Hurricane Irene in Connecticut River Watershed (Flooding in Lower Deerfield River)

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Introduction

Connecticut River is located in the Northeastern part of the United Stated, in New England Region. In 2011 Hurricane Irene passes through the Connecticut River watershed causing flooding in urban and agricultural lands. The initial objective of this project was to create an inundation flood map for Connecticut River using HEC-RAS. Due to lack of Lidar elevation data for the whole region and considering the size of the watershed, a new objective was assumed.

The new purpose of this project is to create inundation flood map for the lower reach of Deerfield River which is a tributary to Connecticut River. Deerfield River is located in Western Massachusetts and it experiences one of the worst floods due to the rainfall dropped off by Hurricane Irene.

Connecticut River Watershed and Hurricane Irene

1. *Connecticut River Watershed*

   Connecticut River is located in New England Region. It begins at Fort Connecticut Lake, passes through the states of New Hampshire, Vermont, Massachusetts, and Connecticut, and flown into Long Island Sound. The river watershed drainage area is about 11264 square miles with elevation between 1916 m and sea level. Connecticut River is about 410 miles long and accounts for about 70% of the fresh water inflow in Long Island Sound.

   The average annual precipitation is about 45 inches in the form of rain and snow. The average flow varies widely with location along the river. Along the main channel of Connecticut River there are about 16 dams and 12 of them are used for hydropower.

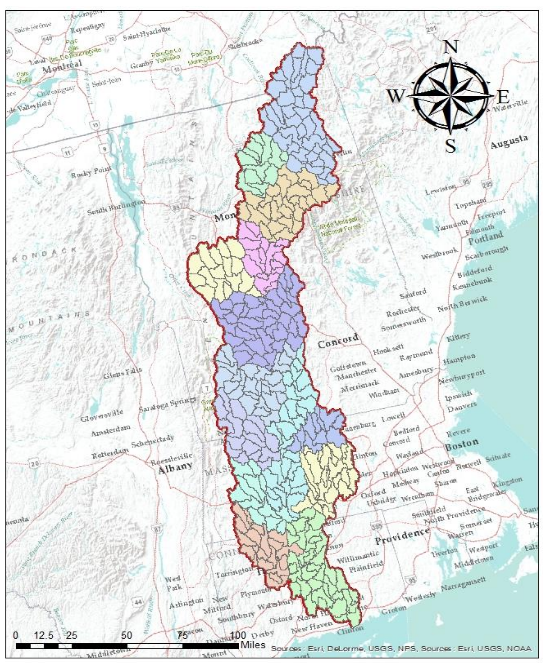

Figure 1. Location of Connecticut River Watershed and its HUC-8 subwatersheds

2. Hurricane Irene in Connecticut River Watershed

Hurricane Irene formed near the Caribbean Islands on 15th of August 2011. It reaches the South East coast of the US on 27th of August. From the moment it touches the east coast of the US, it is degraded to Tropical Storm, but the damage it causes is significant.

Hurricane Irene brings average of 5 inches in Connecticut River Watershed. The maximum daily rainfall occurs in Vermont and it reaches about 8 inches.

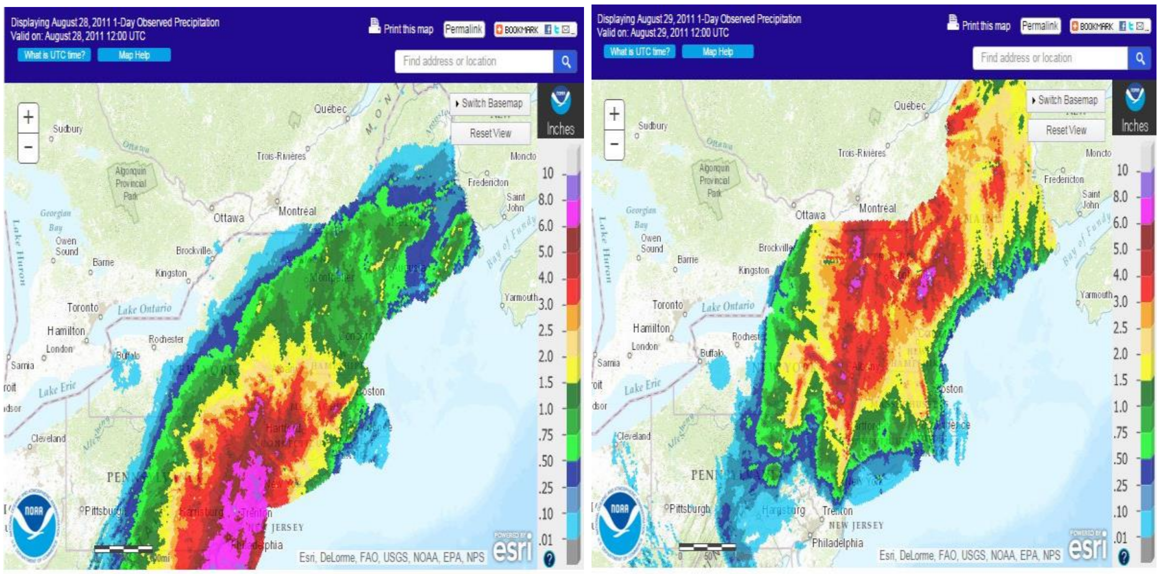

Figure 2. Daily rainfall data from NOAA for 28th and 29th of August 2011

Hurricane Irene cost more than $15 billion to the US. The wind and the flood caused by the hurricane killed about 67 people. The total damages for New England Region cost about $2 billion. More than 2 million households and businesses were left without power.

The most affected state by the flood in Connecticut River was Vermont. There were more than 500 miles of roads and about 15 bridges destroyed. It cost the state of Vermont about $800 million to recover the damaged infrastructure.

Figure 3. Picture of a roadway ripped off by Connecticut River in Vermont 2011

Deerfield River

1. *Location*

Deerfield River is flowing through two states – Vermont and Massachusetts. Its watershed is a subbasin of Connecticut River basin. Deerfield River Watershed has HUC 8 number 01080203 and it includes 16 HUC 12 subbasins shown on Figure 4.

