Resilient NJ

FLOODPLAIN MAPPING METHODOLOGY

February 14, 2020

Regional Planning for a Stronger New Jersey

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1. Introduction

Purpose

New Jersey is exposed to coastal flooding in the form of storm surge, sea level rise, and heavy precipitation. Coastal areas experience flooding from hurricanes, tropical storms, nor'easters, normal rainfall events, cyclical tidal events, and sustained on-shore wind or swell events that may cause flooding even during clear skies. The extent of coastal flooding and location of areas impacted depends on the combination of tides, storm surge, and rainfall (depth and intensity) at the time of the event. This flooding is projected to increase in frequency and magnitude as a result of climate change over the next century.

The following document describes the methods and processes used to produce flood inundation maps for the regions selected as part of NJDEP's Resilient NJ Program. These maps reflect both current and future flooding events and will be used as planning tools for the Consultant Teams to understand the level of potential risk the regions currently face, as well as future risk in light of climate change. The output from these models will be used within the Resilient NJ Risk Assessment Methodology. For further information on that process, refer to the separate Risk Assessment Methodology document.

The STAP Report

The first New Jersey Science and Technical Advisory Panel (STAP) on Sea-Level Rise and Coastal Storms was convened by Rutgers University on behalf of the NJ Climate Change Alliance in 2015, culminating in a 2016 report that identified planning options for practitioners to enhance the resilience of New Jersey's people, places, and assets to sea-level rise, coastal storms, and the resulting flood risk (Kopp et al., 2016). A panel of practitioners were convened to offer insights on the application of the STAP science to state and local planning and decision-making; this innovative approach was used to inform the 2016 report. Following the same process, the same team at Rutgers University was engaged by the State of New Jersey Department of Environmental Protection to update the 2016 report based on the most current scientific information. Similar to the inaugural work, the 2019 STAP was charged with identifying and evaluating the most current science on sea-level rise projections and changing coastal storms, considering the implications for the practices and policies of local and regional stakeholders, and providing practical options for stakeholders to incorporate science into risk-based decision processes. Table 1 below summarizes the sea level rise findings from the 2019 STAP report.

Table 1 Sea Level Rise Projections from the 2019 STAP Report

		2030	2050	2070			2100			2150		
				Emissions								
	Chance SLR Exceeds			Low	Mod.	High	Low	Mod.	High	Low	Mod.	High
Low End	> 95% chance	0.3	0.7	0.9	1	1.1	1.0	1.3	1.5	1.3	2.1	2.9
Likely Range	> 83% chance	0.5	0.9	1.3	1.4	1.5	1.7	2.0	2.3	2.4	3.1	3.8
	~50 % chance	0.8	1.4	1.9	2.2	2.4	2.8	3.3	3.9	4.2	5.2	6.2
	<17% chance	1.1	2.1	2.7	3.1	3.5	3.9	5.1	6.3	6.3	8.3	10.3
High End	< 5% chance	1.3	2.6	3.2	3.8	4.4	5.0	6.9	8.8	8.0	13.8	19.6

**2010 (2001-2019 average) Observed = 0.2 ft*

Notes: All values are 19-year means of sea-level measured with respect to a 1991-2009 baseline centered on the year indicated in the top row of the table. Projections are based on Kopp et al. (2014), Rasmussen et al. (2018), and Bamber et al. (2019). Near-term projections (through 2050) exhibit only minor sensitivity to different emissions scenarios (<0.1 feet). Low and high emissions scenarios correspond to global-mean warming by 2100 of 2°C and 5°C above early Industrial (1850-1900) levels, respectively, or equivalently, about 1°C and 4°C above the current global mean temperature. Moderate (Mod.) emissions are interpolated as the midpoint between the high- and low emissions scenarios and approximately correspond to the warming expected under current global policies. Rows correspond to different projection probabilities. There is at least a 95% chance of SLR exceeding the values in the 'Low End' row, while there is less than a 5% chance of exceeding the values in the 'High End' row. There is at least a 66% chance that SLR will fall within the values in the 'Likely Range'. Note that alternative methods may yield higher or lower estimates of the chance of low-end and high-end outcomes. This table has been reproduced from New Jersey's Rising Seas and Changing Coastal Storms: Report of the 2019 Science and Technical Advisory Panel.

The Resilient NJ floodplain maps were produced for two current and four future flooding conditions. The flooding conditions consider combinations of increased rainfall (both intensity and depth), storm surge, tidal flooding, and sea level rise (SLR).

Flooding Condition Development

The development of the flooding conditions was based upon a combination of rainfall, storm surge, sea level rise (SLR), and tidal flooding. Rainfall considers an intense, short-duration event as well as a longer 24-hour event. No increase in rainfall depth was assumed for current condition models; however, an increase of 10% in rainfall depth was assumed for storms occurring in 2070. (Note: It is widely believed that precipitation amounts will increase within the next century; however, there is uncertainty in the exact rate. A 10% increase was chosen for these models as a central estimate of increased rainfall at 2070.) Storm surge baselines use the Mean Higher High Water (MHHW) elevations reported at the Sandy Hook tide gauge (for northern regions) and the Atlantic City tide gauge (for southern regions). (For regions within the Mullica-Toms watershed, models were produced using both tide gauges. Since communities in this watershed may find one tide gauge MHHW level more applicable to the region than the other, regions will choose what they view as the appropriate MHHW level to use, with approval from DEP.) An increase of 2.4 feet was used for the 2070 SLR projection, which is the central estimate for the high emissions scenario from 2019 Rutgers University's Science and Technical Advisory Panel's (STAP) report, described earlier. Finally, a Sandy surge event equivalent, occurring in 2070, was also modeled.

See *Figure 1* for tide gauges and corresponding watershed applicability.

Figure 1 Map of Divide Between Gauges Used for Mapping

Final Flooding Conditions

Six (two current and four future) models displaying different potential flood conditions will be provided to each region. *Table 1* shows the different model inputs used for each of these conditions.

Table 2 Flooding Conditions Available for Risk Assessment

Flooding Condition	Type
Current	a. MHHW + 2% annual chance, 2-hour storm event
	b. MHHW + 1% annual chance, 24-hour storm event
Future	c. MHHW + SLR 2070 (2.4 ft)
	d. MHHW + SLR 2070 (2.4 ft) + (2% annual chance, 2-hour storm event + 10% increase in rainfall)
	e. MHHW + SLR 2070 (2.4 ft) + (1% annual chance, 24-hour storm event + 10% increase in rainfall)
	f. MHHW + SLR 2070 (2.4 ft) + Superstorm Sandy in 2070 (High Water Mark = 8.3 ft)

Document Overview

The following document describes the methods and processes used to produce flood mapping data for a selection of HUC-8 watersheds within New Jersey. Using the storm event factors described above, as well as terrain data, soil information, and land use data, floodplains were developed using a two-dimensional (2-D) rain on grid model with HEC-RAS. Though the methods used to produce the HEC-RAS 5.0.5 2D Unsteady Flow flood models are the primary focus of the document, methods of data pre-processing in ESRI ArcMap, ArcHydro Tools, and USACE's HEC-HMS software are also detailed below. For information regarding the sources and applications of raw data utilized within this process, see Appendices A, B, and C.

Model Selection

Multiple mapping methods were considered during preliminary map development. Some of these methods included:

- Digitizing the New Jersey Flood Hazard Area Design Flood (NJFHADF)
- One-Dimensional Base Level Engineering Model (RiverSystems – A Michael Baker proprietary software)
- Model Based Mapping of N.J.A.C. 7:13-3.5 (Method 5)- Approximate Method
- HEC-RAS Two-Dimensional Rain on Grid

Ultimately, the two-dimensional rain on grid model was chosen. This modeling method has the ability to provide inundation maps for all areas of a region and was not only limited to state studied streams. It was also one of the more straightforward modeling processes and could be used to model multiple types of flooding events (rainfall, storm surge, etc).

Model Limitations

The terrain data obtained for use in this project, after being clipped to the buffered watershed extents, was processed and reconditioned through ESRI's ArcHydro Tools before being incorporated into the HEC-RAS Models. The goal of ArcHydro Tools in this context was to correct sections of the terrain that cause hydrologically disconnected areas, whether natural or artificial, in the Digital Elevation Model (DEM). This was achieved by "burning" streamlines into the DEM, providing hydraulic connectivity to areas that were previously (and usually incorrectly) separated. While this method can correct hydraulically inaccurate areas within the DEM quickly and for very large areas, it does not account for the characteristics of individual structures that may affect hydraulics, such as bridges, culverts, or other constrictions and obstructions, which was a potential source of inaccuracy in the models. Additionally, no specific stream bed, or channel geometry data were used. Despite this concern, the similarity of floodplain results from models using this method compared to the FEMA Special Flood Hazard Areas suggest that the potential error does not greatly affect results.

Additionally, no urban drainage systems have been modeled. However, in the case of many flooding events, these drainage systems can become quickly inundated, with excess water then remaining on the terrain. In these cases, the model can indicate which areas are most vulnerable to flooding events, but also what may occur when urban drainage is insufficient.

Finally, the maps developed through the methods described below are intended to be used as planning tools for the Resilient NJ Program. These maps are not intended for regulation changes or engineering design standard updates.

2. Terrain Preparation Using ArcHydro Tools

Background Information

Two ArcHydro routines were used for the preparation of the terrain files. The first, called DEM Reconditioning, "burns" selected streamlines into the DEM to an elevation drop specified by the user. The second process, Fill Sinks, refills these burn lines to the depth necessary to allow water to flow unobstructed through the watershed to the exit point of the studied watershed. The streamlines selected to be burned were lines from the National Hydrography Dataset (NHD). The following NHD Flowline types were selected for this process:

Table 3 Selected NHD Flowlines and feature types for ArcHydro DEM Reconditioning

NHD Flowline FCode	Feature Type
33400	CONNECTOR
42803	PIPELINE
55800	ARTIFICIAL PATH

These flowline feature types were selected to capture as many culverts, underground pipes, and other hydraulic structures as possible that may not be reflected in the DEM or may have flow paths blocked by artificial DEM structures.

NHD streamlines were cropped to a distance 1000' from the edge of the DEMs (apart from Lower Hudson, which was cropped to 250' to the edge due to small watershed size). Because the original HU8 extents were buffered 3000' for the creation of the DEMs, the burned streamlines still cover the full extents of the original HU8 once processed in HEC-RAS. Cropping the streamlines was necessary because the Fill Sinks process may not work properly if burned streamlines continue to the very edge of the DEM.

Terrain Preparation

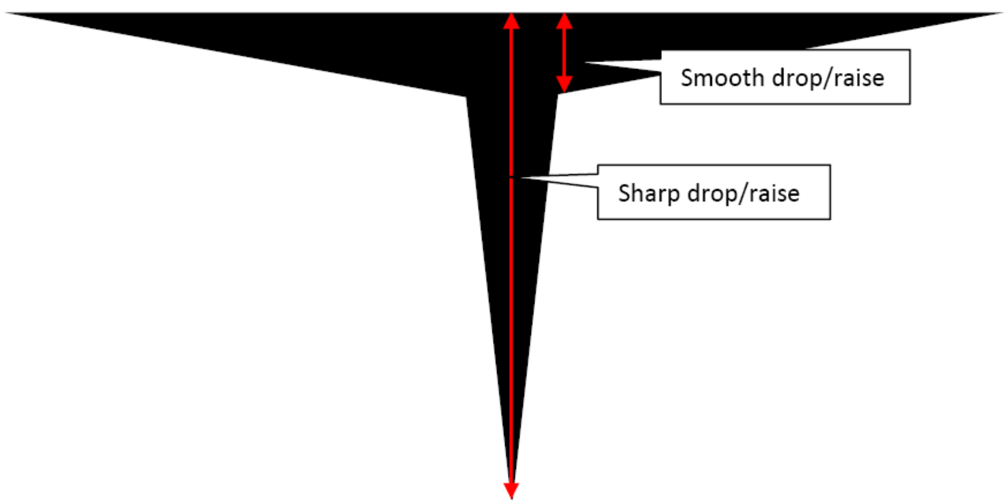
- In a blank MXD, **import** the **DEM** and **NHD streamlines** to be processed into ArcMap.
- Then **save the MXD** to the desired project folder at this point, as this will dictate where ArcHydro Tools will attempt to deliver output files to.

- Once the MXD is saved, specify the file target locations in the ArcHydro Toolbar under **ApUtilities→Set Target Locations**. Verify that the raster data is being delivered to a raster workplace and that the vector data is being delivered to a file geodatabase. Verify that the DEM is in ESRI GRID format and that the streamlines are shapefiles in file geodatabase format, trimmed such that they do not reach the very edge of the DEM. It is also important to ensure that the spatial projection of the data frame, streamlines, and DEM are all the same.
- From the ArcHydro Toolbar, select **Terrain Preprocessing → DEM Manipulation → DEM Reconditioning**

  The DEM Reconditioning routine in this workflow was done with default settings, shown below.

Figure 2 Geometry of ArcHydro Tools' DEM Reconditioning ("burn") routine

Stream buffer (number of cells)	5
Smooth drop/raise (DEM Z-unit)	10
Sharp drop/raise (DEM Z-unit)	1000



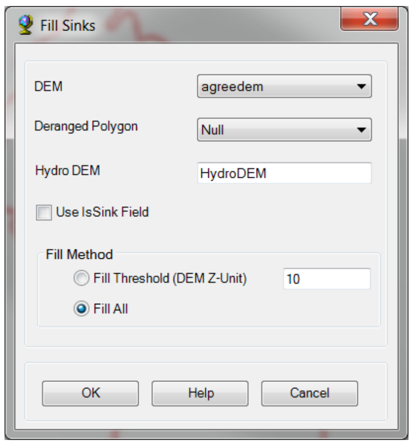
Once complete, the output file, the AgreeDEM, is in the file target location specified by the user in the ArcHydro Toolbar (or to a default location if unspecified). This reconditioned DEM will contain reduced elevation DEM cells with elevation values dropped by 1000' per the sharp drop/raise settings where the selected streamlines were located.

Once the AgreeDEM has been generated, the second ArcHydro process, called **Fill Sinks**, further manipulates the terrain data. The Fill Sinks routine creates a hydrologically-corrected DEM (HydroDEM). The HydroDEM is a terrain that attempts to capture the correct drainage pattern within the watershed. Part of this process involves the analysis and subsequent filling of sinks, which are areas of the terrain that trap water and do not allow flow to continue through the dendritic stream system. Sinks in the terrain may be real features or artificial features.

- From the ArcHydro Toolbar, select **Terrain Processing → DEM Manipulation → Fill Sinks**.

  Once these two processes have been completed, the original terrain file will be a hydrologically-corrected DEM that will serve as the terrain data for the HEC-RAS 2D Unsteady Flow Model.

Figure 3 Default Settings and Inputs for Fill Sinks



3. Determining a Weighted Curve Number

Background Information

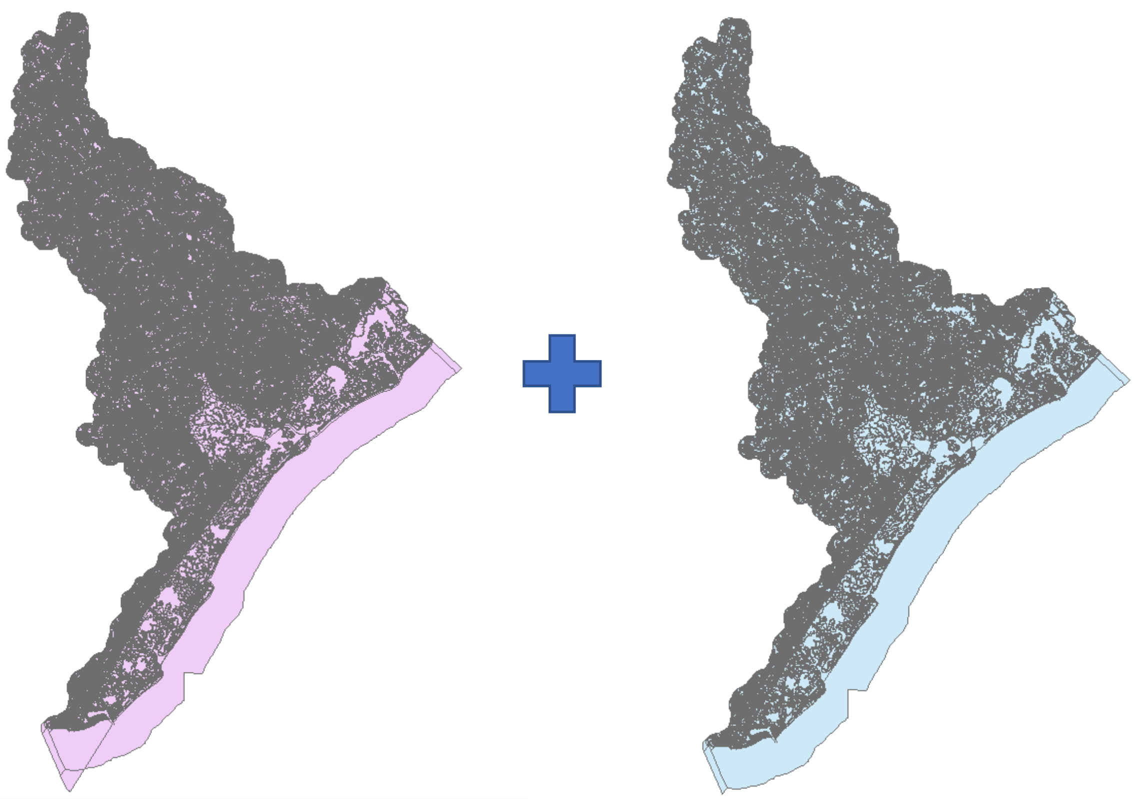
The SCS runoff curve number method was used in this process to determine what proportion of precipitation that falls within the watershed is expected to be captured or become runoff. By using land use data provided by the NJDEP (and NLCD data where applicable), a single weighted curve number was generated for each watershed and inputted into a HEC-HMS model to approximate the excess runoff the watershed will encounter. This method uses approximate values to simplify runoff calculations over large areas. Localized conditions may be considered on a case by case basis, where runoff values may differ from the assigned curve numbers.

Two primary data sources were used to estimate curve numbers within the watersheds: land use and soils. The land use used landcover polygons from New Jersey DEP for in-state areas and National Land Cover Dataset (NLCD 2011) for areas outside of the state boundary. Soil data was collected from the Natural Resources Conversation Service (NRCS) Web Soil Survey, in SSURGO format. Based on tables found on the Web Soil Survey website, each soil type was assigned a Hydrologic Soil Group (HSG) classification (A, B, C, or D). These classifications describe a soil's rate of transmission of water, which influences the amount of stormwater runoff that a surface with that soil type may generate.

