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Final Report

FLOOD MITIGATION ENGINEERING RESOURCE CENTER (FMERC) - PROJECT EC14-005

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ACKNOWLEDGEMENTS

There are simply too many people to acknowledge in this comprehensive multi-disciplinary effort that the FMERC has undertaken. The dedication of faculty, staff and graduate students was remarkable, and allowed us to deliver an integrated perspective to flood mitigation that can be improved and updated dynamically, as the process of analyzing various options intensifies, in coordination with the various key agencies involved.

We want to particularly acknowledge the support of our State of New Jersey sponsors at the New Jersey Department of Environmental Protection (NJDEP) and the Governor's Office of Recovery and rebuilding (GORR), and their invaluable feedback at key milestones and interim presentations of the project status reports. They, along with the key constituents (Mayors, Town Administrators, Superintendents of Public Works, Town Engineers, etc.) in the Boroughs of Little Ferry and Moonachie and the City of Hackensack, the Meadowlands Environmental Research Institute (MERI), the County of Bergen Executives and Flood Coordinator, FEMA and USACE officials and many other parties, were instrumental in supporting and providing important elements of data collection during the forensic and solution development stages. To them and many others, we extend our deep appreciation for enabling the development of multi-dimensional structural and non-structural flood protection and mitigation recommendations and the dynamic planning capability that we hope to apply in future integration efforts, in support of the long-term protection of the State of New Jersey, the North Atlantic Region and the Nation.

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EXECUTIVE SUMMARY

As the deadliest and most destructive tropical cyclone of the 2012 Atlantic hurricane season, Tropical Storm Sandy caused extensive damage to many communities and towns along the coast and inland. Many homes, businesses and other infrastructure along the shoreline and beach fronts were severely damaged. Some are now uninhabited and must be demolished, while others still need major repairs. In response to the request from the New Jersey Department of Environmental Protection (NJDEP) for a study to provide both short-term remediation and long-term solutions to protect many communities from similar future storms, the Flood Mitigation Engineering Resource Center (FMERC) at NJIT was formed.

The FMERC will be a *premier research, engineering and technology resource* for the State of New Jersey in the domain of strategic planning and response to flood analysis and mitigation needs. The main goals are to provide technical assistance to the State of New Jersey's Department of Environmental Protection to reduce the risk to which vulnerable coastal and inland populations are subject to, and also to ensure a sustainable and robust landscape in the state that jointly supports public safety and economic development. The center will be the *nexus* between NJDEP, the public, the US Army Corps. of Engineers, the regional academic research community, and the private sector engaged in the development and implementation of innovative planning, engineering, technologies and services that support the state and its citizens in flood mitigation related issues. The FMERC will conduct related research that complements efforts in place and supports the State of New Jersey's strategic plan. The outputs of the Center can be used to respond to regional, state and local requests to evaluate protection alternatives and develop contingency plans under normal circumstances, and adjust forecasts and propose mitigation measures during storm events to help support the emergency management community with information and solutions to real-time problems.

The first focus of the Center was to perform (as detailed herein) an investigation of alternative measures for flood mitigation in the Hackensack/Moonachie/Little Ferry area as an aftermath to Tropical Storm Sandy. Care was taken to support and enhance rather than duplicate any on-going efforts by the US Army Corps of Engineers and other organizations. The project involved assessment of the flood impacts, and evaluation of a range of capital improvement, maintenance and operations and regulatory measures, including structural and non-structural engineering alternatives, regulatory and system design and redundancy measures. The evaluation included hydraulic modeling, environmental, risk and socio-economic impacts, including estimated capital and maintenance and operating costs of mitigation and protection alternatives.

The FMERC team includes a large cross-section of faculty from the Department of Civil and Environmental Engineering at NJIT, the largest department of its kind in the State with expertise in a range of engineering, construction management, project evaluation and critical infrastructure systems resilience and sustainability areas. Through its association with the National Center for Computational Hydroscience and Engineering (NCCHE) of the University of Mississippi, it also brings strong expertise in hydrodynamic and morpho-dynamic modeling and simulation. It collectively has had a leadership role in numerous projects funded by the National Science Foundation

(NSF), US Department of Transportation, US Environmental Protection Agency, the Department of Homeland Security, NJ Department of Transportation, and NJ Department of Environmental Protection among others. The FMERC team is committed to its partnership with the NJDEP and the State of New Jersey in providing advanced analytics and support for the development of the most cost-effective (optimal) solutions in support of the state's Strategic Action Plan.

The FMERC has been engaged since June 2013 in the Meadowlands proposed study area, and is hereby submitting its final report on the most appropriate set of protection and mitigation strategies, covering a wide range of alternatives, and policies aimed at facing and mitigating the flooding impacts from future potential storms and climate change uncertainties. The FMERC team is working in concert with the US Army Corps of Engineers North Atlantic Comprehensive Study, as well as key Federal, State and local agencies, such as FEMA, NJDEP, the County of Bergen, the NJ Meadowlands Commission and its Meadowlands Environmental Research Institute, the municipalities (the Boroughs of Little Ferry and Moonachie, and the City of Hackensack) and their consulting engineers.

After a thorough investigation consisting of field visits, targeted surveys, data acquisition, inventory of critical assets, and geo-spatial application development, the FMERC Team has reached a high level of understanding of flooding problems from various hazards and sources, and has generated a number of protection alternatives. In particular, the FMERC Team has provided the following recommendations:

1. *Structural Flood Protection Alternatives*: The team has generated a number of strategically located flood protection structures, some involving river crossings, and evaluated their costs and estimated their key benefits.
2. *Non-Structural Mitigation Alternatives:* The project team has identified some of the key problem areas related to the overall regional drainage capability of the study area, which interfaces with the respective municipal stormwater drainage systems. In addition to problems with the stormwater systems, critical deficiencies were identified in pumping capacities and operating standards, drainage network topology, and the blocked condition of ditches and waterways, which are the receiving bodies for many of the key outlet structures. The team has identified the ditches as well as the contiguous berms, as an area worthy of a strategic restoration project, as discussed in more detail in later sections. Also, the team has reviewed opportunities for non-structural green infrastructure solutions, and opportunities such as the proposed Willow Lake dredging project were identified as worthy of further study within a comprehensive framework for alternative (non-structural) solutions.
3. *Maintenance, Asset Management and Regulatory Improvements*: The FMERC team has also examined asset management opportunities related to key flood protection assets, such as tide gates, pumping stations and power generators, as well as the piping links within the drainage network, and has developed a

number of recommendations on the improvement of the network connectivity and drainage capacity. The team has also assessed regulatory, organizational and policy hurdles and is developing recommendations in this category, which will improve the level of coordination, resiliency and organizational effectiveness in support of flood mitigation solution development and implementation.

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1. INTRODUCTION

The NJ Flood Hazard Area (FHA) Control Act Rules N.J.A.C. 7:13, adopted on November 5, 2007, implement the New Jersey Flood Hazard Area Control Act. Unless properly controlled, development within flood hazard areas can exacerbate the intensity and frequency of flooding by reducing flood storage, increasing storm water runoff and obstructing the movement of floodwaters. In addition, structures that are improperly built in flood hazard areas are subject to flood damage and threaten the health, safety and welfare of those who use them. Healthy vegetation adjacent to surface waters is essential for maintaining bank stability and water quality. The indiscriminate disturbance of such vegetation can destabilize channels, leading to increased erosion and sedimentation that exacerbates the intensity and frequency of flooding. The loss of vegetation adjacent to surface waters also reduces filtration of storm water runoff and thus degrades the quality of these waters.

Devastation in the wake of Hurricane Sandy which made landfall near Brigantine, New Jersey on October 29 has brought attention to the vulnerability of the entire east coast and some inland areas putting a large population in coastal regions at great risk. Increase in frequency of high magnitude storm events such as Irene and Sandy has brought attention to the need for long term and effective plans to mitigate flooding in the North Atlantic Coast. Figure 1 shows a color-coded map of the impacted areas in the tri-State area, with purple representing the highest impact recorded.

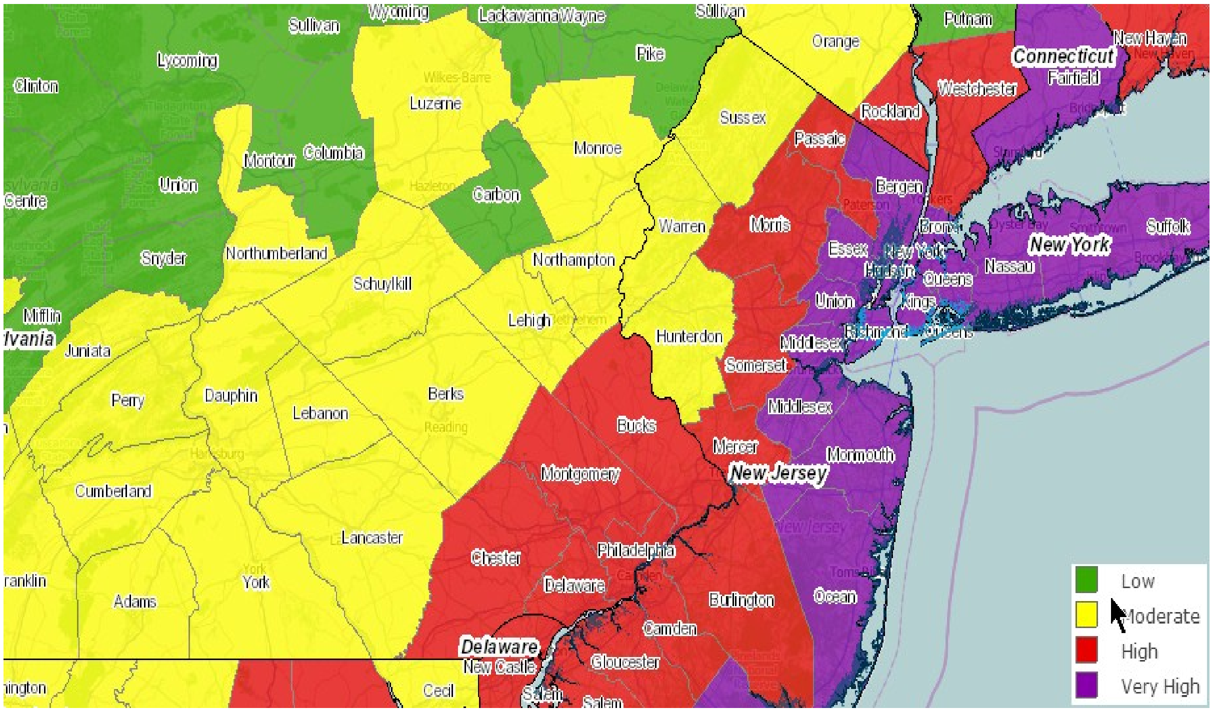


Figure 1. Sandy Impact Analysis (Source: FEMA Modelling Task Force - Hurricane Sandy Impact Analysis. Available from http://fema.maps.arcgis.com/home/webmap)

The Flood Mitigation Engineering Resource Center (FMERC) was created in response to the request from the New Jersey Department of Environmental Protection (NJDEP) for strategic research and studies to provide both short-term remediation and long-term solutions to protect many communities from similar future storms.

The FMERC aims at becoming a *premier research, engineering and technology resource* for the State of New Jersey in the domain of strategic planning, project economic evaluation, engineering design and response to flood analysis and mitigation needs. The main goals are to provide technical assistance to the State of New Jersey and its Department of Environmental Protection to reduce the risk to which vulnerable coastal and inland populations are subject to, and also to ensure a sustainable and robust landscape in the state that supports public safety and economic development. The Center will be the *nexus* between NJDEP, the public, the US Army Corps of Engineers, other academic and research institutions, and the private sector engaged in the development and implementation of innovative planning, engineering, technologies and services that support the state and its citizens in flood mitigation related issues. The FMERC will conduct related research that complements efforts in place and supports the State of New Jersey's strategic plan and associated action plans. The outputs of the Center can be used to respond to regional, state and local requests to evaluate protection alternatives and develop contingency plans in quiet times, and adjust forecasts and propose mitigation measures during storm events to help support the emergency management community with information and solutions to real-time problems.

The short-term focus of the center was to perform an investigation of alternative measures for flood mitigation in the Hackensack/Moonachie/Little Ferry area. Care was taken to support and adapt rather than duplicate any on-going efforts by the US Army Corps of Engineers (i.e. USACE) and other organizations. Best practice approaches were used to the extent possible for the compressed time frame of the study, which parallels the development of a comprehensive strategy by the USACE planned for the first quarter of 2015. The FMERC project involved assessment of the flood impacts, and evaluation of a range of capital improvement, maintenance and operations and regulatory measures, including structural and non-structural engineering alternatives, zoning, code and system design and redundancy measures. The evaluation included hydraulic modeling and simulation of various Sandy-like storm scenarios, associated environmental, risk and socio-economic impacts under the baseline (status quo) and various protection alternatives, and estimated capital, maintenance and operating costs.

The Hackensack study area is part of the Newark Bay, Passaic River and Hackensack River Planning Region, one of eight Regions in the Hudson-Raritan Estuary study area (Figure 2), which was the subject of a comprehensive restoration program by the USACE, as shown in the Draft Hudson-Raritan Estuary Comprehensive Restoration Plan (6). A large section of the study area is part of a larger area known as the Meadowlands watershed.

The Meadowlands watershed is bounded by Route 46 to the north, the Hackensack River to the west, Route 17 to the east, and Routes 280/95/495 to the south. This watershed is comprised of a

30.4-square-mile area known as the Hackensack Meadowlands District (District) with residential and industrial/commercial properties. The District is composed of parts of 14 municipalities in Bergen and Hudson counties (Carlstadt, East Rutherford, Jersey City, Kearny, Little Ferry, Lyndhurst, Moonachie, North Arlington, North Bergen, Ridgefield, Rutherford, Secaucus, South Hackensack, and Teterboro). The Hackensack River is tidally-influenced with a mean high water spring (MHWS) elevation of 2.6 feet (NAVD88). The ground elevation for the Meadowlands watershed is approximately 2 feet to 6 feet (NAVD88). In a 25-year storm event, the water surface elevation is 6.1 feet and during Hurricane Sandy it reached 9.6 feet above sea level (NAVD 88) and remained above 7 feet for 6 hours. Critical issues involved in flood mitigation within the Meadowlands watershed are far reaching and varied. Policy discussions and decisions could possibly include any and all of the following regulators/agencies:

- New Jersey Meadowlands Commission
- United States Army Corps of Engineers (and relevant Interagency Review Team (IRT)/Meadowlands Interagency Mitigation Advisory Committee (MIMAC))
- US Department of Housing and Urban Development (HUD)
- FEMA Regional Office (Region II)
- United States Environmental Protection Agency
- New Jersey Department of Environmental Protection
- New York /New Jersey Port Authority
- New Jersey Department of Economic Development
- New Jersey Department of Community Affairs
- Bergen County Office of Emergency Management
- Hudson County Office of Emergency Management
- New Jersey State Police – Emergency Management Section
- New Jersey Transit
- New Jersey Turnpike Authority
- New Jersey Department of Transportation
- Bergen County Department of Public Works (Mosquito Control)
- Hudson County Division of Engineering
- Bergen, Hudson, Essex and Passaic County Soil Conservation Districts

Figure 2. The eight Planning Regions of the Hudson- Raritan Estuary study area (USACE (6))

1.1. Super Storm Sandy and its Impact on the Study Area

Hurricane Sandy was the second most costly storm in the history of United States (Table 1) with recent U.S. total damage and economic loss estimates at nearly $68 billion. The highest damage during Sandy was experienced in some selected communities (seen in light or dark red in Figure 3), which were exposed to a drainage network failure during and in the aftermath of the Sandy event, likely exacerbated by a problem of blocked and contaminated ditches. Parts of the study area (Little Ferry and Moonachie) experienced the largest percentage of homes damaged due to the widespread inundation and standing waters that were encountered in the aftermath of Sandy.