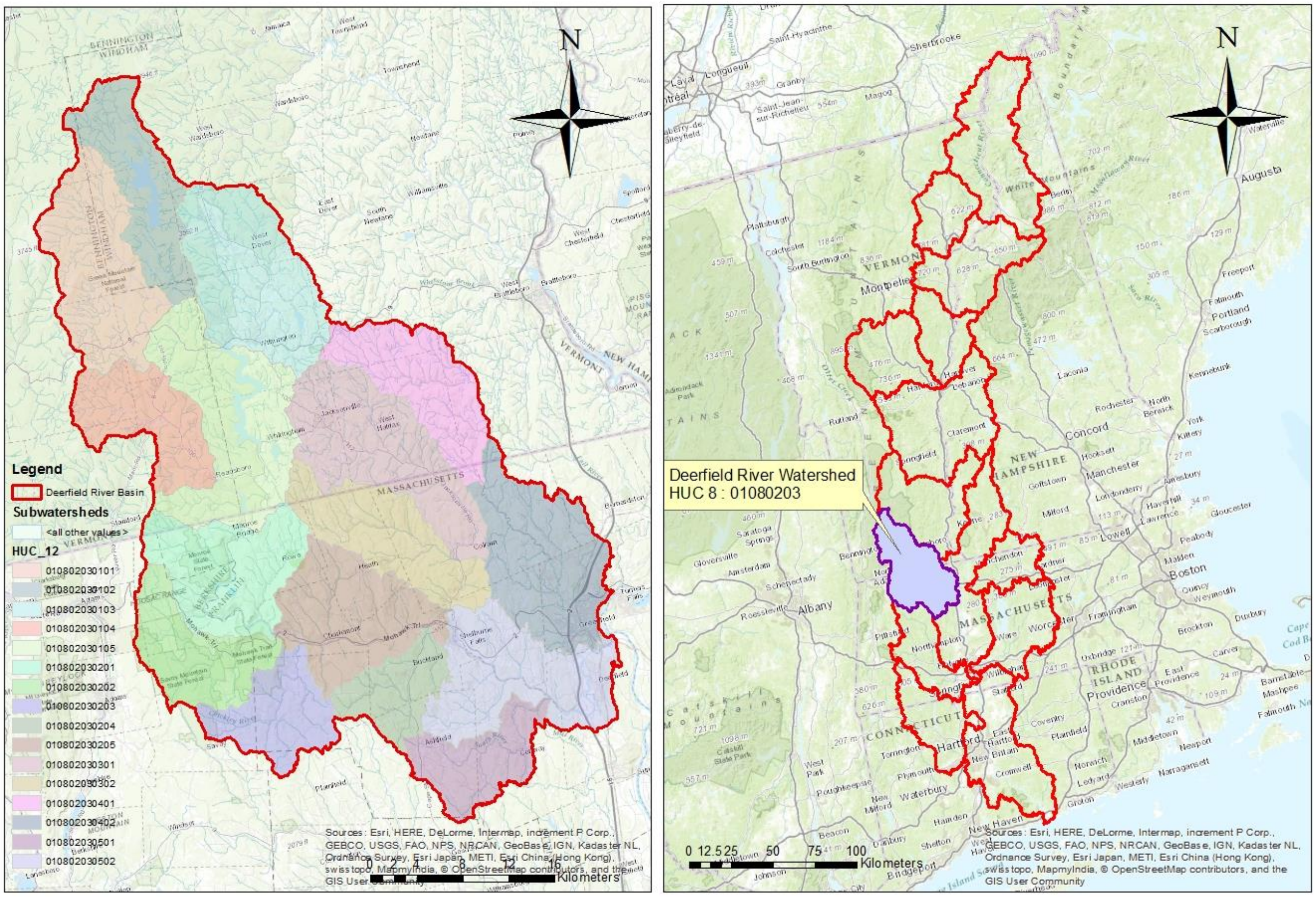

Figure 4. Deerfield River Location and Watershed

2. *Statistics of Deerfield River and Its Watershed*
   - Drainage Area: 665 square miles
   - Deerfield River main stem length: ~ 70 miles
   - Drains into Connecticut River near Greenfield, MA
   - Average annual Precipitation : ~49 inches

Study Area

1. *Location and extent of study area*

As a study area is chosen the location where Deerfield River flows into Connecticut River near Greenfield, MA. The reach of interest is 9.45 miles long and its location is shown on Figure 5.

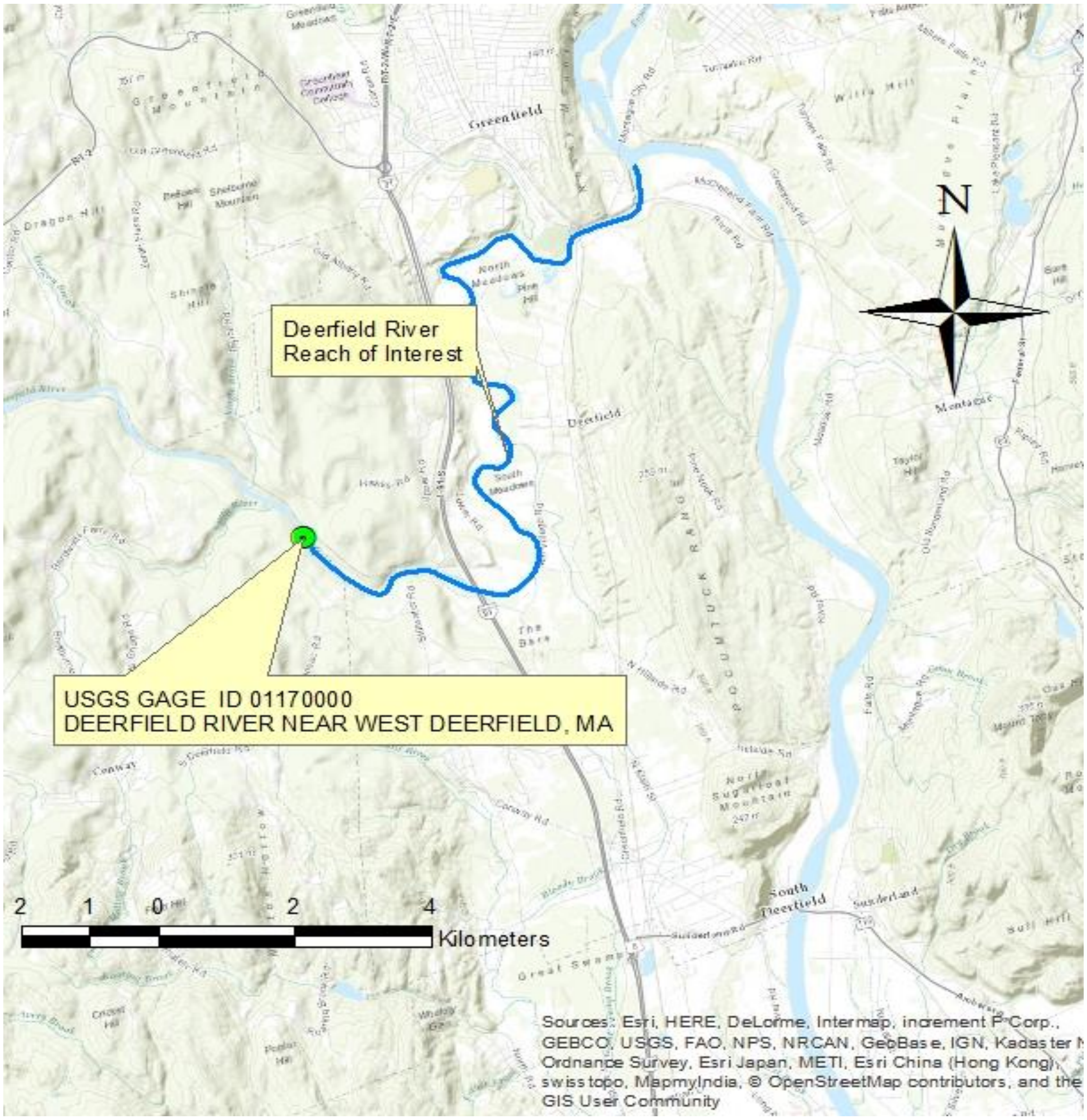

Figure 5. Location and extent of the reach of interest

2. *USGS Gage 01170000 - Deerfield River near West Deerfield, MA*

   The location of the USGS stream gage used for stream flow analysis is shown on Figure 5.