The curve numbers used were derived from Table 2-2 in NRCS' "Urban Hydrology for Small Watersheds" (TR-55), which provides a curve number for combinations of land use type and hydrologic soil group classification. By relating land use and soil types to the closest matching TR-55 land use type and HSG (and by making assumptions where appropriate), a similar curve number rating system was generated for any combination of New Jersey Land Use type and HSG type (and/or NLCD Land Use type and HSG type for non-NJ areas). Refer to Appendix C for a detailed breakdown of these numbers. Curve numbers were assigned to every combination of soil and land use across each watershed, then weighted by the curve number and area of each combination polygon, and as a result a **single weighted curve number** was generated for each watershed.

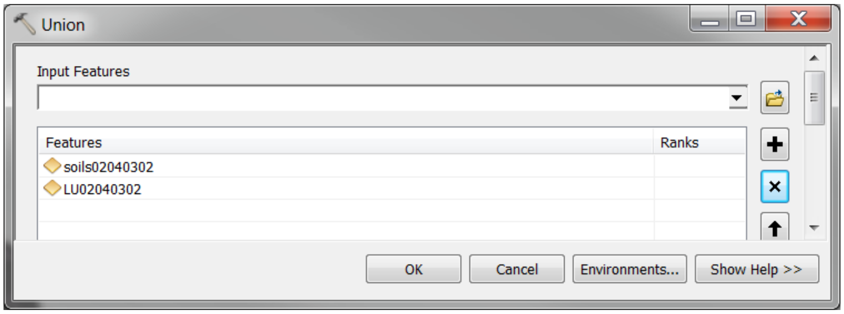
Generating SCS Curve Numbers in ArcGIS

Figure 4 *Shapefile Soils and Land Use Data clipped to watershed extents, to be combined to create land use and soils combination polygons (ArcMap)*



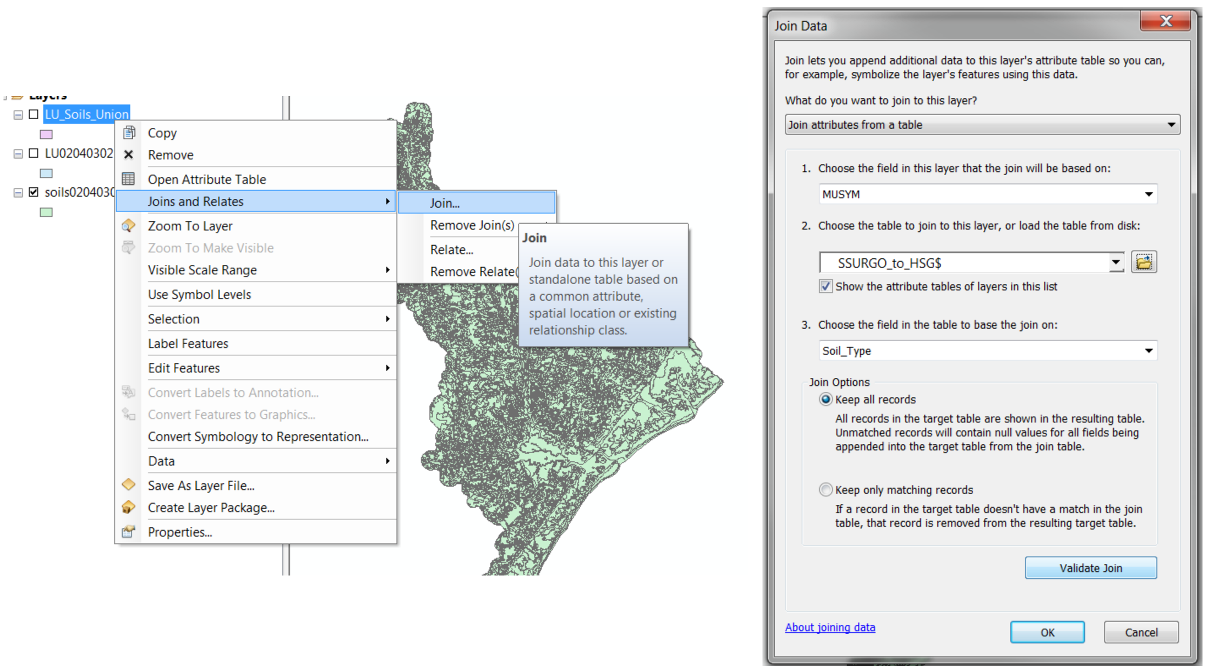
- Start with land use and soils polygons in shapefile format in ArcMap, clipped to the buffered (3000') extents of the watershed. Use the **Union** tool to combine the two datasets and merge the attributes.

Figure 5 Combining datasets with Union tool (ArcMap)



- Next, using the **Join** function in ArcMap, join the SSURGO soil codes (field MUSYM) to a table that links the MUSYM codes to a corresponding HSG.

Figure 6 Performing a join to an external excel file (ArcMap)



- Now, **Add Field** to the attribute table, and use **Field Calculator** on the newly created field to combine the NJLU and HSG fields together, creating single codes which denote a combination of NJ LU code and HSG (such as 1110A or 4200C) for a specific polygon in the dataset, seen as LU12_HSG in the attribute table below.
- **Join** these codes to a table that matches LU+HSG codes to a curve number value, and this will provide curve numbers for the unioned land use/soils polygons.
- Once this is complete, **Add Field** again, and use **Calculate Geometry** to determine the area of each polygon, and export the data to Excel. Once the data is in excel, generate a weighted curve number for the watershed.

Figure 7 *Curve Numbers and Polygon Area calculated in the LU+Soils Unioned dataset. For watersheds that contain NLCD data as well as NJ Land use data, a similar process was used to convert the NLCD and Soils data into curve numbers, where combinations of NLCD grid codes and soils data were paired to a curve number table.*

Table

union2

FID	LU12	LABEL12	MUSYM	HSG	LU12_HSG	CN	Code	Area
4172	1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	DuoC	A	1120A	57	1120A	151934
4173	1130	RESIDENTIAL, SINGLE UNIT, LOW DENSITY	DuoC	A	1130A	51	1130A	124629
4174	4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)	DuoC	A	4120A	30	4120A	320854
4175	4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)	DuoC	A	4120A	30	4120A	9697
4176	6210	DECIDUOUS WOODED WETLANDS	DuoC	A	6210A	87.5	6210A	24902
4177	6210	DECIDUOUS WOODED WETLANDS	DuoC	A	6210A	87.5	6210A	109418
4178	1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	DuuC	A	1120A	57	1120A	220840
4179	1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	DuuC	A	1120A	57	1120A	269362
4180	1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	DuuC	A	1120A	57	1120A	38644
4181	1463	UPLAND RIGHTS-OF-WAY UNDEVELOPED	DuuC	A	1463A	36	1463A	27025
4182	4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)	DuuC	A	4120A	30	4120A	68046
4183	4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)	DuuC	A	4120A	30	4120A	5190
4184	1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	WemC	C	1120C	81	1120C	56530
4185	1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	WemC	C	1120C	81	1120C	23406
4186	1130	RESIDENTIAL, SINGLE UNIT, LOW DENSITY	WemC	C	1130C	79	1130C	4563
4187	1140	RESIDENTIAL, RURAL, SINGLE UNIT	WemC	C	1140C	77	1140C	74325
4188	1200	COMMERCIAL/SERVICES	WemC	C	1200C	94	1200C	8926
4189	1463	UPLAND RIGHTS-OF-WAY UNDEVELOPED	WemC	C	1463C	73	1463C	16358
4190	1710	CEMETERY	WemC	C	1710C	74	1710C	141925
4191	1110	RESIDENTIAL, HIGH DENSITY OR MULTIPLE DWELLING	DuuB	A	1110A	77	1110A	1140
4192	1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	DuuB	A	1120A	57	1120A	429766
4193	1140	RESIDENTIAL, RURAL, SINGLE UNIT	DuuB	A	1140A	46	1140A	106986
4194	4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)	DuuB	A	4120A	30	4120A	125
4195	1110	RESIDENTIAL, HIGH DENSITY OR MULTIPLE DWELLING	DuuD	A	1110A	77	1110A	110352
4196	1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	DuuD	A	1120A	57	1120A	109244
4197	1200	COMMERCIAL/SERVICES	DuuD	A	1200A	89	1200A	10215
4198	1200	COMMERCIAL/SERVICES	DuuD	A	1200A	89	1200A	22362
4199	1200	COMMERCIAL/SERVICES	DuuD	A	1200A	89	1200A	28317
4200	1420	RAILROADS	DuuD	A	1420A	76	1420A	29

4189 (0 out of 217937 Selected)

union2

Figure 8 *Weighted Curve Number determined by Σ(CN*A)/Σ(A)*

6

Weighted Curve Number	$CN_{weighted} = \mathbf{\Sigma}(CN*A)/\mathbf{\Sigma}(A)$
78.1	

CN1	Area (Sq F	Area*CN (Sq Ft)
77	51268	3947636
87	1474	128238
87	14824	1289688
77	9171	706167
77	514	39578
77	6130	472010
77	3556	273812
87	7226	628662
84	9685	813540
87	9686	842682
87	6049	526263
84	19316	1622544
77	6632	510664
77	2348	180796
77	10726	825902
77	33856	2606912
77	30724	2365748
84	17366	1458744
77	9686	745822

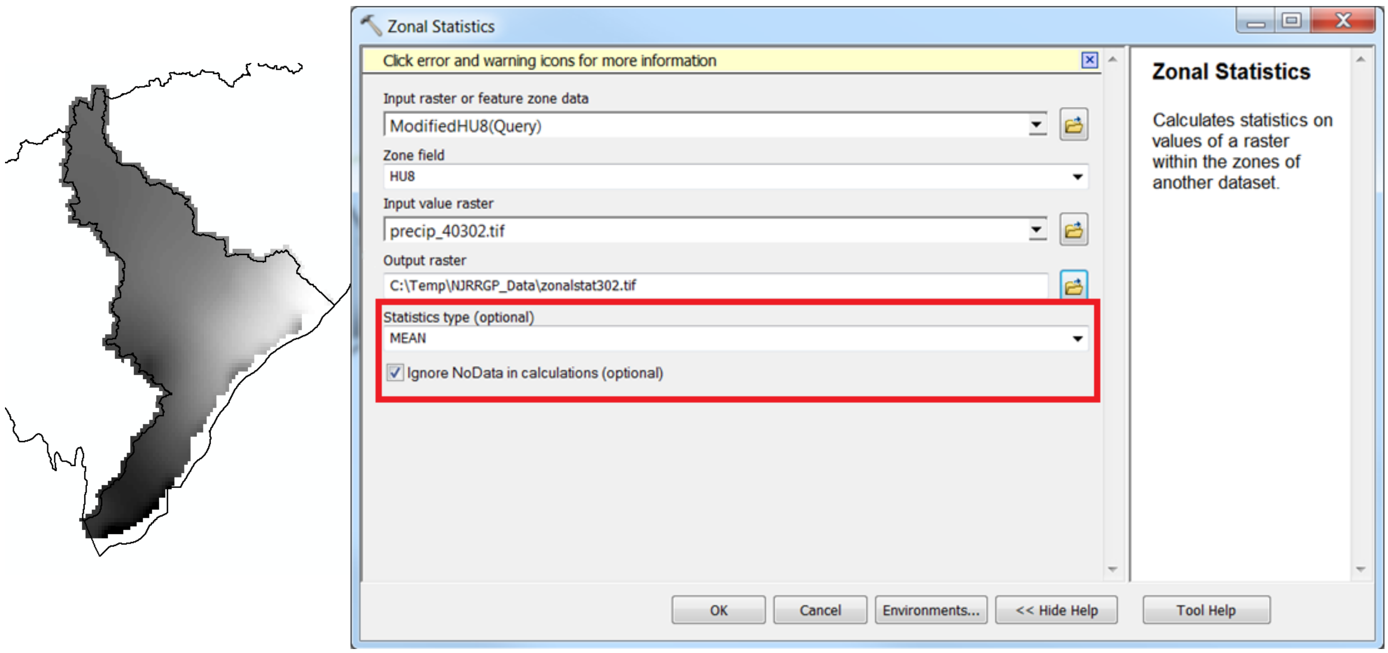
4. Determining Precipitation Excess in HEC-HMS

Background Information

Precipitation data for this process were based around both a 1%, 24-hour storm event, and a 2%, 2-hour storm event. The 100-year, 24-hr distribution is a standard design storm used in flood mapping (especially regulatory mapping). However, changes in climate patterns are resulting in an increasing frequency of short, intense storms which may overwhelm stormwater drainage and impoundment systems and contribute to localized flooding outside of the floodplain. Therefore, both precipitation events were modeled for both current and future flooding conditions. Precipitation depths were increased by 10% when modeling flooding conditions for the year 2070.

Precipitation data was obtained in GIS format from the NOAA Precipitation Frequency Data Server, which provides values derived from NOAA Atlas 14 in the form of precipitation depth rasters. The rasters were then clipped to watershed extents, and the **Zonal Statistics** tool in GIS was performed on the clipped rasters to generate a mean rainfall value for the watershed.

Figure 9 Determining mean rainfall depth from NOAA precipitation rasters



After determining the rainfall depths, HEC-HMS models were built to simulate the hydrologic processes of the watershed system, generating a precipitation excess hyetograph that would serve as the input for the Unsteady Flow files in the HEC-RAS models. The SCS Curve Number method was used to compute the excess runoff that would not be captured within the watershed, using the weighted curve number computed in Section 3.

HEC-HMS Process

- To compute the excess runoff in the watershed, begin with a new HEC-HMS Model, and **create a new project**.
- Be sure to **set the default unit system to U.S. Customary**.

Figure 10 Creating a HEC-HMS model

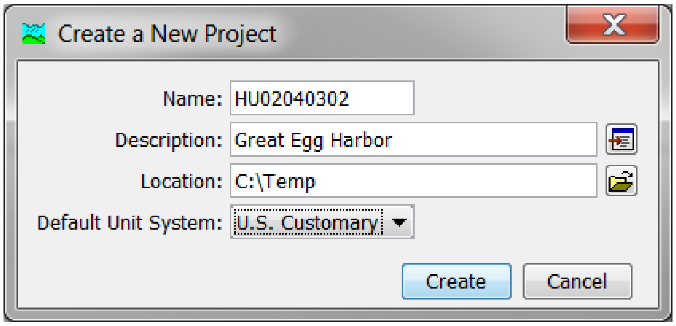
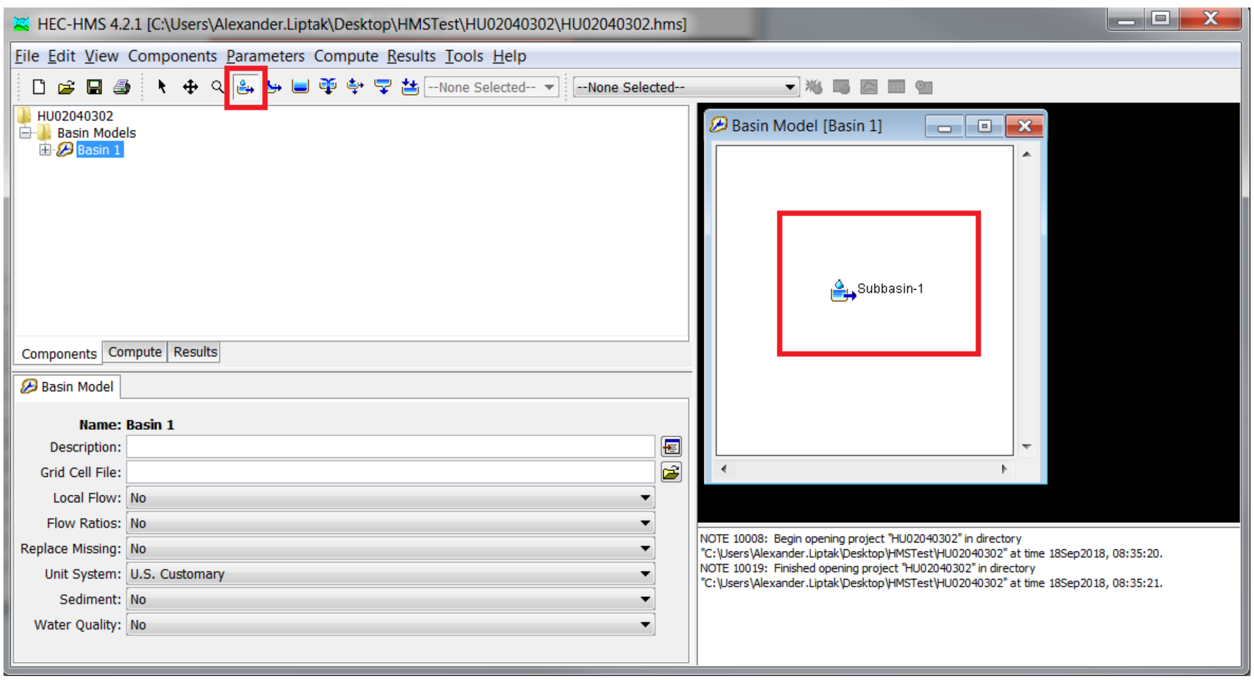


Figure 11 Creating a basin/sub-basin model



- Name and describe (optional) the project and **save** it to the project folder.
- Next, select **Components → Basin Model Manager** and create a new Basin.
- Once the basin is created and named, click the **Subbasin Creation Tool** on the toolbar.
- Then, with the Subbasin Creation Tool selected, **click anywhere in the Basin Model window to create a sub-basin**.
- Once the Sub-basin has been created, select the sub-basin and view the **sub-basin model settings**. **Select Loss Method: SCS Curve Number**.
- Then, go to the Loss tab in the sub-basin model settings, and **input the computed weighted curve number**.

