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Assessment of flood protection strategies for combined critical infrastructure failure and hurricane/storm surge events in the Meadowlands area

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ABSTRACT

ASSESSMENT OF FLOOD PROTECTION STRATEGIES FOR COMBINED CRITICAL INFRASTRUCTURE FAILURE AND HURRICANE/STORM SURGE EVENTS IN THE MEADOWLANDS AREA

by
Nisharg Dipakkumar Dalwadi

As a result of a wide-reaching comprehensive post-Sandy NJIT project entitled "Flood Mitigation Engineering Resource Center (FMERC)", a detailed investigation of alternative measures for flood mitigation in the Meadowlands area was completed in June 2014. The project involved the assessment of flood impacts, and the evaluation of a range of structural and non-structural capital improvement measures, maintenance, operations and regulatory measures, and broad system design and redundancy measures.

The basic objective of this thesis is to develop an innovative procedure for the enumeration and simulation of probability-weighted combined events, e.g., Oradell dam failure under various scenarios (sunny day, water level, etc.) along with a super storm event at various time staging levels. The approach broadens the analytical arsenal available to policy-makers for the purpose of comprehensive risk and resiliency analysis and the selection of optimal protection alternatives. The methodology includes data analysis done with the help of software like Arc GIS and Hazuz MH. Using GIS simulations, the FMERC proposed solutions e.g., Arc wall are simulated under combined event scenarios in order to identify possible modifications or adjustments for maximum risk reduction. An outcome of this research is the development of an empirical approach for simulating combined events and adaptation strategies derived to provide a more comprehensive level of protection.

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by
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ASSESSMENT OF FLOOD PROTECTION STRATEGIES FOR COMBINED CRITICAL INFRASTRUCTURE FAILURE AND HURRICANE/STORM SURGE EVENTS IN THE MEADOWLANDS AREA

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The thesis is dedicated to my beloved family… Love you a lot…

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The last two semesters in my New Jersey Institute of Technology tenure have been great, the reason why it has been thoroughly enjoyable experience because it has changed my outlook towards the environmental planning industry as well as the course that has been offered to us in the past years.

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CHAPTER 1

INTRODUCTION

1.1 Introduction to Critical Infrastructure (Dams)

Critical infrastructure is defined by "The American Heritage Dictionary" as "The basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons." (The American Heritage Dictionary, 2014)

Infrastructure in the United States is becoming more prone to failure as the average age of structures increase. Infrastructure is owned and managed by both the public and private sector, and includes a number of structures that improve living conditions and commerce, including schools, hospitals, roads, bridges, dams, sewers, and energy systems. For some types of infrastructure, such as dams, the age of a structure is a leading indicator of the potential for the failure of the structure, and the average age of infrastructure in the United States is rising. (Dalton, 2009)

Between 2000 and 2009, the average age of government and privately-owned structures (excluding housing) increased by about one year. For government structures, the trend was even more pronounced over the long term—United States structures' average age rose from 18 years in 1970 to 25 in 2009, indicating that structures are being replaced at a slower rate. (Bureau of Economic Analysis, 2010)

There are several examples of infrastructure becoming more prone to failure as it ages. The number of dams rated as deficient—or those with structure or hydraulic deficiencies leaving them susceptible to failure—tripled between 1999 and 2008. Over a third of the Nation's dams are 50 years old, a number that will increase to nearly 70 percent in 10 years. (Associations of state dam safety officicals, 2009)

The average age of the 84,000 dams in the country is 52 years old. The nation's dams are aging and the number of high-hazard dams is on the rise. In the sace high hazard dam is defined as anticipated loss of life in the case of failure. Low Hazard dam is defined as anticipated loss of the dam or damage to the flood plain, but no expected loss od life. Many of these dams were built as low-hazard dams protecting undeveloped agricultural land. However, with an increasing population and greater development below dams, the overall number of high-hazard dams continues to increase, to nearly 14,000 in 2012. The number of deficient dams is estimated at more than 4,000, which includes 2,000 deficient high-hazard dams. The Association of State Dam Safety Officials estimates that it will require an investment of $21 billion to repair these aging, yet critical, high-hazard dams. (ASCE, 2014)

No one knows precisely how many dam failures have occurred in the U.S., but they have been documented in every state. From Jan. 1, 2005 through June 2013, state dam safety programs reported 173 dam failures and 587 "incidents" - episodes that, without intervention, would likely have resulted in dam failure. (ASCE, 2014)

The map below is based on a (non-comprehensive) list of dam and levee failures compiled by Association of State Dam Safety Officials (ASDSO, 2013). The map demonstrates that dam failures are not particularly common but they do continue to occur. Locations are approximate.

The large red dot on the Gulf Coast represents the New Orleans levee failures resulting from Hurricane Katrina. A few other levee failures are included such as all of those indicated in Northern California. If levee failures from the 1993 floods were included, more failures would be indicated in the center of the map. (Dam Safety Organization, 2010)

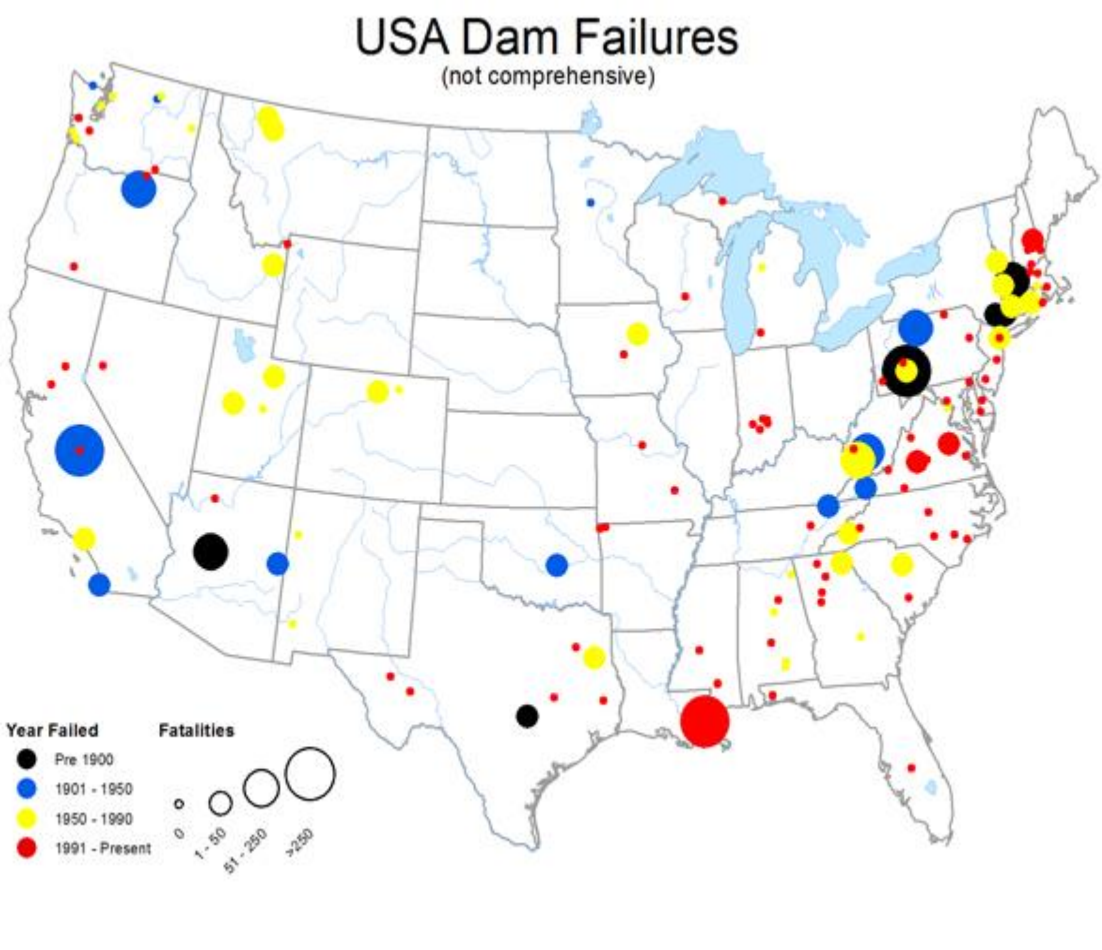


Figure 1.1 USA dam failures.
Source: (Dam Safety Organisation, 2010).

1.2 Background: The New Jersey Meadowlands and Flood Issues During Hurricane Sandy

Super storm Sandy's widespread impact was felt across the entire Atlantic coastline of the United States. 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 USA 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).

The study area for the thesis is focused in the New Jersey Meadowlands, which is located in the North-Eastern corner of New Jersey and is part of the New York City Metropolitan Area. Bergen County which is partially located in the Meadowlands, is divided into a total of 70 townships and boroughs. The Meadowlands area has seen in history, a sudden population shift to the Northeast New Jersey boarders, upon the starting of 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. As a result of sudden population growth, there was a push towards development of the low lying areas. 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 habitat. Such lack of infrastructure planning and maintenance of existing drainage were the major influences in elevating the damage caused by Tropical Storm Sandy.

The report by New Jersey Department of Community Affairs/Community Development Block Grant Disaster Recovery Action Plan shows that 1% of households located in Bergen County had sustained "severe" or "major" damage due to Sandy. 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.

1.3 Oradell Dam

The Oradell Dam is a 22-foot high concrete dam located on the Hackensack River in Bergen County, New Jersey. The Oradell dam was built in 1901 by the dredging of a mill pond. In 1911 the mill pond was replaced by a timber-crib dam to increase storage. The construction of a 22-foot high concrete gravity dam to further increase storage began in 1921 and was completed in 1923.

The Oradell Reservoir has a normal storage volume of 10,740 acre-feet at elevation 22.2 ft NAVD 88. The surface area at normal storage is 796 acres. Maximum storage volume is 13,316 acre-feet at elevation 24.68 ft, which is also the crest elevation of the dam. The hydraulic height of the dam is 25 ft. The reservoir provides drinking water to a population of about 750,000 living in Bergen and Hudson counties.

1.4 Subject Selection

The Flood Mitigation Engineering Resource Centre (FMERC) has submitted a report to the New Jersey Department of Environmental Protection. The report has done a detailed investigation of alternative measures for flood mitigation in the Hackensack/Moonachie and Little Ferry area as an aftermath to Tropical Storm Sandy. The project involved assessment of the flood impacts, and evaluation of a range of capital improvements, maintenance and operations and regulatory measures, including structural and non-structural engineering alternatives, regulatory and system design and redundancy measures. The evaluation included hydraulic modelling, environmental, risk and socio-economic impacts, including estimated capital and maintenance and operating costs of mitigation and protection alternatives.

The report has also considered the scenario of a combined event of Sandy and the Oradell Dam break occurring during same time frame. There is some probability of the Oradell Dam failing during a super storm. The thesis examines the impact of the Oradell Dam failure during a storm surge event such as Hurricane Sandy (2012). The objective is to generate a range of protection alternatives and simulate the protection level under a variety of combined events.

The FMERC project work for Sandy has already performed various simulations for individual dam breach as well as Sandy shown in Appendix E of the report. The Decision Support System for Water Infrastructural Security (DSS – Wise) software is used for the simulation. There are three types of simulations done in this report. The simulations are a sunny day Oradell Dam failure; a sunny day storm event; and a dam break during a super storm event (the combined event). Detailed enumerations and simulations were done for these extreme events. The combined event was not simulated with the actual proposals e.g., Arc Wall. The proposals like Arc Wall, were not simulated in a combined event case. There is an attempt made to give a fresh look to the proposed solutions given by the FMERC team. The outcome also may result in slight modifications to the proposed solution by the FMERC team, which will be value addition to the work done by the FMERC team.

1.5 Objectives

The basic objective of this thesis is to enumerate and simulate combined events, e.g., Oradell Dam failure under various scenarios (sunny day, sea level rise, etc.) along with a super storm event, for the purpose of risk analysis and evaluation of protection alternatives. The central theme is to generate a range of protection alternatives and simulate the protection level under the variety of combined events (Oradell Dam failure during super storm event).

The added goals are as follows. The attempt will be made to estimate the risk and joint probabilities of the combined event. The alternatives proposed in the FMERC report will be simulated for the combined event with the help of the FMERC team. According to the report there is about 1773.9 Acres of land area in the Meadowlands, which is not flooded by Sandy alone, but would be flooded due to the combined event. Such areas will be the identified in the process. An attempt will be made to modify the current proposed solutions to make the proposals more effective in the combined event. In the combined event of Super storm and dam breach and the cost benefit ratio associated therewith risk reduction strategies will be covered in the thesis.

1.6 Research Question to be Explored

The main research questions to be answered is as follows.

- What will happen if the critical infrastructure fails to perform its duty during a hurricane of Sandy magnitude acting alone?

1.6.1. Sub Research Question

The sub research questions for the thesis are as follows.

- Which areas will be affected most due to the combined event?
- What will be the quantifiable property damages and other damages?
- How to modify the currnet solutions in the FMERC report (Arc Wall) to take care of the combined event and how to minimize the impact of such event?

1.7 Scope

The Geographical Scope is the Meadowlands Area, New Jersey, USA. The research is based upon a hypothetical Oradell Dam break (A critical infrastructure failure) during storm surge event like sandy. An attempt is be made to collect and simulate the data accurately via use of Arc-GIS software.

CHAPTER 2

LITERATURE REVIEW

2.1 Global and National Scenario of Natural Disasters

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,2010)

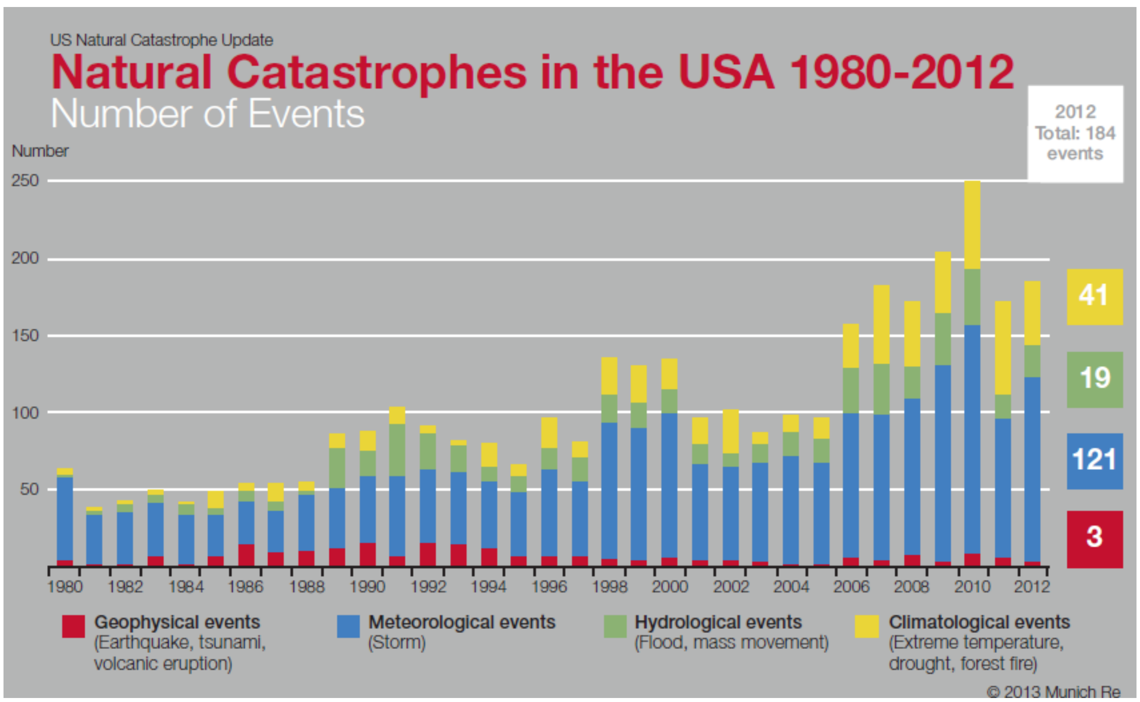


Figure 2.1 Natural catastrophes in the USA 1980 – 2012.
Source: (International Disaster database, 2012).

