ABSTRACT

APPROACH TO FLOOD MITIGATION – A POST SANDY STUDY IN NEW JERSEY MEADOWLANDS AREA

by
Banshari Datta

In the last decade the continuous change in the climate has resulted in an increased frequency of natural catastrophic events and the magnitude of their impact. The immense damage caused by such events brought to light the vulnerabilities of the impacted communities. Coastal communities are alarmingly vulnerable due to flood and storm surge impacts such as those caused by super storm Sandy in 2012. In order to mitigate this risk, the communities need to look beyond the short term recovery measures, and build a sustainable community by implementing long term mitigation measures. The objective of this thesis is to investigate and outline a flood-risk mitigation process that recommends such long term measures.

This study looks into the impact of some of the most recent catastrophic flood and hurricane events in the US with a focus on the damage caused by super storm Sandy particularly in Moonachie and Little Ferry Borough in the New Jersey Meadowlands area. Both boroughs were shut down for several days after Sandy due to the failure of their critical infrastructure systems. As part of this research (1) a Geodatabase is developed as the baseline model to investigate the vulnerability of the existing infrastructure to flooding; (2) fault-tree analysis helped understand the causes of flooding and the vulnerabilities of the study region towards those causes; and (3) Hazus-MH, a non-proprietary software by FEMA, is used along with simulated Sandy inundation data to assess the damage caused by Sandy on these areas. Data from various sources like

DSAT, FEMA, Census data, etc. is used to assess this regional scale damage. This assessment can be refined further by using high resolution data. Finally, the study describes a financial model for performing benefit-cost analysis on the available flood mitigation measures which can help the decision makers when multiple mitigation measures are available for a region. The NJDEP funded Flood Mitigation Project is used to study the flood mitigation measures available in these two areas. The overall process and the benefit-cost analysis model as described in this study can guide the local and government agencies' efforts in analyzing the communities' vulnerabilities and come up with mitigating strategies for resilience design and sustainable development.

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by
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APPROVAL PAGE

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CHAPTER 1

INTRODUCTION

The world has been warming up significantly over the past few decades, and this change in climate towards a warmer environment is causing an increased number of natural disasters which, in the recent past, have caused immense social and economic damage across the globe (Karl, T. R. et al. 2009).

Figure 1.1 shows the statistics of economic damage caused by major disasters all over the world, for the period from 1980 to 2010. Tropical storms and hurricanes, in particular, develop more frequently and gain more strength over warm ocean water and thus, result in catastrophic events. Any such catastrophic disaster weakens the affected community's ability to cope with the next disaster, unless mitigation measures are implemented and resilience is built into the systems.

Resilience refers to the ability of a system: an infrastructure, a society, an individual or an economy, to respond and recover from disasters. Multiple definitions of resilience exist within the literature, with no broadly accepted single definition. Holling (1973) first used "resilience" to describe a "measure of persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling 1973). A resilient system is able to absorb the impact and cope with an event and reorganize into a fully functioning system. A community's overall resilience depends on several types of resilience indicators e.g., infrastructure, ecological, social, economic, etc. (Cutter, S.L. et al. 2008).

Risk assessment and mitigation, on the oth3er hand, refer to assessment of a community's exposure to the disaster or any other threat, the development of a plans or measures to prevent such exposure, and address it, if it occurs.

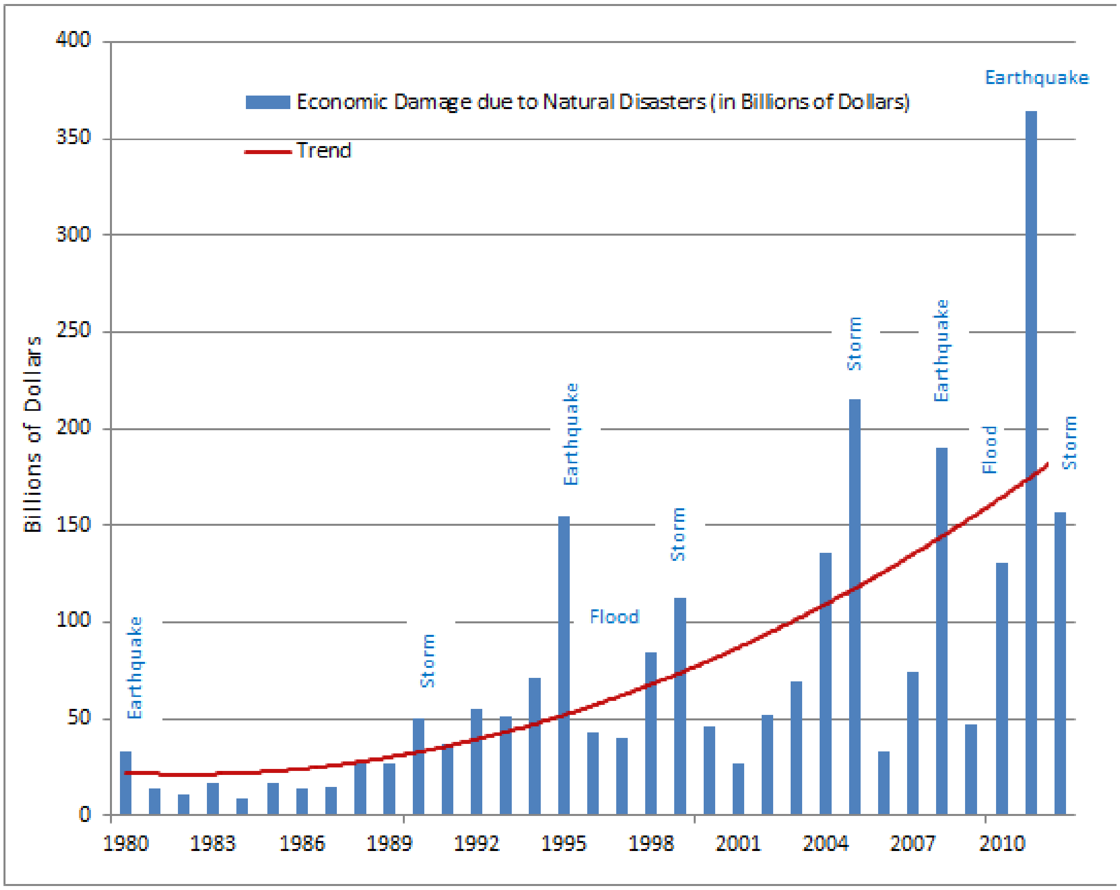

Figure 1.1 Global economic losses and damage due to major natural disasters in the years 1980 to 2012. Labels in the figure show the major disaster type that contributed to high damage and loss in the selected year.

Source: ESCAP based on data from EM-DAT: The OFDA/CRED International Disaster Database. Available from http://www.emdat.be/ (accessed March 2, 2014)

This research focuses on the flood mitigation aspect which, when implemented, will increase the community's ability to cope with similar flooding events and thereby contribute to the community's overall resilience.

1.1 Objective

The objective of this study is to outline a flood-risk mitigation process which can be adapted by any agency to study a community's existing infrastructure, its risk and vulnerability to flooding and come up with one or more long term as well as interim measures to mitigate the flooding risk to a great extent and thereby increase the community's resiliency. This study focuses on the municipalities of Little Ferry and Moonachie in the New Jersey Meadowlands area in the aftermath of Sandy.

1.2 Approach and Methodology

The most important step towards enhancing the resilience of a community involves understanding the community's strengths and vulnerabilities, identifying the hazards, and assessing the risk which needs mitigation. The risk assessment provides a foundation for the decision makers to evaluate the mitigation measures which will help reduce the impact of the hazard in the event of its occurrence. An understanding of the community's history, its geographic characteristics e.g., location and topography, physical characteristics e.g., buildings and infrastructure, procedural characteristics e.g., applicable disaster policies, social characteristics e.g., demographics, community structure, and regulations and plans are critical to this process (Price-Robertson, R. et al. 2012).

Figure 1.2 depicts the high level approach of this study. The process started with studying the history of natural disasters in the US, the impact of hurricane Sandy and then understanding the study areas and their vulnerabilities to flooding. This was done by designing an interview questionnaire, participating in various interviews with the community officials and through literature review. The municipal officers of Moonachie and Little Ferry were also contacted to get the details about the existing flood mitigation structures and the need for improvement, and damage during Sandy and post Sandy response by the municipalities and various other agencies.

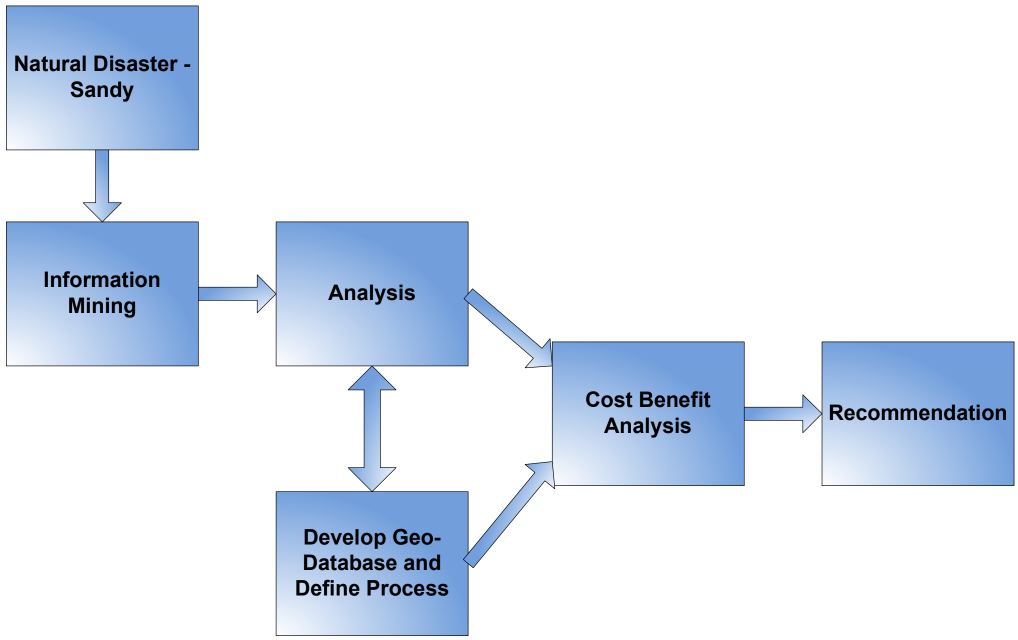

Figure 1.2 High level process flow of the study.

The study also includes an active participation in the Flood Mitigation Research project undertaken by New Jersey Institute of Technology (NJIT) and understanding the recommended alternative solutions and the rationale behind each of those alternatives. Appendix A provides a brief overview of this Flood Mitigation Research project undertaken by NJIT.

A lot of secondary data was collected during this phase. The analysis and execution phase includes setting up the study region, assessing the damage caused by Sandy through the usage of software as well as gathering data from various sources like Federal Emergency Management Agency (FEMA), United States Department of Housing and Urban Development (HUD), etc., comparing and understanding the differences in the data gathered through these two different processes and finally evaluation of NJIT recommended alternatives through benefit cost analysis and overall risk analysis.

Various proprietary as well as non-proprietary systems and tools like ArcGIS, HAZUS-MH and Dams Sector Analysis Tool (DSAT) were used in the process of studying the vulnerabilities of the existing infrastructures of a community. A fault-tree analysis model was used to understand the community's overall risk to flooding. Identifying the benefit cost ratio for the structural measures helped in comparison and ranking of the solutions. In benefit cost analysis, the cost component represents the net present value (NPV) of the construction, operation, maintenance, and repair cost of the mitigation measures. The benefit component of this analysis represents the damage from future Sandy like events which will be mitigated once the measures are implemented.

1.3 History of Natural Disasters in the US

Every year various types of small and large scale natural disasters hit the US and threaten the country's lives, livelihoods and economy. Between 1900 and 2013 more than 865 natural disasters have hit the US causing about $734 billion of damage out of which about $538 billion of damage occurred between the years 2000 and 2013. The share of the total cost from hurricane, storm and flood disasters is about $626 billion.

Figure 1.3 illustrates the distribution of various types of natural disasters that hit the US between 1900 and 2013. Based on the cause or origination, these various natural disasters can be divided into five different groups:

1. Geophysical: disasters originating from solid earth e.g., earthquakes

2. Climatological: events caused by long-lived/meso to macro scale processes e.g., droughts, extreme temperature

3. Meteorological: events caused by short-lived/small to meso scale atmospheric processes e.g., hurricanes

4. Hydrological: events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up e.g., floods

5. Biological: disaster caused by the exposure of living organisms to germs and toxic substances e.g., epidemics

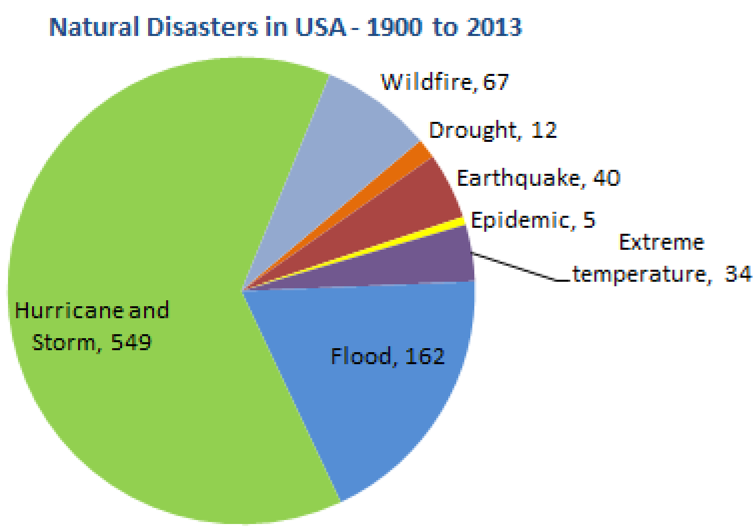

Figure 1.3 Distribution of various types of natural disasters in the US, between the years 1990 and 2013.

Source: ESCAP based on data from EM-DAT: The OFDA/CRED International Disaster Database. Available from http://www.emdat.be/ (accessed March 2, 2014)

The majority of these disasters are in the hurricane/storm category followed by flooding. Out of a total of 869 disasters that occurred in the US between the years 1900 and 2013, the portion from hurricane/storm events is 63% and that from flooding is about 20%.

Figure 1.4 shows the distribution of economic damage (in billion USD) caused by various types of natural disasters in the US, between the years 2000 and 2013. About 80% of the damage was caused by hurricane and storm disasters and about 5% was caused by floods.

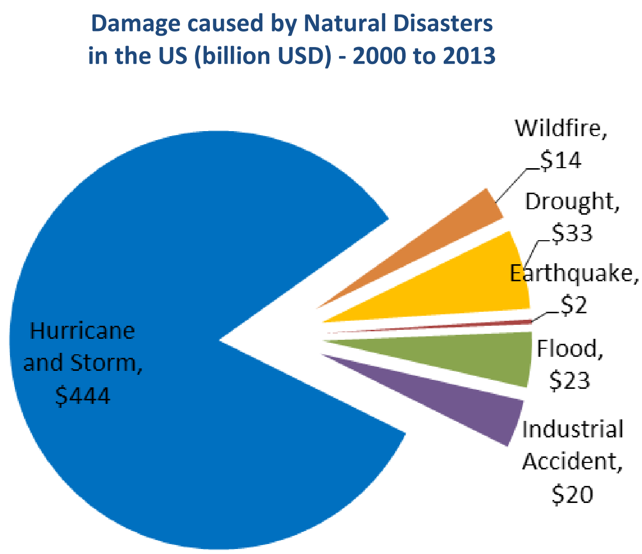

Figure 1.4 Damage (in billion USD) caused by various types of natural disasters in the US, between the years 2000 and 2013.

Source: ESCAP based on data from EM-DAT: The OFDA/CRED International Disaster Database. Available from http://www.emdat.be/ (accessed March 14, 2014)

When a hurricane moves closer to the coast, coastal communities begin to feel the impact. The storm surge created by the hurricane events combined with wave action causes extensive damage, severely erodes beaches and coastal highways, and causes damage to infrastructure and economy. Disruption of any critical infrastructure causes cascading disruption of other critical infrastructure resulting in disruption of daily life of the people. For example, a power failure can lead to disruption in transportation, telecom, and water sectors, and can affect many small and large scale businesses and the citizens in general. With major hurricanes like Hugo (1989), Katrina (2005), and Sandy (2012) complete devastation of coastal communities occurred. Many buildings withstand hurricane force winds until their foundations, undermined by erosion, are weakened and fail.

Table 1.1 provides a chronological summary of the top ten most costly hurricanes in US history. Hurricane Sandy and Katrina were among the most costly disasters in US history causing more than $200 billion of damage. The economic loss column represents the 2013 Consumer Price Index (CPI) cost adjusted value.