	Name	Affected Locations	Economic Loss	Insured Loss
1	**HU Katrina (2005)**	Southeast	147.2 billion	78.8 billion
2	**TS Sandy (2012)**	Eastern U.S.	68.0 billion	29.5 billion
3	**HU Andrew (1992)**	Florida, Louisiana	44.3 billion	25.7 billion
4	**HU Ike (2008)**	Texas, Midwest	31.2 billion	16.2 billion
5	**HU Wilma (2005)**	Florida	24.5 billion	12.4 billion
6	**HU Ivan (2004)**	Eastern U.S.	22.9 billion	10.6 billion
7	**HU Rita (2005)**	Texas, Southeast	18.6 billion	7.1 billion
8	**HU Charley (2004)**	Southeast	18.4 billion	9.2 billion
9	**HU Irene (2011)**	Northeast, Mid-Atlantic	16.1 billion	11.7 billion
10	**HU Hugo (1989)**	Southeast, Puerto Rico, Virgin Islands	15.7 billion	9.8 billion

Table 1. Ranking of 10 Top Tropical Storms (TS)/Hurricanes (HU) by ecomomic loss in US history. (Source: Billion-Dollar Weather/Climate Disasters published by NOAA at https://www.ncdc.noaa.gov/billions/events.pdf)

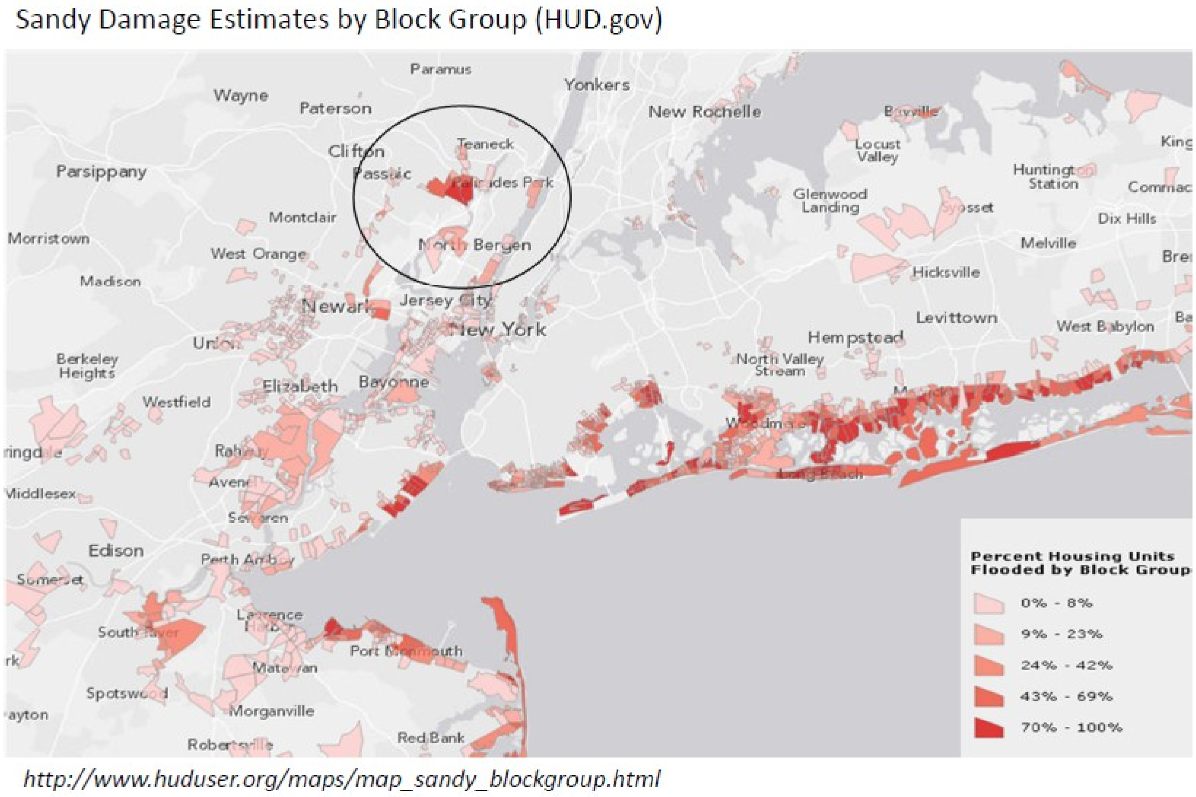


Figure 3. Sandy Damage Estimates by Block Group (HUD)
(Source: Sandy Damage Estimates Based on FEMA IA Registrant Inspection Data. Available from http://hud.maps.arcgis.com/)

As shown in Table 2, for some selected communities, and associations such as the Meadowlands Commission, Sandy was a much more significant flood event than Irene was, with some communities experiencing a much larger damage during Sandy. This was due to the culmination of effects such as first-wave flooding, second-hand flooding from neighboring attempts at draining excess waters, followed by a failure of their own drainage systems. It became apparent that, in the cascade failure that followed Sandy, power shutdown and inundation disabled pumping stations. Consequently, entire drainage systems failed, further exacerbating the flooding problem. But even functioning drainage capabilities would not have entirely prevented the resulting lack of resilience in some communities as an aftermath of Sandy.

TOWN/ BOROUGH	SANDY PRIVATE LOSS /DAMAGE	IRENE PRIVATE LOSS/ DAMAGE	TOTAL RECORDED HISTORICALLY *	RATIO OF SANDY TO IRENE LOSS
LITTLE FERRY	$7,221,287.65	$4,076,838.67	$12,604,378.96	1.77
MOONACHIE	$2,649,860.11	$1,750,086.20	$6,309,688.62	1.51
CARLSTADT	$1,198,013.89	$102,985.04	$2,048,811.20	11.63
HACKENSACK MEADOWLANDS COMMISSION	$6,294,403.51	$4,577,609.02	$12,730,253.46	1.38

Table 2. Comparison of Sandy and Irene Loss Statistics for Select Entities (FEMA)
*Total recorded historically including Irene and Sandy

1.2. Project Objectives and the Relationship to Major Federal, State and Regional Initiatives (North Atlantic Coast Comprehensive Study)

The project key objectives are to:

1- *Provide a flood mitigation comprehensive engineering, maintenance and regulatory solution development and analysis framework*, that is applicable to any area in the State of New Jersey and across the Nation, with an initial focus on the Hackensack area (in particular Hackensack, Moonachie and Little Ferry) including regional and area-specific short-term and long-term measures.

2- *Develop a Flood Mitigation Engineering Resource Center (FMERC) for the State of NJ*: The Center would focus, in partnership with the State of New Jersey and its Departments, on significant risk reduction, consistent with the National Infrastructure Protection Plan and the national goal of increasing community resiliency in coordination with the USACE North Atlantic Division Comprehensive Study, and the directions of other regulatory, and jurisdictional agencies such as HUD, FEMA, EPA and NJDEP.

3- *Create a dynamic planning capability of flood mitigation recommendations*, capable of mutual upgrading and updating, so that flood protection and resilient design investments by the State of NJ and other Federal organizations such as FEMA, USACE, and HUD for coastal and fluvial communities are made as a result of coordination and integration between the State of New Jersey strategy and action plans and the developing comprehensive strategies by Federal agencies addressing the flood protection and mitigation needs of the North Atlantic Coast.

The immediate objective of this project is to provide the needed flood protection and mitigation engineering solutions for the Hackensack area (including the Boroughs of Moonachie and Little Ferry, and the City of Hackensack) by evaluating local and regional alternatives and recommended measures. From the initial launch of this project, the FMERC team was integrated within the key initiatives at the State and Federal levels and has coordinated some of its analytical approaches and data acquisition strategies with current and past work and activities of the US Army Corps of Engineers, FEMA, HUD and other State level initiatives NJDEP (debris removal, permitting, etc.), NJDOT, Port Authority of New York and New Jersey.

Additionally, the FMERC Team worked in concert with the following entities and initiatives:

1. The Meadowlands Environmental Institute and its range of flood protection project, flow monitoring and contaminant tracking in the Meadowlands.
2. Bergen County, its Executives and Flood Coordinator and its affiliates, such as the Mosquito Control Commission, which would have ownership and supervisory responsibility over berm structures, which are contiguous to important drainage waterways (ditches).
3. Municipalities, their administrative, emergency management and engineering departments on a range of infrastructure and other resiliency improvement projects.

1.3. Sandy Before During and After: An Infrastructure Cascade Failure

The impact of Sandy on the municipalities of Moonachie, Little Ferry and Hackensack was devastating as was the situation for much of New Jersey. Recent revisions of the flood impacts placed Sandy at about a 100 year storm event, given the increased frequency of storm surge events in the last few decades. For Moonachie and Little Ferry in particular, the streets were filled with (up to) five feet of water within a thirty-minute period of the onset of flooding. The residents needed the help of emergency personnel to rescue them from their homes. Most observers attributed the flooding conditions in riverine and inland areas along the Hackensack River to the storm surge from the ocean at Newark Bay which generated flooding conditions in the Hackensack River, and caused overtopping of the levees or berms, which were designed to protect the community. As shown herein, the flooding conditions which were uneven in their duration and severity resulted from an infrastructure cascade failure, which was unavoidable due to the height of the tidal surge recorded for several hours, and the ensuing insufficiency and incapacity of the general infrastructure in the subject municipalities to provide relief from the resultant flood waters.

The FEMA Coastal Analysis and Mapping Division made available Hurricane Sandy Advisory Base Flood Elevations (ABFEs) Interactive Maps in New Jersey and New York. Some of the interactive map outputs for Hackensack, Little Ferry and Moonachie are shown in Figures 4 to 6, with the areas in pink showing areas which experienced the highest flood water elevations.

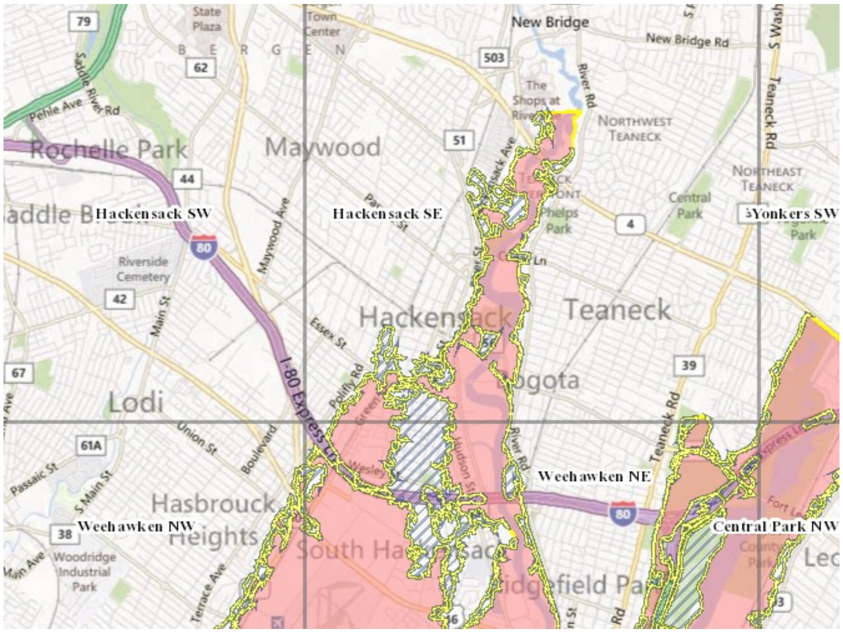


Figure 4. Advisory Base Flood Elevation Map (Interactive) – FEMA: Hackensack

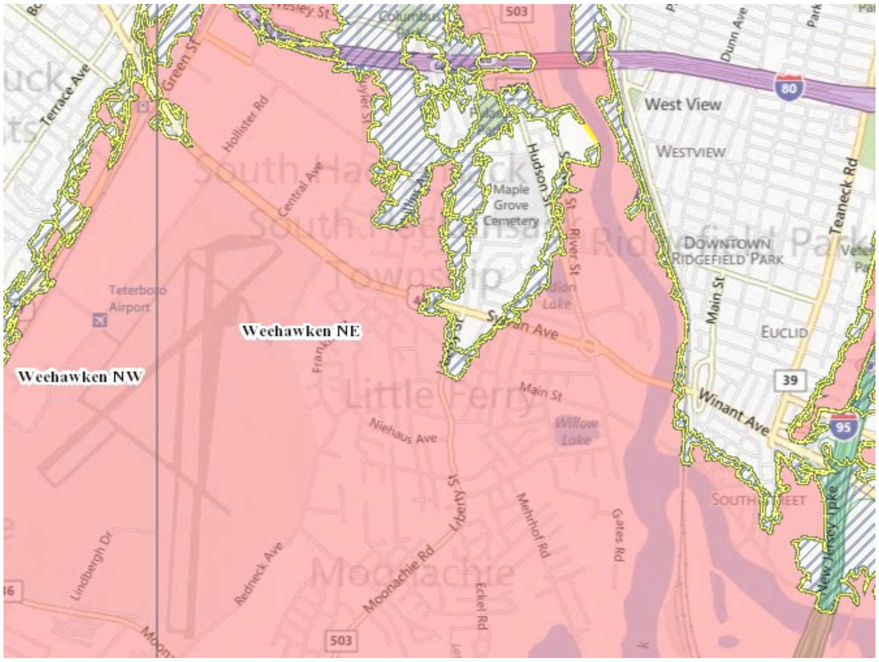


Figure 5. Advisory Base Flood Elevation Map (Interactive) – FEMA: Moonachie

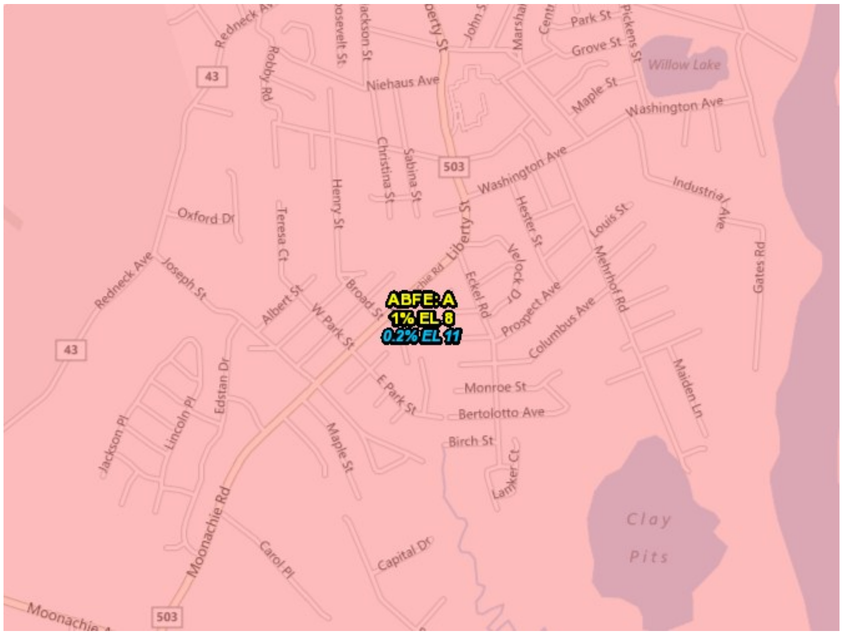


Figure 6. Advisory Base Flood Elevation Map (Interactive) – FEMA: Little Ferry

1.4. Inception of the Project: Damages caused by Sandy

As mentioned above, the damages caused by Sandy in the study area were the result of a combination of a high severity of flooding (5 to 6 feet of water in some neighborhoods) for an extended period of time (5 or more days). The study area is no stranger to flooding, and has seen a disproportionate share of repetitive losses over the recorded past, particularly during the last two major storms, Irene and Sandy.

As can be seen in Figure 7, major flooding occurred in many of the Meadowlands communities surrounding the study area, including industrial areas of Carlstadt, and areas of Lyndhurst, which experienced major damage. The areas that experienced major flooding are delineated in the flood maps clearly showing that the depth of flooding in the Meadowlands goes beyond Little Ferry, and Moonachie, but the lack of mitigation capability in these two communities exacerbated the problem.

What made the extent of damage particularly severe for Moonachie and Little Ferry was the inability of the drainage system to clear some of the standing waters both during and in the aftermath of the storm due to a power shutdown, the unavailability of backup generators to operate the pumping stations, and the inadequacy of the municipal and regional drainage network, due to both undersized main collector pipes, lack of local storage facilities and the widespread blockage of many waterways (ditches), which are major drainage inflow points.

