Key Binding	Default Controller Binding	Description
Decrease Viewer Speed	Left Arrow	Right Directional Arrow	Makes the viewer travel faster. The viewer can only go so slow however.
Turn Left	Unbound	Right Stick Left	Rotates the view to the left
Turn Right	Unbound	Right Stick Right	Rotates the view to the right
Change View Up	Unbound	Right Stick Up	Rotates the view up **(No changeable binding yet)**
Change View Down	Unbound	Right Stick Down	Rotates the view down **(No changeable binding yet)**
Toggle Mouse Pointer	Tab	A Button	Will either show or hide the mouse pointer **(No changeable binding yet)**

Particle Tracing

Table 8 4. Controls for Controlling Particle Tracing.

Option	Description
Speed	Refers to the animation speed of the particle trace. Default value is 1.
Density	Refers to concentration of tracers in an area. Default value is 1.
Width	Refers to the width of the particle. Default value is 5.
Lifetime	Refers to how long the particle exists on screen before it disappears and a new particle spawns in its place. Default value is 300.
a. Particles*	Refers to how many particles are shown at any one time. Default value is 10,000.
RGB	Changes the color of the tracers. Each field accepts an integer between 0 and 255. R corresponds to Red, G corresponds to Green and B corresponds to Blue

Toolbar

The Toolbar is located at the top left of the 3D Viewer window. The following Table describes each of the tools.

Table 8 5. Description of each of the 3D Viewer Tools located on the Toolbar.

Tool		Description
Select		Wherever the select pointer is at, it will show the value of either the terrain elevation or water surface value, dependent on the map type chosen.
		While using the select pointer it's possible to navigate through

Tool		Description
		the terrain through middle-clicking and dragging on the terrain.
Pan	👆	Left click with the pan pointer to navigate through the terrain by clicking and dragging the terrain.
Change Camera Modes	📹	Allows you to change how the 3D Viewer is controlled.
		When in helicopter mode 🚁 , the viewer will move forward, backward, left and right on a plane. Elevation is controlled by the elevation up and down keys
		When in airplane mode ✈ , the viewer will move forward in space in relation to where it is currently looking. For example, this means that looking straight up and going forward will cause the viewer to go straight up. **(Not Implemented Yet)**
Zoom to Entire Extent	🌐	Zooms to the maximum viewable extent of the terrain, and forces the viewer to look straight down.
Measure Tool	📏	Measure the distance in map units. **(Not Implemented Yet)**
Toggle Particle Tracing	〰	Toggles whether particles show on the water surface.
Particle Tracing Options	🔧	A shortcut to get to Particle Tracing Options
Change Results Map	🌈	Changes the results map between 4 different maps, a realistic map, depth map, velocity map, and water surface elevation map
Select a Flight Plan	✈	Opens the flight plan window to choose a flight plan. See Flight Plans/Paths section for more information.
Set to Simulation Maximum	Max	Sets the water surface to simulation maximum. **(Not Implemented Yet)**
Set to Simulation Minimum	Min	Sets the water surface to simulation minimum. **(Not Implemented Yet)**
Animation Bar	‹ ▮ ›	Change the animation bar position to change the time of the simulation. When a portion of the animation bar is grey, it means that the simulation has not loaded at that time yet.
Play/Pause	▶ / ⏸	Plays or pauses the animation
Change Animation Speed	🐌	Changes the delay before changing time step in the animation. Note that there is an inherent delay that is unavoidable for each time step. That delay depends on whether you pre-processed the dataset,

Tool	Description
	and whether you have high resolution water turned on during animation. **(Not Implemented Yet)**

Min map

The mini map is shown to assist with acquiring bearings when using the 3D Viewer. Shown in the Figure below is an example of the mini map, which is displayed in the upper right hand corner of the 3D Viewer.

