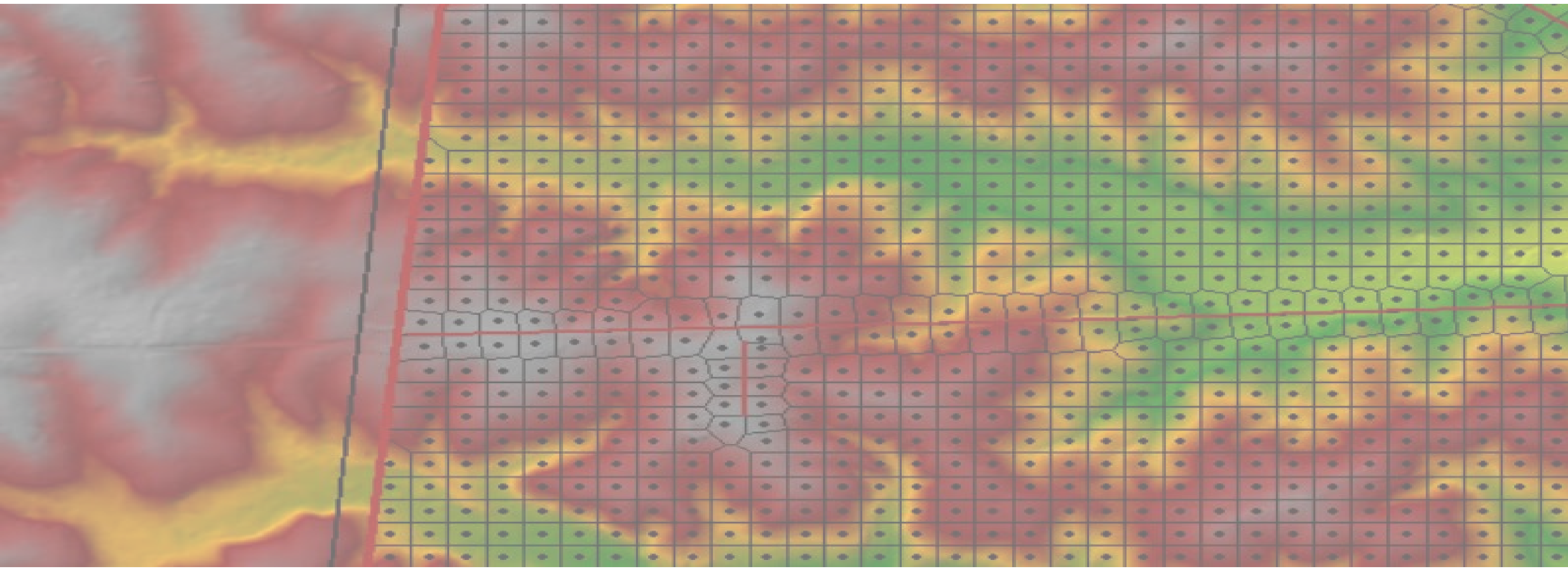
Flood Decision Support Toolbox

Two-Dimensional Hydraulic Model Guidance for FEMA Base Level Engineering Datasets



Version 2022-04

Contents

Introduction

The Flood Decision Support Toolbox (FDST; infrm.us) is an interactive web application that enables emergency managers and decision makers to view and prepare for flooding events before they occur. Potential flooding scenarios are provided as map libraries consisting of depth grids in 0.5-foot (ft) intervals from flood stage to maximum expected flood. Map libraries are associated with select streamgages that display U.S. Geological Survey (USGS) real-time streamgage data, which in turn can also be linked to National Weather Service (NWS) river forecasts and NWS flood categories. The FDST is designed to aid in resource allocation, emergency equipment staging, evacuation decisions and other flood scenario planning during routine operations in preparation for flood events.

Purpose and Scope

The purpose of this document is to determine the suitability, applicability, and subsetting of 2D Federal Emergency Management Agency (FEMA) base level engineering (BLE) models for generating FDST libraries and to provide guidance for extracting portions of 2D models for use in the FDST (FEMA, 2019). With ever-advancing hardware and software computing capabilities, two dimensional (2D) hydraulic modeling is becoming a more common and useful tool in generating flood inundation models and maps. However, 2D models are much more computationally intensive than their simpler 1D model counterparts. This computational demand is compounded by the fact that hydraulic models are be calibrated to numerous 0.5-ft intervals for map library submissions to the FDST. Furthermore, recommended procedures are presented that detail how to extract a smaller study area from a larger model for the purpose of reducing model runtime and model geometry complexity during half-foot interval calibration for the FDST.

Although the “Suitability and Applicability” sections of this guidance document has broad applicability to 2D modeling software applications, the 2D Model Subsetting and Extraction Guidance was written specifically for the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) software (USACE-HEC, 2016).

Suitability and Applicability of a 2D Model for Generating FDST Flood Map Libraries

Before using a 2D model to generate flood map libraries for the FDST, the modeler would be advised to take the following into consideration. First, are the following three required items for FDST map library generation are available: (1) real-time USGS streamgage data, (2) high-resolution light detection and ranging (lidar) data, and (3) a FEMA approved hydraulic model. Second, the modeler would determine if the entire model can be calibrated and used for map library creation or if only a portion of the model can be calibrated and thus be suitable for map library creation.

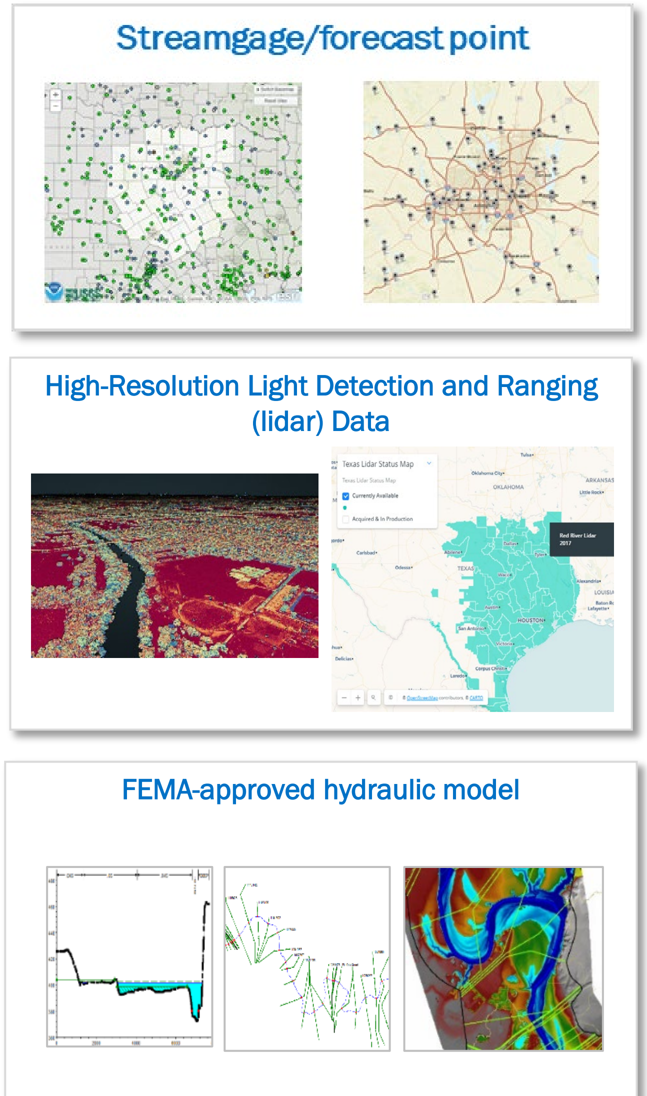


Figure 1: The three required items for FDST map library creation: streamgage/forecast point, high resolution (3 meter or less) light detection and ranging (lidar) data, and a Federal Emergency Management Agency (FEMA)-approved hydraulic model (most likely the Hydrologic Engineering Center's River Analysis System, HEC-RAS).

Hydraulic Model

The modeler would first verify that hydraulic models are FEMA-approved and meet the minimum requirements for map library creation for the FDST. A link to a list of FEMA approved models plus the minimum model requirements can be found in the Interagency Flood Risk Management Group (InFRM) FDST Executive Summary and Submittal Guidance listed on the InFRM webpage (InFRM, 2022). The most commonly used hydraulic software for flood inundation mapping in the region, HEC-RAS, is FEMA approved, and these guidelines were written specifically for HEC-RAS models. If the hydraulic model was created following FEMA's Base Level Engineering guidance, then that model meets the minimum criteria for a Tier B model submission for the FDST (for more information on FDST model Tiers, please refer to the InFRM FDST Executive Summary and Submittal Guidance [InFRM, 2022]).

Lidar Data

The modeler would also verify that high-resolution lidar data are available for the study area encompassing the FDST map library with a resolution of 3 meters or less and are the most recently available in the study area. Furthermore, the lidar data would be recent enough to represent current conditions in the floodplain. For example, an urbanized area is more likely to have alterations to the floodplain or surrounding area in a given year versus a rural area with no development occurring since lidar data were last collected (for more information on FDST lidar data standards, please refer to the InFRM FDST Executive Summary and Submittal Guidance [InFRM, 2022]).

Streamgage Data

It is required that the map library be associated with a real-time (15-minute or less observation frequency) USGS streamgage for stage data to be displayed in the FDST. The streamgage would collect stage data at a minimum, and streamflow data are not required. However, the streamgage would have a rating curve that can be used to calculate the error between the modeled and rated stage at the streamgage for a given quantity of streamflow. For more information on calculating error at the streamgage for the FDST, please refer to the FDST Executive Summary and Submittal Guidance (InFRM, 2022). Sites with an NWS Advanced Hydraulic Prediction Service (AHPS) forecast point are recommended for the added benefit of flood forecasting and flood stage information (NWS, 2021). However, real-time stage data are all that is required to display a flood map library in the FDST. At present (2022), the FDST only accepts map libraries associated with specific USGS streamgages. To develop a map library at a streamgage that meets these criteria but is not a USGS streamgage, please contact the InFRM team to determine if the data can be uploaded into the FDST web application.

Defining a Study Area

The selection process for defining a study area encompassing the FDST map library is described in the FDST Executive Summary and Submittal Guidance (InFRM, 2022). Modeling 2D flows is more complex than modeling 1D flows, but both 1D and 2D models would utilize the same method to define the study area. The purpose of the FDST is to map flooding at a location as measured by a nearby streamgage collecting stage data. Therefore, the FDST only displays flooding associated with the channel on which the streamgage is located. Because libraries map only the flooding measured at a single gaged location, there is no reliable way of displaying tributary flow, overland flooding, or flooding beyond a reasonable distance from the streamgage. For more information on defining a FDST study area, please refer to the FDST Executive Summary and Submittal Guidance (InFRM, 2022).

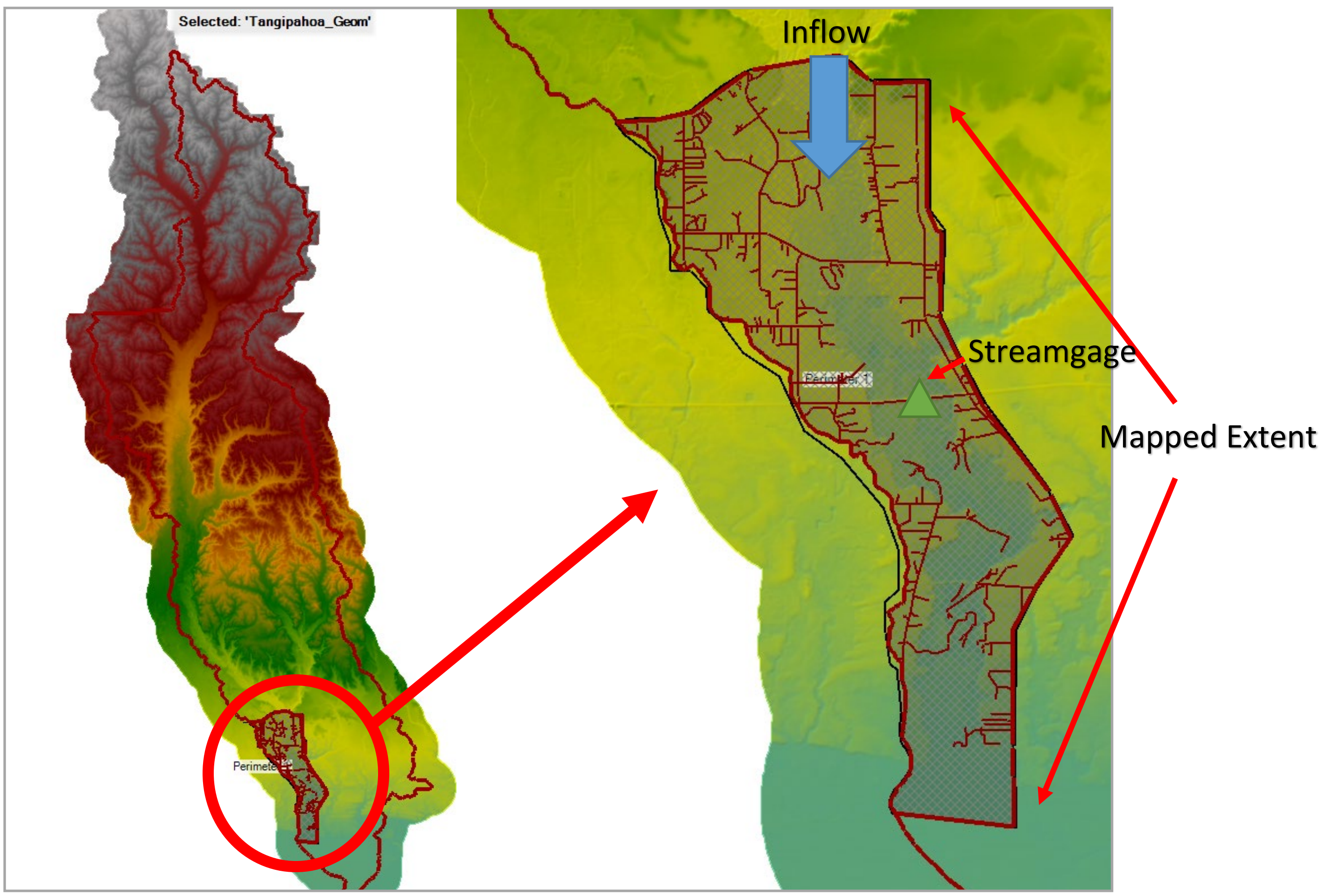


Figure 2: An example study area for a streamgage located within a larger, basin-scale hydraulic model. Even though the model encompasses the entire basin, we only map the flooding associated with the stage measured at the corresponding streamgage.

