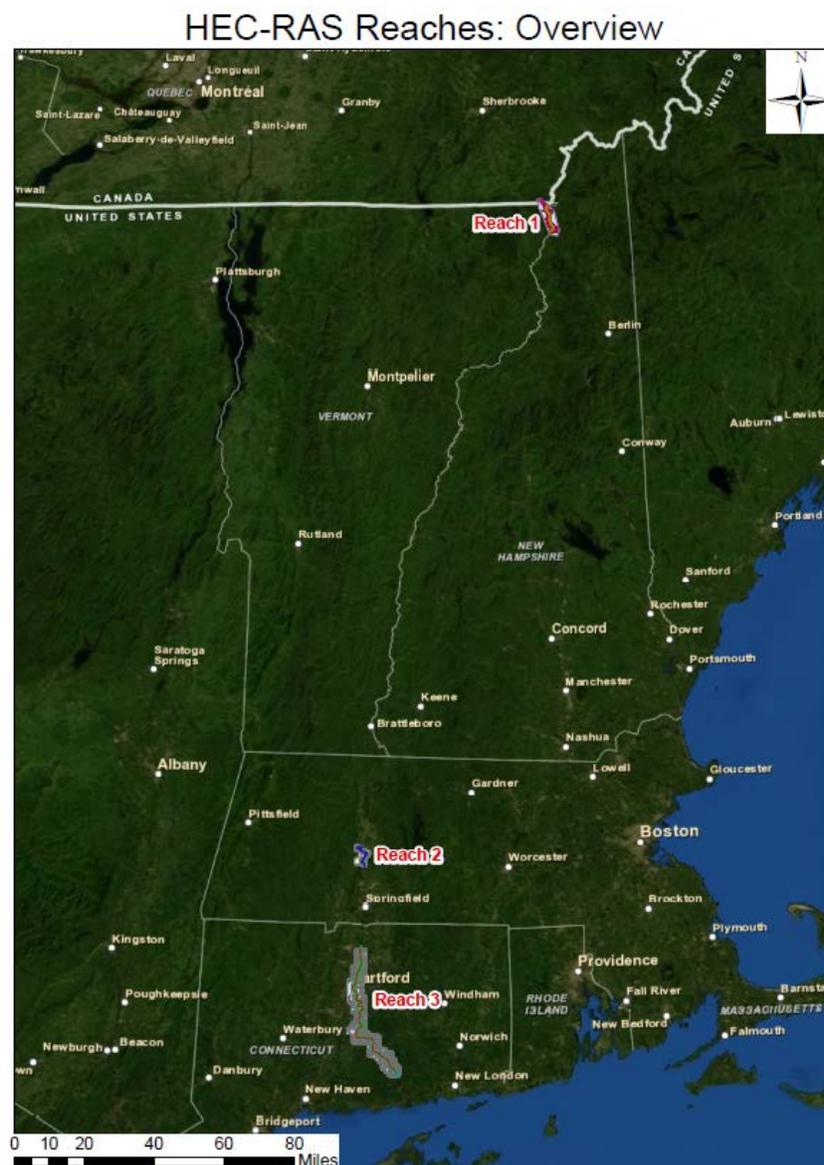


1 Appendix E: Modeled Reaches for the Connecticut River Watershed application of HEC-RAS

Separate from the report for the Decision Support System of the Connecticut River Watershed is this reach reference appendix document. It contains information about the reaches that were modeled in the HEC-RAS model. Information for each reach includes descriptions and assumptions made in the model. Figure 1 shows an overview of where the reaches which were modeled are located along the Connecticut River.

Figure 1: Modeled HEC-RAS Reaches along the Connecticut River



1.1 Introduction:

HEC-RAS is software that allows one-dimensional steady and unsteady river flow hydraulics calculations. Water depth associated with a particular flow depends on channel slope, geometry, and roughness as well as any backwater effects from downstream channel restrictions such as bridges or dams. It is a one-dimensional model, and was used in the steady-state mode, meaning that flows at any point were assumed constant through the simulation, although flows could vary along the length of the modeled sections.

A georeferenced steady flow hydraulic model utilizing The Corps' "River Analysis System model," HEC-RAS (Version 4.1, January 2010), HEC-GeoRAS (Version 4.2 Beta) and ESRI ArcMap (Version 10.02) was developed by USACE for three separate reaches along the Connecticut River. This was used to convert the flows computed by HEC-ResSim into depths and extents of water at selected, ecologically important locations along the mainstem of the Connecticut River, such as wetland forests. HEC-RAS incorporates a graphical user interface, a computational program to determine water depths, data storage and management capabilities, and graphics and reporting facilities. It uses the Data Storage System, HEC-DSS, for storage and retrieval of input and output time-series data. HEC-RAS and DSS are nonproprietary systems.

1.2 Model Development

1.2.1 General:

Hydraulic model development begins with the use of HEC-GeoRAS in ArcGIS and data described in each reach below. Cross sections are cut from ArcGIS maps, wherever the channel geometry changes due to variations in width or roughness, changes in overland characteristics such as forest to meadow, or obstructions such as bridges. HEC-RAS uses a series of channel and overbank cross sections as the basis for simulating river geometry, and the accuracy of a HEC-RAS model's results is highly dependent on the quality of these cross sections. Model geometry is then imported into HEC-RAS for final model development and analysis. Results of the model simulations include tables of flow depths, widths, and velocities for each cross section, and can then be exported back into ArcMap for graphical display and creation of flood maps.

1.2.2 Reaches:

Three reaches were modeled along the Connecticut River. These sections are from Cannan, VT to Colebrook, NH, a distance of approximately 60,000 ft; Northampton, MA, a distance of approximately 37,500 feet; and from Windsor Locks near East Windsor, CT to Chester CT, a distance of approximately 245,000 feet.

1.2.3 Channel Shape:

Digital elevation models (DEMs) do not provide information through the water surface, therefore bathymetry data was required. This was obtained with bathymetric surveys completed along the reaches of the Connecticut River. Along cross sections where bathymetry was surveyed, the bathymetric data was merged using the HEC-RAS graphical cross section editor. Where no bathymetric survey was available, the channel was interpolated from the closest upstream cross section with bathymetry data.

1.2.4 Manning's Roughness coefficients:

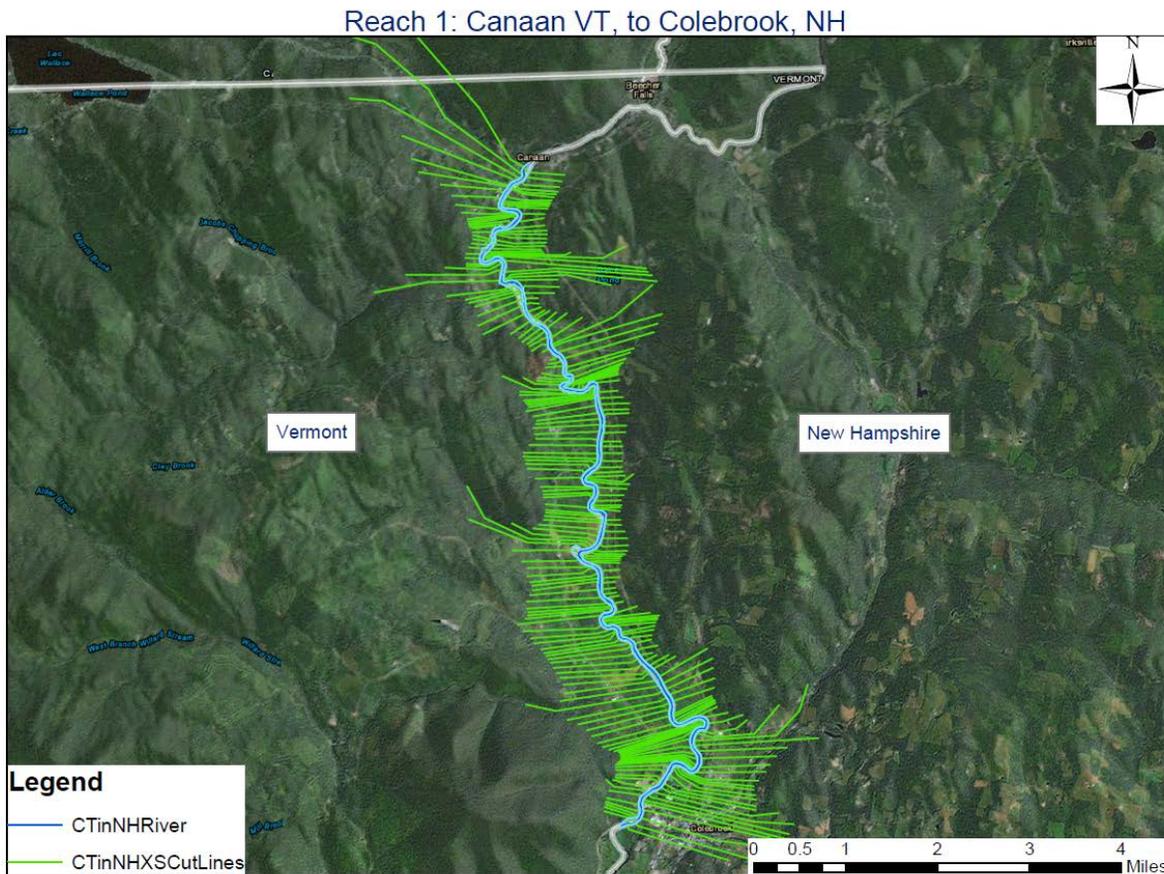
Land use layers were drawn according to imagery and assigned manning's "n" values. The 'n' values in the channel were estimated from typical channel conditions and references from local flood insurance studies. Ranges of "n" values were modified during calibration efforts to effectively represent the true water surface elevations in the Connecticut River.

1.3 Reach 1:

1.3.1 Description:

This reach extended from Canaan, VT to Colebrook, NH. This reach is approximately 60,000 feet along the Connecticut River. The reach is illustrated in Figure 2 below.

Figure 2: Reach 1: Canaan, VT to Colebrook, NH



1.3.2 Base Data:

Based data used in developing the HEC-RAS model was obtained from various sources. The model used the following projection parameters:

- Horizontal Datum: NAD 1983 State Plane, Vermont
- Projection: NAD_1983_StatePlane_Vermont_FIPS_4400_Feet
- Vertical Datum: NAVD 88

- Linear units: U.S. feet

DEM model was obtained from the state of Vermont GIS database.

Figure 3: Shows the cross sections in green on top of the raster DEM and bathymetry points from survey data.