The Figure 2.1 shows the number of catastrophes in the USA since 1980. The major part of the events are due meteorological events like storms. In 2012, about 66% of all catastrophic events are storms. 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.

Every year various types of small and large scale natural disasters affect the USA and threaten the country's lives, livelihoods and economy. Between 1900 and 2013, more than 865 natural disasters have affected in the USA causing about $734 billion of damage out of which about $538 billion damage occurred between the year 2000 and 2013. Contribution from Hurricanes, Storms and Flood disasters is about $626 billion. (International Disaster database, 2012)

The major breakdown shows more than 65 % of catastrpohic events in the USA is based upon storms. Figure 2.2 shows the economical loss due to the top ten natural disasters in the history of United States. (NOAA, 2013)

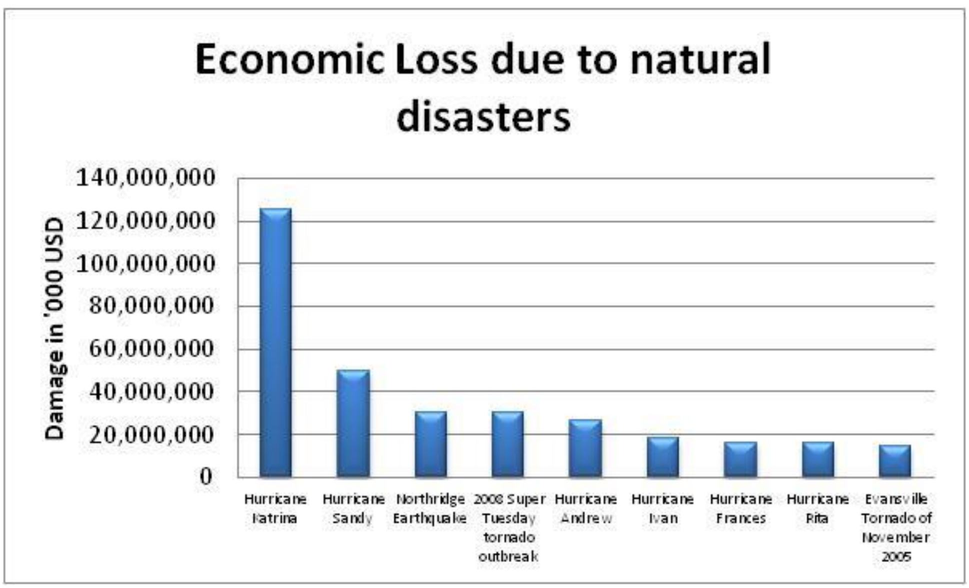


Figure 2.2 Economic loss due to natural disasters**.**
Source: (NOAA, 2013).

2.2 Impact of Hurricane Sandy

Hurricane Sandy did a lot of damage throughout its path. It was the second most costly storm in the history of United States. Preliminary U.S. damage estimates are near $50 billion, making Sandy the second-costliest cyclone to hit the United States since 1900 (Blake et al.).

Figure 2.3 shows devastation in the wake of Hurricane Sandy has brought to attention the vulnerability of the entire east coast and some inland areas putting a large population in coastal regions at great risk. The increase in frequency of high magnitude storm events such as Irene and Sandy has brought to attention the need for long term and effective plans to mitigate flooding in the north Atlantic coast.

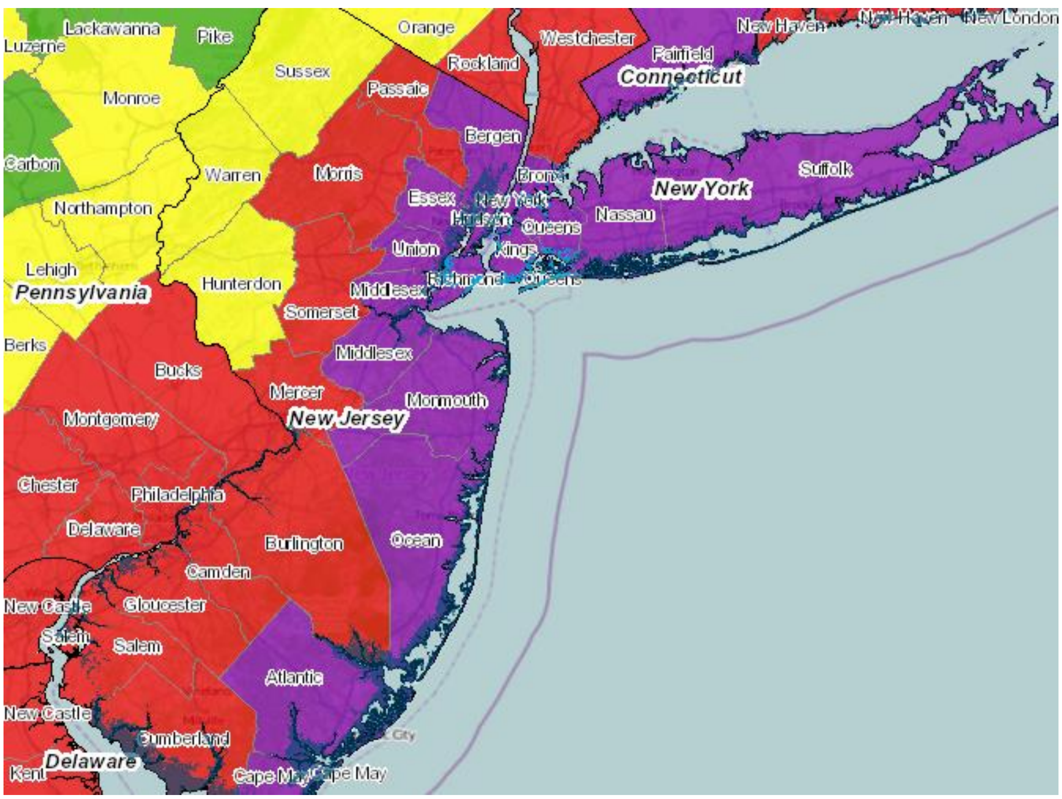


Figure 2.3 Devastation of Hurricane Sandy.
Source : (FEMA,2013)

Half the city of Hoboken was flooded and in excess of 50,000 people were evacuated. A 50-foot piece of the Atlantic City Boardwalk washed away, and the National Guard was mobilized to assist throughout the state. Up to 5 feet of water were observed in the streets of Moonachie and Little Ferry as the towns were devastated by the flood of water. More than 2.6 million customers were without power for several days, and at least 37 people were killed. All this resulted in estimated damages close to $30 billion.

The FEMA Coastal Analysis and Mapping Division have made available Hurricane Sandy Advisory Base Flood Elevations (ABFEs) Interactive Maps in New Jersey and New York. This is a very useful tool in tracking the extent at which the storm affected different areas in the two states. The website also offers a lot of information on how to prepare for storms and steps to follow in case of emergency or voluntary evacuation. The impact of Sandy on the municipalities of Moonachie, Little Ferry and Hackensack was devastating as was the situation for much of New Jersey.

The director of the Meadowlands Environmental Research Institute (MERI) called Sandy a 750 year storm event. For Moonachie and Little Ferry in particular, the streets were filled with (up to) five feet of water within a 30 minute period. The residents needed the help of emergency personnel to rescue them from their homes. Newspaper accounts indicated that as the result of Sandy, a 13 foot surge from the ocean, at Newark Bay, generated flooding conditions in the Hackensack River. This caused overtopping of the levees, which were designed to protect the community.

The damage caused by Hurricane Sandy on houses and businesses along the impacted regions was a result of damaging wind and tidal waves. Many boardwalks were damaged from these two forces, and all floor panels were pulled off the supporting beams and piles as these structures do not have any protecting structures against these forces. Hurricane Sandy forced the release of over 10 billion gallons of raw and partially treated sewage (90%+ of which went into waters in and around New Jersey and New York) causing significant contamination problems never before seen in the past. A lot of environmental contamination also took place along with flooding.

2.3 Flood Mitigation Engineering Resource Centre Proposal (At NJIT)

As a result of a wide-reaching comprehensive post-Sandy project sponsored by the New Jersey Department of Environmental Protection and the Governor's Office for Reconstruction and Recovery, the Flood Mitigation Engineering Resource Center (FMERC) at NJIT completed a detailed investigation of alternative measures for flood mitigation in the Meadowlands area in the aftermath of Tropical Storm Sandy. The project involved the assessment of flood impacts, and the evaluation of a range of structural and non-structural capital improvement measures, maintenance, operations and regulatory measures, and broad system design and redundancy measures.

The outcome of the project was quite significant. There were three major areas in which solutions were given by the FMERC team. The major sections were as follows:

- Structural flood protective alternatives.
- Non structural mitigation alternatives.
- Maintenance, asset management and regulatory improvements.

The NJIT - FMERC Team listed the Arc Wall as a recommended medium term solution. At an initial capital cost estimated at $180 million, it achieves the highest benefit-cost ratio and effectively protects the low-lying areas of the study area and surrounding communities with mixed residential and industrial bases. The Arc Wall is the least risky with regard to the uncertainty in the exposure to sea level rise due to global warming. It is able to provide storm surge protection under a high sea level rise scenario of 37.6 inches. Figure 2.4 shows the conceptual alignment of the Arc Wall.

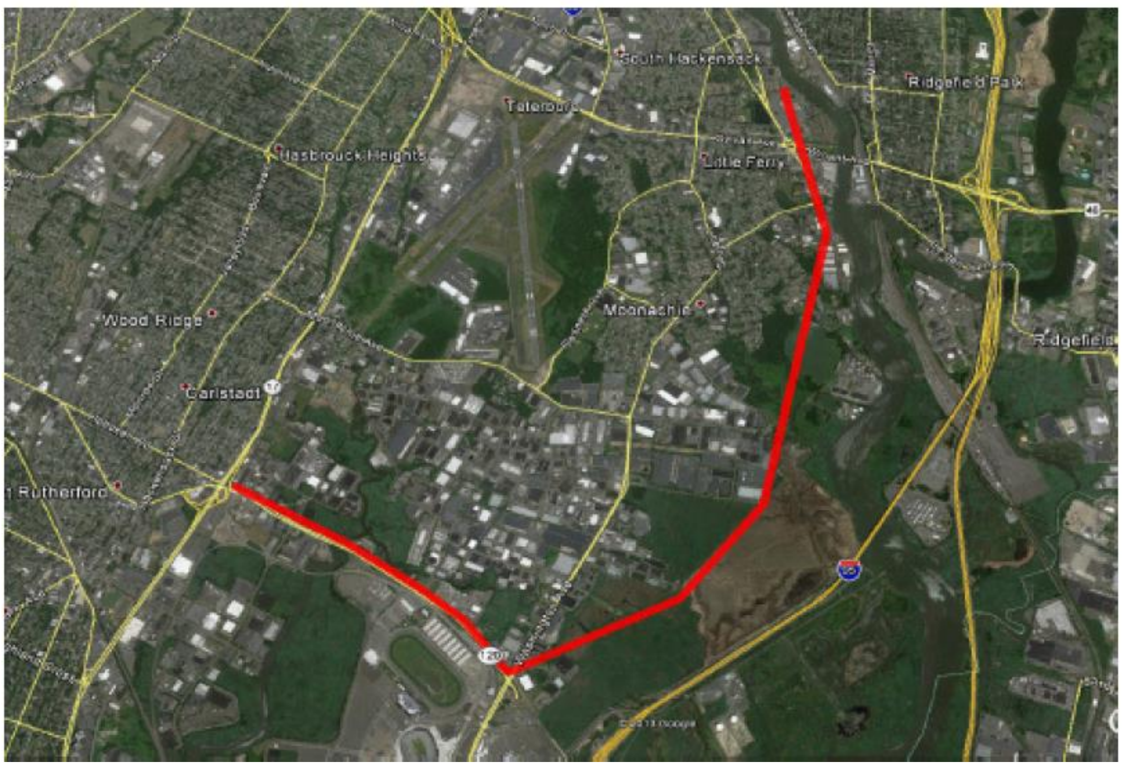


Figure 2.4 Conceptual alignment of the Arc Wall.
Source: (FMERC, 20130.

The report has also considered the probability of the Oradell Dam break and the hurricane sandy as a combined event. Oradell Dam is a critical infrastructure asset, whose failure during a storm surge event such as Super Storm Sandy (2012) may exacerbate flooding and lead to additional loss-of-life and property damage. The hypothetical failure of the Oradell dam during a future Hurricane Sandy was analyzed to determine the consequences in terms of increase of flood extent and flooding depths. (Flood Mitigation Engineering Resource Center, 2014)

The basic objective of this thesis is to develop an innovative procedure for the enumeration and simulation of probability-weighted combined events, e.g., Oradell dam failure under various scenarios (sunny day, sea level rise, etc.) along with a super storm event at various time staging levels. The approach broadens the analytical arsenal available to policy-makers for the purpose of comprehensive risk and resiliency analysis and the selection of optimal protection alternatives.

CHAPTER 3

DATA COLLECTION, PROCESS OF ANALYSIS AND TOOLS

Chapter 3 describes the process of data collection, data analysis and tools used to analyze the condition.

3.1 Data Collection

The data collection for the thesis is basically secondary data collection. From the FMERC team report a lot of data is considered for this study. The FMERC team report Appendix C and Appendix E are the basic data sources. Data collection includes the following information.

- **Collection of base Maps**

The simulations available with the FMERC team are divided in to three portions.

1. Only Sandy – Simulations
2. Simulations for only Oradell dam breach on a sunny day
3. Combined event scenario – 3.00 hours after Sandy, the Oradell Dam breach

There are several agencies included in the process of preparing the mitigation plan herein. The data collection for base layer is done via email sharing with the agencies as well as data mining from the available resources at NJIT.

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/. The base data layers are also downloaded from a lot of other governmental and municipality level websites referenced in the Appendix.

Topographic data - LiDAR was required for the flood inundation study. These datasets were georeferenced appropriately for the project. The data was collected from the FMERC team data base.

- **Super Storm Sandy related other data**

The data collection for damage estimates and literature review is done by secondary data analysis. Available published papers from recognized publishers as well as governmental agencies were utilized. FEMA published documents on websites as well as paper publications were also referred. Data extraction was done by data mining and appropriate data was considered for the analysis work.

3.2 Process of Analysis

The analysis process is highly depended upon the Arc-GIS calculations and other tolls available which work with Arc-GIS extensions. The analysis is also done with several steps. The steps are described as follows.

3.2.1 Establishing Importance of a Dam Break Event

A dam break event is important for making a complete flood protection scenario. A dam breach even on sunny day can cause a lot of damage to the region. With the help of the available dam breach analysis, cost and benefit analysis of Arc wall was calculated with the Hazus extension of Arc-GIS. Analysis phase includes compilation and transformation of data, creation of the geodatbase through transformation and geoprocessing of data from various sources in order to ensure a homogeneous database which was the base for any further analysis, simulation of inundation.