Engineering-scale models, in contrast to BLE models, are calibrated using historical flood data beyond the immediate vicinity of the modeled streamgage and can usually provide limited insights regarding tributary flow, overland flooding, or main-channel flooding at a greater distance from a given streamgage. However, the library would still display only model main channel flooding and not display any tributary or overland flow flooding. The study area for the FDST is necessarily defined such that regardless of flooding source, the flooding associated with the measured stage at the mapped streamgage will remain more or less the same. As an exaggerated example, imagine a streamgage on the Mississippi River below the Missouri River. The mapped library would neither extend up the Missouri River nor extend up the Mississippi upstream from the Missouri. The flooding event that led to the stage at the downstream gage could have originated in either the Missouri or Mississippi Basins, or both, and the current version of the viewer does not allow the user to differentiate between the two.

Suitability of 2D Model Subsetting, Calibration, and Use

Basin-wide or river-length 2D models are generally too large and complex for FDST map library calibration methodology. If the hydraulic model is focused and small enough such that 0.5-ft interval calibration for the FDST is feasible using the modeled reach, then the entire model may be used to generate flood maps. Please refer to the guidelines in the FDST Executive Summary and Submittal Guidance (InFRM, 2022) for detailed guidance on:

- delineating the map library study area,
- creating map library files,
- and geoprocessing.

If the hydraulic model was designed for an area too large for the model to be efficiently calibrated for an FDST map library, please refer to the following section of this document: HECRAS 2D Model Subsetting and Extraction Guidance. This section describes a recommended procedure for extracting a study area for the FDST from a basin-scale FEMA BLE model. The guidance provides a streamlined extraction process. However, modelers are free to deviate from these recommendations to develop a flood map library as long as they adhere to the required guidelines set forth in the FDST Executive Summary and Submittal Guidance (InFRM, 2022).

Coastal Flooding and Other Unique Scenarios

At present, the FDST is designed to only display flood map libraries associated with riverine flooding. Coastal inundation map libraries may be accepted but are not currently (2022) presented in the viewer. Please contact the InFRM team regarding work on coastal flooding or other unique scenarios not currently represented in the FDST, and the team will work together towards integrating those modeled results into the FDST.

HECRAS 2D Model Subsetting and Extraction Guidance

This section describes the recommended process for creating flood-inundation map libraries for the FDST using FEMA BLE 2D models. An example is provided for the Tickfaw River Basin in eastern Louisiana. These guidelines are designed for modelers who have experience creating flood-inundation map libraries for the FDST using FEMA BLE 1D HECRAS models.