   The highest discharge at the USGS gage location occurs on 28th of August. The maximum discharge due to Hurricane Irene is about 90000 cfs, as can be seen on Figure 6. The maximum gage height is measured to be about 29 feet (Figure 7). Just 2 days before Hurricane Irene, the gage height is only 3 feet. This shows that the water surface elevation increased by a factor of 10 after Hurricane Irene has reached Deerfield River.

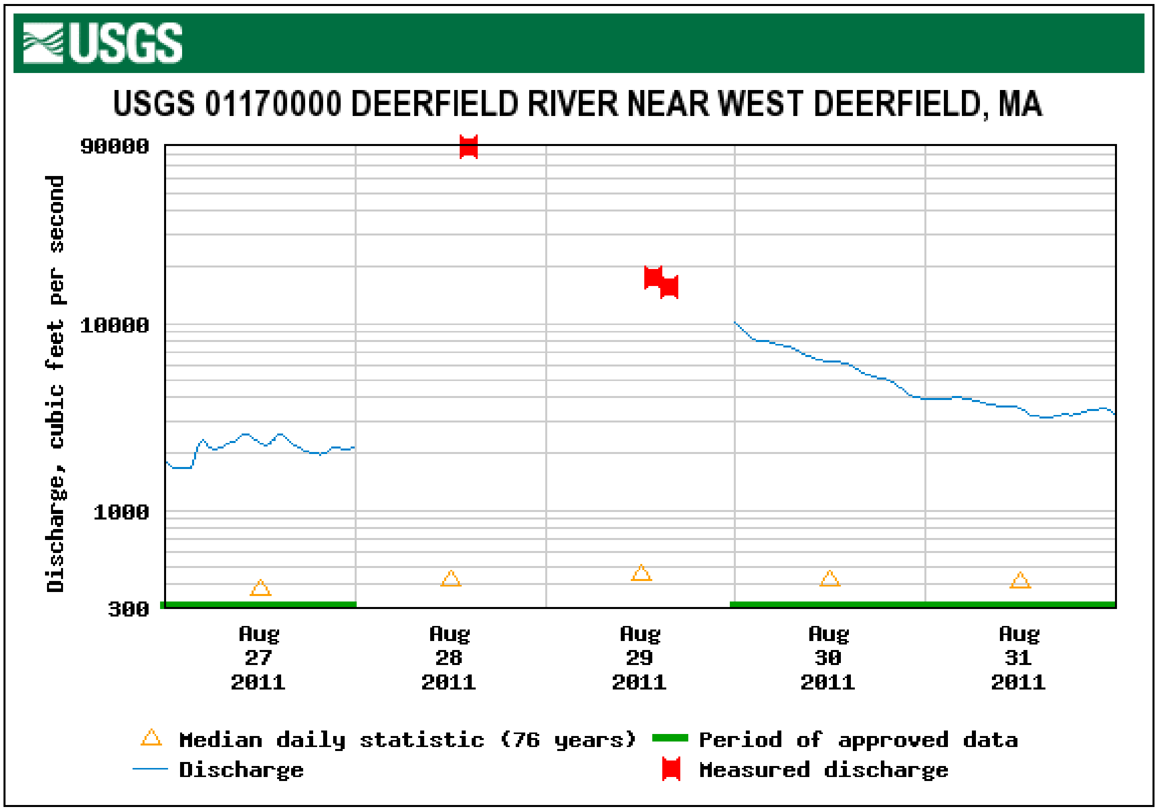

Figure 6. Discharge at USGS Gage 01170000 in August 2011

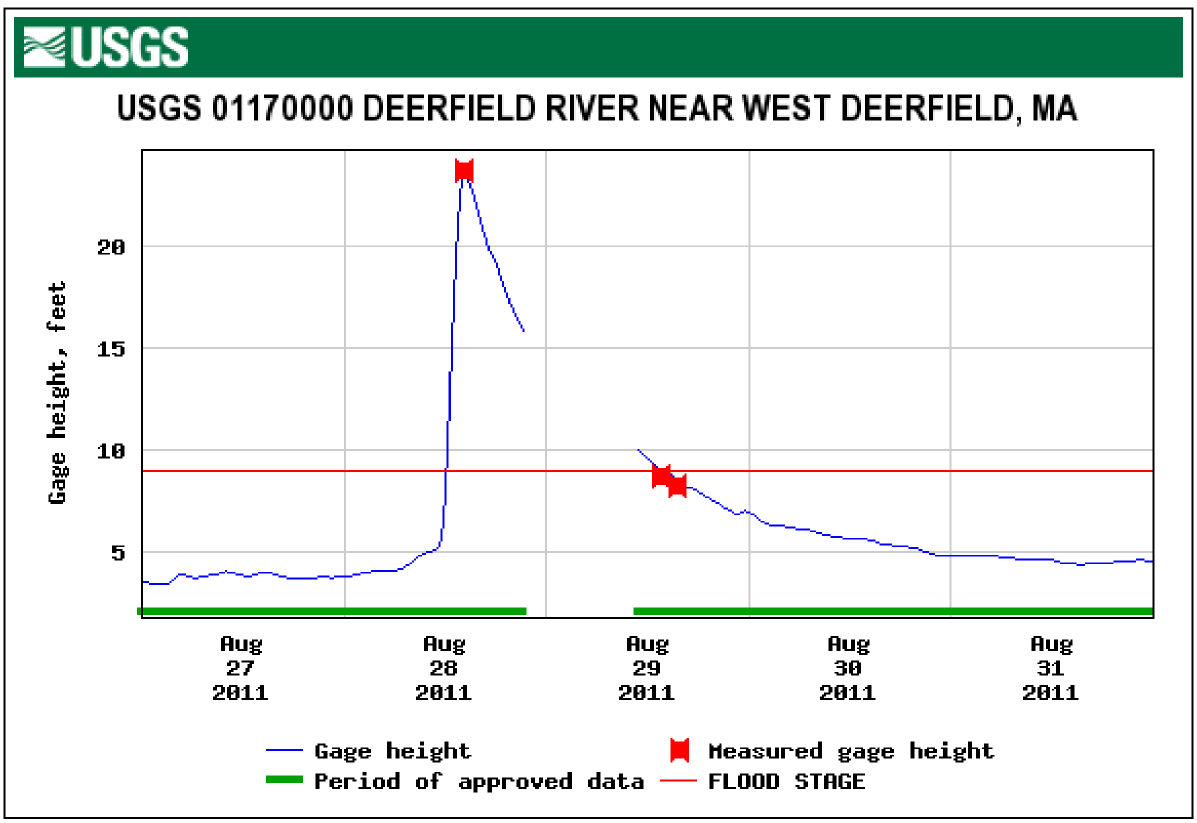

Figure 7. Gage height at USGS Gage 01170000 in August 2011

Flood Mapping

1. *Elevation Dataset*

   LiDAR dataset is obtained from NOAA's Digital Coast website and is provided by FEMA. The data was downloaded as LAZ files, which were converted into LAS files using software called LAStools. LAS Dataset was created in ArcMap and it was used to obtain high resolution triangular