3.2.2 Calculation of Peak Scenario Timings

There are numerus possibilities with the combined event. A dam breach and Sandy can happen with varying timing scenarios. The worst scenario would happen when Sandy as well as the dam breach inundation are peak in the region. The back calculation of time is really important to understand the probabilities of the worst case scenario. With the available data, peak timings are calculated for the event. It is elaborated in the Chapter 4.

3.2.3 Analyzing the Arc Wall Proposed with the Worst Case Condition

The best possible outcome for the selected region is Arc wall according to NJIT proposal. The efficiency of arc wall is cross checked with the different sea level rise and the flood inundation in-front of the Arc wall.

3.2.4 Proposing Modifications of the Arc Wall

The FMERC team allows to slight modifications to fine tune the location in the report. A genuine effort is made to fine-tune the arc wall to protect more possible dense areas located near arc wall.

3.2.5 Benefit Cost Analysis

Benefit cost analysis was done for the proposed structural alternatives. The cost component of this ratio represents the Net Present Value (NPV) of the construction and maintenance and repair cost of the mitigation measures and the benefit component represents the Sandy damage which will be eliminated once the mitigation measures are implemented.

3.3 Tools used for Analysis

In this section of the thesis, tools used for the analysis purpose is described. There are lot of Arc-GIS based tools used for the analysis purpose. The major tools used are as follows.

3.3.1 Arc-GIS

Esri's ArcGIS, 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 Arc-GIS, version 10.0 with Service Pack 1 (SP1) was used for this research. A portion of time calculations and basic work was done by Arc-GIS 9.2. Following components of Arc-GIS were extensively used:

- **Arc-Map**: It is used primarily to view, add and analyze various existing ArcGIS compatible data and shape files required for the project and to create/manipulate data required for the thesis.
- **Arc-Catalog**: It is used for data administration or management application which allows the users to view geodatabase, files, metadata and other data sources.
- **Arc-Toolbox**: It is a collection of toolsets and tools used for geoprocessing e.g., clipping data, conversion of data, import/export of data, etc. (ESRI - Arc-GIS)

3.3.2 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, the Hazus-MH flood model, version 2.1, was used for this research. The service packs 2.1 and service pack 2.1 was also installed to get more detail views. 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. (FEMA - Hazus)

3.3.3 Hazus – MH Flood Model

Figure 3.1 shows the process of using tool Hazus – MH Flood Model. It is quite simple methodology using Arc-GIS. The process is explained below. (Scawthorn.)

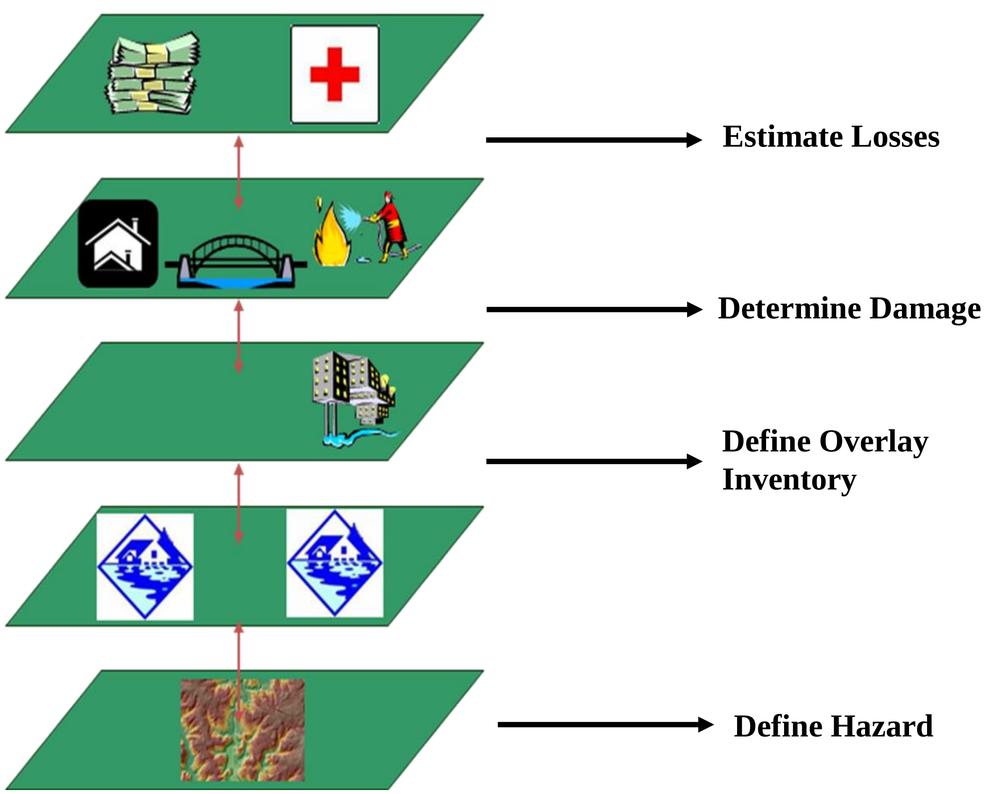


Figure 3.1 Process of Hazus – MH flood modeling.
Source: (Scawthorn,2010)

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 nonproprietary 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.

Input Data:

Basically there are two things which are needed to get the out-put and accurate calculations from the software. Those are as mentioned below.

- Inventory
- Flood Depth Grid

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. 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.

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 a certain degree of caution. Uncertainties can result from the following:

- Approximation and simplification necessary to conduct a specific study
- Incomplete or inaccurate inventories, demographic or economic data.
- 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.

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:

- 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.

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

- The Flood Model does not perform any direct analysis in support of casualty estimation. (Banshari, 2014)

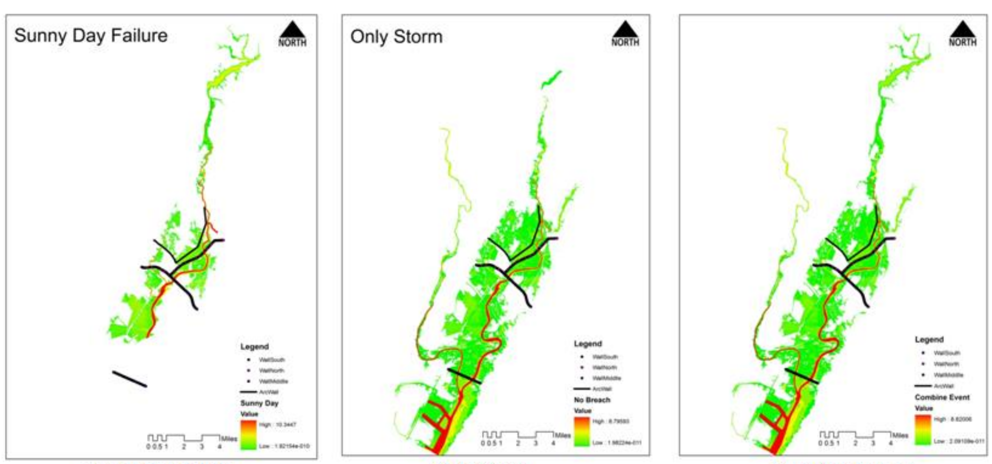
CHAPTER 4

DATA ANALYSIS AND RESULTS

This chapter deals with the process of data analysis and outcome of the data analysis. The data analysis was a step wise process as described in the Chapter 3. The detail analysis of the thesis is described in the chapter.

4.1 Impact of Dam Breach and Sandy – Combined Event

There are three event scenarios considered as described earlier, Dam breach on sunny day, a storm event only and a combined event. As described by the FMERC team Figure 4.1 shows the inundation in each case. The combined event is calculated as a dam breach occuring 3 hours after storm event. The calculations are based upon number of cells of 5m X 5m each. The whole area is sub-divided and estimated by the cells. There are lots of additional flooded cells in the combined event as compare to only the Sandy case. Figure 4.1 shows the comparison of all events. The Appendix A to C shows the detail maps of each case.



Sunny Day Failure Only Storm Combined Event

Figure 4.1 Comparison of inundation maps.

There are lots of densly populated areas which were not flooded in the dam breach only analysis but were flooded in combined event. Table 4.1 shows the additional flooded cells and detailed comparison with other scenarios. The result is based on analysis of 5m X 5m cells. Figure 4.2 shows the common area under flooding due to both the events.

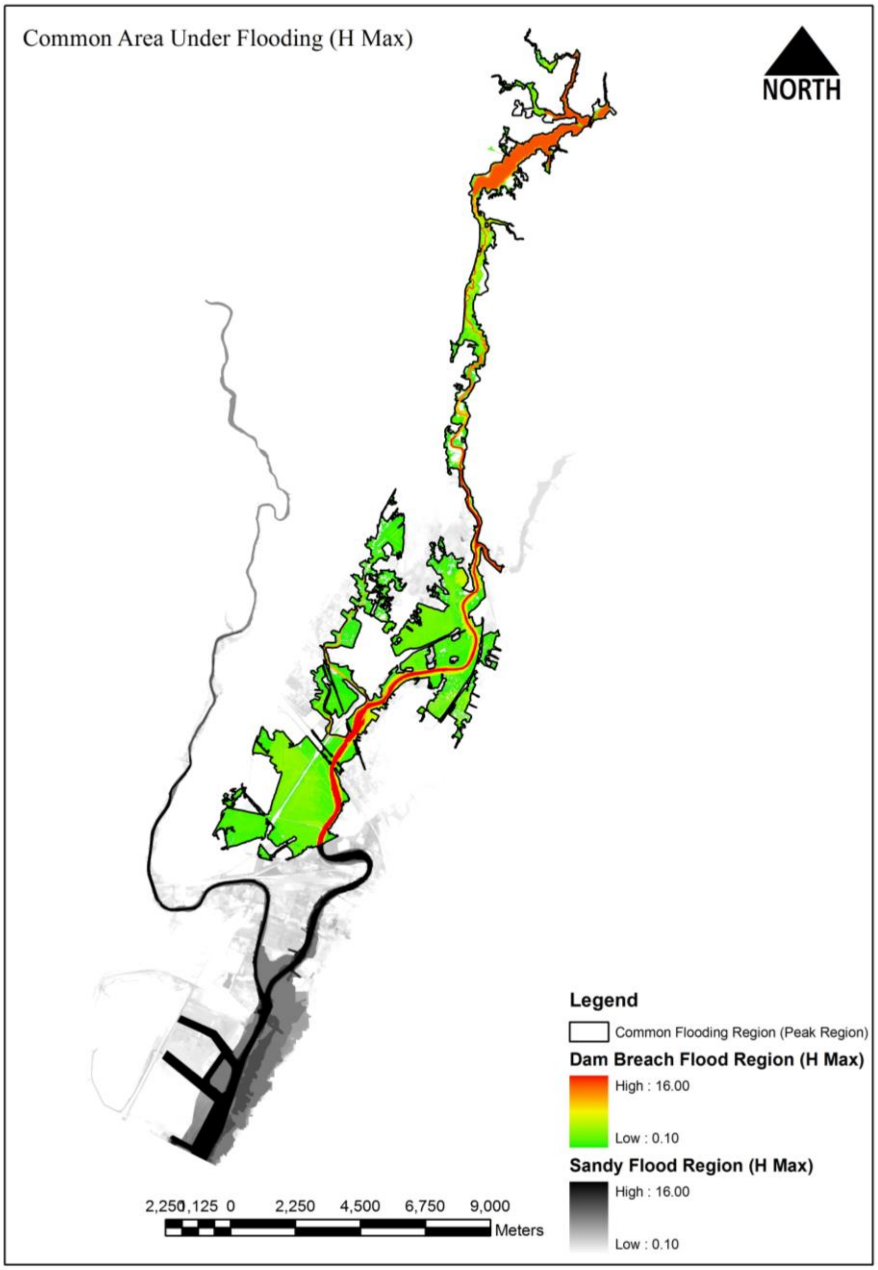


Figure 4.2 Common area under flooding from both the events.
Source : (FMERC, 2014).

Table 4.1 Comparison of Flood Inundation in Various Scenarios

(No of cells flooded)	Sunny Day	Only Storm	Combined Event	% Increase combined event
Open Water	**1934**	**116003**	**90910**	**-21.6**
Developed / Open Spaces	**26367**	**106838**	**126705**	**18.6**
Developed / Low Intensity	**23663**	**266432**	**292325**	**9.7**
Developed / Medium Intensity	**25179**	**563132**	**607019**	**7.8**
Developed / High Intensity	**18629**	**648528**	**687942**	**6.1**
Barren Land	**104**	**6033**	**6103**	**1.2**
Deciduous Forest	**982**	**6213**	**7007**	**12.8**
Evergreen Forest	**3**	**262**	**262**	**0.0**
Shrub	**428**	**5390**	**5427**	**0.7**
Grass Land / Herbaceuous	**283**	**3606**	**3663**	**1.6**
Hay / Pasture	**0**	**6277**	**6312**	**0.6**
Cultivated Crops	**484**	**872**	**1390**	**59.4**
Woody Wetlands	**29678**	**234092**	**255309**	**9.1**
Wetlands	**2384**	**32482**	**32935**	**1.4**
Total	130118	1996160	2123309	

Table 4.1 clearly shows that due to the combined event percentage increase in developed areas are quite significant. The table just shows the additional cells flooded and not those cells which already have flood water and they got some additional flooding. The scenario is quite alarming. There is also a need to look at the combined event. There is a need to look at the only dam breach scenario and how arc wall is protecting against the dam breach. As the Arc wall is a best proposal according to FMERC team, the solution is rechecked for its considerability. For consideration of the process, even if 50 percent economical damage is taking place compare to Sandy Table 4.2 gives an idea about the importance of the dam breach event. The base data is considered from the previous research and represented it as 50 percent of the total loss due to Sandy. (Banshari)

Table 4.2 Building Related Economic Loss Estimates – Arc Wall

Impact of Sandy in the 6 municipalities which will be protected by Arc Wall						
Building-Related Economic Loss Estimates						
Category	Area	Residential	Commercia	Industrial	Others	Total
Building Loss						
(a)	Building	5.735	14.195	9.81	1.34	31.08
(b)	Content	4.26	40.555	19.34	7.085	71.24
(c)	Inventory	0	1.365	3.155	0.01	4.53
	Subtotal	9.995	56.115	32.305	8.435	106.85
Business Interruption						
(d)	Income	0.005	0.455	0.005	0.04	0.505
(e)	Relocation	0.055	0.14	0.01	0.035	0.24
(f)	Rental Inco	0.025	0.095	0	0.01	0.13
(g)	Wage	0.01	0.425	0.01	0.99	1.435
	Subtotal	0.095	1.115	0.025	1.075	2.31
All	Total	10.09	57.23	32.33	9.51	109.16

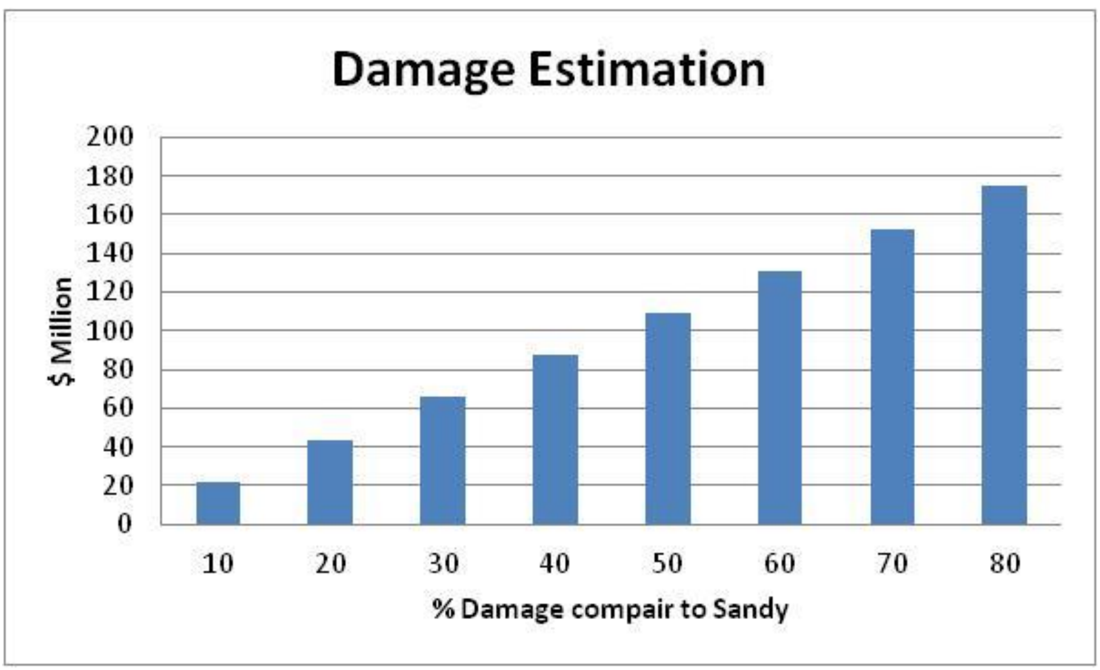


Figure 4.3 Percentage damage compare to Sandy.