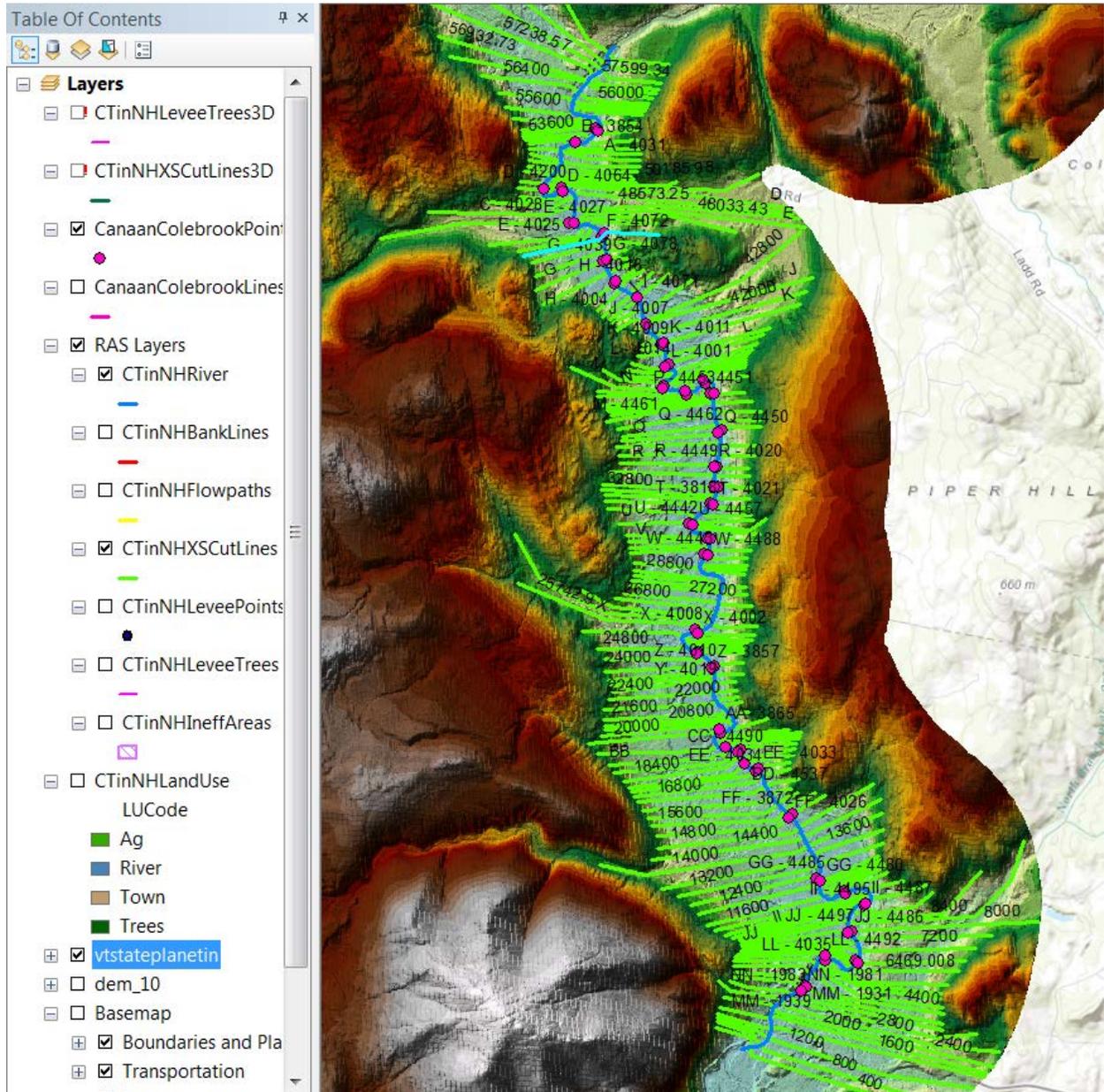
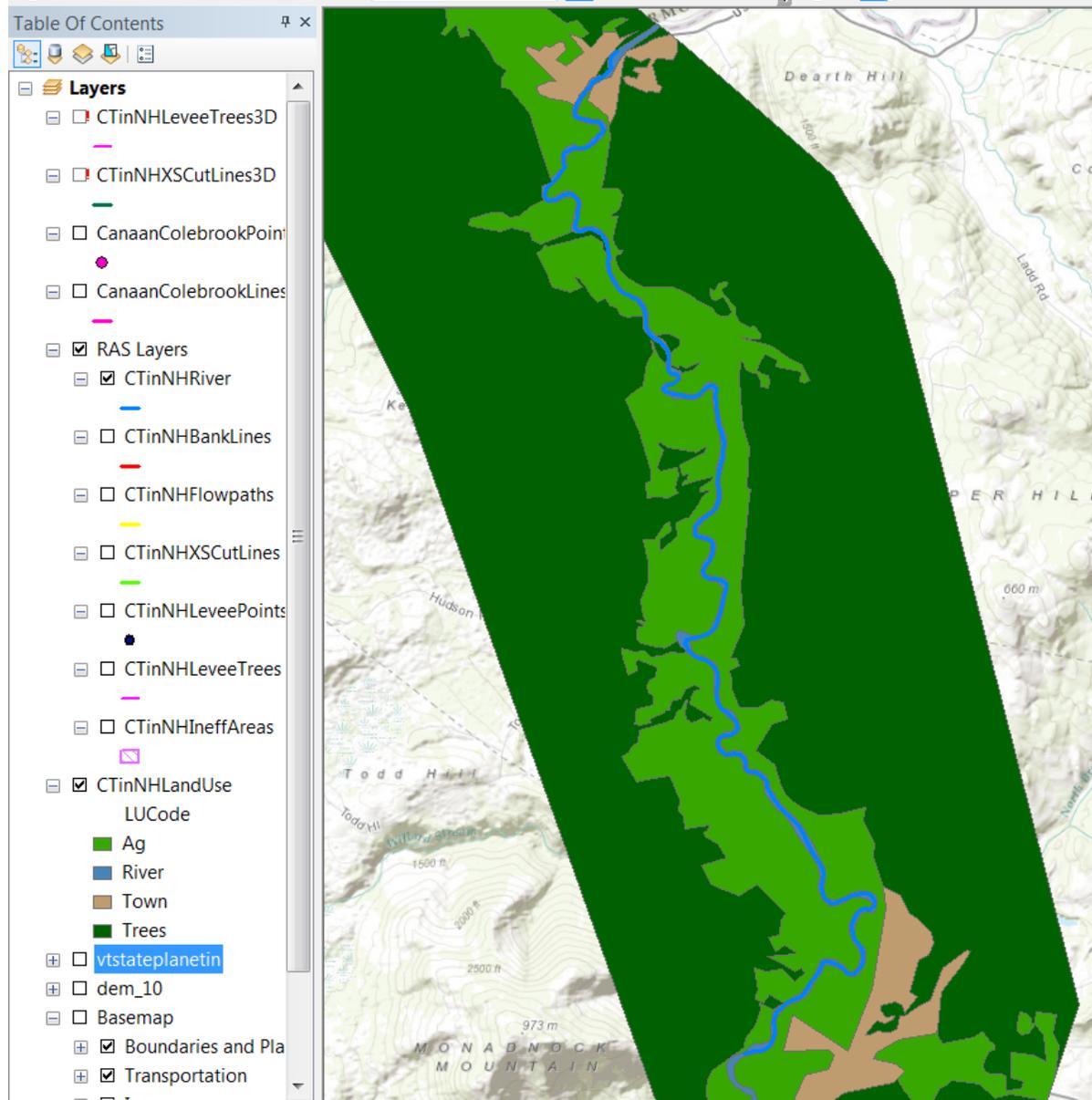


Figure 4: This shows the land use layer which was transformed into manning's roughness values.



1.3.3 Levees

No levees exist along this reach of the model.

1.3.4 Bridges

No bridges exist along this reach of the model.

1.3.5 Boundary Conditions

The boundary condition for this reach was set at normal depth with a downstream slope of $S=0.02$.

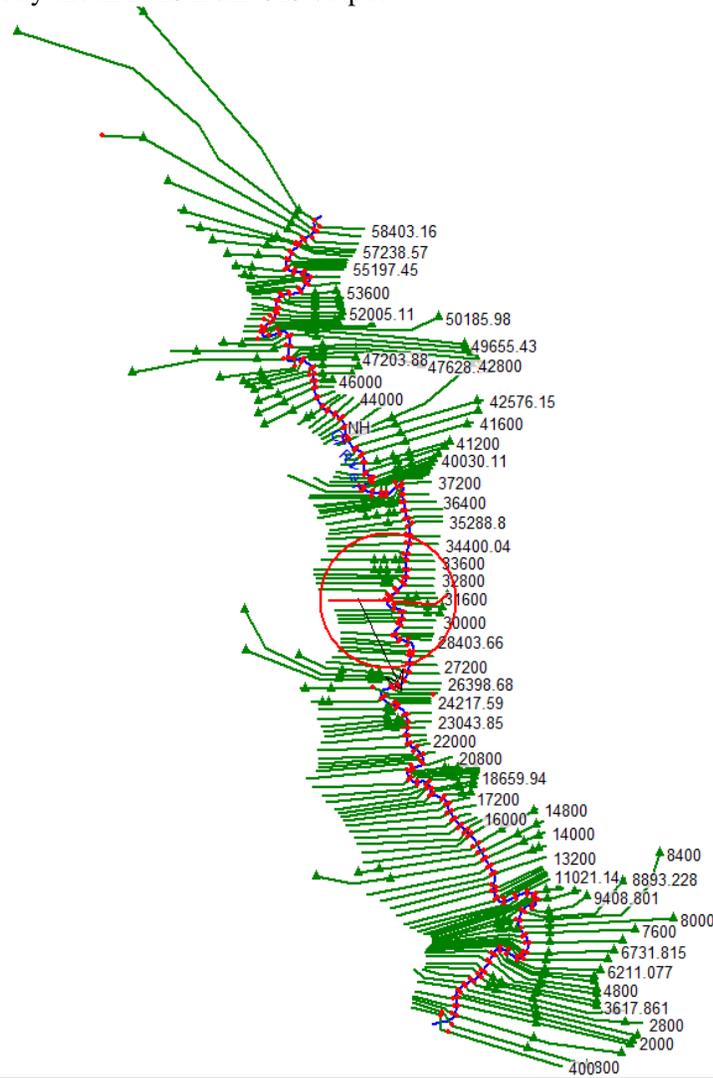
1.3.6 Calibration

The water surface profile was calculated as shown below using the 10 year flood of 7,300 cfs. This corresponds to the location "Just upstream of Leach Creek" as published in the 2013 FIS', as a flow rate

and the downstream boundary of normal depth. This model was not calibrated due to the lack of stage information on this section of the CT River.

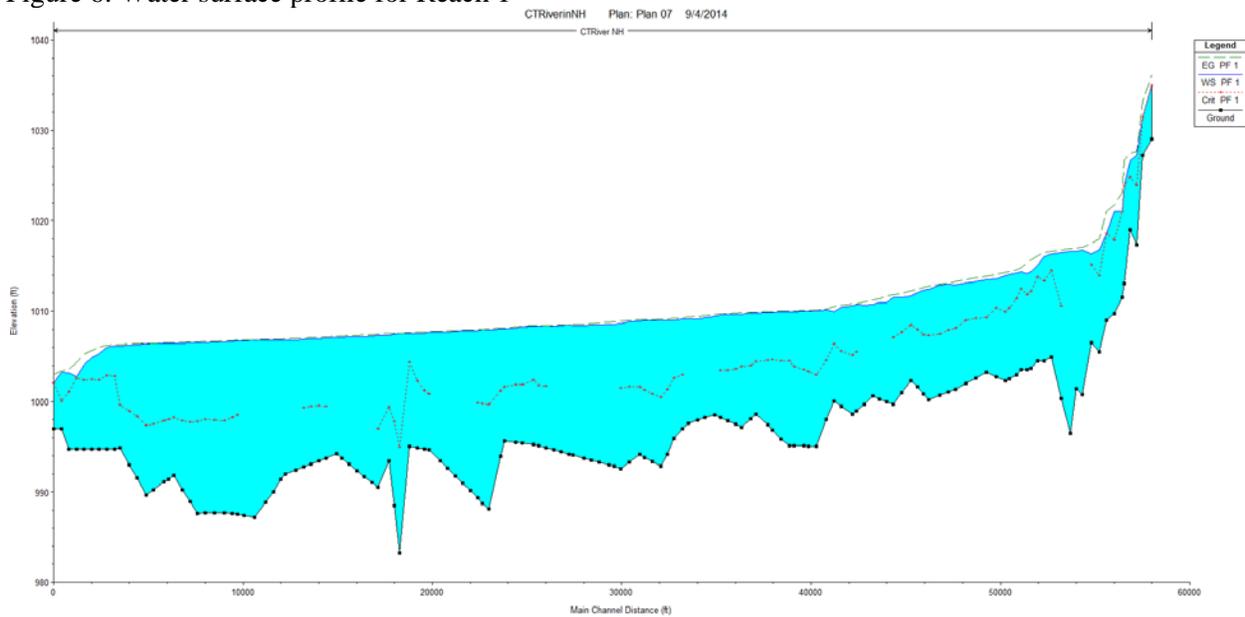
The images below show the final product of drawing banks, centerlines, flow paths, cross sections, surveyed bathymetry points and land use grids used to estimate friction values.