Figure 12 Specifying loss method for a basin/sub-basin model

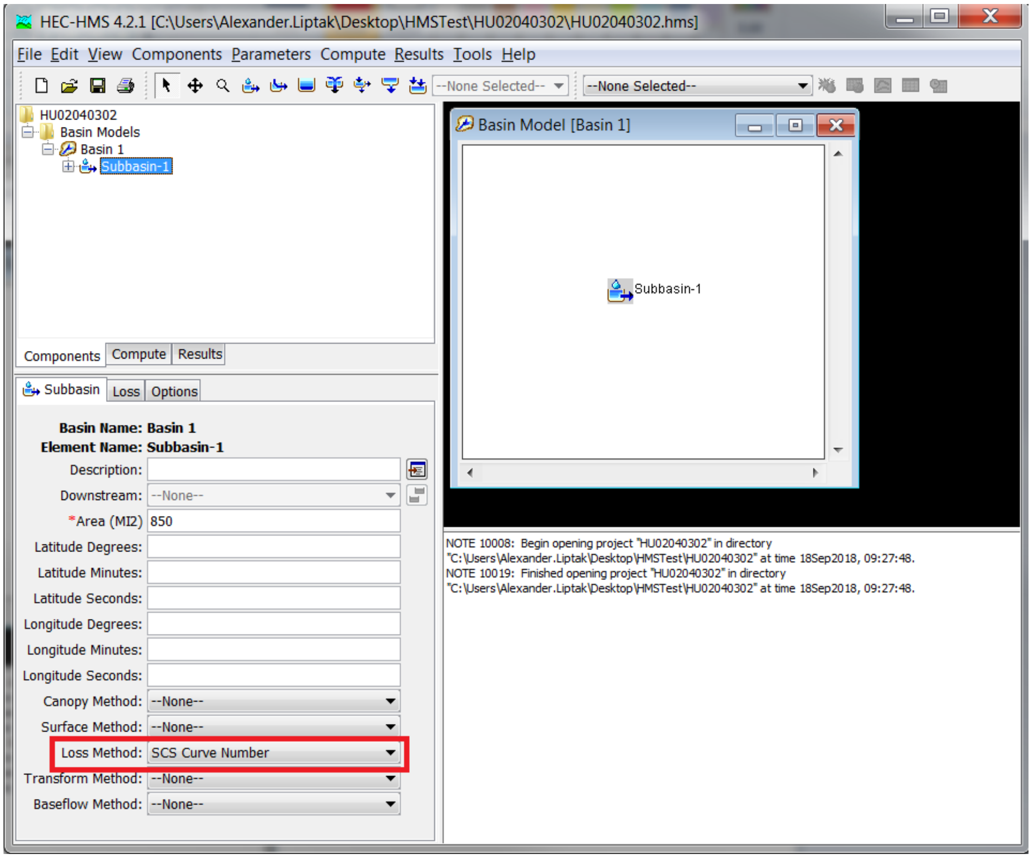
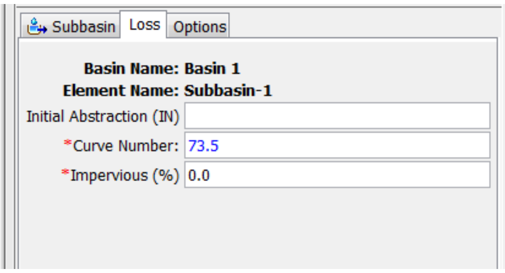
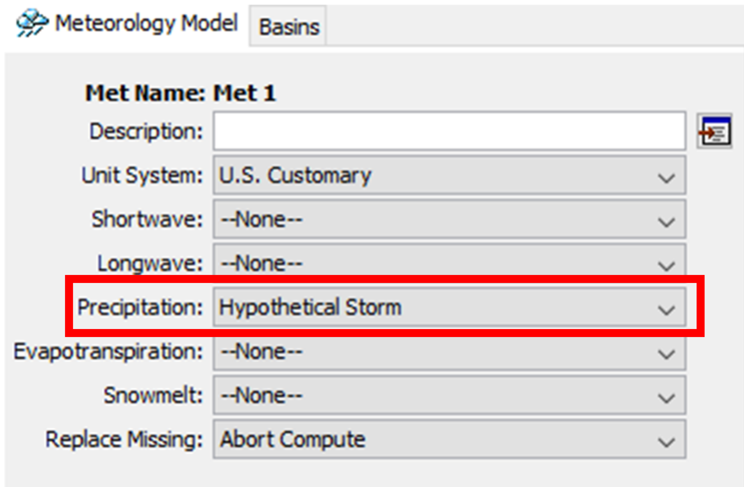


Figure 13 Inputting weighted curve number into HMS



- Next, select **Components → Meteorologic Model Manager**, and **Create** a new meteorologic model.

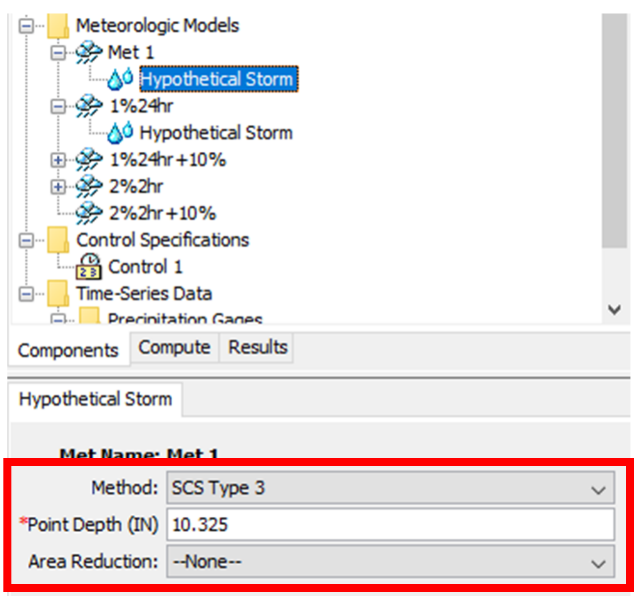
Figure 14 Creating a Meteorology Model in HMS



For modeling the 1%, 24-hour storm event:

- In the Meteorology Model settings, set **Precipitation:** to **Hypothetical Storm**.
- On the next tab, **Basins**, select **Yes** under **Include Subbasins**.
- Next, select **Hypothetical Storm** under Meteorological Models. Select **SCSType 3** for **Method**, and input 1.10x the mean value calculated (this multiplier accounts for expected increase in future severity and frequency of storms) from the Zonal Statistics Tool in ArcMap in the **Depth (IN)** field.

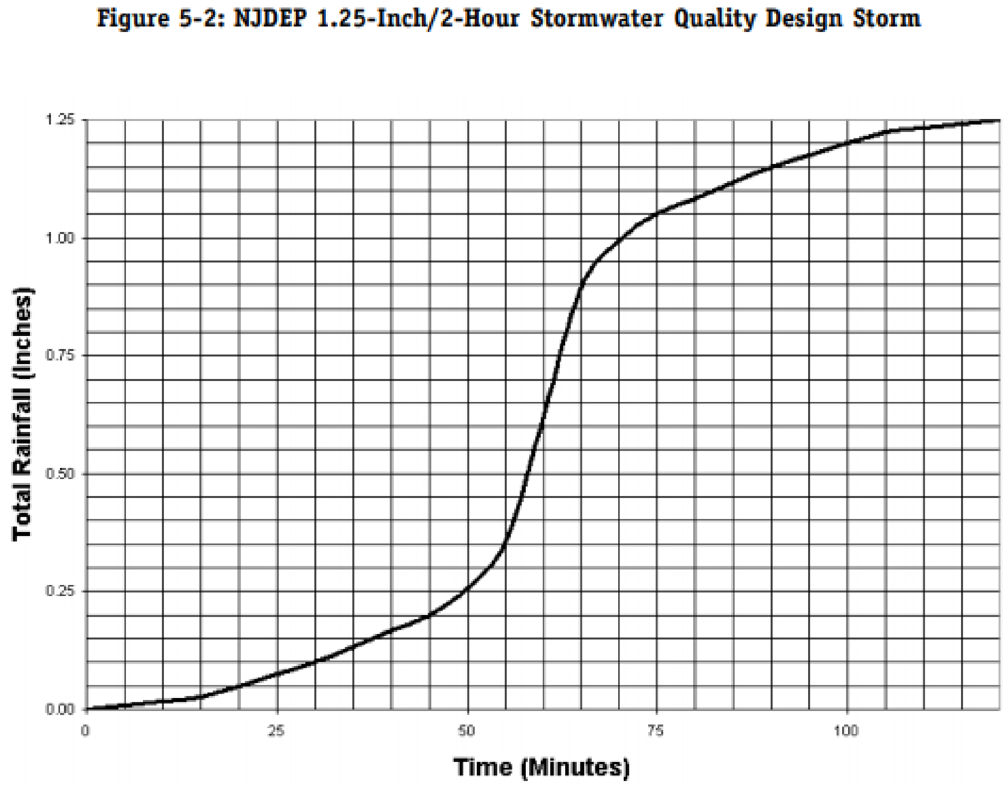
Figure 15 Specifying rainfall depth in the Meteorological Model



For modeling the 2%, 2-hour storm event:

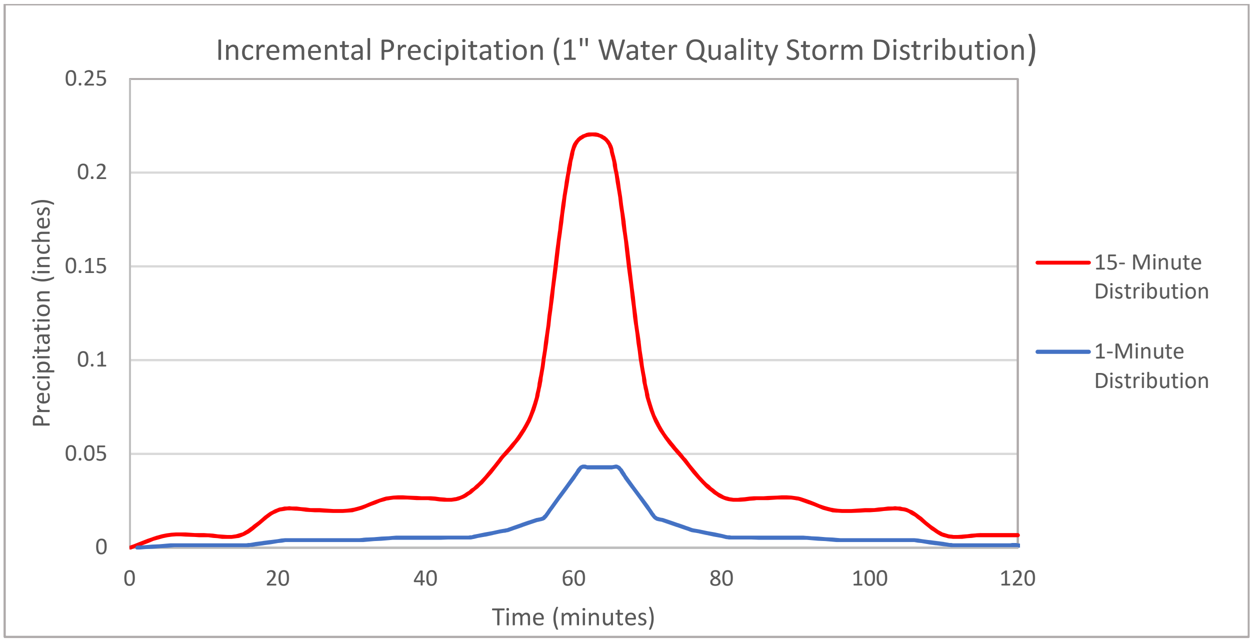
Precipitation data for the 2%, 2-hour storm event was determined based on NOAA rainfall data (discussed earlier) and the water quality storm distribution from the NJDEP BMP manual for the 1.25" depth (Figure 16).

Figure 16 NJDEP Water Quality Design Storm



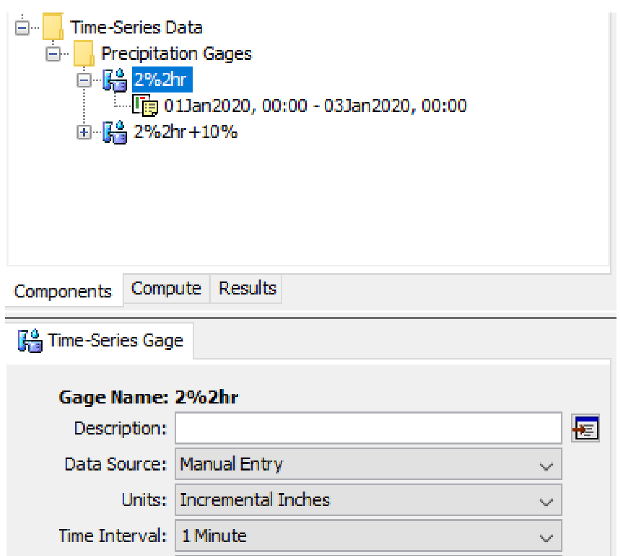
The 15-minute incremental depths were then determined based on this curve for the 1 inch depth. The 1-minute incremental depths were then extracted based on the 15-minute distribution (Figure 17). The 2% rainfall depths for each HUC-8 were multiplied by the 1 minute distribution to obtain time series data to be used within HEC-HMS.

Figure 17 NJDEP Water Quality Design Storm Incremental Precipitation



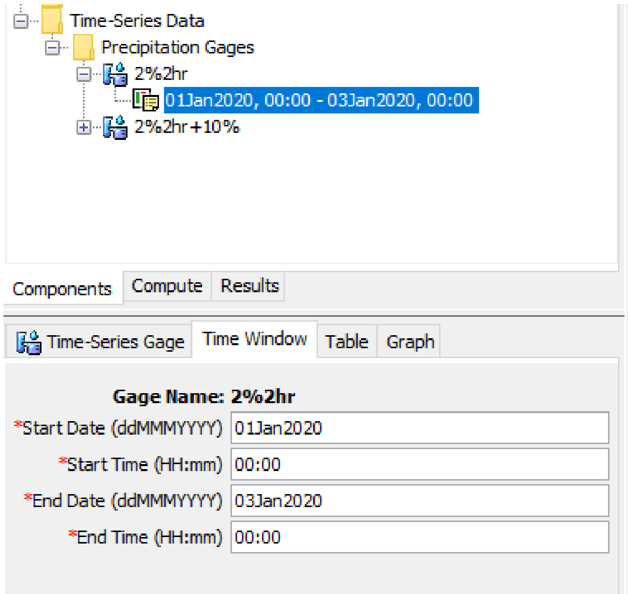
- To import time series data into HEC-HMS select **Components → Time Series Data Manager.** Create a new time series data with the **Data Type: Precipitation Gages**
- In the time series data tab→ precipitation gages→ select **manual entry** in **incremental inches** at a **1-minute** time interval.

Figure 18 Specify Time Series Gage



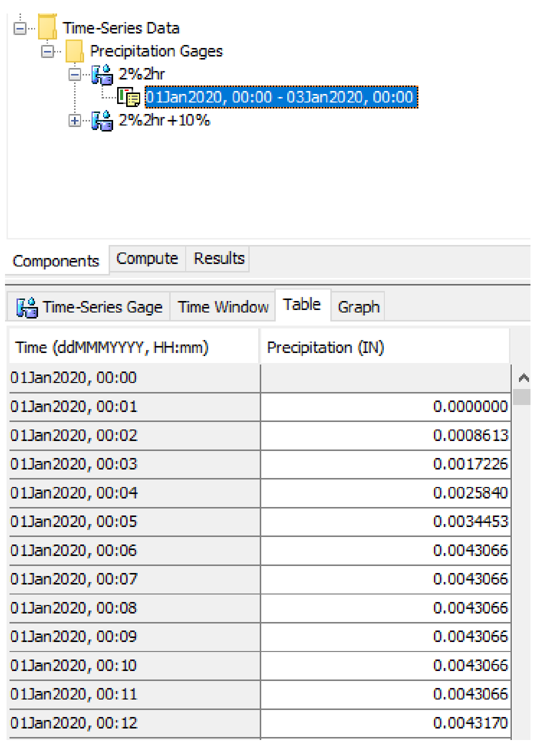
- Choose a date range that the model will run for by selecting the date below the time series event and filling out the **time window**:

Figure 19 Model Time Window



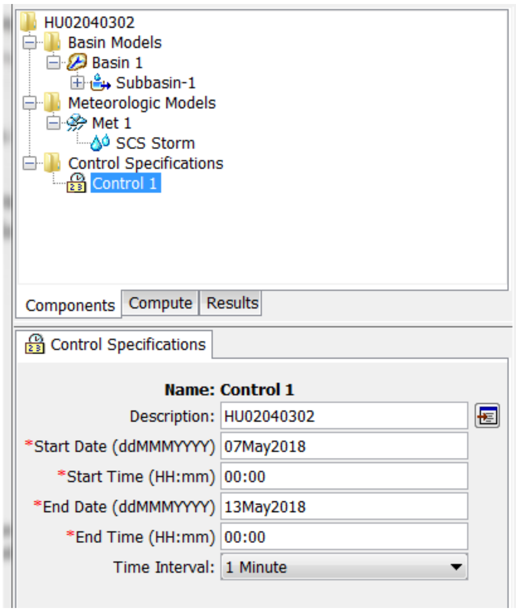
- Last step in the time series data manager is to fill out the precipitation table with the 1-minute distribution for the 2%, 2- hour storm.

Figure 20 Model Time Window



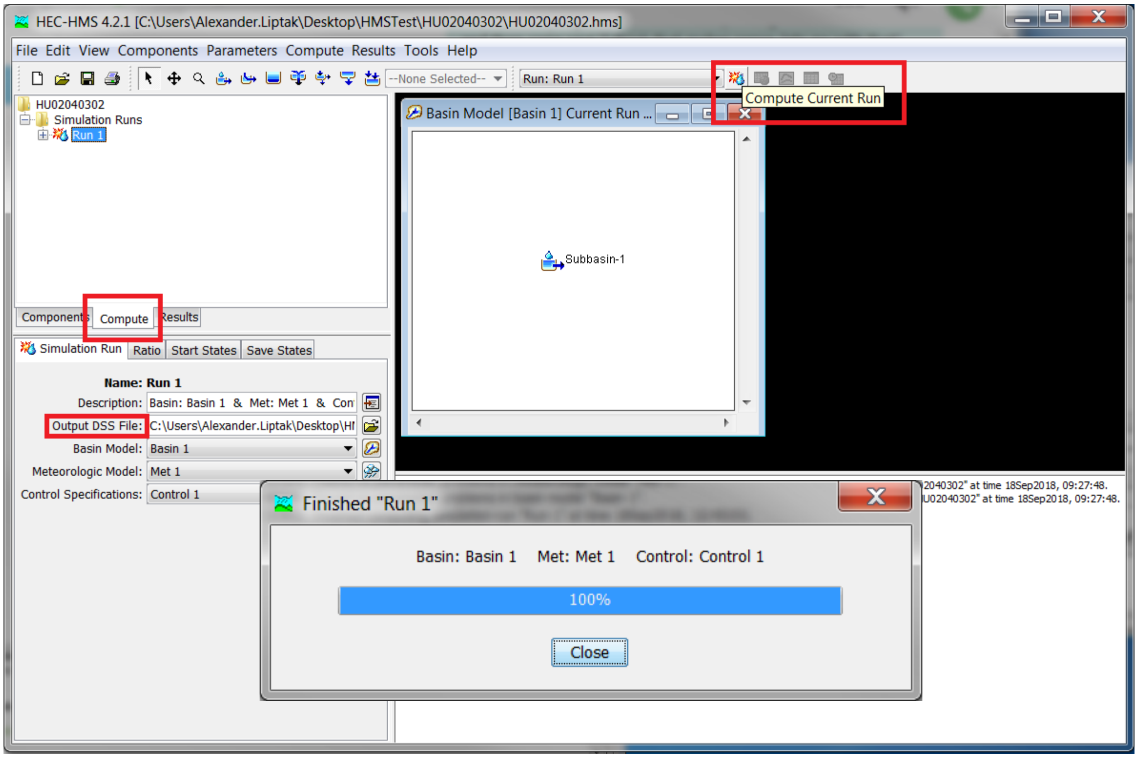
- The final input in the HEC-HMS process is to specify the duration and time interval of the model. Select **Components → Control Specifications Manager** to create a new control specification.