Table 4.3 shows about $109.16 million is at stake with only the event of dam breach. The cost and benefit ratio for Arc wall in the case is coming 1.013. It shows the significance of the dam breach event. For further explanation Figure 4.3 shows how proposed solution of Arc wall is saving the region.

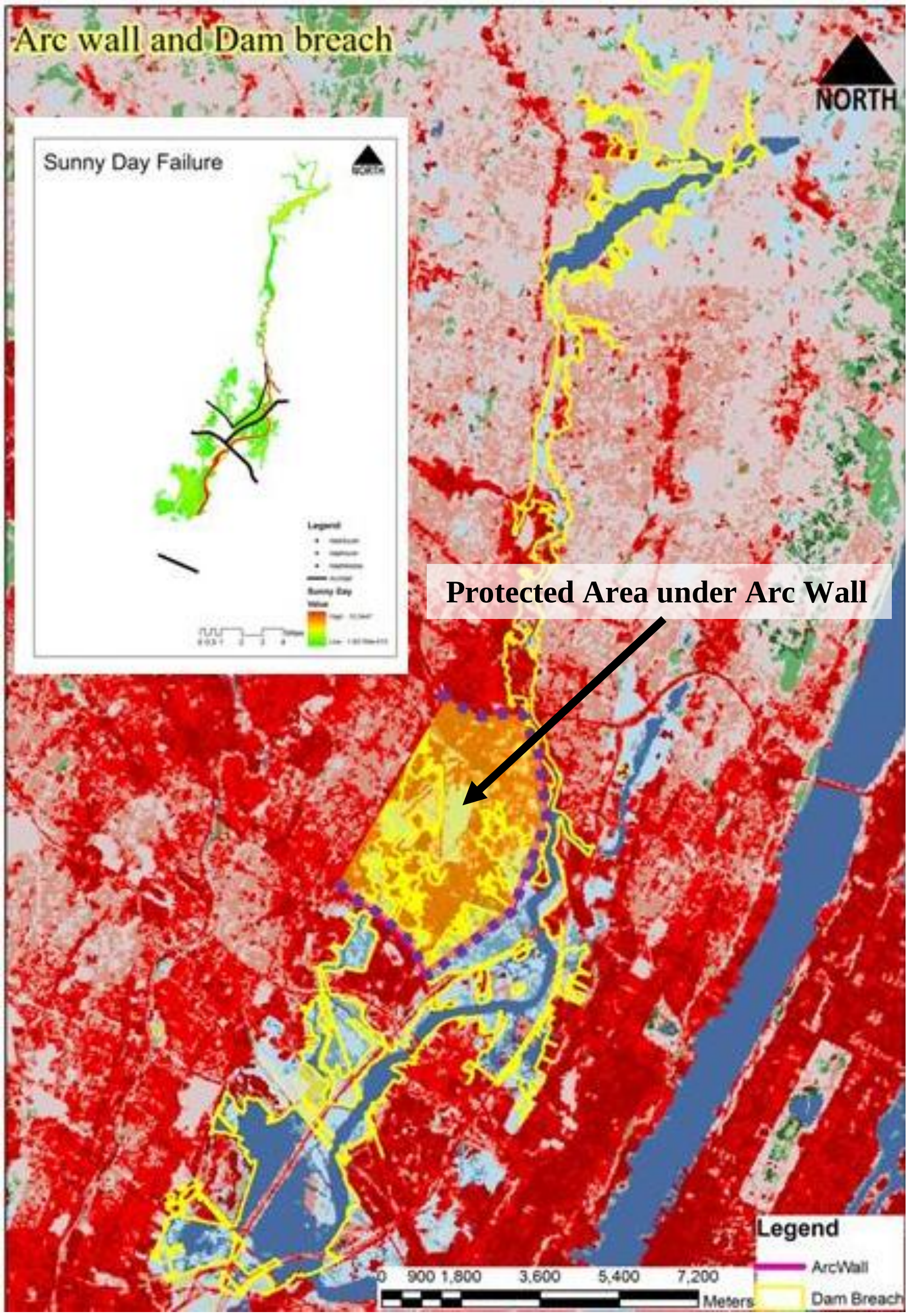


Figure 4.3 Protected area during dam breach by the Arc wall.

Thus, it is established that the dam breach event combined with Sandy will be a big problem and the option proposed by the NJIT – FMERC team should be sufficient enough to cater the needs of combined event.

4.2 Calculation of Peak Scenario Timing

This section deals with the consideration of the peak event. There are millions of possibilities through which this combined event can take place. If the storm starts at time = t_0 , there are millions of possibilities at which the second event can start. It can start together with the super storm or it can start hours before or after super storm. The condition is seen here in the thesis with two different angles. One angle is irespective of time the grid of 5m X 5m each cell at its peak (Micro Level), the other angle is Macro level scenerio in which a lot of cells are at peak at one point of time. Both the scenerios are discussed in detail below.

4.2.1 Micro Level Scenario

In this section Macro level scenario is been discussed. As discussed earlier, both the events can happen in millions of ways. Micro level scenario describes each cell wise peak without consideration of the time value. Each Cell will be at its peak during the time different frames. The maximum height H_{max} is considered and calculations are based upon $H_{max.}$

The data is available in the raster formats. From the Raster formats with the help of Arc GIS, data is converted in to point format via use of conversion tools. Figure 4.4 shows the conversion tools snap shot. The conversion tool will give the point wise information for each 5m X 5m grid. The layers of Sunny day dam failure and Super Storm Sandy were converted with the use of same methodology to point formats.

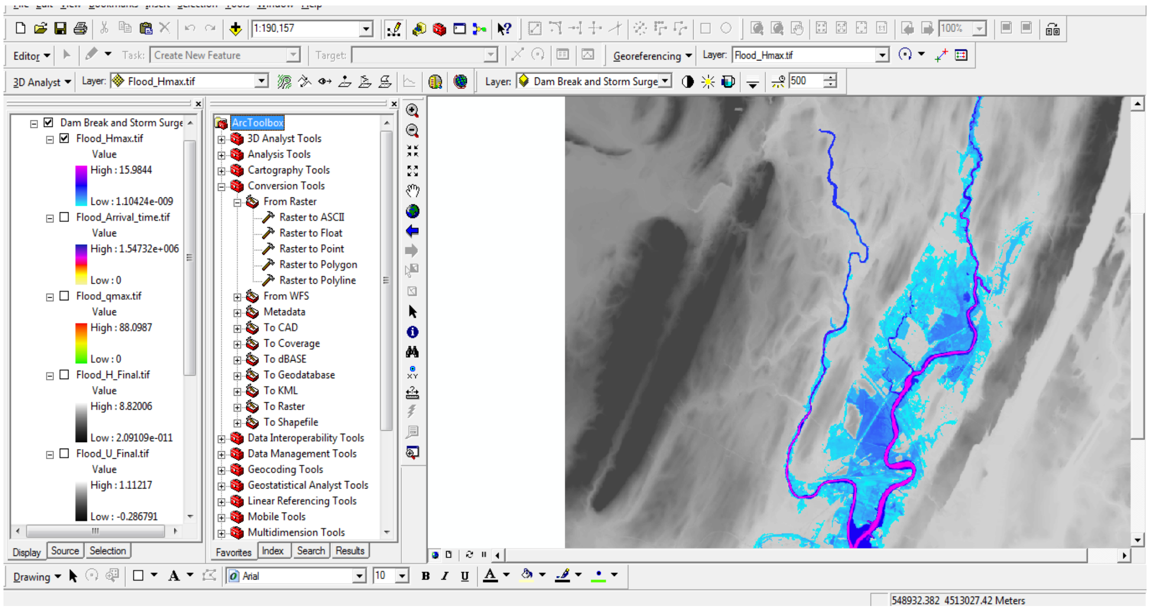


Figure 4.4 Conversion tool.

At this point, both the separate layers are having values for each individual points. There are about 26685 data points found in the region. Each point is having and unique ID number. With the help of Grid tool, addition of heights is done. The peak region is delineated by consideration of following things.

- Land Use
- Population density
- Maximum water elevation during Sandy (h1)
- Maximum water elevation during dam breach (h2)
- No consideration of time factor

Peak Volume of water in Region:

$$\sum_{i} h_{1i} \, X \, a_{1i} + \sum_{j} h_{2j} \, X \, a_{2j} \tag{4.1}$$

Where:

a_1 = Area flooded during Sandy

a_2 = Area flooded during dam breach

h_1 = Maximum water elevation during Sandy

h_2 = Maximum water elevation during dam breach

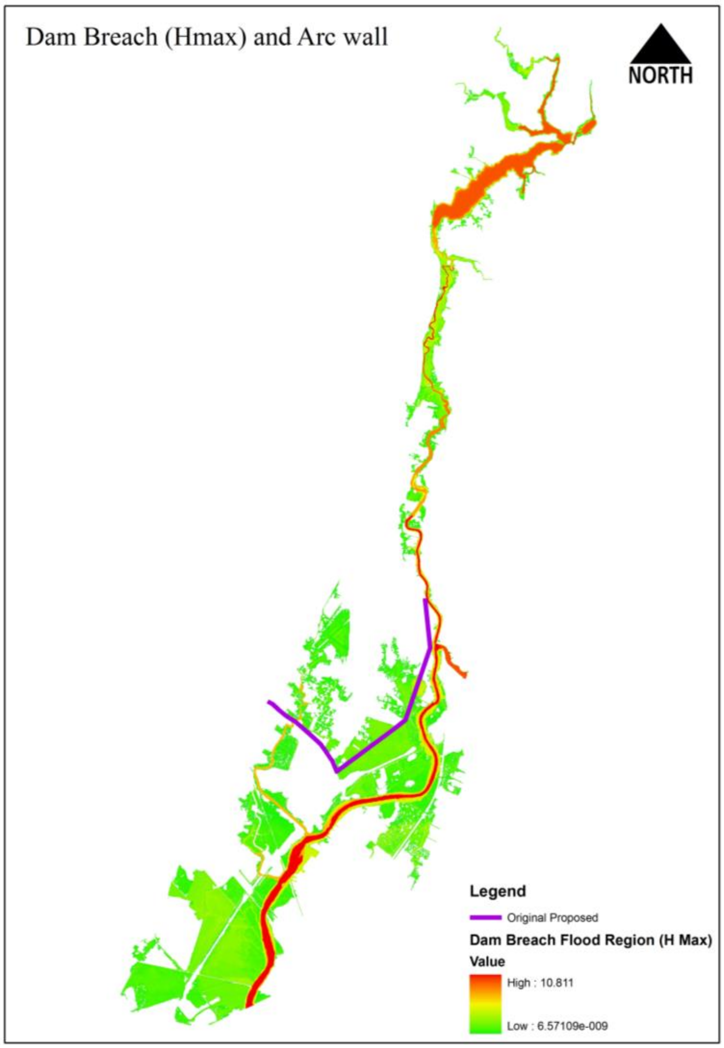


Figure 4.5 Dam Breach on Sunny Day (Hmax) and Arc Wall.

Figure 4.5 and figure 4.6 shows the maximum peak elevations due to Sunny day dam breach and only a super storm inundation H_{max}. Figure 4.7 shows the actual outcome of the process and the area of concentration. Figure 4.7 is the outcome of adding two volumes of water at different point of times at cell by cell bases.

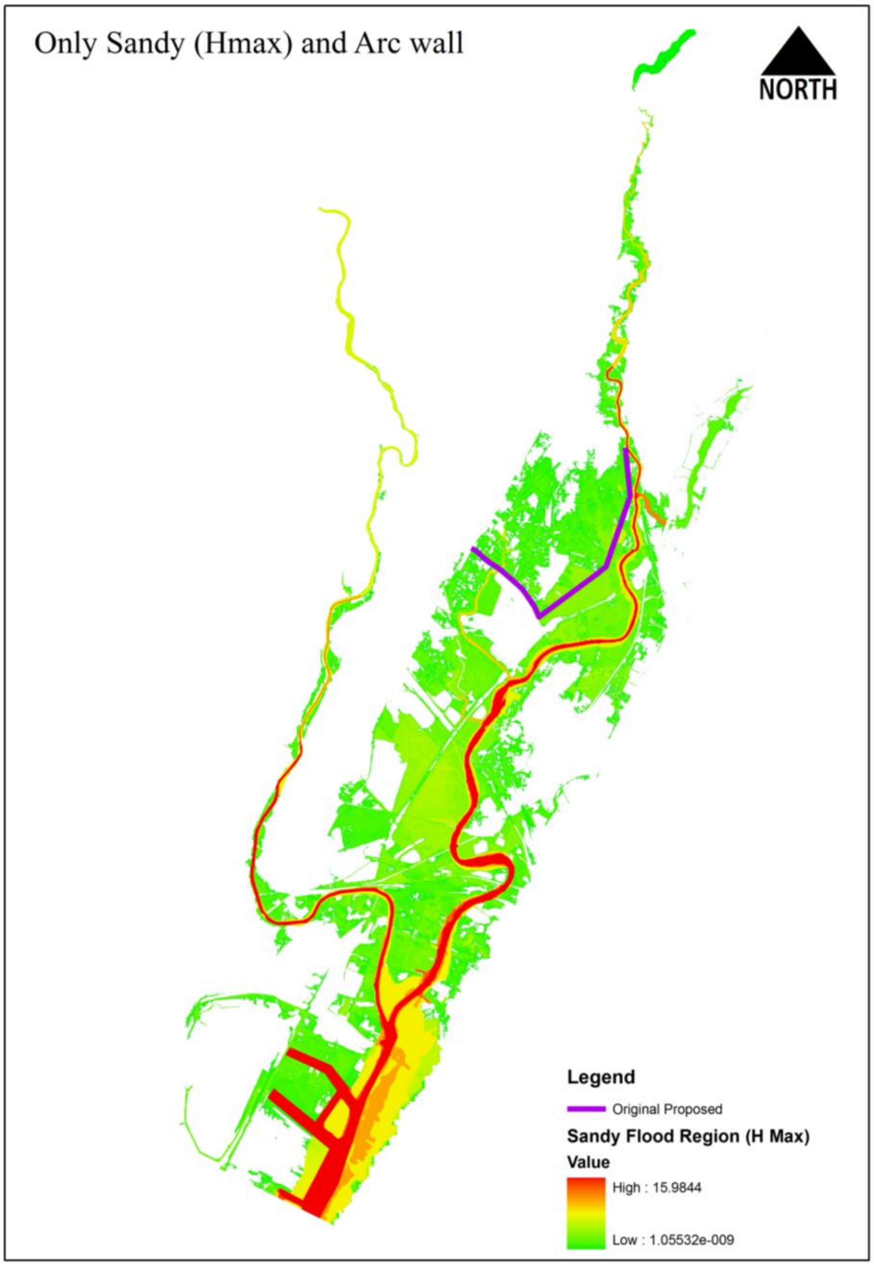


Figure 4.6 Only Super Storm and the Arc wall.
Source: Base data considered from NJIT – FMERC Team. Data was edited for representation.