irregular network (TIN) by applying LAS→Multipoint→Terrain→ TIN tools. The result is presented on Figure 8. The LiDAR dataset consisted of raw data and to build a smooth surface, different methods of creating TIN were applied. Some of these methods are LAS→LAS Dataset→TIN and LAS→LAS Dataset→Raster→TIN. But some of them failed to execute successfully, and other methods gave worse results compared to the one presented on Figure 8..

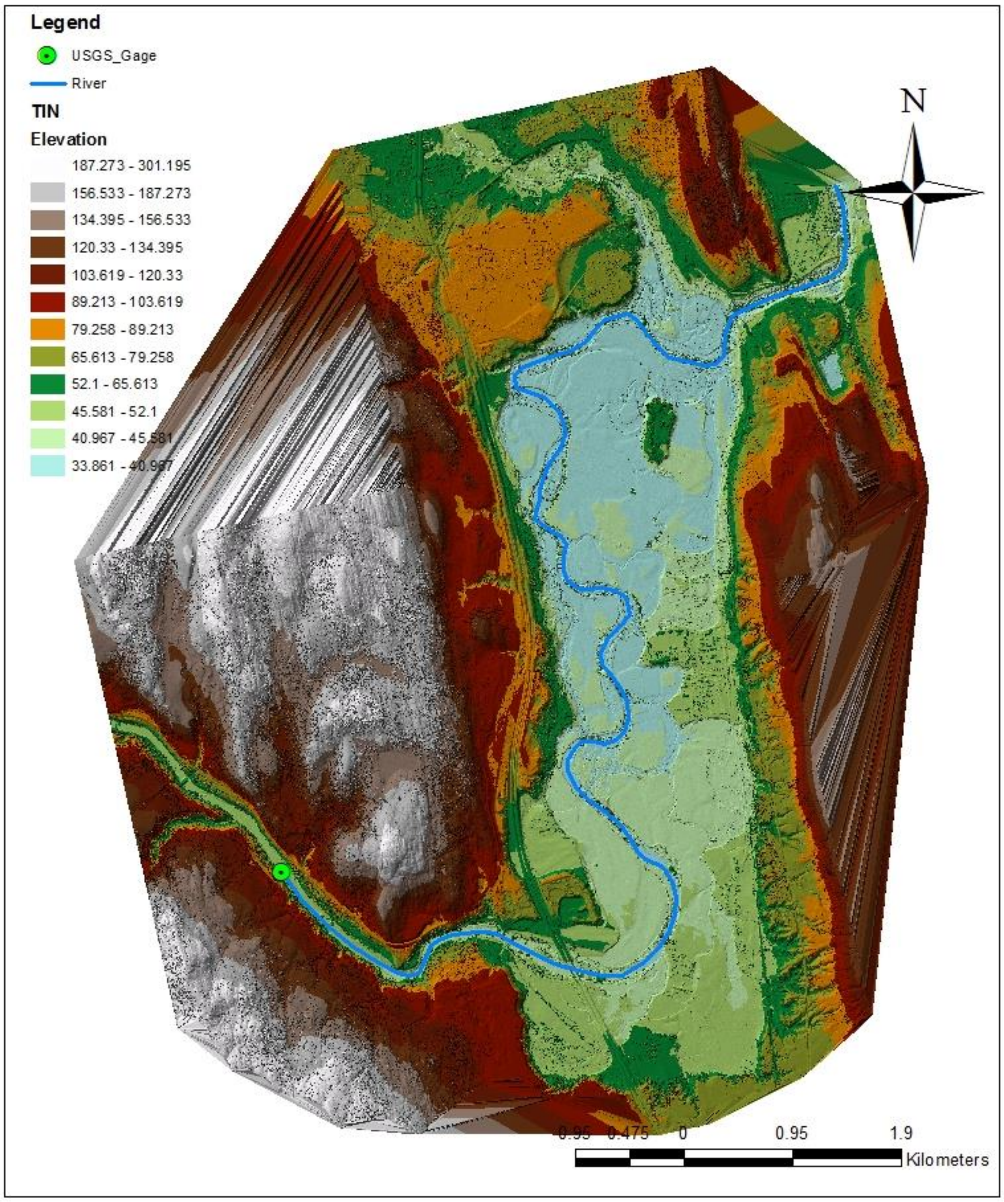

Figure 8. TIN created with LAS Dataset to TIN Tool

2. *Creating RAS Geometry*

RAS geometry was created using HEC-GeoRAS software, provided from USACE. Layouts of the river centerline, banks, flowlines, and cross sections were prepared in ArcMap. The delineation of the geometry features and the location of the river cross sections are shown on Figure 10.

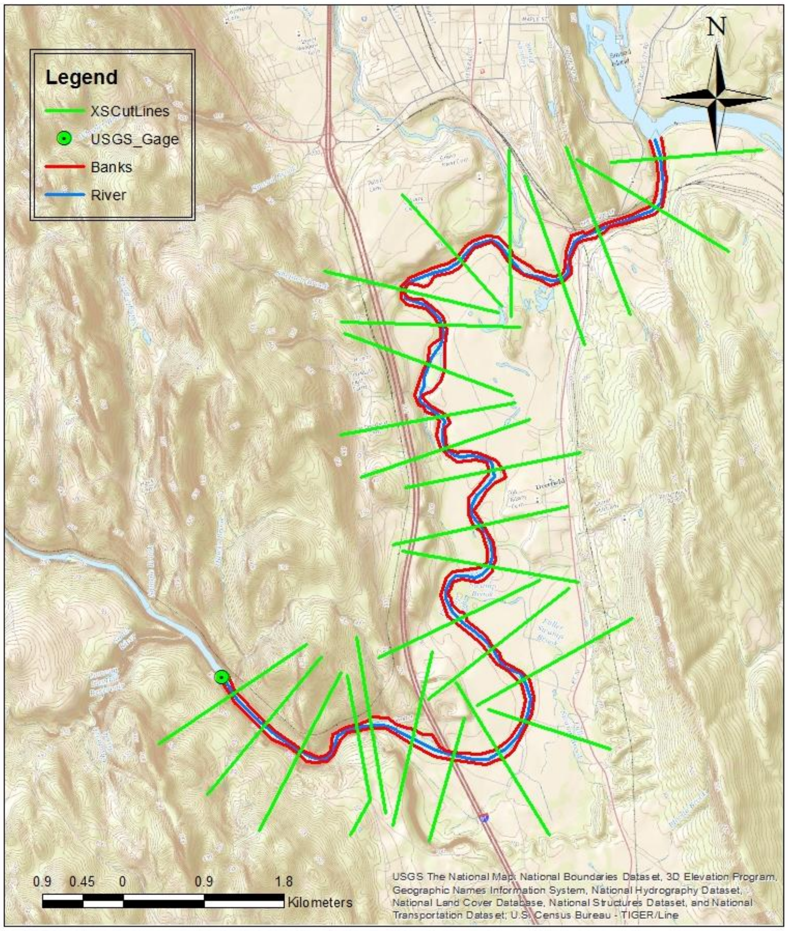

Figure 10. Geometry created in ArcMap using HEC-GeoRAS tools.