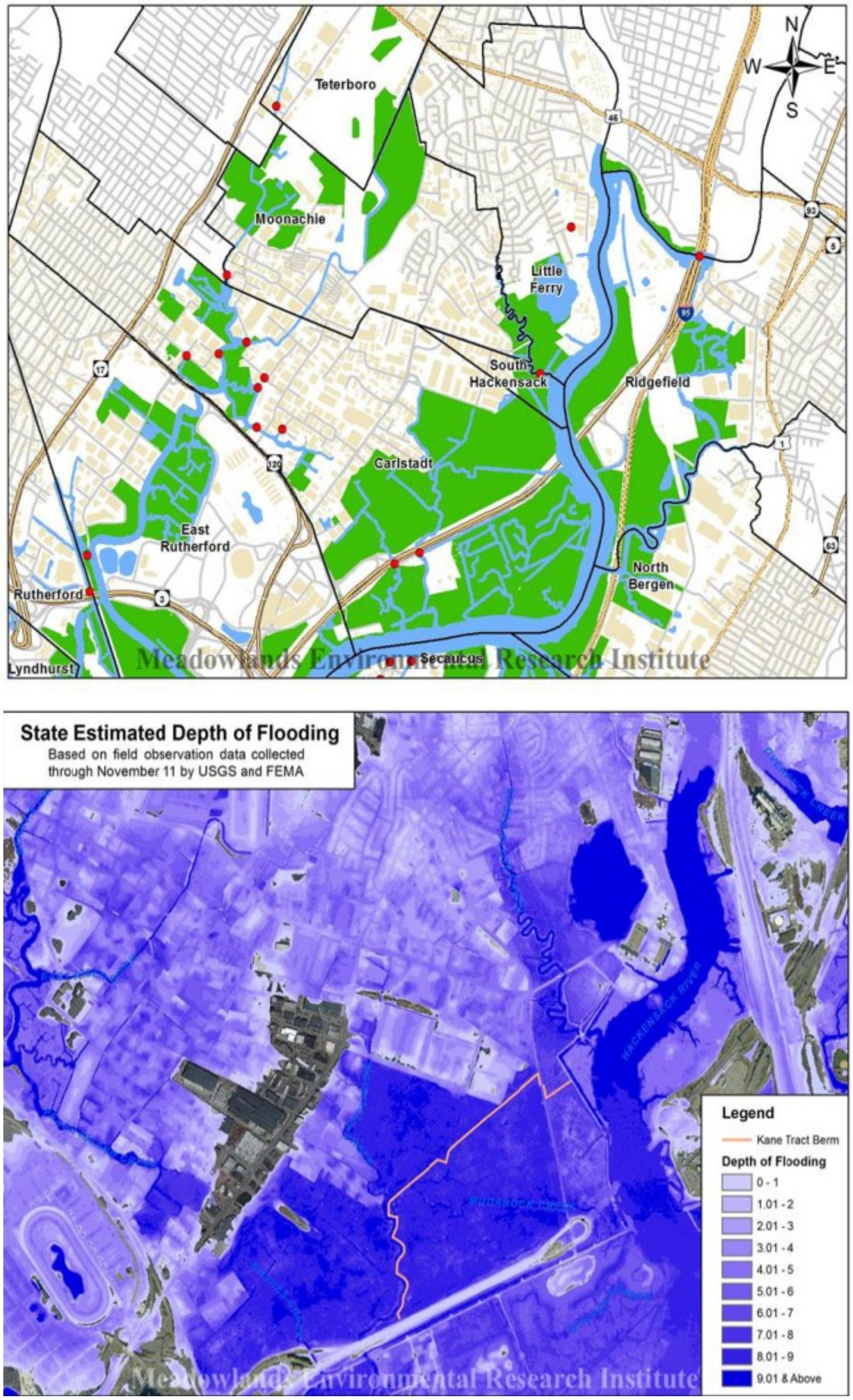
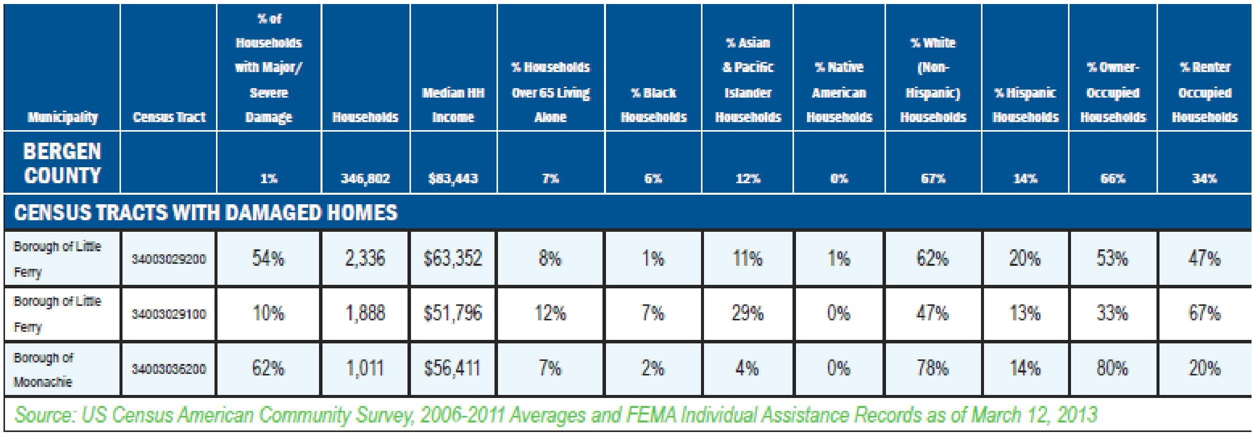


Figure 7. State Estimated Depth of Flooding based on USGS and FEMA field data

In the study area, elevated runoff levels are impacting urban streams, increasing sediment and pollutant loads, and degrading stream habitat. The lack of maintenance of existing drainage systems and channels were a major factor in elevating the damage caused by Sandy.

The damage in Bergen County was largely concentrated in communities and entities along the Hackensack River such as Little Ferry, Moonachie, and Hackensack. Homes with major or severe damage in Bergen County account for almost 5% of all major and severe damage across the State. The vast majority of damage occurred to owner-occupied homes. As shown in table 3, two census tracts had more than 50% of households experience severe or major damage, and one census tract had between 10% and 24% of households experience such damage. In addition to residential, commercial and industrial damage was also experienced.



Municipality	Census Tract	% of Households with Major/ Severe Damage	Households	Median HH Income	% Households Over 65 Living Alone	% Black Households	% Asian & Pacific Islander Households	% Native American Households	% White (Non-Hispanic) Households	% Hispanic Households	% Owner-Occupied Households	% Renter Occupied Households
BERGEN COUNTY		1%	346,802	$83,443	7%	6%	12%	0%	67%	14%	66%	34%
CENSUS TRACTS WITH DAMAGED HOMES												
Borough of Little Ferry	34003029200	54%	2,336	$63,352	8%	1%	11%	1%	62%	20%	53%	47%
Borough of Little Ferry	34003029100	10%	1,888	$51,796	12%	7%	29%	0%	47%	13%	33%	67%
Borough of Moonachie	34003036200	62%	1,011	$56,411	7%	2%	4%	0%	78%	14%	80%	20%

Source: US Census American Community Survey, 2006-2011 Averages and FEMA Individual Assistance Records as of March 12, 2013

Table 3. % of Households with major/Severe Damages in 2 study area Census Tracts and Associated Demographics

As noted above, other communities and entities such as Carlstadt, Lyndhurst and the Hackensack NJ Meadowlands Commission also experienced major damage.

1.4.1. *Flooding in the Meadowlands: A multi-dimensional Problem*

Flooding in the study area, along with other low-lying areas in the Meadowlands is a multi-dimensional problem. The three municipalities are subject to three types of flooding which are fluvial flow, tidal flow and surges.

Fluvial floods occur, on average, approximately every three years in this region. Floods are caused by intense rainfalls that cause overflow onto the floodplains of the rivers and streams. These moderately, frequent flood events do not have major consequences and can normally be handled by the communities and the county. However, in the recent past, due to drainage network deficiencies, flooding frequency has increased in the study area, making flooding a Recurrent or even “Chronic” problem.

Extreme fluvial floods due to heavy rainfalls, such as experienced during Hurricane Irene, are less frequent and produce greater fluvial flooding events that have major damages and impacts on the communities, and 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 protection systems for the three municipalities, which are influenced by drainage and pumping policies of surrounding jurisdictions.

Tidal events are infrequent but can have severe consequences. A tidal event combined with a high fluvial flow can produce even more severe events. Partial protection is currently provided by an incomplete and inadequate system of Berms and Tide Gates, which is in need for extension, raising and reinforcing, as it may not be able to even 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 that the three towns may not have.

A surge event such as Hurricane Sandy is considered very infrequent (Sandy was updated to a 100-year return period Storm). 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. As the analysis that FMERC performed has shown, the protection of study area communities from a surge along the Hackensack River requires significant funding that only the federal government can support. It is therefore clear that the "do nothing" alternative is not an option, as vulnerable areas along the Coast, and along closed bays and low-lying areas of the Meadowlands are at a high flood damage risk level, as was proven by the onslaught of Sandy.

The local flooding problems of the three municipalities are varied as follows:

1- ***Inadequate Maintenance of the current protection system for flooding***: The system of waterways and berms is in major need for upgrading and improvement.

2- ***Interdependency and Negative Impact of Drainage and Pumping Practices***: An example of solving one problem causing another is the drainage of flood waters from Teteboro Airport. Teteboro Airport floods under heavy rainfall as stream overbank flows cause flooding at the Airport. To maintain the functioning of the Airport, flooded areas at the Airport are currently pumped downstream through low capacity ditches and streams. This practice exacerbates the flooding problems downstream in Moonachie. It is general practice that upstream areas should not increase flows downstream by pumping water from their property. Typically, the needed pumping should be delayed until the flood has subsided, unless the ditches in Moonachie are given increased capacity.

3-***Contamination Risks***: The ditches convey waters from the area to the streams and rivers. The flooding from the Sandy "SURGE" caused chemicals to flow into the ditches and thereby contaminated the soils that are part of the ditches. In order to facilitate the flow of the floodwaters, it is necessary to dredge the ditches thereby increasing their flow capacities. However, the contamination of the dredged material and its ultimate disposal is a major issue of itself.

In summary, the study area is vulnerable to three complex types of flooding, which can conceivably compound into a mega-flood event. Additionally, an Oradell dam break is a hazard which may further compound the extent and magnitude of inundation under a combined event in the study area.

The infrastructure cascade failure resulting from the abovenoted modes of flooding can be described by the following sequence of events:

- Initiating Event: Flood Protection Structures Fail (Berms Overtopping and Breach) due to Surge. Both Tide gates and Berms cannot stop the 9 ft wall of water associated with a Storm like Sandy.
- Inundation of Towns like Moonachie with 5 ft to 6 ft of water
- Infrastructure Failures (undersized systems, Storm water pump station failure, unavailability of generators) lead to extended period of "paralysis" and inundation. Even after storm/water levels receded, standing water could not be drained.
- Interdependencies between contiguous communities, their pumping practices lead to second-hand flooding.
- Waterways (Ditches) unable to move water out fast enough creating localized flooding and potential contamination.

As a result of multiple interviews and responses to questionnaire surveys with representatives from Hackensack, Little Ferry and Moonachie, as well as meetings at the offices of the Meadowlands Environmental Institute and Bergen County, the following summarizes the findings of the highlights of Sandy impacts:

1.4.2. *Hackensack Impact Analysis and Survey Results*

- Flooding (Sandy) from Berry's Creek; Hudson Street was vulnerable during Sandy, with approximately 4 ft of water in the street due to storm surge on Hudson Street and River Street (adjacent to Hackensack River).
- There was a few feet of inundation for a duration of about 24-48 hours during Sandy
- The flooding problem was exacerbated by the neighboring Green Street ditches which were not properly maintained (a recurring issue in the City).
- The highest priority project for the City is to obtain generators at an estimated cost of one million dollars.
- Combined Sewer Separation project: $4 Million is proposed out of the $30-50 Million required to do all parts of the separation. This is a major capital project, an integral part of the Main Street Rehabilitation project.

1.4.3. *Little Ferry Impact Analysis and Survey Results*

- The Borough's primary flood prevention and mitigation strategies are focused on pumping water out of Borough lands and waterways and into the Hackensack River. To accomplish this, the Borough has three flood water pumping stations at the following locations: the meeting of Losen Slote Creek and the Hackensack River, 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 NJDOT improvements to Route 46.
- Fluvial flooding occurs every 1 to 2 years during rainfall events; one occurred in June 2013.

- Pumping capacity (see Figure 8 for pump station locations) needs enhancement to insure that during flooding conditions, drainage relief can be accomplished in hours rather than days, when major storm events such as Sandy occur.
- Approximately 1,700 properties were touched by various heights of water (70 homes experienced over 50% damage).
- Major impacts on critical infrastructure/lifeline systems: power loss and natural gas service interruption due to inundation were experienced for almost a week.
- Impacts on sewer and storm water systems: Failures due to power loss and lack of backup generators.
- Infrastructure resilience improvement measures are a must. Many failures in the local and regional drainage network.

Figure 8. Map of Tide Gates, Pump Stations and Berms in Little Ferry, Moonachie and Hackensack

In Figure 9, the Barge Marina water level is displayed for the period of October 27 to October 31, 2012. The red line represents the berm, which was overtopped as 7 feet of tidal water entering Little Ferry and surrounding towns from 8 PM on the 29th to 2 AM on the 30th of October, 2012 flooded the study area (source: MERI, Little Ferry post-Sandy presentations).

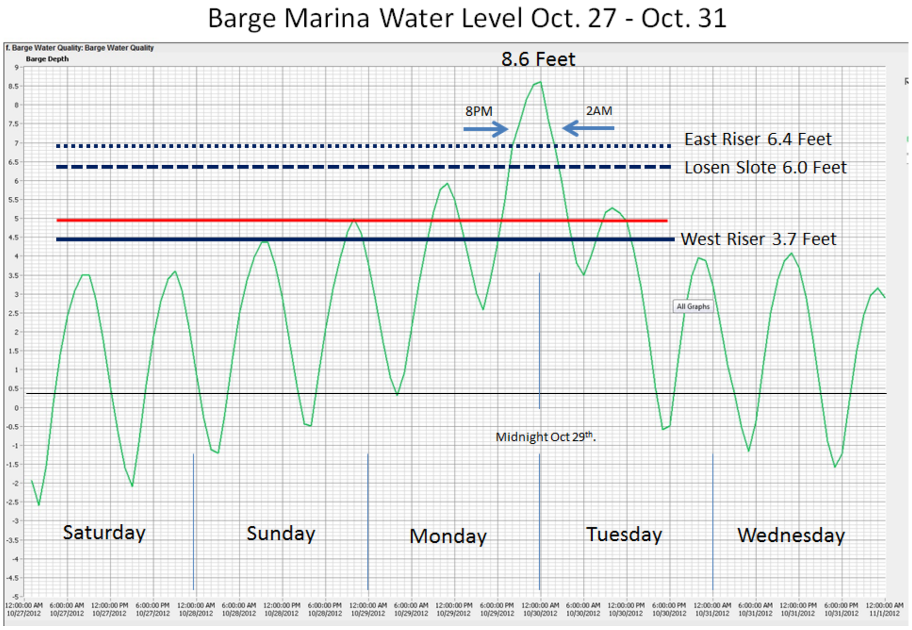


Figure 9. Barge Marina Water Level (Oct. 27- Oct. 31, 2012)

1.4.4. *Moonachie Impact Analysis and Survey Results*

- Moonachie is surrounded by a number of streams and located at a much lower elevation (Much of the town at elevations of +2 to +3 above the datum (NAVD 88), compared to the nearby towns. After the expansion of sprawl development, much more runoff was generated, and forced the borough to install three pumping stations to move the storm water from collection locations to nearby streams.
- All 3 Pumping Stations failed during Sandy (Figure 8 above)
- With hardly any advance notice or early warning, the municipality "all went down in a matter of minutes".
- The berms, currently at elevation +6, were overtopped during Sandy (according to the HMDC, the height of the sea surge reached +9.5 ft and remained above 7 ft for a duration of 6 hours, figure 10 below).
- Due to fluvial flooding, because of its topography, Moonachie experiences flooding approximately every 2 years when it experiences a 3 to 4 inch precipitation event within a 24 hour period.