Table 1.1 Top Ten Hurricanes in US History, by Economic Loss

No	Name	Year of the event	Affected Locations	Economic Loss in Billion (2013 USD)
1	Hugo	1989	Southeast, Puerto Rico, Virgin Islands	16.9
2	Andrew	1992	Florida, Louisiana	44.8
3	Ivan	2004	Eastern U.S.	17.2
4	Charley	2004	Southeast	18.5
7	Katrina	2005	Southeast	148.8
5	Wilma	2005	Florida	19
6	Rita	2005	Texas, Southeast	19
8	Ike	2008	Texas, Midwest	29.2
9	Irene	2011	Northeast, Mid-Atlantic	10.1
10	Sandy	2012	Eastern U.S.	65.7

Source: Billion-Dollar Weather/Climate Disasters published by National Oceanic and Atmospheric Administration (NOAA). Available from https://www.ncdc.noaa.gov/billions/events.pdf (accessed on March 13, 2013)

Hurricane Katrina of August 2005 is by far the most deadly and most expensive natural disaster in US history. Katrina resulted in damages of about $149 billion and around 1,833 fatalities. The hurricane affected some 90,000 square miles of the US. Clean water was a scarcity along with power outages which lasted for weeks. This category-3 hurricane resulted in 20 to 30 foot high storm surges and impacted large parts of Louisiana, Mississippi and Alabama. However, the devastation was concentrated mostly in New Orleans. With an average elevation of 6 feet below sea level and completely surrounded by water, New Orleans faced widespread flooding. The devastation in New Orleans was caused mainly due to the failure of parts of the levee system and drainage canals.

Superstorm Sandy ranks third in the list of most costly disasters in the US and was the second most costly storm in US history with an estimated damage of about $68 billion. Sandy caused the New York Stock Exchange to close for two consecutive business days, which last happened in 1888 due to a major winter storm (Smith, A. et al. 2013). Included in Sandy's impacts in the US are widespread interruption to critical water and electrical services.

Disruption of the critical infrastructures, such as water, power, telecommunication and transportation, impact a large segment of the US population, economy and politics. According to NOAA's report on "Storm Surge and Coastal Inundation", most of the United States' densely populated Atlantic and Gulf Coast coastlines lie less than ten feet above mean sea level which highlights the extreme vulnerability of these coastal region to storm surge and the need for immediate attention.

1.4 Superstorm Sandy – a Catastrophic Event

Superstorm Sandy's widespread impact was felt across the entire Atlantic coastline of the US. Though it was a Category-3 storm at its peak intensity when it made landfall in Cuba, it was a Category-2 storm off the coast of the Northeastern United States. NOAA estimated that more than 60 million people across 24 states of the US were affected by Sandy. More than 20,000 flights were cancelled during the six-day stretch after the landfall of this deadly storm (Mutzabaugh, B. 2012).

Figure 1.5 shows the intensity of the impact of hurricane Sandy in various parts of the US. New Jersey is one of the highly impacted states by this storm.

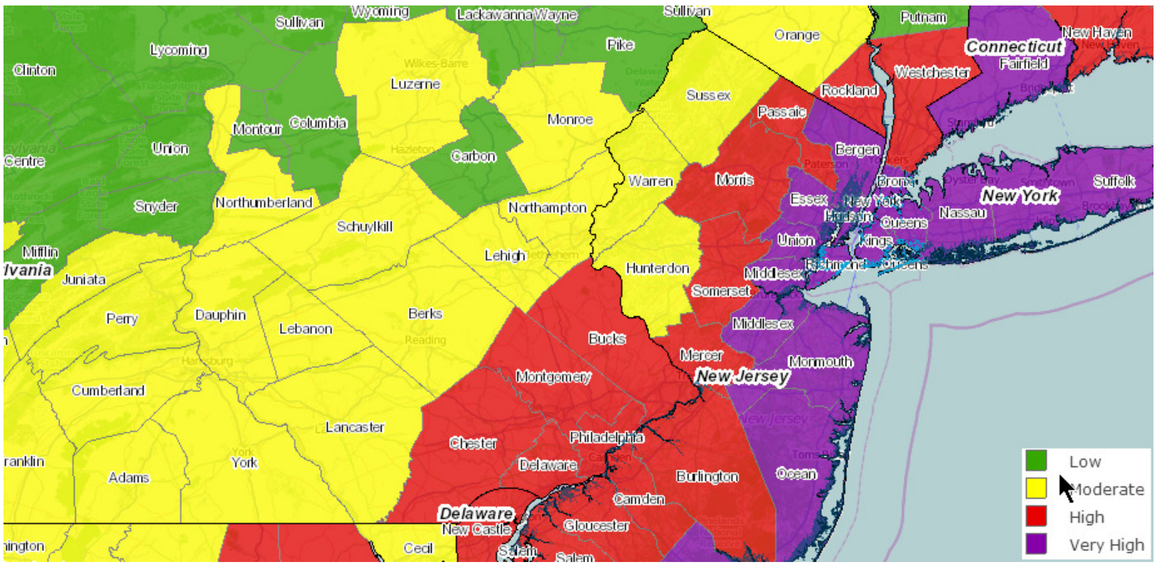

Figure 1.5 Sandy impact analysis by FEMA.

Source: FEMA Modelling Task Force - Hurricane Sandy Impact Analysis. Available from http://fema.maps.arcgis.com/home/webmap/viewer.html?webmap=307dd522499d4a44a33d7296a5da5ea0, (accessed on March 14, 2014)

Sandy made its landfall near Atlantic City, New Jersey on Oct 29 2012 and left 8.7 million cubic yards of debris behind. The storm surge, which measured 8.9 feet at its highpoint in Sandy Hook, inundated and severely affected regions of the State's shore. Many communities throughout New Jersey saw major damage due to the flooding from storm surge along with wind damage and an ensuing snowstorm. Damage included at least 12 direct fatalities out of a total of 72 reported cases, damage of more than 346,000 housing units of which 22,000 were completely destroyed and 19,000 businesses which sustained at least \$250,000 in structural damage. Power restoration required removal or trimming of about 48,000 trees and the expected cost of power and gas line repairs was roughly \$1 billion. Repairs to the waste, water and sewer services are estimated to cost about \$3 billion. (Blake, E.S. et al 2013).

Superstorm Sandy affected, in some way, virtually every household, business and community in New Jersey causing a sales loss for many business owners along the east coast, unpaid hours for many workers, delay in shipment of goods, and delays in seaports and airports. To put Sandy's enormous damage in context, Table 1.1 shows the top ten hurricane events in US history and their economic damage.

The long lasting effects of Sandy are still being faced by many people as they try to recover from the disaster, even after 1.5 years. The dramatic changes in the flood insurance landscape pose a new threat to the residents of coastal areas as they might suddenly find themselves living in high-risk flood zone and liable to pay even a ten times more annual premium than what they are paying now. Though in many cases this rate increase might be phased over a few years, it will ultimately impose financial burdens on some of those very people who are still reeling after Superstorm Sandy struck (Dixon, L. 2013).

1.5 Impact of Sandy Damage in the Study Area

The study area for this thesis comprises two municipalities - Little Ferry and Moonachie. Both municipalities are part of Bergen County, New Jersey (NJ). This county is part of lower Hackensack watersheds known as Hackensack Meadowlands. Ground elevation of this watershed is approximately 2 to 6 feet North American Vertical Datum of 1988 (NAVD88).

1.5.1 Bergen County – History and Impact during Sandy

Bergen County is located in the northeastern corner of New Jersey and is part of the New York City Metropolitan Area. Bergen County is divided into a total of 70 townships and boroughs which were established as a result of a referendum from the New Jersey Legislature for the purpose of administering a Board of Education and expanding the education districts throughout the state. The boundaries of each town were set based on the local community and land use at the time. For instance, Moonachie was created to combine most of the historically Dutch owned farms, but Little Ferry was formed to empower the clays pits business, which brought great wealth when building the City of Newark, while Hackensack was established to preserve the local city businesses. This period was followed by a sudden population shift to the Northeast New Jersey borders, upon the starting of a number of transportation projects between New Jersey and New York. As a result, some of the towns including Little Ferry and Moonachie saw extensive population growth and sprawl development. However, their infrastructure planning did not match the wide expansion and sprawl development, and thus, the region is now facing elevated runoff levels which are impacting urban streams, enlarging the stream channels, increasing sediment and pollutant loads, and degrading stream habitats. Such lack of infrastructure planning and maintenance of existing drainage were the major influences in elevating the damage caused by Sandy.

As shown in Figure 1.6, the damage in Bergen County was largely concentrated in communities along the Hackensack River in Little Ferry, Moonachie, and Hackensack.

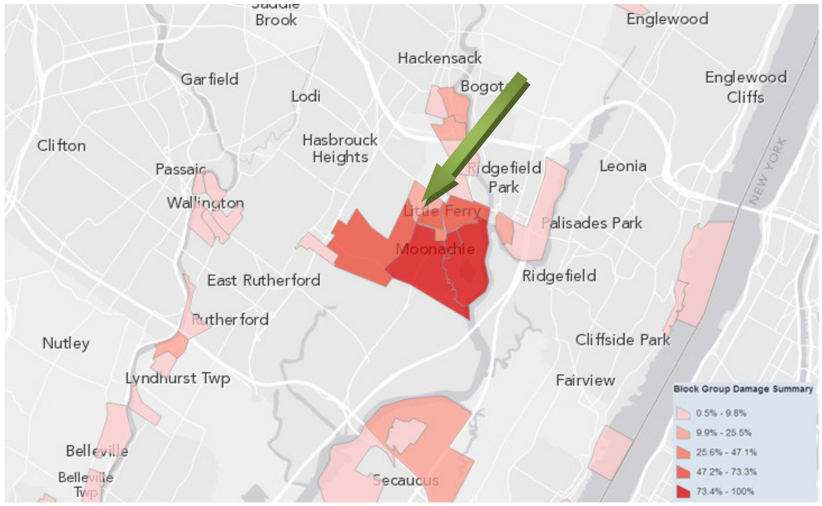

Figure 1.6 Sandy damage estimates by block group provided by FEMA indicates the severity of impact in Little Ferry and Moonachie of Bergen County, NJ.

Source: Sandy Damage Estimates Based on FEMA IA Registrant Inspection Data. Available from http://hud.maps.arcgis.com/apps/TwoPane/main/index.html?appid=ce278b29115a439a918b28e235e1c219, (accessed on November 1, 2013)

The homes with major or severe damage in Bergen County account for almost 5% of all major and severe damage across the State. Majority of this damage was caused to the owner-occupied homes.

Table 1.2 shows that 1% households of Bergen County had sustained “severe” or “major” damage. The entire town of Moonachie (census tract id 34003036200) and part of Little Ferry (census tract id 34003029200) had more than 50% of households with severe or major damage. The other census tract of Little Ferry (34003029100) had between 10% and 24% of households experience such damage. The table also provides a few demographic information of Bergen County and these two municipalities such as total number of households, median income per house hold, and percentage of owner vs. renter occupied households.

Table 1.2 Major/severe Damage in Little Ferry and Moonachie

Municipality	Census Tract	%of Households with Major/Severe Damage	Households	Median HH Income	%Owner-Occupied Households	%Renter-Occupied Households
BERGEN COUNTY		1%	346,802	$83,443	66%	34%
CENSUS TRACTS WITH DAMAGED HOMES						
Borough of Little Ferry	34003029200	54%	2,336	$63,352	53%	47%
Borough of Little Ferry	34003029100	10%	1,888	$51,796	33%	67%
Borough of Moonachie	34003036200	62%	1,011	$56,411	80%	20%

Source: New Jersey Department of Community Affairs/Community Development Block Grant Disaster Recovery Action Plan, Available from http://www.state.nj.us/dca/announcements/pdf/CDBG-DisasterRecoveryActionPlan.pdf (Accessed on March 09, 2014)

According to the hydrologic modeling and analysis values (NJMC 2005), this study area was supposed to face a water elevation of 6.1 feet and 7.3 feet above sea level (NAVD88) during a 25-year flood surge and Category-2 Hurricane respectively. However, during Sandy the flood water elevation went up to about 9.6 feet above sea level (NAVD88) and remained above 7 feet for six hours causing the huge devastation.

1.5.2 Moonachie – History and Impact during Sandy

Most part of the borough of Moonachie is at about 2 to 3 feet elevation (NAVD88) which is much lower compared to the nearby towns. Prior to the expansion of sprawl development, most of rain/storm water used to infiltrate to the ground without flooding the surrounding lands and streams of Moonachie. Thus, the low elevation and poor grading of the area and the fact that some of the areas are major water collector was not an issue. After the sprawl development when much more runoff started to get generated, the borough installed three pumping stations to move the storm water from collection locations to nearby streams.

The Lincoln Place pump station services one of the lowest elevations of residential areas in Moonachie by pumping the collected storm water through an underground pipe to the Losen Slote, which directly connects to Hackensack River. The next pumping system has two stations. One of these two pump stations collects storm water from Teterboro Airport area and pumps it to Moonachie Road pump station which is then pumped out through a six inch pipe to the Moonachie Creek that connects to the Losen Slote.

Due to its flat topography, Moonachie gets flooded approximately every 2 years, whenever it experiences three to four inches precipitation event within a 24 hour period. Due to poor maintenance of the drainage network and because some of the storm water pipelines are covered with silt due to the increase silt settlement, surrounding parts gets constantly flooded.

Impact during Sandy: About 62% of Moonachie was severely flooded during Sandy. Schools and libraries, the ambulance corps building, the Senior Citizen Center, the Civic Center, and Moonachie's trailer park – all were washed away. All three pump stations failed to handle the flooding due to their lack of capacity, power outages, unavailability of back-up generators to operate the pump stations, and due to the lack of maintenance of the drainage network mentioned above. The Berms, currently at elevation +6 feet, were overtopped during Sandy (according to the HMDC, the height of the sea surge reached +9.5 feet and remained above 7 feet for duration of 6 hours).

Figure 1.7 shows that the peak water elevation at Moonachie Tide Gate during the Sandy was about 9.51 feet (NAVD88). This graph was plotted based on the Sandy water elevation data recorded by Meadowland Environmental Research Institute (MERI), at

Moonachie Tide Gate located on Moonachie creek. The peak height was observed at around 11:49 PM on Oct 29 2012.

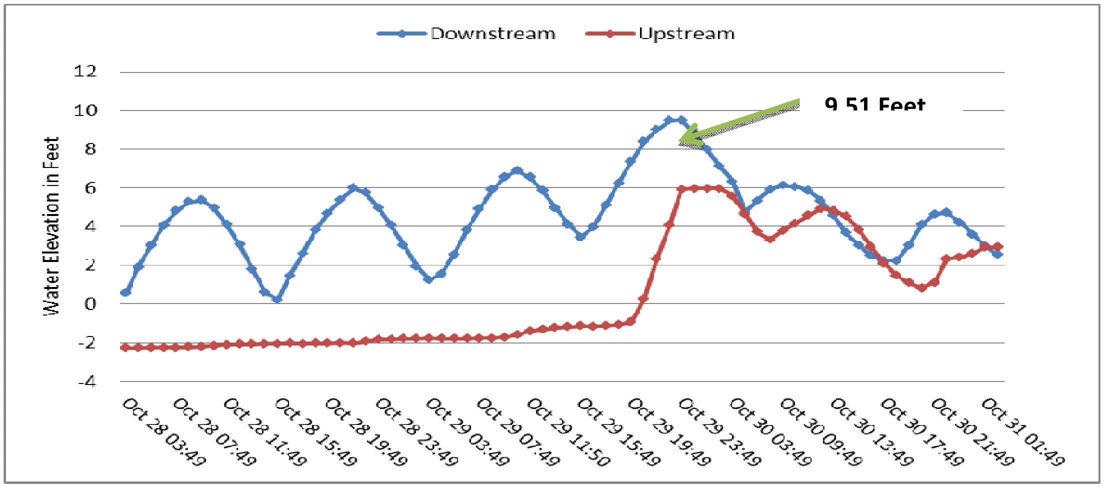

Figure 1.7 Highest water elevations of 9.51 feet at Moonachie Tide Gate during Sandy; this was observed at around 11:49 PM on Oct 29 2012.

Source: Based on water elevation recorded by Meadowland Environmental Research Institute (MERI), at Moonachie Tide Gate. Available from http://www.frontlineaqua.com/aqua/dashboard.html (accessed March 2, 2014)

1.5.3 Little Ferry – History and Impact during Sandy

The storm water system of Little Ferry is serviced primarily with three pumps which discharge to the Hackensack River, Willow Lake, Indian Lake, Bergen County Utilities Authority (BCUA), and Losen Slote. The three flood water pumps are located at the meeting of Losen Slote Creek and the Hackensack River, at Willow Lake Park and at the eastern area of Main Street. An additional pump station is planned proximate to the Route 46 circle as part of the New Jersey Department of Transportation (NJDOT) improvements to Route 46. Similar to Moonachie, this municipality also faces frequent flooding, almost every 1 to 2 years during heavy rainfall events. Hackensack River's rising elevation which passes below an average of two foot embankment is a major concern that the town faces today.

Impact during Sandy: More than 50% of Little Ferry got severely flooded during Sandy and the causes were similar to the causes of flooding in Moonachie. Digital renderings of the progression of floodwaters showed that there was no single source of the deluge in Moonachie and Little Ferry; water came in wherever it could. The borough faced power outages for about a week, due to the inundation. Some of the streets of Little Ferry were two feet under the water even after about 2 weeks of Sandy.