18Feb1999 00:00:00
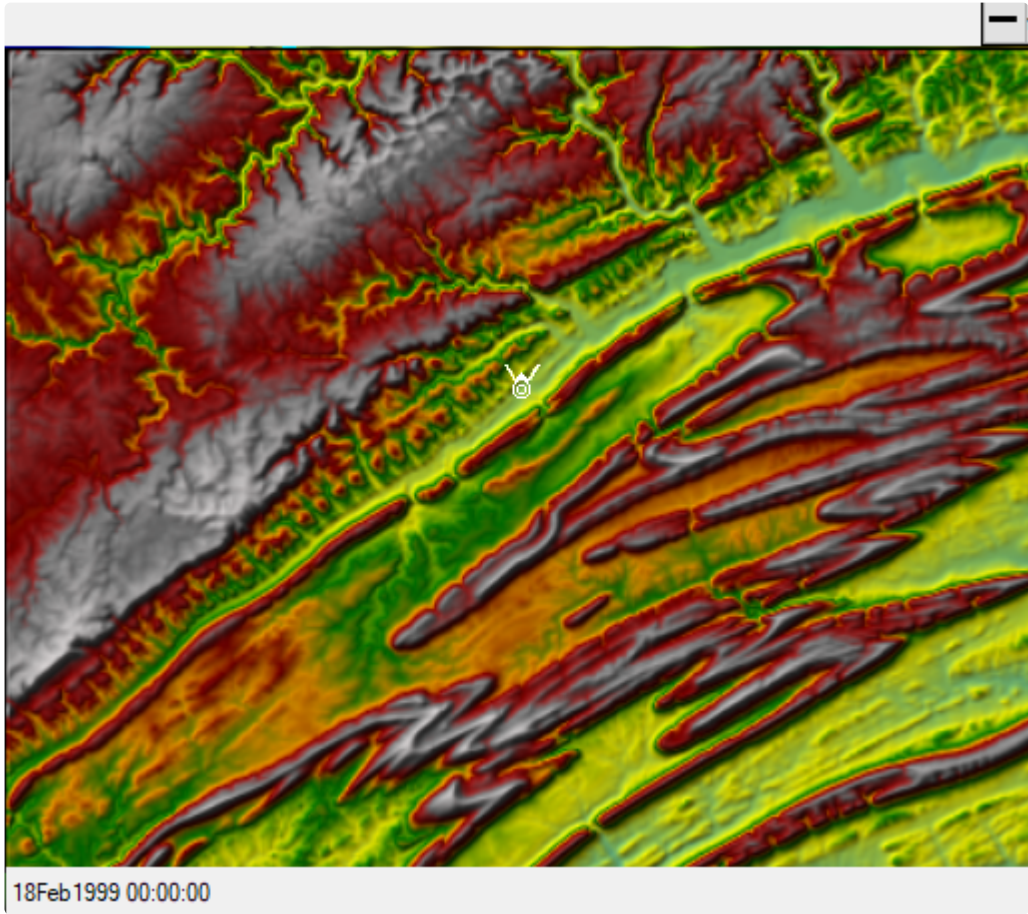
There are three components to the mini map, which are explained in the Table below.

Table 8 6. Components of the 3D Viewer Mini Map.

Component	Description
Hide/Show Button	On the top right of the mini-map is a button that will hide or show the mini-map.
Mini-map	A character on the mini-map ▥ shows where the viewer is in relation to the map, and also shows what direction the viewer is currently facing. Here the character is facing north

Component	Description
	The mini-map also grants the ability for the viewer to be moved anywhere on the map. With either the Select [cursor icon] or Pan [hand icon] tool, left click anywhere to move the viewer to that location. The left mouse button can also be held down to move the viewer with the mouse drag.
Simulation Date/Time	Shows the current Date/Time for the simulation

Speed/Position Information

On the bottom left corner of the viewer is information about the viewer's speed and its position. A description of these components is in the Table below.
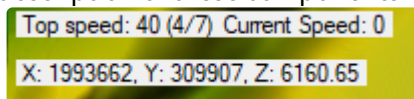
Table 8 7. Speed and Location Components.

Component	Description
Top Speed	The maximum speed that the viewer can currently travel. Can be increased/decreased with the Increase/Decrease Viewer Speed key bindings. The fraction shows what top speed is currently selected out of the possible top speeds. The top speeds are generated based on terrain size.
Current Speed	While the viewer is moving, the current speed will update to show the viewer's current speed.
X,Y	The position of the viewer on the XY plane. These coordinates are the same ones used in RAS Mapper
Z	The elevation of the viewer

How To Use the 3D Viewer

Movement

How movement works on the keyboard/controller depends on what camera mode the 3D Viewer is currently set. By default, the 3D Viewer is set to Helicopter mode ([icon]), which means the movement keys will move the viewer as if it's on a geometric plane. For example, pressing the forward key will move the viewer forward.

Movement for the mouse works the same for either camera mode. If the cursor is currently the Select cursor ([icon]), middle click and drag on the terrain will move the viewer proportional to how much the mouse is dragged. If the cursor is the Pan cursor ([icon]), then a left click and drag is all that is needed.

Changing View/Rotation

Changing the view of the viewer is accomplished through the mouse or the right stick on the controller. It can also be done through the keyboard but the keys are unbound by default to

discourage using the keyboard.

To change the view with the mouse right click and drag on the screen. This only applies when the mouse cursor is visible. If the view changes too little with the mouse drag then you can change the mouse sensitivity in the options. When the mouse cursor is not visible there is no need to right click, the view will change with mouse movement. See Mouse Lock/Unlock for more information.

