GIS in Water Resources

Final Project

Flooding In New York City during Hurricane Sandy

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December 1, 2013

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1.Introduction

Hurricane Sandy approached the east coast of the United States in October,2012. The storm tide brought by Sandy caused a huge flood in New York City. In order to base both recovery operations and rebuilding efforts, we need to learn the flood influence process and area systematically. Here is the goal of this paper.

2.Background

In October 2012, the storm surge of Hurricane Sandy hit the United States. Sandy was the deadliest and most destructive hurricane of the 2012 Atlantic hurricane season, as well as the second-costliest hurricane in United States history. In the United States, Hurricane Sandy affected 24 states, including the entire eastern seaboard from Florida to Maine and west across the Appalachian Mountains to Michigan and Wisconsin. New York was one of the most severely affected by Hurricane Sandy in 2012, particularly New York City, its suburbs, and Long Island. The storm surge of Sandy hit New York City on October 29, flooding streets, tunnels and subway lines and cutting power in and around the city. Sandy's impacts included the flooding of the New York City Subway system, many suburban communities, and all road tunnels entering Manhattan except the Lincoln Tunnel, and the closure of the New York Stock Exchange for two consecutive days. Numerous homes and businesses were destroyed by fire, including over 100 homes in Breezy Point, Queens. Large parts of the city and surrounding areas lost electricity for several days, and several thousand people in midtown Manhattan were evacuated for six days due to the crane collapse at One57. Bellevue Hospital Center and a few other large hospitals were closed and evacuated. At least 53 people died in New York as a result of the storm. Thousands of homes and an estimated 250,000 vehicles were destroyed during the storm. Economic losses across New York were estimated to be at least $18 billion.

3.Objective&Methodology

The objective of this project is to create an hourly-interval flood map series for New York City during Hurricane Sandy. In order to achieve this goal, what I have to do is to collect the water-level data of different points in New York City from different organizations, and combine them with the Digital Elevation Model(DEM) with the help of ArcGIS Interpolation and Raster Calculation tools.

4.Data Source

4.1 DEM Data

The DEM I utilize is the New York City Area Digital Elevation Model, 1/3 Arc Second (feet) got from Columbia University. It is a raster dataset representing elevations in the New York City area. The layer was clipped from the USGS(U.S. Geological Survey) NED(National Elevation Dataset) to New York City and its immediate surrounding environment showing elevation (in feet), and ground units in decimal degrees. The resolution is 1/3 arc second(10meter). The specifications system for the DEM is geographic coordinate system, horizontal datum of NAD83, and vertical datum of NAVD88. A map displaying the elevations in New York City and the surrounding area is displayed in Figure 1. It is apparent that the elevations of coastal area in New York City are relatively low, just close to the sea level.