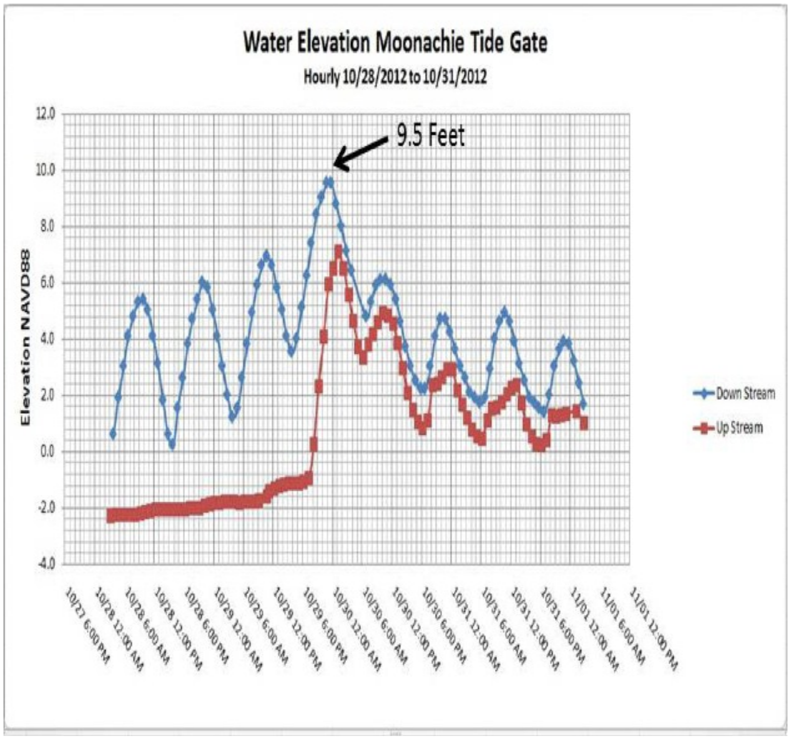


Figure 10. Moonachie Tide gate peaking at 9.5 Ft (MERI)

- Since the Borough is topographically in a “bowl,” relief due to storm water pumping during flood events is affected by power outages, and by generator outages due to elevation issues.
- Fluvial issues are impacted by lack of maintenance in cleaning local ditches and dredging of the Hackensack River due to permitting problems with the NJDEP, EPA and the US Army Corps of Engineers (USACE). Emergency permitting by the State of New Jersey enabled the partial cleaning of ditches in the aftermath of Sandy, but more extensive planning and design of remedial work is still needed.
- Maintenance of berms is an issue as well, breaches occur, on average every 5 years.
- Major impacts on critical infrastructure/ lifeline Systems: Storm water Systems Failures were experienced due to power loss and lack of backup generators.
- Infrastructure resilience improvement measures are a must. Many failures were experienced in the local and regional drainage network.

2. DEVELOPMENT OF FLOOD PROTECTION AND MITIGATION ALTERNATIVES

2.1. Range of Alternative Protection and Mitigation Measures

Protective and adaptive alternative solutions that were considered by this study include three categories: maintenance & operations, capital investments and regulatory. Maintenance and operation type strategies include such measures as sandbagging, portable pumps, temporary flood gates and the cleaning of drainage systems. Capital investments are permanent or mobile adjustable improvements and include installation of new fixed or adjustable flood barriers (e.g. proposed structural measures cited below); designing and building new green infrastructure and storage facilities (see non-structural measures below), elevating elements of critical infrastructure to levels above projected flood elevations; relocation of critical facilities to higher ground, and designing new assets for quick restoration after an extreme event. Regulatory strategies include modification of city building codes and system level and component-level design standards. For example, system-level engineering redundancy such as the interconnection of electric sub-stations can prove to be invaluable during or in the aftermath of a major Storm, when one sub-station fails. The multi-disciplinary team addresses and evaluates the range of alternative solutions including those presented below from an integrated effectiveness, cost-benefit and risk/vulnerability standpoint.

2.2. Capital Investment/Hard-Structure Storm Surge Protection Measures: Feasibility Study of Structural Mitigation Solutions

2.2.1. *Background*

The widespread damage caused by Superstorm Sandy, coupled with the chronic flooding that occurs throughout the study area, prompted the NJIT FMERC Research Team to investigate the feasibility of a variety of large-scale structural mitigation solutions. This is not the first time that such solutions have been proposed to protect these Meadowland communities. For example, in 1981, the U.S. Army Corps of Engineers studied the feasibility of constructing a tidal barrier across the Hackensack River in the vicinity of Kearny Point (USACE & TAMS, 1981). Then, in 1993, the Corps proposed a system of ring dikes around portions of Moonachie to flood proof the community (4). The three dike wall enclosures with total length of 10.5 miles were mainly a reaction to the major coastal storm associated with Hurricane Grace, which occurred two years earlier. More recently in 2004, the Marine Sciences Research Center studied the addition of three tidal barriers to protect New York Harbor (SUNY, 2004). The study concluded positively as to the potential of a 3-barrier system (Figure 17) to provide tidal surge protection to a large coastal and riverine area of NY and NJ surrounding the New York Harbor. If this project was undertaken, it would have negated the need to construct a dedicated tidal barrier across the Hackensack River.

Study Name and Date	Authors	Description	Original Cost/ Benefit-Cost Ratio
Reconnaissance Report for Flood Control Measures, Hackensack River Basin, Hudson and Bergen Counties, New Jersey. January 1981.	U.S. Army Corps of Engineers – New York District & TAMS Consultants, Inc.	Determine federal interest in more detailed engineering studies of flood control measures in the Hackensack Meadowlands. Revaluated the feasibility of a tidal barrier and associated levees and walls across the Hackensack River in the vicinity of Kearny Point using a mathematical model, LATIS.	$202 mil B/C = 2.4:1
Flood Control Study Reconnaissance Report, Hackensack River Basin, New Jersey. June 1993.	U.S. Army Corps of Engineers – New York District	Determined federal interest in a plan to alleviate the flooding problems within the Hackensack River Basin. Investigated several structural and non-structural measures including a system of three ring dike enclosures to protect sections of Moonachie. Also coordinated with NJDEP to determine environmental and cultural impacts.	$138 mil B/C = 2.8:1
Hydrologic Feasibility of Storm Surge Barriers to Protect the Metropolitan New York-New Jersey Region. November 2004.	Marine Sciences Research Center, State University of New York	Examined hydrologic feasibility of storm surge barriers to protect the metropolitan New York–New Jersey region using combined meteorological-hydrodynamic modeling. Three locations proposed: the Narrows, mouth of Arthur Kill, and upper East River. Concluded that 3-barrier system would successfully prevent flooding from storm surges in hurricanes and severe nor'easters.	Cost Estimate not provided.

Table 4. Summary of Historic Flood Protection Studies in Meadowlands Area

A brief summary of the scope and results of the two U.S. Army Corps studies, as well as the 2004 regional tidal barrier study is provided in Table 4. Also included are the cost estimates when provided in the studies, and the benefit-cost ratio, which represents the ratio of the present value of all total yearly benefits, to the present value total yearly ownership costs over the planning horizon. The FMERC Team was able to glean certain useful data from U.S. Army Corps of Engineers studies. However, it quickly became clear that some of the alignments and details of these historic proposals could be improved upon, and more innovative solutions could be developed. Thus, an entirely new strategy of flood protection was developed for Moonachie, Little Ferry, Hackensack, and the adjoining communities, which are described in the next section.

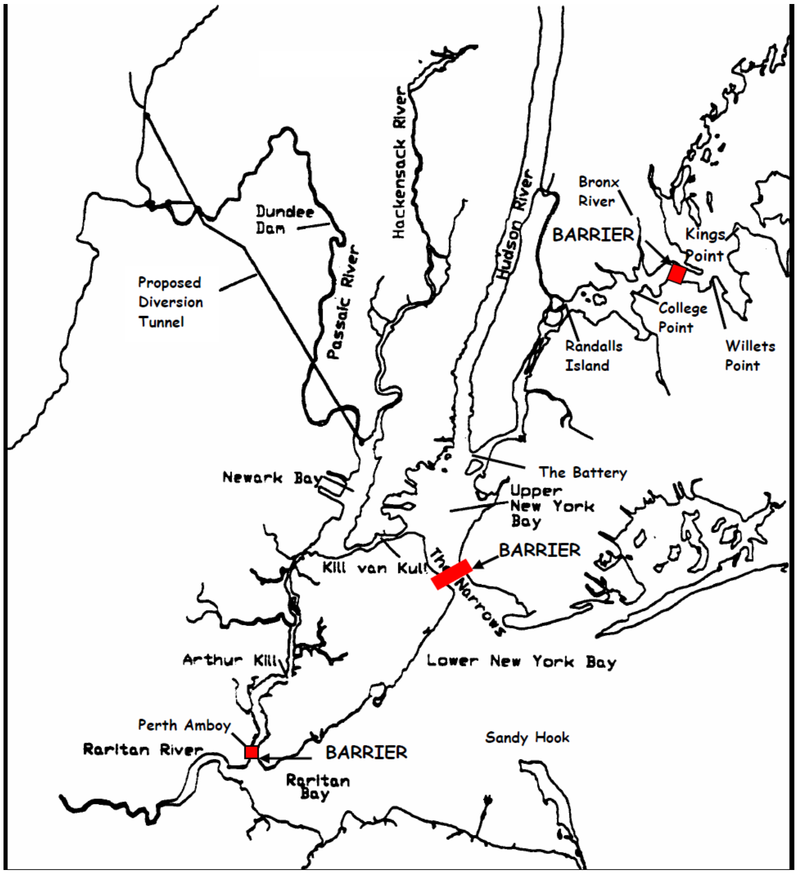


Figure 11. Proposed Three Flood Barriers to protect the waterways surrounding New York City from coastal flooding* (SUNY, 2004)

2.2.2. *Overview of Protection Strategies*

In Summer of 2013, the NJIT Research Team embarked on a feasibility study to evaluate flood mitigation alternatives for Moonachie, Little Ferry, and Hackensack. The result, which is detailed in this chapter section, has been the development of a comprehensive plan of structural flood protection that can benefit not only these target municipalities, but also a number of neighboring communities within the Hackensack Meadowlands. A key feature of the plan is that it is phased, that is, it contains short-term measures that provide some immediate relief, medium-term measures that substantially boost the level of flood protection, and long-term measures that guard against the most extreme weather events, exceeding even Superstorm Sandy. Also, the NJIT proposed plan is graduated with respect to investment in order to facilitate the formation of governmental partnerships and identification of funding sources to accomplish the improvements.

Consistently with the flood types described in Section 1, the protection strategies can be divided into three general categories. The first is Riverine Flood Protection, which is aimed at alleviating floods that result from intense rainfall events as opposed to major storms. These kinds of floods typically involve one or more of the following: (1) overwhelming of the piped storm drainage systems; (2) overtopping of streams and drainage ditches; and (3) overtopping of the Hackensack River. The first two can result from any high intensity, short-duration storm such as may occur during a heavy thundershower. The latter case, flooding of the Hackensack, requires more sustained rainfall over a period of days. The second strategic category is Tidal Surge Protection, which provides protection against storm surges associated with tropical storms or hurricanes. Here the hazard is a wall of water that emanates from New York Harbor and travels inland, up the Hackensack River and into its tributary streams. Such storm surges are caused by a combination of: (1) high tide; (2) water rise due to excessively low atmospheric pressure; and (3) wind driven waves.

The third protection strategy is a combination of Riverine Flood Protection and Tidal Surge Protection. This category seeks a balanced approach that is designed to mitigate both kinds of flooding using the same structure.

A summary of all three kinds of flood protection strategies and the associated structural alternatives is provided in Table 5, and a detailed description of each is given below. Note that the NJIT Research Team conducted a number of field visits to examine the existing site conditions and to verify the feasibility of alignments for each protection alternative. The short-term measures related to targeted improvements at the overall network level to the municipal and regional drainage systems, as well as flood protection structures and community resiliency measures are covered in more detail in the following sections.
A description and review of the medium to long-term hard-structure solutions proposed by our team is the focus of the rest of this section.

R2 – Arc Wall (Medium Term)
The "Arc Wall" involves construction of a continuous 6.5-mile wall to provide substantial relief from chronic flooding of streams, ditches, and the Hackensack River during heavy rainfall events. The wall is an improvement over the ring dikes proposed by the 1993 U.S. Army Corps of Engineers (see Table 4) in that it is a coherent solution for flood protection, rather than have each community fend for itself. Specifically, the Arc Wall is about 40% shorter, yet it protects a land area that is several times greater than the Corps' proposal. It is proposed to build the wall to a top elevation of +10 ft., which was carefully selected to provide a high degree of protection from riverine flooding. Yet, at this elevation, the Arc Wall also affords a moderate degree of protection against storm surges, since area tidal gages during Sandy peaked around Elev. +9.5 ft.

The proposed alignment of the Arc Wall is shown on Figure 12. It starts on the west end in the vicinity of Route 17, where it will anchor into high ground. The wall generally parallels Paterson Plank Road, then striking northeasterly across the Meadowlands to meet the western shore of the Hackensack River, terminating on its east end near Route 46, where the grade rises above Elev. +10. Note that the depicted alignment is conceptual, and the final route would be determined during the preliminary design stage.

Protection Strategy	**Mitigation Alternative**	**Time Horizon**	**Brief Description**	**Estimated Cost & Benefit**	**Principal Communities Protected**
Riverine Flood Protection	R1 – Storm Drainage Improvements	Immediate	Includes various measures identified by the affected communities to construct, repair, and upgrade storm drainage elements including dredging of drainage channels, cleaning of inlets and piping , culvert maintenance or replacement, rebuilding berms, upgrading pump stations and tidal gates, and providing resilient power systems. It is strongly recommended that these be implemented immediately with Post-Sandy emergency funding.	**Initial: $52.1 mil** **Maint: 1 mil/yr**	1. Moonachie 2. Little Ferry 3. Hackensack
Riverine Flood & Tidal Surge Protection	R2 – Arc Wall	Medium Term	Involves construction of a 6.5-mile wall (top Elev. +10 ft) to provide substantial relief from chronic flooding of streams, ditches, and the Hackensack River during heavy rainfall events. The Arc Wall will also provide a moderate degree of protection against storm surges (for example, area tidal gages during Sandy peaked at Elev. ~+9.5 ft). Given the moderate cost and strongly positive cost-benefit ratio, it is recommended that governmental partnerships be formed now to identify funding sources to accomplish the work.	**Initial: $180 mil** **M&R: $3 mil/yr** **B/C = 4.6**	1. Moonachie 2. Little Ferry 3. Hackensack 4. Carlstadt 5. Teterboro 6. South Hackensack
Tidal Surge Protection	T1 – Tidal Barrier North (Alternate 1)	Long Term	Involves construction of a 5.5-mile long navigable tidal barrier across the Hackensack River with adjacent flood walls (top Elev. +12 ft) to provide complete protection against storm surges and rising sea level for centuries. Proposed alignment is generally east-northeast paralleling Route 3 and the NJ Turnpike. Should be coupled with Alternatives R1 and R2 above to provide relief from local riverine flooding.	**Initial: $735 mil** **M&R: $10 mil/yr**	1. Moonachie 2. Little Ferry 3. Hackensack 4. Carlstadt 5. Teterboro 6. South Hackensack 7. East Rutherford 8. Rutherford 9. Ridgefield
Tidal Surge Protection	T2 – Tidal Barrier Middle (Alternate 2)	Long Term	Involves construction of a 4-mile long navigable tidal barrier across the Hackensack River with adjacent flood walls (top Elev. +12 ft) to provide complete protection against storm surges and rising sea level for centuries. Proposed alignment is generally east-west paralleling Route 3. Should be coupled with Alternatives R1 and R2 above to provide relief from local from riverine flooding.	**Initial: $611 mil** **M&R: $11 mil/yr**	1. Moonachie 2. Little Ferry 3. Hackensack 4. Carlstadt 5. Teterboro 6. South Hackensack 7. East Rutherford 8. Rutherford 9. Ridgefield 10. Part of Secaucus 11. Part of North Bergen
Tidal Surge Protection	T3 – Tidal Barrier South (Alternate 3)	Long Term	Involves construction of a 2.5-mile long navigable tidal barrier across both the Hackensack and Passaic Rivers with adjacent flood walls (top Elev. +12 ft) to provide complete protection against storm surges and rising sea level for centuries. Proposed alignment is generally east-west transecting Kearny Point. Should be coupled with Alternatives R1 and R2 above to provide relief from local riverine flooding.	**Initial: $1,590 mil** **M&R: $15 mil/yr**	1. Moonachie 2. Little Ferry 3. Hackensack 4. Carlstadt 5. Teterboro 6. South Hackensack 7. East Rutherford 8. Rutherford 9. Ridgefield 10. Part of Secaucus 11. Part of North Bergen 11. Kearny 12. Kearny Point 13. Part of Jersey City 14. Harrison (?) 15. East Newark (?)