As shown in Figure 1.8, the peak water level at Barge Marina reached at 8.6 feet (NAVD88) during Sandy. This was much higher than the existing flood protection measures such as Berms (5.0 feet), Tide Gates at Losen Slote (6.0 feet), and East Riser (6.4 feet) in Little Ferry and neighboring areas. This graph in Figure 1.8 is created based on the data collected from Barge Marina in municipality of Carlstadt, a neighboring community to Little Ferry.

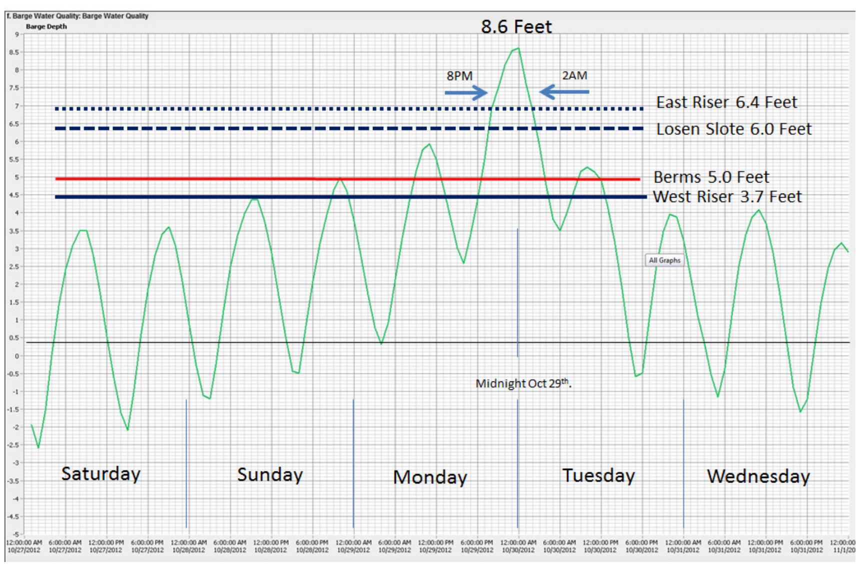

Figure 1.8 Barge Marina Water Level between Oct 27 ’12 and Oct 31 ’12; 7 feet of tidal water entered Little Ferry and surrounding towns from 8 PM on the 29th to 2 AM on the 30th October 2012.

Source: Borough of Little Ferry - Superstorm Sandy Public Presentation. Retrieved from “Sandy - PowerPoint public presentation - Borough of Little Ferry” (accessed on Feb 17, 2014)

CHAPTER 2

PROCESS, DATA AND TOOLS

Chapter 2 describes the whole process, data and tools used to support the study of risk and damage assessment for the study area - Little Ferry and Moonachie.

2.1 Analysis Process

Figure 2.1 outlines the overall approach to vulnerability and damage assessment and financial impact analysis for flood mitigation measures.

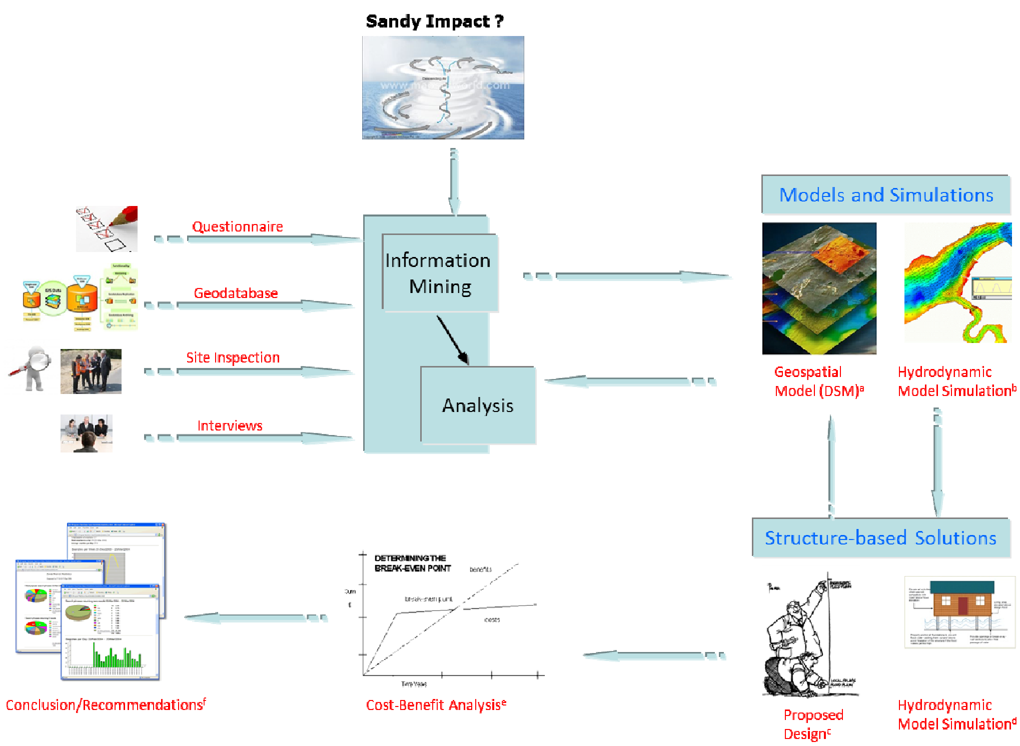

Figure 2.1 Approach to risk assessment and flood mitigation.

Image Sources:
a) http://www.satimagingcorp.com/svc/geospatial.html
b) http://archive.nrc-cnrc.gc.ca/eng/ibp/chc/coastal/wave.html
c) Colorado.edu, climatetechwiki.org
d) http://www.hsc.csu.edu.au/
e) http://www.wrensoft.com/zoom/tour_reports.html
f) http://www.greendiary.com/blame-human-activities-for-raising-hurricane-forming-ocean-temperatures.html

Information Mining:

Information mining phase included designing interview questionnaire, meeting and interviewing various officials from the selected municipalities and from agencies like MERI, and inspecting the site.

Objective of designing the *interview questionnaire* was to understand the Sandy's impact on the community, community's existing resilience to flooding, and what changes were implemented in post-Sandy phase. Municipality and town officials from Little Ferry and Moonachie were the targeted stakeholders for this questionnaire. At a high level the questionnaire included the five categories of questions.

A sample set of questions for each of these five categories are listed in Table 2.1.

Table 2.1 Sample Questions from the Interview Questionnaire

Categories	Number of Questions	Same questions from the questionnaire
Community Plans and Agreement	6	What contingency plans existed What warning systems existed pre-Sandy?
Involved Agency related information	5	Identify agency(s) involvement?
Impact on Community	23	Cost of damage to dwellings? Cost and extent of damage to life-critical structures? Zoning changes post-Sandy?
Critical Infrastructure	7	Identify important systems and accessibility Measures of community response to needs
Community structure and Mitigation/Protection Measures	23	Ensure conformance with NFIS? Pre-Sandy disaster preparedness programs? Identify sensitive habitats and assistance-critical population groups

Site Inspection of the study area provided first-hand information on the existing flood mitigation structures and their current conditions which was then supplemented by the *interviews and meeting* with town and municipality officials. Data was also gathered from various sources like Federal Emergency Management Agency (FEMA), United States Department of Housing and Urban Development (HUD), etc.

Analysis:

Analysis phase included compiling and transforming data, *creating the geodatbase* through transformation, and geoprocessing of data from various sources in order to ensure a homogeneous database. The homogeneous database was the base for any further analysis, simulation of Sandy inundation as well as design and evaluation of flood mitigation measures.

Sandy Modeling and Simulation:

Sandy modeling and simulation was done as part of the Flood Mitigation Project by NJIT. Based on the topographic data, bathymetric data and the 3D coordinates of the proposed as well as the existing flood mitigation structures, NJIT team performed hydraulic modeling to simulate the inundation of Sandy. The flood depth grid generated from this simulation was used to execute various flood scenarios and generate the loss estimate.

Designing Solutions for Flood Mitigation

Various structural and non-structural solutions options were evaluated and proposed based on the information gathered during information mining and analysis.

Benefit Cost Analysis

The benefit cost analysis, which was done for the proposed structural alternatives, helped in comparison and ranking of the solutions. As explained in Chapter 1, the cost component represents the NPV of the construction, operation, maintenance, and repair cost of the mitigation measures, and the benefit component represents the damage from future Sandy like events which will be mitigated once the measures are implemented.

2.2 Data and Tools Used

Identifying the software and data requirement for this research involves a clear understanding of the scope and approach, and research on availability of state of the art software for assessing and analyzing the impact of flooding on a community. Data was collected from various publicly available sources e.g., http://msc.fema.gov/, http://www.usgs.gov/, https://njgin.state.nj.us/, and from interviewing various agencies like MERI and municipality officials.

The Dams Sector Analysis Tool (DSAT) was another source of data which was used to view the utility and infrastructure data for the study region that was either incomplete or unavailable in other sources. This tool is created by Department of Homeland Security in collaboration with the US Army Corps of Engineers.

2.2.1 Data and Data Sources

Figure 2.2 is a pictorial view of the workstation and the geodatabase and tools used in the study. Development of the geodatabase involved data acquisition from multiple sources and several applications of geodetic coordinate conversions and datum transformations to ensure a homogenous and unified geospatial data model. The geodatabase includes topographic data that provides information about the elevation of the surface of the earth, bathymetric data that describe the river morphology, 3D coordinates of proposed structures as well as previously USACE-proposed measures to mitigate surge inundation, and polygon data describing the geographic extent of the Sandy-induced flooding. Various geodetic datum are explained in Section 2.4.

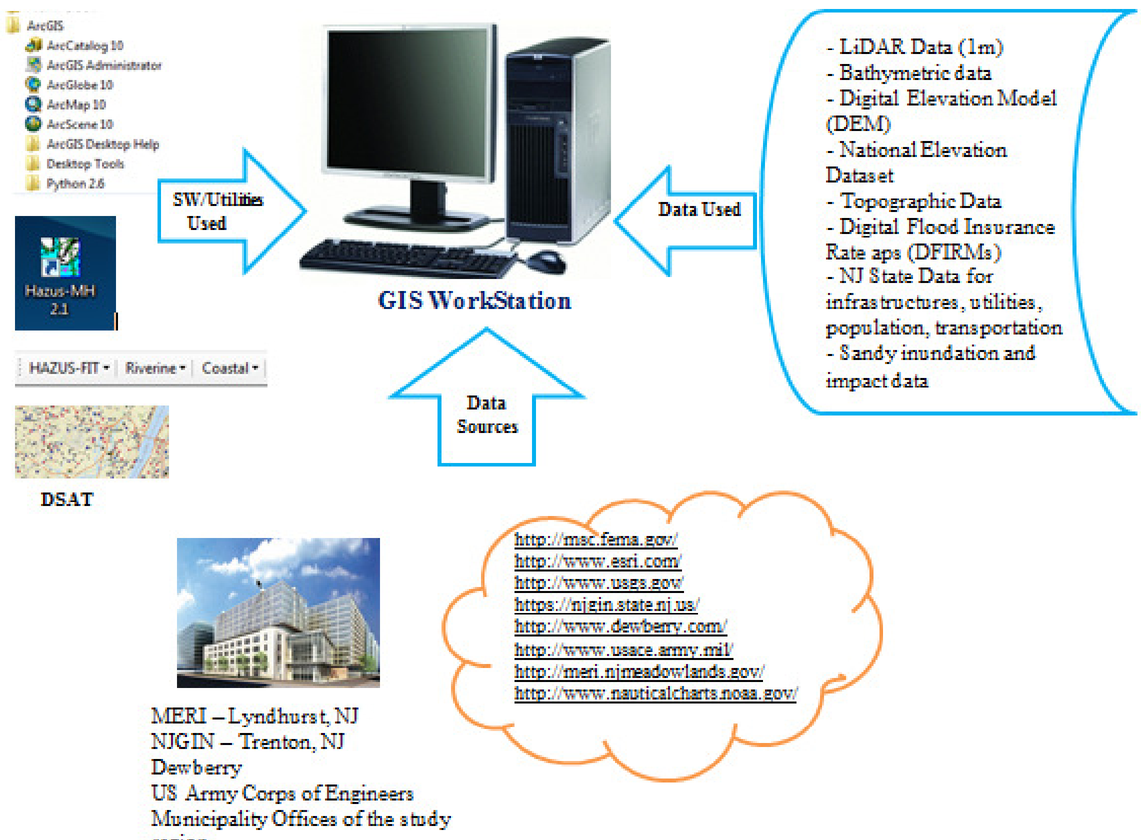

Figure 2.2 Graphical representation of the GIS Workstation and tools and data used.

Topographic data from LiDAR was required for the flood inundation study. High resolution processed LiDAR data was acquired from the MERI. Data preparation included scrubbing the LiDAR data using the Geospatial Data Abstraction Library (GDAL) utility (GDAL is open source software) to extract “bare earth” topography which is fundamental to ensure realistic outputs from hydrodynamics simulation runs. However, MERI data was incomplete for the intended study, and hence, it was supplemented with lower resolution topographic data which was downloaded from the US Geological Survey (USGS) website. These datasets were georeferenced appropriately for the project.

River morphology data was derived from bathymetric data. Data preparation included inversion of the z-axis followed by a transformation from Mean Sea Level (MSL) to the NAVD88 using the VDatum tool developed by NOAA.

The *geographic extent of Sandy-induced flooding* was derived from the analysis of TGate time series. Data and models provided by MERI were compared against time series from TG data at Battery (NY), Sandy Hook (NJ), and Newark Bay (NJ). The flood depth was verified. The assumption was that the water level at maximum flood stage rose and maintained an equipotential distance before the waters receded. Surface water elevation from TGate data were analyzed for flood elevation from the Superstorm Sandy.

Part of the geodatabase also included a) the geodetic description of the *proposed design structures* related to mitigation of Sandy inundation, and b) previously proposed strategies by the USACE including mosquito berms.

2.2.2 ArcGIS

Esri's ArcGIS, which is a Geographic Information System (GIS), was used to build the geodatabase, analyze the regions of interest, and learn analysis and execution of various scenarios. It was also used to delineate some of the existing and all of the proposed flood mitigation structures for further analysis. Since Hazus-MH is currently not compatible with any later versions of ArcGIS, version 10.0 with Service Pack 2 (SP2) was used for this research. Following components of ArcGIS were extensively used:

- **ArcMap** was used primarily to view, add and analyze various existing ArcGIS compatible data and shapefiles and to create/manipulate data
- **ArcCatalog** was used for data administration or management application which allows the users to view geodatabase, files, metadata and other data sources
- **ArcToolbox** is a collection of toolsets and tools, and it was used for geoprocessing e.g., clipping data, conversion of data, import/export of data, etc.

2.2.3 Hazus-MH

Hazus-MH (Multi Hazard) is FEMA's nationally applicable non- proprietary software program that estimates potential building and infrastructure losses from floods, earthquakes, and hurricane winds. Initially it was developed only for earthquake hazard in response to the need for more effective national, state, and community-level planning, and the need to identify areas that face the highest risk and potential for loss. Later it was expanded into a multi-hazard methodology and included models for estimating potential losses from wind (hurricanes) and flood (riverine and coastal) hazards.

The loss estimation model of Hazus-MH reflects state-of-the-art scientific and engineering knowledge and assist in informed decision-making by providing a reasonable basis for developing mitigation measures, emergency preparedness, and response and recovery plans and policies. Though the basic default data is same for all three types of hazards, some attributes are more critical to one model than others due to the unique nature of each hazard type. Thus, based on the type of disaster under investigation, users need to select appropriate model and ensure the accuracy of the data that is more critical to that model. The default Hazus-MH data can be supplemented with local data to provide a more refined analysis.

Hazus-MH uses GIS technology to graphically map and display hazard data, the results of damage and economic loss analyses, and potential effects on area populations. Users have the ability to either query and map the inventory and loss estimation or use the in-built loss estimation summary reports. Crystal reporting is used to generate the summary reports. Although Hazus-MH itself is free, it requires the users to have ArcGIS with ArcView license level. In addition, ArcGIS Spatial Analyst extension is required for Flood Model.

Out of the three currently available models, Hazus-MH flood model, version 2.1, was used for this research. The flood model is usually used to assess riverine and coastal flooding. However, user generated flood depth grid can also be used to estimate the potential damage and loss to buildings, essential facilities, bridges, vehicles, agricultural crops, etc. from that flood event.

FEMA's website http://www.fema.gov/hazus can be referred for information and assistance on Hazus-MH installation and/or any technical support.

2.3 Hazus-MH Flood Model

Hazus-MH Flood Model produces loss estimates which can be used by local, state and regional officials to assess the region's vulnerability and to plan for flood risk mitigation measures, emergency preparedness, and response and recovery. The methodology includes only non-proprietary loss estimation methods. The software application is non-proprietary to the extent permitted by the ESRI (ArcGIS) related requirements.

The Flood Model has widely been used by many state and local officials for risk assessment and mitigation planning e.g., for flood loss estimates and CRS flood mitigation planning in the city of Savannah, Georgia; to speed up disaster recovery from 2008 Iowa flood, etc.