Model Download

As was the case with 1D BLE models, 2D models may be downloaded using the USGS/FEMA web application, the estBFE viewer (https://webapps.usgs.gov/infrm/estBFE/). Upon loading the webpage, select “Download Datasets and Models” in the Quick Start section. 2D models are extremely large compared to their 1D counterparts, so ensure hard disk space is adequate and a stable connection exists before commencing download. Some models are so large that they cannot be hosted on the estBFE viewer. Instead, a direct link to an Amazon web services download may be provided. After selecting a basin, select “Download Data”, then select “Download” next to the HECRAS models. Either the model itself will download, or in the case of an extremely large file size, a simple text file will download, providing further links to download specific portions of the 2D model hosted elsewhere (Figure 3).

```
Model file URLs for 08070202_Amite

Size            URL
2.0 MB          https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/2D_Model_Inventory_Amite.xlsx

667.1 MB                https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/Input.zip

69.6 MB         https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/LandUse.zip

3.2 GB          https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/Terrain.zip

843.3 MB                https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/Output/WA1.zip

3.7 GB          https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/Output/WA2.zip

9.8 GB          https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/Output/WA3.zip

6.3 GB          https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/Output/WA4.zip

6.7             https://ebfedata.s3-us-west-2.amazonaws.com/08070202_Amite/Models/Output/WA5.zip
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Figure 3: Example links to download Amite River Basin, Louisiana 2D BLE model.

For map library generation, output is not typically needed, but model input, land use, and terrain data are all needed. It is also recommended to download the documentation accompanying the model. Upon opening the model in HEC-RAS and exploring the model domain in RASMapper, the modeler will notice that the model domain typically covers the entire modeled watershed, or at least major portions of each subbasin. In the Tickfaw River Basin model, the entire basin in Louisiana is covered by the 2D mesh (Figure 4). In other '2D' BLE models, some portions may be 1D, but typically they are not joined together in a combined 1D-2D model.

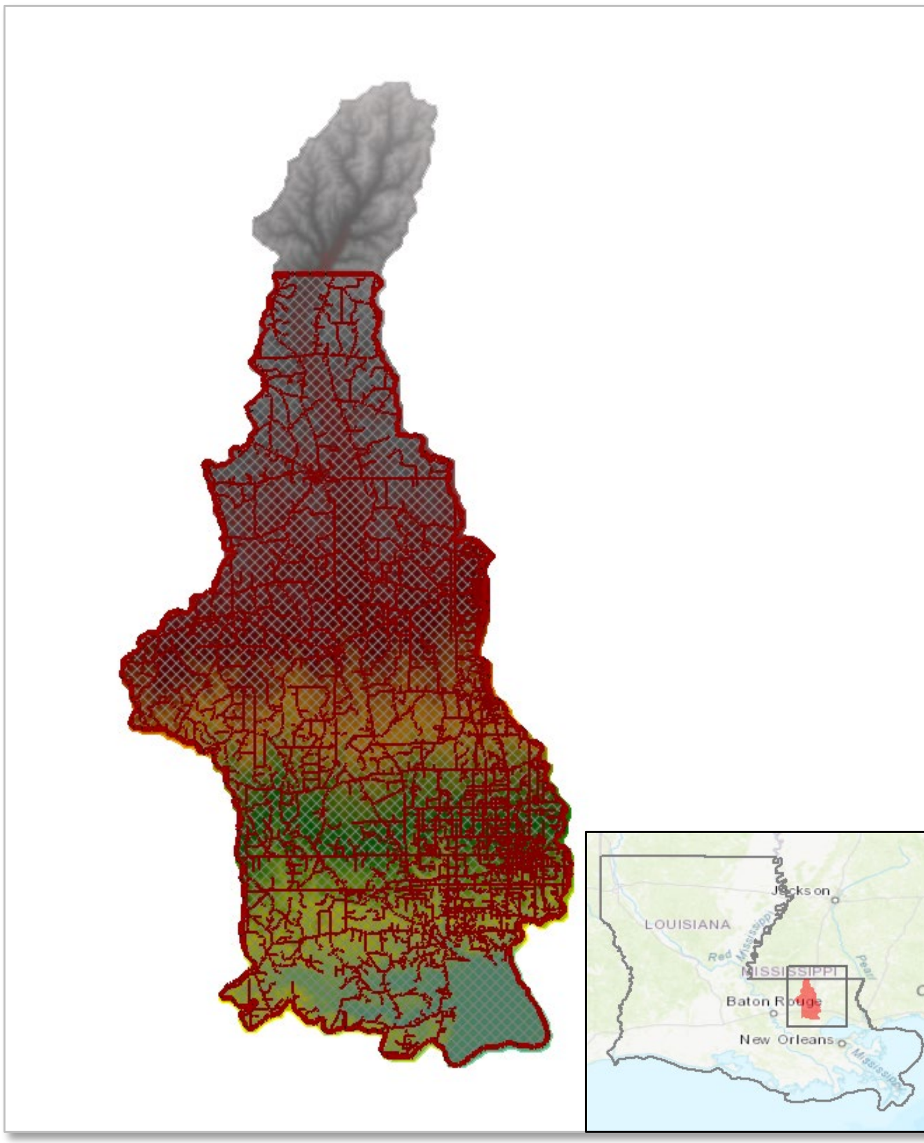

Figure 4: 2D mesh, boundary lines, break lines, and terrain for the Tickfaw River BLE model, Tickfaw River Basin in eastern Louisiana (2018).

Results in the original model are provided for the same annual exceedance probability (AEP) as the 1D models: 10-, 4-, 2-, 1-, 1+-, 1--, and 0.2-percent AEP. Also note that 2D models are time-dependent, which means that steady-state flow plans cannot be run here. Instead, an unsteady flow simulation would be designed for the model to run. Running each of these plans can take hours. This is not feasible for FDST map library development, which requires the model to be run many times to calibrate stages at the streamgage location. A different approach would be taken to calibrate 2D models.

The solution presented here is to create unique geometries for each map library or gaged location. While this is considered editing the original model geometry, steps will be taken to ensure that the 'clipped' geometry is as close to the original geometry as possible. This includes using a mesh with the same grid size as the original, tracing break lines, and using the same boundary conditions as the original model geometry. In the Tickfaw example, similar inundation was found between the calibrated FDST model using the clipped geometry and the original BLE model.

Defining a Study Area

Defining a study area in a 2D model is done in much the same way as in a 1D model. Mapping is based on the flooding associated with the stage at a specified streamgage, so the boundaries of the model are defined in the same manner as a 1D model, considering slope change, tributary flow, and engineering judgment. It is recommended to check the model terrain and inundation results before deciding upon the study-area extent (Figure 5). For USGS streamgage 07376000 Tickfaw River at Holden, La., the study area was defined as a reach of approximately 4.5 miles extending 1.5 miles upstream from the streamgage to 3 miles downstream from the streamgage near the confluence with the Hog Branch tributary.

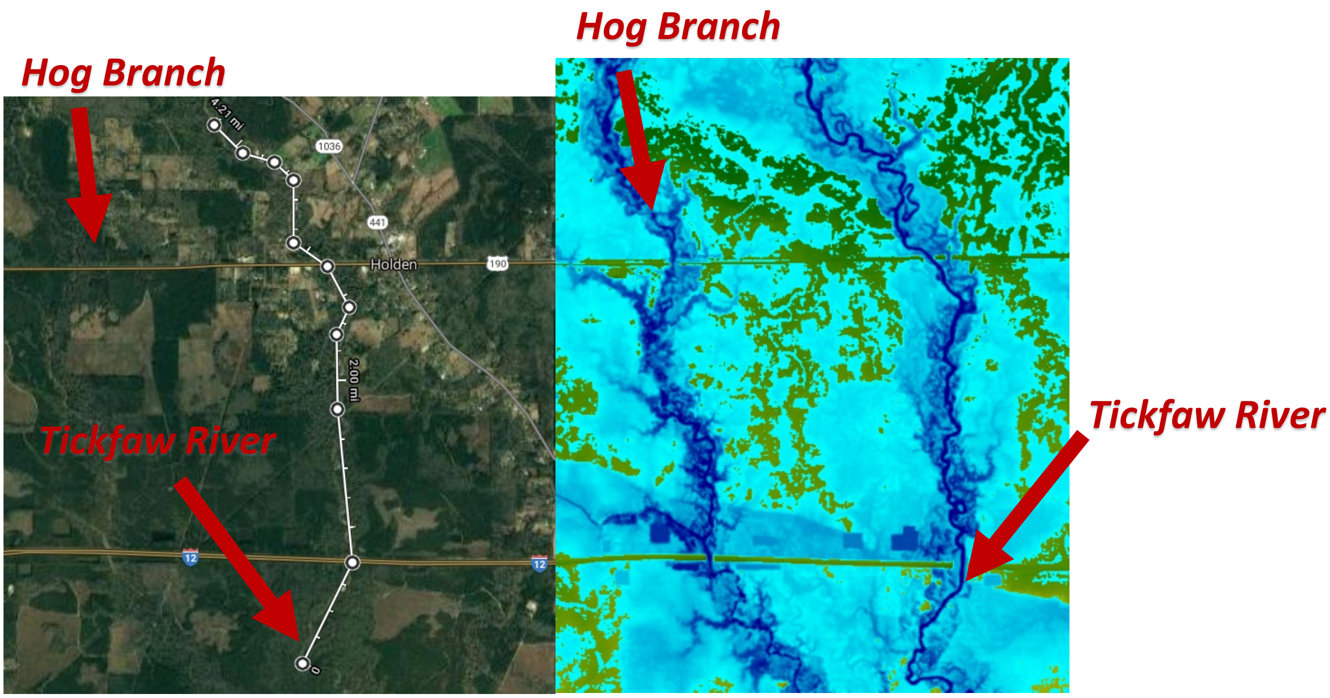

Figure 5: Google maps screenshot and 10 percent annual exceedance probability (AEP) depth grid results for the Tickfaw River at Holden, Louisiana. The Tickfaw River is to the East of the Hog Branch, which is also shown in the inundation.

A relatively short upstream segment was chosen because the Hog Branch and Tickfaw Rivers come close enough that their waters may mix in large floods, complicating modeling. The inundation shown in Figure 5 is for a 10 percent AEP event. Unlike 1-D modeling, in 2-D modeling it is possible that flooding may cross the right- and left-bank boundaries of the model, and appropriate boundary conditions would be set to address this. This will be discussed further in the section “Troubleshooting Rating Curve Discrepancies.”

Creating a New Geometry

Once the study area is defined, the next step is to create a unique geometry for that area. First, turn on the original model geometry and ensure that the break lines are displayed. When tracing the new perimeter, follow break lines as much as possible because they represent where flow would meet a natural divide. To add a new Geometry, in RAS Mapper navigation window, right-click on Geometries, then "Add New Geometry." Name the geometry the same name as the libraries. For example, "Holden" for USGS streamgage 07376000 Tickfaw River at Holden, La (hereinafter referred to as the Holden streamgage). Right click on the new **2D Flow Areas** and select **Edit Geometry (BETA)**. The original geometry may have to be turned back on. Highlight Perimeters and trace the new geometry. Right click on the new perimeter, then select **Edit 2D Area Properties**. Enter the same mesh properties as the original geometry and select **Generate Computation Points** (Figure 6).