Table 5. Summary of Recommended Flood Mitigation Strategies and Improvements

The design and composition of the wall will vary according to the required height, right of way availability, and local geologic conditions. Many wall sections will likely consist of a combination of raised berms, sheet pile walls, raised roadways, tidal gates, and movable roadway gates. Schematic designs of potential structural wall designs are illustrated in Figure 13. In addition, a number of innovative design options for fixed and moveable walls have been investigated for possible use, including some developed by the NJIT Team.

Active roadways and railways will necessarily penetrate the Arc Wall at a number of locations. Wherever possible, roads and rails will be raised to maintain a continuous line of flood protection, while still accommodating normal traffic. In areas where raising is not feasible due to geometric considerations, potential gaps in the wall line will exist. To prevent entry of floodwaters through such depressions, moveable gates will be installed that can be closed when flooding is anticipated, and traffic will be diverted to adjacent roadways.

The Hackensack Meadowlands is the remnant of an ancient glacial lake formed during the retreat of the Pleistocene ice sheet. Thus, the whole area is low and poorly drained, and the natural surficial soil is a highly organic layer known as “meadowmat.” This, in turn, is underlain by soft glacial silts and clays, and a veneer of surface fill is also present at many locations. These layers are generally weak and often compressible, so the construction of special foundations will be required to support the Arc Wall in many areas. Depth to bedrock varies widely along the Arc Wall, with top of rock elevations ranging from approximately -20 to -100 ft. The bedrock surface is similarly variable for the other alternate wall alignments, reaching Elev. -200 ft. in some locations.

All sections of the Arc Wall must be designed to resist both the erosive action of riverine flood waters and the pressure of storm surge waves. Global stability and underseepage of each wall section must also be checked to prevent deep-seated foundation failures. New and resilient pumping stations will also be required at intervals along the Arc Wall to eject rainwater that falls within the wall enclosure.

To control cost, the Arc Wall will take advantage of existing embankments, berms, and levees, wherever possible. For example, the earth embankment supporting the recently constructed NJ Transit spur serving the MetLife Stadium is well positioned and of sufficient height to provide over 1000 ft. of “free” flood wall. Similarly, existing earth berms and levees parallel large sections of the west shore of the Hackensack River. Most of these rise to approximately Elev. +6 ft., so extending them just a few feet higher can be done at moderate cost and will not be architecturally obtrusive.

The preliminary budget cost estimates developed for the Arc Wall and all other alternative alignments (see below) are for complete, in-place construction based on 2014 costs. Project costs include: design, right-of-way acquisition, wetlands mitigation, construction of project elements (berms, walls, gates, road raising, etc.), and overhead and profit. The costs of deep foundations and/or preloading are also included in sections where the subsurface soils are weak and compressible. Annual maintenance, repair, and operating costs cover all wall and berm structures, as well as appurtenant elements such as drainage ditches, drainage structures, closure gates, tide gates, pump stations, and generators.

It is noteworthy that the Arc Wall protects not only the target municipalities of Moonachie, Little Ferry and Hackensack, but it also will alleviate chronic flooding within the “upstream” communities of Carlstadt, South Hackensack, and Teterboro.

The estimated total cost to construct the Arc Wall is $180m, with an annual maintenance, repair, and replacement cost of $3m. The quantity takeoff and unit costs used for the estimate are summarized in Appendix A2.

Consistently with the assumptions made in the 1993 USACE study (4), and assuming an average of 50% increase in development for a planning period of 50 years, a benefit/cost (B/C) ratio was calculated for the Arc Wall, assuming a 50 year life and an annualized using a capital recovery factor of 4% (See Appendix A1). The B/C ratio for the project was determined to be 4.6, which is many times greater than unity. Thus, it is clear that the Arc Wall is an excellent investment, especially given the number of communities protected and the fact that the wall provides substantial protection from both riverine flooding and storm surge. The Arc Wall is therefore considered to be a basic need, and it is recommended that governmental partnerships be formed immediately to identify funding sources to accomplish the project.

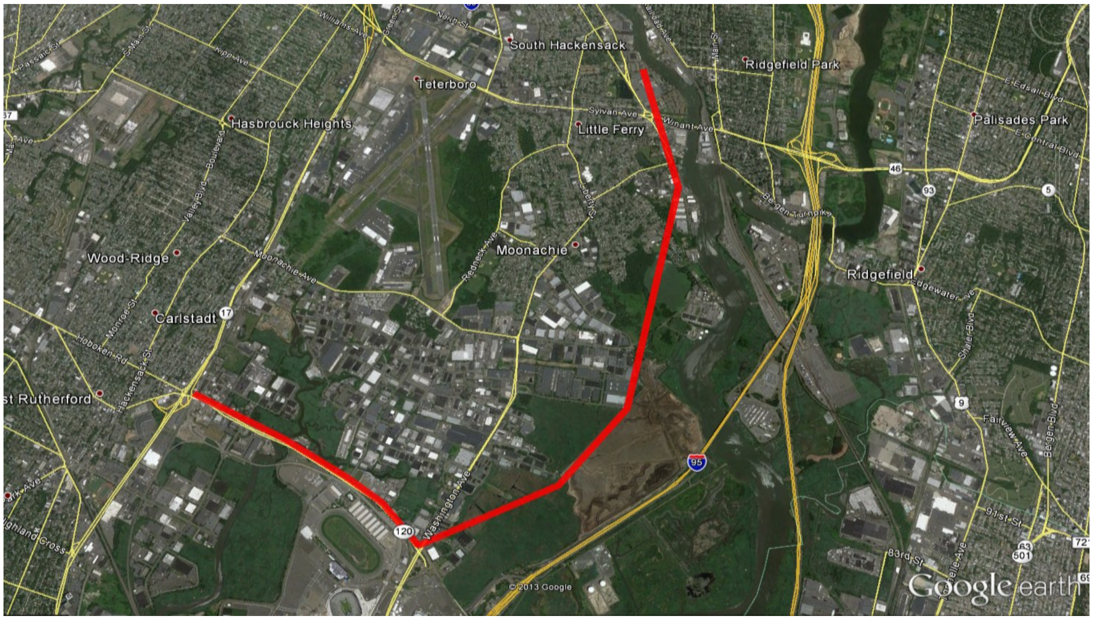


Figure 12. Conceptual Alignment of Arc Wall (R2) Alternative

Note that none of the tidal barrier options provide relief from local riverine flooding within the target communities of Moonachie, Little Ferry, and Hackensack. Thus, it will be necessary to couple any of the tidal options with alternatives R1 and R2, as described above.

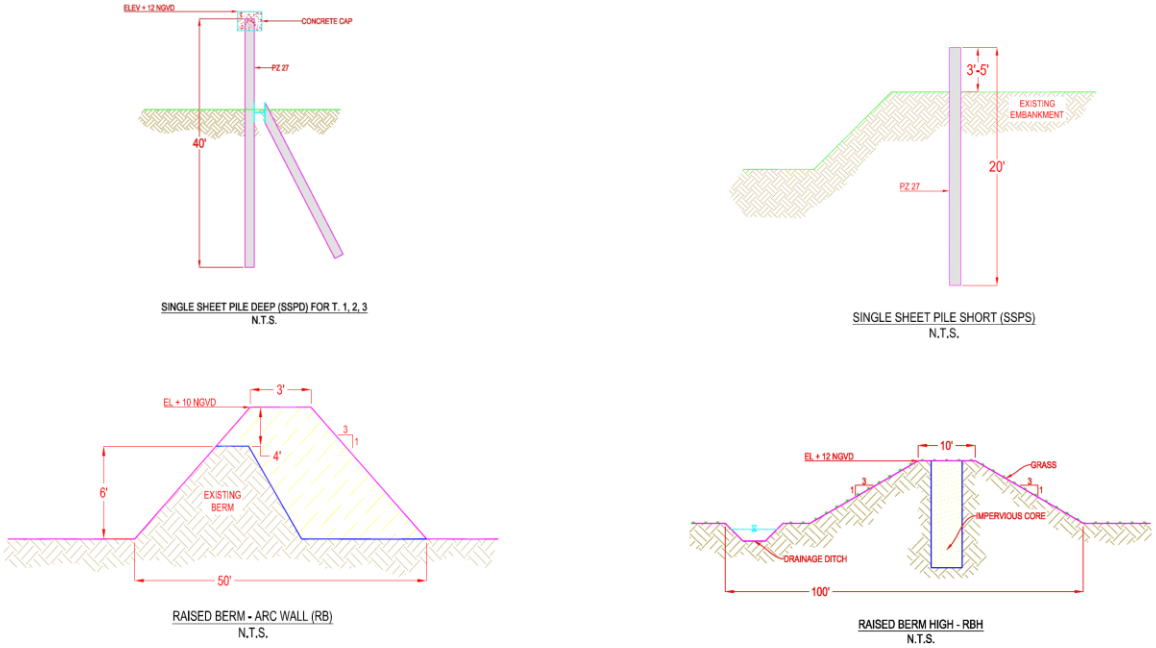


Figure 13. Schematic Designs of Potential Wall Sections

T1 – Tidal Barrier North (Long-Term Alternate 1)

The total length of this most northerly tidal barrier will be 5.5 miles, and its alignment is shown conceptually on Figure 14. The proposed barrier will start on the west end at Route 17 where it will anchor into high ground. The wall then parallels Route 3 to the intersection with the Turnpike, where it turns northward following the shoulder of the Turnpike, eventually crossing the Hackensack River with a navigable tidal barrier and terminating on its east end into elevated ground in Ridgefield. Existing roadway embankments at the interchanges of Route 3/Route 17 and Route 3/Turnpike will be incorporated into the wall to reduce costs. Additional cost savings can be realized by utilizing the shoulder of the Turnpike as a construction platform for the part of the wall that parallels this toll road.

The estimated total cost to construct the Tidal Barrier North is $735m, with an annual maintenance, repair, and replacement cost of $10m. The quantity takeoff and unit costs used for the estimate are summarized in Appendix A3. Note that the Tidal Barrier North will protect a total of 9 communities from the effects of storm surge (see list in Table 5).

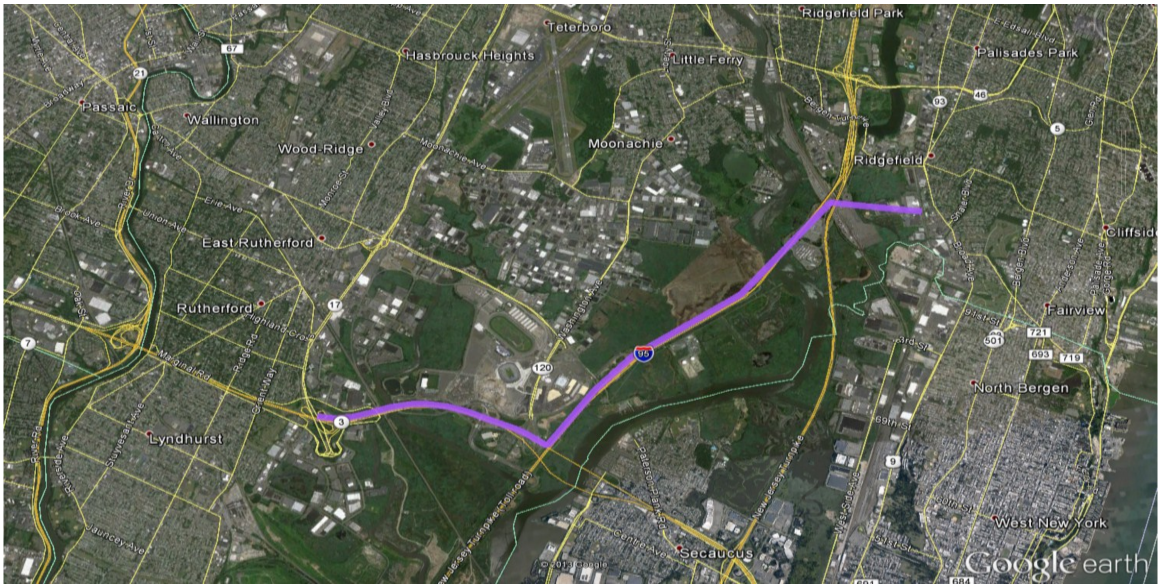


Figure 14. Conceptual Alignment Tidal Barrier North (T1) - Route 17 to Route 3/Turnpike to Hackensack River Crossing to Ridgefield

T2 – Tidal Barrier Middle (Long-Term Alternate 2)

Tidal Barrier Middle is the shortest barrier alternate with a total length of 4 miles. As shown conceptually in Figure 15, the barrier parallels Route 3 for its entire length. The flood wall starts on the west end at Route 17 and extends easterly along Route 3 crossing the Hackensack River with a navigable tidal barrier. Barrier Middle is then interrupted by the rise of land on which the Town of Secaucus is located, providing more than a mile of "free" flood wall. The wall continues to the east end in North Bergen, terminating at the foot of the Palisades ridge and the ramp leading towards the Lincoln Tunnel. To reduce costs, his barrier also takes advantage of existing roadway embankments at the interchanges of Route 3/Route 17, Route 3/Turnpike, and Route 3/Tonnelle Ave.

The estimated total cost to construct the Tidal Barrier Middle is $611m, with an annual maintenance, repair, and replacement cost of $11m. The quantity takeoff and unit costs used for the estimate are summarized in Appendix A4. Note that the Tidal Barrier Middle will protect a total of 11 communities from the effects of storm surge (see list in Table 5).

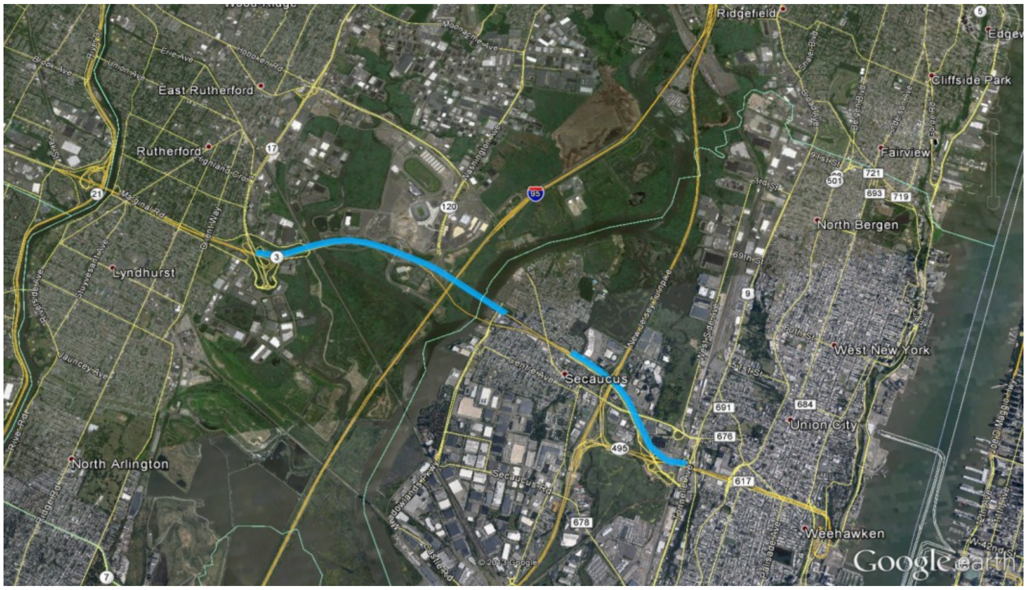


Figure 15. Conceptual Alignment Tidal Barrier Middle (T2) Alternative (Parallels Route 3 from Route 17 (West) to ramp to Lincoln Tunnel Entrance (East))

T3 – Tidal Barrier South (Long-Term Alternate 3)

The proposed alignment of Tidal Barrier South is shown conceptually on Figure 16. At a length of 2.5 miles, it is the shortest of the barrier options, but since it spans both the Hackensack and Passaic Rivers with navigable barriers, it is the most expensive from a cost perspective. Notably, though, it does protect the majority of two entire watersheds from the effects of storm surge and serves the greatest number of communities. Barrier South begins on the west end in East Newark and extends easterly, 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. Note that during the preliminary design phase, alternate alignments for Barrier South could also be examined involving only the Hackensack River, which would reduce cost but also the benefits.