10Meterx10Meter DEM for New York City
Prepared By Xing Zheng, Dec. 1st

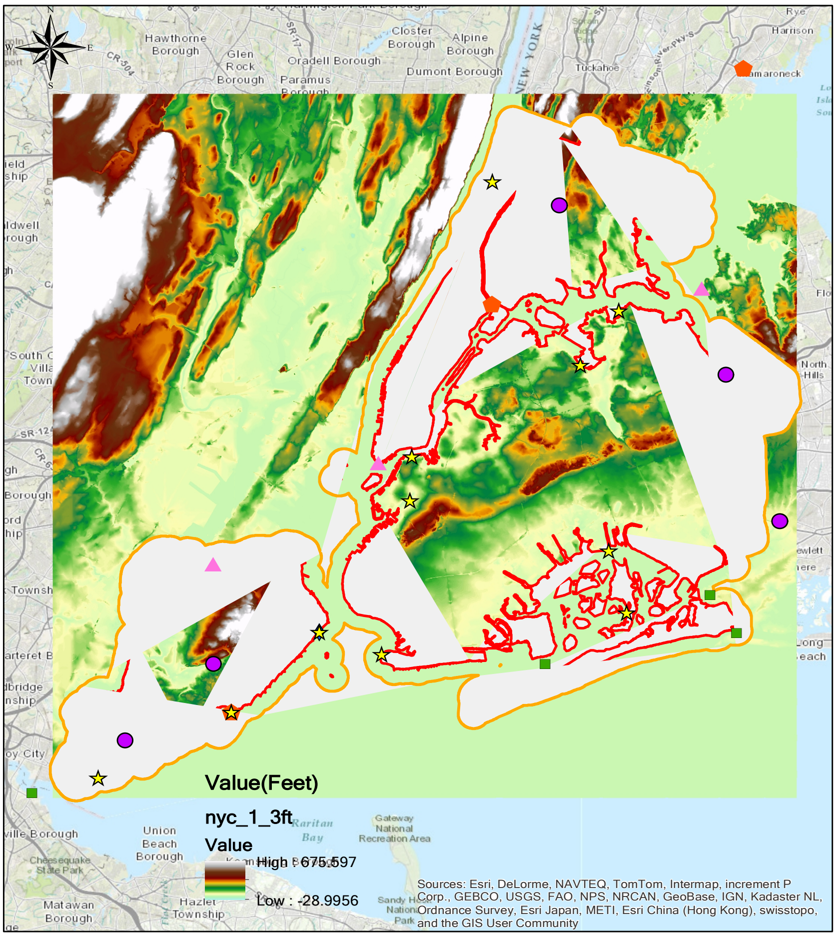

Figure 1. DEM for New York City

4.2 Water-Level Data

There are several different sources to get the water-level data. First of all, there are some longstanding observational fixed-place networks. The networks used in this project are the USGS real-time streamgage network, the USGS coastal tide gage network, and the NOAA(National Oceanic and Atmospheric Administration) coastal tide gage network. In order to supply more data to get timely flood information, the USGS deployed a temporary monitoring network of water-level and barometric pressure sensors at 224 locations along the Atlantic coast from Virginia to Maine to continuously record the timing, areal extent, and magnitude of hurricane storm tide. A total of 162 water-level and wave-height sensors were deployed at 147 locations during October 26-29 prior to landfall. Of the 162 water-level sensors, 145 sensors were programmed to record water pressure at 30-second intervals, and 9 sensors recorded wave-height measured every 2 seconds, both expressed as water level in feet above the North American Vertical Datum of 1988 (NAVD 88). An example of water-level elevation and barometric pressure data collected is shown in figure 2. An additional eight locations were rapid-deployment gages (RDG) instrumented with real-time telemetered sensors that recorded water-level elevations and meteorological data every 15 minutes during the hurricane and transmitted hourly to USGS Webpages. The coordinates of these gages are collected and displayed in ArcGIS.

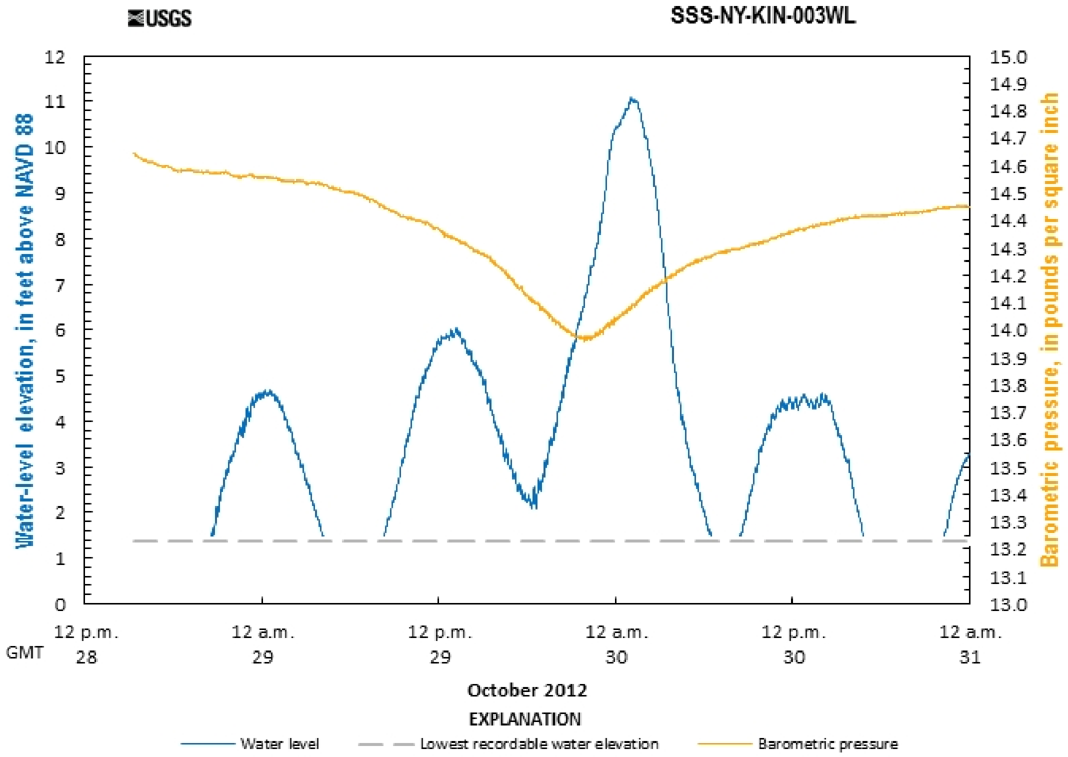

Figure 2.Example of a hydrograph displaying storm-tide elevation and barometric pressure data recorded at SSS-NY-KIN-003WL Gowanus Canal at Gowanus at Brooklyn, New York during Hurricane Sandy

Then what I need to next is to decide how many gages of these networks are located in the region of New York City. A 10km buffer layer of NYC boundary is created to achieve this goal. I select all the sites contained by the buffer area in the attribute tables, and export them separately. Details about different types of gage in NYC region are showed in figure 3 and table 1. Note that some gages near NYC but not included in the buffer area are also selected.