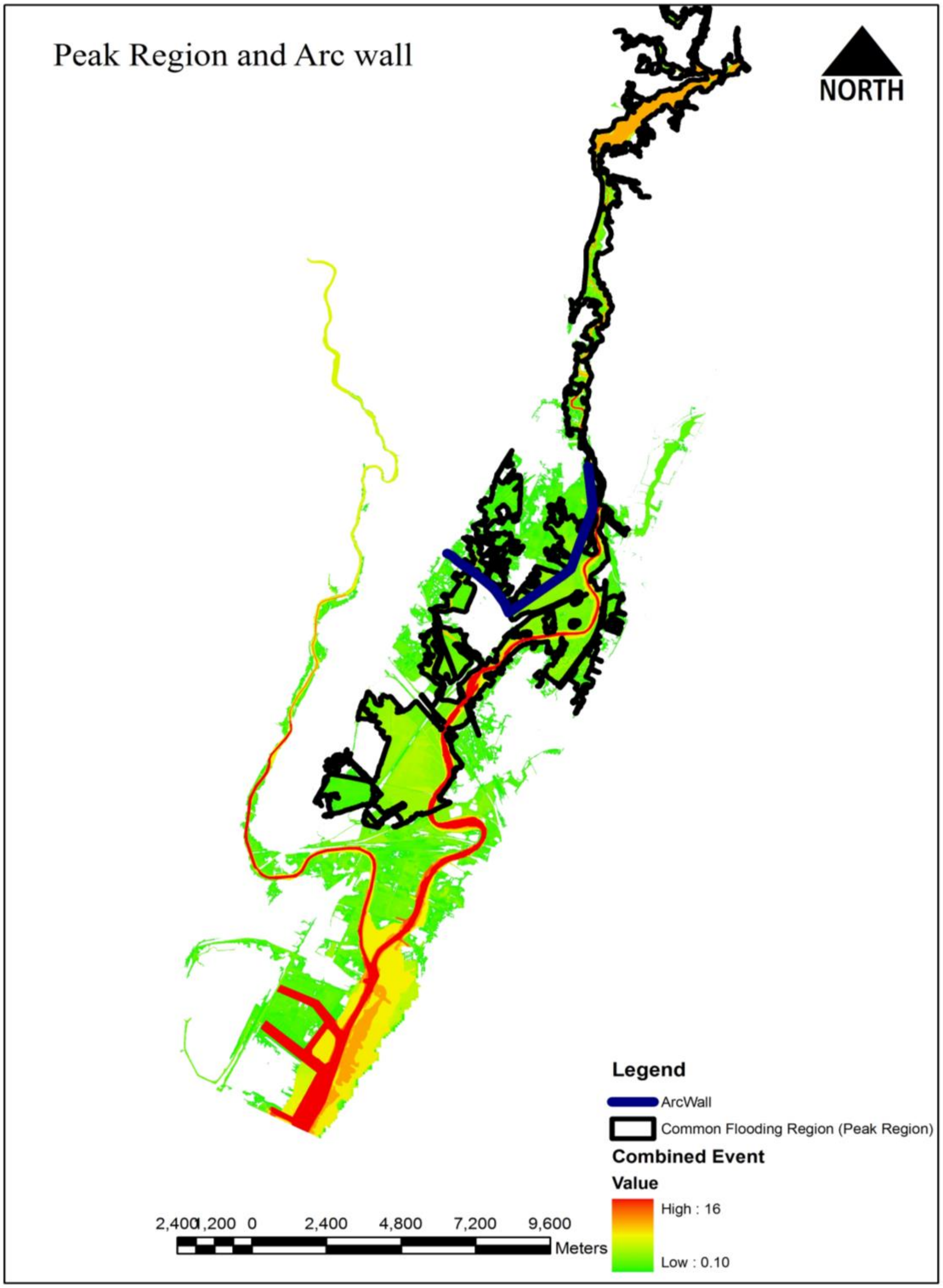


Figure 4.7 Delineation of peak region.

Thus, the section provides the worst case scenario cell by cell bases which is practically not possible. It gives an idea about the local level scenario. With the help of the analysis one can identify the area and get the idea about worst case scenario at the local neighborhood or factory / critical infrastructure level.

4.2.2 Macro Level Scenario

For the process of identifying the Macro level scenario, some studies were performed as indicated herein. Here the major difference is the consideration of time as a factor. At all available 26000 points, the scenario will be different at a particular time. One grid might be at the peak height and another might not be at its peak. The flood passes by the region, so the criticality of the event will vary with the time and location. In this section an attempt is made to look at a regional level and check the estimated peak flood in the overall region during a particular point of time. According to data availability, the process is done with two different methods.

Process - 1

The first process is done with the available data set of 24 concentration points and the region surrounding the data points / concentration region. Figure 4.8 shows the 24 data concentration points. From the NJIT FMERC team studies, the simulation logs are available. From the simulation logs, flood height for a sunny day dam breach and Sandy was considered. At different time frames the values of the flood height will be different at above locations. For both the events, at one particular time, the flood height for all 24 concentration points will be at its peak. Even though individual heights will not be at its peak but for overall region number of points will be near to its peak. Most points will be at or close to their peak heights during the time frame. That will be the worst timing for the region.

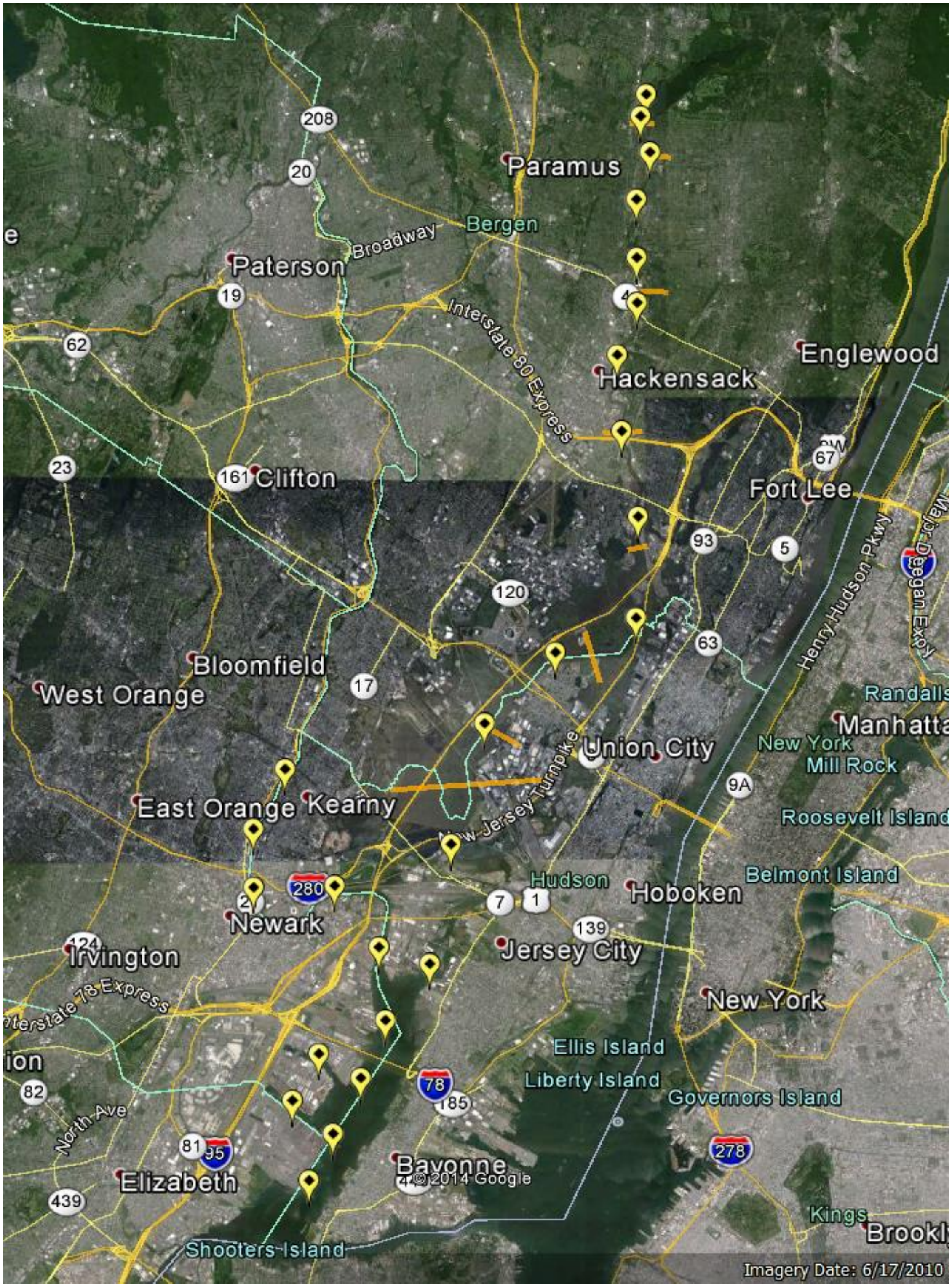


Figure 4.8 Locations of concentration points.
Source : (FMERC, 2014).

For both the events individual calculation are done in a similar way as for the micro level analysis. The equation for analysis is shown below.

$$\text{For Max}_t \left[\sum_i h_{1i} \text{ X } a_{1i} + \sum_j h_{2j} \text{ X } a_{2j} \right]_t \tag{4.2}$$

Where:

a_1 = Area flooded during Sandy

a_2 = Area flooded during dam breach

h_1 = Maximum water elevation during Sandy

h_2 = Maximum water elevation during dam breach

Peak Time Calculation for Sandy

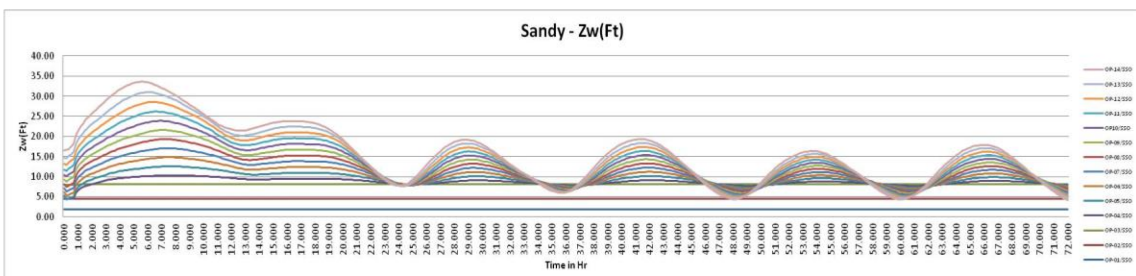


Figure 4.9 Sandy inundation height Zw at 10 min time intervals.

From the data analysis, it is confirmed that all the 24 points as a cumulative effect, comes at a peak volume after 5.33 hours of Sandy. If Sandy starts at time T = 00 hours, than after T = 5.33 hours the surroundings of all 24 areas will be at its peak height cumulatively. For the estimation of the time, data analysis is performed with the help of 5 point moving averages as well as the averages. Thus, at 5.33 hours after Sandy starts the height of water will as well as the volume of water in 5m X 5m grid will be at or near to peak for all 24 points.

Peak Time Calculation for Dam Breach

From the data analysis, it is confirmed that all the 24 points as a cumulative effect, comes at a peak after 3.40 hours of dam breach. If dam breach starts at time T = 00 hours, than after T = 3.40 hours the surroundings of all 24 areas will be at its peak height cumulatively. For the estimation of the time, data analysis is performed with the help of 5 point moving averages as well as the averages. Thus, at 3.40 hours after Sandy starts the height of water will as well as the volume of water in 5m X 5m grid will be at its peak for all 24 points. Figure 4.10 shows the dam breach inundation height at 10 min interval.

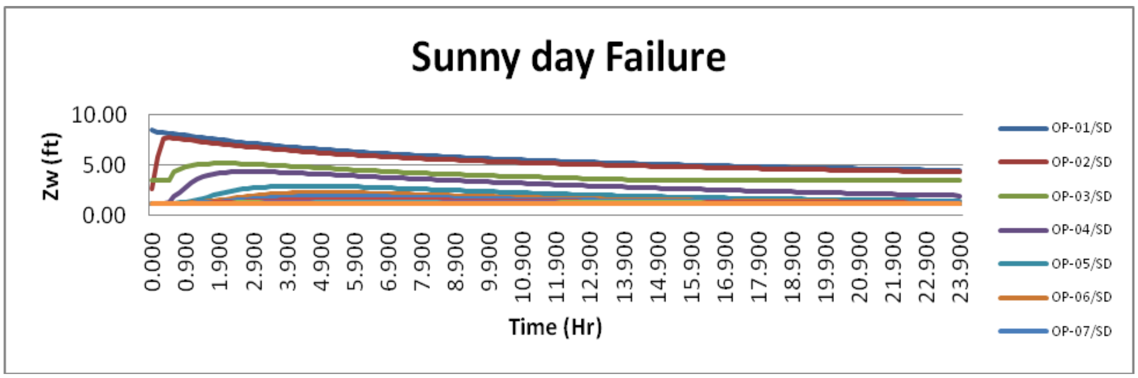


Figure 4.10 dam breach inundation height Zw at 10 min time intervals.

Peak Time Calculation for Combined Event

As mentioned earlier, the Sandy effect is at its peak at time T = 5.33 hours after Sandy starts. The Dam breach will be at its peak after time T = 3.40 hours. The worst case scenario for the region will be, if one considers a super storm like Sandy happens at time T = 0.00 hours, dam breaks at time T = 1.93 hours after 0.00 hours. If the dam breaks after 1hour 56 min when super storm starts will be the worst case scenario as both the events individually will be at its peak during the same time frame. The methodology is not precise but empirically it shows the result. Due to the computing and software limitations, an empirical method has been adopted. To get the precise result at the time frame, one needs to run the simulations during the exact time frame to see the Q results for the combined event. Figure 4.11 shows the combined heights for the combined event at peak time. Cumulative Flow (Qmax) is shown in appendix D.