Figure 5: Geometry file in RAS from GIS output



The water surface profile was calculated as shown below using the 10 year flood of 7,300 cfs. This corresponds to the location “Just upstream of Leach Creek” as published in the 2013 FIS’ (Flood Insurance Study, Coos County, NH, FIS # 33007CV001A), as a flow rate and the downstream boundary of normal depth. This model was not calibrated due to the lack of stage information on this section of the CT River.

Figure 6: Water surface profile for Reach 1

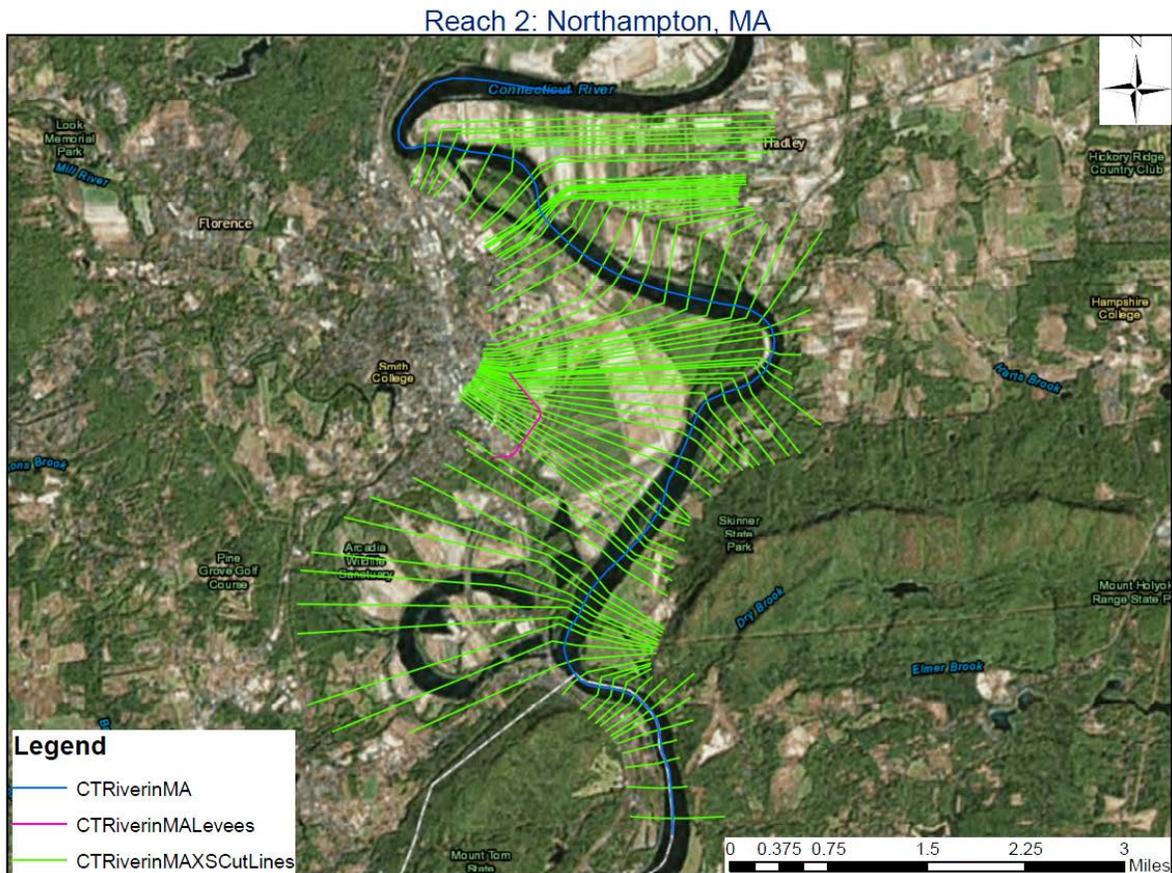


1.4 Reach 2: Northampton, MA

1.4.1 Description:

This reach is located in Northampton, MA near Interstate 91 and the Northampton Airport. It extends through numerous state conservation and recreation areas, ending near the Mt. Tom State Reservation.

Figure 7: Location of Reach 2: Northampton, MA



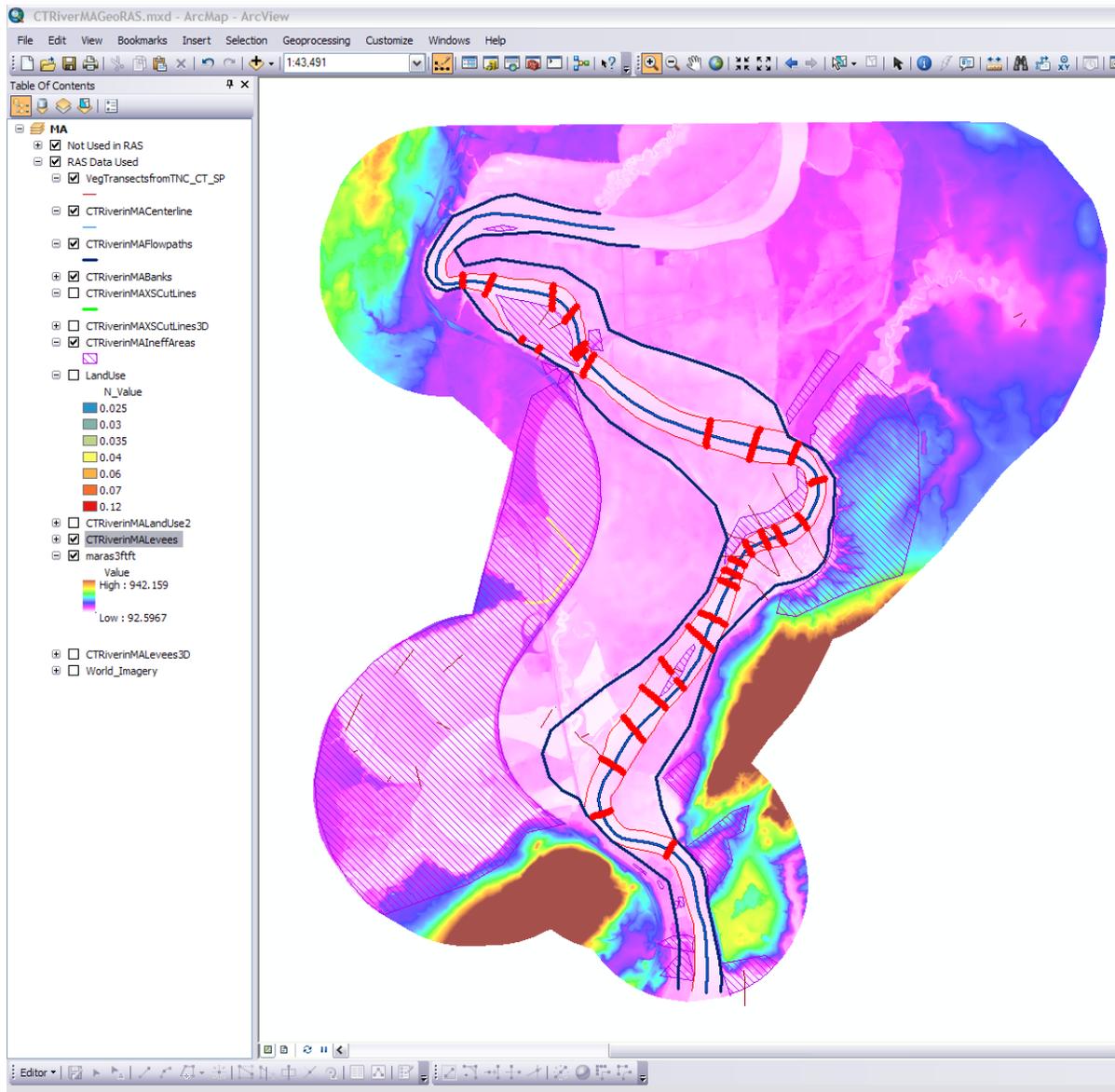
1.4.2 Base Data:

This reach of the model used the following parameters:

- Horizontal Datum: MA Stateplane NAD 83 feet
- Projection: NAD_1983_StatePlane_Massachusetts_Mainland_FIPS_2001_Feet
- Vertical Datum: NAVD 88
- Linear units: U.S. feet

The DEM and land use layer was based off of 2005 MassGIS data. The data cites an accuracy of 2 meters, but is likely better than that.

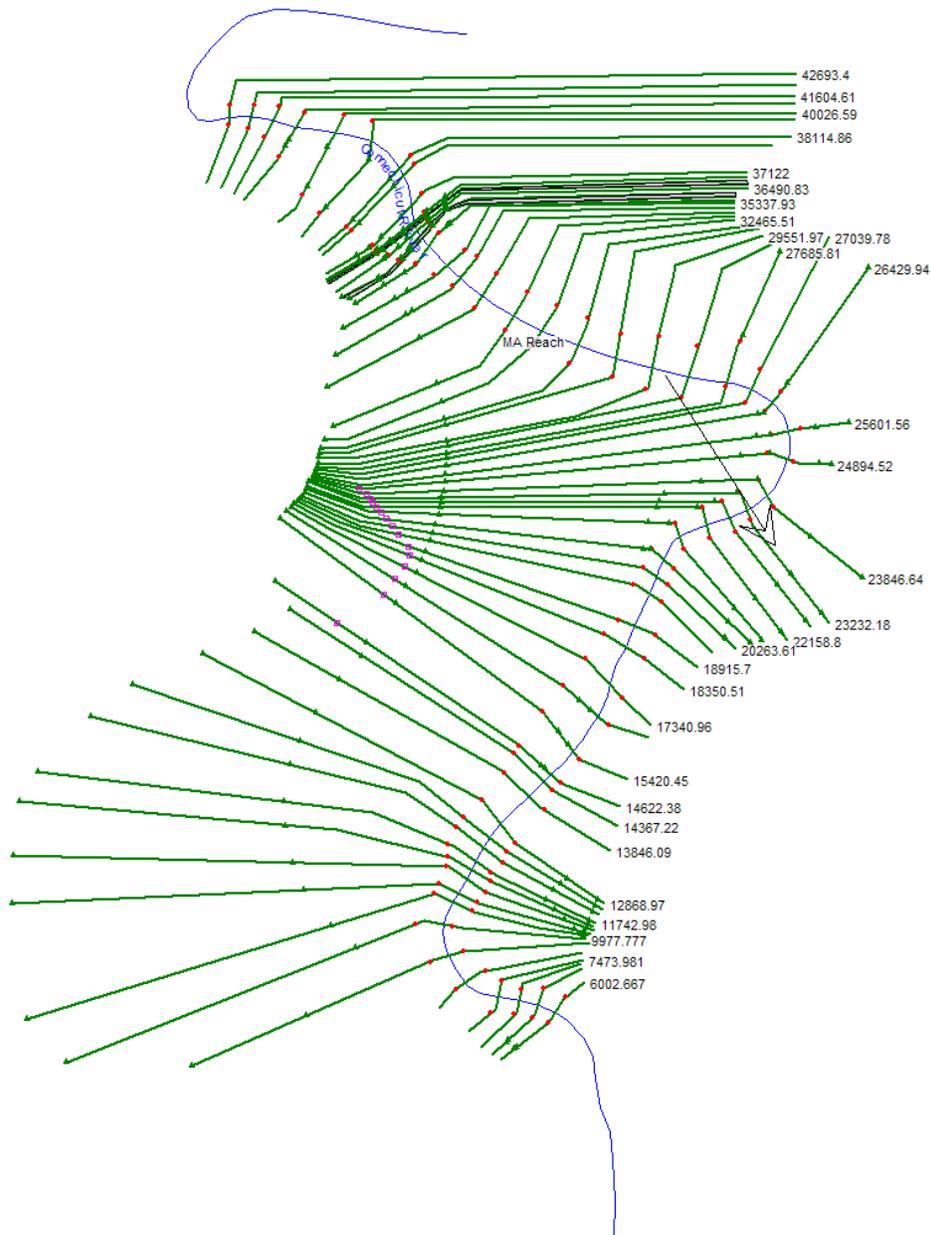
Figure 8: Shows the cross sections in green on top of the raster DEM and bathymetry points from survey data.