Figure 21 Specifying time controls



- The basin, storm, and time information have now been defined. The last step is to create a run file and run the model. Select **Compute → Simulation Run Manager** and **create a new simulation run**. Select the **Compute** tab, specify the desired output of the DSS file (this will be imported into HEC-RAS for precipitation data), and click the **Compute Current Run** icon in the toolbar.

Figure 22 Successful computation of HEC-HMS model



This will write the excess precipitation hyetograph (among additional data) to the .DSS file at the specified location. **Save** and **Close** HEC-HMS.

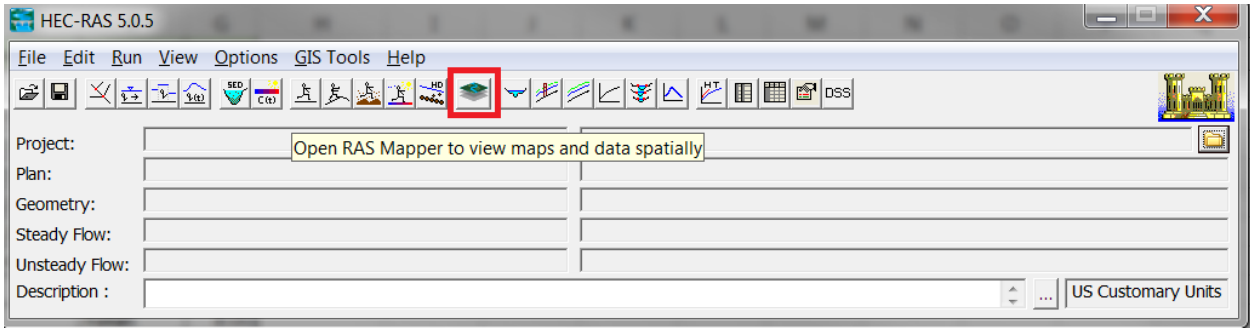
5. Building a HEC-RAS 2D Unsteady Flow Model

The flood mapping files were generated from 2D Unsteady Flow Models in HEC-RAS 5.0.5. These models use a precipitation hyetograph on a 2D computational mesh grid to compute water elevation, velocity, and depth across the watershed over a defined time period.

Starting a New Project

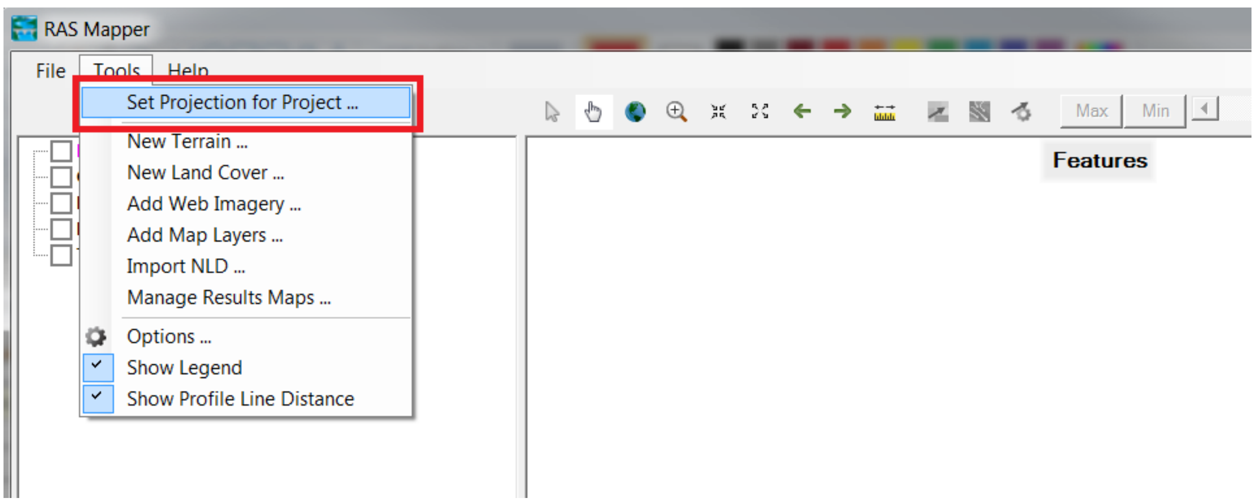
- To begin building a model, open HEC-RAS 5.0.5. **Select File → New Project**.
- **Name the project** and **save** it to the local drive. Next, **open RAS Mapper**:

Figure 23 New HEC-RAS Project



- Once in RAS Mapper, specify the spatial projection for the project. This is done by selecting a file with the same projection as the one used in the model. **Select Tools → Set Projection for Project**, and select a file (such as a .shp file) with the desired projection.

Figure 24 Setting Spatial Projection for a Project



Creating a Terrain

- Now, import the hydrologically-corrected terrain into RAS Mapper. To begin, **select Tools → New Terrain**. It is recommended to convert the terrain file to .tif format before continuing with this step. Navigate to the HydroDEM file, select it, and then select **Create** in the New Terrain Layer window. This will begin processing the terrain file and importing it into RAS. This may take some time. Once completed, **save** and **close** RAS Mapper.

Creating a Land Cover Layer

The next step in building the model is to assign friction coefficients (Manning's N) to the terrain surface. This is done by importing Land Cover Data (NJ Land Use Data), associating it with the terrain file, and assigning a Manning's N value for each land cover type. The Manning's N values were determined using TR-55 roughness coefficients values in combination with roughness coefficients from Chow (1959) and Calenda, et al. (2005).

- The first step in creating a new land cover layer is to open RAS Mapper, and select **Tools→New Land Cover**.
- Next, in the resulting Manning's n Value Layer window, press the + symbol to select the land cover file.

Figure 25 Adding a Land Cover file

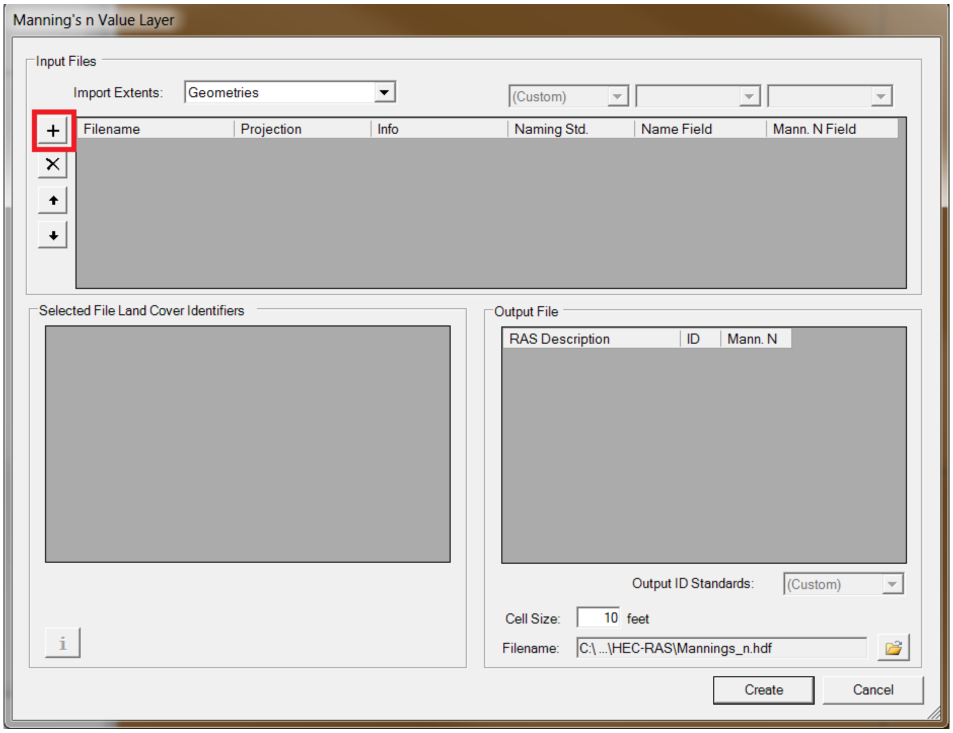
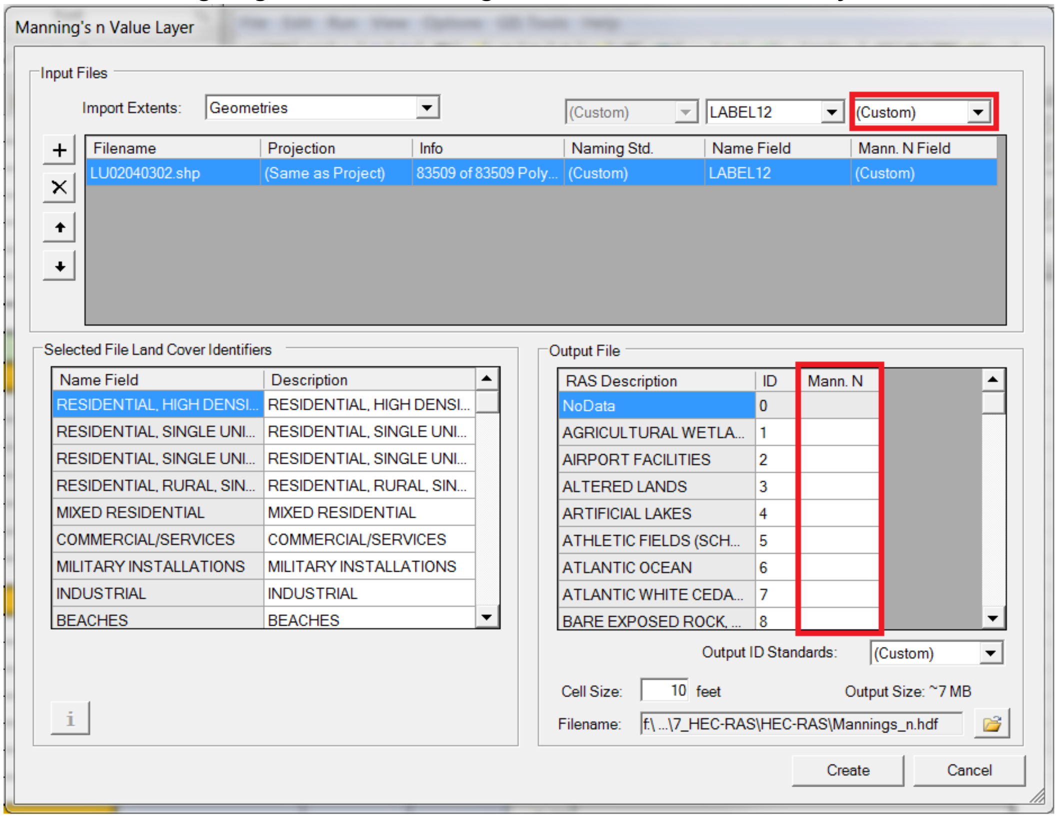


Figure 26 Assigning custom Manning's N values to a land cover file.



- Once the appropriate land cover layer is determined, **select the field to be used for Land Cover Identifiers** (in this case the labels for the NJ LU12 codes, seen as LABEL12), and select **(Custom)**.
- **Assign custom Manning's N values** to the land use types found within the selected data.
- Once all land cover types have been assigned a Manning's N value, press **Create** to complete the land cover layer. Refer to Appendix B for a table of the Manning's N values used in these models.
- For watersheds that combine NJ Land Use data and NLCD Data, convert the NLCD **raster to polygons**, then assign the grid codes in the NLCD data to a New Jersey Land Use category that shares the same Manning's N. Now, all the land use data will be classified by the same set of labels. Merge the two datasets together and use the combined dataset as the land cover input file.

Creating a 2D Mesh Computational Grid

The next step in the creation of the model is generating the 2D mesh grid. This computational grid defines the extents of the computational area within the watershed. The user must define the cell size of the 2D Grid.

- To start, **obtain a shapefile with the extents of the watershed in GIS**.

- Using the **Feature Vertices to Points** tool, convert the shapefile into a polygon with points at each vertex.

Figure 27 Converting HU8 outline to points

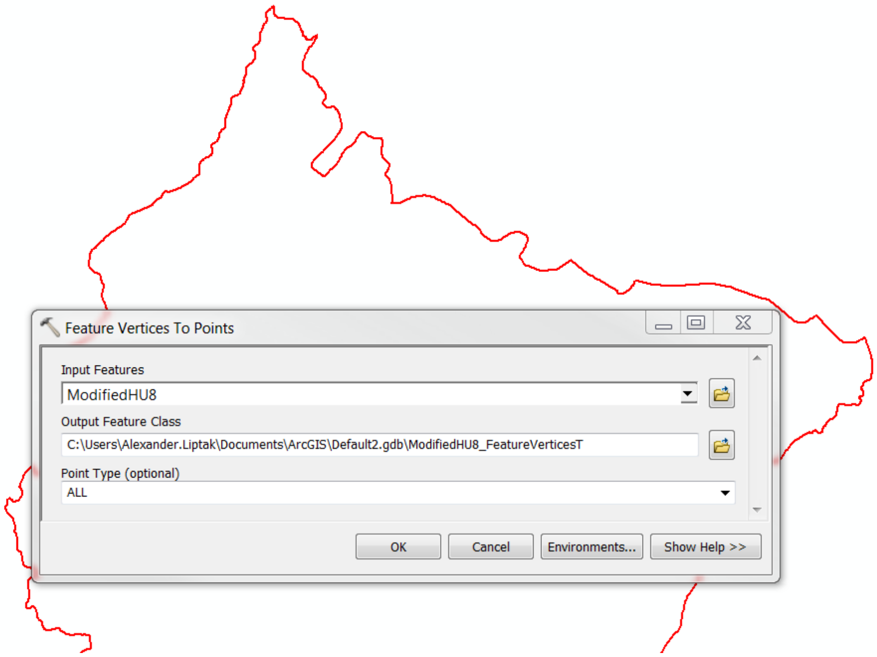
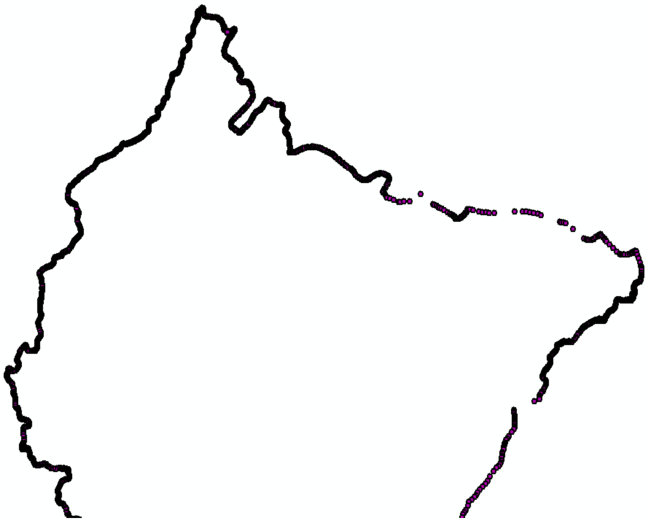


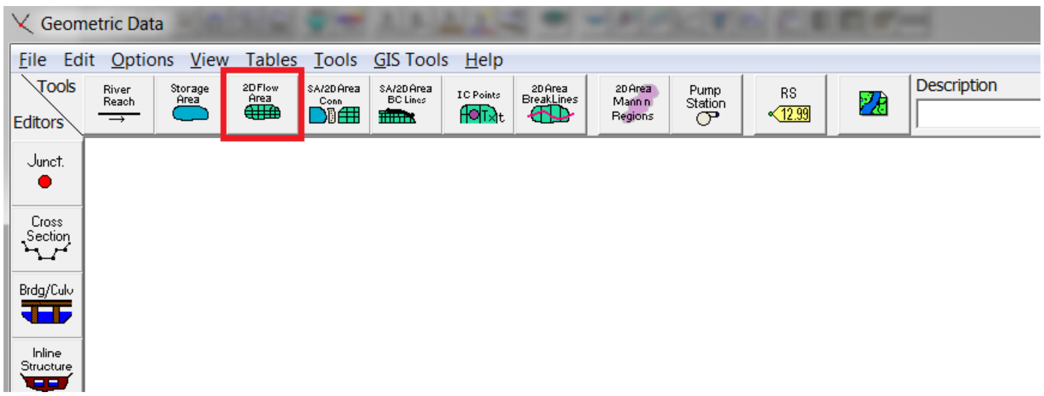
Figure 28 HU8 Outline in Points



- Next, add coordinates to these points so that they may be brought into HEC-RAS. The **Add XY Coordinates (Data Management)** tool will add two columns to the attribute table of the points layer, one for X and one for Y. Make sure that the projection of the points layer is set to the same projection as the HEC-RAS model.

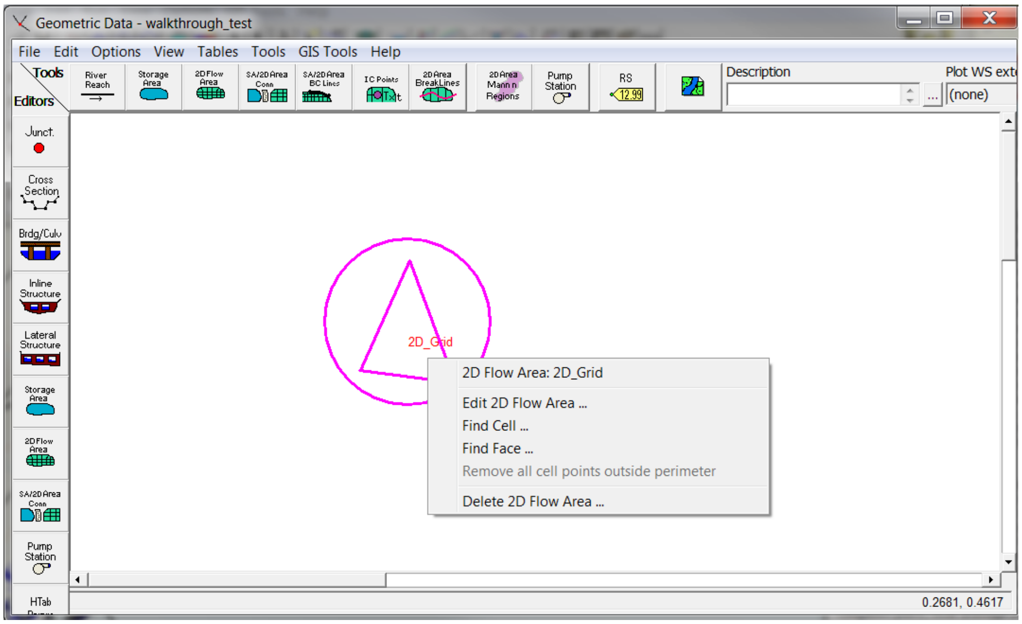
- Once the X and Y coordinates have been defined, export the data so it can later be brought into HEC-RAS. A simple way to do this is the **Table to Excel** tool, which will export the attribute table of the point layer into a Microsoft Excel file. From the Excel file that is generated, simply select the X and Y coordinates of the extents layer, copy to the clipboard, and return to HEC-RAS.
- In the Geometry Window, select **2D Flow Area** in the Tools toolbar.

Figure 29 2D Flow Area Creation Tool



- Draw a small polygon and double click to finalize.
- Name the grid and click on the newly created polygon, then select **Edit 2D Flow Area** window.