2.3.1 Input Data

Inventory:

Estimating the loss from a flood event requires identification and valuation of the building stock, infrastructure, and population exposed to flood hazard. The default inventory for the study region consists of a proxy for general building stock (GBS) which includes residential, commercial, industrial, agricultural, religious, government and education buildings as well as data for essential facilities, high potential loss facilities, selected transportation and lifeline systems, demographics, agriculture, and vehicles. Demographic data is used methodology to compute shelter requirements. Electric power generation and sub-station of Little Ferry were missing in the default inventory and were added manually for loss estimation.

General building stock data for Hazus Flood Model is available at census block level due to its relatively small geographic size and the capability of the census to identify data at that level of detail. Residential building counts are based on 2000 census housing unit counts and non-residential structures at the census block level are provided by Dun & Bradstreet (D&B) 2006. Building valuations conform to R.S. Means 2006.

Digital Elevation Model:

Digital Elevation Model (DEM) is another input required for the flood loss estimation since floods are inherently dependent on the terrain. The DEM for the study region was defined by obtaining the National Elevation Dataset (NED) from the USGS website using the default option available in the Flood Model. However, user can also provide their own DEM that meets the needs of the model.

Flood Depth Grid:

Flood loss assessment also needs the flood depth grid in order to calculate the inundation and estimate the impact. Flood depth is the difference between flood and ground surface elevations (DEM) at each grid cell. For this research, a user defined flood depth grid, which depicts the flooding occurred in the study area during Sandy, was used as an input to the Flood Model instead of building the flood depth grids using riverine or coastal analysis option. This user defined depth grid provided the extent, depth and elevation of flooding that occurred in the study region during Sandy. The detailed process is described in Section 3.1.

2.3.2 Damage Estimation Methodology

The methodology incorporates available state-of-the-art models in the flood loss estimation methodology. For example, users can develop their depth grids based on their hydrologic and hydraulic models and use the most current depth damage functions.

Flood hazard analysis and flood loss estimation analysis are the two basic analytical processes which builds the flood loss estimation methodology. The flood frequency, discharge, and ground elevation are some of the hazard characteristics which are used to estimate flood depth, flood elevation, and flow velocity. The physical damage and economic loss are calculated by the flood loss estimation module.

As shown in Figure 2.3, the model estimates the risk in three steps. For example, the direct physical damage for the GBS is estimated in percent and is weighted by the area of inundation at a given depth for a given census block. It is assumed that the entire composition of the GBS within a given census block is evenly distributed throughout the block.

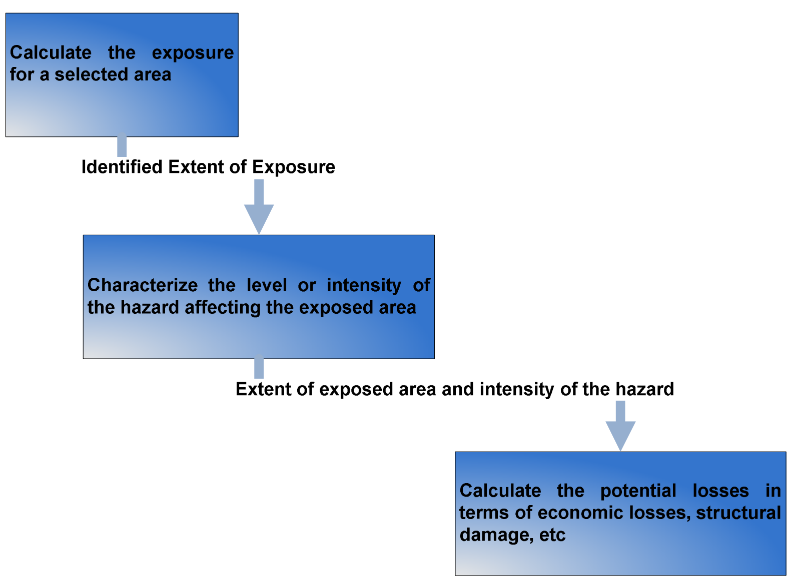

Figure 2.3 Physical damage and economic loss estimation process by Hazus-MH Flood Model.

2.3.3 Uncertainties in Loss Estimation

Like any other loss estimation methodology, uncertainties do exist in this methodology as well. Thus, the loss estimation should be used with certain degree of caution (FEMA 2010).Uncertainties can result from the following:

- Approximation and simplification necessary to conduct a specific study
- Incomplete or inaccurate inventories, demographic or economic data. For example, Census data was based on 2000 census and not 2010. Similarly, valuation of the building is according to R.S. Means 2006. Since the flood scenarios were executed based on this default inventory, the calculated damage might be different than what Sandy had actually caused in 2012
- Lack of in-depth scientific knowledge concerning floods and their effects upon buildings and facilities
- User input can also have a great effect on the uncertainty associated with the results.

Due to the above mentioned factors, the calculated hazard exposure and the loss estimations are approximate and do not predict results with 100% accuracy. However, it does allow users to identify and manage the flood hazard, risk, losses and in response and mitigation planning. The quality of the analysis and results improve with more complete data.

2.3.4 Limitations of using Hazus-MH

There are certain limitations in using Hazus-MH flood module and those were taken into consideration while using this tool. Following are some of the limitations encountered during the research:

1. It was learned that the study region must be completely contained by the DEM data that is imported into the HAZUS model. If the DEM does not entirely cover the study region, HAZUS does not allow it to be used for the hydrologic analysis. To avoid this limitation, DEM for the study region was defined by using the

default option of accessing USGS website, as available in the Flood Model.

2. The current version of the Flood Model does not calculate the damage and loss for Hazardous Materials sites

3. The Flood Model does not perform any direct analysis in support of casualty estimation

2.3 Geodetic Datum

Figure 2.4 provides a graphical representation of various geodetic datum, a reference from which measurements are made.

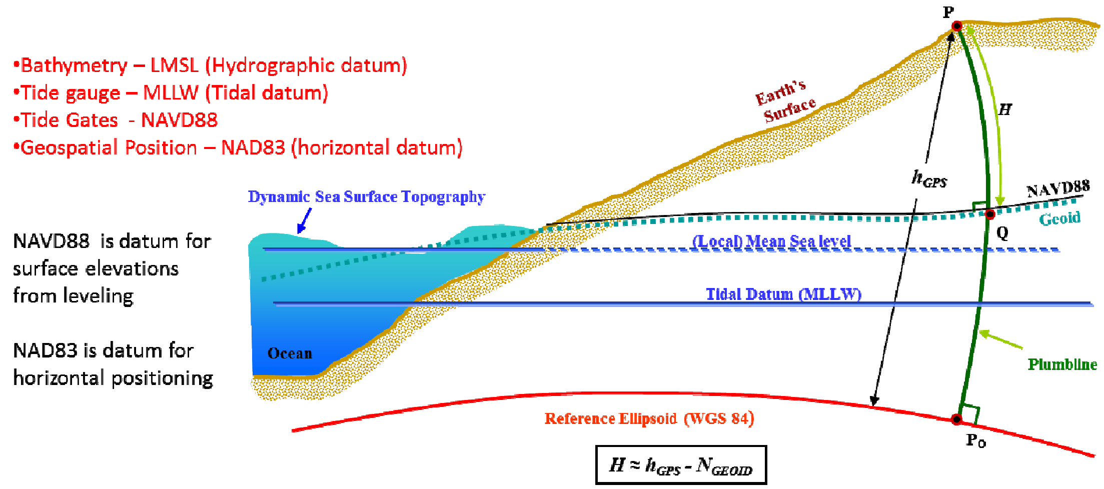

Figure 2.4 Graphical representation of geodetic datum.

The North American Vertical Datum of 1988 (NAVD88) is a surface to which heights are referred. The NAVD88 datum surface is realized through a network of geodetic control points that describes Orthometric (gravity-based) heights relative to a datum that was fixed at a specific date. The physical reference for Orthometric heights is loosely described as the (global) mean sea level (MSL). MSL is computed from daily averages of high and low water over 18.6 years. However, changes in sea level over several decades means that Orthometric heights will also change relative to the MSL datum of a specific epoch. Surface topography is typically described as Orthometric heights relative to a fixed vertical datum – the NAVD88 in this case. NAVD88 is the current vertical datum in use for mapping and supersedes the previous National Geodetic Vertical Datum of 1929 (NGVD29). Specific transformation values are available from National Geodetic Survey (NGS) to convert data from NGVD29 to NAVD88.

Coastal and riverbed bathymetries are heights relative to the local tidal datum. Tidal datums are planar surfaces that are specified over a limited local region because of variations in local mean sea level (LMSL). Variability of LMSL depends on regional variations of the coastline configuration, morphology of the continental shelf, and oceanographic effects along the coast. The tidal datum for this study is the mean lower low water (MLLW). The geometric relationship between NAVD88 and the MLLW tidal datum has been established by the National Geodetic Survey (NGS) at main tide gauge stations like Sandy Hook in New Jersey, Bergen Point in Newark Bay, and the Battery in New York.

Horizontal positions of topography and bathymetric data are given in 2-D geographic coordinates. In particular, the location of mapped features for the study area is given in state (New Jersey) plane coordinates (SPC). The NJ SPC are based on the North American Datum of 1983 (NAD83) which, in turn, references the global best-fit World Geodetic System of 1984 (WGS84) ellipsoid. The geospatial data models for this project were prepared for modeling in ArcGIS.

CHAPTER 3

VULNERABILITY AND DAMAGE ASSESSMENT

This chapter describes the process that was implemented in setting up the study region, installation and execution of Hazus-MH flood module and assessment of the flood damage from Sandy, for the study area.

3.1 Setting up Study Region and Topography

3.1.1 Study Region

Setting up of the study region begins with identification of the study area. Since the basic inventory of Hazus is stored at census block level, the study area can be as small as a specific Census block or it can be built at Census tract, county or state level. Study region can also be built based on the watershed as shown in Figure 3.1.

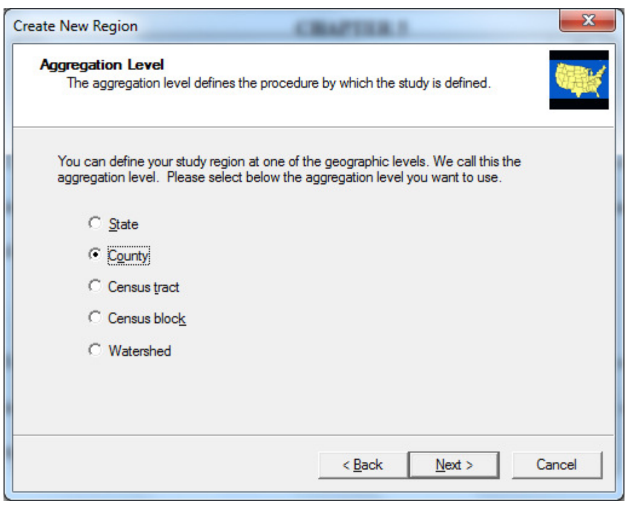

Figure 3.1 Selecting aggregation level while creating a new study region in Hazus-MH.

When the region is created at Census tract level, further validation is needed as there is no direct relation between the municipality boundaries and Census tract ids. For example, Moonachie municipality can be mapped to Census tract 34003036200 and Little Ferry can be mapped to Census tract 34003029200 and 34003029100. However, Census tract 34003036200 is used by both Moonachie as well as South Hackensack.

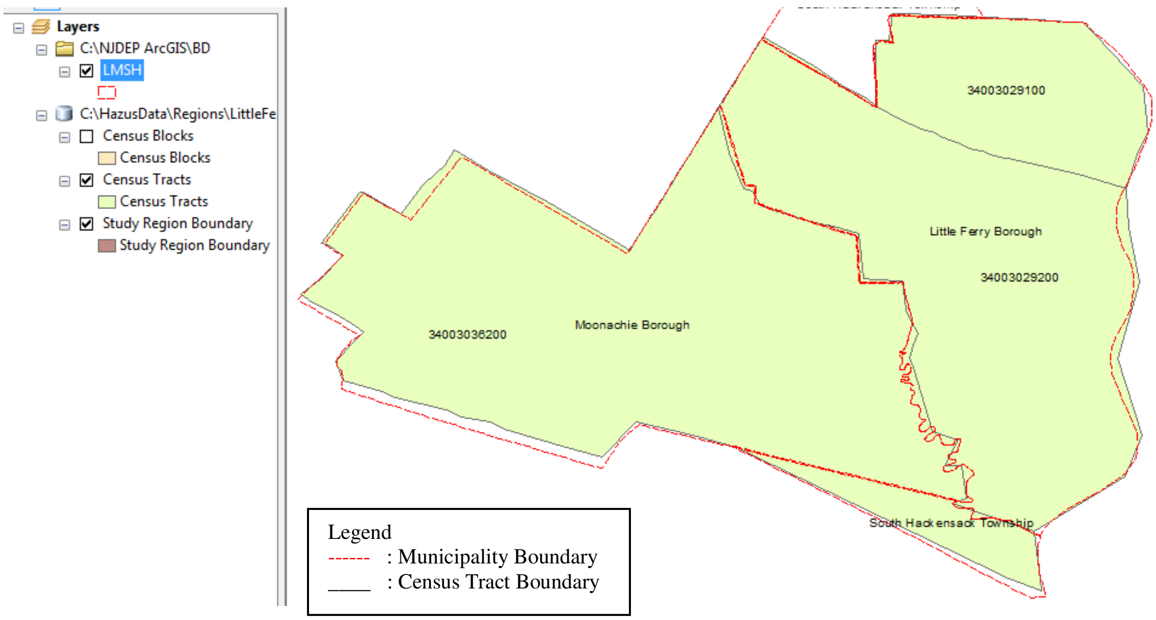

Figure 3.2 Overlapping of census tract and municipality boundaries (for Census tract id # 34003036200).

Figure 3.2 shows the overlapping of Census tract and municipality boundary. To avoid this issue, the study region for this research was built at Census block level. There were a total of 158 Census blocks in the municipalities of Little Ferry and Moonachie. After creating the study region, the flood hazard type needs to be defined as “Riverine only”, “Coastal only” or “Riverine and coastal”. Since this study region contains no coastal shoreline, coastal hazard was not applicable and hence, the hazard was chosen as “Riverine only”.

3.1.2 Topography

Defining the topography is a critical step in flood hazard analysis. Hazus Flood Model identified the data extent of digital elevation based on the defined study region. The DEM was then downloaded to the local drive, from USGS website, by directly navigating to NED using the option provided by the Flood Model.

Figure 3.3 displays the Hazus-MH screen which was used to download the required data. The downloaded data was then imported into the Flood Model by browsing it to the local drive. This DEM data from the USGS web site uses the NAVD88 vertical datum and a resolution of one arc-second (approximately 30 meters). User has the option to either use the coordinates generated by the Flood Model and get the data from USGS website or add own DEM layer that satisfies the requirement.

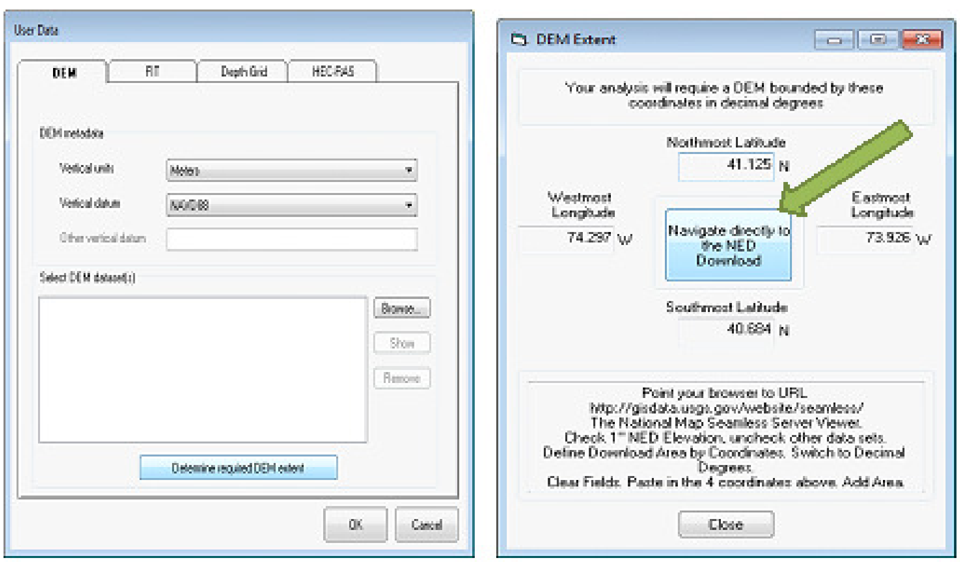

Figure 3.3 Adding DEM data to Hazus-MH Flood Model.