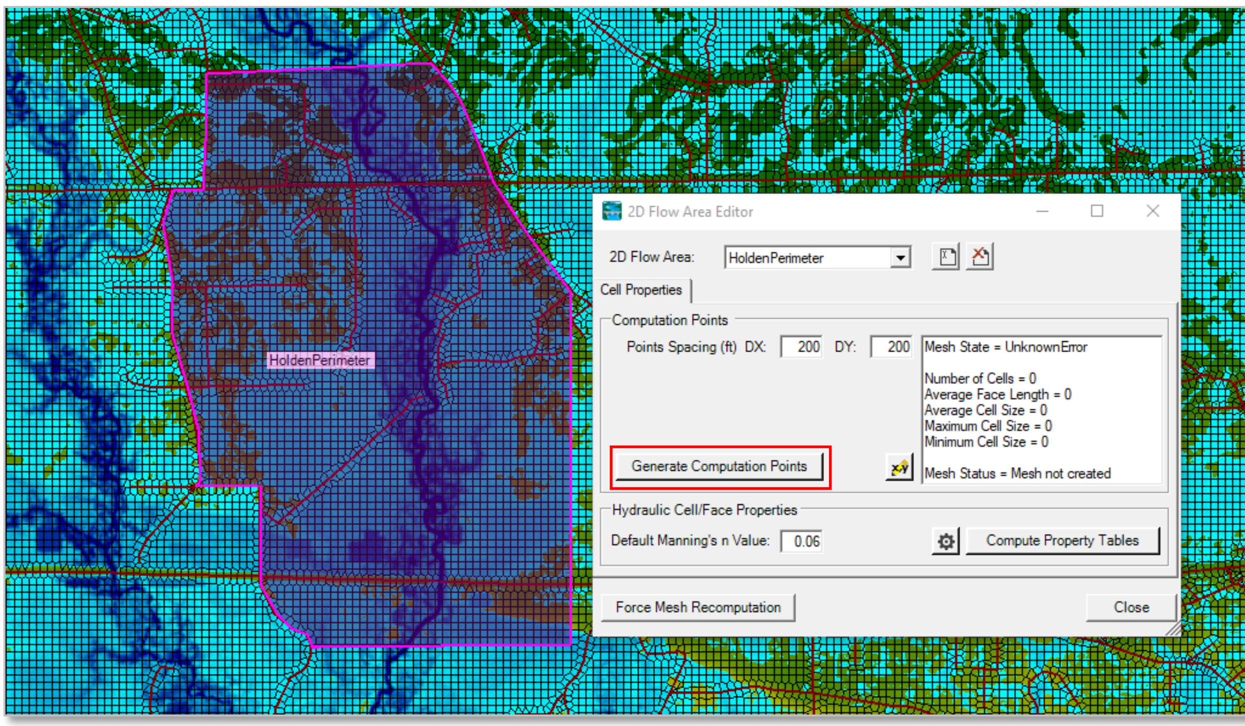

Figure 6: Newly created perimeter laid on top of original mesh geometry as well as the 2D Flow Area Editor dialog box. The generate computation points button is circled in red.

Though the cells will not align perfectly, they would match somewhat between the original and new geometry if the original mesh is traced with the new perimeter. Next, turn on the computation points layer to ensure they were created properly. Any errors with the computation points will be highlighted in red. For more information on errors, see the HEC-RAS documentation (USACE-HEC, 2016).

Next, begin tracing the break lines. Double-click to end each line. It is not necessary to trace the lines at the edge of the perimeter because they will be superseded by the boundary conditions. Keep the default names for each break line, unique names are not needed (Figure 7).

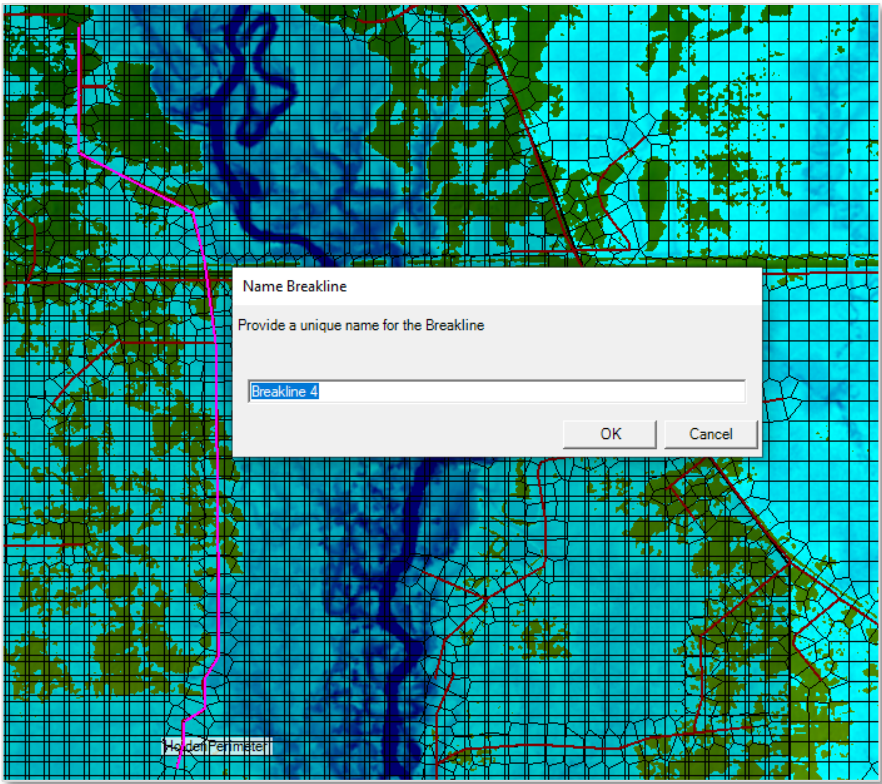

Figure 7: Break line 4 has been traced over an existing break line from the original model.

After creating the break lines, check to ensure that these break lines follow the terrain used in the model. Break lines play a large role in determining how flow moves through the 2D model, and if they are misplaced, they may result in erroneous model results. Break lines may need to be shifted for multiple reasons including erroneous placement in the original BLE model or slight differences in the BLE model's terrain and the terrain used for map library creation. Figure 8 shows an example where a break line would be shifted further east on top of the levee and the noticeable change in results.

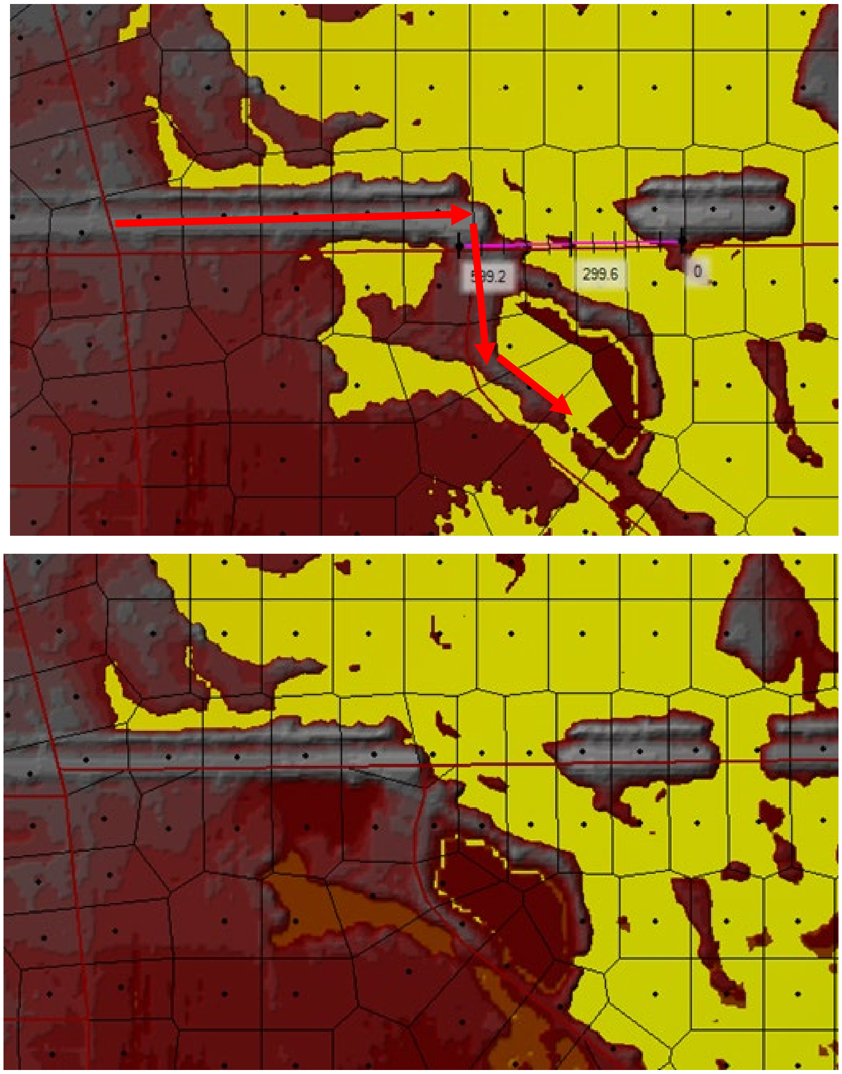

Figure 8: Be sure to check to ensure that the original model's break lines follow the terrain.

After the break lines are created, ensure that the break lines are enforced in the mesh. Right click on **Break Lines**, then select **Enforce All Break Lines** (Figure 9).

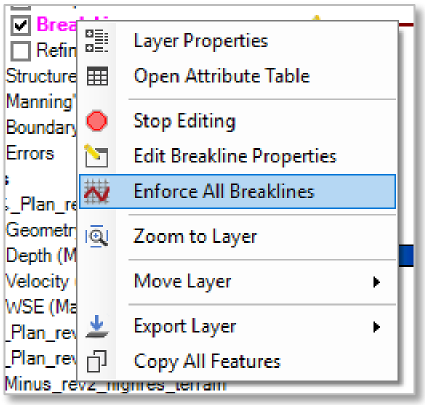

Figure 9: Be sure to enforce the break lines in the computed mesh (The option is only available in the editing mode).

The final and arguably most critical step in geometry creation is setting the boundary conditions. Boundary conditions would be set for all sides of a model where flow may enter or exit. In 2D models, this might encompass the entire perimeter. Additionally, separate boundary conditions would be set for each location in the model at which flow may enter or exit. For example, if there is a small tributary entering the study area, an additional boundary condition would be set specifically for that inflow. Figure 10 shows an example of one such inflow.

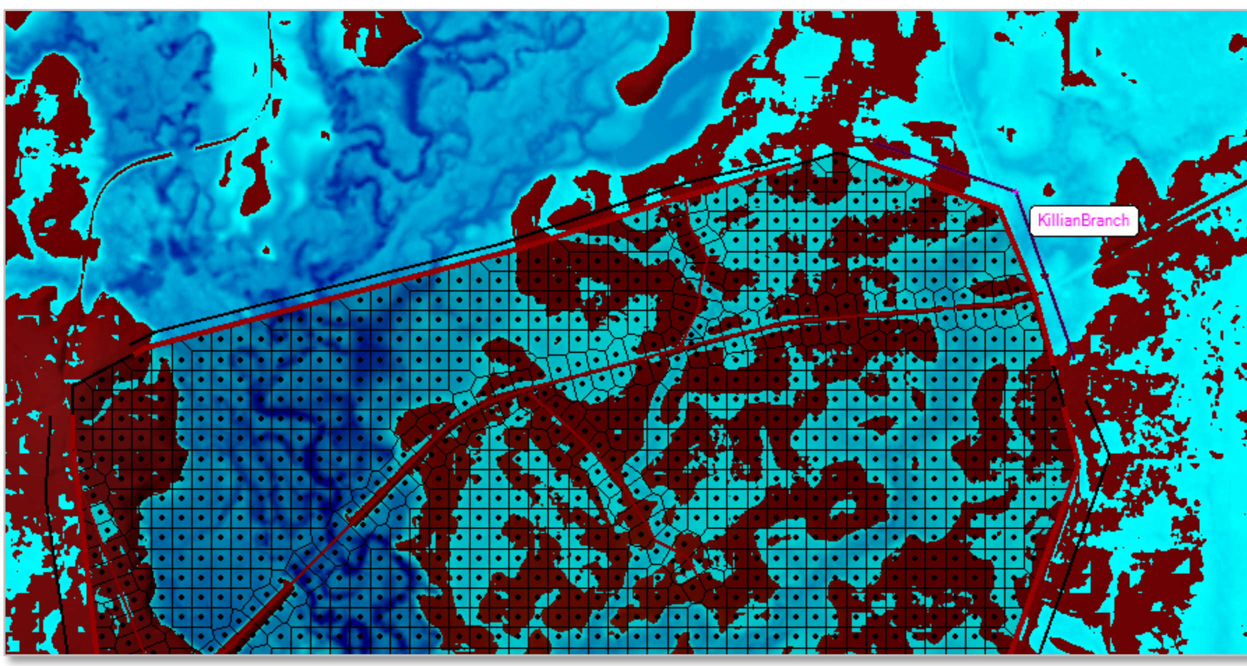

Figure 10: Example boundary conditions for the Tickfaw River at Montpelier, Louisiana. Notice on the right that a separate inflow has been created for the Killian Branch tributary, to ensure flow enters at this location and does not spill out of the model here. Note that flow in the screenshot travels from north (top of image) to south (bottom of image).

For a basic model, four boundary conditions may be created: left-bank, right-bank, inflow, and outflow. The left- and right-bank boundaries may be omitted if flow is not expected to exit at these boundaries. Double-check the original model boundary conditions to ensure that the model mirrors the original BLE model despite the smaller footprint (*for example, do they have just four sides, are there more unique conditions for some of the model sides, and so forth*). Trace these four boundary conditions. Note that only the boundary condition lines are being traced here. The actual boundary conditions are specified later in the Unsteady Flow Data editor window (Figure 16, in section "Creating an Example Flow Profile"). Tracing occurs outside of the model perimeter, and RASMapper will automatically "snap" the line to the nearest mesh grid cell. It is also important to note that boundary conditions may not overlap by sharing mesh grid cells. Once the boundary conditions have been created, ensure that they do not touch the same mesh grid cell (Figure 11).

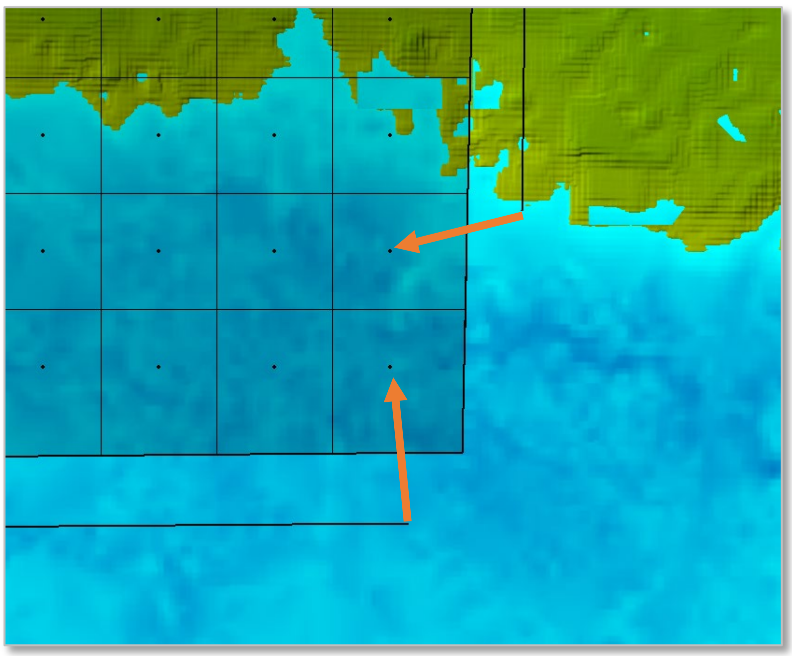

Figure 11: Boundary conditions do not overlap cells here.

After the geometry is created, stop editing and be sure to **SAVE** the changes.

Creating a Terrain for the Geometry

Creating a terrain file for a 2D FDST model is different from a 1D model in that it will now be creating a terrain specific to the geometry after that geometry has been created. It is recommended to create a unique terrain for the unique site geometry because RASMapper will create a spatial domain for the depth grid output that is the size of the entire basin if the original model terrain is used. There is nothing inherently wrong with using a spatial domain that is the size of the entire basin as there is no inundation outside the site geometry, but it makes the file sizes larger than needed and cumbersome for geoprocessing, so it is easier to create a new terrain file.

If the original terrain conforms to the FDST standards of 3-meter resolution or smaller, then the original terrain may simply be clipped to the new geometry using a separate GIS software. The perimeter may then be exported as a shapefile for use as a mask on the terrain raster, just be sure to leave some buffer around the geometry. Many GIS systems have a "Buffer" tool to automatically extend the shapefile with a given buffer. However, if the original terrain does not conform to FDST standards, then new terrain info would be downloaded. In this example for the Tickfaw River Basin, the original terrain has a resolution of 5-meters and new terrain is downloaded from USGS The National Map (TNM) (Louisiana Statewide 1/9 arc-second DEM; 1/9 arc-second is approximately equivalent to 3 meters, and represents the coarsest resolution allowed for the FDST). A screenshot of the final geometry overlain on the terrain is shown in Figure 12.

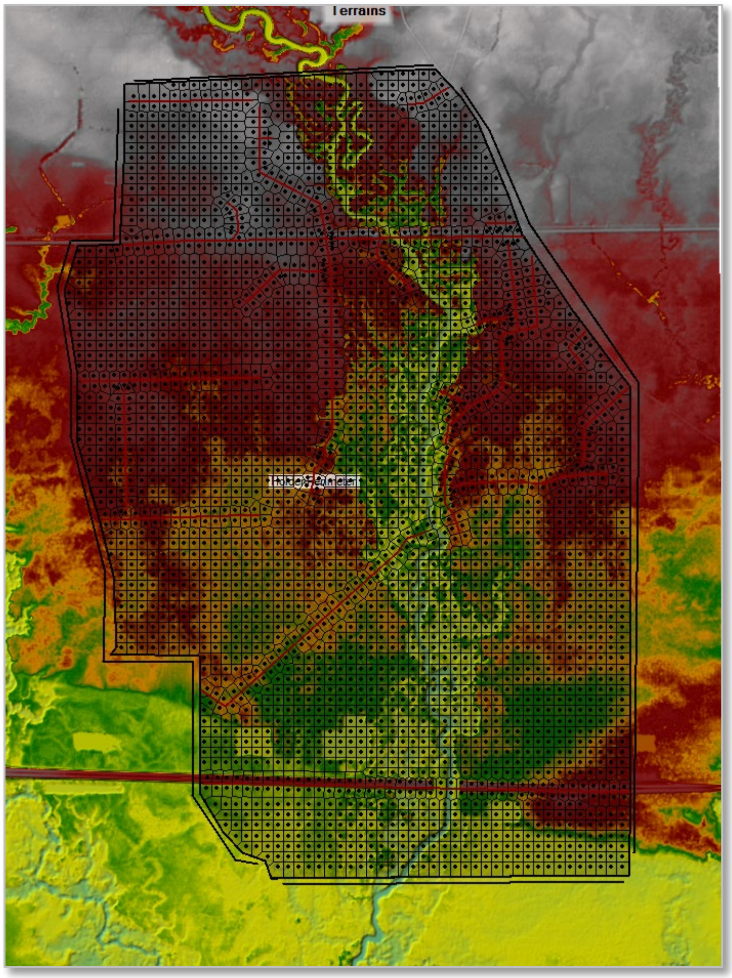

Figure 12: Example terrain and geometry for U.S. Geological Survey streamgage 07376000 Tickfaw River at Holden, Louisiana.