Table 1. Information about Gages in New York City Region

SiteName	Lat(Deg)	Long(Deg)	Source
Lower New York Bay at South Beach at Staten Island, NY	40.593884	-74.059845	TDS
Raritan Bay at Tottenville Beach at Staten Island, NY	40.501881	-74.230339	TDS
Great Kills Harbor at Great Kills Park at Staten Island, NY	40.54345	-74.12768	TDS
Lower New York Bay at Sea Gate at Brooklyn, NY	40.579998	-74.011612	TDS
Gowanus Canal at Gowanus at Brooklyn, NY	40.676878	-73.989839	TDS
Harlem River at Inwood Hill Park at Manhattan, NY	40.877565	-73.926331	TDS
Flushing Bay at Worlds Fair Marina at Queens, NY	40.762294	-73.858278	TDS
Jamaica Bay at Spring Creek Park at Queens, NY	40.64533	-73.836384	TDS
Long Island Sound at Whitestone at Queens, NY	40.796509	-73.828785	TDS
Jamaica Bay at Broad Channel at Queens, NY	40.606152	-73.822651	TDS
VALLEY STREAM AT VALLEY STREAM NY	40.66361111	-73.70444444	USGSSG
Lower New York Bay at South Beach at Staten Island, NY	40.593884	-74.059845	USGSWH
Bergen Point West Reach	40.6367	-74.1417	NOAA
Kings Point	40.8103	-73.7649	NOAA
The Battery	40.7006	-74.0142	NOAA
ROCKAWAY INLET NEAR FLOYD BENNETT FIELD NY	40.57361111	-73.88555556	USGSCT
JAMAICA BAY AT INWOOD NY	40.61722222	-73.75833333	USGSCT
EAST ROCKAWAY INLET AT ATLANTIC BEACH NY	40.59305556	-73.73777778	USGSCT
Raritan River at South Amboy NJ	40.49222222	-74.28138889	USGSCT
Great Kills Harbor at Great Kills Park at Staten Island, NY	40.5434	-74.12773	Rapid
Harlem River at Randall's Island at Manhattan, NY	40.800589	-73.926474	Rapid

Water-Level Gages in New York City Region
Prepared By Xing Zheng, Dec. 1st

Figure 3. Water-Level Gages in New York City Region

Next, we need to get the water level data of different gages at a certain time. But not all the gages recorded the data at that time, because some gages are temporary and only recorded the data for a certain period. Hence, I must search the data from all gages and to collect the data I want. That’s a boring task. So I write a program in C language to do it. The operation interface is showed in figure 4.