To change the view with a game controller, use the right stick. This only applies when the mouse cursor is not visible. If the view changes too little with the right stick then you can change the controller sensitivity in the options. When the cursor is visible the left stick controls the mouse. See Mouse Lock/Unlock for more information.

Changing Elevation

To change the elevation with the mouse, scroll up to decrease in elevation, scroll down to increase in elevation

Changing elevation with the keyboard or game controller depends on what camera mode the 3D Viewer is currently set. By default, the 3D Viewer is set to Helicopter mode (🚁), in Helicopter mode elevation is changed by pressing the Elevation Up or Elevation Down keys. In Airplane mode (✈), these keys are disabled, and to change elevation in this mode look in the direction you wish to ascend/descend.

Mouse Lock/Unlock

By default, the mouse is shown and it considered to be "unlocked". The purpose of an unlocked mouse is to allow easy access to the buttons on the user interface.

To make changing the view with the mouse less tedious, the mouse can be "locked" to the screen by pressing the Tab key. This will hide the mouse cursor but will no longer require the mouse to right click to change view.

Flight Plans/Paths

The 3D Viewer allows the user to specify a flight path polyline in RAS Mapper for the viewer to follow like a train on tracks

Laying Out the Flight Path in RAS Mapper

To lay out a flight path, first open RAS Mapper. To open RAS Mapper, on the main RAS window select the **GIS Tools | RAS Mapper** menu item or by pressing the　　　　 **RAS Mapper** button, shown below.
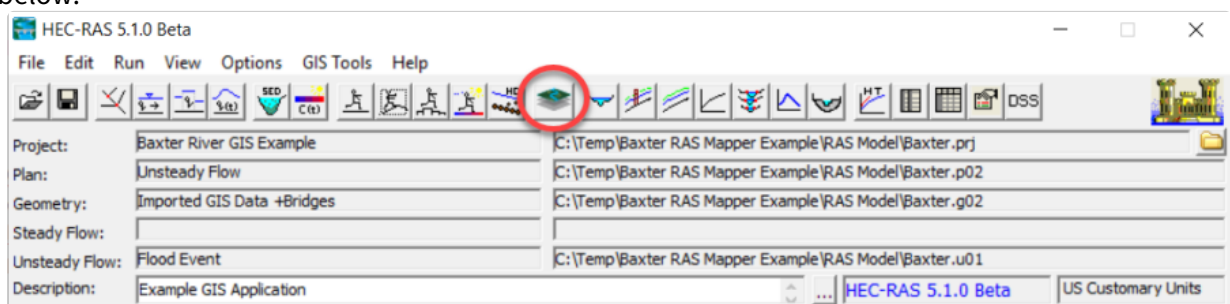
A flight path layer will be needed to lay out flight paths. To do that right click on **Features** Group in the tree view, and then select **Create New Layer > Flightpath Layer**
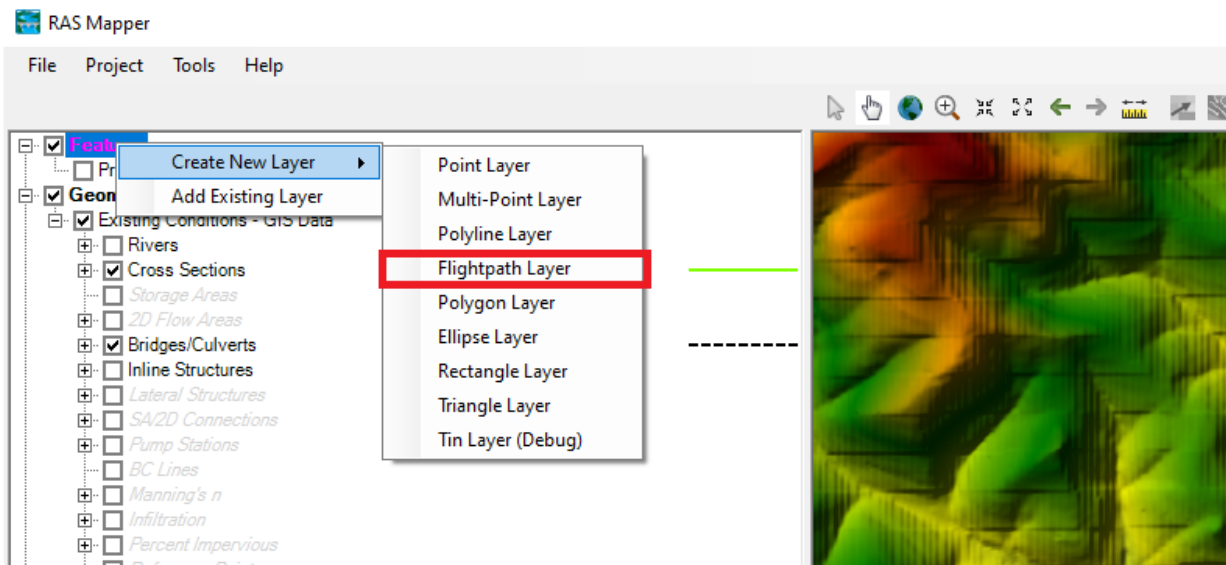
Then lay out the polyline you want to use for the flight plan. When you have finished right click the layer and select Stop Editing.