Finally, associate the geometry with the newly created terrain. Right-click on **Geometries**, then select **Manage Terrain Associations**. A dialog box will appear (Figure 13). Select the terrain previously created for the geometry and the **Land Cover** file that is used by the original BLE model. The land cover dataset will assign the Manning's n values to the model according to land use type. Save and exit RASMapper.

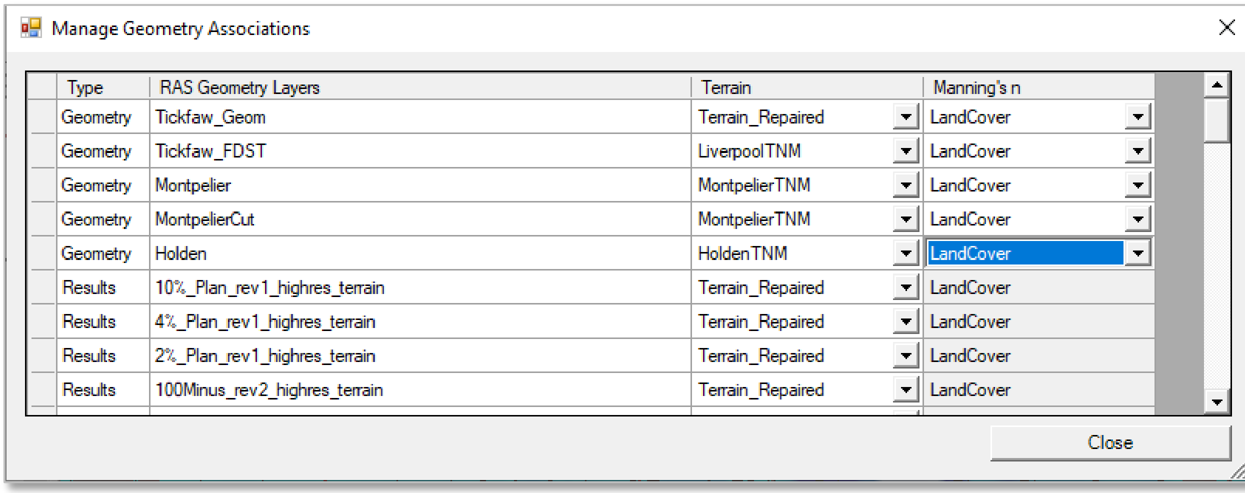

Figure 13: The Holden geometry is set to the Terrain file HoldenTNM and the existing base level engineering land cover file LandCover.

Creating an Example Flow Profile

As mentioned previously, only unsteady state flow simulations will work with 2D models. However, this does not mean simulation of a single flow profile at the gaged location cannot be done. Instead of a more realistic hydrograph, a hydrograph with a single flow value that continues for the duration of the simulation is created. The only difference between this approach and 2D modeling is knowing when in the results that the flow has reached an equilibrium throughout the entire model domain, because the unsteady state flow model is time dependent.

Before creating a new unsteady flow profile, create another calibration excel file as previously done with 1D models (Figure 14). The file will mostly be the same except for one important change.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	No. ordinates	Flow (cfs)	Time	Target				*Profiles*										
2	1	4900	9/1/16 0:00	15				*15*	*15.5*	*16*	*16.5*	*17*	*17.5*	*18*	*18.5*	*19*	*19.5*	*20*
3	2	4900	9/1/2016 1:00	15				**33.65**	**34.15**	**34.65**	**35.15**	**35.65**	**36.15**	**36.65**	**37.15**	**37.65**	**38.15**	**38.65**
4	3	4900	9/1/16 2:00	15				4900	5520	6300	7200	8380	9670	11400	13120	15300	17600	20500
5	4	4900	9/1/2016 3:00	15														
6	5	4900	9/1/16 4:00	15			*Target:*	33.65	34.15	34.65	35.15	35.65	36.15	36.65	37.15	37.65	38.15	38.65
7	6	4900	9/1/2016 5:00	15			*Actual:*	33.64	34.14	34.64	35.14	35.66	36.14	36.66	37.14	37.66	38.15	38.66
8	7	4900	9/1/16 6:00	15			*Difference:*	0.01	0.01	0.01	0.01	-0.01	0.01	-0.01	0.01	-0.01	0	-0.01
9	8	4900	9/1/2016 7:00	15														
10	9	4900	9/1/16 8:00	15														
11	10	4900	9/1/2016 9:00	15		9/1/2016 12:00	15	33.64										
12	11	4900	9/1/16 10:00	15		9/2/2016 0:00	15.5	34.14										
13	12	4900	9/1/2016 11:00	15		9/2/2016 12:00	16	34.64										
14	13	4900	9/1/16 12:00	15		9/3/2016 0:00	16.5	35.14										
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21	20	5520	9/1/2016 19:00	15.5		9/6/2016 12:00	20	38.66										
22	21	5520	9/1/16 20:00	15.5		9/7/2016 0:00	20.5	39.14										
23	22	5520	9/1/2016 21:00	15.5		9/7/2016 12:00	21	39.64										
24	23	5520	9/1/16 22:00	15.5		9/8/2016 0:00	21.5	40.15										
25	24	5520	9/1/2016 23:00	15.5		9/8/2016 12:00	22	40.64										
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27	26	6300	9/2/2016 1:00	16														

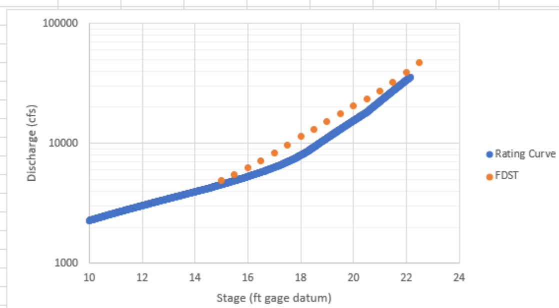

Figure 14: Example calibration file for 2D models. Note the ordinates in column A and model timestep in column C.

In addition to the normal calibration calculations, a timestep flow profile is included. For the initial calibration phase, it is recommended to use a "step-ladder" approach to the unsteady flow profile. Essentially, a flow value is set and kept until stage at the streamgage reaches a steady state, then the flow is increased to the next target (Figure 15). For typical FDST map library extents such as these examples (reach lengths less than 10 miles), a time "step" in the ladder of 12 hours is probably adequate. However, this will vary based on reach length and stream velocity. To check whether the 12-hour duration is adequate at the streamgage, right-click on the map at the gage location and select **Plot Time** Series, then **WSE** for water surface elevation. If 12 hours is an adequate duration for the water surface profile at the streamgage to reach equilibrium, then the water-surface elevation time series plot at the streamgage would have clear “steps” prior to each 12-hour flow change where the water surface stabilizes at a single value (Figure 16). If the 12-hour assumption does not work for the model, the time to reach equilibrium would follow Equation 1:

$$t = \frac{d_L}{v}$$

where t is the time to reach equilibrium, d_L is the longest flow path in the modeled area, and v is the flow velocity. For example, a reach flow path of 4 miles (21,120 ft) divided by a mean channel velocity of 0.66 ft/s equals 8.9 hours (about 32,000 seconds). After an adequate time to equilibrate has been reached, the stage may then be read in RASMapper at the gaged location to calibrate that flow to the desired stage. Ensuring the flood stage has stabilized across the entire study area is addressed in a subsequent section, “Measuring Stage at the Streamgage”.

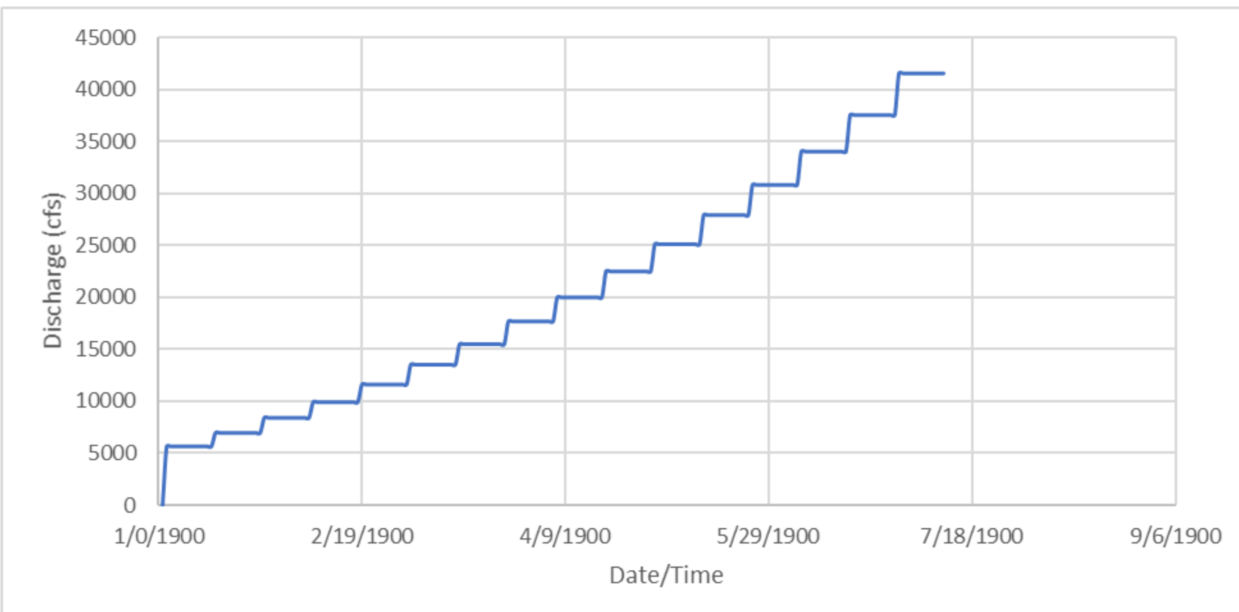

Figure 15: Example “step-ladder” approach to calibrating flows at the 0.5-ft intervals at the gaged location.

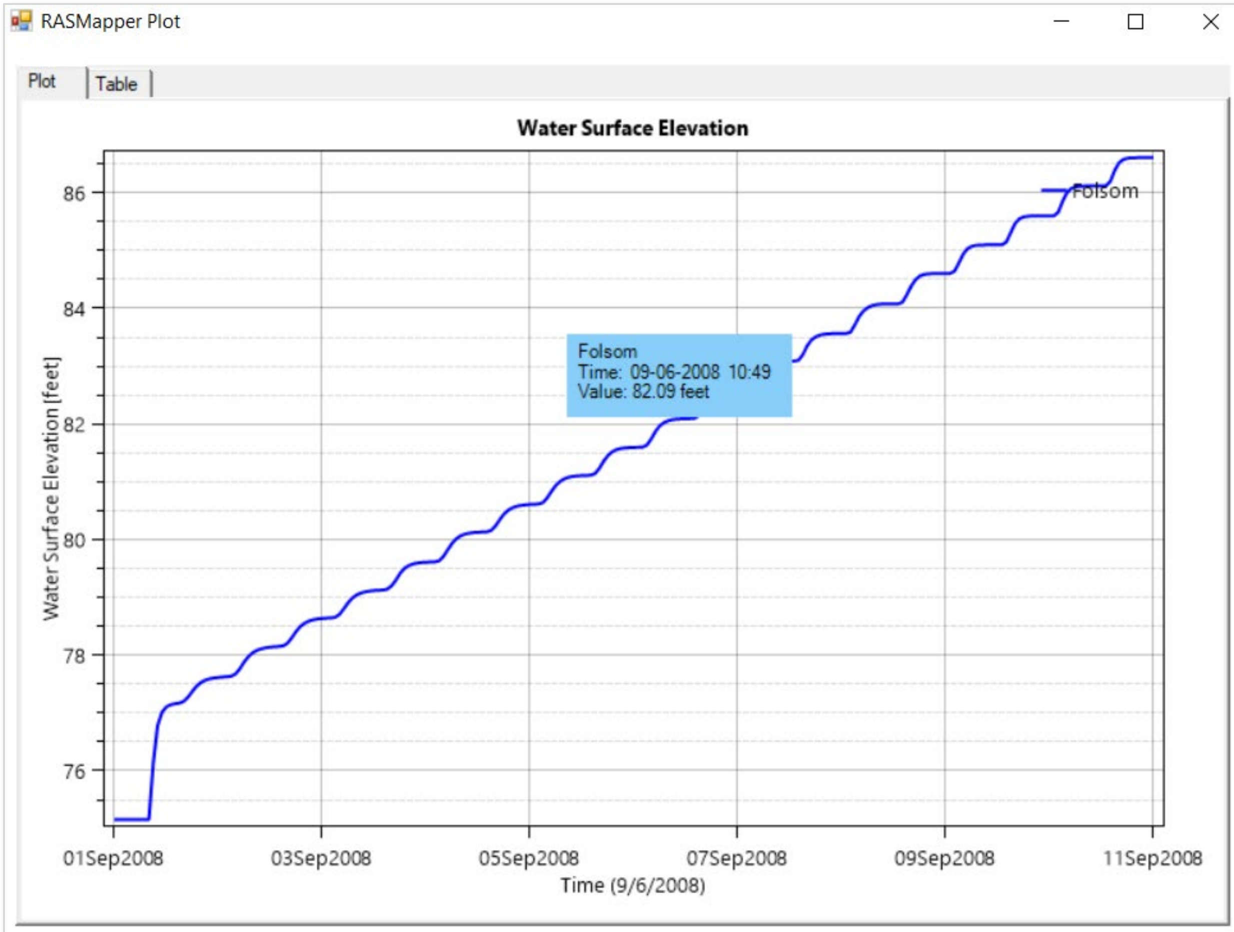

Figure 16: Time series plot of surface water elevation at the mapped streamgage location exhibiting the example "step-ladder" approach to calibrating flows at the 0.5-foot intervals at the gaged location. Notice that water surface elevation values reach a stable value prior to each flow change.

For the example dataset, it was determined that 12 hours was more than adequate to allow stage to reach a steady state at the gaged location. The time needed stage to reach a steady state will vary depending on basin characteristics, distance from inflow to the gaged location, or other hydrologic or hydraulic factors. At this step in the calibration process, it is only important that the water surface elevation has reached equilibrium at the gaged location. In a later section, "Measuring Stage at the Streamgage", an additional check will be performed to ensure that the flow and stage have reached a steady state throughout the modeled area. Note that the unsteady flow profile would follow the same time step as the original plan. For example, if the original BLE plan had a time step of 1 hour, then the unsteady calibration and final result profiles would have time steps of 1 hour as well.