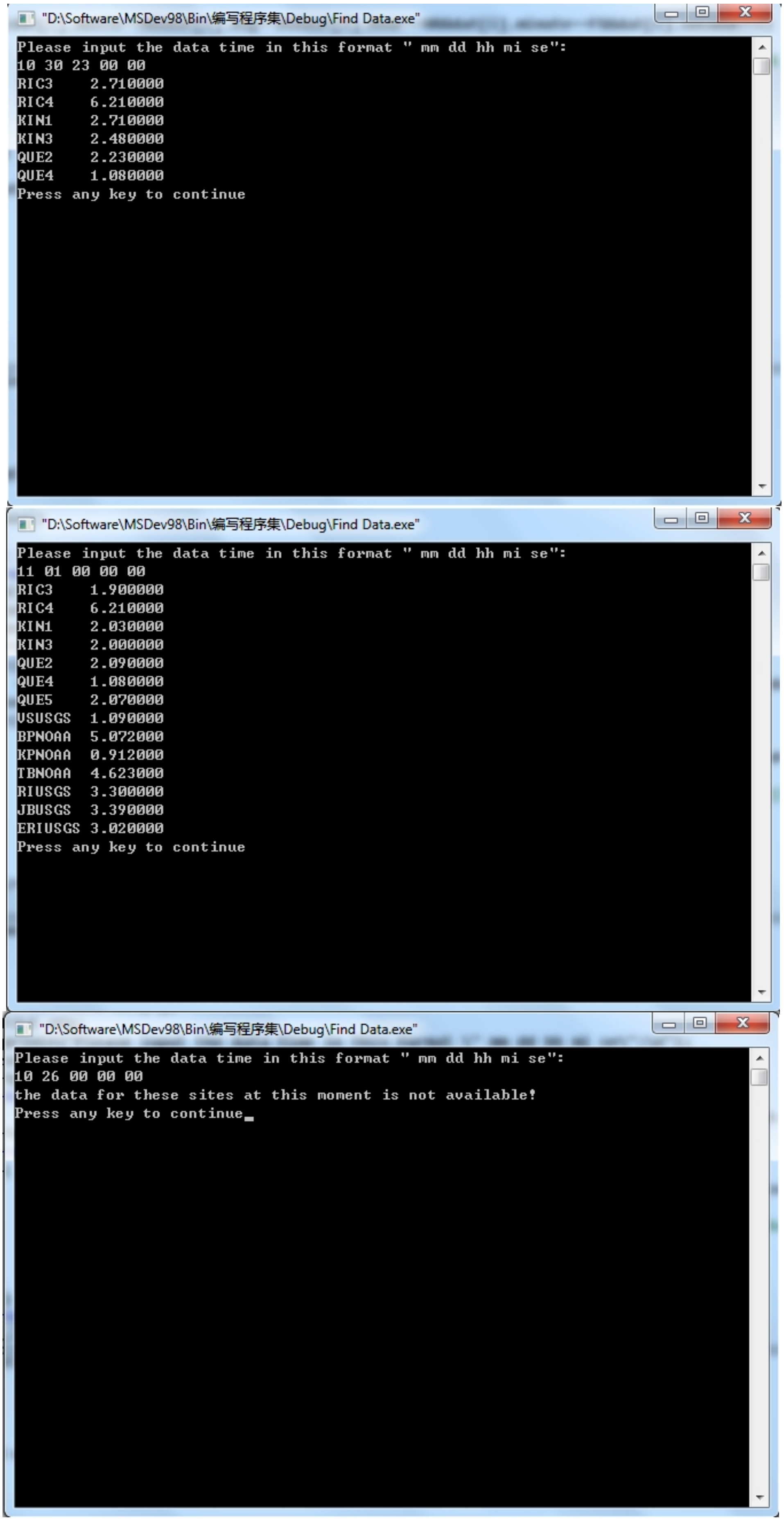

Figure 4. Operation Windows of Data Collection Program

5.Interpolation

Now we have water-level values from different gages at a certain time. In order to get a water surface for the whole region, we must rely on the interpolation tools in ArcGIS Spatial Analysy Toolbox. Three kinds of interpolation methods are used in this project, Inverse Distance Weighting(IDW), Kriging, and Spline.

5.1 Inverse Distance Weighting

In IDW method, the assigned values to unknown points are calculated with a weighted average of the values available at the known points. It resorts to the inverse of the distance to each known point ("amount of proximity") when assigning weights. Example of the water surface generated by IDW is showed in figure 5.

Interpolated Water Surface Using IDW
Prepared by Xing Zheng, Dec. 3

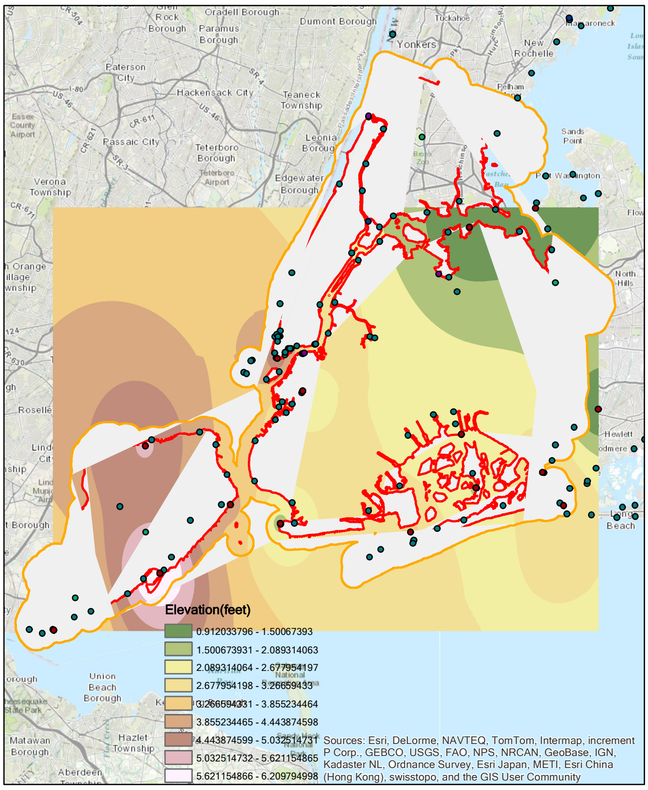

Figure 5. Interpolated Water Surface At 12 P.M.,Oct. 31,2012 by IDW

5.2 Kriging

Kriging is a method of interpolation for which the interpolated values are modeled by a Gaussian process governed by prior covariances. Under suitable assumptions on the priors, it gives the best linear unbiased prediction of the intermediate values. Example of the water surface generated by IDW is showed in figure 6.