3.2 Building User-Defined Flood Depth Grid

Hazus-MH compatible flood depth grid was created by the hydraulics team at University of Mississippi, as part of the Flood Mitigation Research project by NJIT. The team had generated the Sandy water elevations data to define the boundary condition and collected the discharge data at Hackensack and Passaic River upstream. The NAVD88 datum and a modeling tool CCHE2D-GUI was used for this modeling. The hydraulic process was executed to simulate the flooding and inundation occurred in Meadowlands area, NJ. The output from this process was a file with maximum water elevation and bed elevation for the domain for which the hydraulic process was run.

```
File  Edit  Format  View  Help
TITLE      = "MAX. Water elevation and Bed Elevations"
VARIABLES = "X"
"Y"
"BED(m)"
ZONE T="t=final"
 STRANDID=0, SOLUTIONTIME=0
 I=2071, J=1104, K=1, ZONETYPE=Ordered
 DATAPACKING=POINT
 DT=(SINGLE SINGLE SINGLE )
 5.7247025000000E+005 4.5297045000000E+006 3.3109779357910E+001
 5.7246956250000E+005 4.5296990000000E+006 3.2959911346436E+001
 5.7246893750000E+005 4.5296940000000E+006 3.2901309967041E+001
 5.7246837500000E+005 4.5296895000000E+006 3.3033321380615E+001
```

Figure 3.4 Simulated Sandy inundation data - maximum water elevation and bed elevation.

Figure 3.4 shows an excerpt of the *.DAT output file generated by the hydraulic process. This file was then used as the input to the next steps where the file was imported to Microsoft Access Database and a *.mdb file was created with X, Y and Z co-ordinates for each of the data points. This was then imported to ArcGIS for further processing. An excerpt of the sample *.mdb file is shown in Figure 3.5.

	X_Cord	Y_Cord	Z_Cord
	571481.9375	4514832	1.28307295963168E-02
	571480.5625	4514819.5	0.254733294248581
	571503.5625	4514823.5	0.439532488584518
	571502.25	4514810.5	0.882640600204468
	571500.5	4514798	0.549694776535034
	571526.0625	4514827.5	0.652906715869904
	571525.125	4514814.5	0.91372537612915
	571523.8125	4514802	0.950178921222687
	571522.125	4514789.5	0.447766810655594
	571519.9375	4514776.5	0.512276887893677

Figure 3.5 Excerpt of *.mdb file which is an intermediate file used in the process of creating flood depth grid for Hazus-MH Flood Model.

Once the *.mdb file was created, it was imported to ArcGIS through Arc-Catalog using the "Database Connections" menu and then adding it as a layer to the map. If the co-ordinates are not already assigned, appropriate co-ordinate should to be assigned. Following coordinates were used for this project:

- Projected Coordinate System: NAD_1983_UTM_Zone_18N
- Geographic Coordinate System: GCS_North_American_1983
- Vertical Coordinate System: NAVD_1988

A Shapefile was then created which was again converted to a raster file. The raster file should be in GRID format. This is the format that can be imported to Hazus-MH Flood Model as the user defined flood depth grid.

Figure 3.6 displays the ArcGIS view of the raster file which displays the flood depth grid of the simulated Sandy inundation, for the selected region. The extent is larger than the study region for this thesis as it was built using the data generated as part of NJIT Flood Mitigation project.

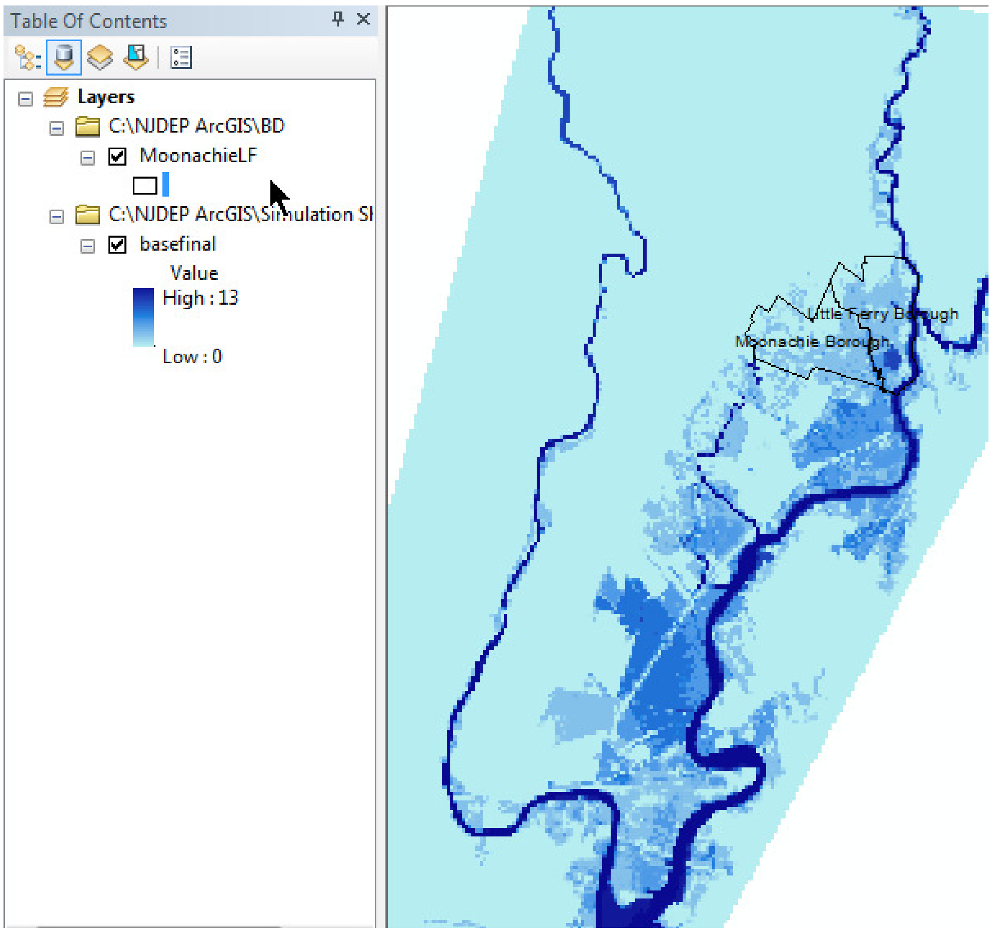

Figure 3.6 Hazus-MH Flood Model compatible user defined flood depth grid and municipality boundaries for Little Ferry and Moonachie.

After creating the study region and defining the DEM in Hazus, as shown in Sections 3.1.1 and 3.1.2, this flood depth grid can be added to Hazus-MH. The return period as an optional parameter and the unit (Feet or Meter) needs to be specified.

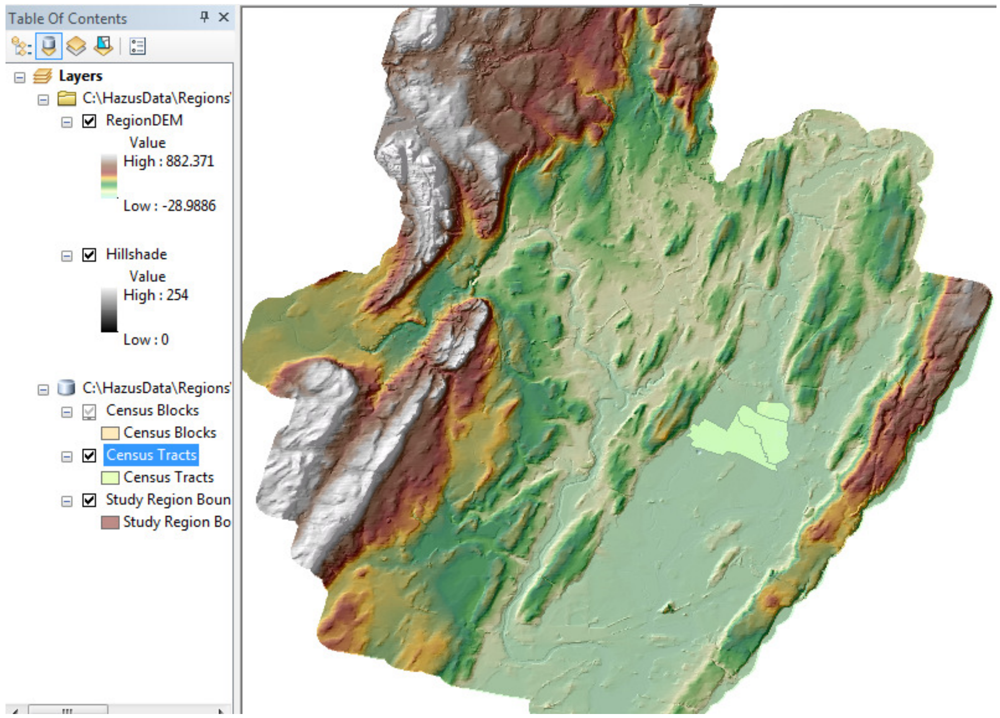

Figure 3.7 Hazus-MH Flood Model map after adding DEM and flood depth grid to the study region.

Figure 3.7 displays the screen which appears on Hazus-MH once raster processing for adding the DEM and the flood depth grid is completed.

3.3 Execution of Various Flood Scenarios

A set of flood scenarios were executed to assess the flood damage from Sandy and to evaluate the alternate structural flood mitigation measures proposed by NJIT as part of the Flood Mitigation Research project. The study regions, one for each scenario, included the list of municipalities that are being protected by each structural solution. Each scenario used the simulated Sandy inundation data to assess the flood damage in that particular region. Once the scenario is successfully created, the floodplain was delineated for the given depth grid. “Delineate Floodplain” submenu option in Hazus-MH Flood Model is enabled only after a scenario is successfully defined. All these processes are run by accessing the options available under “Hazard” menu.

Other scenarios which were executed as part of this research are based on the flood depth grid generated by the hydraulics team of University of Mississippi by adding the proposed structural alternatives to their region of interest and simulating Sandy like event. The output generated by this team was then taken through the similar process as mentioned in Section 3.2 and four different flood depth grids were created for the following four structural alternatives:

- Arc Wall
- Barrier Wall North
- Barrier Wall Middle
- Barrier Wall South

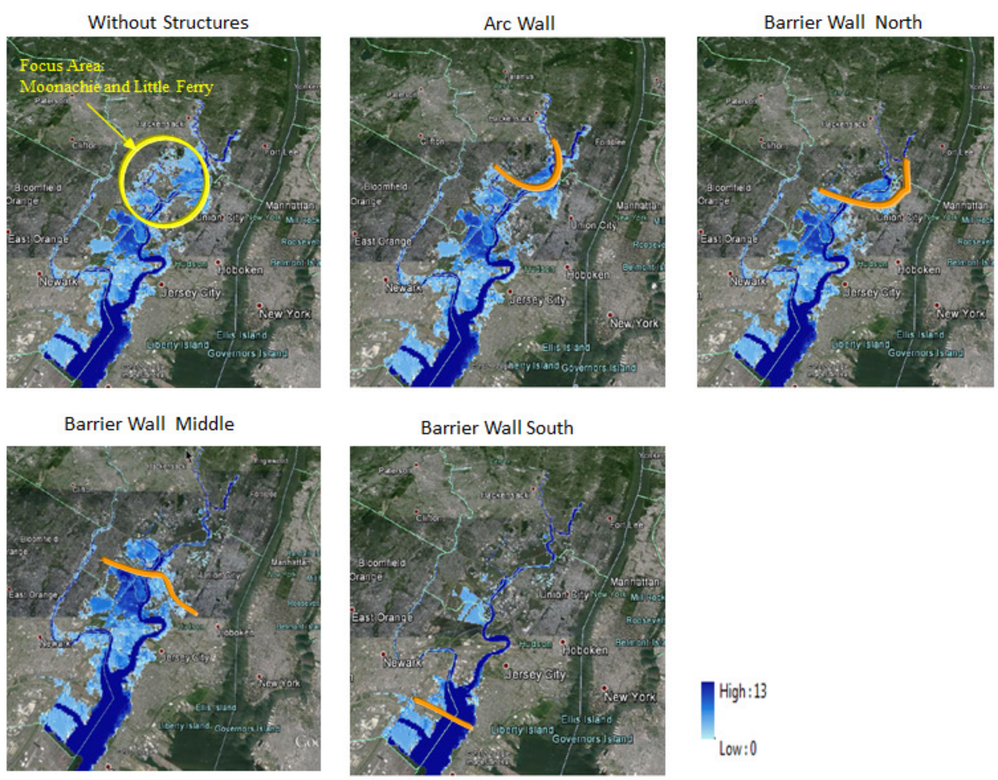

Figure 3.8 Comparison of extent of inundation with structural solutions in place.

Figure 3.8 shows a comparison of the structural solutions and the corresponding flood depth grids generated for each. The main purpose for executing these scenarios is to assess the extent of protection that each of these structural alternatives would provide in future, during Sandy like events. When the digitized structural alternatives and the corresponding flood depth grids are superimposed on a Base-Map, the output could easily be compared with original the simulated Sandy inundation (without any structural measures). This process had also helped in identifying the protected areas by each alternative.

3.4 Assess the Flood Damage from Sandy, for the Study Area

Flood damage assessment for the study area was mainly done by using Hazus-MH Flood Model. The damage data was also collected from various publicly available sources and compared against Hazus-MH generated damage data.

3.4.1 Damage Estimation by Hazus-MH

Hazus-MH Flood Model analyzes the different characteristics of the structures and people of the study region to the flood which have been calculated in the scenario based on the given flood depth grid. Various damage functions are used by the model to assess the damage and dollar exposure. Flood damage functions are in the form of depth-damage curves, relating depth of flooding (in feet), as measured from the top of the first finished floor, to damage expressed as a percent of replacement cost (FEMA 2010). For example, the default damage function estimates percent damage relative to the depth of floodwater as measured from the top of the first finished floor for riverine flood hazard.

To assess the damage, analysis should be run from "Run" submenu option under "Analysis" menu. Analysis on General Building Stock needs to be performed before executing the damage assessment analysis on any other category e.g., Transportation System, Utility System, etc. After the successful execution of the analysis process, the results or damage estimates can be viewed from the "Results" menu.

Table 3.1 Summary of Estimated Economic Losses based on Building Loss and Business Interruption, as Generated by Hazus-MH Flood Model for Little Ferry and Moonachie

Building-Related Economic Loss Estimates (Millions of USD)						
Category	Area	Residential	Commercial	Industrial	Others	Total
A. Building Loss						
(a)	Building	15.54	23.09	15.06	1.99	55.68
(b)	Content	9.33	62.79	31.18	11.8	115.1
(c)	Inventory	0	2.31	5.03	0.02	7.36
A = (a)+(b)+(c)	Subtotal	24.87	88.19	51.27	13.81	178.14
B. Business Interruption						
(d)	Income	0	0.6	0.01	0.05	0.66
(e)	Relocation	0.11	0.21	0.02	0.03	0.37
(f)	Rental Income	0.05	0.14	0	0	0.19
(g)	Wage	0	0.61	0.02	0.59	1.22
B= (d)+(e)+(f)+(g)	Subtotal	0.16	1.56	0.05	0.67	2.44
All (A+B)	Total	25.03	89.75	51.32	14.48	180.58
Total economic loss of $180.58 Million represents 12.34% of the total replacement value ($1,463.26 Million) of the scenario buildings						
Shelter Requirement : 13,304 people out of a total of 13,554 will seek temporary shelter in pubic shelters						

Table 3.1 shows a sample loss estimation output generated by Hazus-MH Flood Model. This output includes the summary of estimated economic losses based on building loss and business interruption and the shelter requirement, as estimated by Hazus-MH Flood Model, for the study area – Little Ferry and Moonachie.

Building losses in this table are summarized at residential, commercial, industrial and other category. These categories are defined based on the type of occupancy. The "other" column includes all buildings with occupancy type as agriculture, religion, government, or education. The losses are divided into two categories: A. Direct Building Loss and B. Business Interruption Loss.

A. Direct Building Loss category includes the following loss estimates:

(a) *Repair or replacement* of the building structure. Using the flood depth and various building properties e.g., age, number of floors, material used (wood, concrete, etc.), etc., the flood damage percentage is determined and used in calculating the building repair/replacement cost. When a building is estimated to be damaged by 50% or more, it's considered to be a complete loss i.e. the building has to be demolished and re-built.

(b) *Loss of its contents* e.g., furniture, equipment or other supplies which are not integral with the building structure. Non-structural components e.g., lighting, ceilings, mechanical and electrical equipment and other fixtures are not included in this category (FEMA 2010).

(c) *Loss of Inventory.* Inventory loss amount is calculated only for non-residential buildings. Total inventory value, calculated as floor area times the percent of gross sales or production per square foot (FEMA 2010), is an input to this loss damage function.

B. **Business Interruption Loss** category includes the losses associated with inability to operate a business due to the damage sustained during the flood. It includes four components and estimations for each of those components are dependent on building restoration or outage time. Building Restoration time is linked to the flood depth and it will increase with an increase in the flood depth until the building reaches the 50%

damage threshold beyond which the damage is considered to be a complete loss i.e. the building has to be demolished and re-built. Building's physical restoration time as well as the time for clean-up, inspection, obtaining approval, etc. is included in the calculation of the restoration time. The four components of this category are:

(d) *Loss of income* - for the occupants of the building

(e) *Relocation expense* - caused to the building owners due to the disruption caused by the flood. This cost includes the cost of shifting and transferring, and the rental of temporary space and is not calculated for some of the occupancies such as entertainment, theatres, parking facilities, and heavy industry. If building damage threshold is less than 10%, it's assumed that the occupants will not have to relocate.