Next, create this “step-ladder” calibration file in HEC-RAS. First, open the newly created geometry file in the **Geometric Data** editor in the main HEC-RAS window. This will ensure that when a new unsteady flow profile is created, it is assigned to the new geometry. Next, open the **Unsteady Flow Data** editor. Note that the newly created boundary conditions are listed in the table at the bottom of the window. For all boundary conditions except the inflow, use the same boundary conditions that were used in the initial model. For this model, the boundaries running parallel to the flow of the basin (East and West) were set to a **Normal Depth** of 0.003, and the outflow (South) was set to a **Normal Depth** of 0.001 (Figure 17).

At this point, the modeler would consider whether the original model’s boundary conditions are appropriate for the clipped FDST geometry. Where is the FDST model located? Do the parallel boundary conditions make sense in regard to the BLE model’s parallel boundary conditions, which may include more than one boundary per side? Furthermore, the inflow and outflow boundaries would also be considered. If the BLE geometry outflow is located at the coast and the FDST geometry terminates far upstream and up-gradient of that, then its outflow boundary condition may need to be adjusted. Likewise, if a BLE geometry inflow is up-gradient of the coast in hilly terrain, and the FDST geometry is entirely located in a flat, coastal environment, then the inflow boundary may need to be adjusted. Ultimately, there is more leeway to adjust a 2D model than a 1D model because of this practice of “clipping” the model to a smaller study area, which may have unique terrain properties from the larger BLE model. Another technique that may be attempted to lessen the effects of the Outflow boundary is to move the boundary further downstream from the end of the study area. The benefit is that the further this boundary is moved downstream, the less influence it has on the model. The downside is that moving the boundary far from the study area his will lead to an increased computation time for each 0.5- ft interval computed for the FDST.

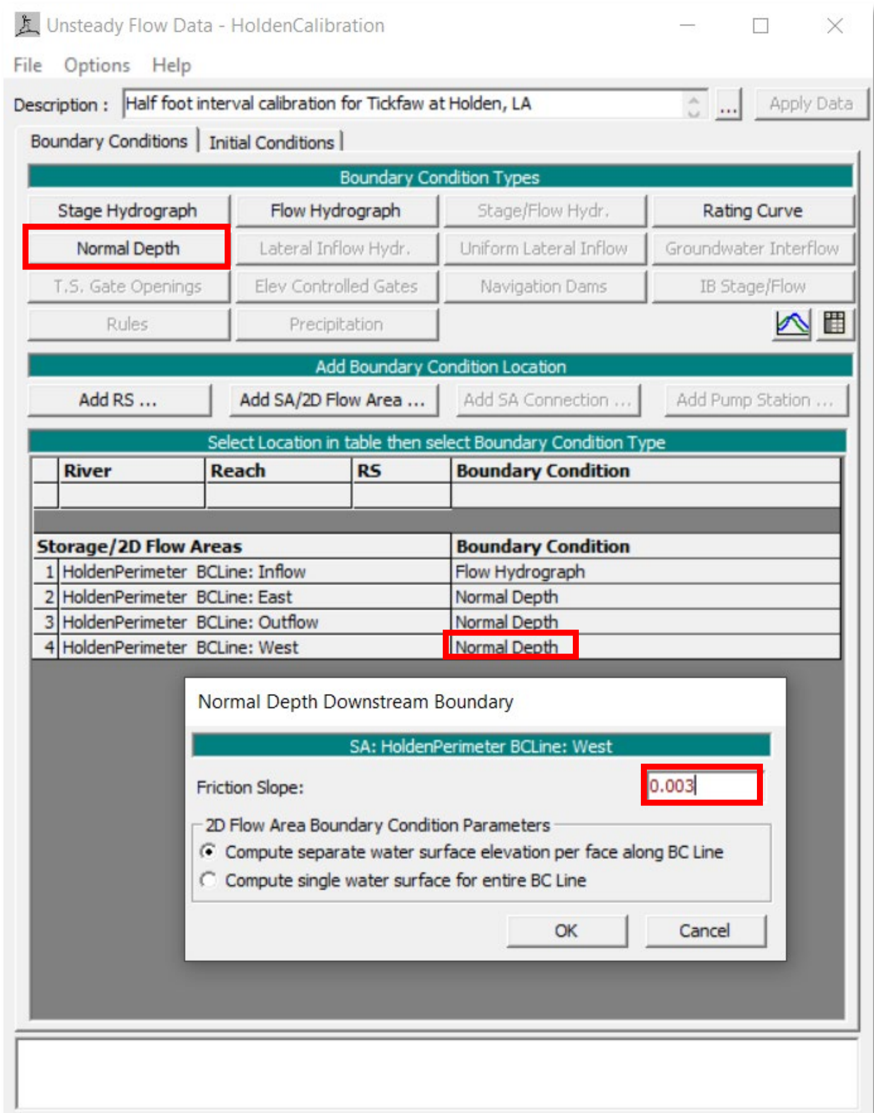

Figure 17: Set the boundary conditions for each boundary according to the initial BLE model except for the inflow. Here boundary conditions are set to a normal depth.

Next, select the inflow boundary and select **Flow Hydrograph** to begin entering the "step-ladder" calibration flow. The **Data time interval** is set to 1 hour in this example because that is the same time step as the initial model. This may differ depending on the model used, and it is recommended to use the same model timestep for FDST calibration as was used in the original BLE model. Also keep the radial button next to **Use Simulation Time** checked. If the example 2D calibration file provided above has been followed, then the list of ordinates, flow, time, and target on the left will provide the number of ordinates needed for the calibration profile (Figure 14). Select **No. Ordinates** and enter the number of ordinates from the Excel calibration file (Figure 18).

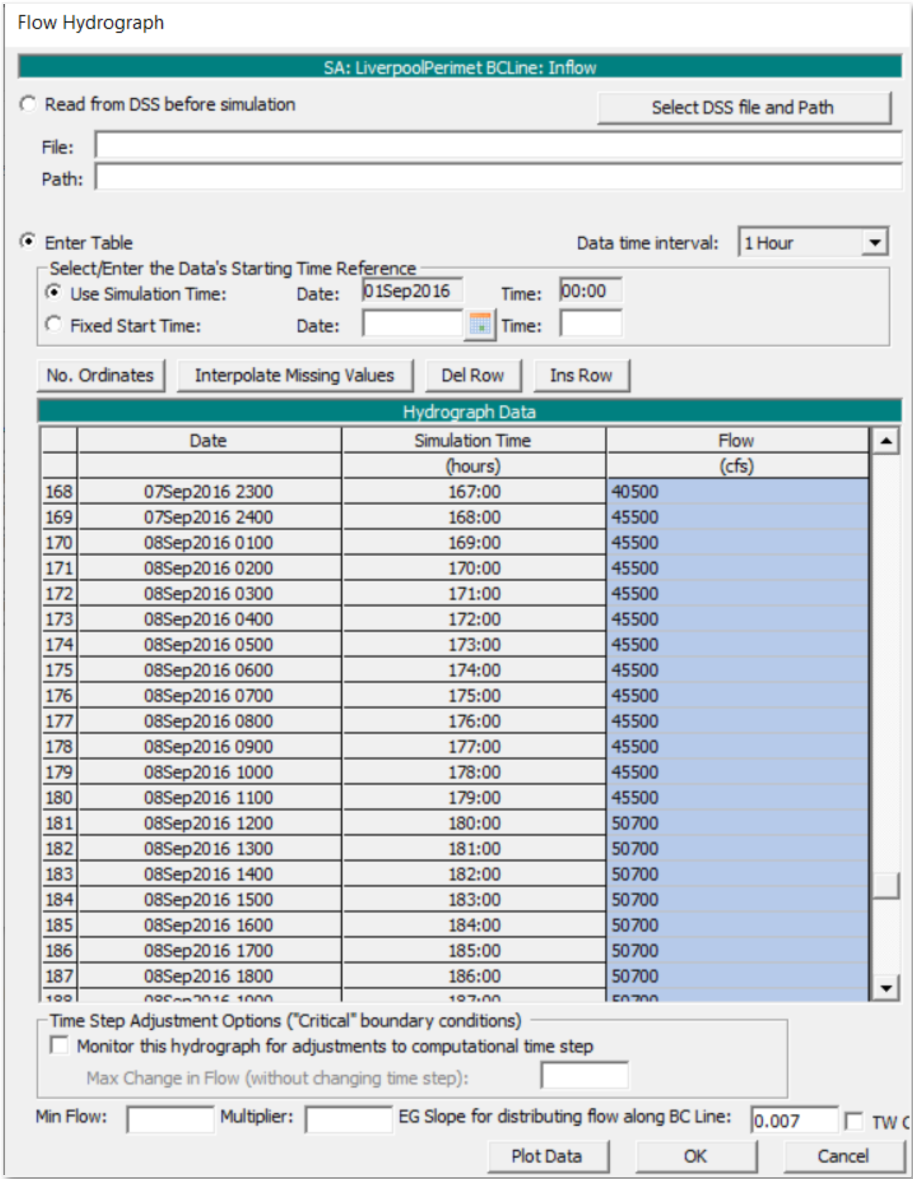

Figure 18: Flow Hydrograph parameter setup for the initial "step-ladder" calibration unsteady flow profile.

Then, enter the flow from the calibration spreadsheet that would be in the correct format on the left.

Finally, enter an **EG Slope for distributing flow along BC Line** that is the same as the parameter for the original BLE data. Save the unsteady flow data.

Create an Unsteady Plan for Calibration

Open the **Unsteady Flow Analysis** editor in HEC-RAS and create a new plan. Set the **Geometry File** to the newly created geometry file and the **Unsteady Flow File** to the file created in the last section. In **Programs to Run**, select **Geometry Preprocessor**, **Unsteady Flow Simulation**, and **Post Processor**. For the **Starting Date** and **Starting Time**, use the date and time from the original model. For the **Ending Date** and **Ending Time**, consult the Excel spreadsheet which will have the last time step listed. Ensure that the ending time matches, otherwise the model will not run. Also visually check the last simulation time in the flow hydrograph to ensure values were entered correctly (Figure 18). Do not change the **Computation Settings** and confirm that the settings are the same as in the original BLE model plans (Figure 19).

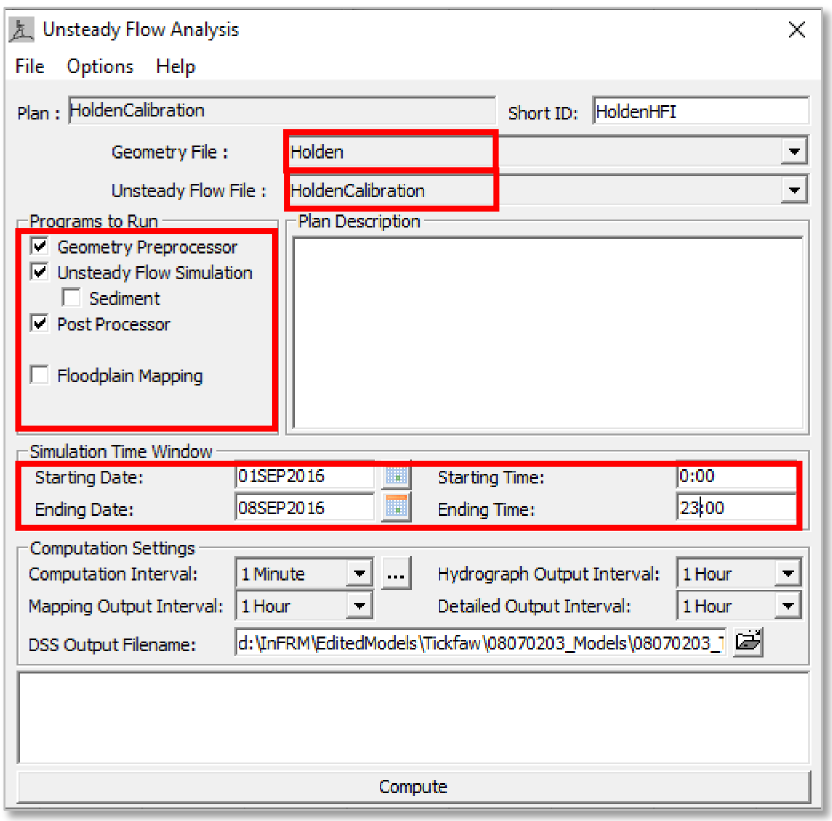

Figure 19: Example unsteady flow analysis with all parameters filled out. Note highlighted areas requiring entry.

Save the plan and compute.

Measuring the Stage at the Streamgage

Open RASMapper, right click on the plan modeled under Results, then select **Manage Results Maps**. Add an entry for water surface elevation for each of the times in the Excel calibration spreadsheet that correspond to when the stage has settled at the gaged location, or the last time associated with each depth. For example, the Holden streamgage reaches a steady state at the streamgage in 12 hours, and the simulation time starts at 0:00, so final intervals will be at the 12th and 24th (00:00) hour of each day (Figure 20). Select **Add New Map**, make sure **Water Surface Elevation** is highlighted, and select the required profile time. Ensure the dialog box matches Figure 19 and repeat for each 0.5-ft interval.

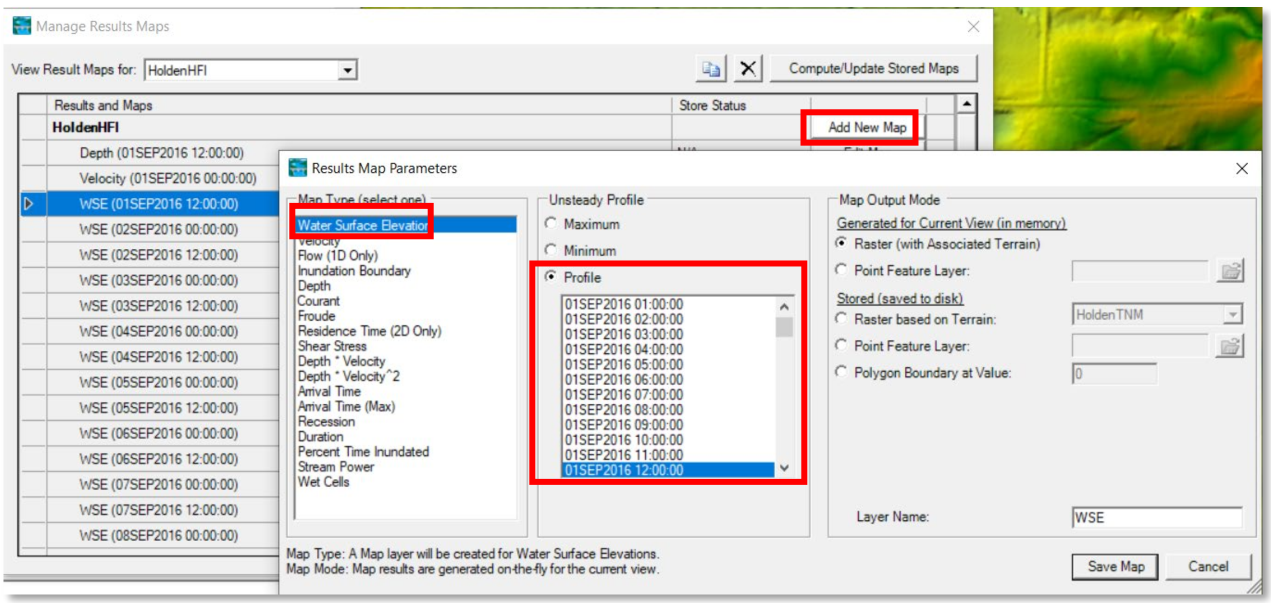

Figure 20: Result map properties dialog box for the calibration phase of 2D modeling.

Before measuring the water surface elevation, check to ensure that a steady state condition of the water surface elevation has been reached at the gaged location. Turn on one of the water surface elevation results layers. Right-click on the grid cell just downstream from the gaged location in the main channel, then, under **All Enabled Results** select **Plot Time Series** and then select **WSE** for water surface elevation. Ensure that water surface has reached a steady state at each step in the "step-ladder" before moving on (Figure 21). If the water surface has not reached a steady state at each step in the "step-ladder," the flow profile may need to be adjusted to ensure that the flow persists long enough to reach steady state. Not reaching steady state is most common in the first profile, which starts with an empty basin, so it may need longer time to reach steady state. Alternatively, in the unsteady flow editor, an initial elevation for the 2D model can be set, resulting in less time needed to add water during the model run.