1.4.3 Levees

Levee elevation data and location was estimated from aerial images and assigned to the lateral structures in the model.

Figure 10: Geometry file in HEC-RAS from GIS output, note the levees are represented with pink dots

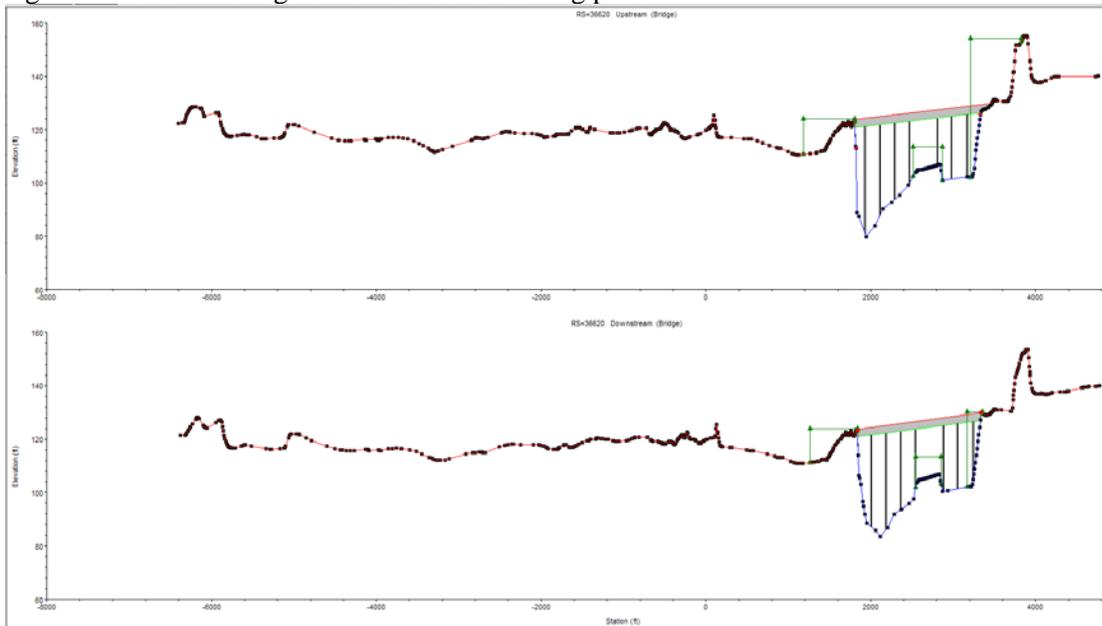


1.4.4 Bridges

Two bridges exist along this reach to be modeled.

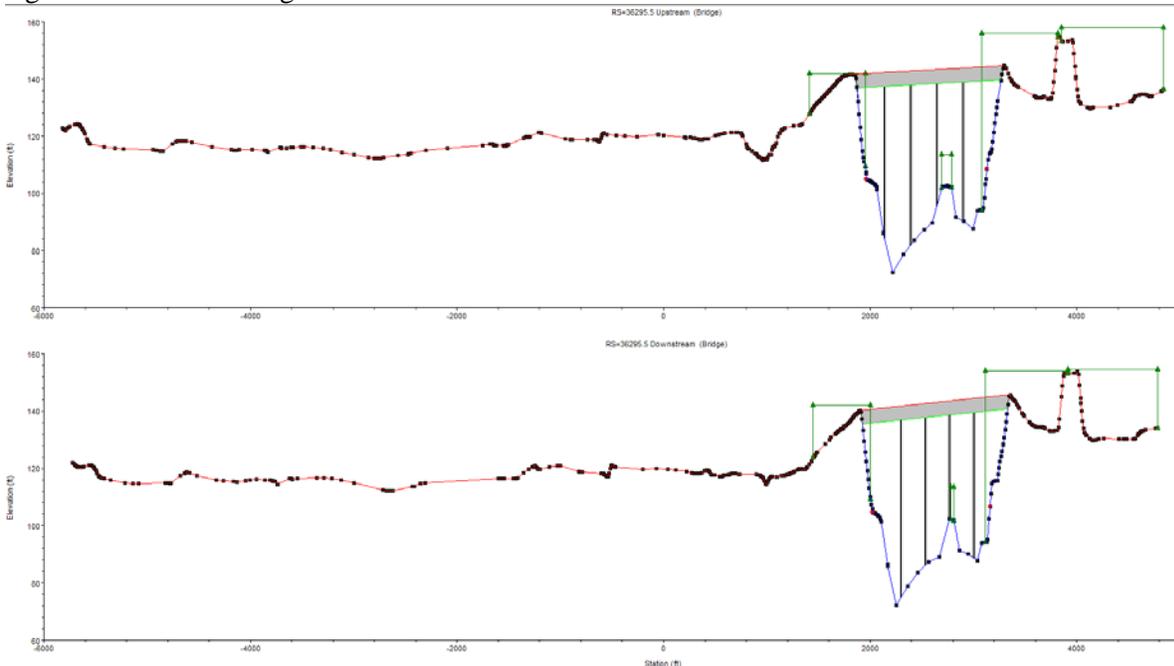
The first bridge seen in Figure 7 was modeled using the highest energy answer out of the following low flow methods: Energy (Standard Step), Momentum, and Yarnell (Class A only). The drag coefficient was set to 2, corresponding to a pier with an elliptical shape with an 8:1 ratio of length to width.

Figure 11: Old RR bridge which is now a walking path.



The second bridge modeled in this reach is seen in Figure 8. This was modeled using the highest energy answer from the Energy (Standard Step) and Momentum low flow methods. The drag coefficient was set to 0.6 which corresponds to elliptical piers with 2:1 ratio length to width.

Figure 12: Route 9 Bridge.



1.4.5 Boundary Conditions

The downstream boundary condition was set as a known water surface elevation of 115.3 ft based on the 1979 FIS.

1.4.6 Calibration

The model was calibrated to the 10 year flood of 112,000 cfs using the 1979 FIS and water surface profiles. This method was chosen due to the lack of information on flow rates and stages on this section of the CT River. A rating curve was also used to help calibrate the model. The rating curve came from a USACE provided Local Protection Project Analysis for the existing levee systems in Northampton MA, and can be seen in Figure 13 below. Modifications were made to the model to make it more reasonable to what should be expected and the WS profile was calculated as is shown below using the 112,000 cfs as a flow rate. Manning's n values and cross section points had to be consolidated based on RAS limitations.