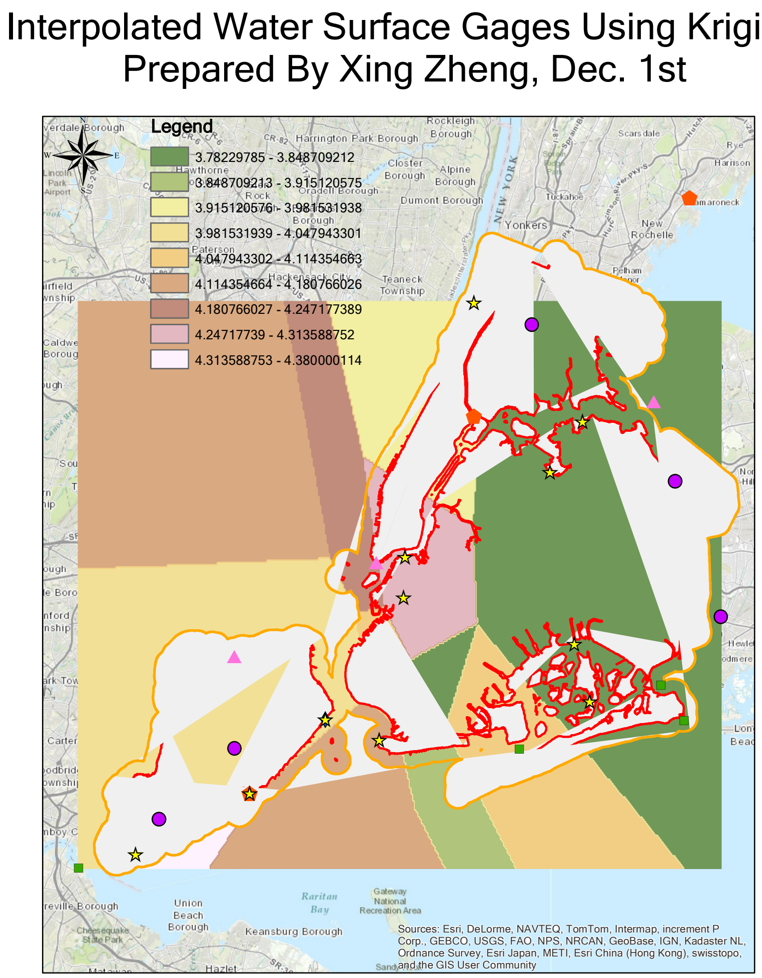

Figure 6. Interpolated Water Surface At 12 A.M.,Oct. 28,2012 by Kriging

5.3 Spline

The smoothing spline is a method of smoothing (fitting a smooth curve to a set of noisy observations) using a spline function. Example of the water surface generated by Spline is showed in figure 7.

Interpolated Water Surface Using Spline
Prepared by Xing Zheng, Dec. 3

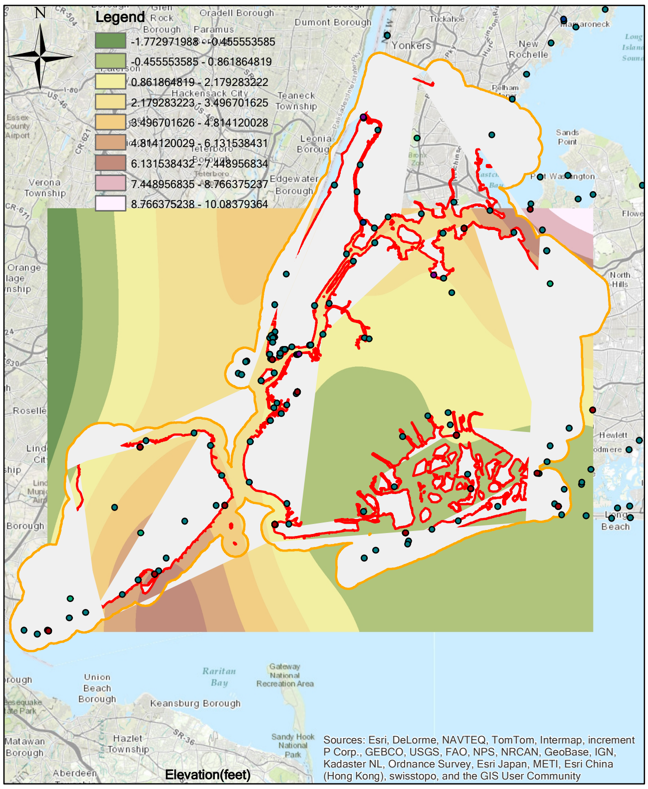

Figure 7. Interpolated Water Surface At 6 A.M.,Nov. 1,2012 by Spline

6.Results

Using the raster calculator tool, and set the condition as "dem"-"sea surface "<0, and do the raster calculation.The output provided a raster file with values of 1 where the DEM < sea surface and 0 everywhere else. Finally, we get the flood maps we want. Example of the flood map is showed in figre 8,9,and 10.