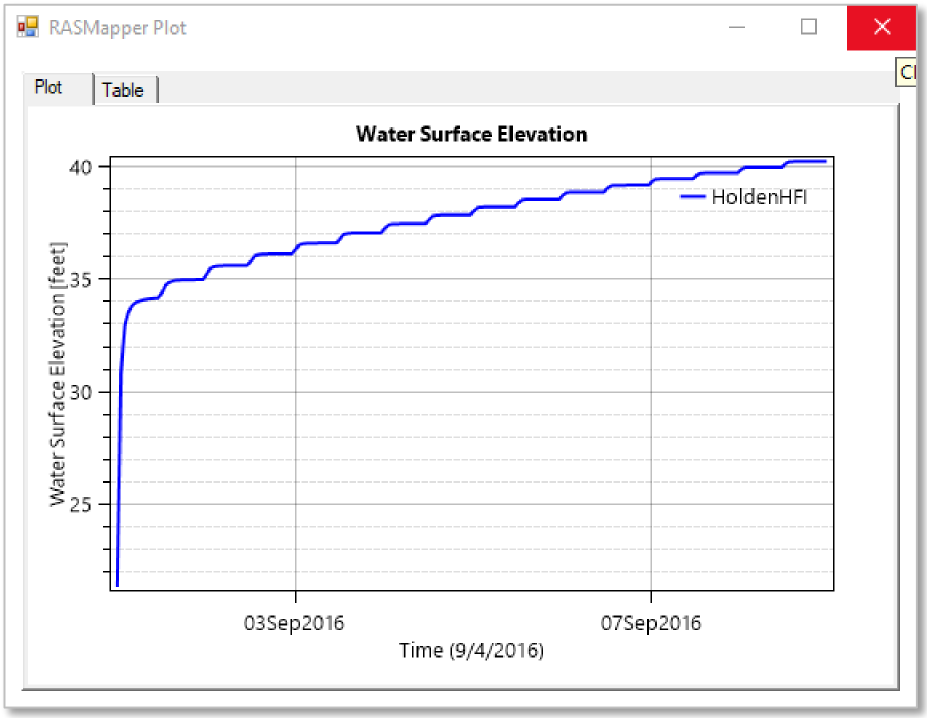

Figure 21: Time series plot of water surface elevation at a point near the gaged location.

The next step is to determine where to measure the water-surface elevation for the gaged location. In 1D modeling, this is simply the cross-section closest to the location of the streamgage, and on the downstream side of the bridge if located on a bridge. In 1D modeling, that cross-section has a single water surface elevation. Conversely, in 2D modeling not only does the water surface elevation change in time and river stationing, but also horizontally across the river's surface. In the bottom of the left-hand dialog box of RASMapper, select to view **Profile Lines**. The dialog box may have to be opened as it defaults to closed (Figure 22).

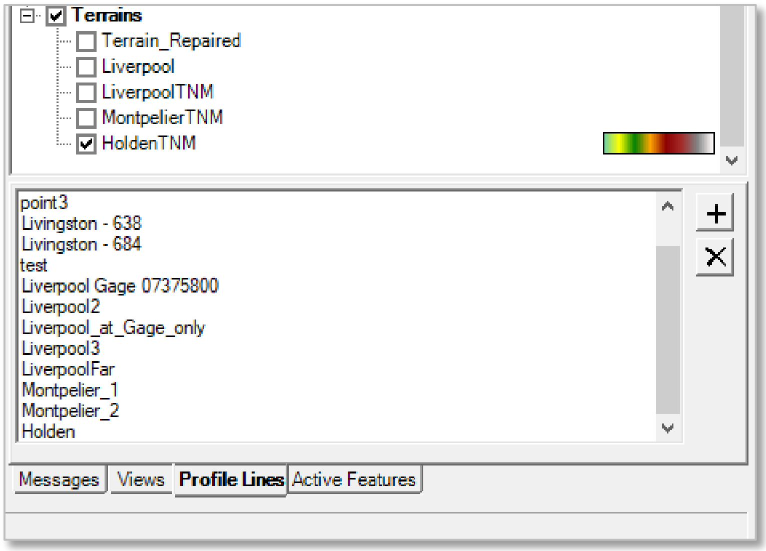

Figure 22: The dialog box at the bottom of the left-hand side of the RASMapper main menu. It may have to be opened by dragging the top of the window up as it defaults to closed.

Click the plus button to add a new profile line. Draw a profile line at the gaged location just downstream from the bridge, ensuring that the profile line is perpendicular to the stream channel (Figure 23). Draw the line from the left bank to right bank when looking downstream. Double-click to complete the line and name it.

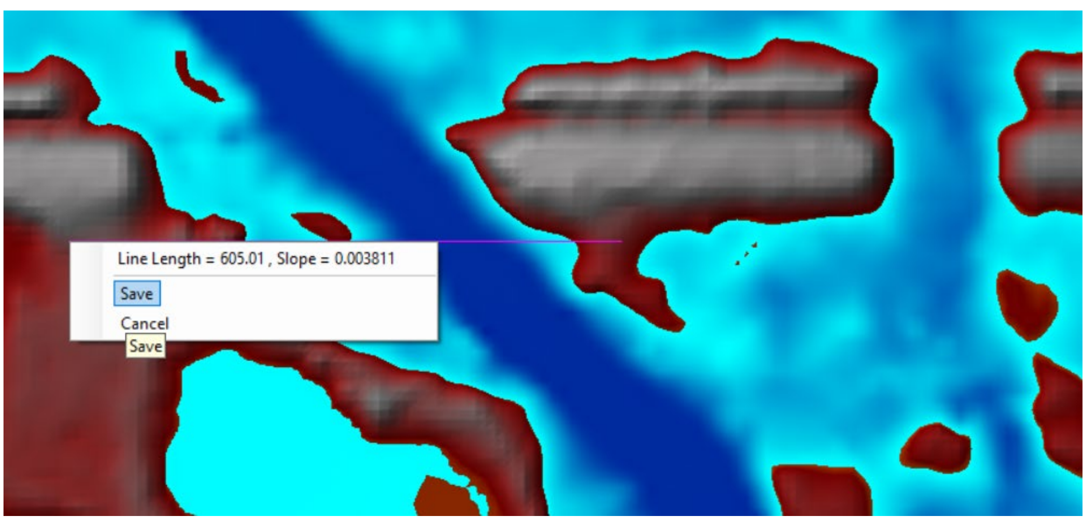

Figure 23: Profile line drawn on the downstream side of a bridge for Tickfaw River at USGS streamgage 07376000 Tickfaw River at Holden, Louisiana.

Turn on the first water surface elevation profile in the results layer. Then, in the **Profile Lines** dialog box, right click on the newly created profile line and select **Plot Profile** then **WSE** for water surface elevation (Figure 24).

Water-surface elevation can be determined by either moving the mouse across the profile line or by selecting to view the table of values. Set the water-surface elevation value as the maximum water surface value for that profile unless the profile only reaches that water surface value for a point or two. For example, in Figure 24 the water surface elevation reaches 34.19 feet. However, this value is only listed for one or two points on the one side of the channel, and the remainder of the profile is listed at 34.18 feet. Therefore, the water surface elevation for this profile is 34.18 feet above the North American Vertical Datum of 1988 (NAVD 88).

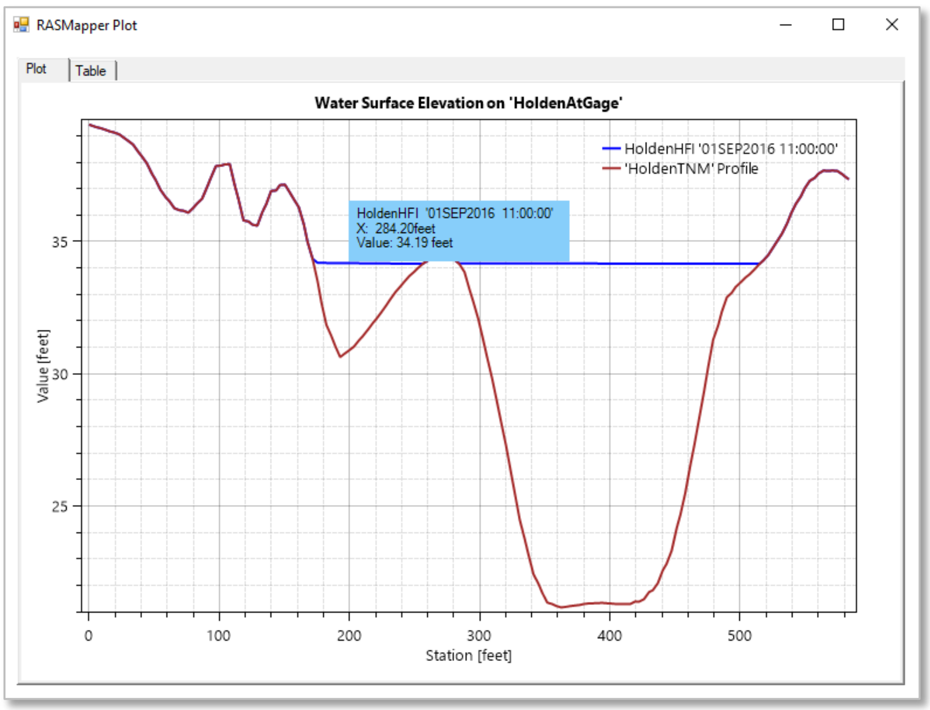

Figure 24: Water surface elevation profile for U.S. Geological Survey streamgage 07376000 Tickfaw River at Holden, Louisiana. Move the mouse over the profile line to view the elevation.

Enter this value into the calibration spreadsheet and repeat for each target water surface elevation. The remainder of the calibration remains the same as 1D modeling. The target is still +/- 0.1 feet from the target water surface elevation. Please refer to the InFRM Executive Summary and Submittal Guidance for details on calculated water surface elevations (InFRM, 2022). Update the flows in the calibration spreadsheet, copy to the unsteady calibration file, and repeat until the target is reached.

Troubleshooting Rating Curve Discrepancies

If the modeled FDST results are not matching the rating curve well, boundary conditions may need to be revisited. A common issue encountered with 2D modeling in flat floodplains is FDST results in which more flow is required in the 2D model than is specified in the rating curve. See the plot in Figure 14 for an example of what this might look like. If water extends beyond the cross-sections in a 1D model, the water outside of the main channel still contributes to the total conveyance of the cross-section which makes the water surface elevation of the cross-section to be artificially higher than it would be in reality. In a 2D model, however, the model edges are boundary conditions where flow can exit the model, and flow that extends all the way across the model may be artificially lower than it is in reality. If this is the case, then it may be necessary to check the boundary conditions at the site.

A prime suspect of water loss from an incorrect location in the model is at the intersection of tributaries with the model perimeter. If, as described in the above paragraph, a greater flow is required to reach a given stage than what is presented in the rating curve, check to make sure there is not a **Normal Depth** boundary condition at a tributary. In the example site in Figure 25, two tributaries enter the Tickfaw River in the study area upstream from the streamgage. An **Inflow** boundary condition would be set for each inflow to ensure water enters the system here and is not lost. In the example, inflow was set at both the Twelvemile Creek and Killian Branch tributaries. However, in this case Twelvemile Creek is a major tributary, and the complexities of flow could not adequately be modeled in relation to the Tickfaw River inflow. Therefore, the upstream boundary was moved further downstream to what can be viewed in Figure 10, and the only tributary inflow set was for the Killian Branch. This means that the flows from Twelvemile Creek and the Tickfaw River are now combined in a new Flow Hydrograph boundary downstream from the junction of the two streams.

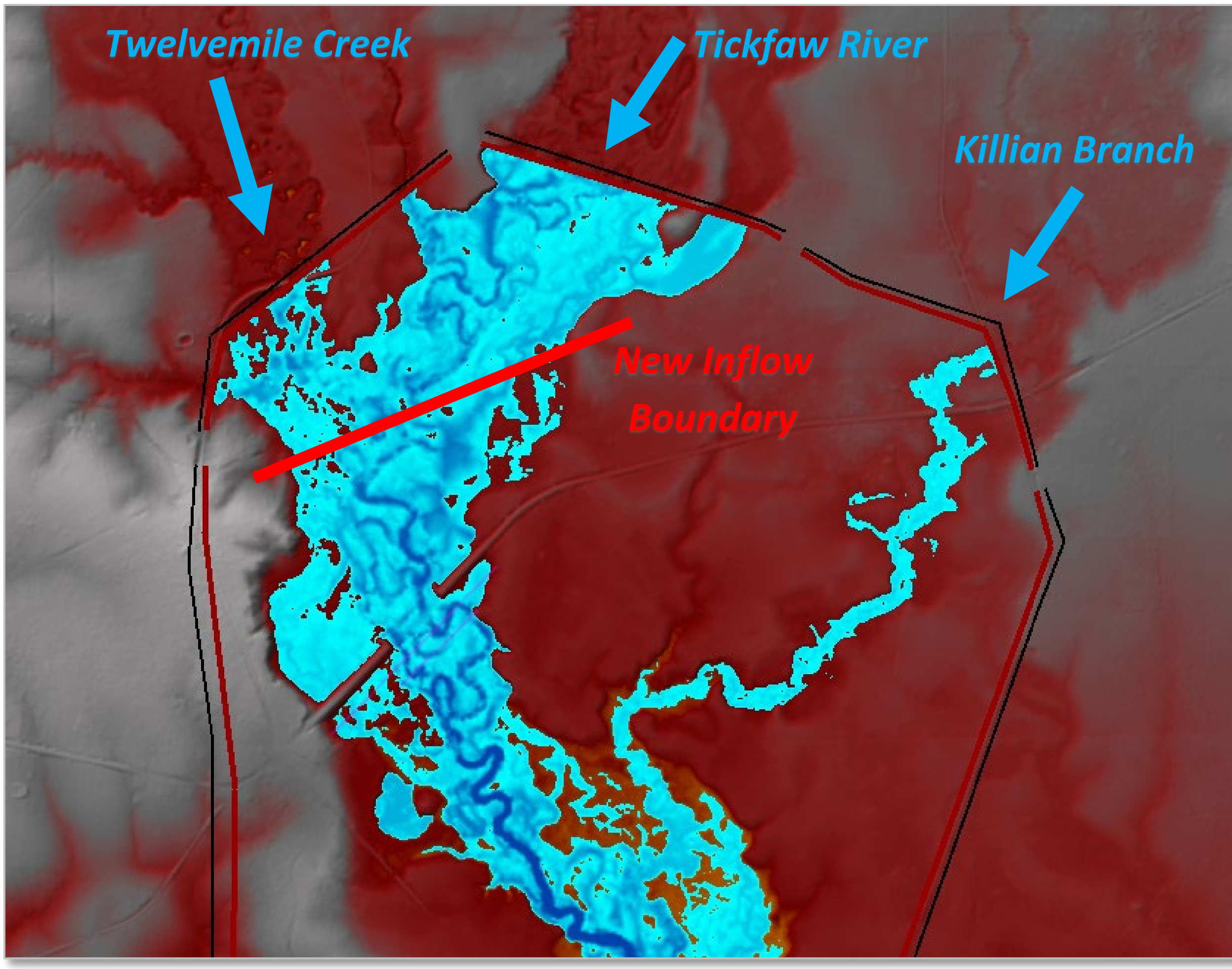

Figure 25: Example reach at U.S. Geological Survey streamgage 07375960 Tickfaw River at Montpelier, Louisiana. Note the new inflow boundary condition downstream from the junction of Twelvemile Creek and the Tickfaw River.

Another scenario that may be encountered with a 2D modeled floodplain is where the entire basin is inundated and flow spills out the sides of the model (Figure 26). At this point, there are two options. The first is to change the boundary conditions to **Flow Hydrograph** and set a small inflow value to ensure that water does not exit the basin if known flooding is occurring outside the basin as well. This would only be done if it is certain that a limited amount or no flow at all is leaving the modeled area. For example, if the adjoining basin is experiencing similar flooding, then the floodwaters would be mixing at the boundary of the two basins rather than simply spilling out of one basin into the other. Simply removing the boundary condition would be another alternative. The second option is to stop mapping once the basin is essentially fully inundated. The purpose of the FDST is to map where inundation is occurring, and once all of the basin is fully inundated, including major roads and structures, then it is known that any additional stage beyond what has been mapped will only add further depth to the water rather than add to the inundation extent. Furthermore, modeling a specific location is no longer feasible in areas where major floods cross river basins and becomes more of a regional flooding issue rather than a site-specific flooding issue. At this point, it would be prudent to end the map library at the stage at which this occurs.