Stream Centerline and XS Cut Lines attributes were created based on the elevation data from the TIN presented on Figure 8. RAS Geometry was exported from ArcMap and imported into HEC-RAS to be used in a hydraulic analysis.

Manning's n values were derived from NLCD 2011 Land Use database. Land cover map is shown on Figure 11. LU – Manning Table was created with HEC-GeoRAS and n values were assigned to each land cover class. The n-values were obtained from "Effect of land use-based surface roughness on hydrologic model output" article (Kalyanapu et al. 2009). Manning n-values were assigned to each cross section by using Extract N-Values tool, referring to the class name attribute in land use dataset and LU – Manning Table.

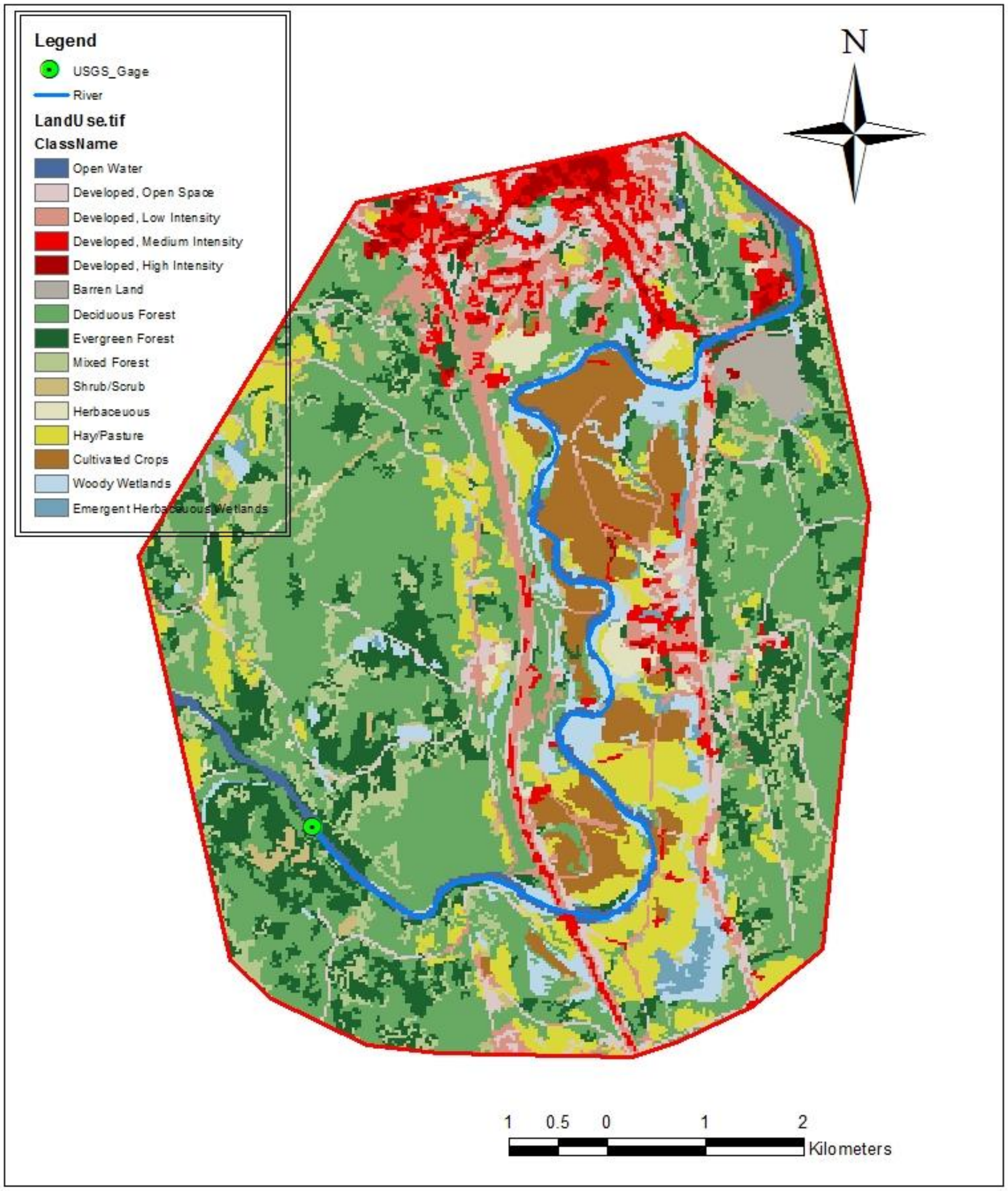

Figure 11. NLCD Land Cover

3. *RAS Model*

Hydraulic model of Deerfield River was created using HEC-RAS. This is software provided from USACE to be used in development of hydraulic models.

The geometry created in ArcMap using HEC-GeoRAS tools was imported in HEC-RAS. The points in each cross section were filtered to decrease their number. The cross sections were slightly adjusted to create smoother surface. Cross sections were interpolated at approximate distance of 100 ft to insure better flow modeling. One of the cross sections is presented on Figure 12.