A shape file will be generated under the Flight Paths folder in the root project directory. Go back to

the 3D Viewer and press the Select a Flight Plan button in the toolbar ( )

An example 3D Perspective plot is shown in Figure 6-38. The older X-Y-Z Perspective Plot of 1D cross sections is still available from the View menu.
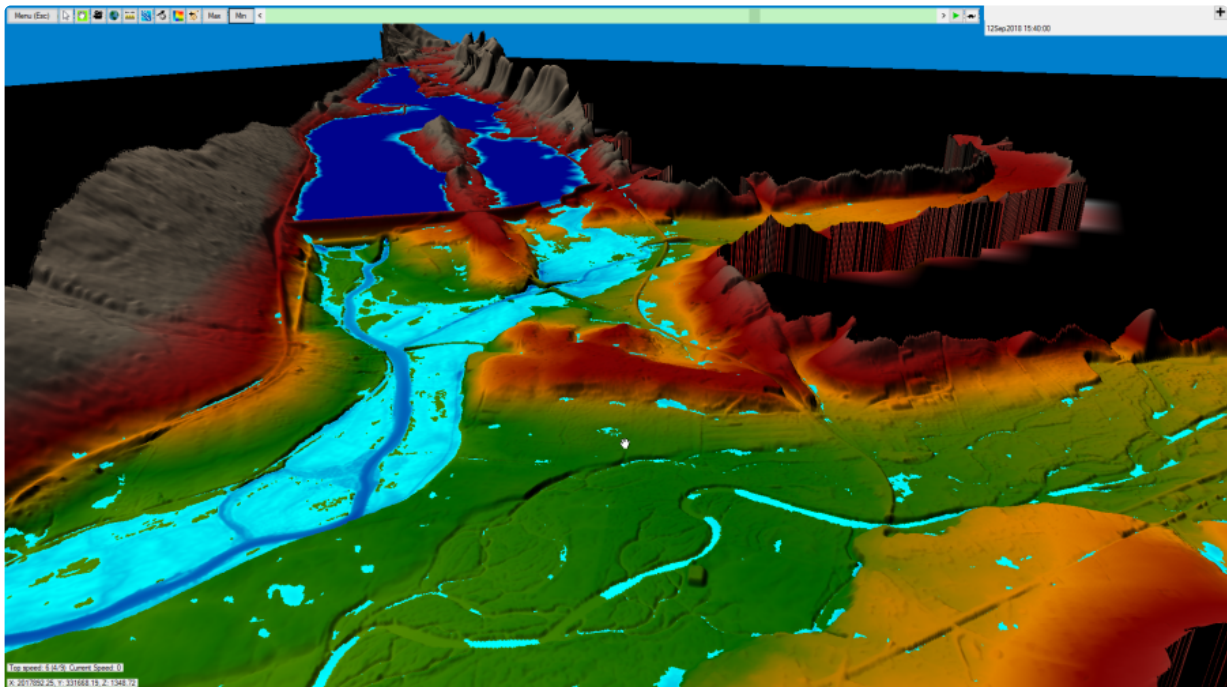
8 STEADY VS. UNSTEADY FLOW AND 1D VS. 2D MODELING

For a detailed discussion on this topic, go to the HEC-RAS Documentation Webpage and download the document called "Modeler Application Guidance for Steady vs. Unsteady, and 1D vs 2D vs 3D Hydraulic Modeling". Here is a link to that document:

https://www.hec.usace.army.mil/publications/TrainingDocuments/TD-41.pdf

The following is a short summary of what is in that document. First the user should think about "When do I need unsteady flow modeling over steady flow modeling? Where should I use 2D Flow Areas over 1D river reaches and/or storage areas ?"