Figure 30 Editing a 2D Flow Area



- In the Edit 2D Flow Area window, select **GIS Outline**. In this window, it is possible to replace the coordinates of the small placeholder shape created with the coordinates copied from the excel file.

Figure 31 2D Flow Area Editor Window

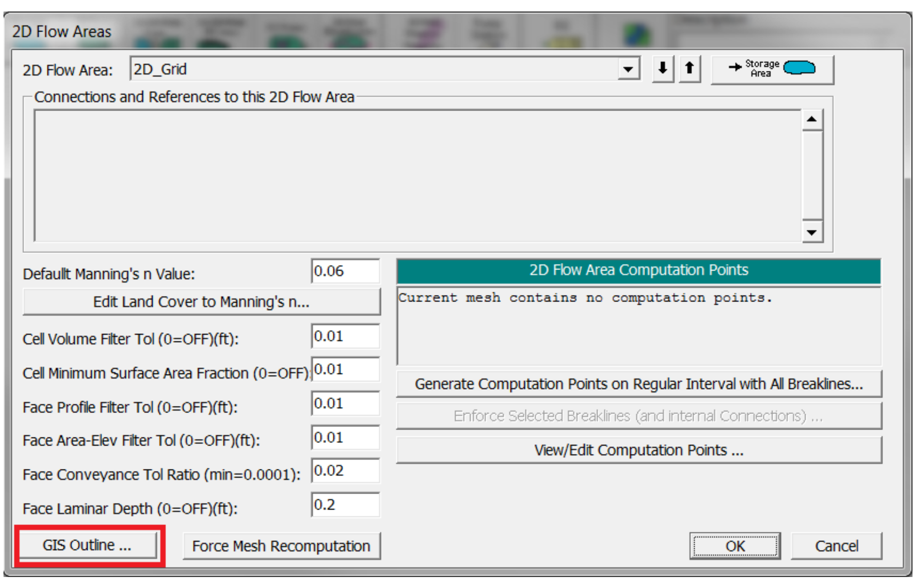
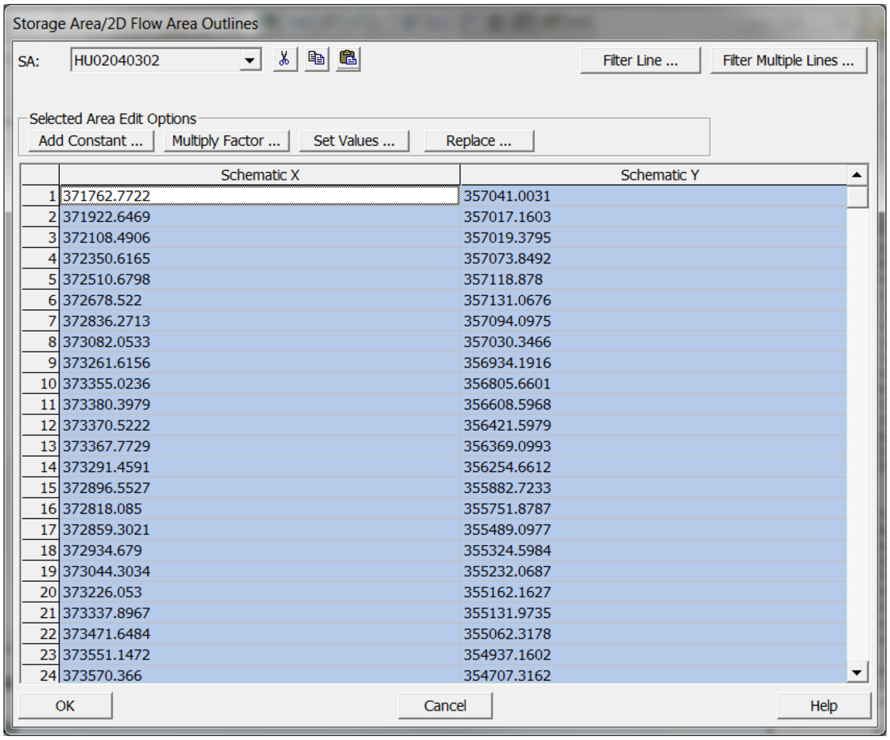


Figure 32 Replacing dummy coordinates with HU8 outline coordinates



- Once the coordinates are pasted into the table, press OK. In the 2D Flow Areas editor window, press OK.
- The new watershed extents generated will likely exceed the view extents of the previously drawn 2D shape. To view the new extents of the 2D Flow Area, Select **View → Set Schematic Plot Extents**. Then, select **Set to Computed Extents**.

Figure 33 Reset geometry window to computed extents

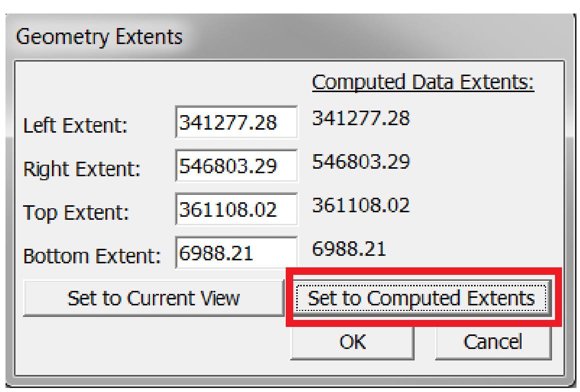
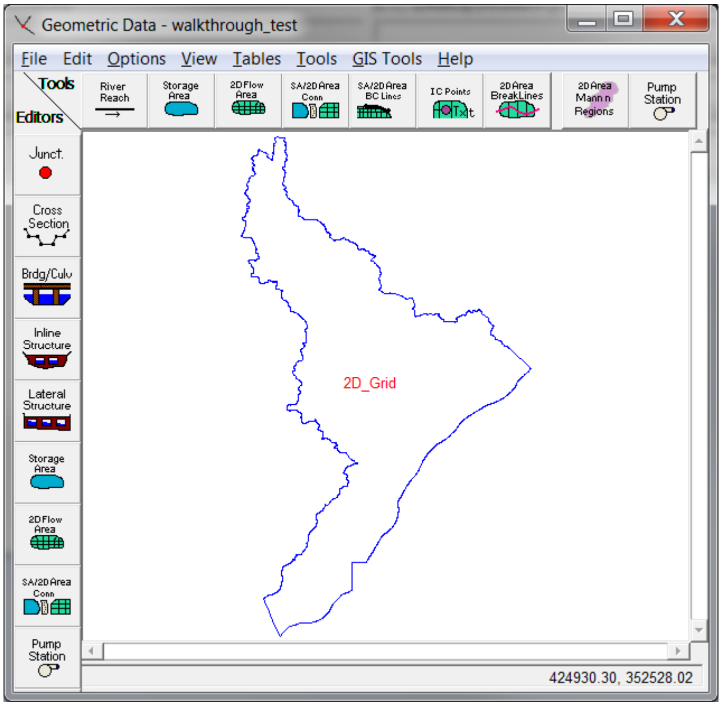
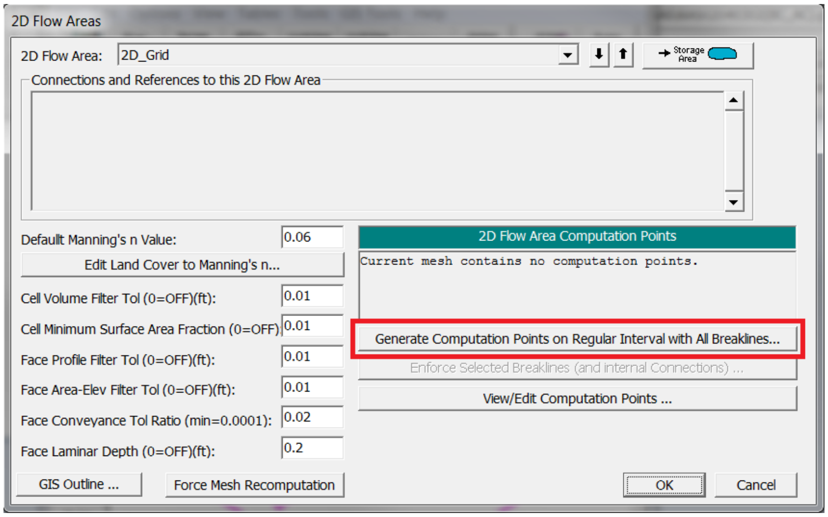


Figure 34 2D Grid with extents of HU8



- Press OK and return to the geometry window and review the extent of the watershed in the geometry window.
- Specify the cell sizing and alignment and generate the grid. Go back to the 2D Flow Area editor window and select **Generate Computation Points on Regular Interval with All Breaklines**.

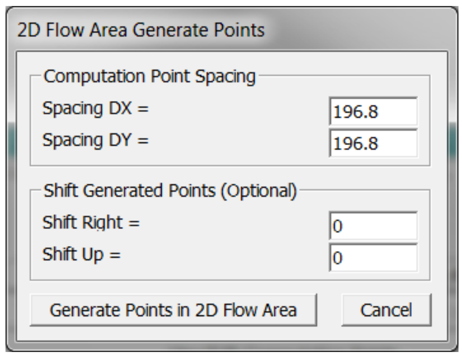
Figure 35 Generating computational cells in the 2D mesh



- The resulting window will allow the user to specify the cell size and to shift the cells from the default computed position.

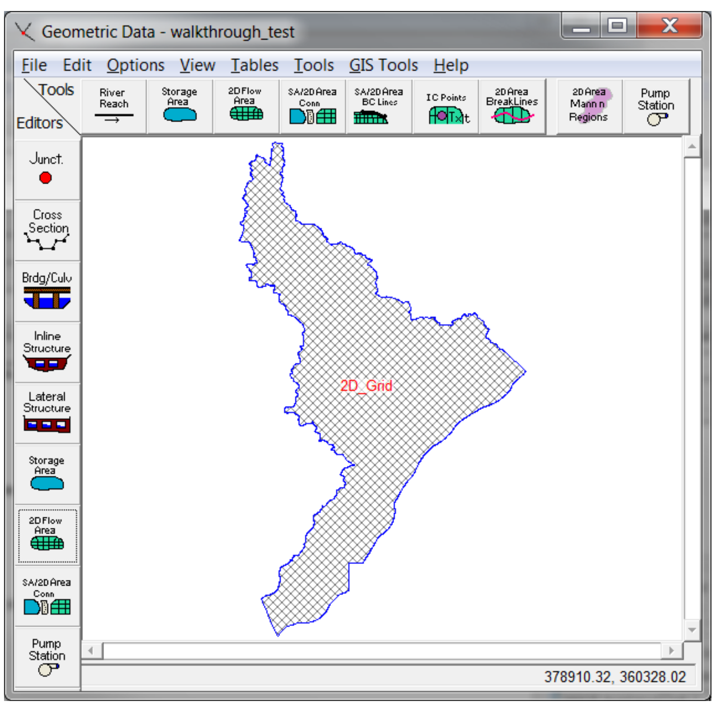
  Cell sizing for this process was selected at 196.8’, to be as close to 200’x200’ (industry standard) cell sizing while still allowing DEM cells to be wholly divisible within each computational cell (60 terrain cells wide at 3.28’ per cell = 196.8’ wide computational cells).

Figure 36 Specifying computational grid cell size



- Select **Generate Points in 2D Flow Area,** return to the 2D Flow Areas window, and select **OK.** HEC-RAS will then generate the 2D mesh grid, which should appear in the Geometry Window once it is done computing.

Figure 37 Completed 2D computational mesh

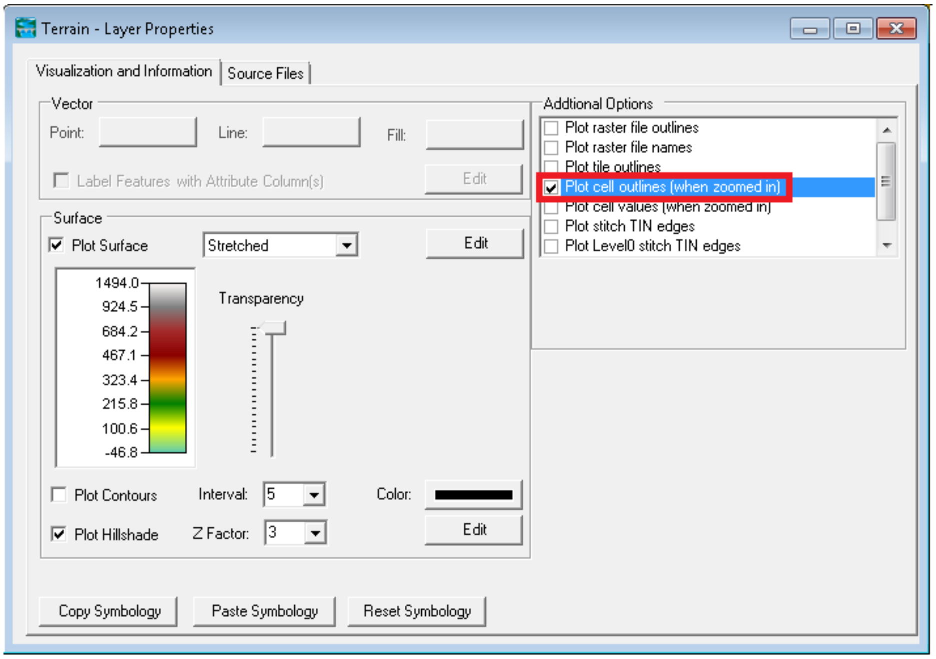


Aligning Computational Cells with Terrain Cells (Optional)

An optional step in this process is to align the edges of the terrain cells with the cells of the 2D mesh grid.

- To achieve this, go to RAS Mapper, **right click Terrain**, and select **Image Display Properties**.
- In the properties window, select **Plot cell outlines (when zoomed in)**.

Figure 38 Viewing terrain cell outlines



- Next, zoom in to a corner of a computational cell in RAS Mapper until the boundaries of the terrain cells appear.
- Using the **Measure distance** tool, measure the required shift in terms of Shift Right and Shift Up. View the measured distance in the bottom left of the RAS Mapper window for a higher precision measurement.

Figure 39 Measuring distance to higher precision in RAS Mapper

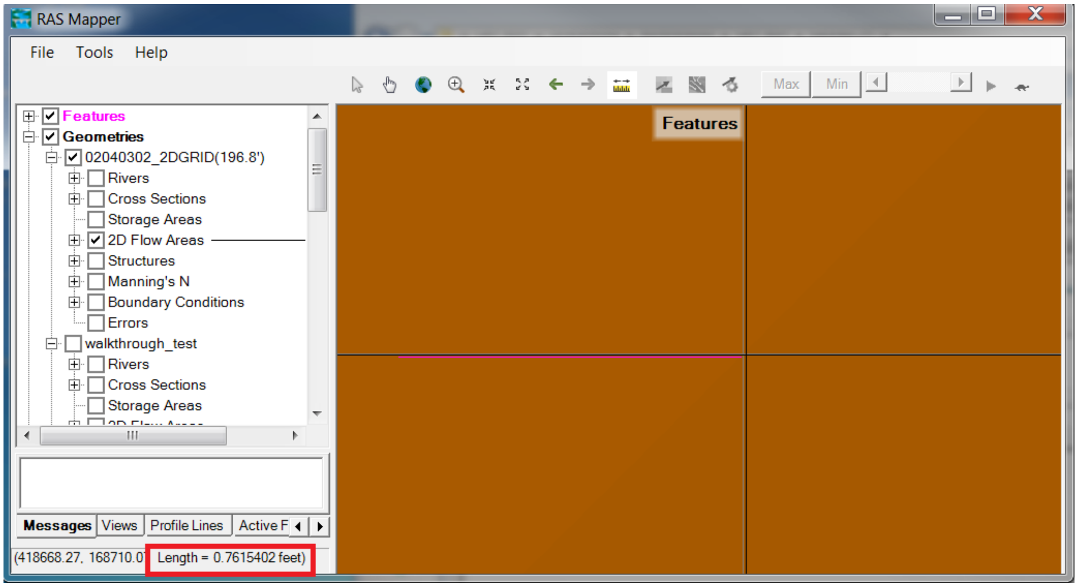
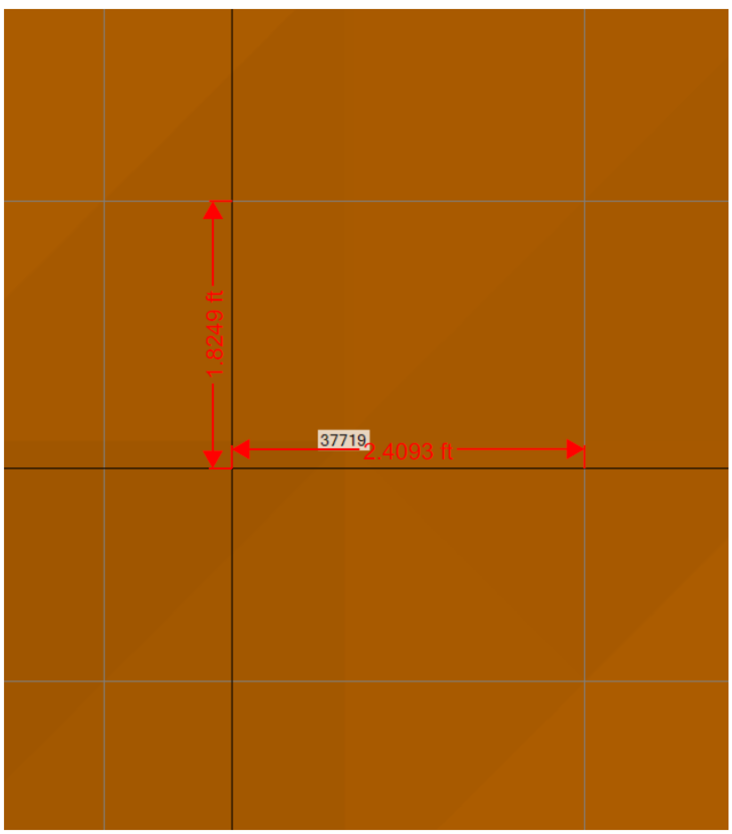


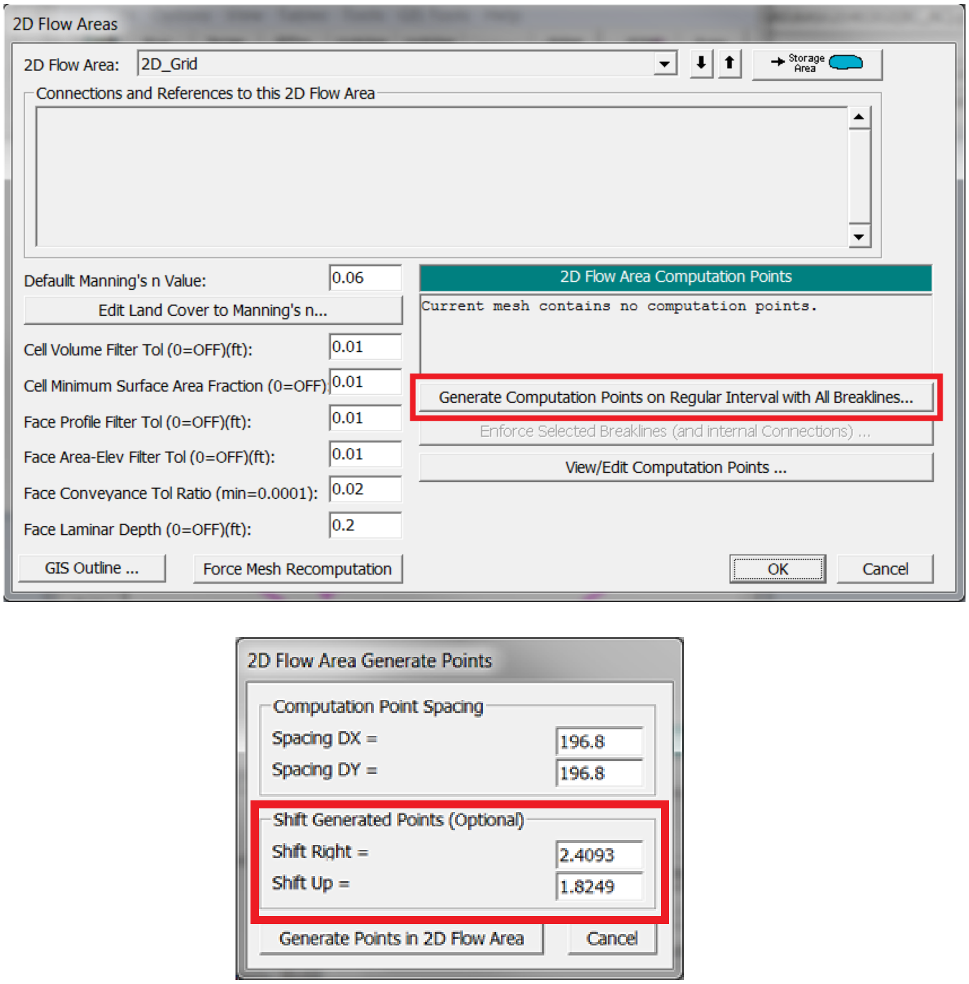
Figure 40 Measuring required Right and Up shift of computational cells



- Return to the geometry window, open the 2D Flow Area editor window, and again select **Generate Computation Points on Regular Interval with All Breaklines**. Enter the shifts into the editor window that appears.