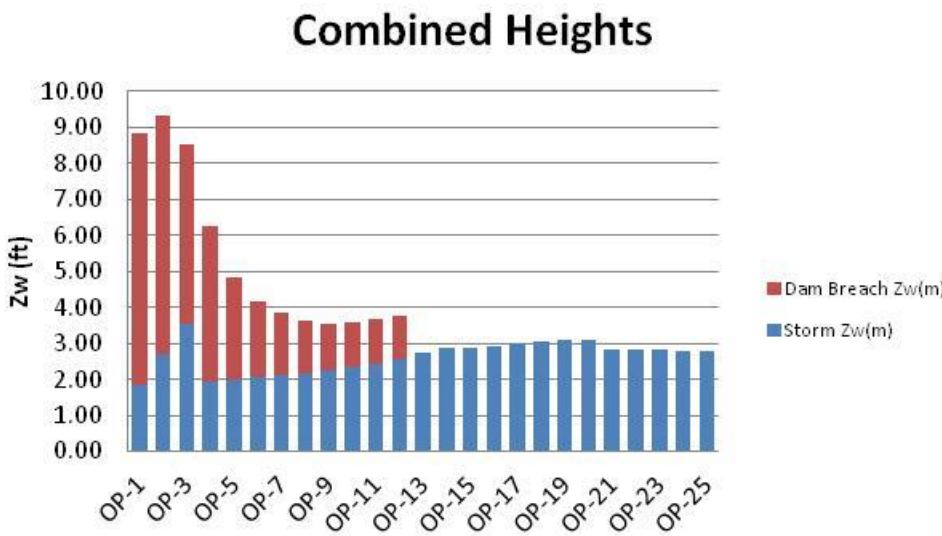


Figure 4.12 Combined Heights at Peak time for Combined Event.

Process-2

Due to the lack of data availability, it was not possible to get the outcome for the whole region in Process 1. It shows the result around the selected 24 points and region nearby. In process 2 an attempt is made to get the homogeneous out come for whole region. The base data available from the FMERC team at NJIT are raster formats with rasters of peak heights and rasters of flood arrival time. The flood arrival is also shown with the use of Google Earth Files (KML) files with time tags. It is difficult to get the time tag versus actual flood height in both the events. The available rasters for a dam breach on a sunny day is shown in Figure 4.11 (Hmax and Flood Arrival Time).

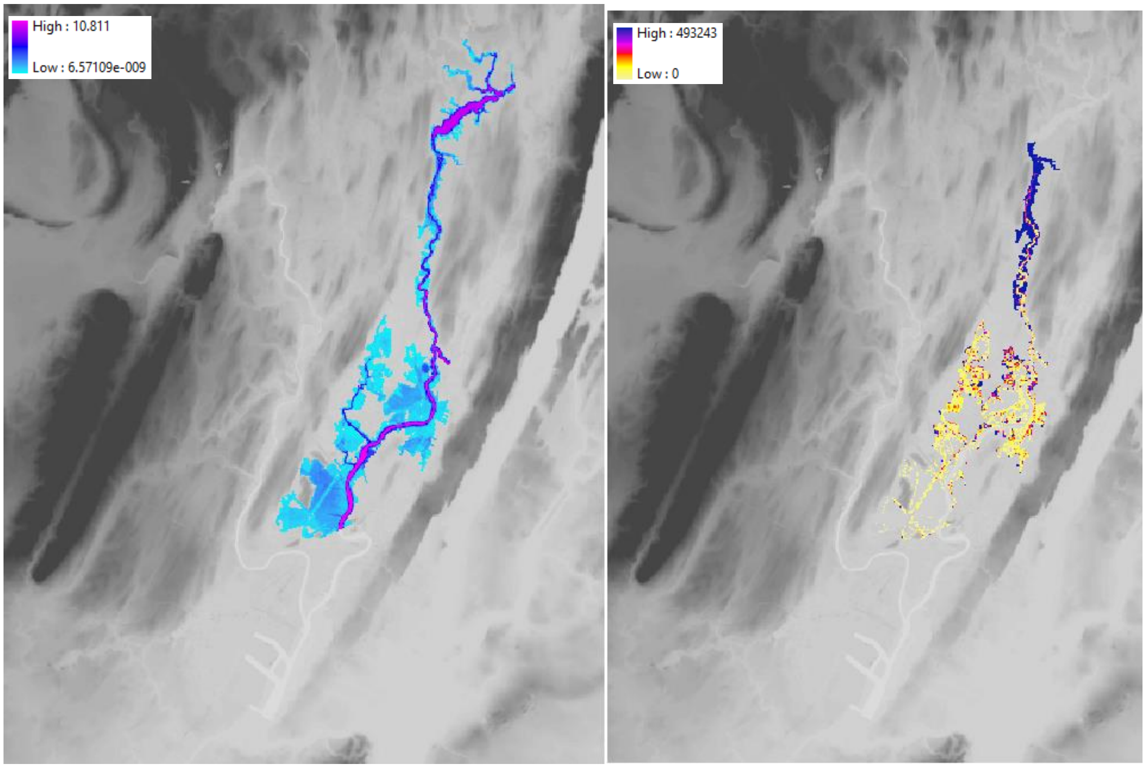


Figure 4.12 H max and flood arrival time for a dam breach.

From the raster files, it is converted to point files, which was explained earlier in this respect. The height raster is easily converted but the time raster is in a different format and it was not possible to convert the same in to point files. Another process through which it is possible to get time and height factors is through KML files. The KML files have data at 10 minute time intervals. It is also not possible to get the direct inundation and flood elevation data from KML files. The time frame under consideration was peak time plus 50 minutes and peak time -20 minutes with compare to process - 1.

From the KML files, output is shown in the Figure 4.13. From the KML files high resolution images were taken through the help of Google Earth Pro with a pixcel size of 0.50M X 0.50M. The high resolution images are processed with the help of Adobe Photoshope – 6.0. With the use of command layer via cut and select by color, each individual layer of height with a difference of 1 inch, is separated. The separated layers then were transferred and overlaid to base maps. Then the process is converting image in to raster with the particular height value attached to the raster. The last step is to overlay rasters with the Hmax value and converting that raster in to point files.

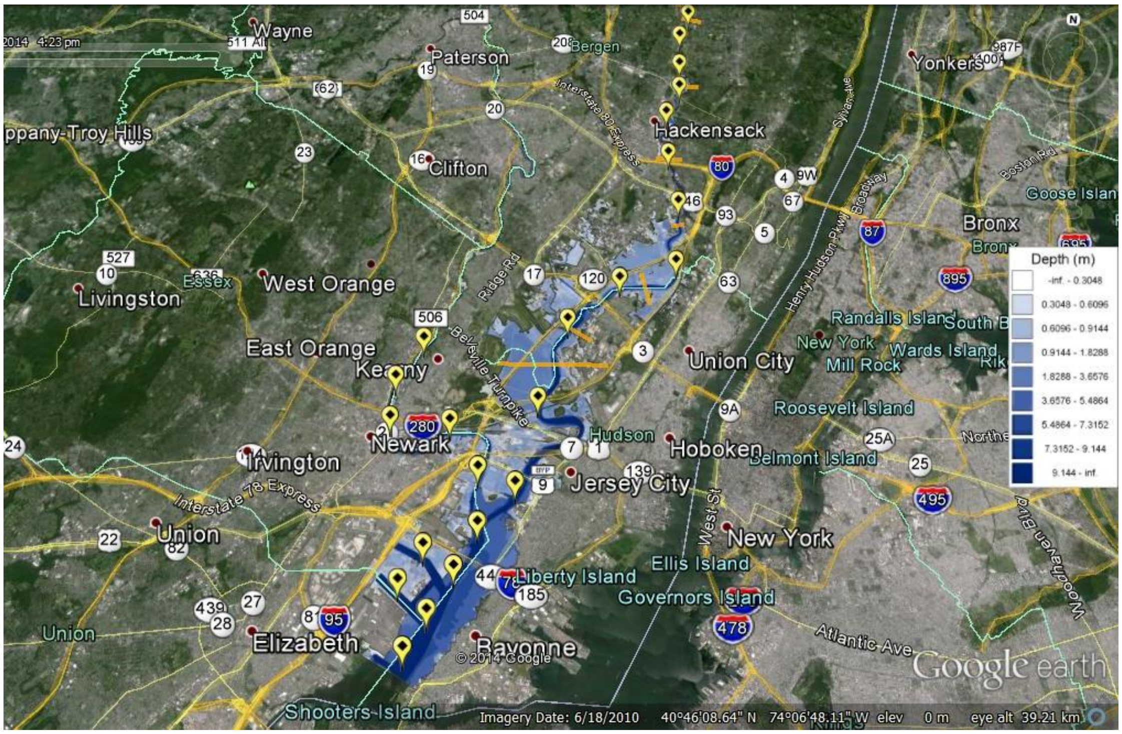


Figure 4.13 Sunny Day Dam Breach Inundation at Peak Time

The outcome of the tedious process is the value of flood height (flood inundation) at a snap shot of time. The time and the height moment both are in the same layer. For both the scenarios, a dam breach one a sunny day and Sandy only the process is repeated to get the result. Cell by cell scenarios also show similar results as Process -1. The critical time for Sandy only with this process is time frame of 5.30 to 5.40 hours after T = 00 (Sandy). The critical time frame for peak sunny day dam failure is 3.40 to 3.50 hours after T = 00 (Dam breach). Thus, the peak timing for both of the events is 1.80 hours to 2.00 hours time frame after T = 00 hours (Sandy). The results are similar and quite matching to the Process -1.

4.3 Analyzing the Arc Wall

The best possible solution proposed by FMERC team is the Arc wall, thus, in the section of the Arc wall is analyzed for the combined event worst case scenario. The height of the Arc wall is proposed as 12 feet in height. With the help of Arc-GIS, all the points in the combined event, are checked for the over topping factor. Flood indudation height and the height of the Arc wall is checked. The Figure 4.14 shows overtopping location for a sea level rise of 37.6 inches. There are 60 cells, which means 30 meter length of wall, overflows. Figure 4.15 shows the height comparison at the same point during different sea level rise. In case of sea level rise 37.6 inches the are wall is over topped by 0.3 feet.

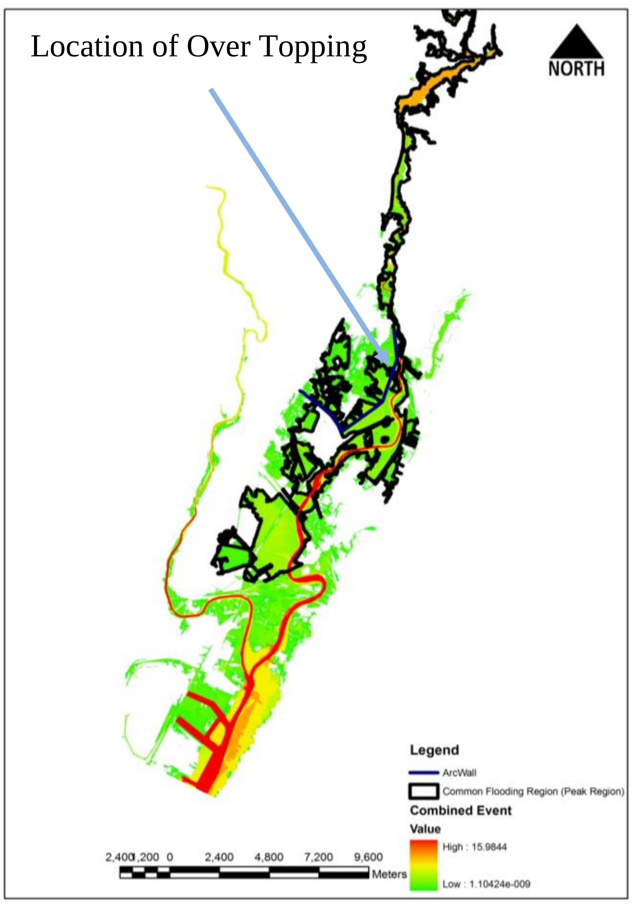
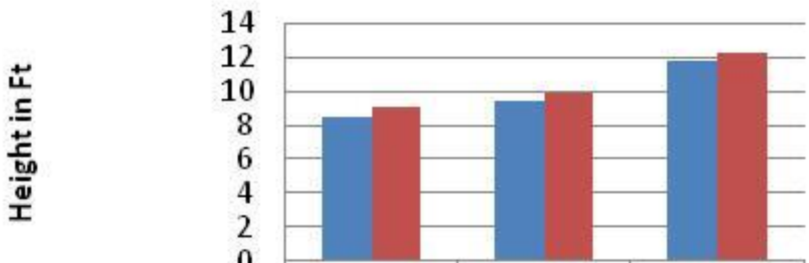


Figure 4.14 Location of over topping during combined event



	0.0	9.6	37.6
Only Sandy	8.54	9.4	11.78
Combined Event	9.06	9.92	12.3

Figure 4.15 – Height comparison at location of overtopping with different sea level rise.

The possibility of a combined event with a sea level rise of 37.6 inches is very low but there are chances of overtopping during the event. The over topping is 0.3 ft. Thus, there is need to rethink the proposed height of the Arc-wall. There is a need to simulate during the time frame just infront of the arc wall for the combined event to get the accurate result.

4.4 Modifications to the Arc wall

The FMERC report suggests that there are possible modifications to the Arc wall to make it more effective. By considering the factores of density, environmental sensitivity, land use pattern, direction of incoming flood, slight modifications are proposed by using Arc-GIS. There are basic two options proposed. There is a need to extend the Arc wall by 150 feet in the North direction. The inflow of water during dam breach is coming from the north of the Arc wall. Thus, the realignment will save the six municipalities from flooding due to a dam breach. There are environmental factors also considered for e.g., marine life, pollution due to construction process of the Arc wall etc.

4.4.1 Option 1

Option 1 is proposed by considering the direction of flood coming to the region and by considering the geometry of the bay. Here there is an attempt made to extednd the wall by about 15o feet in the North direction, due to the incoming flow of water during the dam breach. The geographic pattern of the land is followed for the Southern portion to aviod damages to the marine eco-system. Figure 4.16 shows the option 1 in compare to the original proposal. The length of the arc wall is almost doubled to 8.78 miles in length in this case.