To answer the questions of Steady vs Unsteady Flow, and 1D vs 2D modeling approaches, requires additional information regarding the purpose of the model and the data available. Each river system will have site specific information that must be considered in order to answer the questions of Steady versus Unsteady flow and 1D versus 2D modeling. The following is a partial list of some of the things that the modeler should typically consider when trying to make a modeling approach decision:

1. Physical description of the river channels, floodplain areas, bridges/culverts, other hydraulic structures, levees, roads, etc. that the model will be applied to.
2. What is the typical size, length, and complexity of the systems that these models will be applied to? Is it a 1 mile, 10, 50, 100, 500, or 1000 mile river system
3. What is the source and level of accuracy of the terrain data, cross section data, and hydraulic structure data?
4. What is the general level of accuracy of the hydrology used to drive the models?
5. Will this model be used for Planning type studies, or will it be used for real time modeling and mapping?
6. .What type of events (hydrology and boundary conditions) will the models be used to analyze (Dambreak, flash floods, normal rainfall runoff events, steady flows)?
7. What is the typical duration of a flood event on this river system? (1-3 days, 1- week, 1-month, 6-months, years)
8. Is the flow path of the water generally known for the full range of events?
9. Are there unique aspects of the system that will significantly affect the computed results? Such as: is the river tidally influenced; do wind speed and directions affect the water surface elevations; is the river affected by floating ice or ice jams; does there tend to be debris issues during flood, and does the debris tend to pile up at hydraulic structures; will levee overtopping, breaching, and interior flow routing need to be addressed, Are there any significant bridges and culverts that will cause water to backup behind them during significant flood events, etc…?
10. What are the required outputs from the model (water surface elevations, water depths, arrival times, average velocities, detailed velocities in two dimensions at specific point locations, etc…)?
11. What is the model purpose and expected level of accuracy required?
12. How much time and money do you have to get it done?
13. What experience does the modeler have with 1D and/or 2D modeling?

With that said, I will try to offer both a theoretical opinion and a practical application opinion to the question posed above.

> ⓘ **Note:** a much more detailed and extensive discussion on this subject is contained in **HEC Training Document 41 (TD-41) "Modeler Application Guidance for Steady vs Unsteady, and**

1D vs 2D vs 3D Hydraulic Modeling". This document can be obtained from the Publications area of HEC's website.

Steady vs. Unsteady Flow Modeling

Steady flow models, or even running an unsteady flow model (1D or 2D) in a steady flow mode (constant flow) should generally not be used when the following situations exist in the river system being analyzed (this is not an exhaustive list):

- The river is tidally influenced, and the tide has a significant effect on the water surface elevations for the area of interest.
- The events being modeled are very dynamic with respect to time (i.e., dam break flood waves; flash floods; river systems in which the peak flow comes up very quickly, stays high for a very short time, and then recedes quickly).
- Complex flow networks and/or flow reversals occur during the event.
- Dynamic events such as levee overtopping and breaching occur during the event.
- Extremely flat river systems, where gravity, hydrostatic pressure, and friction are not necessarily the only significant force acting on the flow (i.e. local and convective acceleration forces).
- Systems with Pump stations that move a significant amount of water.
- Systems with structures that have complex gate operations based on stages and flows in the system

In addition to the specific items listed above, a successful application of any steady-flow model requires that flow rates have already been accurately computed by a hydrologic model or measured by an accurate and complete set of stream gages. If a hydrologic model is being used to not only compute the rainfall-runoff over the watershed, but perform all of the routing within the system, then the flow rates used in the steady-flow model are only as accurate as the hydrologic model could compute them. So, the use of a steady-flow hydraulic model, is predicated on the fact that a hydrologic model was considered to be appropriate for not only developing the flow rate from rainfall runoff computations, but also routing all of the flows through the system during the event. Therefore, a large part of the decision of steady-flow versus unsteady flow hydraulic modeling comes down to the question: is hydrologic stream flow routing accurate enough to produce flow rates that can be used in the corresponding steady-flow hydraulics models.

Even considering all of what is stated above. There are still many areas in which a good hydrologic model (one that is representative of the watershed and has been well calibrated) can be used in conjunction with a steady flow hydraulics model to perform watershed studies requiring hydraulic model results. However, it is up to the modeler to decide when using a steady flow modeling approach is not appropriate.

1D vs. 2D Hydraulic Modeling

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

Here are some areas where I think 2D modeling can give better results than 1D modeling:

- When modeling an area behind a leveed system, and the levee will be overtopped and/or breached, the water can go in many directions. If that interior area has a slope to it, water will travel overland in potentially many directions before it finds its way to the lowest point of the protected area, and then it will begin to pond and potentially overtop and/or breach the levee on the lower end of the system. However, if a protected area is small, and ultimately the whole area will fill to a level pool, then 1D model is fine for predicting the final water surface and extent of the inundation.
- Bays and estuaries in which the flow will continuously go in multiple directions due to tidal fluctuations and river flows coming into the bay/estuary at multiple locations and times.
- Areas and/or events in which the flow path of the water is not completely known.
- Highly braided streams
- Alluvial fans – however, this is very debatable that any numerical model can capture a flood event accurately on an alluvial fan, due to the episodic nature of flow evolutions that can change the whole direction of the channels during the event.
- Flow around abrupt bends in which a significant amount of super elevation will occur during the event.
- Very wide and flat flood plains, such that when the flows goes out into the overbank area, the water will take multiple flow paths and have varying water surface elevations and velocities in multiple directions.
- Applications where it is very important to obtain detailed velocities for the hydraulics of flow around an object, such as a bridge abutment or bridge piers, etc…