The estimated total cost to construct the Tidal Barrier South is $1,590m, with an annual maintenance, repair, and replacement cost of $15m. The quantity takeoff and unit costs used for the estimate are summarized in Appendix A5. Note that the Tidal Barrier South will protect a total of 15 communities from the effects of storm surge (see list in Table 5).

Figure 16. Conceptual Alignment Tidal Barrier South (T3) Alternative (East Newark (West) to Passaic River and Hackensack River Crossings to Palisade Ridge (East))

2.3. Maintenance and Upgrading of Current Flood Protection Structures

The Boroughs of Little Ferry and Moonachie and the City of Hackensack have a long history of flooding. Beginning in the late 1600s, residents found ways to manage flooding and salt contamination from tides by digging ditches and constructing gates. The construction of canals began in the early 1900s by the Mosquito Commission, which was charged with the responsibility of preventing standing water as a mosquito control strategy. This effort resulted in the development of a complicated network of “legacy” berms, canals and ditches that, to a limited degree, continue to serve as flood control structures. The average elevation of the berms in Little Ferry, Moonachie and Hackensack is 5 feet above sea level (North American Vertical Datum of 1988 or NAVD 88). These berms and flood control structures such as tide gates are located on both private and public properties. Those structures in Little Ferry, Moonachie and Hackensack towns are shown in Figure 8 above and detailed information is provided in Table 7. The following sections describe condition states of flood controlling structures listed in Table 7 (DePeyster Creek Pump Station and Tide Gate, Losen Slote Tide Gate and Pump Station, Teterboro Pump Station, Willow Lake Pump Station, West Riser Tide Gate and Mosquito berms).

Figure 17. Sandy-damaged berm and contiguous ditch (Carlstadt, Meadowlands)

2.4. Short-Term, Non-structural and Green Infrastructure Measures

<u>R1 – Storm Drainage Improvements (Short Term)</u>

The municipal engineers and public works departments of Moonachie, Little Ferry and Hackensack have identified a number of structural measures to construct, repair, and upgrade storm drainage elements within these communities. These include dredging of drainage channels, cleaning of inlets and piping, culvert maintenance or replacement, rebuilding berms, upgrading pump stations and tidal gates, and providing resilient power systems. A listing of the major projects is shown in Table 6.

This alternative protects the target municipalities of Moonachie, Little Ferry and Hackensack, and it is considered essential to provide some immediate relief from the chronic flooding problem within these communities. While the specific projects do little to prevent entry of flood waters into the area, they will at least expedite the removal of runoff and standing water following storm events.

The total estimated cost of these storm drainage improvements is $52.1 million dollars (see Table 6). It is strongly recommended that these be implemented immediately with available Post-Sandy emergency funding.

Municipality	**Projects**	**Estimated Cost**
Moonachie	1. Elevation of electrical generators in low areas and additional emergency generators: Moonachie School, Moonachie Street Station, Senior Center, Fire Department, Municipal Building, Lincoln Street Station.	$6.2 m
	2. Dredging of drainage channels.	$4.3 m
	3. Construction of berms at Mobile Home Parks.	$1.3 m*
	4. Replacement/Upgrade of 10,000 ft of Storm Sewer	$2.0 m
	Subtotal for Moonachie	**$11.8 m**
Little Ferry	1. Installation of emergency backup electrical generators for Police Department, Fire Department, Memorial School, and all pump stations	$2m
	2. Improvements to storm water collection and removal via pumping: • Losen Slote Creek clean up, remediation and gate upgrade • Industrial Ave./Gater Road • Main Street Corridor • Robby Road Park • Willow Lake Dredging and Expansion • De Peyster Creek Pump Station	 $5 m* $2 m $1 m $0.1 m $1.5 m $1.5 m
	Subtotal for Little Ferry	**$13.1 m**
Hackensack	1. Installation of emergency backup electrical generators for key locations: Police Department, Fire Department, schools, etc.	$1.0 m
	2. Repair/upgrade sewers to improve drainage.	$4.5 m
	Subtotal for Hackensack	**$5.5 m**
System-Wide	Designing, Dredging and Widening of Drainage Channels	$15 m
	Elevating, Replacing or Adding Berms to a Better Design	$ 5 m
	Dredging of Hackensack River	**$ 5 m**
	TOTAL FOR ALL MUNICIPALITIES AND SYSTEM-WIDE	**$52.1 m**
	*** INCLUDED IN SYSTEM-WIDE PROJECTS**	

Table 6. Summary of Storm Drainage, Waterway, Berm and Infrastructure Improvements for Target Municipalities and System-Wide (MERI, Borough and Community Files)

2.4.1. *Improved Flow Management: Cleaning and Widening of Ditches and Waterways*

The implementation project consists of the cleaning and localized dredging of high-priority blockage areas in the ditches and waterways. This project is supported by the County of Bergen, which has oversight over the Mosquito Commission that owns the berms.

The Ditch Dredging project for 14 Miles of Ditches (a portion of the overall ditch waterways in our study) in Bergen County by the Bergen County Mosquito Commission is budgeted at $15,000,000.00, assuming the availability of construction and maintenance of easements. Proposed herein is a two-stage implementation with a pilot $1,500,000 for cleaning and dredging in the areas most problematic with sedimentation and blockage, concurrently with a detailed analysis and optimal design of the ditches. Our evaluation of the drainage and flooding problems in the area has concluded that the ditches/waterways are a major choking element and a key failing portion of the overall network. Optimizing the ditch design would greatly improve flood protection as it is very likely that the capacity of these ditches would need to be increased to provide the required network drainage capacity. The new network design should work downstream up in order to insure the overall system works beyond each municipal boundary.

2.4.2. *Improved Tidal Protection: Strengthening and Extending the Berms/Levees*

Protective berms in Moonachie were overtopped and failed. Optimizing the berm elevations would serve an important purpose, as it is very likely that the height of these berms would need to be increased to a minimum of 6 feet, and that the protection level of the berms would also need to be optimized, as part of a holistic planning approach for the overall cross-municipal infrastructure, which would extend the berms to areas such as the Mobile Park area in Moonachie.

2.4.3. *Reconstruction and Rehabilitation of Critical Pump Stations*

Table 7 lists some of the key pumping stations serving the study area. Improvements to some of these stations are included in Table 6. Additionally, the Lincoln Street pump Station in Moonachie is planned for complete reconstruction. Lincoln Street is a stormwater pumping station within a small building structure, and is equipped with two non-submersible pumps. This station collects runoff from the Panorama City development and discharges into the “East Riser Ditch” which is the marshy area East of Teterboro Airport. There are also several large stormdrains under Lincoln Street that are used for storage in what is termed the “fish bowl” area. 50% of Moonachie housing (excluding the trailer parks) is dependent on the Lincoln Street Pump Station.

#	Name	Elevation (NAVD88)	Latitude	Longitude	Location
1	DePeyster Creek Pump Station and Tide Gate-Protect Little Ferry	2.1ft-4.0ft	+ 40° 50' 30.52"	-74° 2' 3.21"	At the end of Dietrich Street
2	Losen Slote Tide Gate and Pump Station- Protect Little Ferry and Moonachie	6.1ft-8.0ft	+ 40° 49' 45.60"	-74° 2' 17.15"	Inter section of Empire Blvd and State street
3	Teterboro Pump Station- Protect Teterboro Airport up to 4’of of storm surge	N/A	+40° 51' 7.17"	-74° 4' 13.04"	Industrial Ave
4	Willow Lake Pump Station-- Protect Little Ferry	4.1ft-6.0ft	+40° 50' 51.73"	-74° 2' 5.09"	Willow Lake, Little Ferry
5	West Riser Tide Gate- Protect Moonachie and Teterboro Airport up to 4’ of storm surge	2.1ft-4.0ft	+40° 50' 16.43"	-74° 4' 34.06"	At the end of Purcell Ct
6	Lincoln Place storm water pump station		+40°50'25.0"	-74°03'06.1"	30-48 Diamond Way, Moonachie, NJ 07074
7	*Mosquito Wall*- Protect Little Ferry and Moonachie	Average 5.0ft	+40° 50' 6.23"N +40°49'46.12"N	-74° 2' 0.45"E -74° 2' 28.95"E	Losen Slote Tide Gate and Pump station to Empire Blvd.(Figure 2)

Table 7. List of Key Pump Stations in Study Area

The capacity of the pump stations can be increased to handle the precipitation from a major storm. Our analysis shows that most of the pump stations have inadequate pumping capacity for a significant flood event. Hence, improvement of the pump station pumping capacities will help to eradicate flooding behind the tide protection barriers. The analysis of the existing pumping systems indicates that they are resilient to handle small storm events whereas almost all of them are unable to handle 25 year storm event. However, the Sandy created a +100 year storm event which needs significant measures to manage the flooding. The improvements of the pump stations include the improvement and updating the tidal gates and increasing their surge heights. These will allow the existing system to handle a storm with a 25 year return period.

Based on an analysis of the pumping capacities of the various pump stations, the following improvement recommendations can be made:

#	Name	Current Pump condition	Requirement for improvement
1	DePeyster Creek Pump station and Tidal gauge	The DePeyster Creek Pump Station at the end of Dietrich Street has been completely refurbished around 2006 and is now in good working condition. The station has three 15 Hp, 1100GPM pumps	The system is inadequate to handle a 25 year storm event.
2	Losen Slote Tide Gate and Pump station	The pump performed beyond expectations during the Hurricane Floyd. NJMC inspections listed it as a pump station in excellent condition. The station consists of 3 150Hp 43000 GPM pumps	The system is inadequate to handle a 25 year storm event.
3	Teterboro Pump Station	175 cubic feet per second storm water pump station utilizing six-foot diameter Archimedes screw pumps. The water is pumped to an upper ditch 110 feet from the pump level, which flows by gravity towards Berry's Creek.	The system only can handle a flood up to 4'. Hence needed to be reanalyzed for an upgrade in the system
4	Lincoln Place storm water pump station	With the repairs and renovations the pump station will carry two pumps each with a capacity of 6000 GPM with an additional duty point of 4000 GMP.	Enough capacity for a major storm up to an intensity of 6" per hour. However, it needs a backup generator.
5	Willow Lake Pump Station	The Willow Lake Pump Station is responsible for moving water out of Willow Lake into the Hackensack River. The pump station is in poor condition. The station has two 50Hp with 5500 GPM pumps.	Need to increase the capacity of the pumps and need to add a backup generator.

Table 8. List of Key Improvement recommendations to Pump Stations in Study Area

A detailed assessment of tide gates, pump stations and berms can be found in Appendix F.

2.4.4. *Buffer/Storage Management: Willow Lake Dredging*

Willow Lake acts as a storm water detention basin for numerous residential areas in the Borough of Little Ferry. Water from the surrounding area drains into the Lake and is pumped out of the

Borough by the local pumping station. The Willow Lake Pump Station enables the movement of water out of Willow Lake and into the Hackensack River. However, the Lake does not have the capacity to handle the most recent tidal and fluvial storms. The resulting flooding area not only impacts local EMS and traffic but also floods two Bergen County roadways.

The increased water volume has resulted in this vital area being under water for days when the rest of the Borough of Little Ferry is dry. Hence it is suggested that the lake be dredged and its storage capacity expanded to handle the increased water volume that the last storms have created. Figure 18 shows a photo of the Willow Lake pumping station, which is currently rated as in "poor condition", and without a backup generator.

Figure 18. Willow Lake Pumping Station

2.5. Regulatory and Policy Measures

In recognition of the toll that major storm effects impact lives and property and the financial burdens associated therewith, Congress, in 1968 adopted the National Flood Insurance Program (NFIP). The Program offered flood insurance to homeowners, renters and business owners in communities which participated in the program by complying with regulations associated with the NFIP. In essence, participating communities agreed to adopt and enforce ordinances that would meet or exceed the Federal Emergency Management Agency (FEMA) requirements to reduce risk of flooding. FEMA was charged to administer the flood insurance program. The Flood Insurance Rate Map (FIRM) developed in conjunction with the NFIP was first established in the late 1960's.

Under the law, residential and commercial structures that were constructed prior to the development of the Flood Insurance Rate Map were not subject to the law, but were protected by the law with limited flood insurance costs thereafter. Many residential units in Moonachie and Little Ferry, built prior to 1968, because of their low elevations, have been subjected to flooding with insurance coverage not truly reflecting the true cost and risk of their potential for flood damage. The situation in these communities, as well as many others in the United States located in low lying areas in proximity to major watercourses, has produced costs associated with the National Flood Insurance Program far in excess of the insurance premiums from those covered under the program.

In addition to the above, many properties built before the community joined the NFIP in Moonachie and Little Ferry do not meet current standards for construction and elevation as promulgated by FEMA. In discussions with local officials and engineering personnel in these Boroughs, they estimate that approximately seventy (70%) percent of the residential dwellings are not required to comply with regulations governed by the NFIP of 1968. A number of site visitations in both Boroughs by the NJIT research team does indicate a relatively small number of structures that appear to have either raised their structures and/or provided stairs up to the living areas in the respective dwellings.

In order to rectify this disparity between revenues received and cost outlays in the approximate 45 years since the NFIP was enacted, Congress, in 2012, enacted the Biggert-Waters Reform Act. The Act requires the NFIP to raise insurance rates for some older properties in high risk areas to reflect the true flood risk in those locales. In addition, properties formerly grandfathered before the NFIP will have subsidies removed from second homes, rental units and businesses as well as primary dwellings that have had repeated flood losses.

Under the Act, elevated rates were initiated on October 1, 2013. Discussions with Borough officials in Moonachie and Little Ferry in October and November of 2013 indicated that some of their homeowners have seen their flood insurance premiums increase annually from a current range of one to two thousand dollars up to a range of eight to ten thousand dollars. Concerns are that many of these residents may not be financially able to meet this obligation.

Although, the current premiums may truly reflect the flood risks in these communities, the municipal officials have suggested that the flood insurance rates be increased over a longer period so that dwellers will not be forced to vacate (forfeit) their homes. In addition to the above burdens currently placed on the grandfathered dwellings, they cannot be sold unless they meet the current elevation and construction regulations imposed by FEMA. In addition, new purchasers will be required to pay insurance at the current full rate.

Lastly, as a result of Sandy, homes that are determined to have been "substantially" damaged from Sandy (more than 50 percent of their value needed to pay for repairs) are required to be elevated in order to get flood insurance.

Impacts of the Biggert-Waters Reform Act and Sandy of 2012 on the Boroughs of Moonachie and Little Ferry

The enactment of the Biggert-Waters Act on July 6, 2012, and the subsequent damage incurred by Sandy in October 2012 has created a major impact on the boroughs of Moonachie and Little Ferry, and to the municipal officials entrusted with the responsibility of governing and protecting these municipalities on a daily basis.

Both communities, because of their topographical conditions, lie in a high-risk area (Special Flood Hazard Area). Furthermore, since many of the structures in both locations were constructed prior to the National Flood Insurance Program enacted in 1968, their flood insurance rates were subsidized prior to passage of the Biggert-Waters Act of 2012.
Also, the so-called "Pre–FIRM" structures, built before the two Boroughs developed the Flood Insurance Rate Map (FIRM), were not required to raise their structures in accordance with the FIRM.

The passage of the Biggert-Waters Act of 2012 and Sandy have produced a major stress on the above-mentioned Boroughs. The Act will have a major financial impact on local property owners in that the intent is to raise the flood insurance rates either immediately or phased in over a 5 year period (the Act extends the NFIP for 5 years). Because the current rates are heavily subsidized, the rate increases to the homeowners will be substantial. The Act also forces purchasers of these structures to pay the full insurance rate immediately. As such, current homeowners will have great difficulty selling their homes unless at a considerably reduced market value price.

Lastly, because of implementation of the Act is still in progress (i.e., further guidance on grandfathered rates and premium changes required by Section 100207 of the Act when flood maps are revised or updated will be released in late 2014 at the earliest), and FEMA payment resulting from Sandy is still ongoing in these communities, the local population and their municipal officials find themselves in a state of flux regarding the ultimate outcome associated with the two events of 2012.