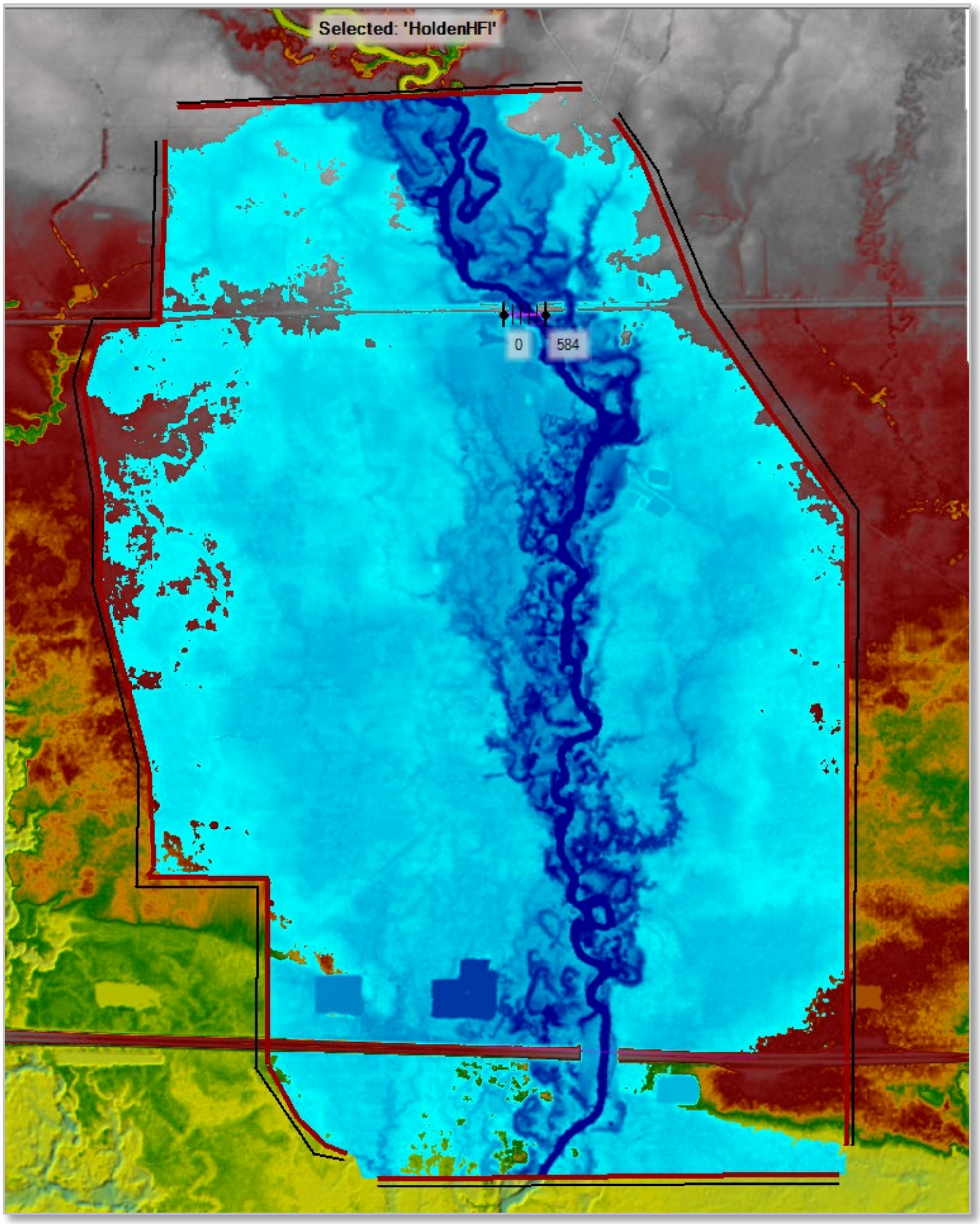

Figure 26: An example depth grid where inundation extends across nearly the entire study area.

Creating Depth Grids for Export

Now that flows associated with each 0.5-ft interval stage at the streamgage have been determined, the flood maps associated with each interval can be created. As noted previously, 2D models are time-dependent, and although flow may have reached a steady state at the gaged location, that does not mean that flows have reached a steady state throughout the entire modeled reach. Therefore, a new plan for each interval with a longer time step would be created to ensure that flows have reached this steady state throughout the entire model.

In the main HEC-RAS window, open the **Unsteady Flow Data** editor and create a new unsteady flow data file. Save it as the first target elevation. For example, **Holden_337** for 33.65 feet above NAVD 88 at the Holden, Louisiana streamgage location. Set the boundary conditions to the same as the "step-ladder" calibration model. All parameters would be the same except for the time frame for the **Flow Hydrograph** which will be edited such that it lasts long enough for the entire basin to reach a steady state. A 100-ordinate (100 hour) timeframe was adequate for the example location on the Tickfaw River at Holden. For the Flow Hydrograph, set all values to the calibrated flow for the target stage (Figure 27).

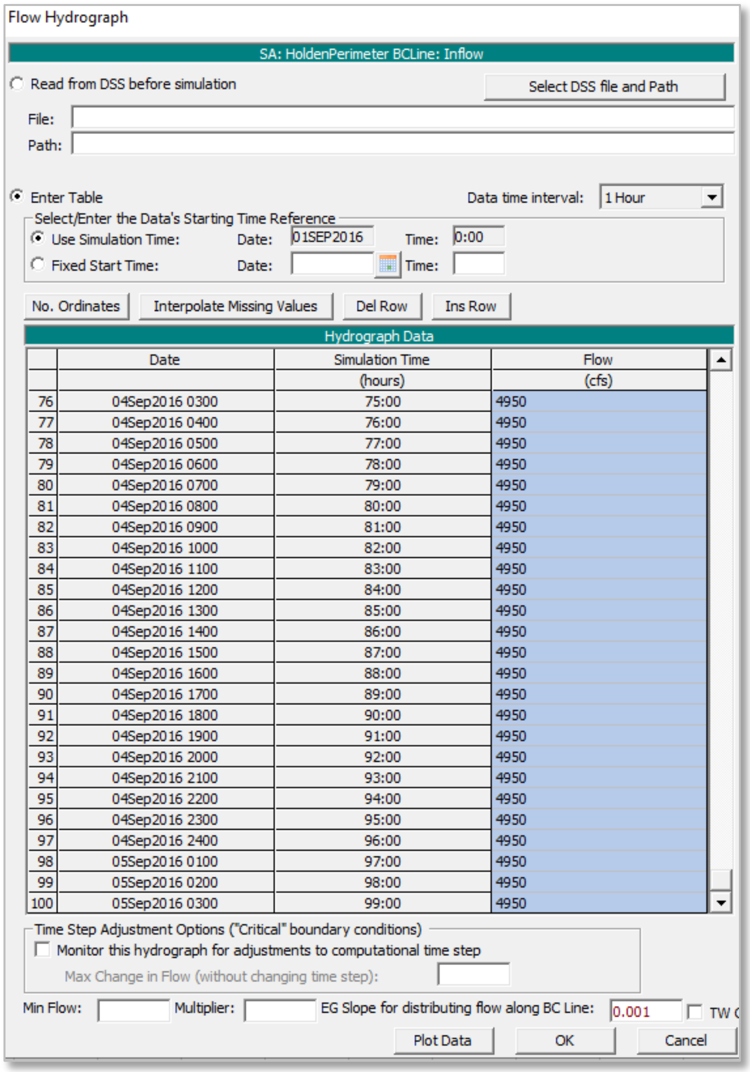

Figure 27: Example final flow hydrograph for depth grid creation.

Repeat this process for each target stage by selecting **File** then **Save As** and saving the previous work as a template for the next stage. Next, a plan for each one of these flow profiles will be developed. Open the **Unsteady Flow Analysis** editor in the main HEC-RAS window and create a new plan. Save it with the same name as the unsteady flow profile. Enter the target stage for the **shortID**, for example, **337**. Next, ensure that the correct **Geometry File** is being used, the **Unsteady Flow File** for the target stage is selected, and that **Geometry Preprocessor**, **Unsteady Flow Simulation**, and **Post Processor** are all checked under **Programs to Run**. In the simulation time window, enter the starting and ending dates and times from the unsteady flow data. And lastly, ensure that the computation settings are set to the same as they were in the original BLE model (Figure 28).

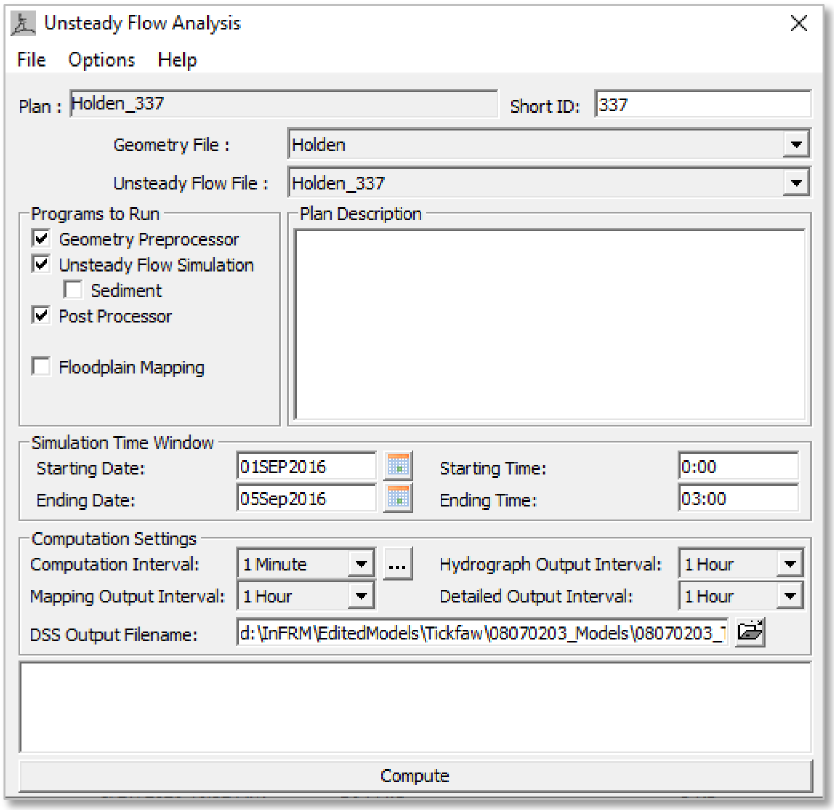

Figure 28: Example Unsteady Flow Analysis plan for final depth grid creation for target stage 33.65 feet above the North American Vertical Datum of 1988 at U.S. Geological Survey streamgage 07376000 Tickfaw River at Holden, Louisiana.

Compute this first plan to ensure the plan has been set up properly, then repeat this process for each target stage, using the **File**… **Save As** process to use the previous plan as a template for the next. Run each of the plans that were created then open RASMapper.

In RASMapper, right-click on the **Results** layer, then select **Manage Results Maps**. Scroll down to the plans created for the 0.5-ft intervals. Each plan would be pre-populated with **Depth (max)**, **Velocity (max)**, and **WSE (max)**. The **max** refers to the maximum value the layer has obtained during the plan. Before continuing to the next step, it would be prudent to ensure that each of the **WSE (max)** layers retains the same stage at the streamgage as the “step-ladder” calibration file and that the flow has reached a steady-state throughout the entire study area.

After performing these last checks, for each **Depth (max)** layer in each of the 0.5-ft interval plans, select **Edit Map**. In the **Results Map Parameters** dialog box, change the **Map Output Mode** to **Raster based on Terrain** and ensure that the terrain is set correctly (Figure 29).

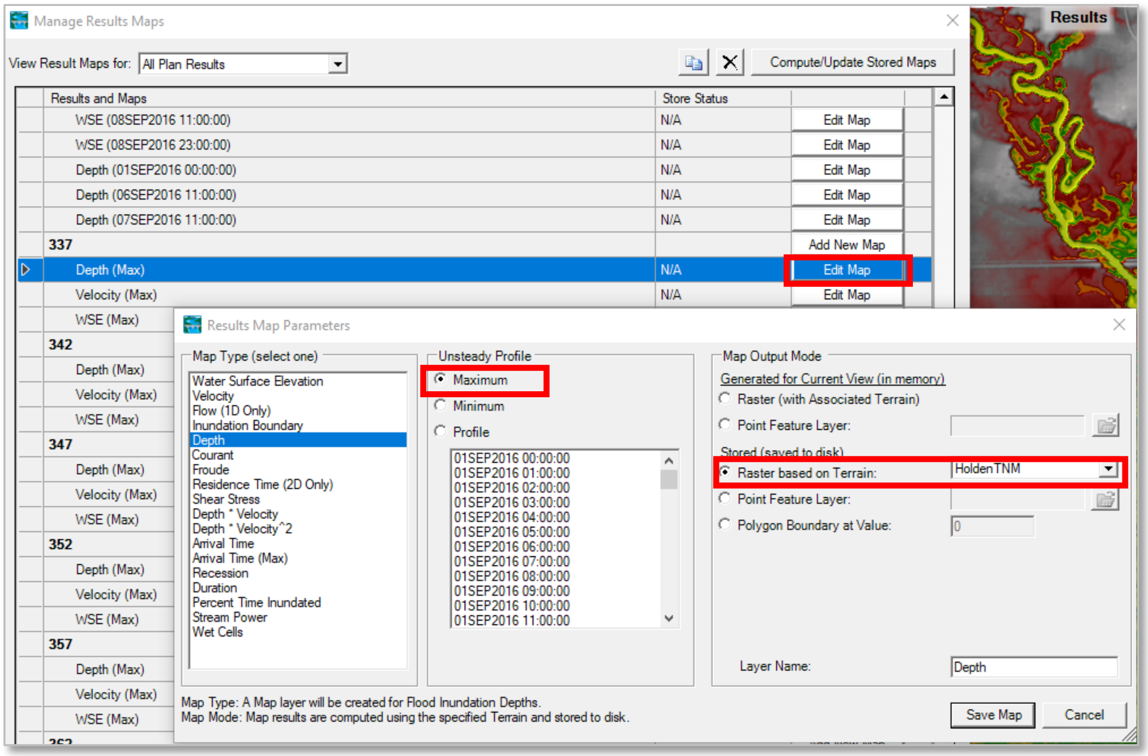

Figure 29: Manage Results Maps and Results Map Parameters dialog boxes with parameters set for FDST 0.5-ft interval depth grid creation.

Once parameters have been updated for all plans, the **Store Status** in the **Manage Results Maps** window will change to **Map not created**. Ctrl-select each of these maps, then select **Compute/Update Stored Maps** to generate the depth grids on the computer.

Depth Grid Geoprocessing

Depth grid geoprocessing for libraries created from 2D models at this point follows the exact same process as 1D models (InFRM, 2022). There is only one minor difference. Because there are no cross sections, the study extent will be built from the 2D Flow Area **Perimeters**. Use the perimeter exported in the **Creating a Terrain for the Geometry** section and create a new polyline feature using the **Draw Feature** functionality in ArcMap to trace the edges of the perimeter. After converting the drawn lines to a feature, be sure to edit the feature and snap it to the perimeter sides so that the extent follows the perimeter exactly. This is much more important in 2D models where the flow may reach all the way to the edge of the study extent. The study extent for the Tickfaw River at Holden, Louisiana example is shown in Figure 30.

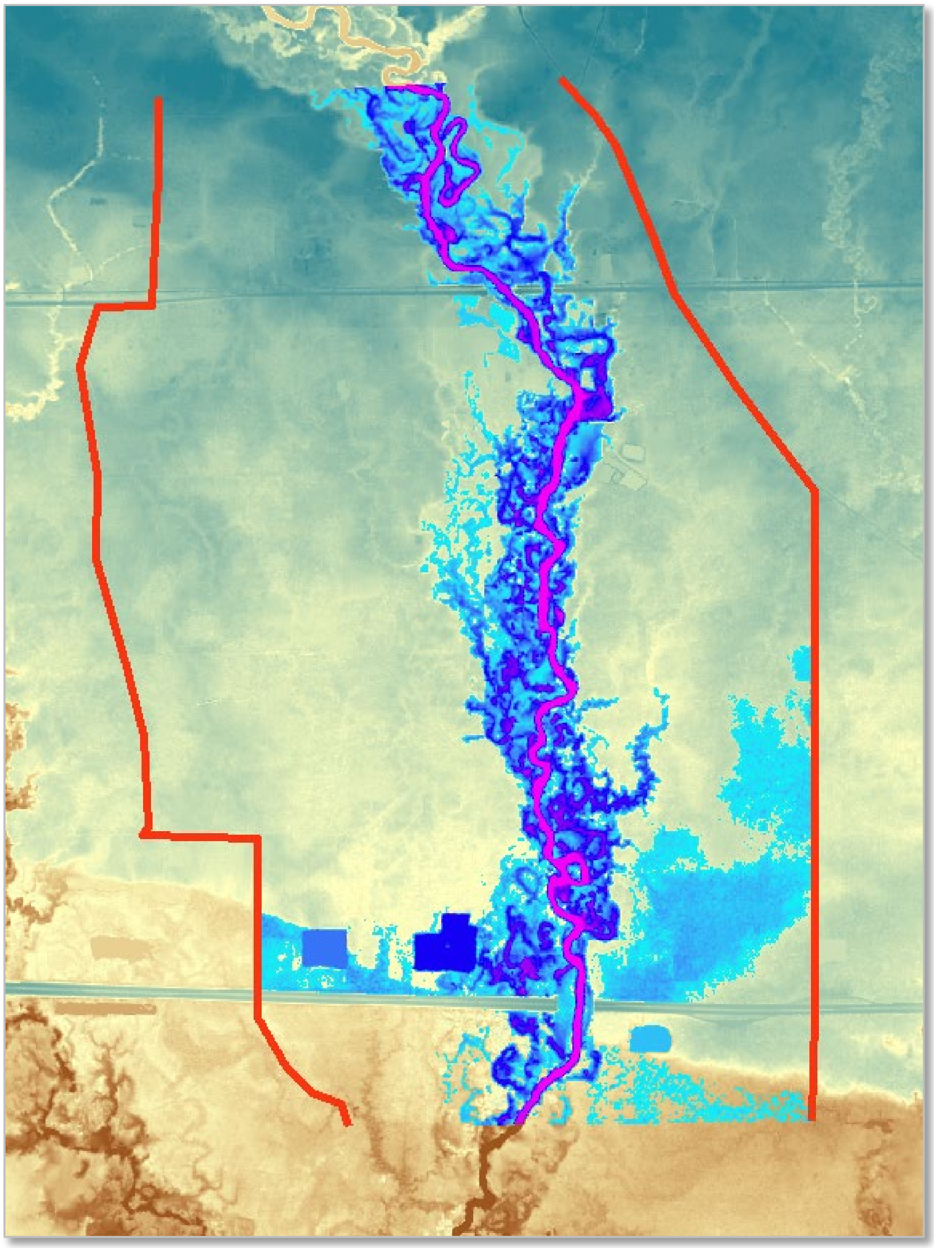

Figure 30: Flood depth grid (blue-purple) overlain on top of the terrain digital elevation model (DEM; brown-green) shown with the study extent lines (red) derived from the perimeter for the 2D model geometry for U.S. Geological Survey streamgage 07376000 Tickfaw River at Holden, Louisiana.

Contact

The InFRM team may be reached at the following monitored email address:

InFRM@usgs.gov

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