Figure 13: Rating curve used during calibration process

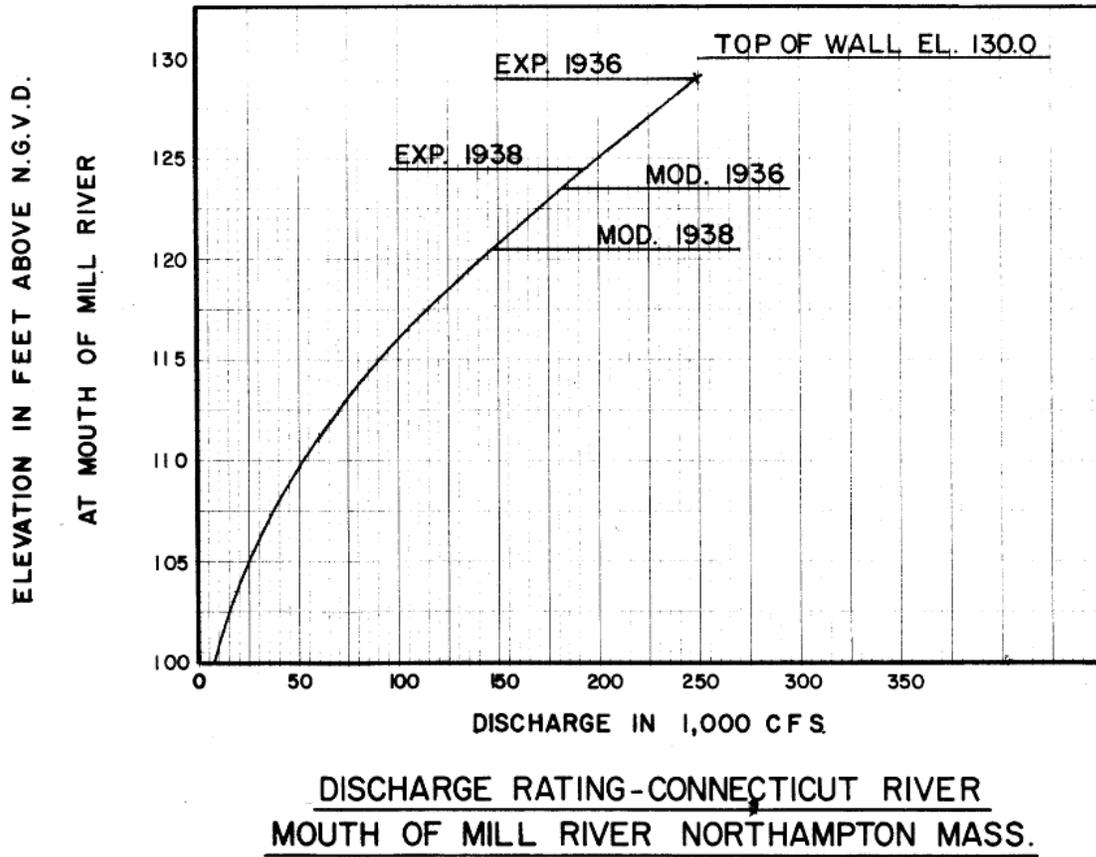


Figure 14: Land use layer, used to determine manning's "n" values

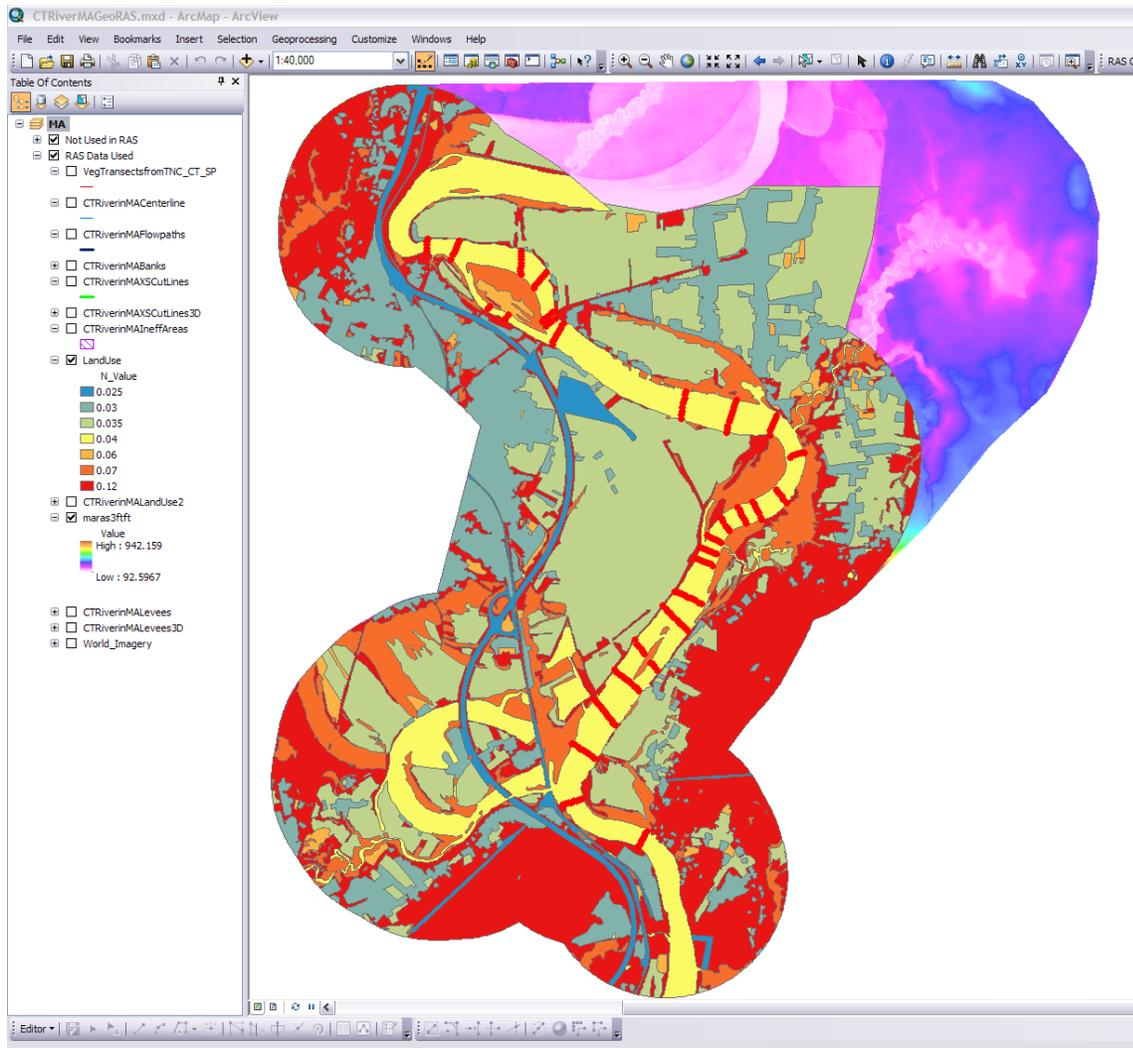
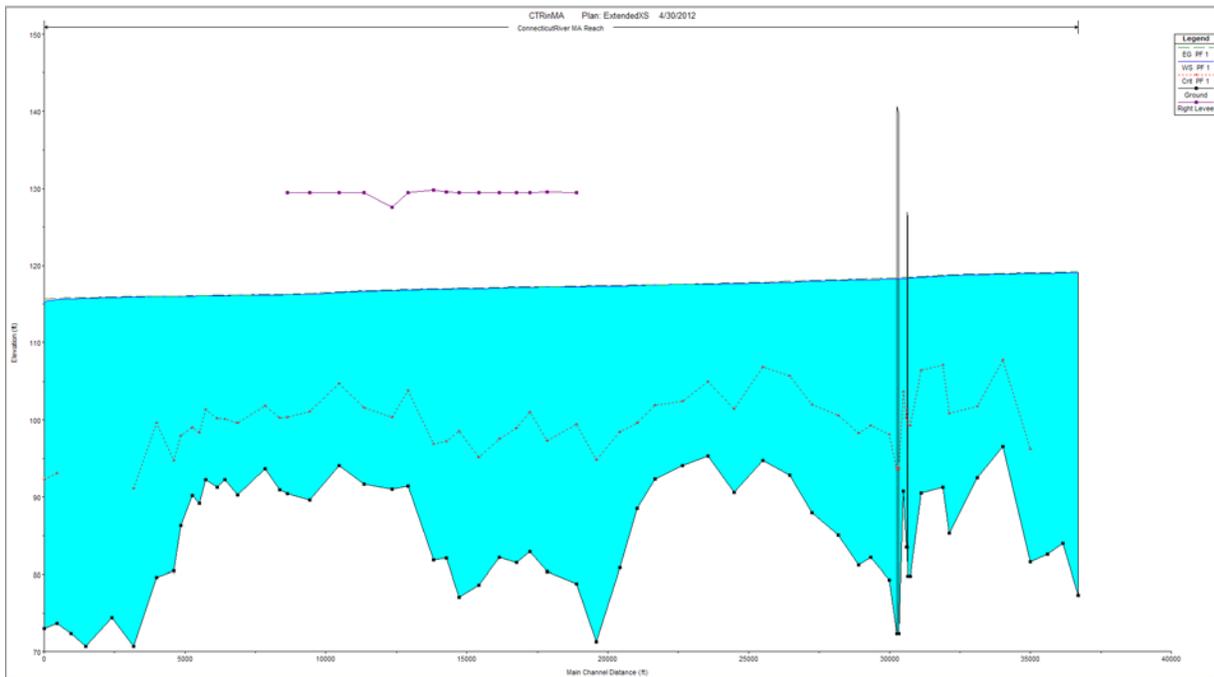


Figure 15: HEC-RAS calibrated water surface profile for reach 2



1.5 Reach 3: Connecticut River in Connecticut

1.5.1 Description:

This reach is approximately 48 river miles. The study area begins near Windsor Locks in East Windsor, CT and the Bradley International Airport. It extends southwards through Hartford, Cromwell, Middletown, and ends near Chester, CT. This expanse of river has many islands and conservation areas along the banks of the river, but also goes through heavily populated areas.

Figure 16: Reach 3 in Connecticut

Reach 3: East Windsor, CT to Chester, CT

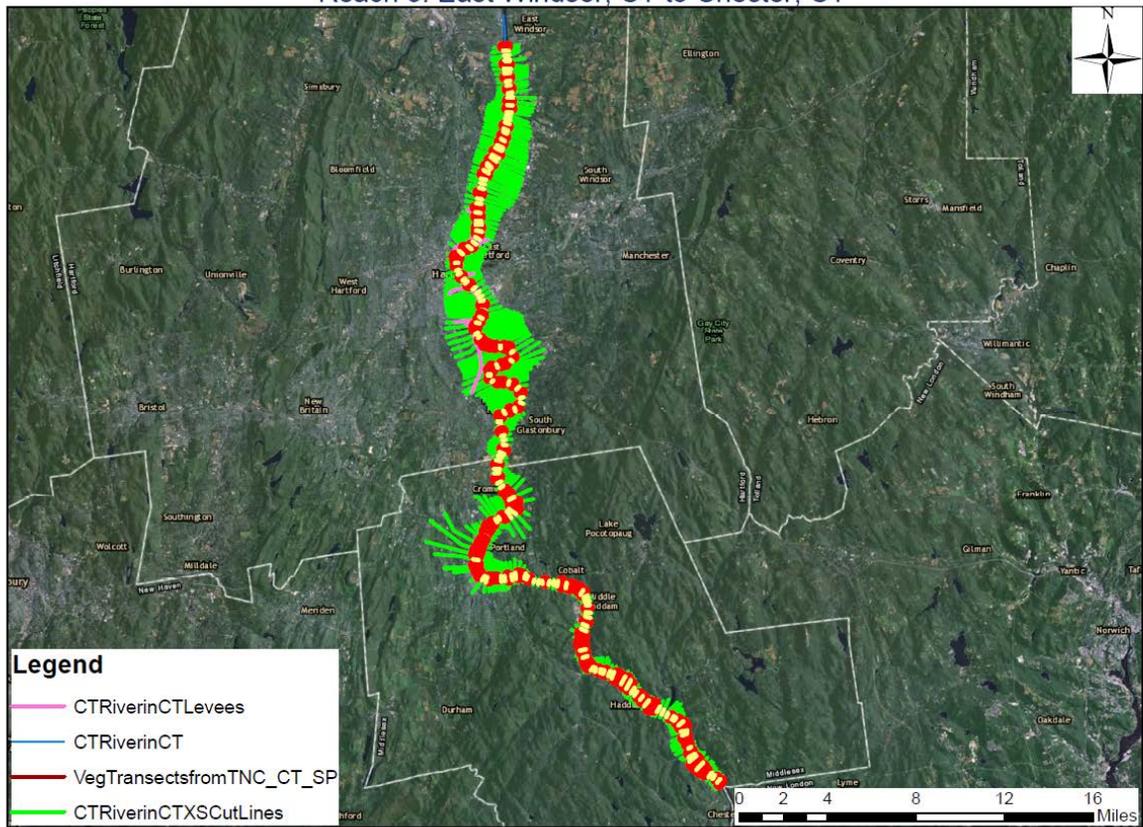
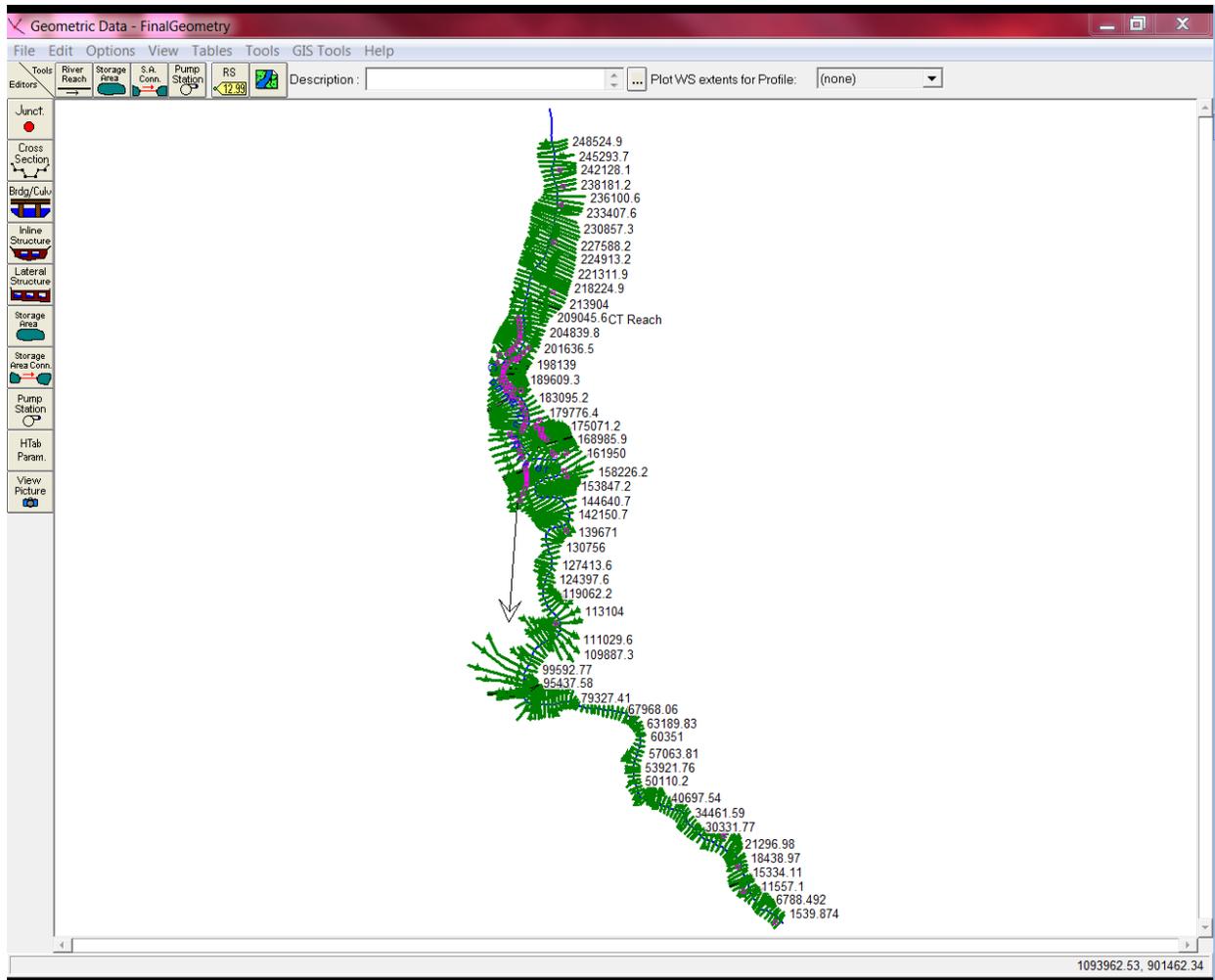