(f) *Rental income loss* – factors like floor area (in square feet), rental cost ($ /square feet/day), restoration time are among others which are used in calculating this loss.

(g) *Loss of wage* – Hazus uses pre-defined wage factor ($/square feet/day) in this loss estimation.

Total Loss Estimation:

Total estimated loss from building damage and business interruption is calculated to be $180.55 Million with $2.42 Million loss occurring from business interruption alone. The residential occupancies made up 13.86% of the total loss. Total economic loss of $180.58 Million represents 12.34% of the total replacement value ($1,463.26 Million) of the scenario buildings.

The Global Summary Report, one of the loss estimation reports generated by Hazus-MH Flood Model, also indicates that 13,304 people out of a total population of 13,554 people will seek temporary shelter in pubic shelters. A sample inventory for the study area is added in Appendix B.

This loss estimation highlights the severity of Sandy damage occurred in these two municipalities. Similar process can be carried out to assess a community's damage both during pre or post disaster period and take necessary step to mitigate the risk as well as in response and recovery process.

3.4.2 Damage Estimated by Public Sources

Since the accuracy of Hazus-MH loss estimate depends on various factors and there are uncertainties and limitation (FEMA 2010) as described in Chapter 2, the Sandy damage estimates were also collected from various publicly available sources which had recorded the post-Sandy damage estimates by surveys of damage, existing assets, contacting affected people, by using insurance claims, etc.

Table 3.2 Sandy Damage in Little Ferry and Moonachie – based on Assumptions and Publicly Available Damage Estimates

Category	Description	Little Ferry Borough	Moonachie Borough
CAT_{POP}	Population - 2010[1]	10626	2708
CAT_{HD}	Total No. of Housing Damage[2]	1525	674
$CAT_{AVG\text{-}INDV}$	Average Cost of Individual Damage[3]	$12269.81	$11728.05
CAT_{BI}	Total No. of Businesses Impacted[2]	488	378
$CAT_{AVG\text{-}BIZ}$	Assumed Average Cost to Impacted Businesses	15000	15000
T_1	**Total Structural Damage**	**$63,454,381**	**$29,384,117**
CAT_{MI}	Median Income[3]	$60000	$48,306.00
CAT_{EMP}	Assumed Percentage of Employed People	50%	60%
T_2	**Income Loss for 7 days**	**$6,113,589**	**$1,505,241**
$CAT_{\%HD}$	% of Homes Damaged[4]	0.9	0.95
T_3	**Productivity Loss for Inhabitants of Damaged Homes/Displaced**	**$11,004,460**	**$1,645,277**
$CAT_{BIZ\text{-}LOSS}$	Total Loss for Business, assuming an income of $800 for a small business	$2,732,800	$2,116,800
$CAT_{SUPP\text{-}MLT}$	Multiplier Effect for Suppliers	$2,732,800	$2,116,800
T_4	**Total loss from Business**	**$5,465,600**	**$4,233,600**
T_5	**Infrastructure Loss[5]**	**$2,378,775**	**$606,223**
T_6	**Environmental/Contamination**	**$5,000,000**	**$5,000,000**
	Total Damage in each Municipalities (In Million)	**$ 93**	**$ 42**
T_{TOT} = Total Damage for the study region (In Million)		**$ 136**	

Sources:
1. http://www.census.gov/2010census/
2. http://www.njspotlight.com/stories/13/03/14/assessing-damage-from-superstorm-sandy/
3. http://www.njspotlight.com/stories/13/03/14/sany-s-monetary-damages/
4. Sandy Damage Estimates by Block Group accessed from http://hud.maps.arcgis.com/home/
5. Sandy Damage Estimates by Block Group accessed from

Table 3.2 shows the estimated damage for Little Ferry and Moonachie which cross-reference some of the demographic (population size, median income, etc.) with the community area, number of damaged homes and rental units, as well as damage severity levels incurred to owned and rented homes categories. Following components were used to estimate the total damage:

1. T_1 is the total Structural Damage to Homes (Owned and Rented), based on severity of damage reported after Sandy in these two communities, and Businesses, using the number of impacted businesses and is given as:

   $$T_1 = (CAT_{HD})*(CAT_{AVG\text{-}INDV})*3 + (CAT_{BI})*(CAT_{AVG\text{-}BIZ}) \quad (3.1)$$

2. Income Loss, T_2, for residents of impacted communities for 7 days is given as:

   $$T_2 = (CAT_{POP})*(CAT_{EMP})*(CAT_{MI})*7/365 \quad (3.2)$$

3. Income Loss for Residents of Damaged Homes for an additional 2 weeks due to the loss of productivity,

   $$T_3 = T_2 *(CAT_{\%HD})*2 \quad (3.3)$$

4. Total Loss for Business, assuming an income of \$800 for small businesses, average closure of the businesses were 7 days, and that there is a similar multiplier effect to the corresponding supplier base,

   $$T_4 = CAT_{BIZ\text{-}LOSS} + CAT_{SUPP\text{-}MLT} = [(CAT_{BI}) *800*7]*2 \quad (3.4)$$

5. Infrastructure Loss, T_5 is calculated based on State-wide per capita estimate. Sandy caused a total infrastructure loss of \$1.97 billion in New Jersey

6. Environmental/Contamination related loss T_6 is assumed to be \$5 Million for both municipalities, based on per acre contamination cost

7. The Total Damage, T_{TOT}, for the study area can be calculated using the formula:

$$T_{TOT} = \sum_{j=1}^{M} \sum_{i=1}^{n} T_i \tag{3.5}$$

Where, i = number of categories, varies from 1 to n; n = 6 for this study

j= number of communities or municipalities under consideration and it varies from 1 to M. For this Study M =2 as there were two municipalities – Little Ferry and Moonachie

Unlike Hazus-MH damage estimates, estimates from the publicly available sources can only be obtained and used during the post disaster period as those are based on the assessment of actual damage and losses.

Table 3.2 above lists only a sample set of categories. This list need to be supplemented with various other categories such as insurance claims from vehicle owners, other insurance claims, medical cost, etc., to obtain a more comprehensive damage estimates for the selected communities. This computed total damage might vary from what is calculated by Hazus-MH as Hazus-MH estimates are based on the inventory available, the damage functions used in the calculation and the inundation depth grid.

CHAPTER 4

BENEFIT COST ANALYSIS

This chapter describes the financial model and the process of executing benefit cost analysis to evaluate various mitigation measures and ranking the measures based on their benefit cost ratio. The computed benefit cost ratio can be one of the critical inputs for the decision makers when there are multiple mitigation alternatives available but due to various constraints not all of the option can be implemented. To establish this process, NJIT led Flood Mitigation Research project, as described in Appendix A, was used as the case study.

4.1 Proposed Alternative Solutions

As part of the research project, NJIT had considered a range of protective and adaptive solutions which could be implemented in the Meadowlands area of NJ to mitigate the flood risk from any future Sandy like events. The proposed solutions also address some of the existing infrastructure issues which result in flooding this area during every heavy rain season. These solutions were broadly categorized into following three groups:

- Maintenance and Operations e.g., cleaning drainage network, ditches and dikes, investing in portable pump for backup, etc.

- Capital investments e.g., constructing barrier walls, elevating or relocating structures falling in the critical flood zone, building new green infrastructure and storage facilities, etc.

- Regulatory improvements includes modification of city building codes and system level and component-level design standards e.g., building in redundancy in the critical failure point such as power sub-station, etc.

Out of the above mentioned categories and alternatives, only the proposed new structural solutions were considered for establishing the benefit cost analysis process. However, this same process can be utilized to evaluate and/or rank any categories of solutions. The team at NJIT proposed the following four medium or long term structural solutions as part of the Flood Mitigation Research project:

- Arc Wall
- Barrier Wall North
- Barrier Wall Middle
- Barrier Wall South

Arc Wall in general is targeted at protecting the municipality of Moonachie, Little Ferry and Hackensack from riverine flooding whereas Tidal Barrier Walls are expected to provide complete protection from tidal surges like what was experienced during Sandy. These Barrier Walls will not provide relief from local riverine flooding within the target communities of Moonachie, Little Ferry, and Hackensack.

4.1.1 Arc Wall

The Arc Wall, with an approximate length of 6.5 miles, extends from East Rutherford to South Hackensack. It starts on the west end in the vicinity of Route 17, goes mostly in parallel to Paterson Plank Road, and then goes towards northeast direction across the Meadowlands to meet the western shore of the Hackensack River, terminating on its east end near Route 46.

Figure 4.1 shows the conceptual alignment of proposed the Arc Wall. It is expected to provide substantial relief from chronic flooding during heavy rainfall events and moderate degree of protection against storm surges. To achieve this level of protection, the proposed design recommends a top elevation of >8ft for the Arc Wall.

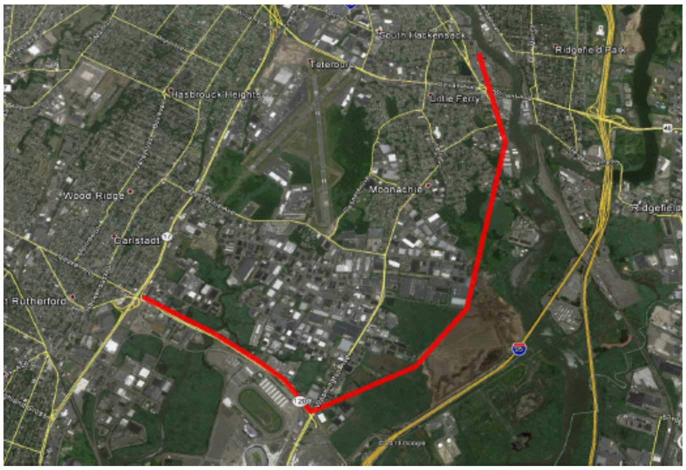

Figure 4.1 Conceptual alignment of Arc Wall.

The estimated total cost of construction is $180m and annual maintenance, repair, and replacement cost is estimated to be $3m. To control the cost, the conceptual design of the Arc Wall takes advantage of existing high ground elevation, wherever feasible. This solution does not have any major water crossing. It only crosses Berry Creek. The Arc Wall will provide flood protection to municipalities of Moonachie, Little Ferry, Hackensack, Carlstadt, South Hackensack, and Teterboro.

4.1.2 Barrier Wall North

The Barrier Wall North is proposed to be 5.5 miles in length and will start on the west end at Route 17, then it will go in parallel to Route 3 to the intersection with the New Jersey Turnpike and turn toward north following the shoulder of the Turnpike, and eventually will cross the Hackensack River before terminating on its east end into the elevated ground in Ridgefield.

Figure 4.2 shows the conceptual alignment of the Barrier Wall North which crosses Berry Creek and Hackensack River. Crossing at the Hackensack River should be navigable which adds to the higher construction and maintenance cost of this solution compared to Arc Wall. Existing roadway embankments and high ground elevations have been utilized to reduce costs. The estimated total cost of construction is $735m and annual maintenance, repair, and replacement cost is estimated to be $10m. The proposed design and alignment of Barrier Wall North will provide tidal storm surge protection to a total of nine communities – Moonachie, Little Ferry, Hackensack, Carlstadt, Teterboro, South Hackensack, East Rutherford, Rutherford and Ridgefield.

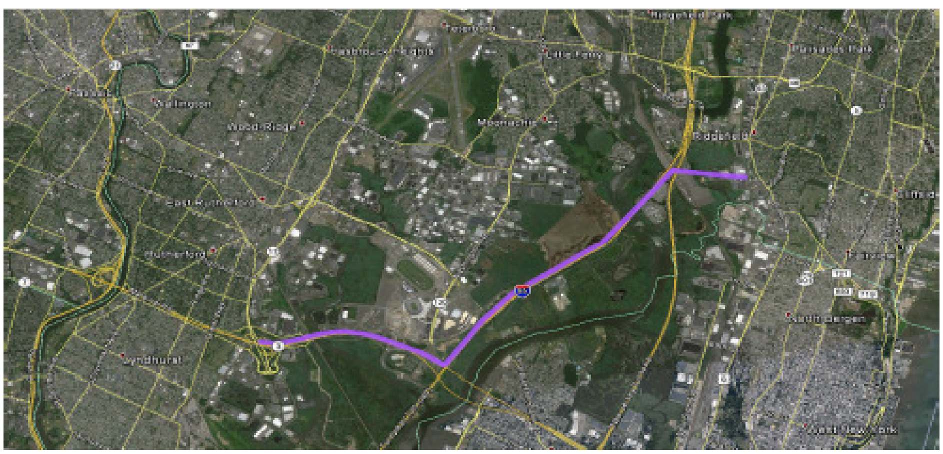

Figure 4.2 Conceptual alignment of Tidal Barrier Wall North.

4.1.3 Barrier Wall Middle

The Barrier Wall Middle is proposed to start on the west end at Route 17 (same as the starting point of Barrier Wall North), and then continue in parallel to Route 3 till it reaches the high ground elevation of the Town of Secaucus. The Barrier Wall is interrupted here and the high elevation of Secaucus is utilized to provide the flood protection for a length of more than a mile. This allows the length of this Barrier Wall to be limited to 4 miles only. The structure then resumes and continues to the east end in Jersey City and terminates at the foot of the Palisades ridge and the ramp leading towards the Lincoln Tunnel. Figure 4.3 shows the conceptual alignment.

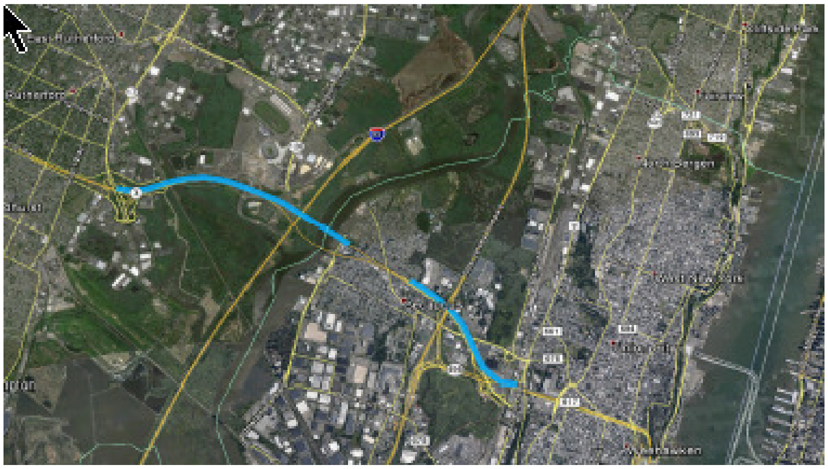

Figure 4.3 Conceptual alignment of Tidal Barrier Wall Middle.

Proposed alignment of this Barrier Wall crosses Hackensack River and the crossing should be navigable. Like other options, this one also utilizes existing roadway embankments and high ground elevations to reduce costs. The estimated total cost of construction is $611m and annual maintenance, repair, and replacement cost is estimated to be $11m. The proposed design and alignment of Barrier Wall North will provide tidal storm surge protection to a total of eleven communities in the middle and upper Hackensack River Watershed – Moonachie, Little Ferry, Hackensack, Carlstadt, Teterboro, South Hackensack, East Rutherford, Rutherford, Ridgefield, part of Secaucus and part of North Bergen.

4.1.4 Barrier Wall South

Barrier Wall South is 2.5 miles long and begins on the west end in East Newark and extends towards east, crossing the Passaic River with a navigable barrier that connects with Kearny Point, which is an elevated section of land that requires no flood wall. The alignment continues to a second navigable barrier that spans the Hackensack River, and then to a flood wall on the east end that joins with the rising ground of the Palisades ridge in Jersey City. Since it spans both the Hackensack and Passaic Rivers with navigable barriers, it is a very costly option. NJIT suggested that the design phase might examine the possibility of alternate alignments involving only the Hackensack River to reduce cost but that might reduce the benefit as well. Figure 4.4 shows the conceptual alignment of this structure.

Figure 4.4 Conceptual alignment of Tidal Barrier Wall South.

The estimated total cost of construction for this Tidal Wall is $1,590m and annual maintenance, repair, and replacement cost is estimated to be $15m. Though Barrier Wall South is the shortest in length, it is the most costliest option and provides the maximum protection as it protects the entire Hackensack and Passaic River Watershed which includes municipality of Moonachie, Little Ferry, Hackensack, Carlstadt, Teterboro, South Hackensack, East Rutherford, Rutherford, Ridgefield, part of Secaucus, part of North Bergen, Kearny, Kearny Point, Part of Jersey City and Harrison.