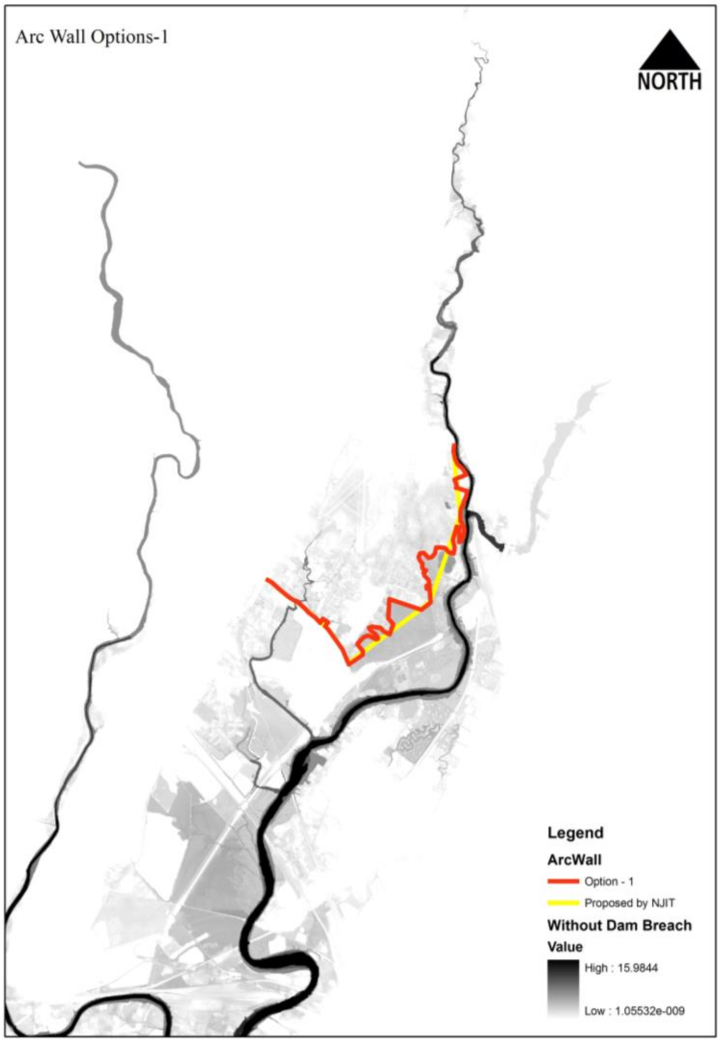


Figure 4.16 Arc wall option 1.

4.4.2 Option 2

Option 2 is proposed by considering the direction of flood coming to the region and the dense population areas near the Arc wall. There is an attempt made to extednd the wall by about 150 feets in the north direction, to aviod the incoming flow of water during a dam breach. Nearby dense areas are also incorporated within the wall. Figure 4.17 shows the option 2 in compare to the original proposal. The length of the arc wall is almost to 6.27 miles in the case. Detailed calculations of benefit and cost ratios are shown in the Section 4.5.

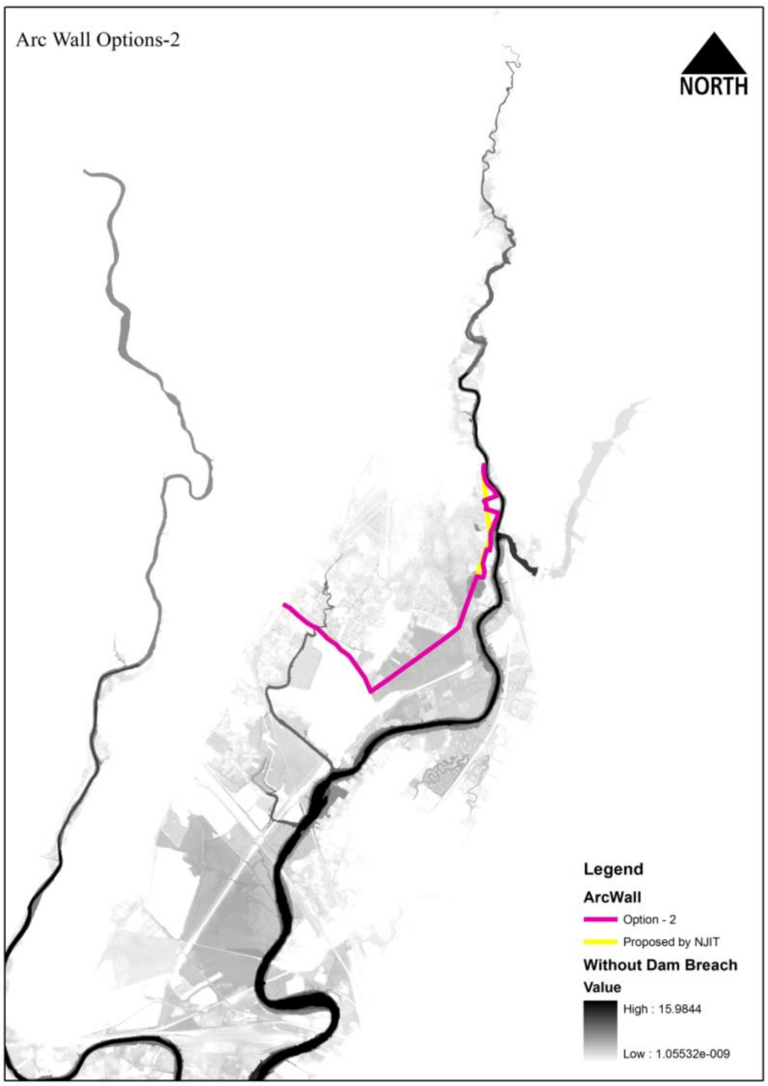


Figure 4.17 – Arc wall option – 2.

4.5 Damage Assessment

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

Setting up of the study region begins with identification of the study area. Since the basic inventory of Hazus is stored at the 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. The study region can also be built based on the Watershed.

Building the region based on census tract needs further validation as there is direct mapping between the municipality boundaries and census tract ids. For example, Moonachie municipality can be mapped to Census Tract Id 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.

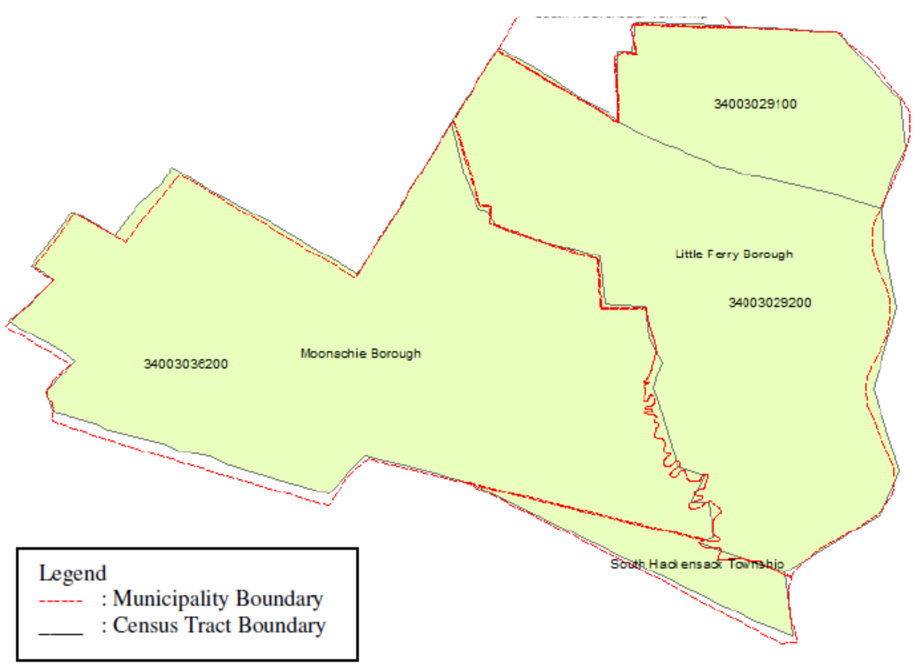


Figure 4.17 Overlapping of municipal boundary and census tract.

Figure 4.17 shows the overlapping of census tract and municipality boundaries. To avoid this issue, the study region for this research was built at the census block level. There are a total of 158 census blocks covering the Little Ferry and Moonachie municipalities. 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 is not applicable and hence the hazard was chosen as riverine only.

Defining the topography is the most critical step in flood hazard analysis. Hazus Flood Model identifies the data extent of digital elevation based on the defined study region. The DEM was then downloaded to the local drive, from the USGS website, by directly navigating to NED using the option provided by the Flood Model. The downloaded data was then imported into the Flood Model by browsing to the local drive. This downloaded 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 the USGS website or add one’s own DEM layer that satisfies the requirement.

The process of building the Hazus-MH compatible flood depth grid started with combining both the Sandy and Dam breach events at critical time. The Flood indundation data is already in the point format. The files are converted to rasters and rasters are overlayed on each other via raster overlay tool in Arc-GIS. The used defined flood depth grid is than imported to the Hazuz-MH.

4.5.1 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 the "Run" submenu 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. Once the Analysis process runs, the results or damage estimates can be viewed from the "Results" menu.

4.6 Benefit Cost Analysis

This section describes the financial model and the process of executing benefit cost analysis to evaluate modifications of the originally proposed Arc Wall. This can be one of the inputs for the decision makers when there are multiple mitigation alternatives available but not all of those or the one resulting most benefit can be chosen due to limited funds.

The 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.

4.6.1 Cost Assumptions

Based on the quantity take-off for each alternative, the 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 high level estimation of the following items:

- Design and Approval
- Mobilization
- Clearing and Grubbing
- Construction of Access Roads
- Construction of Drainage Ditches
- Cost of Raising the roads
- Relocation of Utilities
- Procurement of the Real Estate and Easements
- Mitigation of Wetland
- Installing 40’ Long Sheet Piles.
- 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 a certain period of time. For this analysis, it's assumed that 50% of the pumps or other mechanical equipment will need to be replaced after every 20 years of operations.

Estimated Life Span is the total estimated life span for each alternative is assumed to be 70 years. It is assumed that at the end of 70 years, nonmechanical 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.

4.6.2 Benefit Assessment and Assumptions

Benefits are considered to be the positive impacts which will be created by the alternative structural solutions which will help protect the targeted communities from a future Sandy like event. The process of identifying the benefits associated with each alternative solution is two-fold. First, Sandy damage which will be eliminated or mitigated 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. Second, 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. For the purpose of analysis, building related economic losses for Sandy is considered the same as consiederd by the FMERC team at NJIT. Table 4.3 shows estimated building related losses due to dam breach and Table 4.4 shows the building related losses in the combined event scenario.

Table 4.3 Building Related Economic Losses – Dam Breach

Impact of dam breach in the 6 municipalities which will be protected by Arc Wall						
Building-Related Economic Loss Estimates - Dam Breach (Millions of USD)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
(a)	Building	6.08	9.94	8.24	0.94	25.19
(b)	Content	2.90	34.88	18.57	6.09	62.43
(c)	Inventory	0.00	0.90	3.41	0.01	4.31
	Subtotal	10.00	56.12	32.31	8.44	91.94
Business Interruption						
(d)	Income	0.00	0.48	0.00	0.04	0.53
(e)	Relocation	0.04	0.10	0.01	0.04	0.18
(f)	Rental Income	0.02	0.11	0.00	0.01	0.13
(g)	Wage	0.00	0.00	0.00	0.00	0.00
	Subtotal	0.06	0.68	0.01	0.08	0.84
All	Total	10.06	56.80	32.32	8.52	92.78

Table 4.4 Building Related Economic Losses – Combined Event

Building-Related Economic Loss Estimates - Combined Event (Millions of USD)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
(a)	Building	14.22	43.44	27.86	3.30	88.82
(b)	Content	10.91	108.69	57.25	19.13	195.97
(c)	Inventory	0.00	4.26	9.72	0.03	14.00
	Subtotal	5.00	28.06	16.15	4.22	298.79
Business Interruption						
(d)	Income	0.01	1.23	0.01	0.10	1.36
(e)	Relocation	0.17	0.40	0.03	0.10	0.70
(f)	Rental Income	0.07	0.25	0.00	0.03	0.35
(g)	Wage	0.00	0.00	0.00	0.00	0.00
	Subtotal	0.25	1.88	0.04	0.22	2.40
All	Total	5.25	29.94	16.20	4.44	301.19

The benefit and cost ratio is calculated for all the events described earlier. A life cycle cost benefit analysis was performed for each of the structural alternatives. The Net Present value (NPV) of Costs of each Alternative 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 4.5 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 4.4 – Building Related Economic Losses – Sandy

Benefit Cost Ratio - Arc Wall (Millions of USD)					
Category	**Net Present Value of Cost**	**Damage Estimates**	**Induced Benefit (30% of Construction cost)**	**1 Case B/C**	**2 Case B/C**
Only Sandy	262.68	218.32	157.61	1.43	2.26
Only Dam Breach	262.68	92.78	157.61	0.95	1.31
Combined Event	262.68	301.19	157.61	1.75	2.89
Incresed Ht 0.3 ft	269.25	301.19	161.55	1.72	2.84
Option - 1	411.22	329.71	246.74	1.40	2.20
Option - 2	293.67	315.34	176.2	1.67	2.75

In the event when there is one disaster in 70 years of life span, the Arc Wall for combined event is the most justifiable. However, even for only dam breach in two case scenerio are wall is soly justified. Thus the Arc wall is proven justified option in case of combined as well as independent events of dam breach and thunder storm. Benefit-Cost ratio can be an input to decision makers while choosing the feasible solution given the budget is limited.

CHAPTER 5

CONCLUSION

As a result of a wide-reaching comprehensive post-Sandy NJIT project entitled "Flood Mitigation Engineering Resource Center (FMERC)" and sponsored by the New Jersey Department of Environmental Protection and the Governor's Office for Reconstruction and Recovery, a detailed investigation of alternative measures for flood mitigation in the Meadowlands area was completed in June 2014. The project involved the assessment of flood impacts, and the evaluation of a range of structural and non-structural capital improvement measures, maintenance, operations and regulatory measures, and broad system design and redundancy measures.

The basic objective of this thesis was to develop an innovative procedure for the enumeration and simulation of probability-weighted combined events, e.g., Oradell dam failure under various scenarios (sunny day, water level, etc.) along with a super storm event at various time staging levels. The approach broadens the analytical arsenal available to policy-makers for the purpose of comprehensive risk and resiliency analysis and the selection of optimal protection alternatives.