- Re-generate the 2D Flow Area and return to RAS Mapper to inspect the changes. The faces of the terrain cells should now align with the faces of the computational cells.

Figure 41   Shifting generated computational cells



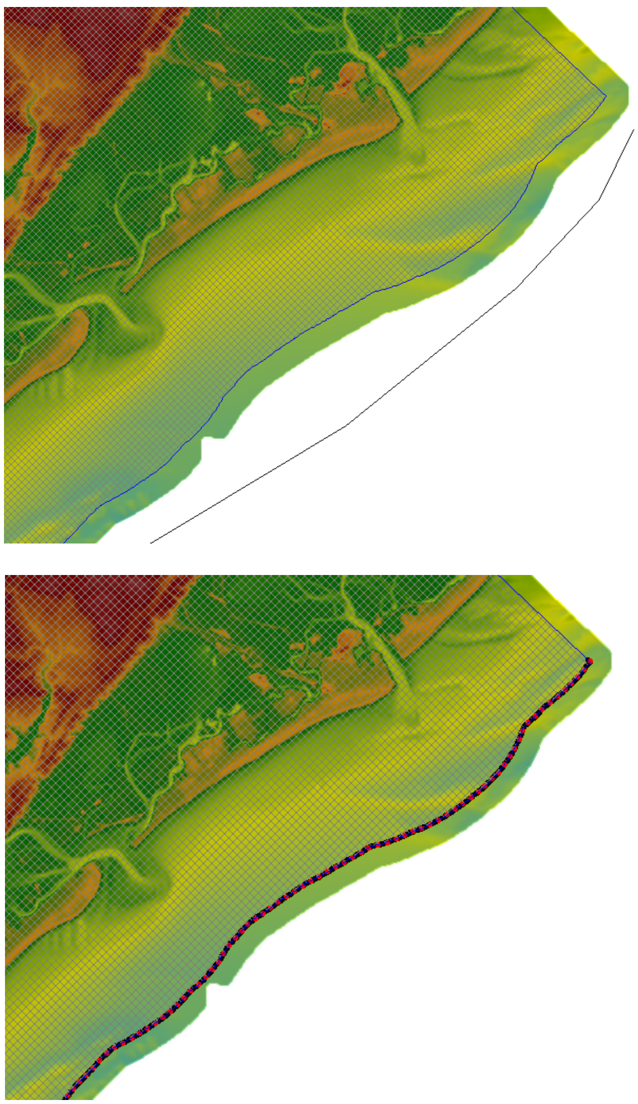
Creating 2D Flow Area Boundary Condition Lines

A crucial step in building a HEC-RAS model is defining the boundary conditions of the model, particularly the tailwater elevation and location of the exit point. For 2D models, the boundary condition line is drawn at the exit point of the modeled area along the cell faces that make up the edge of the 2D mesh grid. In the example used below, a coastal HU8 has a boundary condition line that runs all along the coastal face of the watershed. Watersheds with a riverine boundary condition will draw the boundary condition line across the waterway at the exit point of the watershed.

This modeling process derived boundary condition values from two tidal gages, one located in Sandy Hook, NJ (Station ID 8531680) and the other in Atlantic City, NJ (Station ID 8534720). Mean Higher High Water (MHHW) gage datum elevations were converted to NAVD88 and then water surface elevation increases corresponding to sea level rise and/or storm surge conditions (where appropriate) were added to the gage elevations. See the introduction earlier in this document or the Risk Assessment Methodology for more information on boundary condition values used and the flooding conditions those values are associated with.

- To specify the location of the boundary condition line in a 2D Model, begin by opening the **Geometry Window**.
- In the Tools toolbar, select **SA/2D Area BC Lines**. This will turn the cursor into a pencil, allowing the user to specify the start point of the boundary condition line. Place the start point outside of the computational grid, but close to the cell that is the start of the boundary condition. Precision is not necessary when drawing boundary condition lines, as HEC-RAS will snap the line to the edge of the computational grid once the user is done drawing.

Figure 42 Drawing boundary condition lines on the 2D Grid

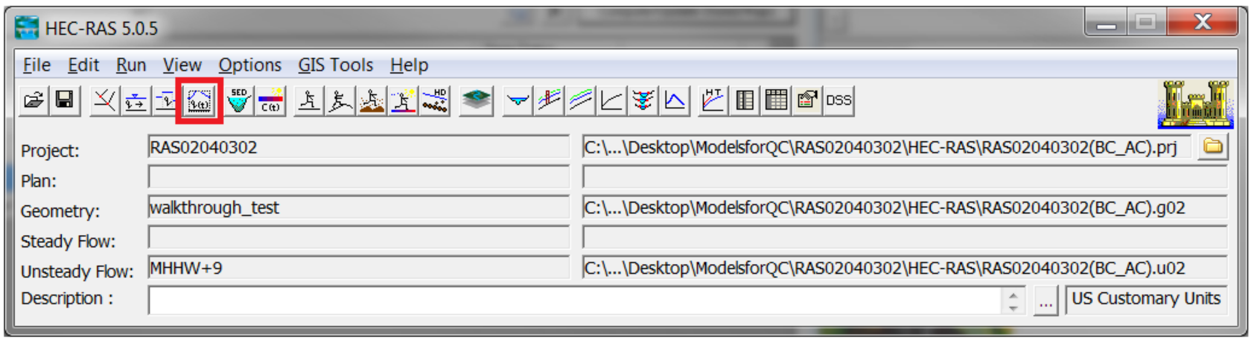


- To complete the boundary condition line, draw to the desired endpoint of the boundary condition and double click. This will finish the line and a prompt to name the boundary condition will appear.
- Name the boundary condition line and save the geometry file.

Creating Unsteady Flow Files

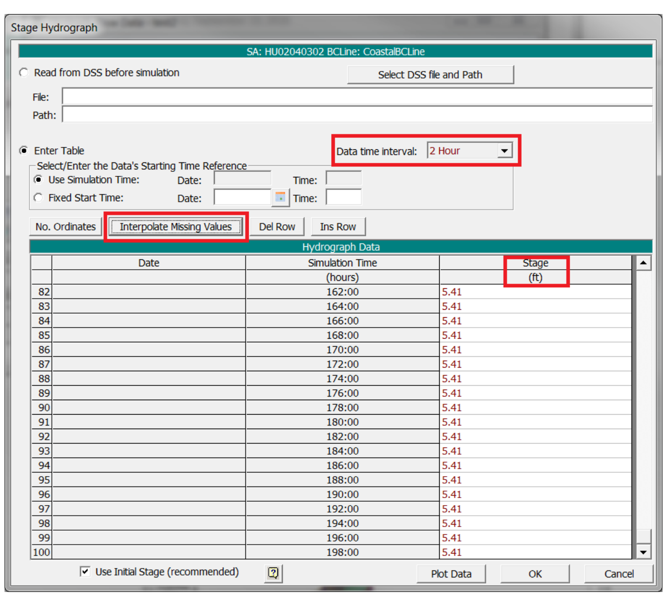
The final step in creating the HEC-RAS model is to create the unsteady flow files, which contain data regarding the boundary condition tailwater elevation and the data contained in the stage hydrograph from HEC-HMS. One unsteady flow file will be created for each boundary condition that is being modeled.

Figure 43 Boundary Condition Line (Red and Black) snapped to 2D Grid Extents



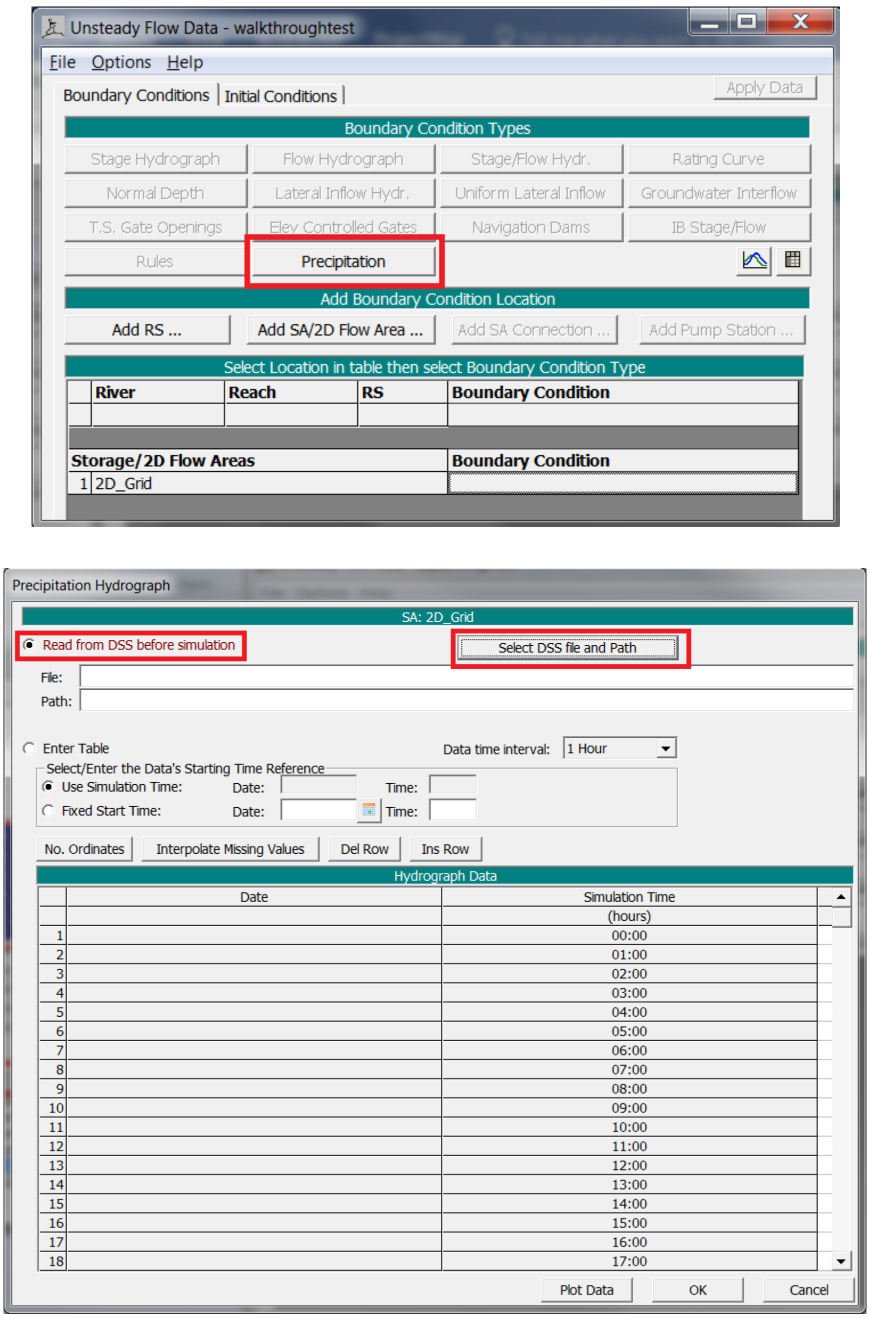
- To start, select **View/Edit Unsteady Flow Data** in the HEC-RAS main window.
- In the Unsteady Flow Data window, select **File→New Unsteady Flow Data**. Name and save the file to the project folder. In the Unsteady Flow Data window, the previously defined Boundary Condition line will appear under Storage/2D Flow Areas.
- To define the tailwater elevation of the Boundary Condition, select **"Stage Hydrograph" under Boundary Condition Types**.

Figure 44 Assigning tailwater elevations to the boundary condition line



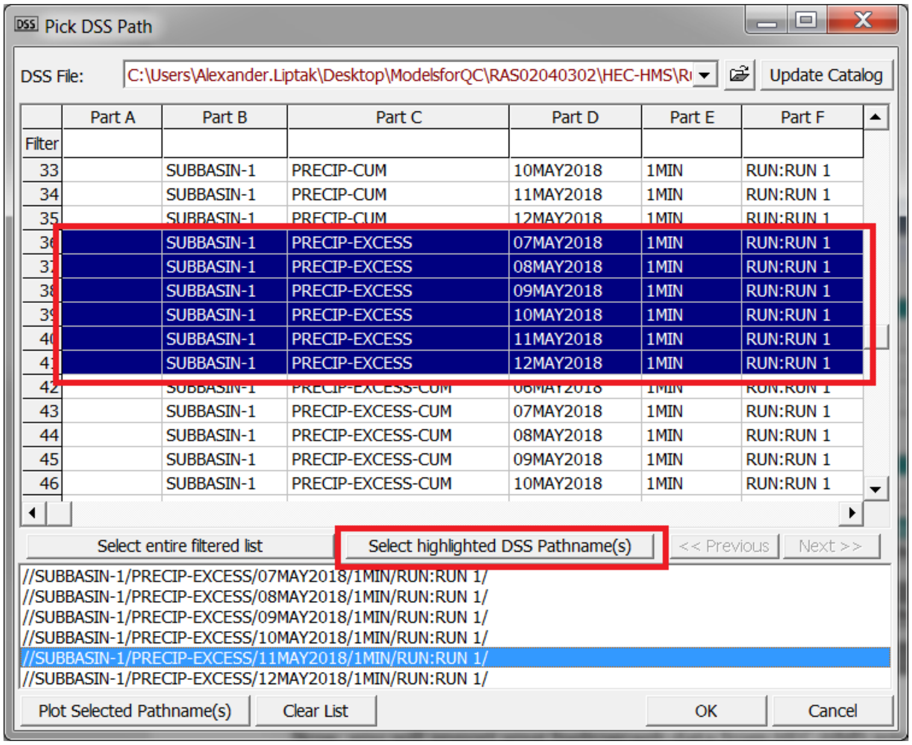
- In the Stage Hydrograph window, select a **Data time interval** that will provide elevation values at all simulation timesteps in the model.
- To enter this, **enter the tailwater elevation under Stage (ft)** for the first and last timesteps in the hydrograph, then select **Interpolate Missing Values** to fill in the rest.
- Next, select **Add SA/2D Flow Area.**
- **Select the 2D grid created and add it to the Select Storage Areas for BC's list**. Press OK to confirm.
- Close the window and select **Precipitation** from the Boundary Condition Types.
- Now, import the hyetograph data from HEC-HMS into RAS. In the Precipitation Hydrograph window, select **Read from DSS Before Simulation** and **Select DSS file and Path.** This is where the model run DSS file that was generated in HEC-HMS is located.

Figure 45 Select only the PRECIP-EXCESS files from the HMS run.



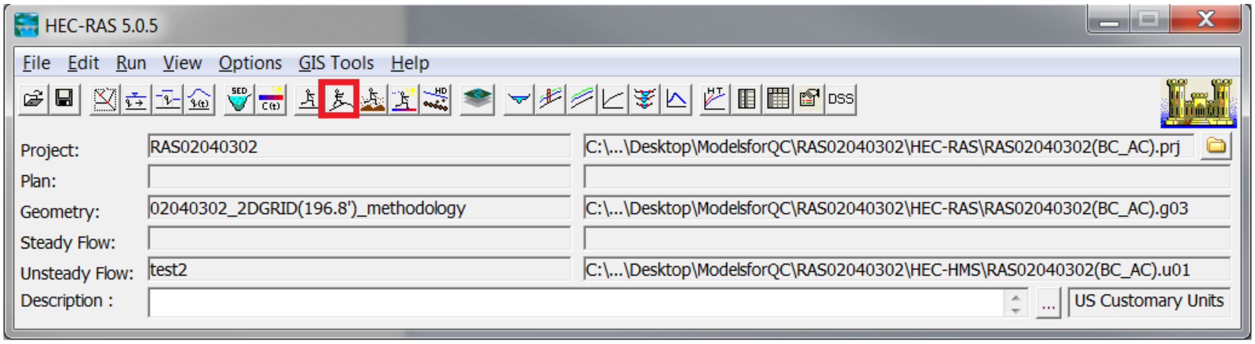
- Find the .DSS file created by the HEC-HMS run, and select the PRECIP-EXCESS pathnames. This will serve as the precipitation hyetograph for the model.