4.2 Cost Estimation and Assumptions

Based on the quantity take-off for each alternative, following categories of cost components were identified and used in the cost-benefit analysis:

- **Initial Capital Cost** is the cost required to construct or build the protection measures. The conceptual capital cost estimation includes an high level estimation of the following items:
    - Design and Approval
    - Mobilization
    - Clearing and Grubbing
    - Construction of Access Roads
    - Construction of Drainage Pitches
    - Cost of Raising the roads
    - Relocation of Utilities
    - Procurement of the Real Estate and Easements
    - Mitigation of Wetland
    - Installing 40’ Long Sheet Piles. 12’ of the length will be elevated and 28’ will be below ground
    - Navigable water crossing
    - Movable gates on road and railroad
    - Tide Gates wherever the walls are crossing a water stream
    - Pump Stations to pump out the collected water
    - Overhead and Profit

- **Annual Maintenance and Repair cost** includes the cost of following items:

    - Operating the tide gates
    - Operating the movable gates on road or railroad
    - Operation of the Pump Station
    - Maintenance of all components of the solution e.g., Tide Gates, Movable Gates, Pump Station, Ditches, etc.

- **Periodic Maintenance Cost** includes any other cost required to invest periodically to maintain the serviceability of the alternatives. For example, the pump station might have to be replaced after certain period of time. For this analysis, it's assumed that 50% of the pumping machines or other mechanical equipment will be replaced after every 20 years of operations

- **Estimated Life Span** is the total estimated Life span for each alternative, as a whole, is assumed to be 70 years. It is assumed that at the end of this 70 years, non-mechanical portions of each alternative will have a remaining residual value

- **Remaining Residual Value** is the value of the alternative option at the end of its proposed life span. This is assumed to be at 20% of the initial capital costs minus all mechanical costs associated with pumping stations.

Table 4.1 Sample Net Present Value Calculation based on the Estimated Cost for Each Alternatives

Alternatives - recommended structure	Project Cash Flow / Cost					
	$R_{INITIAL}$: Construction Cost (in Millions)	R_{OMR} : Annual Operating, Maintenance and Repair Cost (in Millions)	R_{OTHER} : Other Future Cost (in Millions)	$R_{RESIDUAL}$: Residual Value (in Millions)	Life Span	Net Present Value of Cost (in Millions)
Arc Wall	$ 180.00	$ 3.00	$ 60.00	$ 42.00	70 yrs	$ 262.68
Barrier Wall North	$ 735.00	$ 10.00	$ 150.00	$ 162.00	70 yrs	$ 996.53
Barrier Wall Middle	$ 611.00	$ 11.00	$ 165.00	$ 138.70	70 yrs	$ 901.22
Barrier Wall South	$ 1,590.00	$ 15.00	$ 300.00	$ 340.50	70 yrs	$ 1,983.16

Table 4.1 shows a sample Net Present Value (NPV) calculation based on the estimated cost for each alternatives. The NPV of the total cost for each alternative structural solution is needed to calculate the benefit cost ratio and is calculated using the following formula:

$$\text{NPV} = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \tag{4.1}$$

Where, t = time in years which ranges from 0 to N=70 years

i = Inflation-adjusted return which is considered to be 4%

R_t = Cash flow for each year = $R_{INITIAL} + \Sigma R_{OMR} + \Sigma R_{OTHER} + R_{RESIDUAL}$

$R_{INITIAL}$ = Initial Construction Cost

R_{OMR} = Annual Operating, Maintenance and Repair Cost

R_{OTHER} = Other future cost which includes period maintenance cost as described in Section 4.2

$R_{RESIDUAL}$ = The remaining value of the alternative option at the end of its proposed life span of 70 years and calculated using the formula: $[0.2(R_{INITIAL} - R_{OTHER}) – 0.5(R_{OTHER})]$

4.3 Benefit Assessment and Assumptions

The benefits are considered to be the protections that will be provided by the alternative structural solutions which will help mitigate the flood risk and damage from any future Sandy like event. The total benefit associated with each alternative solution has two components. The first component is the damage which will be eliminated or mitigated, in the future, to a great extent once the selected solution is built. Thus, the benefit is almost a direct translation of the loss/cost incurred due to the damage caused by Sandy. The second component is the induced benefits due to wage content and the multiplier effect from recycling wages through the supplier chain.

Using the simulated Sandy inundation flood depth grid various flood scenarios were executed and losses from Sandy were estimated for each set of communities which are being protected by various structural alternatives. Chapter 3 describes this process in detail.

Table 4.2 presents a sample set of loss estimation by Hazus-MH flood Model, based on Building Loss and Business Interruption during Sandy and for Little Ferry and Moonachie. It is expected that these losses will be mitigated when the alternative structural solutions are implemented. Detailed of this estimation is provided in Appendix C.

Table 4.2 Sandy Damage Estimates for the Set of Communities which will be protected by each Alternative Structural Solutions

Building-Related Economic Loss Estimates (Millions of USD)					
Category	Area	Arc Wall	Barrier Wall North	Barrier Wall Middle	Barrier Wall South
Building Loss					
(a)	Building	62.16	81.79	103.62	155.66
(b)	Content	142.48	186.82	239.97	350.12
(c)	Inventory	9.06	10.35	13.2	24.53
	Subtotal	213.7	278.96	356.79	530.31
Business Interruption					
(d)	Income	1.01	1.28	1.8	2.25
(e)	Relocation	0.48	0.57	0.8	1.02
(f)	Rental Income	0.26	0.31	0.49	0.63
(g)	Wage	2.87	3.25	3.9	4.68
	Subtotal	4.62	5.41	6.99	8.58
Total		218.32	284.37	363.78	538.89

4.4 Evaluation of Alternative Solutions through Benefit Cost Analysis

A life cycle cost benefit analysis was performed for each of the structural alternatives. The net present value of costs for each alternative solution is the denominator of the Benefit cost Ratio. The numerator represents the benefits derived from a given protection alternative, which integrates the removal of damage and economic losses from protected communities, as well as the induced benefits from large-scale infrastructure projects.

Table 4.3 provides the benefit cost ratio for the various structural alternatives. The ratio is calculated for two different scenarios – (1) assuming there will be just one Sandy like event during the 70 year time horizon (2) there will be two such events in the 70 year time horizon.

Table 4.3 Benefit Cost Ratio for Each Structural Alternative

Alternatives - recommended structure	Project Cash Flow / Cost	Project Benefits (in Millions)		One Disaster in the Life Span of 70 Years	Two Disaster in the Life Span of 70 Years
	Net Present Value of Cost (in Millions)	2012 Sandy damages that will prevented by the solutions (in Millions)	Induced Benefit (30% of Construction Cost in Wages) (in Millions)	Benefit cost Ratio	Benefit cost Ratio
Arc Wall	$ 262.68	$ 218.32	$ 157.61	1.43	2.26
Barrier Wall North	$ 996.53	$ 284.37	$ 597.92	0.89	1.17
Barrier Wall Middle	$ 901.22	$ 363.78	$ 540.73	1.00	1.41
Barrier Wall South	$ 1,983.16	$ 538.89	$ 1,189.90	0.87	1.14

In the event when there is one disaster in 70 years of life span, the Arc Wall and the Barrier Wall Middle are justifiable. However, if there are two or more such events to occur, all 4 alternatives would be justifiable. The Arc Wall has the highest benefit cost Ratio of 1.43 (one event) to 2.26 (two events), followed by Barrier Wall Middle which achieves a benefit cost Ratio of 1.0 (one event) to 1.41 (two events). Ranking of these various options based on their benefit cost ratio can be an input to decision makers while choosing the feasible solution given the budget is limited.

CHAPTER 5

FLOOD RISK ANALYSIS FOR THE STUDY REGION

Little Ferry and Moonachie boroughs in the New Jersey Meadowlands area were severely damaged during both Irene and Sandy. However, flooding in these areas is not just a result of these two events but it's an on-going problem due to low-lying topography and a combination of flood management in the neighboring towns. Little Ferry and Moonachie flood almost every year, during heavy rain period.

5.1 Flood Zoning of the Study Area

Moonachie and Little Ferry fall under flood zone "AE" as designated by FEMA based on their study of coastal flood risk. When an area falls under Special Flood Hazard Area (SFHA), it indicates that the area is subject to inundation by a 1-percent-annual chance flood. Zone "AE" indicates that this area is subjected to waves less 1.5 foot in height.

5.2 Types of Flooding

The Study Area faces primarily three types of flooding subjected to fluvial flow, tidal flow, and surges.

Fluvial flooding occurs approximately every three years, on an average. (NJIT 2014) This type of flooding occurs in the floodplains of rivers when the capacity of rivers or streams is exceeded as a result of heavy rainfall or sometime due to snow and ice melts within catchment areas further upstream. Though these moderate and frequent flood events should not have any major consequences, due to drainage network deficiencies the flooding frequency has increased here in the recent past. Events like Hurricane Irene are less frequent and produce greater fluvial flooding which impacts the communities and causes major damages. These events are often more dense and widespread in their geographic reach and impact. To solve these problems, significant federal and state funding may be required to improve drainage and storage capacity, and build flood protection systems for these two municipalities. Flood management of a community is usually influenced by the drainage and pumping policies of the surrounding jurisdictions as well.

Tidal events are infrequent but can have severe consequences as it is often sudden and the extreme forces that drive it pose a significant danger. A tidal event combined with a high fluvial flow can produce even more severe events. However, most of the times, tidal events are forecasted with reasonable accuracy which helps prepare the community. Duration of flooding from tidal event is usually limited by the cycle of the tides provided the where drainage network is adequate and operational and typically, the solutions implemented for high fluvial flows should be able to protect the area from tidal events as well. However, the current flood protection system of berms and tide gates of the study area may not be able to withstand future tidal events, particularly as climate change and sea level rise are taken into account. Maintenance of the current protection systems also requires funding. (NJIT 2014)

Storm surge is the abnormal rise of water level generated by a storm over and above the predicted astronomical tides or wave conditions. This rise in total water level can cause extreme flooding in coastal areas, particularly when storm surge coincides with high tide. A surge event such as Hurricane Sandy is considered very infrequent. However, another surge event took place 20 years ago, putting in question the notion of return periods for extreme events under the current outlook of climate change. Surge events can produce severe yet selective flooding as seen by Sandy.

5.3 Fault-Tree Analysis

Fault Tree is a visual depiction of possible faults in a network or system. Building a fault tree needs an understanding of the components, their dependencies and probability of threat occurring and the damage. This section identifies the probability of various types of flooding in the study area and through fault-tree analysis, evaluates the overall probability and exposure of flooding in this area.

<u>Heavy Rainfalls</u>: Probability of flooding from heavy rainfalls is considered to be 33% as the study area gets flooded from heavy rainfall, almost once in every 2-3 years. (NJIT 2014) To estimate the exposure of this event in Moonachie and Little Ferry, *Riverine* flood hazard analysis was done on this study area, using Hazus-MH Flood Module. The estimated damage calculated by Hazus-MH Flood Model for this event is $65.19 Million.

<u>Storm Surge:</u> For the analysis of Storm Surge related events, Sandy related data is used. Timothy M. Hall, a senior scientist at the NASA Goddard Institute for Space Studies, estimates that Sandy's trajectory is a one-in-a-700-year-event and by that he means 0.14 percent chance of hitting New Jersey in any given year (Schuerman 2013). However, with the climate change and sea level rise both exposure and probability of these events increases. This would mean, as Timothy M. Hall explained, if everything else being equal, a 500 year storm would become a 100 year storm (Schuerman 2013). The US Army Corps of Engineers is now recommending designing to the 100-year Storm + 3 feet (for sea level rise). Hence, for the fault-tree analysis, Sandy is considered to be a 100 year

event i.e. the probability is 1%. Exposure of this event, as calculated in Chapter 3, is \$180.58 Million.

Tidal Events: Due to lack of available data, the probability and exposure number for this type of events are only a guesstimate. Since tidal events are more frequent than storm surge and less frequent than heavy rainfall, probability is assumed to be once in 20 years i.e. 5% and exposure about \$100 Million.

Figure 5.1 describes the fault tree analysis for flooding in the study area. This fault tree is built based on the probability and exposure of flooding for each event as described above. Various forms of FTPlus software are available to perform the fault-tree analysis.

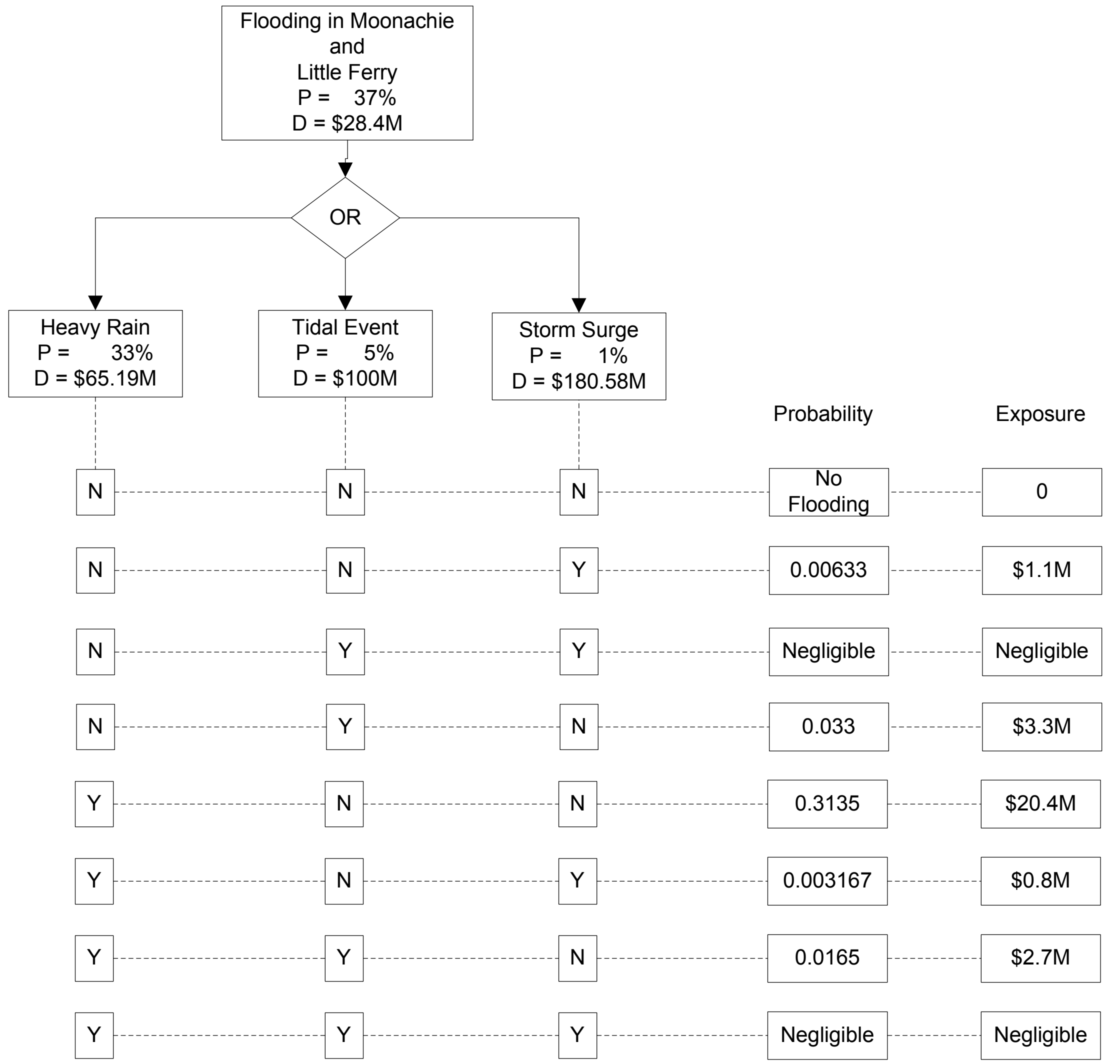

Figure 5.1 Fault tree analysis for flooding in Moonachie and Little Ferry.

"P" in the above diagram indicates the probability of the event occurring and "D" indicates the damage that will be caused by the event. In this analysis, "OR" logic gate is used as flooding can be caused by any of these three types of events or a combination of those. There are a total of eight possible scenarios based on the probability occurrence of various combinations of events.

The probability of flooding in the study area can be calculated as:

$$P_{FLOOD} = \sum_{s=1}^{N} P_s \tag{5.1}$$

Where, N = total number of scenarios; N=8 for this analysis

s = Number of scenario, varying from 1 to N

P_s = Probability of each scenario and is calculated as the product of probability for each contributing event.

For Example, in Figure 5.1, the first line indicates N-N-N which means no chance of flooding from any of the three events and hence P_1 indicates "No Flooding".

The second line indicates N-N-Y i.e. the probability of flooding when there are no Heavy Rains or Tidal events but the flooding occurs only from Storm Surges. Probability for this combination of events, P_2 can be computed as:

$$P_2 = (1 - P_{HEAVY\text{-}RAIN}) * (1 - P_{TIDAL\text{-}EVENT})) * (P_{STORM\text{-}SURGE}) \tag{5.2}$$

Based on these probabilities, exposure to the events i.e. the damage is calculated using the following formula:

$$D_{FLOOD} = \sum_{s=1}^{N} P_s * \left(\sum_{i=1}^{M} D_{EVENT} \right) \tag{5.3}$$

Where, N = total number of scenarios; N=8 for this analysis

s = Number of scenario, varying from 1 to N

P_s = Probability of each scenario

M = total number of events with probability of occurring as true ("Y")

i = Number of scenario with probability of occurring as true and varies from 1 to M

D_{EVENT} = Damage of each event with probability of occurring as true ("Y")

Analysis and Assumptions:

As seen in Figure 5.1, the fault-tree analysis calculates that the municipalities of Moonachie and Little Ferry are subjected to a 37% probability of flooding each year and the exposure to this flooding could be about $28.4M.