The following are areas in which 1D modeling can potentially produce results as good as 2D modeling (from the perspective of computed water surface elevations, and flow/stage hydrographs), with less effort (from a model development, calibration, and application viewpoint, as well as a computational time viewpoint):

- Rivers and floodplains in which the dominant flow directions and forces follow the general river flow path. This covers a lot of river systems in my opinion, but it is obviously debatable as to the significance that lateral and vertical velocities and forces impact the computed water surface elevations and the resulting flood inundation boundary.
- Steep streams that are highly gravity driven and have small overbank areas.
- River systems that contain a lot of bridges/culvert crossings, weirs, dams and other gated structures, levees, pump stations, etc…. and these structures impact the computed stages and flows within the river system. I have not seen any 2D model yet that has a comprehensive set of hydraulic structure modules/capabilities that can handle the full range of hydraulic flow situations that can come up on many of our river systems. This is an area that the current state of the art in 1D models is far ahead of the 2D models. This statement does not mean that these capabilities cannot be incorporated into a 2D model, It just means that I have not seen a widely used 2D model that has such a comprehensive set of capabilities.
- Medium to large river systems, where we are modeling a large portion of the system (100 or more miles), and it is necessary to run longer time period forecasts (i.e. 2 week to 6 month forecasts). Even with the tremendous advancements in multi-processor computing, and GPU (Graphics Processor Units) computing, there are still significant spatial and simulation time limitations on what we can effectively use 2D models for in the real time forecasting domain. This will obviously be changing over time.
- Areas in which the basic data does not support the potential gain of using a 2D model. If you do not have detailed overbank and channel bathymetry, or you only have detailed cross sections at representative distances apart, many of the benefits of the 2D model will not be realized due to the poor accuracy of the terrain data.

With all of that said, there are many areas in which it will be highly debatable as to the relevant accuracy of using a 1D or a 2D modeling approach for a specific application. There are many aspects to consider, other than purely "am I solving the full Saint Venant equations in one dimension or two dimensions". I believe that there are both knowledge gaps in understanding when 1D versus 2D should be used, and there are tool gaps. I personally believe that combined 1D/2D models will play

an important role in our modeling efforts in the near term. This is an area where the hydraulic modeling tools need to be improved.

I am also of the view point that the majority of uncertainty and ability to accurately forecast stages and flows in river systems is mostly due to poor estimation of rainfall both spatially and temporally, and hydrologic modeling, which often includes large portions of ungaged areas in which little to no calibration could be performed. This can often be a much greater contributor to forecast/modeling error than any differences arising from 1D versus 2D model choices.

9 OPTIMIZE YOUR COMPUTER FOR FAST COMPUTATIONS

Now that 2D modeling is becoming widespread in the HEC-RAS community, a lot of modelers are wanting to know what kind of computer to get to maximize computation speed when running those large 2D datasets.

Before moving into suggestions for 2D modeling, first in 1D modeling, multiple processing cores are NOT currently used. If you plan to only do 1D modeling, having extra cores will not help you with speed. In this case, the processor speed is everything. So get the fastest processor you can for 1D model (e.g. 3.4 Ghz or higher).

For the rest of this post, I'll assume you want to optimize your computer for 2D HEC-RAS modeling, since those are the models that typically will take longest to run.

- More cores is not always better. In fact, it has been found that for smaller 2D areas (e.g. less than 10,000 cells or so), 8 cores may indeed run slower than 4 or 6 cores. The reason behind this is that there is a level of computing overhead used just to transfer data between cores. Fortunately, HEC-RAS has an option to change the number of cores you wish to use in the Computation Options and Tolerances window (from the unsteady flow analysis window…Options…Calculation Options and Tolerances…2D Flow Options tab). For smaller datasets, I suggest experimenting with this to optimize computation speed. "All Available" may not necessarily be the fastest. But for large numbers of cells, you're going to want as many cores as you can get your hands on.

So for the number of Cores, get as many as you can, but not at the expense of processor speed. Make sure you get at least 3.2 to 3.4 Ghz or higher processors, no matter how many cores you get.

Hyper-threading is an Intel technology that attempts to keep CPU resources as busy as possible. Each real CPU core has what appears to be two cores. However, there is really only one true core. For example, the typical Intel I7 chip has four real CPU cores, but if you open Task Manager and go to the Performance Tab, you will see four across the top, and what appears to be four more below it. These are virtual cores. Each real CPU core has only one true math processing unit, but with Hyper-threading it has two instruction feeders. Hyper-threading tries to eliminate stalls by always having another thread at the ready in a second virtual core. If one thread stalls (not requiring the math unit) on virtual core A, virtual core B will instantly start picking up the slack, so the execution units keep working at 100%.