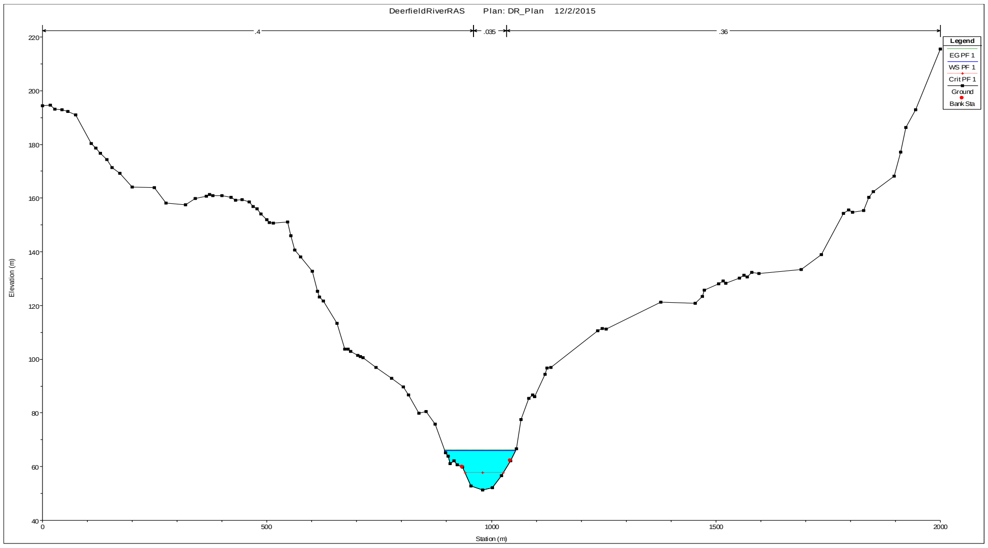

Figure 12. Cross Section 15000 (Just downstream of USGS Gage 01170000

The flow in Deerfield River as a result of Hurricane Irene was analyzed under steady state conditions. The steady flow analysis was performed for the maximum flow measured at the location of Gage 01170000, which is estimated to be 90,000 cfs. As an upstream boundary condition was used rating curve obtained from USGS discharge and gage height information for gage 01170000. The downstream boundary condition was used critical depth. The water surface profile along the river is presented on Figure 13, and axonometric view is presented on Figure 14.

The model was also run considering flow under normal conditions with discharge of 350 cfs to confirm that the model is somewhat realistic (See Figure 15.)