This fault-tree analysis highlights the vulnerability of the study area to flooding and indicates the need for flood protection. Any improvement to flood mitigation measures, structural or non-structural solutions, will help mitigate not only the severe flood damages occurring from Sandy like events but also from heavy rain which is more frequent and inundates these areas almost every 2-3 years.

The underlying assumption of this analysis is that an occurrence of a particular event type is independent of the other two types of events.

CHAPTER 6

CONCLUSION

The focus of this thesis was two of the municipalities in the New Jersey Meadowlands area – Little Ferry and Moonachie, in the aftermath of Sandy. This study attempts to highlight the increasing rate of natural disasters, particularly hurricane and storm events and the need for mitigation measures to reduce the risk. The process of information mining, geodatabase creation, flood damage estimation, and the financial model described here focus on flooding events only. However, these processes and the model can be adapted for other types of events such as earthquakes, hurricanes, etc., and can guide the decision makers in an informed decision making process.

Since the study area is highly vulnerable to flooding, various non-structural solutions as well as regulatory improvements might have to be recommended along with the structural solutions, to ensure flood protection in the interim and in long-run.

The proposed long-term structural measures which were considered for the benefit cost analysis are: Arc Wall, Barrier Wall North, Barrier Wall Middle and Barrier Wall South. Out of these four proposed solutions, Arc Wall provides the highest benefit cost ratio.

However, the interim solutions are of utmost importance to these two vulnerable coastal communities as the long term structural solutions are time consuming and might need a few years of planning and construction. Some of the interim and less expensive measures, compared to the more expensive structural alternatives described in this study, are:

- Cleaning and widening of ditches and waterways
- Improvement of the pump stations such as the Lincoln Street pump station in Moonachie
- Installation of emergency backup electrical generators for police and fire departments as well as for all pump stations
- Construction of berms at mobile home parks
- Modification of the existing site grading to provide positive flow away from occupied properties, if deemed needed

Implications to future study:

The assessment in this study was done using the default Hazus-MH data which is at census block level and includes: demographic and residential building counts based on 2000 Census, non-residential structures provided by Dun & Bradstreet (D&B) 2006, and building valuations conforming to R.S. Means 2006. Loss estimation done by Hazus-MH Flood Model is sensitive to the granularity of asset information. High resolution and more current data can further refine the assessment.

The fault tree analysis, done to assess the overall risk to flooding for this area, assumes that the occurrences of various event types are independent of each other. However, in future the coastal communities might be faced with combined events. The probability and impact of those events need to be researched further.

APPENDICES

APPENDIX A

FLOOD MITIGATION PROJECT – A RESEARCH BY FMER CENTER

A brief overview of the flood mitigation research project which was used as a case study for this report is described in this section.

In order to assess this flood risk and to identify potential resilient solutions for the affected communities, New Jersey Department of Environmental Protection (NJDEP) engaged the experts from various agencies and universities and assigned certain locations to those groups to analyze Sandy's flooding and surge data for various locations. In response to this engagement, New Jersey Institute of Technology (NJIT) proposed the Flood Mitigation Engineering Resource Center (FMERC) which will study the Meadowlands areas of NJ and propose both short-term remediation and long-term solutions to protect many communities from similar future storms. At a high level, this flood mitigation project includes a comprehensive analysis of damage due to Sandy, studying the existing flood control measures vs. their performance during Sandy, identifying important assets and critical infrastructures which must be protected from flood event and then suggesting various alternative measures to mitigate any future risk and thereby increase the community resiliency. NJIT suggested alternatives will include various structural, environmental and nature-based (green infrastructure) measures. Final recommendation to NJDEP will be made based on the alternatives' cost and their ability to reduce the communities' risk and vulnerabilities as well as the development of an acceptable level of resiliency to future storm events and other sources of flooding.

Though the project started with an objective of recommending flood protection measures for Moonachie, Hackensack and Little ferry, it was important to consider the adjoining cities as well in the analysis because it is likely that a protective measure for one city may adversely affect its neighboring cities.

Data gathering and Ground-truthing, Sandy Simulation and hydraulic model development and design and costing of Structural Solutions were some of the critical phases of this flood mitigation research initiative.

Data Gathering and Ground-truthing

During this phase, the research team reached out to the personnel from the municipalities and counties of the study area as well as agencies like Meadowlands Environmental Research Institute (MERI), Federal Emergency Management Agency (FEMA) and US Army Corps of Engineers and many other state and local agencies to collect the data and facts about the study region and to understand the extent of damage from Sandy and gauge the current level of resiliency of the communities. This process continued throughout the project and was critical to the subsequent phases of the project e.g., during hydraulic modeling and in designing the range of solutions.

Hydraulic Modeling and Sandy Simulation

A GIS workstation was built to house various information needed for Sandy simulation, hydraulic model development and for digitization of existing as well as proposed flood mitigation structures. Information layers include topographic and data, shapefiles of the geodetic description of many existing and proposed barrier structures, and sea level trends and inundation maps.

The NCCHE team of University of Mississippi partnered with NJIT team to build the hydraulic models for this study and develop Sandy Baseline Model to simulate the storm surge occurred during Sandy. Simulation conditions are set up through CCHE2D-GUI and as per the NCCHE team, the process for three day storm surge simulation, October 29 ’12 to November 1 ’12, took about 18.3 hours on a single CPU of Intel(R) Xeon® CPU E5-2687W 0 CPU@3.10GHz. The resulting output emulated the surge boundary provide by FEMA for this study region. Figure A.1 and Figure A.2 shows the output of Sandy surge simulation and the original Sandy surge boundary respectively.

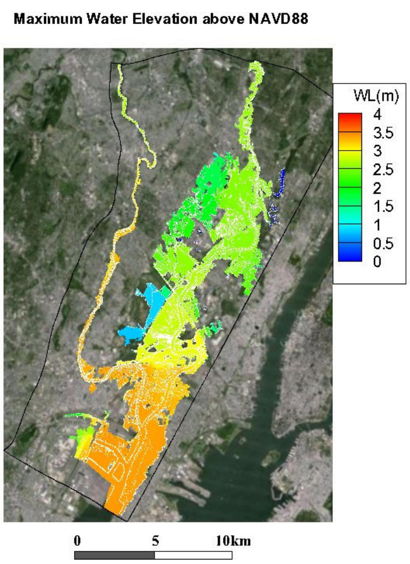

Figure A.1 Simulated Sandy surge boundary from CCHE2D Model.

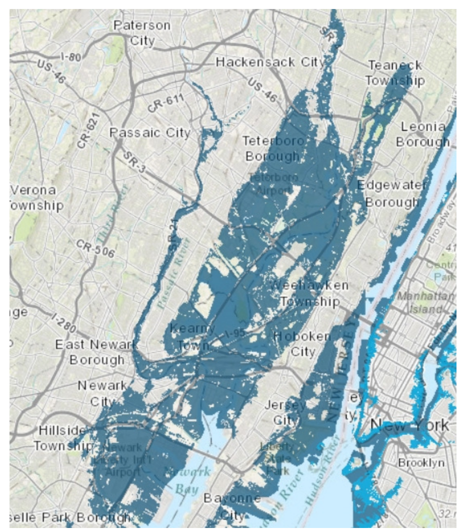

Figure A.2 Sandy surge boundary as per FEMA.

Source: Preliminary Results of Flood and Inundation in Hurricane Sandy in the Area of New Jersey Retrieved from “prelimianry_baseline_case0_noani.ppt” (accessed on Feb 17, 2014)

The NCCHE team also simulated the futuristic inundation for this area by adding the proposed alternative flood mitigation structures. These results were then used in benefit cost and risk analysis for the proposed alternatives.

APPENDIX B

HAZUS-MH INVENTORY FOR THE STUDY AREA

A few samples of the default inventory for the study area, as available in Hazus-MH Flood Model, are provided in the tables and figures below:

Table B.1 Total Building Count of Various Building Types, by Occupancy, for each Census Block

By Occupancy | By Building Type

Table Type:

General Occupancy Type | Bergen, NJ (34003)

Show Scenario Census Blocks

	CensusBlock	Total	Residential	Commercial	Industrial	Agriculture	Religion	Government	Education
1	340030291001000	122	118	4	0	0	0	0	0
2	340030291001001	41	38	2	1	0	0	0	0
3	340030291001002	18	15	2	1	0	0	0	0
4	340030291001003	13	13	0	0	0	0	0	0
5	340030291001004	33	28	4	0	1	0	0	0
6	340030291001005	14	9	4	1	0	0	0	0
7	340030291001006	27	25	1	1	0	0	0	0
8	340030291001007	19	18	1	0	0	0	0	0
9	340030291001008	22	18	2	2	0	0	0	0
10	340030291001009	22	15	3	3	1	0	0	0
11	340030291001010	6	6	0	0	0	0	0	0
12	340030291002000	17	5	10	2	0	0	0	0
13	340030291002001	23	23	0	0	0	0	0	0
14	340030291002002	44	43	1	0	0	0	0	0
15	340030291002003	33	30	2	1	0	0	0	0
16	340030291002004	35	29	5	1	0	0	0	0
17	340030291002005	28	25	2	1	0	0	0	0
18	340030291002006	13	12	0	0	0	1	0	0

Table B.2 Dollar Exposure of Various Building Types, by Occupancy, for each Census Block

By Occupancy | By Building Type

Table Type:

General Occupancy Type | Bergen, NJ (34003) | Building

Show Scenario Census Blocks

	CensusBlock	TotalExposure	Residential	Commercial	Industrial	Agriculture	Religion	Government	Education
1	340030291001000	35260	34325	935	0	0	0	0	0
2	340030291001001	11425	10494	772	159	0	0	0	0
3	340030291001002	6158	3400	2609	149	0	0	0	0
4	340030291001003	2689	2689	0	0	0	0	0	0
5	340030291001004	8382	7232	1098	0	52	0	0	0
6	340030291001005	2836	1134	1262	440	0	0	0	0
7	340030291001006	6562	6239	200	123	0	0	0	0
8	340030291001007	4161	3970	191	0	0	0	0	0
9	340030291001008	5647	3835	1012	800	0	0	0	0
10	340030291001009	8840	3261	3993	1402	184	0	0	0
11	340030291001010	74	74	0	0	0	0	0	0
12	340030291002000	14879	159	13953	767	0	0	0	0
13	340030291002001	4414	4414	0	0	0	0	0	0
14	340030291002002	9526	8667	859	0	0	0	0	0
15	340030291002003	6718	5784	802	132	0	0	0	0
16	340030291002004	8818	5626	3125	67	0	0	0	0
17	340030291002005	5623	4570	873	180	0	0	0	0
18	340030291002006	2410	1977	0	0	0	433	0	0

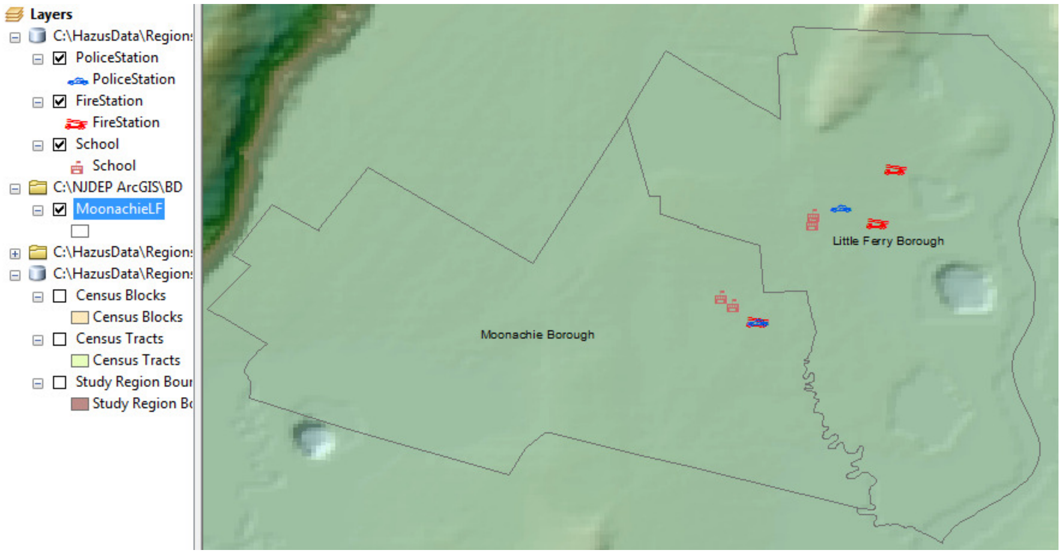

Figure B.1 Essential facilities (police station, fire station and schools) in study area. Same information can be viewed in tabular format as well.

APPENDIX C

SANDY LOSS ESTIMATION BY HAZUS

Following tables shows the building related loss estimation for various groups of communities. The study areas for these groups of communities were built based on the list of communities or municipalities which will be protected by each alternative structural solution.

Table C.1 Impact of Sandy in the Six Municipalities which will be Protected by Arc Wall

Building-Related Economic Loss Estimates (Millions of USD)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
(a)	Building	11.47	28.39	19.62	2.68	62.16
(b)	Content	8.52	81.11	38.68	14.17	142.48
(c)	Inventory	0	2.73	6.31	0.02	9.06
	Subtotal	19.99	112.23	64.61	16.87	213.7
Business Interruption						
(d)	Income	0.01	0.91	0.01	0.08	1.01
(e)	Relocation	0.11	0.28	0.02	0.07	0.48
(f)	Rental Income	0.05	0.19	0	0.02	0.26
(g)	Wage	0.02	0.85	0.02	1.98	2.87
	Subtotal	0.19	2.23	0.05	2.15	4.62
All	Total	20.18	114.46	64.66	19.02	218.32
Total economic loss of $218.32 Million represents 2.58% of the total replacement value ($8,473.97 Million) of the scenario buildings						
Shelter Requirement : 63,279 people out of a total of 64,351 will seek temporary shelter in pubic shelters						

Table C.2 Impact of Sandy in the Nine Municipalities which will be Protected by Barrier Wall North

Building-Related Economic Loss Estimates (Millions of USD)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	15.78	39.08	22.78	4.15	81.79
	Content	11.1	105.73	46.97	23.02	186.82
	Inventory	0	3.18	7.14	0.03	10.35
	Subtotal	26.88	147.99	76.89	27.2	278.96
Business Interruption						
	Income	0.01	1.18	0.01	0.08	1.28
	Relocation	0.11	0.36	0.03	0.07	0.57
	Rental Income	0.06	0.24	0	0.01	0.31
	Wage	0.03	1.09	0.03	2.1	3.25
	Subtotal	0.21	2.87	0.07	2.26	5.41
All	Total	27.09	150.86	76.96	29.46	284.37
Total economic loss of $284.37 Million represents 2.32% of the total replacement value ($12,494.25 Million) of the scenario buildings						
Shelter Requirement : 96,404 people out of a total of 102,007 will seek temporary shelter in pubic shelters						

Table C.3 Impact of Sandy in the 11 Municipalities which will be Protected by Barrier Wall Middle

Building-Related Economic Loss Estimates (Millions of USD)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	20.36	51.86	26.89	4.51	103.62
	Content	14.61	141.56	58.82	24.98	239.97
	Inventory	0	4.55	8.62	0.03	13.2
	Subtotal	34.97	197.97	94.33	29.52	356.79
Business Interruption						
	Income	0.04	1.66	0.01	0.09	1.8
	Relocation	0.14	0.56	0.03	0.07	0.8
	Rental Income	0.12	0.36	0	0.01	0.49
	Wage	0.09	1.66	0.03	2.12	3.9
	Subtotal	0.39	4.24	0.07	2.3	6.99
All	Total	35.36	202.21	94.4	31.82	363.78
Total economic loss of $363.78 Million represents 2.22% of the total replacement value ($19,945.02 Million) of the scenario buildings						
Shelter Requirement : 112,654 people out of a total of 176,030 will seek temporary shelter in pubic shelters						

Table C.4 Impact of Sandy in the 14 Municipalities which will be Protected by Barrier Wall South

Building-Related Economic Loss Estimates (Millions of USD)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	32.75	67.85	50.74	4.32	155.66
	Content	22.08	187.26	117.99	22.79	350.12
	Inventory	0	6.22	18.21	0.1	24.53
	Subtotal	54.83	261.33	186.94	27.21	530.31
Business Interruption						
	Income	0.04	2.07	0.04	0.1	2.25
	Relocation	0.16	0.71	0.07	0.08	1.02
	Rental Income	0.14	0.46	0.01	0.02	0.63
	Wage	0.09	2.17	0.07	2.35	4.68
	Subtotal	0.43	5.41	0.19	2.55	8.58
All	Total	55.26	266.74	187.13	29.76	538.89
Total economic loss of $538.89 Million represents 1.34% of the total replacement value ($46,117.95 Million) of the scenario buildings						
Shelter Requirement : 394,532 people out of a total of 513,558 will seek temporary shelter in pubic shelters						

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