Flood Map of New York City at 12 A.M., Oct. 28, 2012(Kriging)
Prepared by Xing Zheng, Dec.3

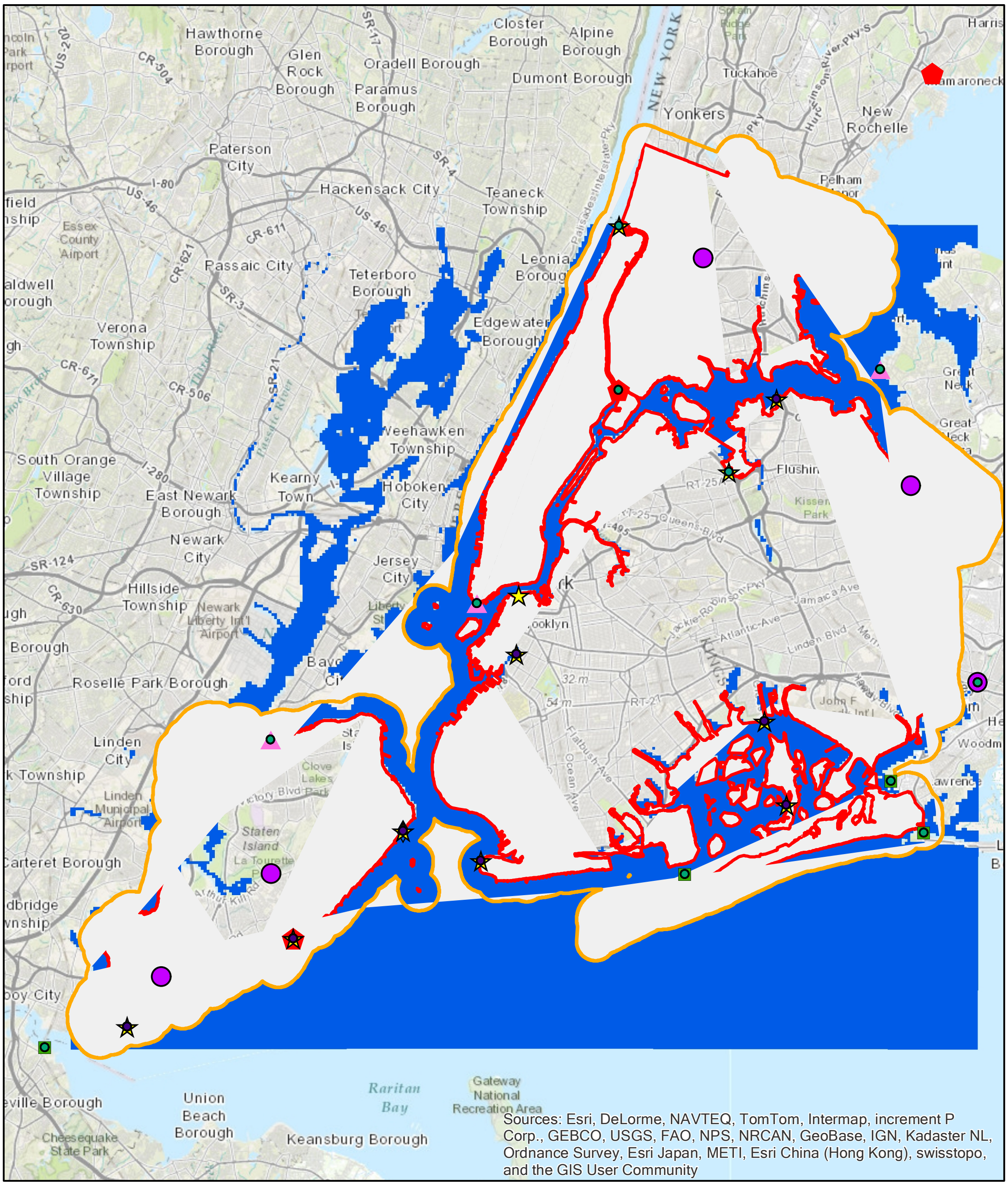

Figure 8. Flood Map of New York City At 12 A.M.,Oct. 28,2012 (Kriging)