The RAS 2D compute engine is extremely math heavy. So for each core it utilizes, it is almost always using 100% of the math unit. So the second virtual core (Hyper-thread) is never used. So back to our Intel I7 chip example. An Intel I7 has 4 real cores, but appears to have 8 cores (4 virtual cores). RAS will only use the four real cores, and it will keep them almost 100% busy. However, Task Manager reports this as only 50% utilization of the CPU. However, this is truly 100% utilization of the four real cores math units.
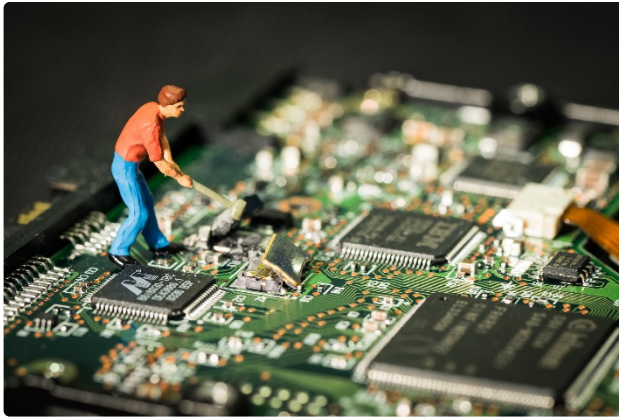
- Processor speed is still paramount. Do NOT think you will have fast HEC-RAS model run times just because you have a computer with 16 cores or more. If all of your cores have slow processor speeds, you'll get some benefit out of the number of cores, but you will be disappointed in the overall speed for a wide range of model types (1D/2D) and sizes. So make sure even if you get a large number of cores, you are not doing so at the expense of fast processor clock speeds. As of the date of this article (August 2016) and the current version of HEC-RAS (5.0.1), 3.2 to 3.4 GHz or higher is a good clock speed for fast running models.
- Your hard drive is important. Especially if you are producing a lot of output. Small detailed output intervals, small mapping output intervals, writing computation level output, etc. All of these settings affect how much and how often output is written to the hard drive during run time. Solid state hard drives (SSD) are typically going to be better than the traditional spinning hard drive (HDD).
- RAM is important, but not as much as you might think. While RAM is definitely important, it is not as important for 2D modeling as number of cores and processor speed. You do want enough RAM to run your operating system and have your entire HEC-RAS model in memory, without the operating system having to swap things in and out of memory. That being said, if you plan to do multiple HEC-RAS models at the same time, or you have a habit of keeping lots of programs open and running in the background of your computer, you may want to get a computer with a lot of RAM. I would venture to guess that if you are buying a computer with a lot of cores with fast clock speeds, I'm guessing that computer will have enough RAM. But RAM is cheap, so you might as well load up on it while you're building the HEC-RAS computer of your dreams.
- Graphics card does not matter. While some of your other programs run best on a super-charged graphics card, HEC-RAS currently does not support GPU computing. For HEC-RAS modeling, don't waste your money on an expensive graphics card. However, you may seem so noticeable improvement in the snappiness of image rendering or particle tracing with a better graphics card. If money is no object, get a top-of-the-line graphics card, but this is one area you can sacrifice if you need to save some dough.

To sum up, my recommendation for building a computer to optimize 2D runs in HEC-RAS is as follows:

Get as many processing cores as you can, but do not do so in expense of processor speed. Make sure your computer has processors that are 3.2 to 3.4 Ghz or even higher (the faster the better). Get an SSD hard drive, and max out your RAM. 32 Gb is a good amount and can run large models (millions of cells). If you plan to run really large models (many millions of cells), you may want more RAM. Pretty simple really. And by the way, 24-inch (or larger) dual monitors really helps with viewing all those HEC-RAS windows you have open.

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11 RAS MAPPER SUPPORTED FILE FORMATS

The following is a list of the file formats that can currently be imported into HEC RAS Mapper:

VRT : Virtual Raster

GTiff : GeoTIFF

NITF : National Imagery Transmission Format

RPFTOC : Raster Product Format TOC format

ECRGTOC : ECRG TOC format

HFA : Erdas Imagine Images (.img)

SAR_CEOS : CEOS SAR Image

CEOS : CEOS Image

JAXAPALSAR : JAXA PALSAR Product Reader (Level 1.1/1.5)

GFF : Ground-based SAR Applications Testbed File Format (.gff)

ELAS : ELAS

AIG : Arc/Info Binary Grid

AAIGrid : Arc/Info ASCII Grid

GRASSASCIIGrid : GRASS ASCII Grid

SDTS : SDTS Raster

DTED : DTED Elevation Raster

PNG : Portable Network Graphics

JPEG : JPEG JFIF

MEM : In Memory Raster

JDEM : Japanese DEM (.mem)