While the above impacts are still being resolved, protection of these communities resulting from the structural non-structural flood mitigation proposals posed herein for both the short-term and long-term become all the more critical until (unless) construction and elevation changes that will be mandated by the Biggert-Waters Act are able to take their full effect.

Details related to the Biggert-Waters Act published by FEMA, and fact questions and answers related to same published by FEMA and North Jersey.com are presented herein.

3. STORM SIMULATION, MODEL DEVELOPMENT AND CALIBRATION

3.1. Background, Objectives and Scope of Modeling and Simulation Task

3.1.1. *Modeling and Simulation Objectives*

The main objective of the modeling and simulation task is to evaluate the performance of the proposed engineering solutions for mitigating flood and inundation in the Hackensack area, including Moonachie and Little Ferry, by simulating storm surges driven by a Sandy-like hurricane, the possible dam break of the Oradell Reservoir, and the potential sea level rise (SLR) due to the future climate variations. The major sub-tasks are outlined as follows:

1. Collection of various types of data for simulations of flood and inundation from the entire US East Coast to Northeast New Jersey including the Hackensack area,
2. Validation of the storm-surge model, using CCHE2D-Coast described below, by reproducing storm surges and waves driven by Hurricane Sandy (2012) in the US East Coast,
3. Model validation by simulating flood and inundation induced by Sandy in the Hackensack area by using a high-resolution computational grid,
4. Evaluation of flood mitigation measures by simulating flooding and inundation due to Sandy,
5. Prediction of flood and inundation under the combined conditions of Hurricane Sandy and the potential SLR scenarios,
6. Evaluation of flood mitigation performance by installing the alternative solutions under the future conditions of hurricane and SLR,
7. Simulation of flood and inundation by assuming that the Oradell dam-break happens at the peak of the Sandy's storm surge, and
8. Simulation of contaminant leaching processes from a potential leaching site during the period of occurrence of Sandy.

3.1.2. *Model Used*

In order to accomplish the objectives and tasks listed above, an integrated coast-ocean model called CCHE2D-Coast and developed in the NCCHE at the University of Mississippi, which is an integral part of the FMERC Team, was used. This integrated model is used to simulate the hydrodynamic processes in a hurricane, and to produce the flood water extent maps for different cases with the combined conditions of hurricane and SLR. The model consists of a multidirectional wave spectral model, a coastal hydrodynamic model, and a sediment transport and morphological change model (Ding et al. 2006, Ding and Wang 2008ab, Ding et al 2013c). It is capable of simulating hydrodynamic and morphodynamic processes in coasts, estuaries, rivers, and oceans such as (1) storm surges and waves driven by cyclonic wind which is calculated by a parametric cyclonic wind and air pressure model (Ding et al. 2013b), (2) irregular wave deformations and transformation, (3) tidal and river flows, (4) nearshore currents and wave setup/setdown, and (5) sediment transport and morphological changes induced by waves and currents. This model generally employs a non-orthogonal grid that can model complex coastlines (Ding and Wang 2008a, Zhang and Jia 2009). This integrated coastal process model can run through a graphical user interface, CCHE2D-Coast GUI. The details of the GUI and the user guidance can be found in Ding et al. (2013c) and Zhang (2013). Hereafter, the wave and flow models of CCHE2D-Coast are adopted for computing hurricane wind, storm surges, and waves; the sediment transport model for morphodynamic processes modeling was not used in this project.

Figure 19 presents a flow chart and structure of the integrated wind-storm-surge model. The wind and pressure field model is to produce the hurricane conditions for the coast-ocean model. In addition to the parameters for calculating the wind field, the required data for simulating storm surges in a coast region include bathymetrical/topographic data, hydrological data (tides, hydrographs of rivers, waves, etc.), and structure data which are used for generating a computational grid and specifying boundary conditions of tides and river flows.

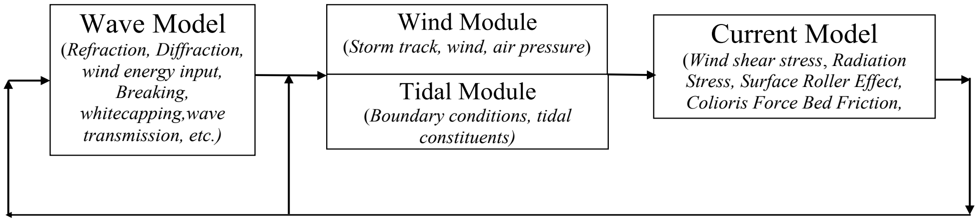


Figure 19. Flow chart of the integrated wind-storm-surge model

The modeling and simulation task was performed by the NCCHE team, with full support and coordination by a team from the NJIT dedicated to the FMERC GIS workstation and data acquisition effort, as well as the simulation and analysis of the flood mitigation alternatives under the scenarios of Storm surge and sea level rise listed above.

3.2. Data Acquisition and Support of Model Development

3.2.1. *Data Gathering and Field Verification*

The team gathered facts from the municipalities with regard to impacts on the area and the people who reside there, response to the Storm and elements of resiliency. The study interviewed, coordinated data acquisition in support of the modeling effort and contacted representatives from the following agencies and entities:

- The municipal and county engineering offices.
- The Hackensack Meadowlands Development Commission that maintains the flood mitigation infrastructure and the Meadowlands Environmental Research Institute.
- Engineering consultants to the Boroughs and City in the study area.
- FEMA and the U.S. Army Corps of Engineers.
- State and local agencies.
- A cross-section of critical Infrastructure system and facility operators.
- Emergency Management Systems, including police and fire departments

- The Mayors and Freeholders in the area.
- Select concerned residents, business people and environmental advocacy in the area.

The interviews of the above-cited agencies gave a picture of the extent of the devastation, and helped identify elements of the range of solutions to be considered and their associated costs.

Field surveys of flood protection structures (tide gates, berms, ditches, etc.) (Figure 20) and Sandy-damaged areas as well as field verification for proposed protection and mitigation alternatives trips were undertaken throughout the project duration from July 1, 2013 to February 28, 2013 and continued into April 2014. The areas devastated by the Storm, including both residential and infrastructure facilities were toured by the FMERC Team.

Figure 20. FMERC Team surveying flood protection structures (tide gates and berms at various Meadowlands locations)

3.2.2. *Geospatial Data Preparation and Applications: GIS Workstation*

The baseline performance of storm simulation, vulnerability and impact modeling depends in part on a high quality, accurate and homogenous Geodatabase. The development of a Geodatabase for this project involves working with various sources of data, and developing various layers of information in support of simulation model development, damage assessment, benefit/cost and risk analysis. Information layers include topographic and bathymetric (e.g. riverbed) data, shapefiles of the geodetic description of proposed barrier structures, and sea level trends and inundation maps.

Geodatabase

Development of the Geodatabase in support of the investigation on vulnerability assessment to storm surge involved data acquisition from multiple sources as well as data scrubbing and preparation. The Geodatabase includes topographic data, 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. In addition, time series data of water elevation data including tide gauge (TG) and river stage from Tide Gates (TGate) were archived for analysis on estimates for sea level rise within the Newark Bay and river flood stage elevation from future Sandy-like surge events. Data preparation was required to ensure a homogenous and unified geospatial data model which, in turn, required several applications of geodetic coordinate conversions and datum transformations.

Inspection of the FEMA flood maps provided additional guidance on the extent of coastal inundation from Sandy. The hydrodynamic model results of the FMERC CCH2D implementations efforts were qualitatively compared with results from the MERI model and observations. The comparison provided initial estimates on the veracity of our hydrological/hydrodynamic solutions provided by the modeling team.

Data Sources and Verification

Goal of Data Flood Modeling and Simulation Study: As mentioned in the previous section, The main initial goal of the flood modeling study is to develop an integrated global hydrodynamic model capable of producing a simulation and calibration of the Sandy baseline storm, as well as a range of other scenarios of future sea level rise under the current (status quo) topographic conditions. Once this model is established, the same range of storm scenarios would be simulated under a number of proposed protection alternatives in order to analyze and compare their flood protection performance.

Bare Earth Model**:** Topographic data from LiDAR (Light Detection and Ranging) was required for the flood inundation study. The high resolution processed LiDAR data was acquired from the Meadowland Environmental Research Institute (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. The bare earth model is fundamental to ensure realistic outputs from hydrodynamics simulation runs.

The high resolution LiDAR topographic model provides the surface shape for the developing grid cells to simulate inundation extent and maximum water levels in the study area due to Sandy. This high resolution topographic model is essential in the modeling input because local changes in topography (and this adjustment in element size and interpolation method) drastically alter simulated storm surge impacts locally and regionally. However, the MERI data was limited in scope so that their dataset did not provide all the comprehensive coverage needed for this investigation. Supplemental topographic data to cover a much broader region of influence for the flood inundation simulation was therefore sought. Lower resolution topographic data was downloaded from the US Geological Survey (USGS) website. These datasets were geo-referenced appropriately for the project.

Bathymetric Data: River morphology data was derived from bathymetric data obtained from the latest available FEMA released files. The soundings of cross-sectional profiles of the Hackensack and Passaic rivers were acquired. Data preparation included inversion of the vertical axis followed by a transformation from MSL to the NAVD88 using the VDatum tool developed by NOAA.

Next, the geographic extent of Sandy-induced flood was derived from the analysis of TGate time series. Data and models provided by MERI were compared against time series from TG data at The Battery (NY), Sandy Hook (NJ), and Newark Bay (NJ), and the flood depth was verified. Sea level trend analysis was determined from tidal datum analyses. High frequency (i.e., 6-minute intervals) sea surface elevation from Tide Gate (TG) data over a period of 18.6 years defines the dataset that is acceptable to describe the tidal datum for specified regions along the NJ coast. Tidal behavior within an estuary or “protected” bay is tempered by many factors so that the behavior of the tide within the bay regions and estuaries is different from tidal excursions seen by Tide Gates that face the open coast. The issue of sea level rise is important for constraints on the height of proposed barrier structures that will protect the region from future storm surges and to ensure a positive return on investment (ROI). Our efforts to estimate the future (100, 200, 300, 500 year) sea level elevation in Newark Bay included a regression analysis of the tidal datums over the past 100 years and data from the current tidal epoch. Our estimate on the rate of sea level rise was compared and validated by other published estimates for the north east coast of the US. The design team included the predicted sea level to enhance the design and height of the proposed barrier structures, and the simulation of the performance of various alternatives was undertaken under two different levels of predicted sea level rise.

Structures outline: Part of the Geodatabase included at least two items a) the geodetic description of the proposed design structures related to Sandy inundation, b) previously proposed strategies by the US Army Corp of Engineers (USACE) and c) existing flood protection structures including mosquito berms.

The design team finalized four mitigation strategies for physical barriers to prevent surge inundation. The group proposed four solutions namely, 1) Arc Wall, 2) Wall North, 3) Wall Middle, 4) Kearny Wall (see expanded section on same defining their proposed alignments). Additionally the ring walls solution proposed in the Corps of Engineers report of 1993 (4) was evaluated for comparison purposes. Another structure representing an extension to Route 78 was added for simulation purposes only, although the design team did not evaluate it as a key protection option for the study area.

The proposed structures include a combination of variety of wall designs and sluice gates. After the design team had specified the geographic parameters of the flood mitigating structure, the geospatial analytics team digitized the designs (five simulated strategies in all) and prepared a set of shapefiles of 3-D coordinates for the proposed structures. A shapefile is the ArcGIS industry standard of file format and most of the advanced simulation software systems are compatible with the ArcGIS software.

In addition, previously proposed water control structures within the NJ Meadowlands District were reviewed and inspected. These maps were reviewed for qualitative assessment and comparison of flood control structures as proposed in this investigation.

The FMERC GIS workstation (Figure 21) was built to integrate the capabilities described above as an analytical hub, and interface with a range of key servers and sources of information, including the NCCHE simulation and modeling server, and the Department of Homeland Security (DHS) DSAT system, which supports a range of key information on critical assets and key resources such as Oradell dam, which is the focus of an independent simulation and inundation analysis.

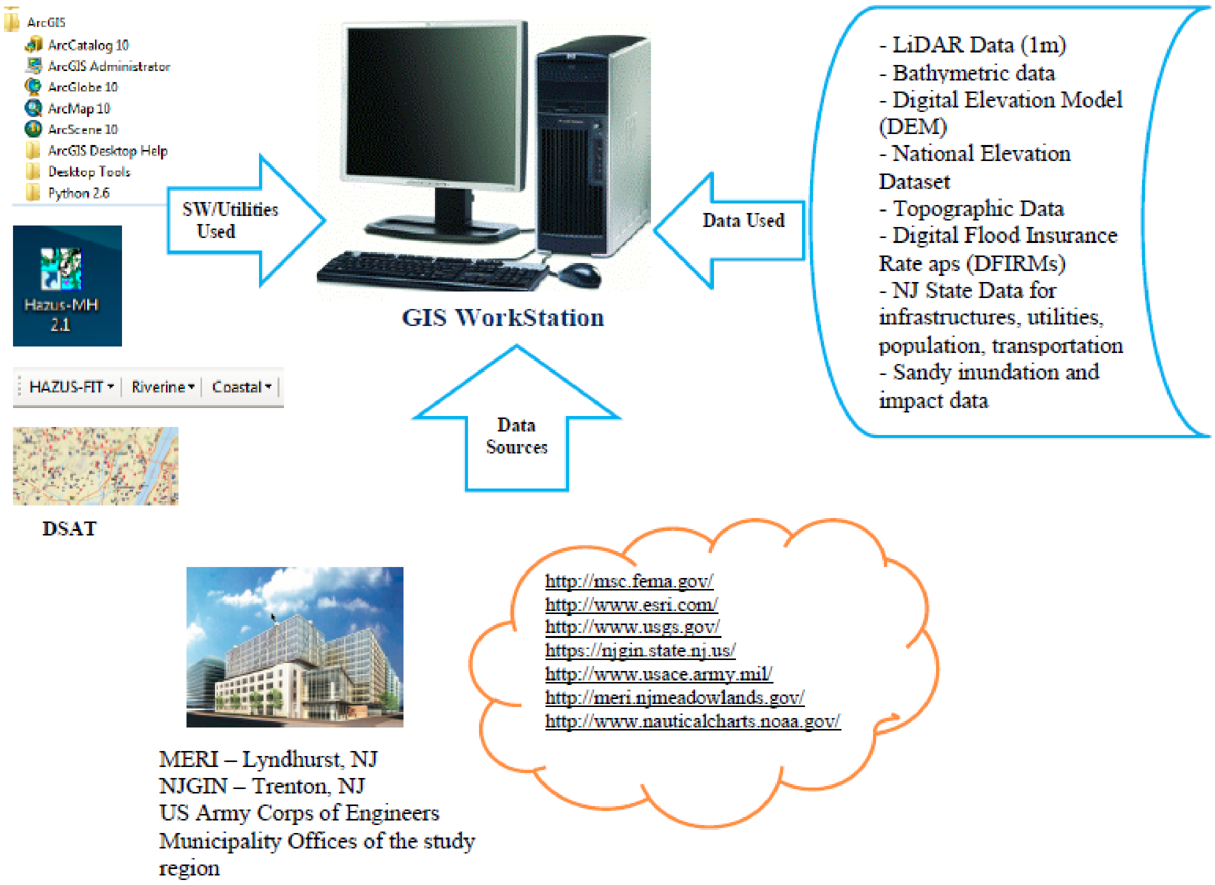


Figure 21: NJIT/FMERC GIS Workstation

3.3. Sandy Baseline Model Development and Calibration

3.3.1. *Sandy Large-Scale Coastal Model Development and Modeling Effort Planning*

To build and validate the storm-surge model to simulate winds, tides, storm surges, waves, and currents in the track of Hurricane Sandy in the US East Coast, the FMERC has collected various types of data such as geospatial data, hurricane track data, and meteorological/oceanographic/hydrological data, from different data sources listed above.

Hurricane Sandy was formed in the southwestern Caribbean Sea in late October of 2012, which is a classic late-season hurricane. The cyclone made landfall as a category 1 hurricane in Jamaica, and gained strength to a 100-knot (kt) category 3 hurricane in eastern Cuba. Sandy underwent a complex evolution and grew considerably in size while over the Bahamas, and continued to grow despite weakening into a tropical storm north of those islands. The system re-strengthened into a hurricane while it moved northeastward, parallel to the coast of the southeastern United States, and reached a secondary peak intensity of 85 kt while it turned northwestward toward the mid-Atlantic states. Although at the landfall of Hurricane Sandy (2012), this cyclone weakened to a post-tropical storm near Brigantine, New Jersey due to its tremendous size, Sandy drove a catastrophic storm surge into the New Jersey and New York coastlines.