Flood Map of New York City at 12 A.M., Oct. 29, 2012(Kriging)
Prepared by Xing Zheng, Dec.3

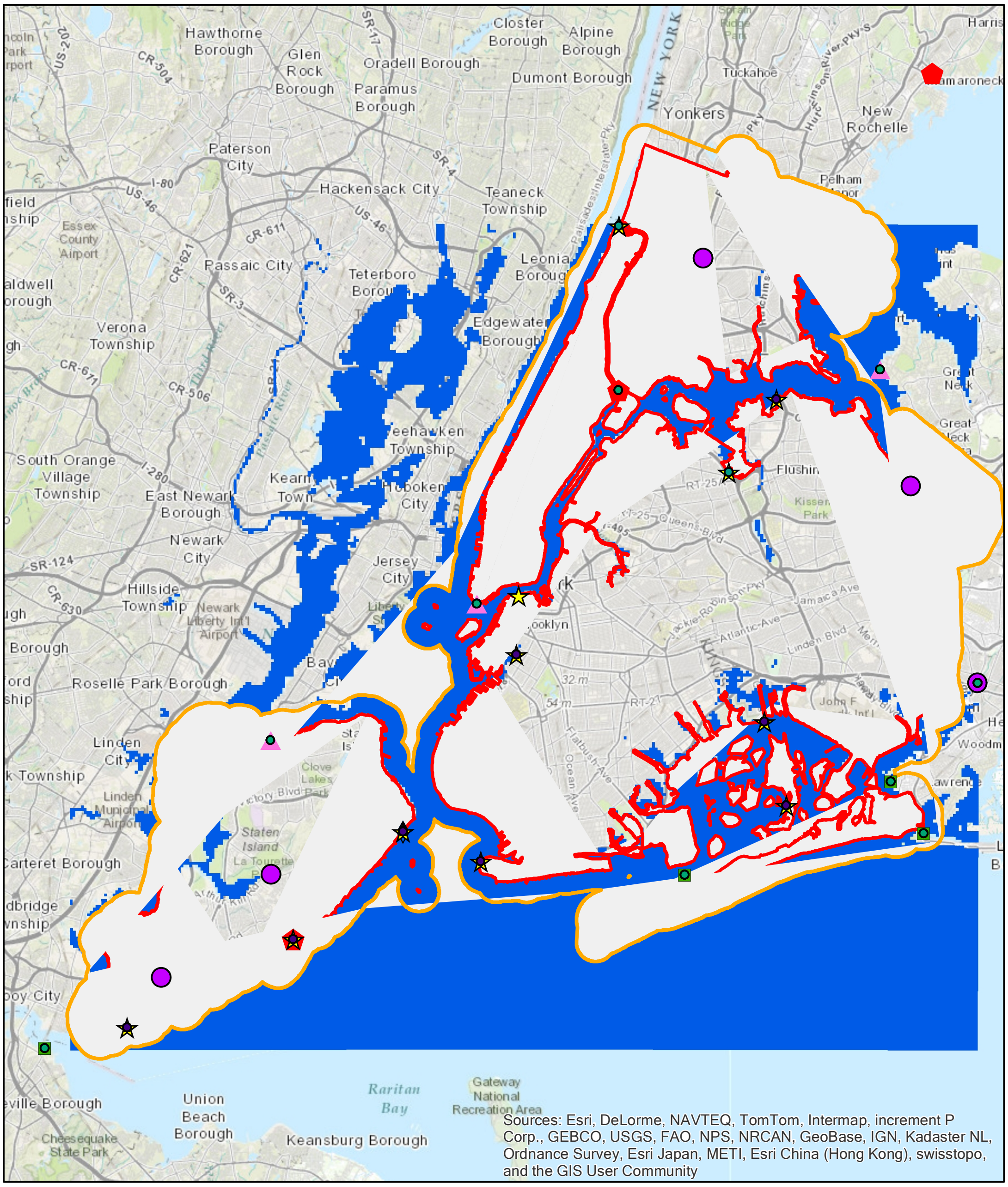

Figure 9. Flood Map of New York City At 12 A.M.,Oct. 29,2012 (Kriging)

Flood Map of New York City at 12 A.M., Oct. 30, 2012(Kriging)
Prepared by Xing Zheng, Dec.3