Figure 46 Linking HEC-HMS excess precipitation to HEC-RAS



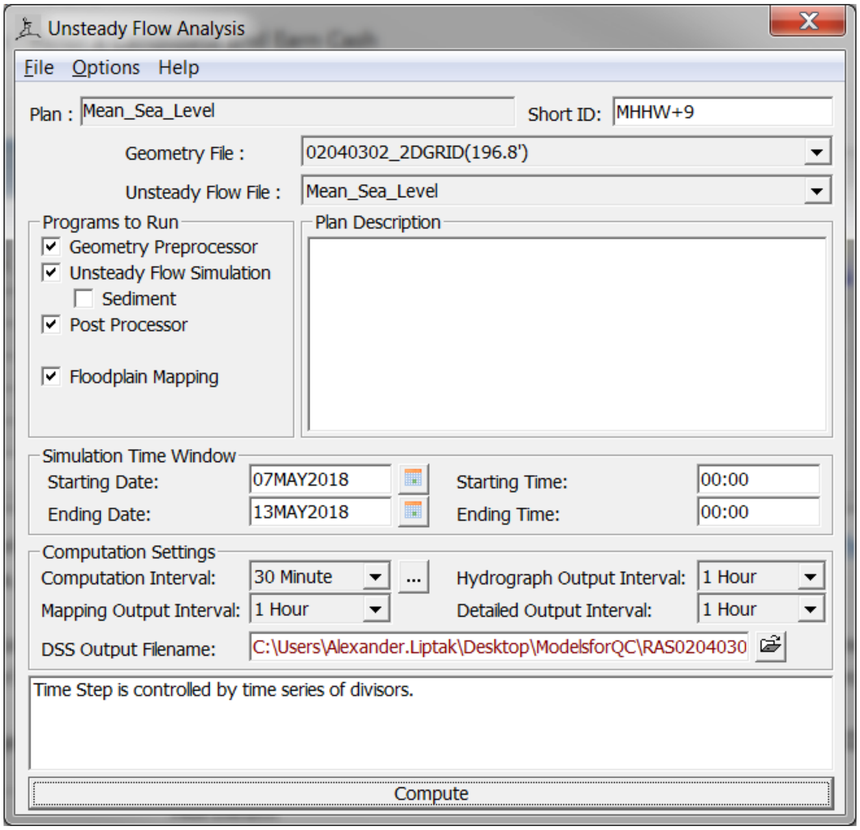
- Press OK and return to the Unsteady Flow window.
- To create additional Unsteady Flow files with other boundary conditions, simply change the tailwater elevation values in the boundary condition stage hydrograph editor, and Save As… to a new unsteady flow file.
- Once the desired Unsteady flow files have been created, it is time to run the model.

Figure 47 Unsteady Flow Simulation from the HEC-RAS main window



- Back in the HEC-RAS main window, select the Unsteady Flow Simulation button. This will bring up the Unsteady Flow analysis window. Here, create plan files that specify and save the selections of the Geometry file, Unsteady flow file, computation settings, and more.

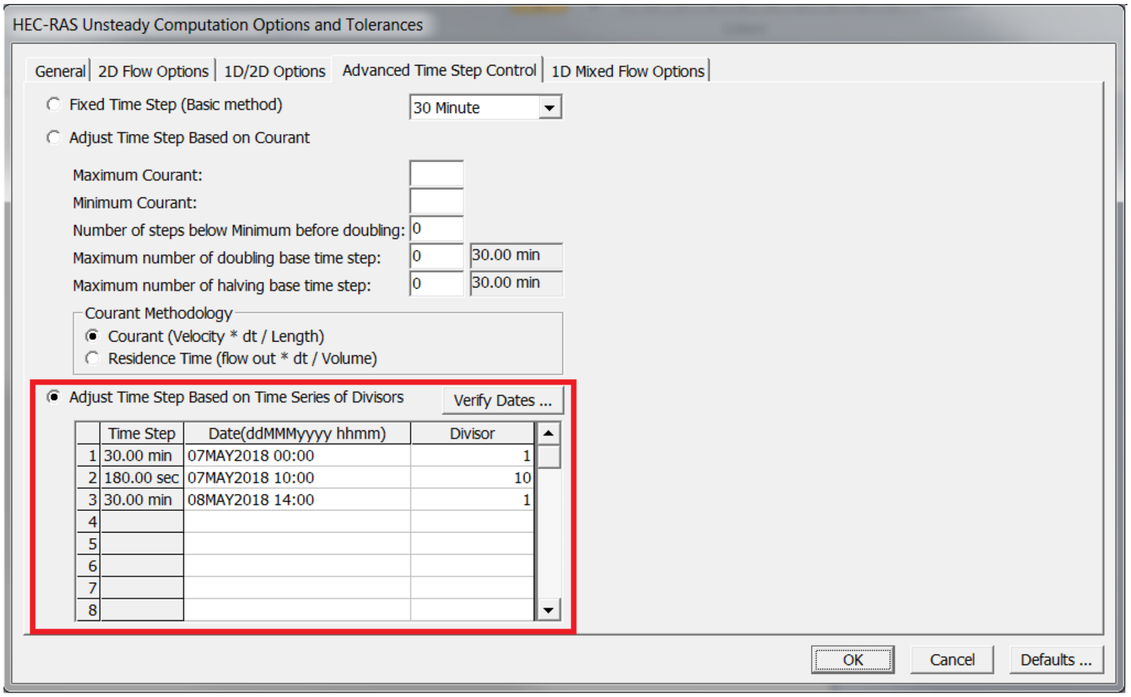
Figure 48 Specifying desired files and settings for a run Plan file



The new (to HEC-RAS) variable timestep function was used during this process to increase model output quality and precision while also not dramatically increase runtimes. The variable timestep function allows the user to control the computation time interval over certain periods of the model duration. Increasing computational frequency in a desired time period of the model will increase the accuracy of the results in that time period, then allow the rest of the model to run on a longer time step, minimizing increase in total processing time. In this case, a 3-minute computation interval was used for 30 hours starting just before the water level rises, to achieve more precise computation for the period containing the maximum inundation and peak flows. After the 30 hours elapsed, the model would return to a 30-minute time step for the remainder of the computations.

- To set variable timestep settings, click the symbol next to the Computation Interval setting.

Figure 49 Using variable time steps to increase computation frequency in a specified time window



In cases where model results generated from the variable timestep settings above did not produce the desired results (such as artificially high spikes in max flood depth, or very sharp and frequent increases/decreases in depths throughout the model run), another method of computational timestep determination was used. This method allowed HEC-RAS to automatically adjust the timestep based on the computed Courant numbers between cells in the mesh.

Figure 50 Depth profile of a cell from Courant Method variable timestep adjustment (MSL_c3) compared to Series of Divisors 3-min timestep selection

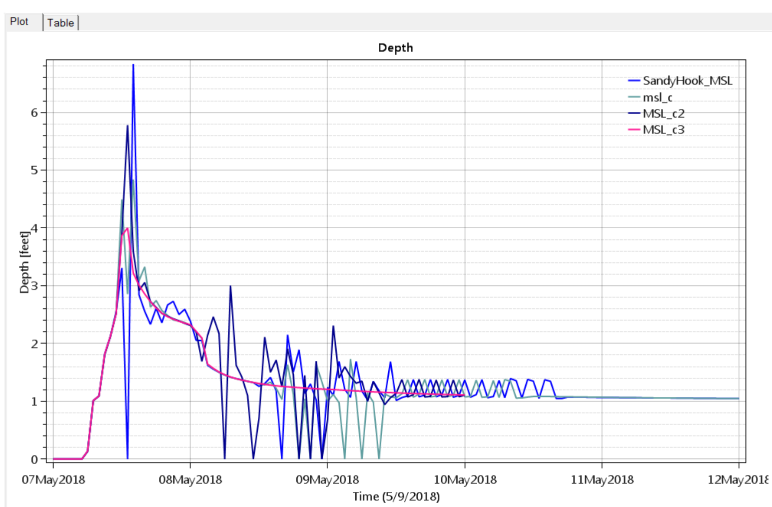
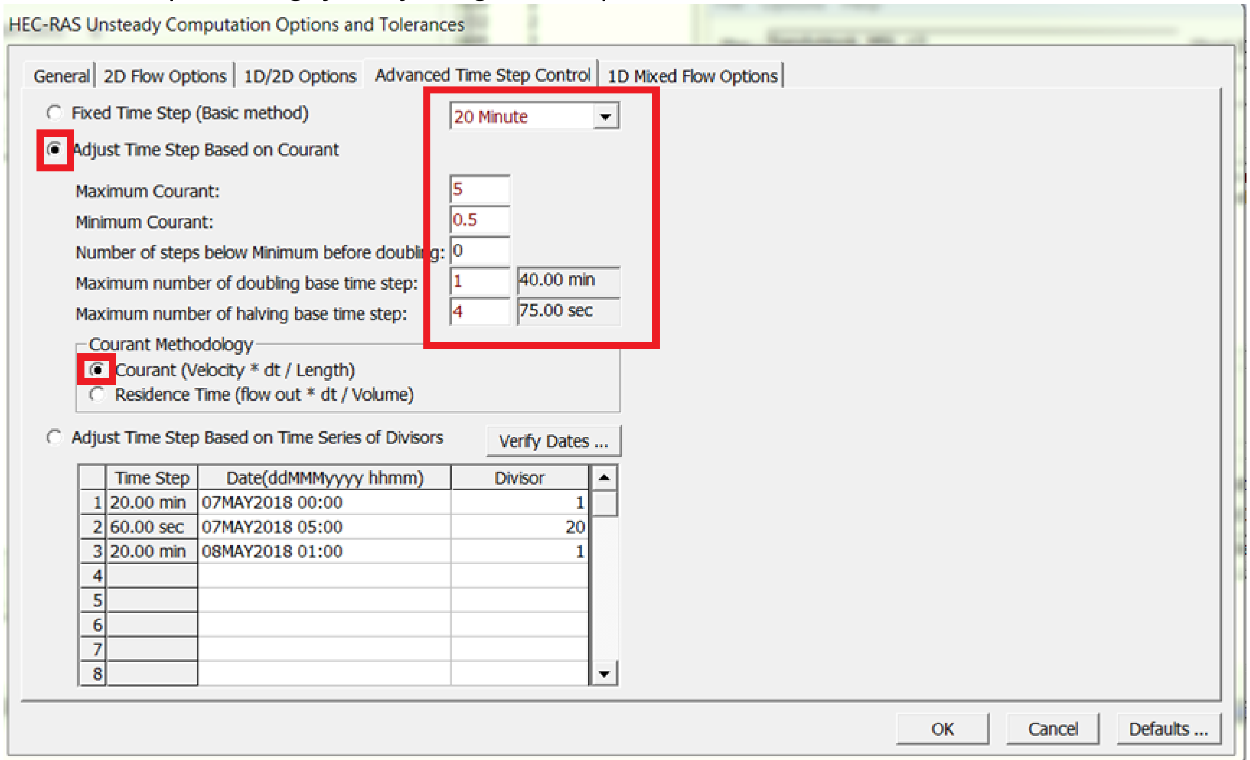


Figure 51 Example settings for adjusting time step based on Courant numbers



- Once the computation interval is set and the desired run settings and file selections are specified, **Name and Save the Plan file**. Give the plan an ID that will allow identification of which boundary conditions were used in the Unsteady Flow file that is saved to that plan.
- Finally, hit **Compute** to run the model.

Viewing Results and Generating Results Maps

- Once the model is run successfully, view the results in RAS Mapper. **Open RAS Mapper** to view and generate mapping results.
- To generate results maps, right click on the plan/run of the user's choice and select **Add New Results Map Layer**. Then, select the model condition being generated, where it should be saved, and select **Add Map**.

Figure 52   Creating new results map layers

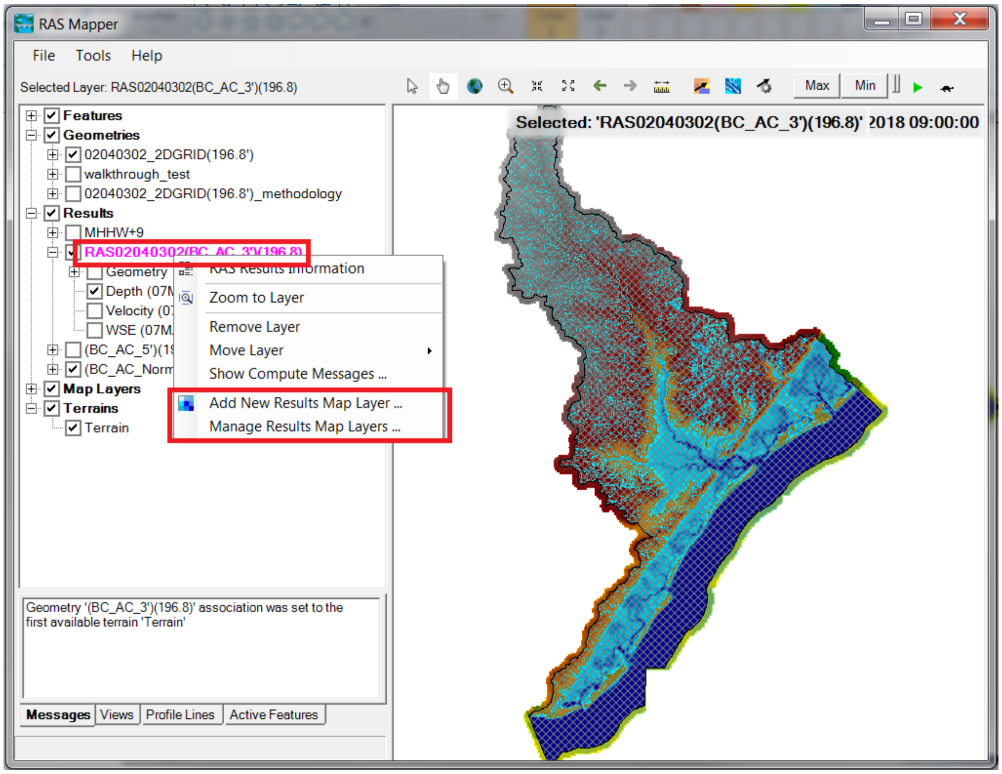
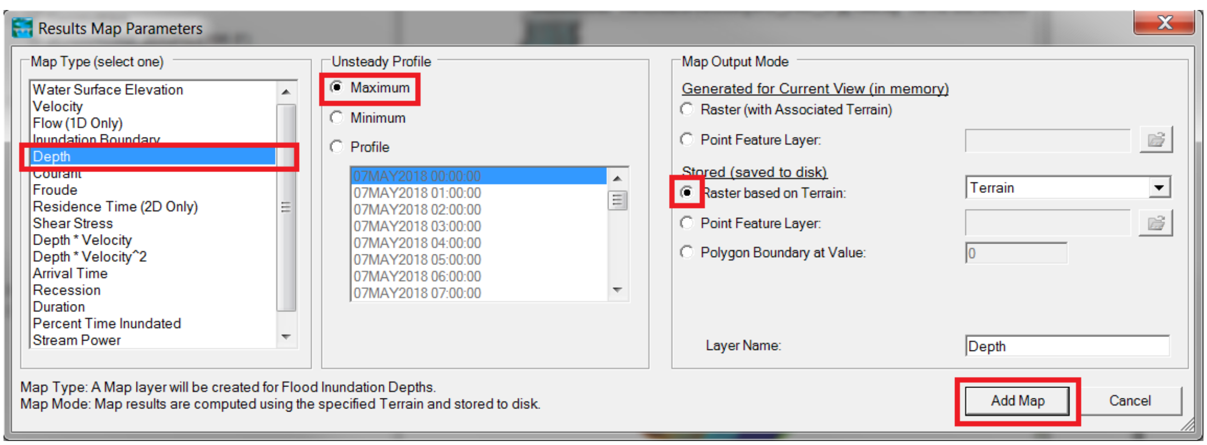
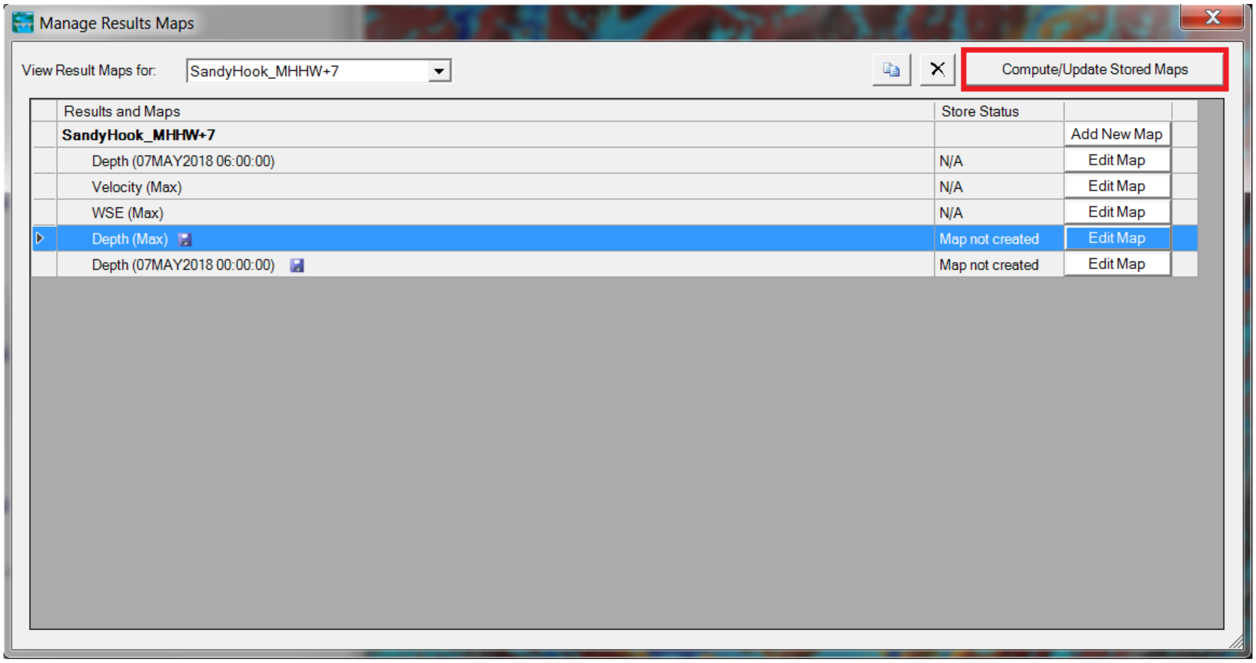


Figure 53   Specifying results map type, profile, and file location



- Once the desired results maps have been added, generate the maps. In RAS Mapper, right click on the model run that contains the results map and select **Manage Results Maps Layers**.

Figure 54 Computing stored results maps



- Now, select the results map being generated, and hit Compute/Update Stored Maps. This will generate a results map and store it in the HEC-RAS project folder in .tiff format.

Appendix A: Data Sources and Uses for Floodplain Modeling and Mapping

Data Type	Data Source	Data Use
Coastal Water Surface Elevations	*A Process for Analyzing Current and Future Coastal Flood Exposures Using a Total Water Levels Approach* (Sept. 18)	Used for boundary condition water surface elevations for coastal watersheds.
Digital Elevation Model (DEM)	2015 CoNED NJ/DE DEM (3.28') (Link) 2016 CoNED NE DEM (3.28') (Link)	Used to create terrain files for HEC-RAS 2D models. All DEMs converted to 3.28' cell size and mosaiced together in GIS. Each terrain file for each watershed may contain DEM data from both sources.
Land Use	2011 NLCD (Non-NJ Areas) (Link) 2012 NJ Statewide Land Use (NJ Areas – 2015 Update) (Link)	NLCD Manning's n values were matched to most similar NJDEP Land Use category Manning's n and updated in the HEC-RAS 2D model. Land Use data used for land surface friction values in HEC-RAS 2D models, and for determining curve numbers for HEC-HMS models.
Precipitation	2006 NOAA Precipitation Frequency Data Server (PFDS) GIS Format Precipitation Depth Raster Files (Link)	Input into HEC-HMS to determine excess rainfall for HEC-RAS 2D models.
Soils	NRCS WebSoilSurvey (SSURGO Data) (Link)	Combined with land use data to create curve numbers for HEC-HMS models.
Streamlines	2016 National Hydrography Dataset (NHD) (Link)	Stream lines used to hydrologically correct DEMs, in ArcHydro Tools processing.