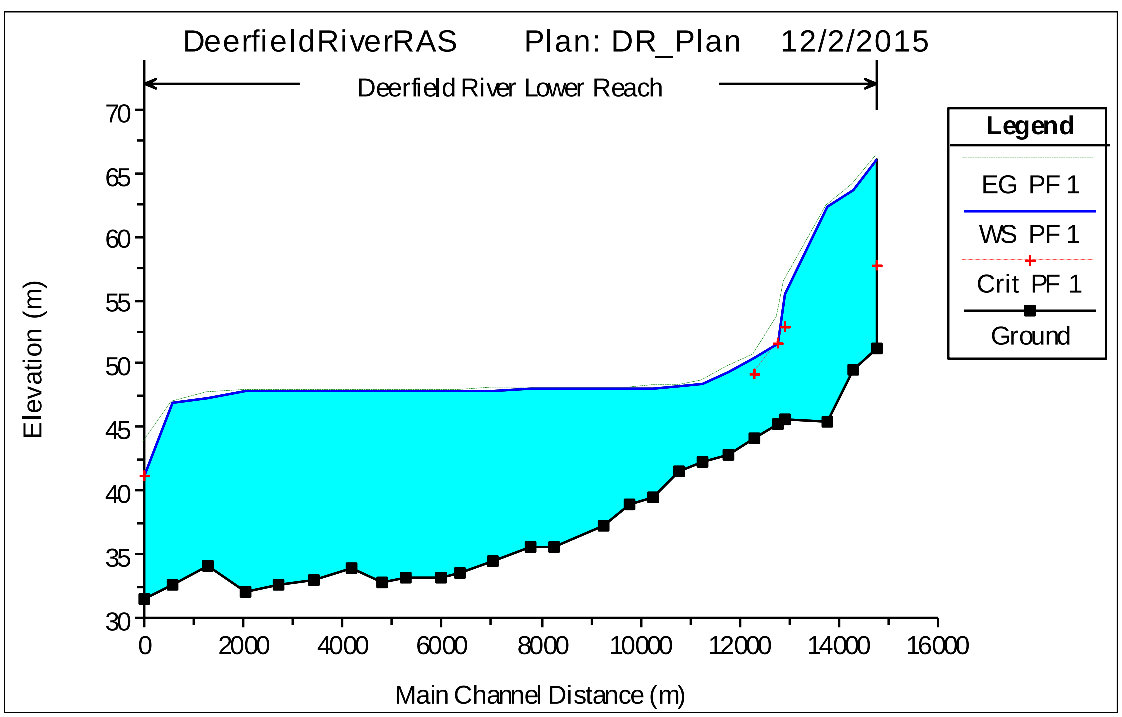

Figure 13. Water surface profile as a result of steady flow analysis in HEC-RAS

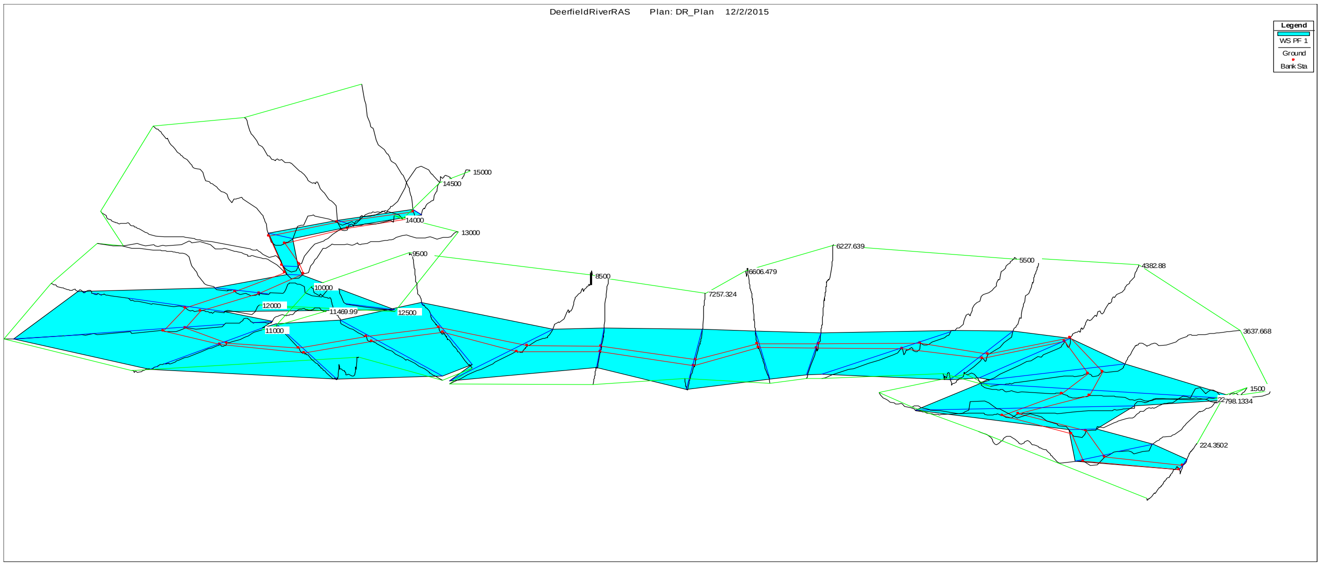

Figure 14. 3-D view of water surface profile during flooding

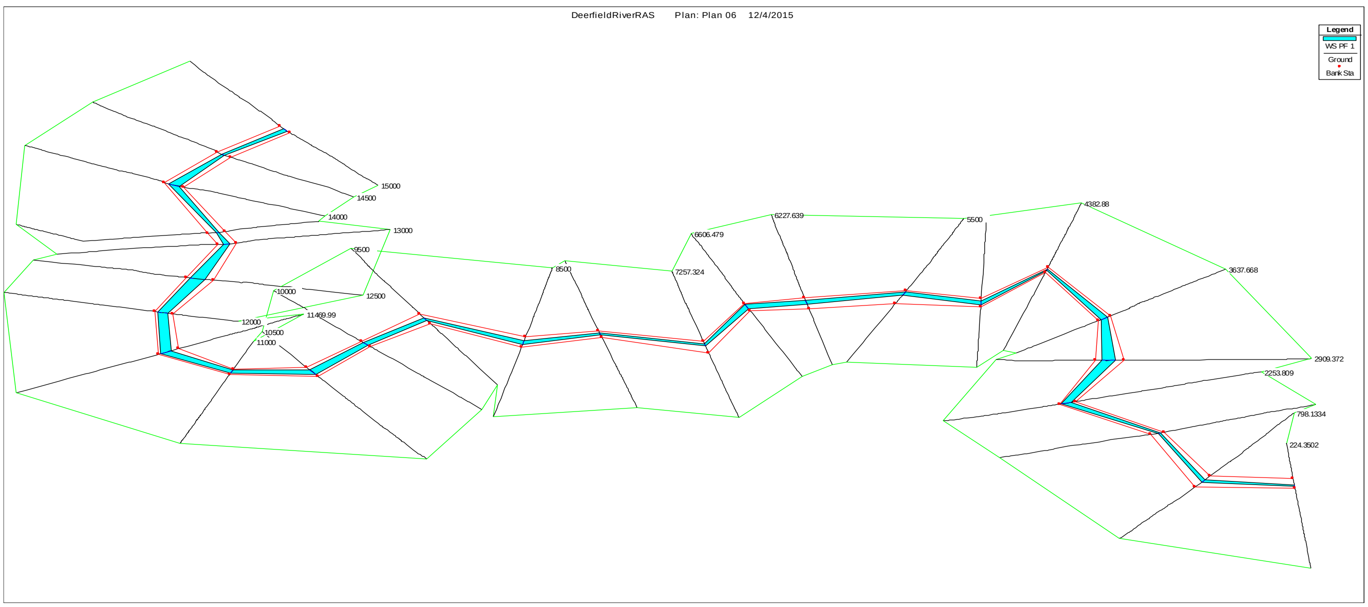

Figure 15. 3-D view of water surface profile under normal flow conditions

4. *Shortcomings of the RAS model*

- The TIN surface was not smooth and the cross sections were adjusted in HEC-RAS
- HEC-RAS model does not account for the two bridges passing over the river, and does not include the ineffective flow areas and obstructions
- There is a tributary river, whose flow is not known and therefore it is not included in the model

5. *Exporting water surface profile from HEC-RAS and importing it in ArcMap*

The results from the steady flow analysis were exported from HEC-RAS by creating GIS Export file. Following the ‘Introduction to HEC-RAS and Floodplain Mapping’ exercise instructions, prepared by Dean Djokic and Prof. David R. Maidment, flood map was created in ArcMap. The result is presented on Figure 16.

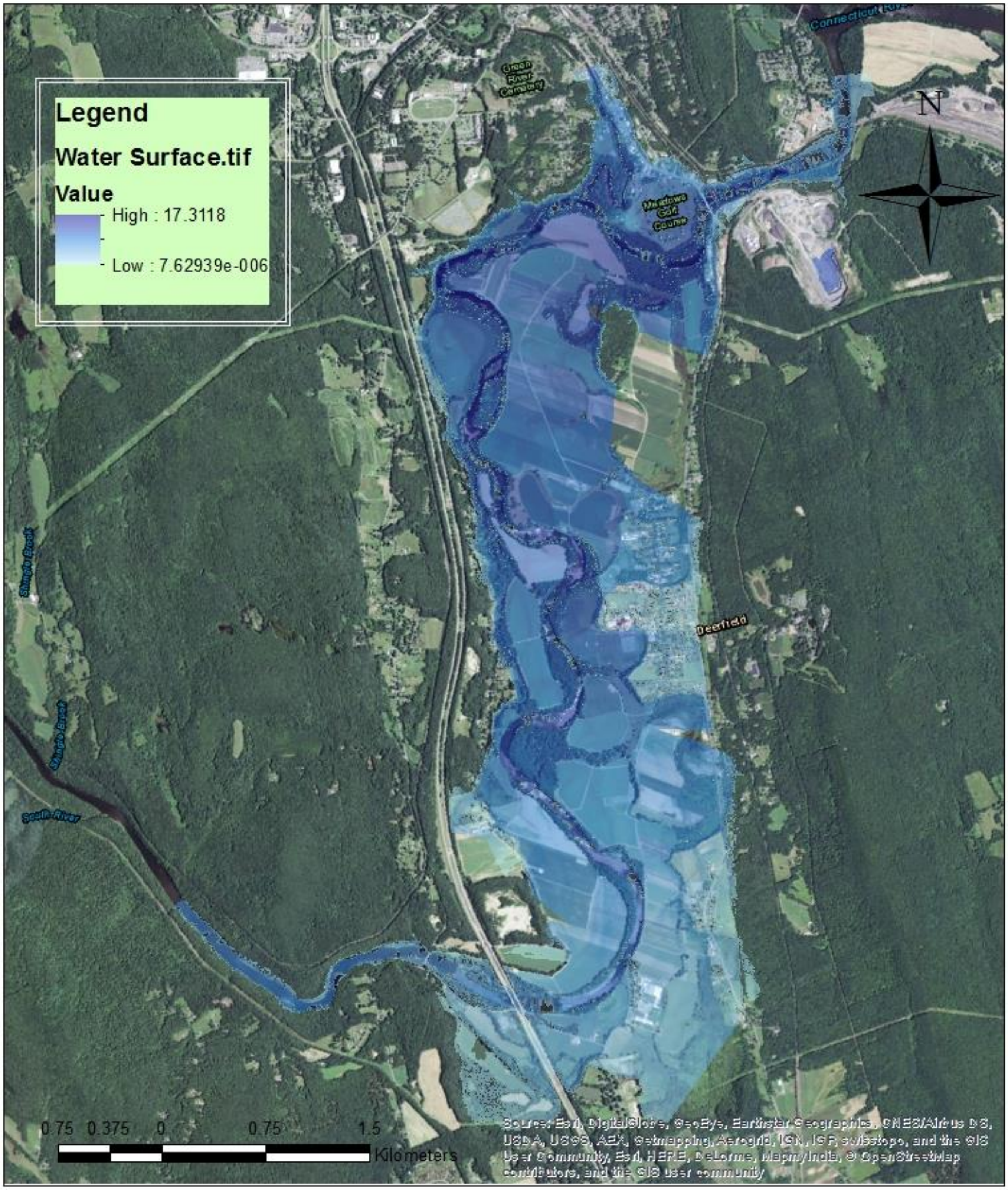

Figure 16. Flood map resulting from HEC-RAS hydraulic analysis

6. Verification of Results

The flood map generated from HEC-RAS was compared to a flood map created by USGS. The result of this comparison is shown on Figure 17. It can be seen that the extent of the flood is similar. The differences are probably due to the elevation model used in the analysis, noting that USGS also uses Gage 01170000 in their analysis.