Figure 17: Reach 3 geometry in HEC-RAS



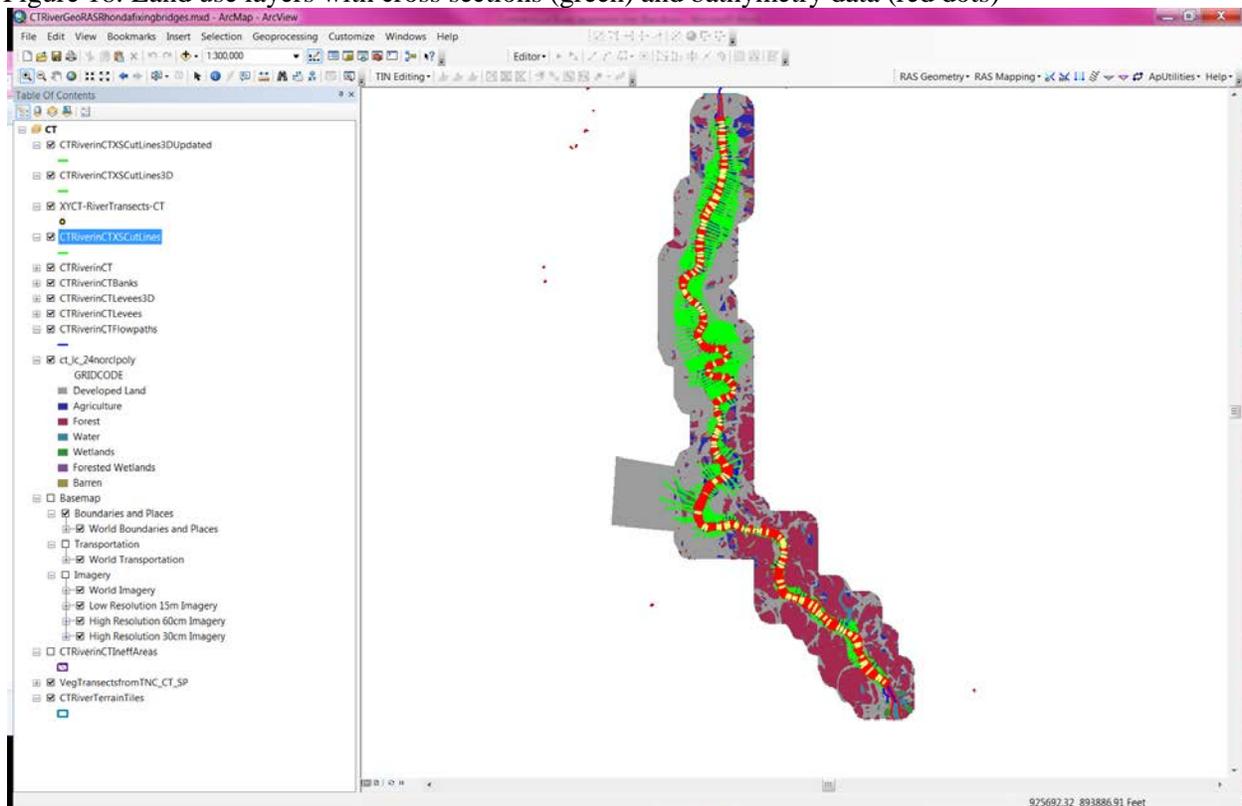
1.5.2 Base Data:

This reach of the model used the following parameters:

- Horizontal Datum: CT Stateplane NAD 83 feet
- Projection: NAD_1983_StatePlane_Connecticut_FIPS_0600_Feet
- Vertical Datum: Feet, NAVD 88
- Linear units: U.S. feet

The DEM was created from LiDAR collected in 2004. The data cites a vertical accuracy of 0.147 feet. The DEM was created by merging 100 small rasters.

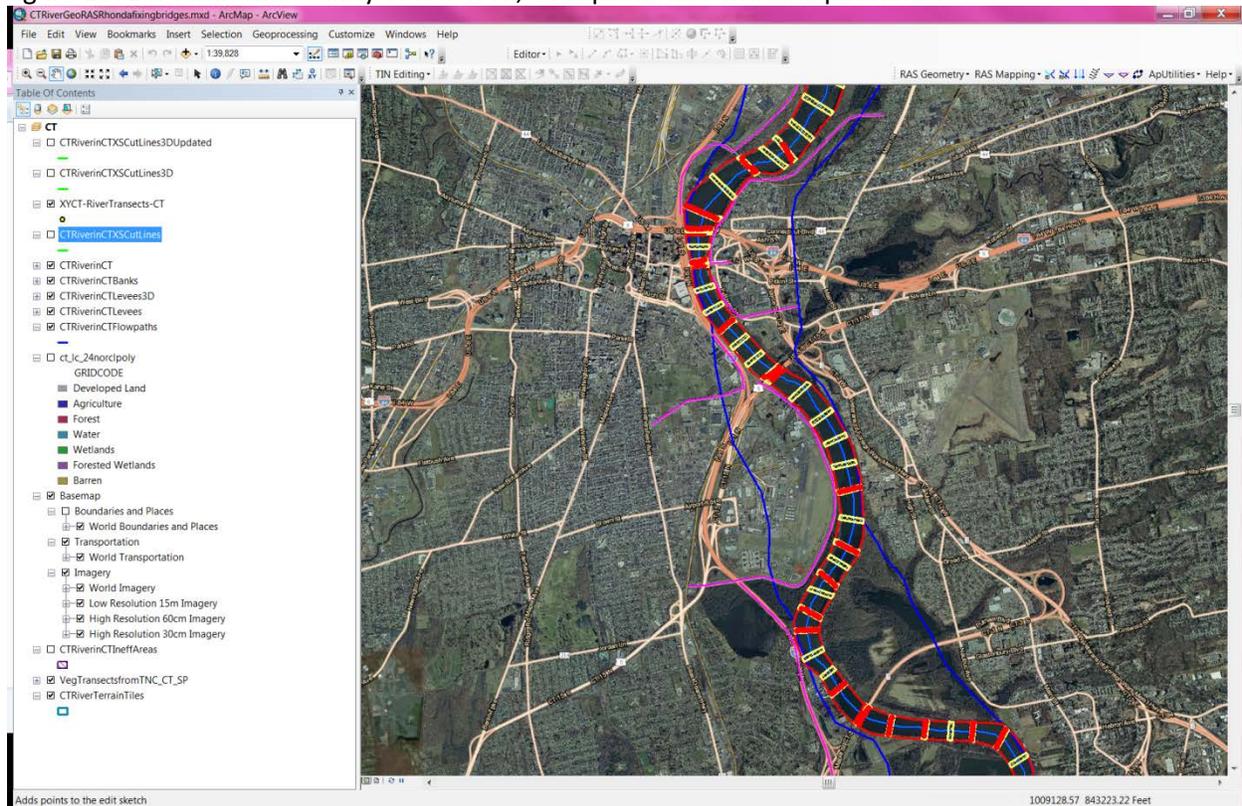
Figure 18: Land use layers with cross sections (green) and bathymetry data (red dots)



1.5.3 Levees

Several levees exist along this portion of this portion of the Connecticut River and were modeled with lateral structures digitized in ArcGIS and then brought into the RAS model. Levee elevation data was extracted from the terrain layer and assigned to the lateral structures in the model.

Figure 19: Levees in the Vicinity of Hartford, CT represented with the pink lines.



1.5.4 Bridges

Nine bridges were modeled along this reach. Many of these bridges are located in the Hartford, CT section of the model. The bridge modeling approach used the highest energy answer for the low flow method, between energy (Standard Step) and a momentum computation. The coefficient of drag was 1.2. Piers were estimated based off of aerial photos, site visit photographs, and schematics provided by the survey crew. The deck and roadways were modeled as a broad crested weir. Figure 21 through Figure 29 below show the bridge profiles for this reach.