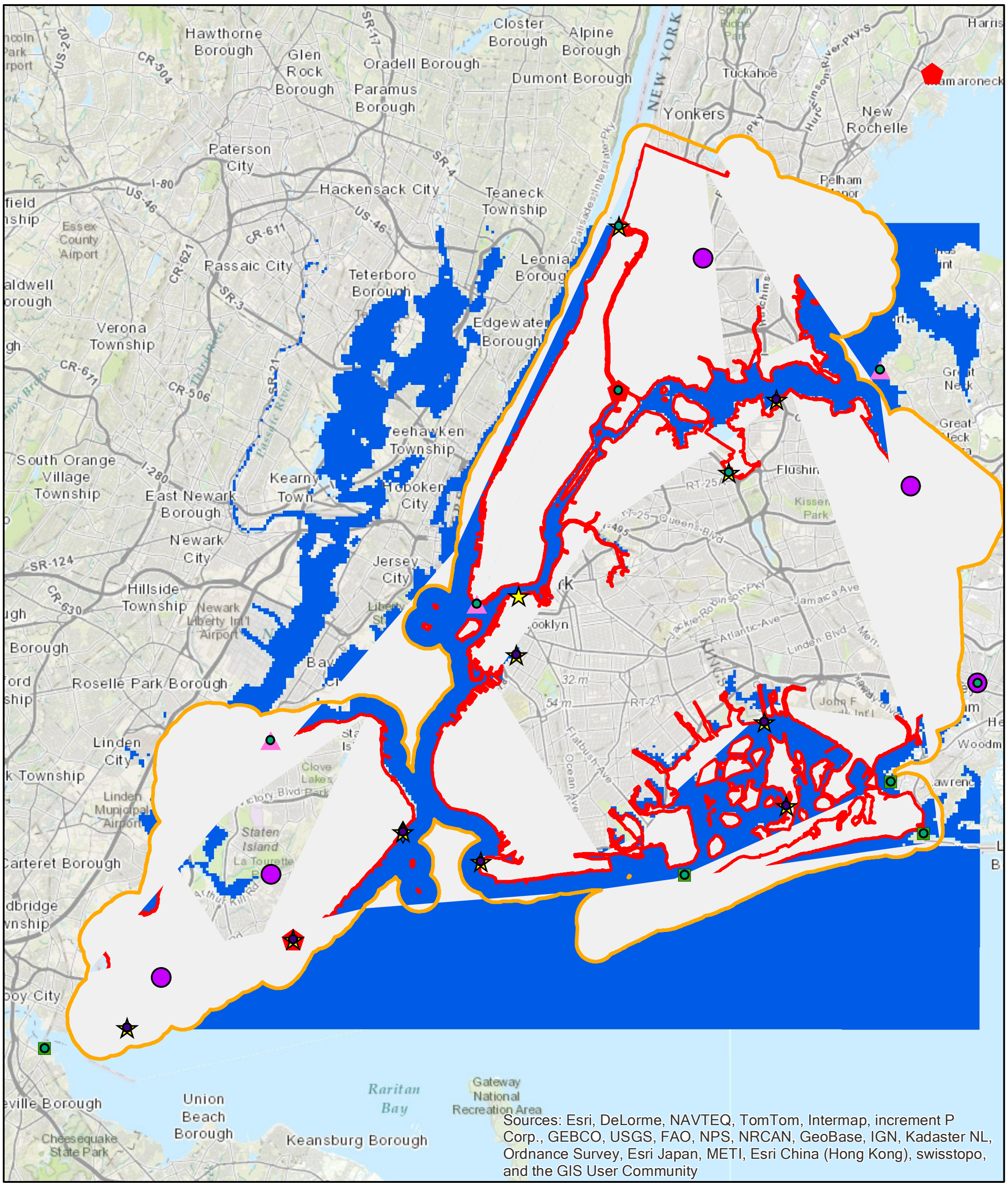

Figure 10. Flood Map of New York City At 12 A.M.,Oct. 30,2012 (Kriging)

7.Discussion

This project successfully carries out a flood map drawing mission with the help of GIS. Deciding water-levels using interpolation methods is a simple and effective way to create flood map. The underlying principle of this method is Tobler's First Law of Geography, “all attribute values on a geographic surface are related to each other, but closer values are more strongly related than are more distant ones.” However, since this method just consider the relationship of neighboring elements and use some mathematic functions to decide the values, without consider the physical mechanism behind the relationship. It is not the ideal method of flood mapping. Many projects carried out by students in our class (including myself) take advantage of interpolation without understanding the mechanism of these methods. It is dangerous that we may produce some specious results that we are not even aware of. So If we want to get the ideal flood map, we must go back to hydraulics and hydrology, building a sea-wave model to decide the water surface.

8.Reference

Brian E. McCallum, Shaun M. Wicklein, Robert G. Reiser, Ronald Busciolano, Jonathan Morrison, Richard J. Verdi, Jaime A. Painter, Eric R. Frantz, and Anthony J. Gotvald, 2013, Monitoring Storm Tide and Flooding from Hurricane Sandy along the Atlantic Coast of the United States, October 2012

coastal flooding generated by Hurricane Sandy