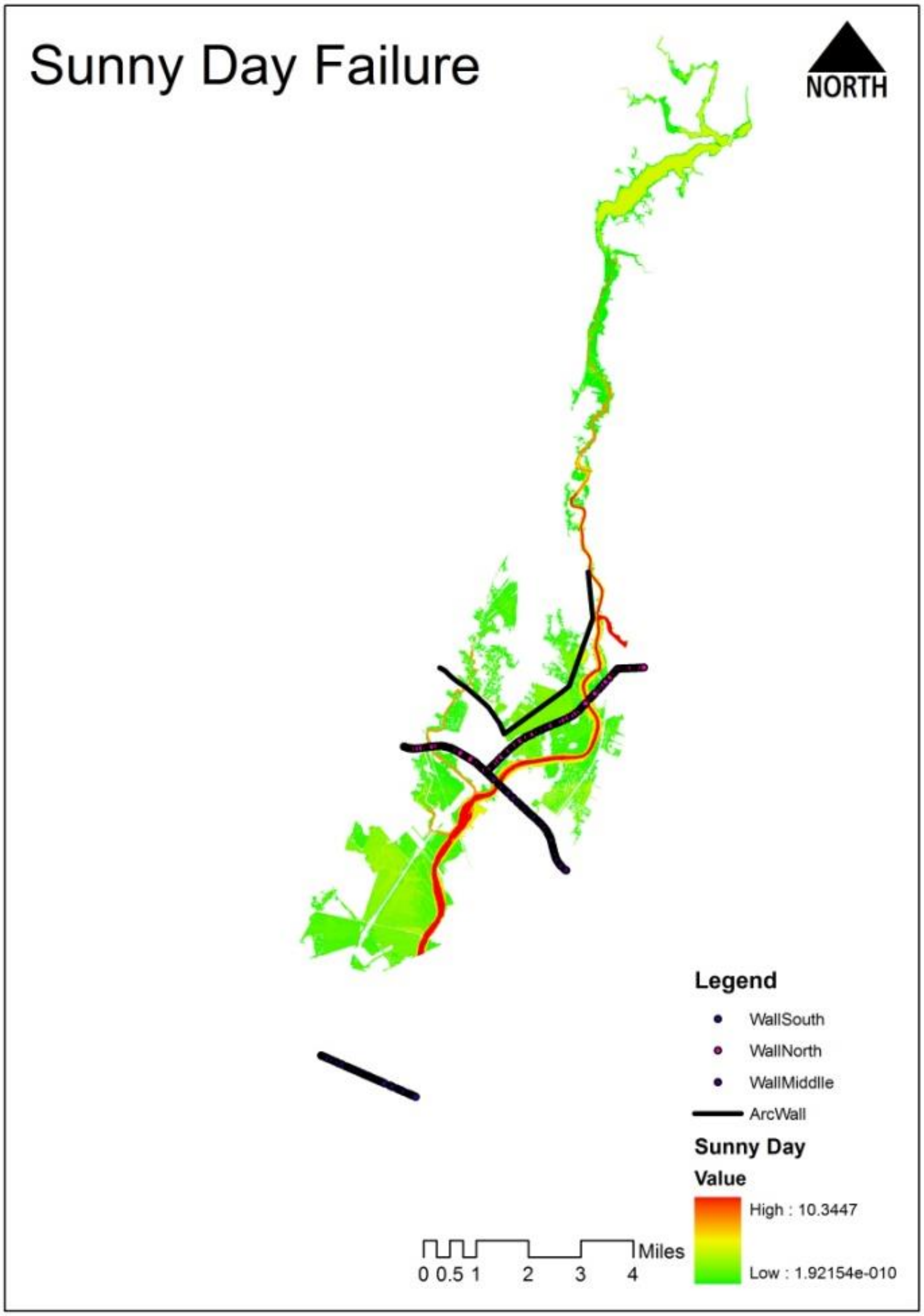
The methodology includes data analysis done with the help of software like Arc GIS and Hec-Ras / Hec-Geo-HMS. Using GIS simulations, the FMERC proposed solutions e.g., Arc Wall are simulated under combined event scenarios in order to identify possible modifications or adjustments for maximum risk reduction. According to the FMERC report there is a land area in the Meadowlands of about 1773.9 acres, which is not flooded by Sandy alone, but would be flooded due to the combined event under a specific event lag scenario. In order to consider the whole range of combined event scenarios, a new approach was derived to identify relative timings at which the combined event is at its peak. Accordingly, adapted strategies which are modifications to the latest FMERC structural solutions are proposed in order to provide cost-effective protection and risk management in the combined event. The incremental benefit-cost ratio associated with these adapted strategies was also calculated in this report, as risk reduction levels (benefits) are compared to the costs of modified alternatives.

An outcome of this research is the development of an empirical approach for simulating combined events and identifying the least desirable relative timing of the two flood events. Consequently, the robustness and risk reduction of various protection investments under consideration can be assessed for combined flooding event scenarios, and adaptation strategies derived to provide a more comprehensive level of protection.

APPENDIX A

SUNNY DAY DAM BREACH

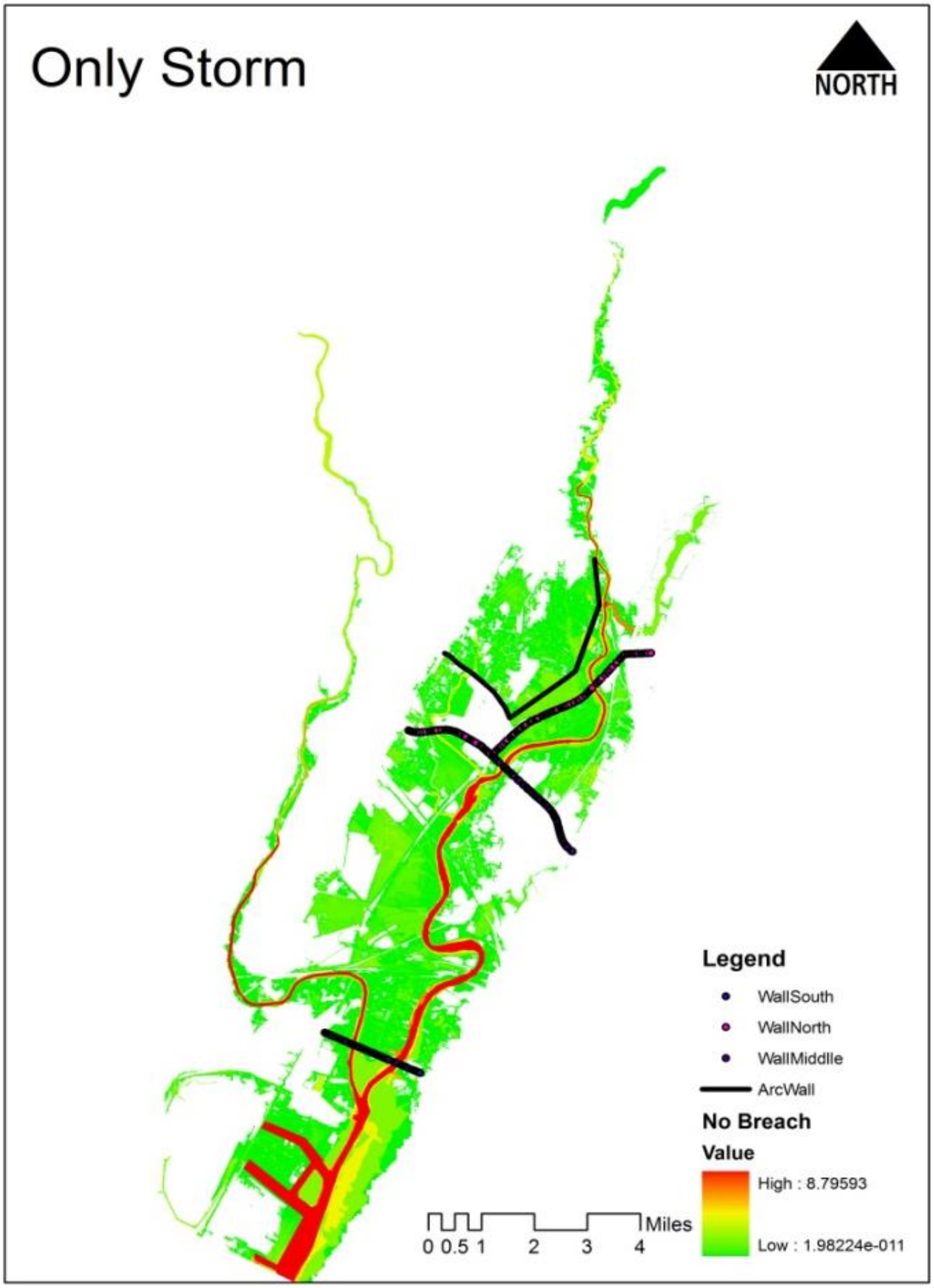
Appendix A shows the map of flood inundation due to sunny day dam breach.



APPENDIX B

SUPER STORM SANDY

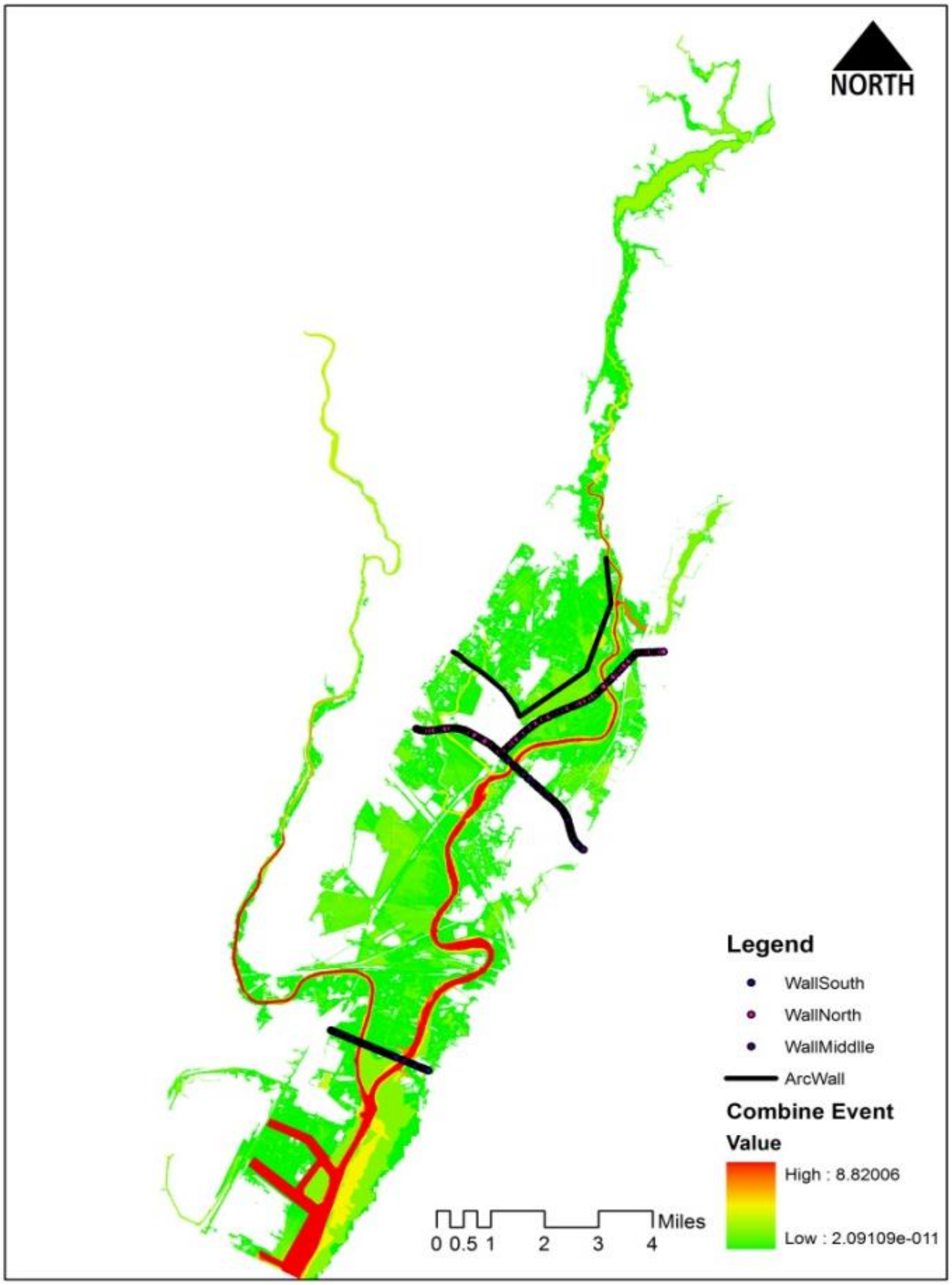
Appendix B shows the map of flood inundation due to super storm Sandy.



APPENDIX C

COMBINED EVENT SCENARIO

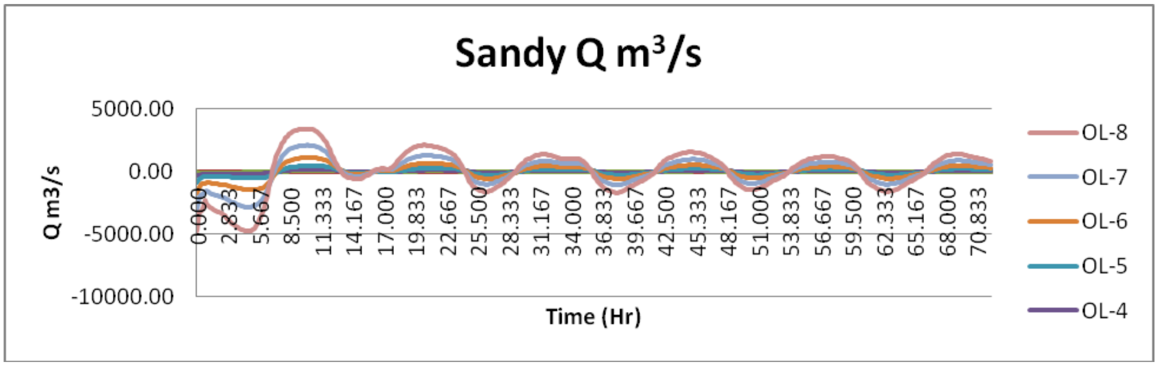
Appendix C shows the map of flood inundation due to combined event.

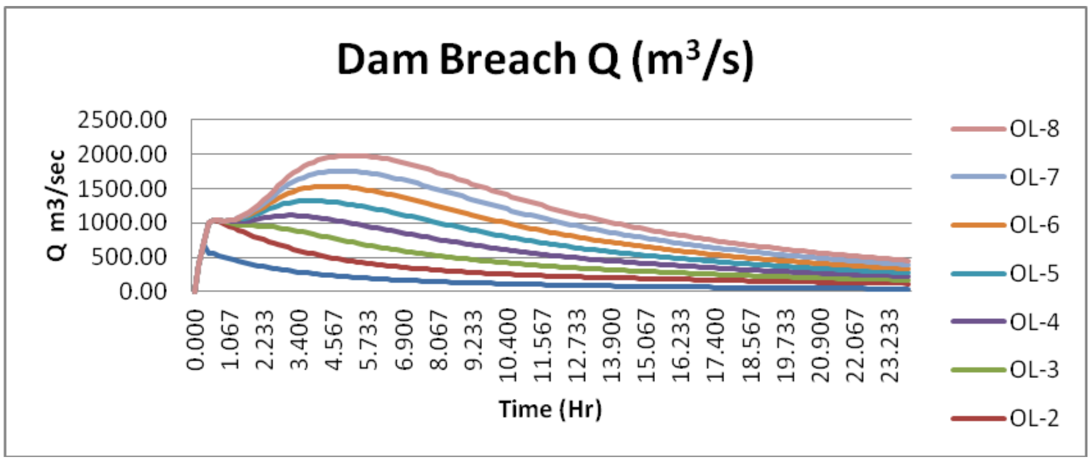


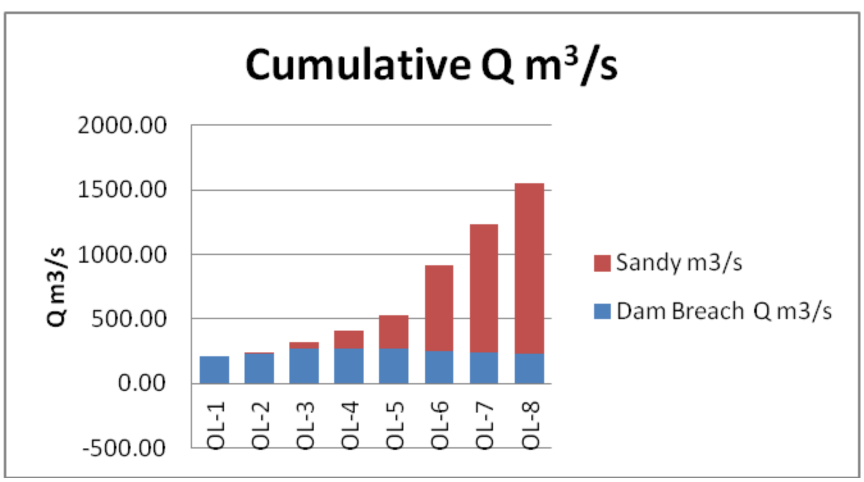
APPENDIX D

CUMULATIVE FLOW IN COMBINED EVENT

Appendix D shows the cumulative flow Qmax in combined event.







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