Figure 20: Example of a bridge sketch provided by the survey crew

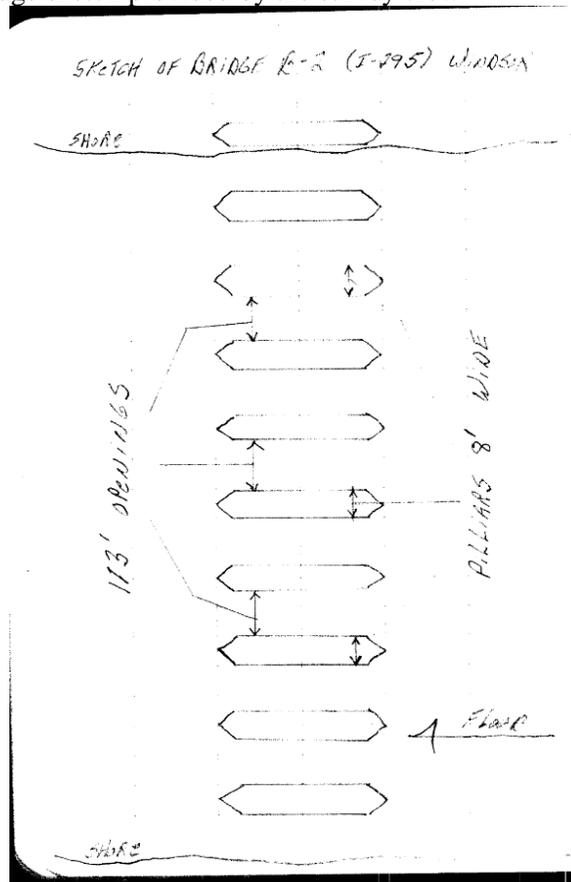


Figure 21: Bissell Bridge, I291, Windsor, CT

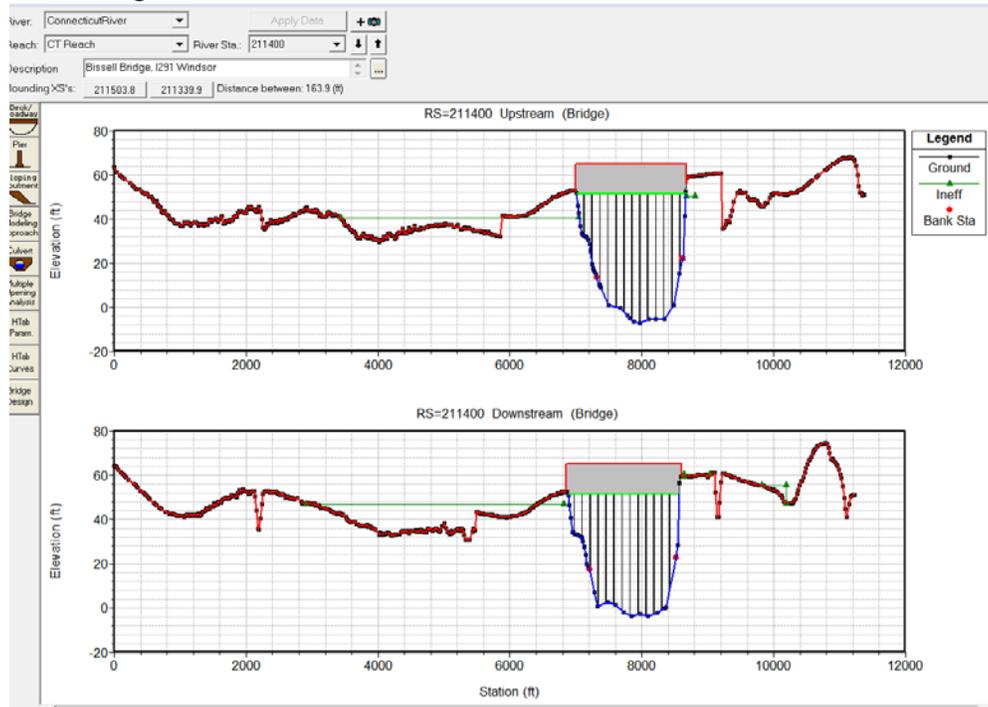


Figure 22: CT SE Railroad

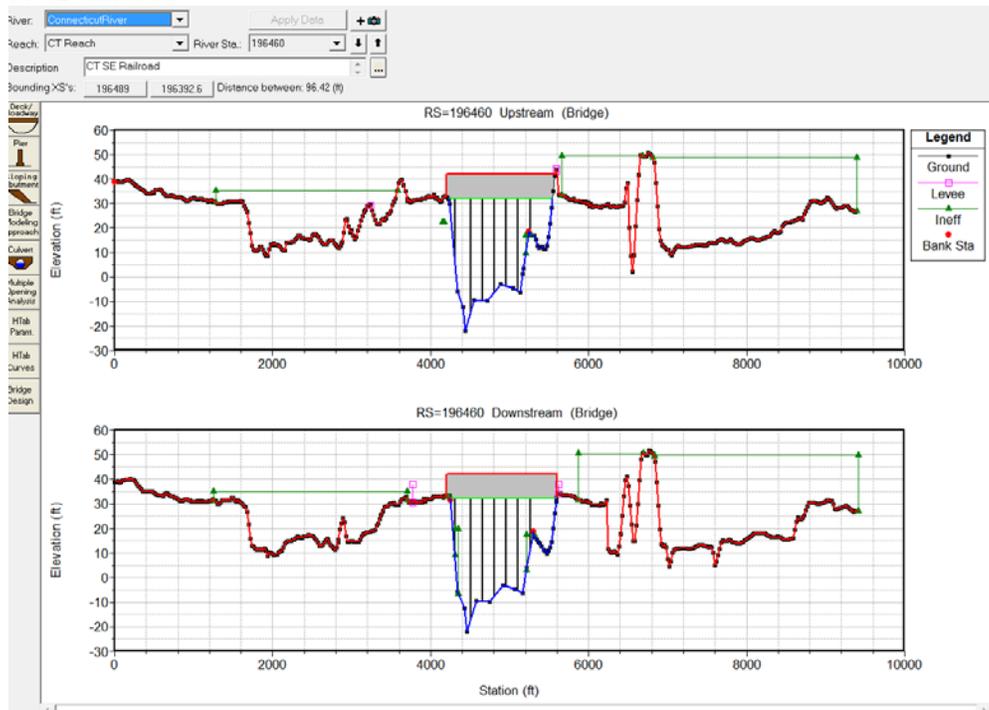


Figure 23: Interstate 84/Bulkeley Bridge, Hartford, CT: Modeled with abutments

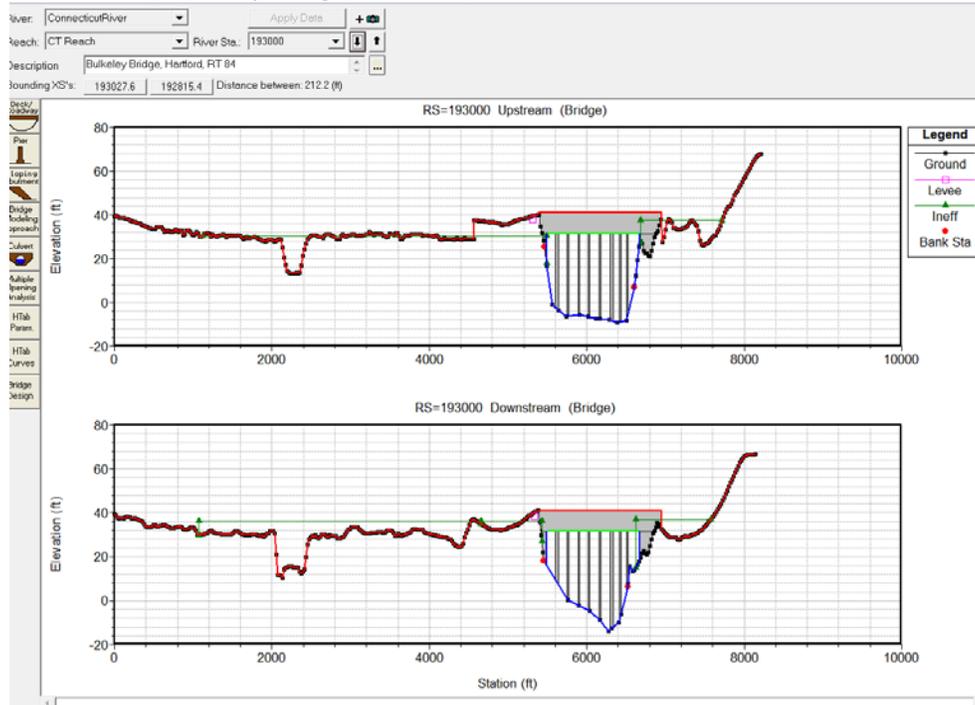


Figure 24: State Route 2/Founder's Bridge

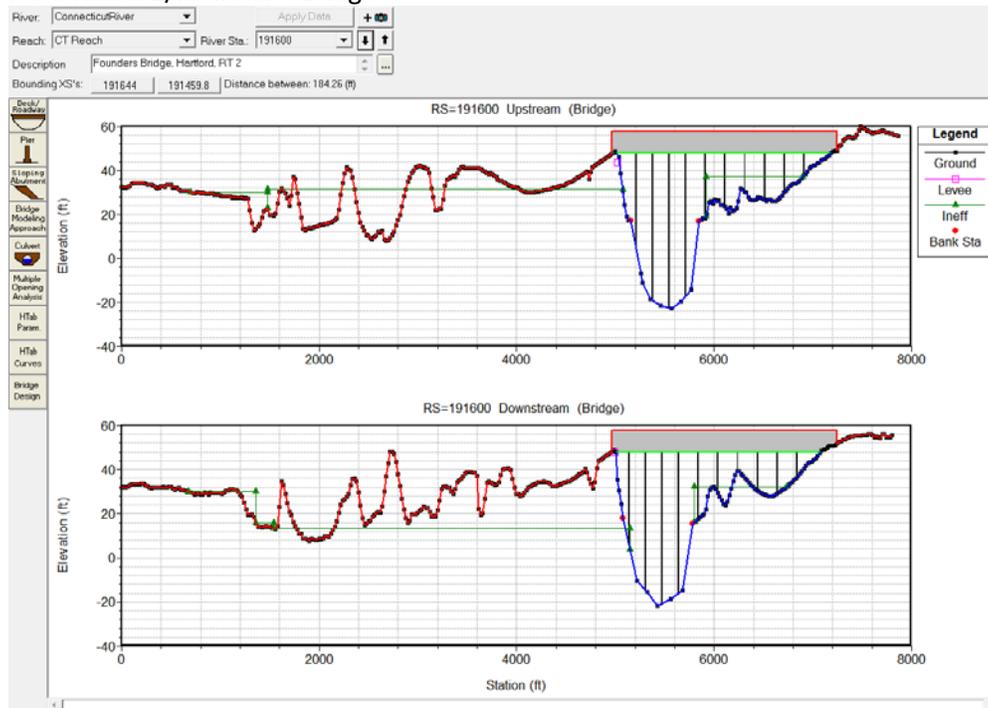


Figure 25: Charter Oak/Wilbur Cross Highway

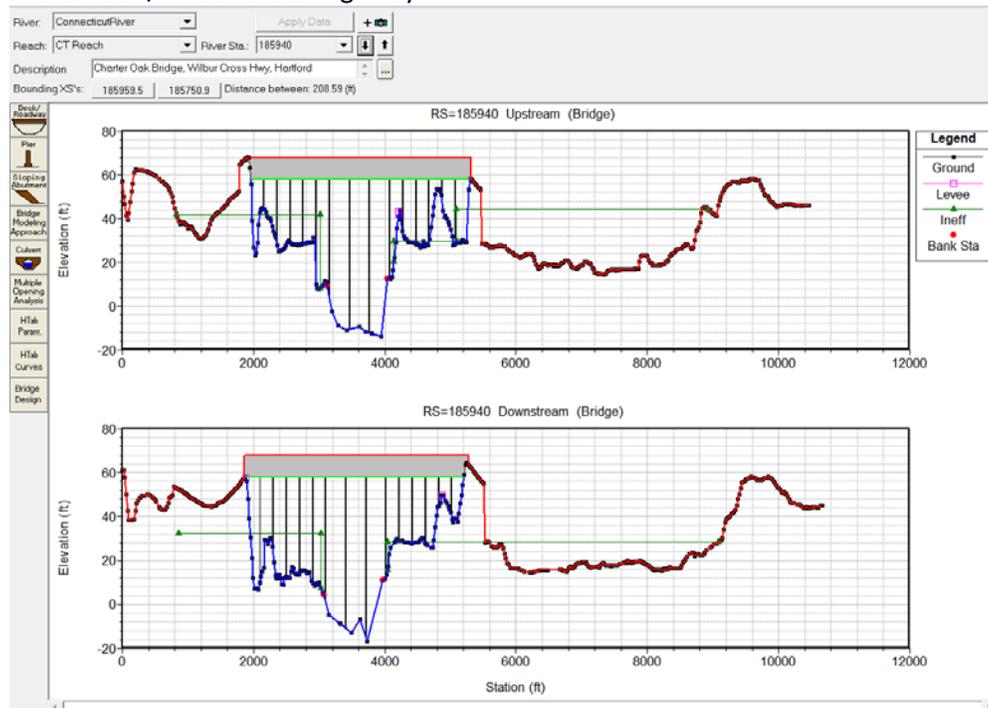


Figure 26: William Putnam/State Route 3

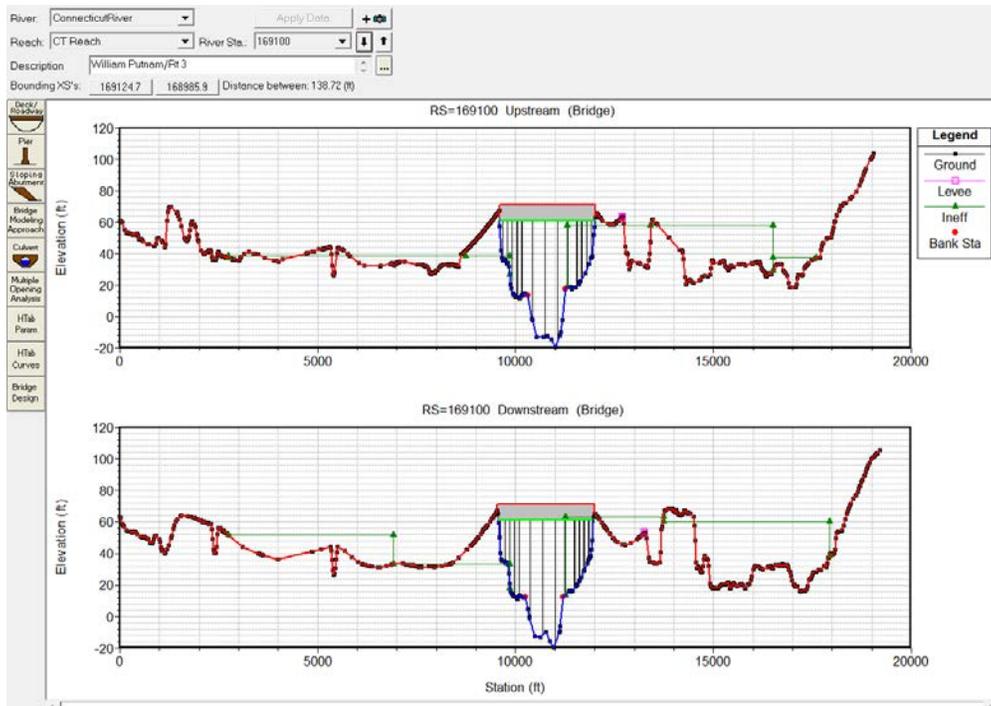


Figure 27: Arrigoni Bridge

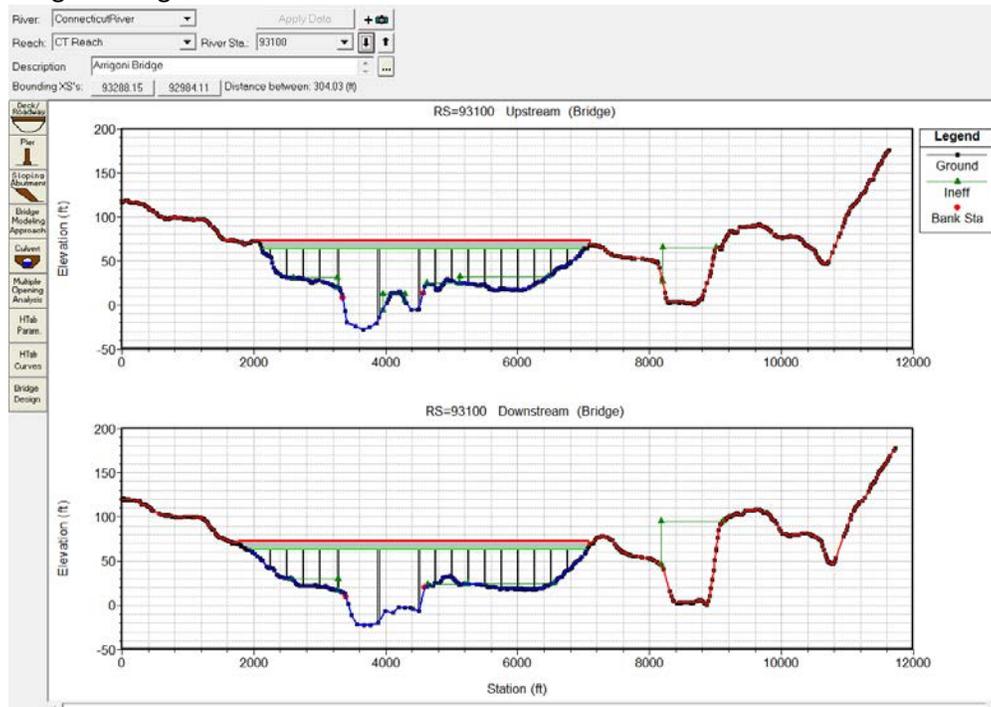


Figure 28: Middletown/Portland Railroad Bridge, turned railroad bridge

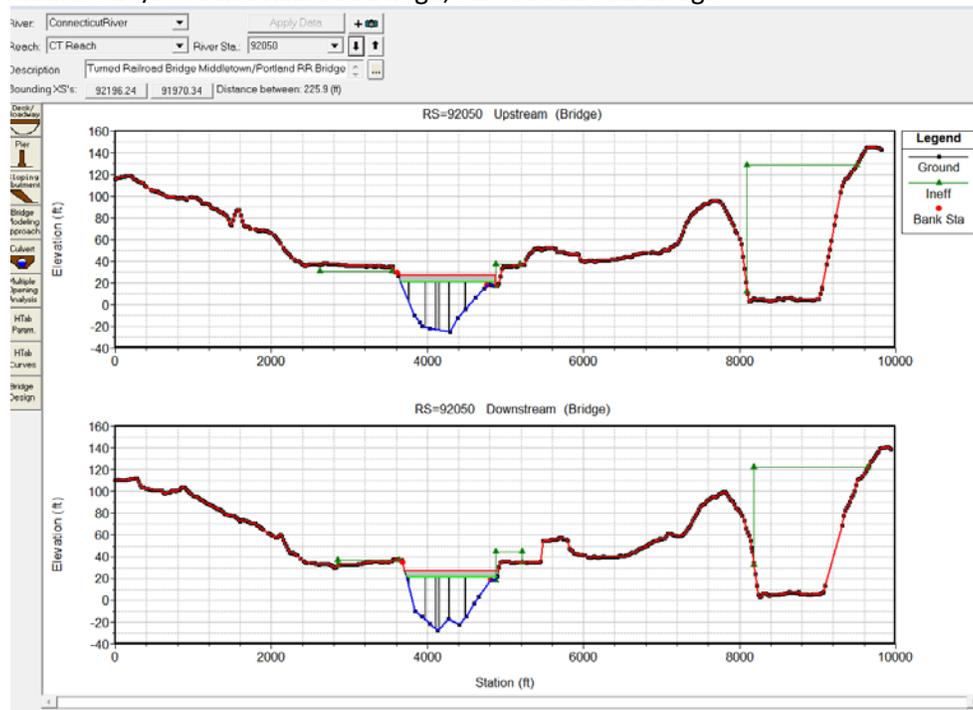
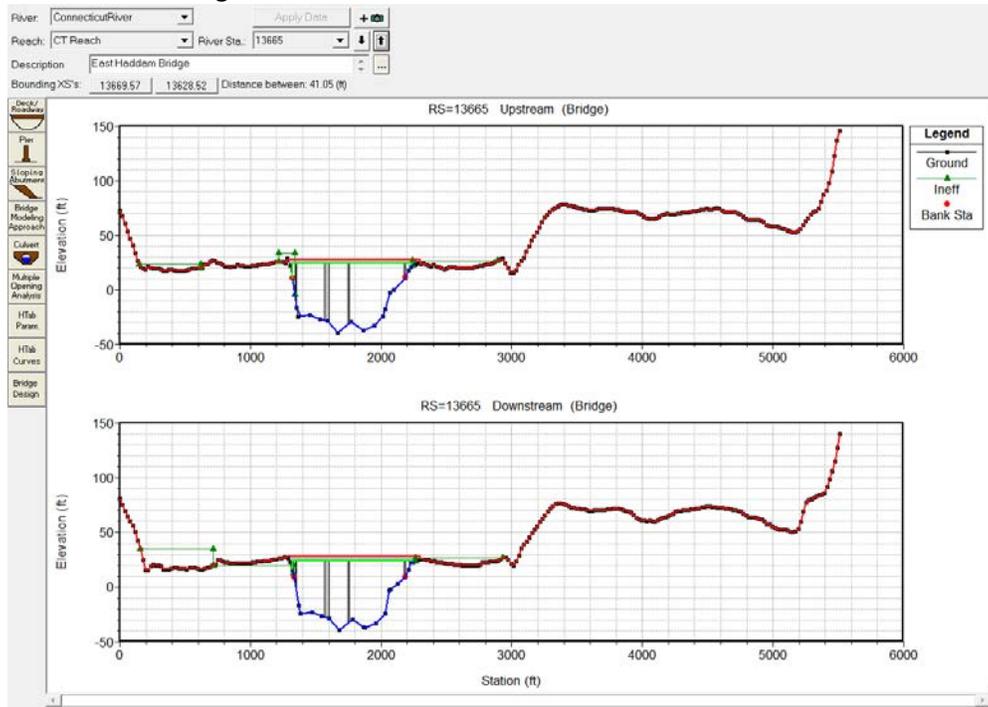


Figure 29: East Haddam Bridge



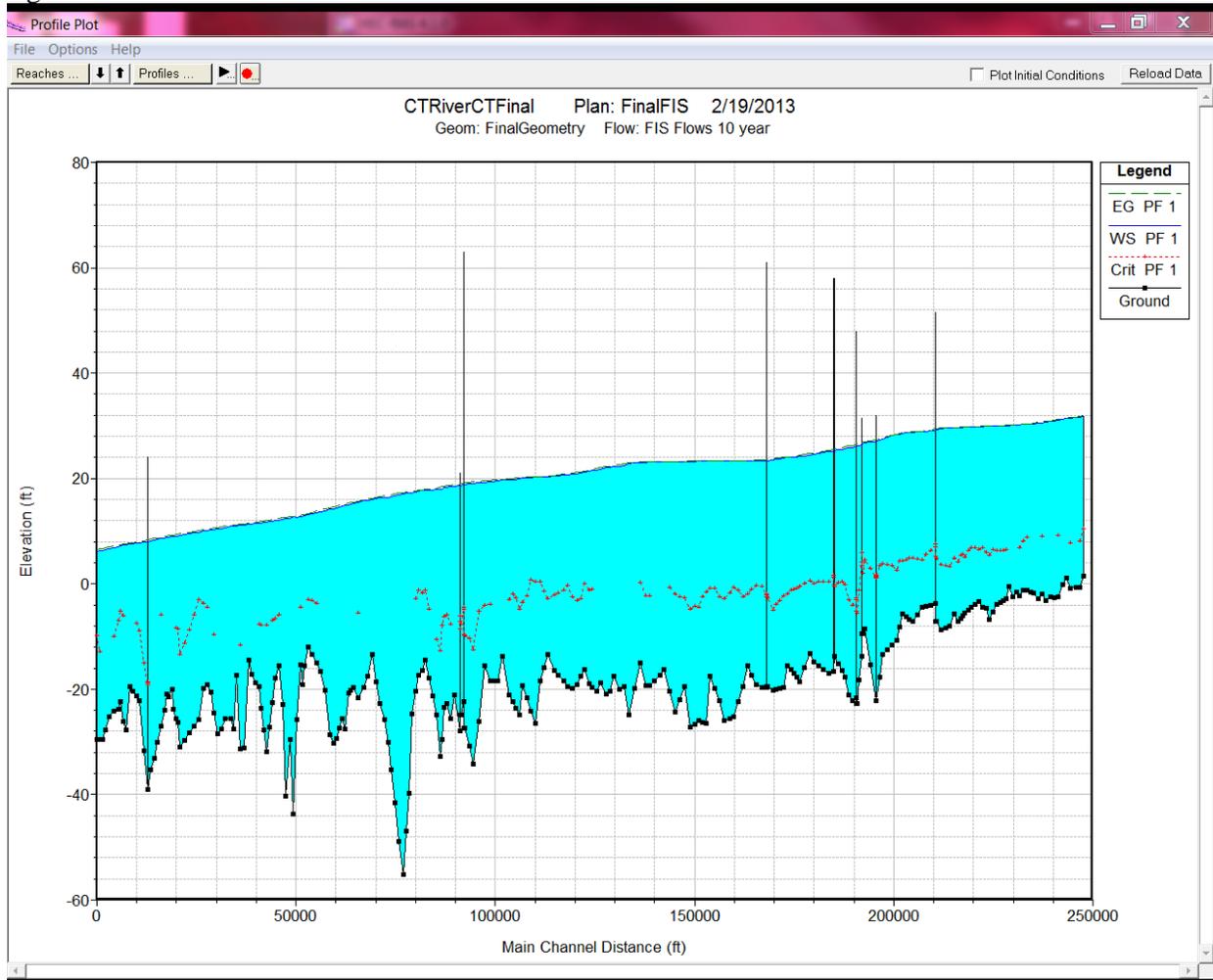
1.5.5 Boundary Conditions

Downstream boundary condition was set as a known water surface elevation of 2.5 ft, MHW taken from the FIS.

1.5.6 Calibration

Water-surface profiles for the 10-year flood as given in flood insurance studies (FIS) were used for calibration, which was accomplished mainly by varying Manning's "n" values, which simulate channel and overbank hydraulic roughness. However, since the data used for this study was better than that used in backwater programs to compute FIS profiles, and since the FIS was more concerned with the 100-year flood while this study was more interested in lesser events, "n" values were not varied beyond what was deemed reasonable to exactly match FIS results. Additionally two USGS gages exist in the vicinity of this reach along the Connecticut River: USGS 01193050 Connecticut River at Middle Haddam CT, and USGS 01184000 Connecticut River at Thompsonville, CT. Data from these gages was used to assist with the calibration process.

Figure 30: HEC-RAS calibrated water surface for Reach 3



1.6 Modeling Difficulties and Assumptions

HEC-RAS is typically used to model high flow situations, not low flow situations.

Bathymetry data was not available in all locations, and was interpolated between cross sections.

Bridge data was estimated from aerial imagery and online research. As-built data for the bridges should be included where available in future efforts. The bridges throughout Reach 3 (the Connecticut reach) were all modeled using the same modeling approach. For more accurate energy losses, they should be modeled according to their specific pier shape.