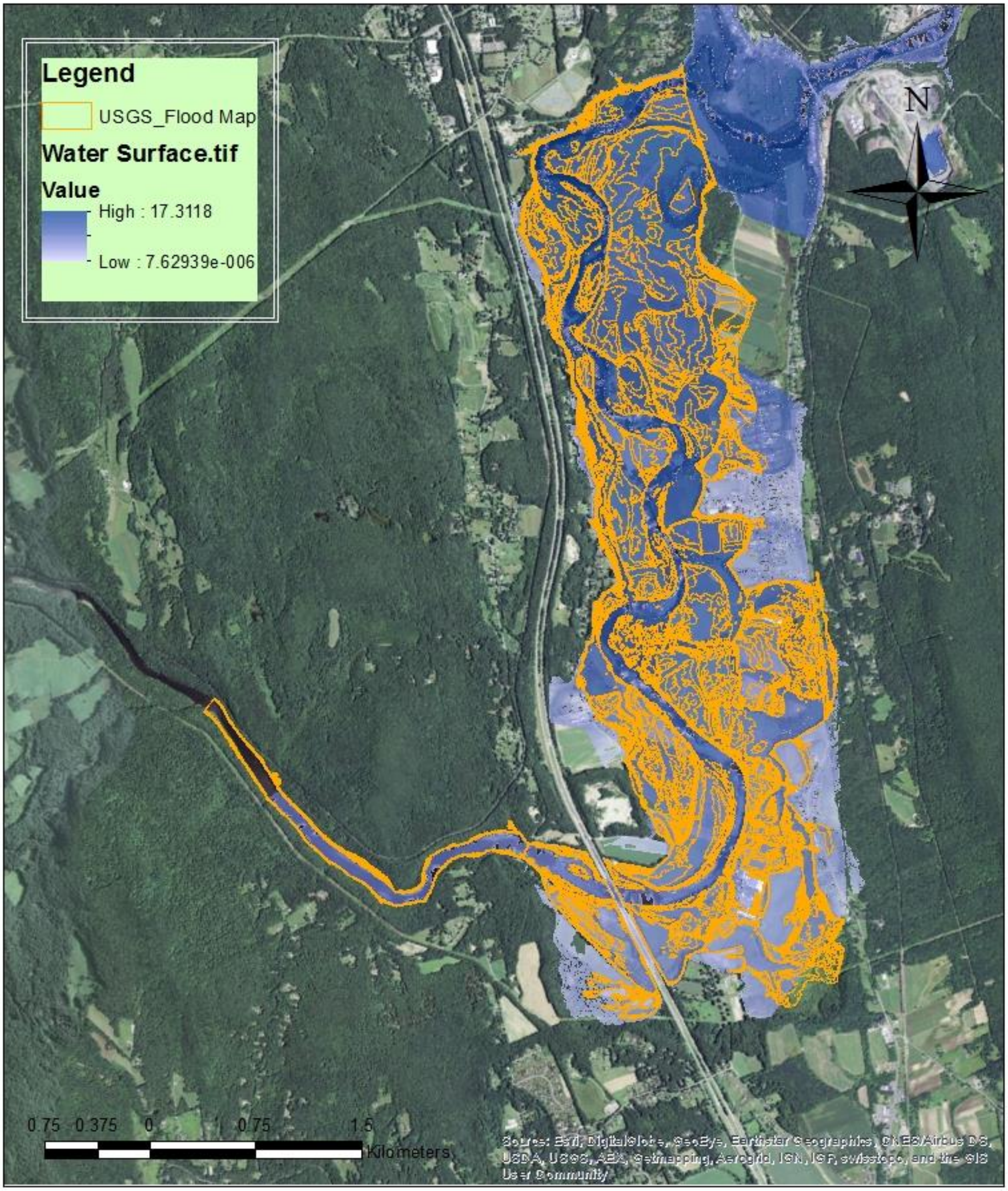

Figure 17. Verification of results by comparison with USGS existing flood map

Conclusions

The results from the HEC-RAS hydraulic analysis are considered to be reasonable, keeping in mind the shortcomings discussed in Flood Mapping section. LiDAR data allows creating precise elevation dataset to be used in hydraulic models. However, it has to be processed to eliminate noise points and to create smooth terrain.

The extent of the flood occurred in the lower part of Deerfield River are presented on Figure 16. Using satellite basemap it can be seen that the flood covers some developed areas is Deerfield, as well as agricultural lands. Part of highway I-91 was also underwater.

References

Ackerman, Cameron T. "HEC-GeoRAS: A User's Manual." *Graphing Jane Austen* (2012): n. pag. *USACE*. Web. 29 Nov. 2015. <http://www.hec.usace.army.mil/>.

"AHPS Precipitation Analysis." AHPS Precipitation Analysis. N.p., n.d. Web. 10 Nov. 2015. <http://water.weather.gov/precip/>.

"Deerfield River Watershed Association." *Deerfield River Watershed Association*. N.p., n.d. Web. 29 Nov. 2015. <http://deerfieldriver.org/>.

Djokic, Dean, and David Maidment. "Introduction to HEC-RAS and Floodplain Mapping." *University of Texas*. N.p., n.d. Web. 29 Nov. 2015. <http://www.ce.utexas.edu/prof/maidment/CE374KSpr12/Ex4/Ex4.htm>.

"Fast Facts about the Connecticut River." *Fast Facts about the Connecticut River*. N.p., n.d. Web. 29 Nov. 2015. <http://www.crjc.org/facts.htm>.

Kalyanapu, Alfred J., Steven J. Burian, and Timothy N. McPherson. "Http://www.spatialhydrology.net/index.php/JOSH/article/viewFile/84/83." *Journal of Spatial Hydrology*. N.p., n.d. Web. 29 Nov. 2015. <http://www.spatialhydrology.net/index.php/JOSH/article/viewFile/84/83>.

Lombard, Pamela J., and Gardner C. Bent. "Flood-inundation Maps for the Deerfield River, Franklin County, Massachusetts, from the Confluence with the Cold River Tributary to the Connecticut River." *Scientific Investigations Report* (2015): n. pag. *USGS*. Web. 01 Dec. 2015. <http://pubs.usgs.gov/sir/2015/5104/sir20155104.pdf>.

Leader, Jessica. "Hurricane Irene Facts: A Region-By-Region Look At The Storm's Toll." *The Huffington Post*. TheHuffingtonPost.com, n.d. Web. 29 Nov. 2015. <http://www.huffingtonpost.com/2012/08/27/hurricane-irene-damage-statistics-2011_n_1832342.html>.

Meekma, Ryan, and Gregory Byard. "HEC-GeoRAS Walkthrough Workshop." (n.d.): n. pag. *Illinois Floods Organization*. Web. <http://www.illinoisfloods.org/>.