GIF : Graphics Interchange Format (.gif)

BIGGIF : Graphics Interchange Format (.gif)

ESAT : Envisat Image Format

BSB : Maptech BSB Nautical Charts

XPM : X11 PixMap Format

BMP : MS Windows Device Independent Bitmap

DIMAP : SPOT DIMAP

AirSAR : AirSAR Polarimetric Image

RS2 : RadarSat 2 XML Product

PCIDSK : PCIDSK Database File

PCRaster : PCRaster Raster File

ILWIS : ILWIS Raster Map

SGI : SGI Image File Format 1.0

SRTMHGT : SRTMHGT File Format

Leveller : Leveller heightfield

Terragen : Terragen heightfield

GMT : GMT NetCDF Grid Format

netCDF : Network Common Data Format

ISIS3 : USGS Astrogeology ISIS cube (Version 3)

ISIS2 : USGS Astrogeology ISIS cube (Version 2)

PDS : NASA Planetary Data System

TIL : EarthWatch .TIL

ERS : ERMapper .ers Labelled

JPEG2000 : JPEG-2000 part 1 (ISO/IEC 15444-1)

L1B : NOAA Polar Orbiter Level 1b Data Set

FIT : FIT Image

GRIB : GRIdded Binary (.grb)

MrSID : Multi-resolution Seamless Image Database (MrSID)

JP2MrSID : MrSID JPEG2000

MG4Lidar : MrSID Generation 4 / Lidar (.sid)

RMF : Raster Matrix Format

WCS : OGC Web Coverage Service

WMS : OGC Web Map Service

MSGN : EUMETSAT Archive native (.nat)

RST : Idrisi Raster A.1

INGR : Intergraph Raster

GSAG : Golden Software ASCII Grid (.grd)

GSBG : Golden Software Binary Grid (.grd)

GS7BG : Golden Software 7 Binary Grid (.grd)

COSAR : COSAR Annotated Binary Matrix (TerraSAR-X)

TSX : TerraSAR-X Product

COASP : DRDC COASP SAR Processor Raster

R : R Object Data Store

MAP : OziExplorer .MAP

PNM : Portable Pixmap Format (netpbm)

DOQ1 : USGS DOQ (Old Style)

DOQ2 : USGS DOQ (New Style)

ENVI : ENVI .hdr Labelled

EHdr : ESRI .hdr Labelled

GenBin : Generic Binary (.hdr Labelled)

PAux : PCI .aux Labelled

MFF : Vexcel MFF Raster

MFF2 : Vexcel MFF2 (HKV) Raster

FujiBAS : Fuji BAS Scanner Image

GSC : GSC Geogrid

FAST : EOSAT FAST Format

BT : VTP .bt (Binary Terrain) 1.3 Format

LAN : Erdas .LAN/.GIS

CPG : Convair PolGASP

IDA : Image Data and Analysis

NDF : NLAPS Data Format

EIR : Erdas Imagine Raw

DIPEx : DIPEx

LCP : FARSITE v.4 Landscape File (.lcp)

GTX : NOAA Vertical Datum .GTX

LOSLAS : NADCON .los/.las Datum Grid Shift

NTv2 : NTv2 Datum Grid Shift

CTable2 : CTable2 Datum Grid Shift

ACE2 : ACE2

SNODAS : Snow Data Assimilation System

ARG : Azavea Raster Grid format

RIK : Swedish Grid RIK (.rik)

USGSDEM : USGS Optional ASCII DEM (and CDED)

GXF : GeoSoft Grid Exchange Format

HTTP : HTTP Fetching Wrapper

NWT_GRD : Northwood Numeric Grid Format .grd/.tab

NWT_GRC : Northwood Classified Grid Format .grc/.tab

ADRG : ARC Digitized Raster Graphics

SRP : Standard Raster Product (ASRP/USRP)

BLX : Magellan topo (.blx)

GeoRaster : Oracle Spatial GeoRaster

Rasterlite : Rasterlite

SAGA : SAGA GIS Binary Grid (.sdat)

KMLSUPEROVERLAY : Kml Super Overlay

XYZ : ASCII Gridded XYZ

HF2 : HF2/HFZ heightfield raster

PDF : Geospatial PDF

OZI : OziExplorer Image File

CTG : USGS LULC Composite Theme Grid

E00GRID : Arc/Info Export E00 GRID

ZMap : ZMap Plus Grid

NGSGEOID : NOAA NGS Geoid Height Grids

MBTiles : MBTiles

IRIS : IRIS data (.PPI, .CAPPi etc)

12 TERMS AND CONDITIONS OF USE

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