Appendix B: Assigned Roughness Coefficients of NJDEP Land Use Types

NJDEP Land Use Category	Code	Manning N	Manning's N Source
Agricultural Wetlands Cranberry Farms & Modified Uplands	2140	0.1	NLCD Emergent Herbaceous Wetlands
Airport Facilities	1440	0.013	NLCD Developed, Open Space
Altered Lands	7400	0.03	NLCD Barren Land
Artificial Lakes	5300	0.03	NLCD Open Water
Athletic Fields Schools	1804	0.03	NLCD Grassland/Herbaceous
Atlantic Ocean	5430	0.03	NLCD Open Water
Atlantic White Cedar Wetlands	6221	0.1	NLCD Woody Wetlands
Bare Exposed Rock, Rockslides, etc.	7200	0.03	NLCD Barren Land
Bays, Estuaries & other Tidal Waters	5400	0.03	NLCD Open Water
Beaches	7100	0.03	NLCD Barren Land
Bridge Over Water	1419	0.013	NLCD Developed, Open Space
Brush-Dominate and Bog Wetlands	6230	0.1	NLCD Emergent Herbaceous Wetland
Brushland/Shrubland	4400	0.05	NLCD Scrub/Shrub
Cemetery	1710	0.04	TR-55 Table 3-1 Trees: Cleared land with tree stumps, no sprouts
Cemetery on Wetland	1711	0.04	TR-55 Table 3-1 Trees: Cleared land with tree stumps, no sprouts
Coastal Wetlands	6100	0.1	NLCD Emergent Herbaceous Wetland
Commercial and Services	1200	0.1	NLCD Developed, High Intensity
Confined Feeding Operations	2300	0.05	NLCD Developed, low intensity.
Coniferous Brush/Shrubland	4430	0.1	TR-55 Table 3-1 Trees: Same as above, but heavy sprouts
Coniferous Forest	4200	0.12	NLCD Evergreen Forest
Coniferous Forest >50% Crown Closure	4220	0.16	NLCD Evergreen Forest (maximum)
Coniferous Forest 10-50% Crown Closure	4210	0.1	NLCD Evergreen Forest (minimum)
Coniferous Scrub/Shrub Wetlands	6232	0.1	NLCD Emergent Herbaceous Wetland
Coniferous Wooded Wetlands	6220	0.1	NLCD Woody Wetlands
Cropland and Pastureland	2100	0.04	NLCD Pasture/Hay
Deciduous Brush/Shrubland	4420	0.1	TR-55 Table 3-1 Trees: Same as above, but heavy sprouts
Deciduous Forest	4100	0.12	NLCD Deciduous Forest
Deciduous Forest >50% Crown Closure	4120	0.16	NLCD Deciduous Forest (maximum)
Deciduous Forest 10-50% Crown Closure	4110	0.1	NLCD Deciduous Forest (minimum)
Deciduous Scrub/Shrub Wetlands	6231	0.1	NLCD Emergent Herbaceous Wetland
Deciduous Wooded Wetlands	6210	0.1	NLCD Woody Wetlands
Disturbed Tidal Wetlands	7440	0.1	NLCD Emergent Herbaceous Wetland
Disturbed Wetlands Modified	7430	0.1	NLCD Emergent Herbaceous Wetland
Dredged Lagoon	5420	0.03	NLCD Open Water
Exposed Flats	5190	0.03	NLCD Grassland/Herbaceous
Extractive Mining	7300	0.03	NLCD Barren Land
Former Agricultural Wetlands Becoming Shrubby not Built-up	2150	0.1	NLCD Woody Wetlands
Former Military; Indeterminate Use	1214	0.075	NLCD Developed, Medium Intensity
Freshwater Tidal Marshes	6120	0.1	NLCD Emergent Herbaceous Wetland
Herbaceous Wetlands	6240	0.1	NLCD Emergent Herbaceous Wetland
Industrial	1300	0.1	NLCD Developed, High Intensity

Industrial and Commercial Complexes	1500	0.1	NLCD Developed, High Intensity
Interior Wetlands	6200	0.1	NLCD Woody Wetlands
Major Roadway	1410	0.013	NLCD Developed, Open Space
Managed Wetland, in Built-up Maintained Rec Area	1850	0.05	NLCD Scrub/Shrub
Managed Wetland, in Maintained Lawn Green space	1750	0.05	NLCD Scrub/Shrub
Managed Wetlands Modified	8000	0.075	NLCD Emergent Herbaceous Wetland (minimum)
Military Installations	1211	0.075	NLCD Developed, Medium Intensity
Mixed Deciduous/Coniferous Brush/Shrubland	4440	0.1	TR-55 Table 3-1 Trees: Same as above, but heavy sprouts
Mixed Forest	4300	0.12	NLCD Deciduous Forest
Mixed Forest >50% Coniferous with >50% Crown Closure	4312	0.16	NLCD Evergreen Forest (maximum)
Mixed Forest >50% Coniferous with 10-50% Crown Closure	4311	0.1	NLCD Evergreen Forest (minimum)
Mixed Forest >50% Deciduous with >50% Crown Closure	4322	0.16	NLCD Deciduous Forest (maximum)
Mixed Forest >50% Deciduous with 10-50% Crown Closure	4321	0.1	NLCD Deciduous Forest (minimum)
Mixed Forested Wetlands Coniferous Dom.	6252	0.1	NLCD Woody Wetlands
Mixed Forested Wetlands Deciduous Dom.	6251	0.1	NLCD Woody Wetlands
Mixed Residential	1150	0.075	NLCD Developed, Medium Intensity
Mixed Scrub/Shrub Wetlands Coniferous Dom.	6234	0.1	NLCD Emergent Herbaceous Wetland
Mixed Scrub/Shrub Wetlands Deciduous Dom.	6233	0.1	NLCD Emergent Herbaceous Wetland
Mixed transportation Corridor Overlap Areas	1411	0.05	NLCD Developed, Low Intensity
Mixed Urban or Built-up Land	1600	0.075	NLCD Developed, Medium Intensity
Mixed Wooded Wetlands	6250	0.1	NLCD Woody Wetlands
Natural Lakes	5200	0.03	NLCD Open Water
Old Field < 25% Brush Covered	4410	0.04	NLCD Pasture/Hay
Open Tidal Bays	5411	0.03	NLCD Open Water
Orchards, Vineyards, Nurseries, Horticultural Areas, Sod Farms	2200	0.035	NLCD Cultivated Crops
Other Agriculture	2400	0.035	NLCD, Cultivated Crops
Other Urban or Built-up Land	1700	0.075	NLCD Developed, Medium Intensity
Phragmites Dominate Coastal Wetlands	6141	0.1	NLCD Woody Wetlands
Phragmites Dominate Interior Wetlands	6241	0.1	NLCD Woody Wetlands
Phragmites Dominate Old Field	4411	0.05	NLCD Scrub/Shrub
Phragmites Dominate Urban Area	1741	0.1	NLCD Woody Wetlands
Plantation	4230	0.035	NLCD Cultivated Crops
Railroad Facilities	1420	0.05	NLCD Developed, Low Intensity
Recreational Land	1800	0.013	NLCD Developed, Low Intensity
Residential	1100	0.075	NLCD Developed, Medium Intensity
Residential High Density or Multiple Dwelling	1110	0.1	NLCD Developed, High Intensity
Residential Rural, Single Unit	1140	0.013	NLCD Developed, Open Space
Residential Single Unit, Low Density	1130	0.05	NLCD Developed, Low Intensity
Residential Single Unit, Medium Density	1120	0.075	NLCD Developed, Medium Intensity
Saline Marshes	6110	0.1	NLCD Emergent Herbaceous Wetland
Saline Marshes High marsh vegetation	6112	0.15	NLCD Emergent Herbaceous Wetland (maximum)
Saline Marshes Low marsh vegetation	6111	0.075	NLCD Emergent Herbaceous Wetland (minimum)
Severe Burned Upland Vegetation	4500	0.03	NLCD Barren Land
Severe Burned Wetlands	6500	0.075	NLCD Emergent Herbaceous Wetland (minimum)
Stadium, Theaters, Cultural Centers, and Zoos	1810	0.075	NLCD Developed, Medium Intensity

Stormwater Basin	1499	0.013	NLCD Developed, Open Space
Streams and Canals	5100	0.03	NLCD Open Water
Tidal Mud Flats	5412	0.03	NLCD Barren Land
Tidal Rivers, Inland Bays and other Tidal Waters	5410	0.03	NLCD Open Water
Transitional Areas sites under construction	7500	0.075	NLCD Emergent Herbaceous Wetland (minimum)
Transportation/Communication/Utilities	1400	0.05	NLCD Developed, Low Intensity
Undifferentiated Barren Lands	7600	0.03	NLCD Barren Land
Unvegetated Flats	6290	0.03	NLCD Barren Land
Upland Rights-of-Way, Developed	1462	0.013	NLCD Developed, Open Space
Upland Rights-of-Way, Undeveloped	1463	0.03	NLCD Barren Land
Vegetated Dune Communities	6130	0.05	NLCD Scrub/Shrub
Wetland Rights-of-Way	1461	0.1	NLCD Emergent Herbaceous Wetlands

Appendix C: Assigned Curve Number by NJDEP Land Use Type and HSG

LU7Code	NJDEP - Anderson_Type	TR-55_Type	SCS Curve Number				Notes and Assumptions
			A	B	C	D	
1110	RESIDENTIAL, HIGH DENSITY OR MULTIPLE DWELLING	Residential (1/8 acre)	77	85	90	92	
1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	Residential (1/3 acre)	57	72	81	86	
1130	RESIDENTIAL, SINGLE UNIT, LOW DENSITY	Residential (1 acre)	51	68	79	84	
1140	RESIDENTIAL, RURAL, SINGLE UNIT	Residential (2 acres)	46	65	77	82	
1150	MIXED RESIDENTIAL	Residential (averaged over lot sizes)	58	73	82	86	Average of 1110-1140
1200	COMMERCIAL/SERVICES	Urban districts (commercial and business)	89	92	94	95	
1211	MILITARY INSTALLATIONS	Urban districts (commercial and business)	89	92	94	95	
1214	NO LONGER MILITARY	Urban districts (commercial and business)	89	92	94	95	
1300	INDUSTRIAL	Urban districts (industrial)	81	88	91	93	
1400	TRANSPORTATION/COMMUNICATION/UTILITIES	Impervious Areas (Paved, open ditches)	83	89	92	93	
1410	MAJOR ROADWAY	Impervious Areas (Streets and roads, paved, curbs)	98	98	98	98	
1411	MIXED TRANSPORTATION CORRIDOR OVERLAP AREA	Impervious Areas (Paved, open ditches)	83	89	92	93	
1419	BRIDGE OVER WATER	Impervious Areas (Paved, open ditches)	83	89	92	93	
1420	RAILROADS	Impervious Areas (Gravel)	76	85	89	91	
1440	AIRPORT FACILITIES	Impervious Areas (Paved, open ditches)	83	89	92	93	
1461	WETLAND RIGHTS-OF-WAY	Woods (Poor)	45	66	77	83	Assumed woodlands wetland with higher runoff
1462	UPLAND RIGHTS-OF-WAY DEVELOPED	Residential (averaged over lot sizes)	58	73	82	86	Averaged
1463	UPLAND RIGHTS-OF-WAY UNDEVELOPED	Woods (Fair)	36	60	73	79	
1499	STORMWATER BASIN	Open space (good)	39	61	74	80	
1500	INDUSTRIAL AND COMMERCIAL COMPLEXES	Urban districts (commercial and business)	89	92	94	95	
1600	MIXED URBAN OR BUILT-UP LAND	Residential (averaged over lot sizes)	58	73	82	86	Averaged

1700	OTHER URBAN OR BUILT-UP LAND	Residential (averaged over lot sizes)	58	73	82	86	Averaged
1710	CEMETERY	Open space (good)	39	61	74	80	
1711	CEMETERY ON WETLAND	Open space (poor)	68	79	86	89	Assumed cemetery with higher runoff
1741	PHRAGMITES DOMINATE URBAN AREA	Brush (Fair)	35	56	70	77	
1750	MANAGED WETLAND IN MAINTAINED LAWN GREENSPACE	Open space (fair)	49	69	79	84	
1800	RECREATIONAL LAND	Open space (fair)	49	69	79	84	
1804	ATHLETIC FIELDS (SCHOOLS)	Open space (good)	39	61	74	80	
1810	STADIUM, THEATERS, CULTURAL CENTERS AND ZOOS	Urban districts (commercial and business)	89	92	94	95	
1850	MANAGED WETLAND IN BUILT-UP MAINTAINED REC AREA	Open space (fair)	49	69	79	84	
2100	CROPLAND AND PASTURELAND	Pasture, grassland, or range (good)	39	61	74	80	
2140	AGRICULTURAL WETLANDS (MODIFIED)	Pasture, grassland, or range (poor)	68	79	86	89	Assumed higher runoff than dry pasture
2150	FORMER AGRICULTURAL WETLAND (BECOMING SHRUBBY, NOT BUILT-UP)	Brush (poor)	48	67	77	83	
2200	ORCHARDS/VINEYARDS/NURSERIES/HORTICULTURAL AREAS	Row Crops (SR Good)	67	78	85	89	
2300	CONFINED FEEDING OPERATIONS	Farmsteads	59	74	82	86	
2400	OTHER AGRICULTURE	Pasture, grassland, or range (fair)	49	69	79	84	
4110	DECIDUOUS FOREST (10-50% CROWN CLOSURE)	Woods (Fair)	36	60	73	79	
4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)	Woods (good)	30	55	70	77	
4210	CONIFEROUS FOREST (10-50% CROWN CLOSURE)	Woods (Fair)	36	60	73	79	
4220	CONIFEROUS FOREST (>50% CROWN CLOSURE)	Woods (good)	30	55	70	77	
4230	PLANTATION	Row Crops (SR Good)	67	78	85	89	
4311	MIXED FOREST (>50% CONIFEROUS WITH 10-50% CROWN CLOSURE)	Woods (Fair)	36	60	73	79	
4312	MIXED FOREST (>50% CONIFEROUS WITH >50% CROWN CLOSURE)	Woods (good)	30	55	70	77	
4321	MIXED FOREST (>50% DECIDUOUS WITH 10-50% CROWN CLOSURE)	Woods (Fair)	36	60	73	79	
4322	MIXED FOREST (>50% DECIDUOUS WITH >50% CROWN CLOSURE)	Woods (good)	30	55	70	77	
4410	OLD FIELD (< 25% BRUSH COVERED)	Brush (poor)	48	67	77	83	
4411	PHRAGMITES DOMINATE OLD FIELD	Meadow	30	58	71	78	
4420	DECIDUOUS BRUSH/SHRUBLAND	Brush (good)	30	48	65	73	
4430	CONIFEROUS BRUSH/SHRUBLAND	Brush (good)	30	48	65	73	
4440	MIXED DECIDUOUS/CONIFEROUS BRUSH/SHRUBLAND	Brush (good)	30	48	65	73	
4500	SEVERE BURNED UPLAND VEGETATION	Brush (poor)	48	67	77	83	
5100	STREAMS AND CANALS	See Notes	100	100	100	100	From U Texas Report (pg 101)

5190	EXPOSED FLATS	See Notes	25	25	25	25	From U Texas Report (pg 101)
5200	NATURAL LAKES	See Notes	100	100	100	100	From U Texas Report (pg 101)
5300	ARTIFICIAL LAKES	See Notes	100	100	100	100	From U Texas Report (pg 101)
5410	TIDAL RIVERS, INLAND BAYS, AND OTHER TIDAL WATERS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
5411	OPEN TIDAL BAYS	See Notes	100	100	100	100	Used same values as open water from U Texas Report
5412	TIDAL MUD FLATS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
5420	DREDGED LAGOON	Herbaceous (poor)*	91.7	92.6	94.7	96.5	*Assumed 70% open water (CN 98), HSG A value assumed
5430	ATLANTIC OCEAN	U Texas Report	100	100	100	100	Used same values as open water from U Texas Report
6111	SALINE MARSH (LOW MARSH)	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6112	SALINE MARSH (HIGH MARSH)	Herbaceous (poor)*	91.7	92.6	94.7	96.5	*Assumed 70% open water (CN 98), HSG A value assumed
6130	VEGETATED DUNE COMMUNITIES	Brush (good)	30	48	65	73	
6120	FRESHWATER TIDAL MARSHES	Herbaceous (poor)*	91.7	92.6	94.7	96.5	*Assumed 70% open water (CN 98), HSG A value assumed
6141	PHRAGMITES DOMINATE COASTAL WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6210	DECIDUOUS WOODED WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6220	CONIFEROUS WOODED WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6221	ATLANTIC WHITE CEDAR WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6231	DECIDUOUS SCRUB/SHRUB WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6232	CONIFEROUS SCRUB/SHRUB WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed

6233	MIXED SCRUB/SHRUB WETLANDS (DECIDUOUS DOM.)	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6234	MIXED SCRUB/SHRUB WETLANDS (CONIFEROUS DOM.)	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6240	HERBACEOUS WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6241	PHRAGMITES DOMINATE INTERIOR WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6251	MIXED WOODED WETLANDS (DECIDUOUS DOM.)	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6252	MIXED WOODED WETLANDS (CONIFEROUS DOM.)	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
6290	UNVEGETATED FLATS	Herbaceous (poor)*	93.8	94.4	95.8	97	*Assumed 20% open water (CN 98), HSG A value assumed
6500	SEVERE BURNED WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
7100	BEACHES	See Notes	25	25	25	25	From U Texas Report (pg 101)
7200	BARE EXPOSED ROCK, ROCK SLIDES, ETC	paved parking lots/bare rock	98	98	98	98	From EPA Report
7300	EXTRACTIVE MINING	paved parking lots/bare rock	98	98	98	98	From EPA Report
7400	ALTERED LANDS	Newly graded areas	77	86	91	94	
7430	DISTURBED WETLANDS (MODIFIED)	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
7440	DISTURBED TIDAL WETLANDS	Herbaceous (poor)*	87.5	89	92.5	95.5	*Assumed 50% open water (CN 98), HSG A value assumed
7500	TRANSITIONAL AREAS	Newly graded areas	77	86	91	94	
7600	UNDIFFERENTIATED BARREN LANDS	Newly graded areas	77	86	91	94	