Since coastal and ocean water motions are not just stimulated by astronomical tide and storm surges, coastal flood and inundation can be driven by multiple hydrodynamic processes (coastal and oceanographic processes) such as wind-induced currents, tidal flows, waves, earth rotation, river flows, etc, at the same time. The total water surface elevation increase during a hurricane is the sum of the expected high tide, storm surge caused by low barometric pressure and onshore winds, wave setup in the surf zone, and inflow caused by flooding rivers. To correctly and accurately compute the spatiotemporal variations of flood and inundation in coasts, one has to adopt an integrated coastal-ocean process model which is capable of taking into account various factors such as tide, wave, flow, wind, air pressure, and river flows if there are tributaries flowing to coasts. This was achieved in the application of the CCH2D model mentioned above.

The computational domain for the CCH2D-Coast Sandy-related storm-surge modeling covers the entire US east coast from Florida to Maine. The bathymetric data of the Atlantic Ocean were prepared using two types of bathymetry data. One is the NOAA geophysical Data Center (NGDC), and USACE-ERDC. The NGDC data is bathymetric topographic data, which includes both topography and bathymetric data at about 100-m resolution. The other one is an existing grid used in the ADCIRC storm-surge simulations, which is a finite elemental mesh data. This ADCIRC depth grid is called SL15. It contains 2,137,978 nodes and 4,184,778 triangular elements in total, which covers a very large area including Gulf of Mexico, Caribbean Sea and part of the Atlantic Ocean up to Maine and Nova Scotia.

3.3.2. *Extension of Model to Study Area: Multi-Scale Grid*

The topographical data were obtained from three different sources: NGDC, USGS, and the FMERC NJIT data acquisition and transformation team. The NGDC 100 m bathymetric topographic data were used for the coastal areas and the islands in the Atlantic Ocean. The USGS 3-m DEM and the NJIT 1-m Lidar data were used in New York, New Jersey, and the surrounding areas.

For simulations of flood and inundation induced by Sandy in the Hackensack area in northeast New Jersey, the computational domain contains two rivers in the area, i.e. Hackensack and Passaic Rivers. The south boundary stretches to the estuary in the south, and covers Newark Bay. It also has considered the installations of flood mitigation measures (dikes and barriers). The domain size is approximately 15km x 33km.

The resulting model was in good agreement with a range of monitored storm conditions and inundation levels, which completed the validation of the Sandy baseline model. For more details on the model development and detailed results, as well as the references listed in Section 3.2 and 3.3, please refer to Appendix C.

3.4. Simulation of Performance of Alternative Flood Protection Structures

Using the validated CCHE2D-Coast model as a baseline model, the performance of structural measures identified by the FMERC flood mitigation design team can be assessed by simulating under these various protection measures, the resulting flood and inundation of a Sandy-like storm. Furthermore, these simulations can be performed under several sea level rise scenarios, in order to take into account the uncertainty in future storm impacts due to climate change.

As described in more detail in Section 2 above, four structural measures (mitigation solutions) for flood prevention from storm surges in the Hackensack area were proposed by the FMERC flood mitigation integrated design team. They are:

- R2: Arc Wall: a levee (approximately 6.5-mile long) to protect the areas including Hackensack, Little Ferry, Moonachie, Carlstadt, Teterboro and South Hackensack.
- T1: Wall North: a 5.5-mile-long levee with installation of a tide gate crossing the Hackensack River to protect most areas of Moonachie, Little Ferry, Hackensack.
- T2: Wall Middle: a 4 mile-long levee with a tide gate installed, which follows Route #3 crossing the Hackensack River, and
- T3: Kearny Wall: a 2.5 mile-long wall (barrier) with tide gates to protect almost all of the two river basin areas.

Additionally, a Wall 78 solution, consisting of a 1.5-mile-long wall with a tide gate to cross Newark bay, was also simulated for comparison purposes, although not evaluated in detail in the ranking of alternatives.

Since Tropical Storm Sandy was the deadliest and most destructive tropical cyclone of the 2012 Atlantic hurricane season, as well as the second-costliest hurricane in United States history, the meteorological and hydrological conditions in Sandy are used as the driving force for conditions of the extreme storm to assess flood and inundation in the computational domain of Northeast New Jersey.

To determine the future sea level scenarios, after having reviewed a variety of literature on the projected global and local (the East Coast) sea level rise (SLR) (e.g. Frumhoof et al. 2007; Cooper et al. 2005), it was decided to assume two possible future SLR scenarios based on Frumhoff et al (2007) (Figure 38) to model the sea level in 2100, i.e.:
(1) SLR = 9.6 inches (24.4 cm), and
(2) SLR = 37.6 inches (95.5 cm).

The performance results of the flood mitigation alternatives are shown in Section 4, which summarizes the protection provided by each solution under a Sandy baseline, a Sandy + SLR=9.6 inches, and a Sandy + SLR= 37.6 inches.

3.5. Oradell Dam Break Simulation and Impact Analysis

Oradell Dam is a 22-foot high concrete dam located on Hackensack River in Bergen County, New Jersey. 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. Due to the vulnerability of the study area to a potential failure of the dam, the analysis of dam break scenarios, including an extreme combined storm and dam break event, was performed using a specialized and comprehensive decision support tool for dam break analysis. The consequences of the hypothetical failure of the Oradell Dam during a major storm surge event such as the one caused by Hurricane Sandy in 2012 were derived and can be used for possible insight into future comprehensive protection and response management strategies.

Oradell Dam is a critical infrastructure asset, whose failure during a storm surge event such as Superstorm Sandy (2012) may exacerbate flooding and lead to 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.

The dam-break simulations were performed using DSS-WISE™ software developed by the National center for Computational Hydroscience and Engineering (NCCHE) at the University of Mississippi. DSS-WISE™ is an integrated software for dam-break flood analysis which includes a state of the art solver that can handle mixed flow regimes, and wetting and drying. It has a GIS-based graphical user interface and the results provided by the DSS-WISE™ are compatible with HAZUS-MH for consequence analysis. More details on the model, the case studies and related references can be found in Appendix E.

The initial and boundary conditions for the simulations with storm surge were taken from the base-scenario of Hurricane Sandy simulation using CCHE2D, which is described in Sections 2.2 and 2.3 above.

Three scenarios were considered for impact and response management comparison purposes:

Spillway Design Failure (abbreviated as SD): For the failure scenario of Spillway Design Flood, the downstream floodplain was assumed to be completely dry. A constant water surface elevation of 1.175m (NAVD 88) was assumed in the downstream channel and bay. This value corresponds to high tide value at 407,160 s in the base scenario of storm surge simulations.

The spillway design flood for Oradell Dam is the 0.3 PMF event based on the Owner's consultant. The 0.3 PMF event produces a peak water surface elevation of approximately 29 ft NGVD 29, which was assumed to be the initial water surface elevation for the simulation. Oradell Dam is a concrete dam. There are no standard guidelines for selecting the breach width and formation time for concrete dams. The following values were assumed based on the information received from New Jersey Department of Environmental Quality (NJDEP):

Pool elevation at failure:	28.01 ft NAVD 88 (29.0 ft NGVD 29)
Storage volume at failure:	15,756 acre-ft
Final Breach Width:	200 ft (corresponds to about six out of 11 blocks failing together)
Breach Formation Time:	0.1 hrs (USACE MMC recommends a short time for concrete dam failure)
Breach Invert Elevation:	2.67 ft NAVD88

It was assumed that the dam breaches at the beginning of the simulation (t = 0 s). The simulation was computed for 24 hours of flood time and it took 3 hours and 52 minutes of wall time to complete on a desktop computer with 16 processors. At the end of the simulation 1,444,479 cells (5m×5m) were containing water.

Storm Surge Only (abbreviated as SSO): This scenario simulates the storm surge for the base scenario of Hurricane Sandy during a three day period extending from 22:00hr on 10/29/2012 to 22:00hr on 11/1/2012. The beginning of the simulation (1,288,800 s) is at about 3 hours 24 minutes before the peak surge tide, which occurs at 1,301,040 s (i.e. at 1:24hr on 10/30/2012).

The initial conditions at the beginning of the simulations were taken from the results of the base scenario of Hurricane Sandy simulated using CCHE2D-Coast software ("Frame 23" in the history file). These included the water surface map and velocity components in x and y directions. CCHE2D-Coast uses a structured, non-orthogonal finite element mesh with variable element sizes. It was therefore necessary to resample the results computed with CCHE2D-Coast into 5m raster projected with UTM zone 18. Since small differences in ground elevation may exist between the mesh used by CCHE2D and DSS-WISE™, the depth grid was obtained by subtracting the DEM from the rasterized water surface elevation. In addition, a discharge hydrograph was imposed immediately downstream of the Oradell Dam in the same way as it was done in storm surge base scenario. The time variation of the water surface elevation along the south boundary of the CCHE2D-Coast mesh during the three day simulation period was imposed as downstream boundary condition.

The simulation was computed for 3 days and it took 2 days 12 hours wall time to complete on a desktop computer with 16 processors while other jobs were also running. At the end of the simulation, 3,834,361 computational cells (5m×5m) were containing water.

Dam-Break Failure during Storm Surge (abbreviated as DB&SS): This scenario simulates the dam-break during the base scenario of Hurricane Sandy. The time period is the same as the one used in SSO. The three-day simulation begins at 22:00hr on 10/29/2012, approximately 3 hours before the peak surge tide, and terminates at 22:00hr on 11/1/2012.

The initial and boundary conditions related to storm surge are the same as for the scenario SSO. The failure conditions for the Oradell Dam are the same as for the scenario SDF. The simulation begins at 1,288,800 s corresponding to 22:00hr on 10/29/2012. The Oradell Dam is breached at 1,290,240 s (22:24hr on 10/29/2012), which is 24 minutes after the beginning of the simulation. The initiation of the breach is timed to occur three hours before the peak of the surge tide, which occurs at 1,301,040 s (i.e. at 1:24hr on 10/30/2012).

The simulation was computed for 3 days and it took 1 day 19 hours wall time to complete on a desktop computer with 16 processors. At the end of the simulation, 4,135,474 computational cells (5m×5m) were containing water.

The consequences of these scenarios, particularly the combined event, are worth further investigation, in order to analyze if the Arc Wall, the alternative with the highest benefit-cost ratio, can be possibly adjusted to provide additional protection to Oradell dam failures, and combined events.

The comprehensive report of the consequences of these scenarios and their comparison, including a brief description of the DSS-WISE™ model, is provided in Appendix E.

3.6. Environmental Flood Impact Modeling: Simulation of Key Contaminant Sites

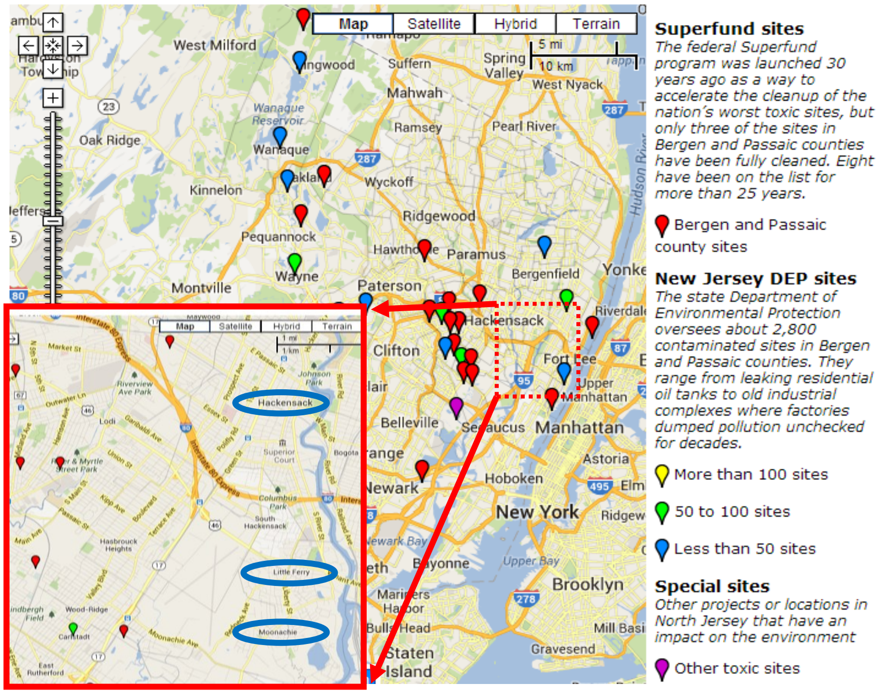
Flooding surge after an extreme hurricane often brings heavy land contamination near coastal or riverine/channel regions. Typical contaminants include spilled oil, persistent organic pollutants (POPs), pesticides that contain endocrine disrupting compounds (EDCs), heavy metals, microbial pathogens or other invasive and infectious disease-causing species. For instance, 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. The FMERC has applied the CCHE2D-

Chem models to environmental contamination to determine its extent in the studied region. Furthermore, the potential of in situ nanoremediation as a way to rapidly eliminate these contaminations from soil or ground water (even sediment) was evaluated.

Superstorm Sandy inundated hundreds of homes in Moonachie and Little Ferry with dirty floodwater and caused one of the largest sewage spills in North Jersey history. Figure 22 shows a close-up of the geographic distribution of potential toxic sites near Hackensack, little Ferry, and Moonachie areas. In a heavily developed region dotted with toxic sites–2,835 in Bergen County and 1,394 in Passaic County –flooding tends to bring a barrage of pollution within close proximity to residents. Superfund sites–the worst toxic sites in the United States present the biggest problems because they contain deadlier pollution (see Figure 22). Specifically, the following contamination sites are highlighted here as examples that are worth further investigation and protective measures for future possible pollution spread during flooding because of their proximity to the study area investigated herein.

Site 1: Superfund site in Kearny (Diamond Head Oil, New Jersey, EPA ID#: NJD092226000), which is in the New Jersey Meadowlands and is next to the Hackensack River, is contaminated with a number of hazardous chemicals including polychlorinated biphenyls (PCBs), dioxin, and asbestos.

Site 2: The Standard Chlorine Chemical Company Superfund Site (Standard Chlorine Chem Co. Inc. New Jersey EPA ID#: NJD002175057) is a 25-acre site located in the town of Kearny, New Jersey, on an industrialized peninsula along the Hackensack River the release of dioxins, benzenes, naphthalene, PCBs and other semi-volatile or volatile compounds into the Hackensack River and adjacent wetlands. (http://www.epa.gov/superfund/sites/npl/nar1672.htm)



Superfund sites
The federal Superfund program was launched 30 years ago as a way to accelerate the cleanup of the nation's worst toxic sites, but only three of the sites in Bergen and Passaic counties have been fully cleaned. Eight have been on the list for more than 25 years.

🔴 Bergen and Passaic county sites

New Jersey DEP sites
The state Department of Environmental Protection oversees about 2,800 contaminated sites in Bergen and Passaic counties. They range from leaking residential oil tanks to old industrial complexes where factories dumped pollution unchecked for decades.

🟡 More than 100 sites
🟢 50 to 100 sites
🔵 Less than 50 sites

Special sites
Other projects or locations in North Jersey that have an impact on the environment

🟣 Other toxic sites

Figure 22. Distribution of superfund sites and other potential toxic sites near or around the Hackensack areas.

Site 3: Kearny freshwater marsh site (Fig. 23): Elevated concentrations of arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and mercury (Hg) that exceeded the Ontario Aquatic Sediment Quality Lower Effect Levels were found in the sediment at this site.

Site 4: The trace level organic chemical contaminants in the sediment of Hackensack River. For instance, organic contaminants such as TCDDs and total DDTs may reach up to 0.02 μg/g. Perturbation of sediment during the hurricane and flooding may facilitate the resuspension and spread of these toxic chemicals onto the inland areas of Hackensack.

Based on available information to date, Sites 1 and 3 were retained for the detailed simulation of the contaminant propagation. The detailed background and simulation of the contaminant migration under the Sandy scenario can be found in Appendix D, entitled "Pollution Prevention Analysis during Sandy's Hurricane and Flooding".

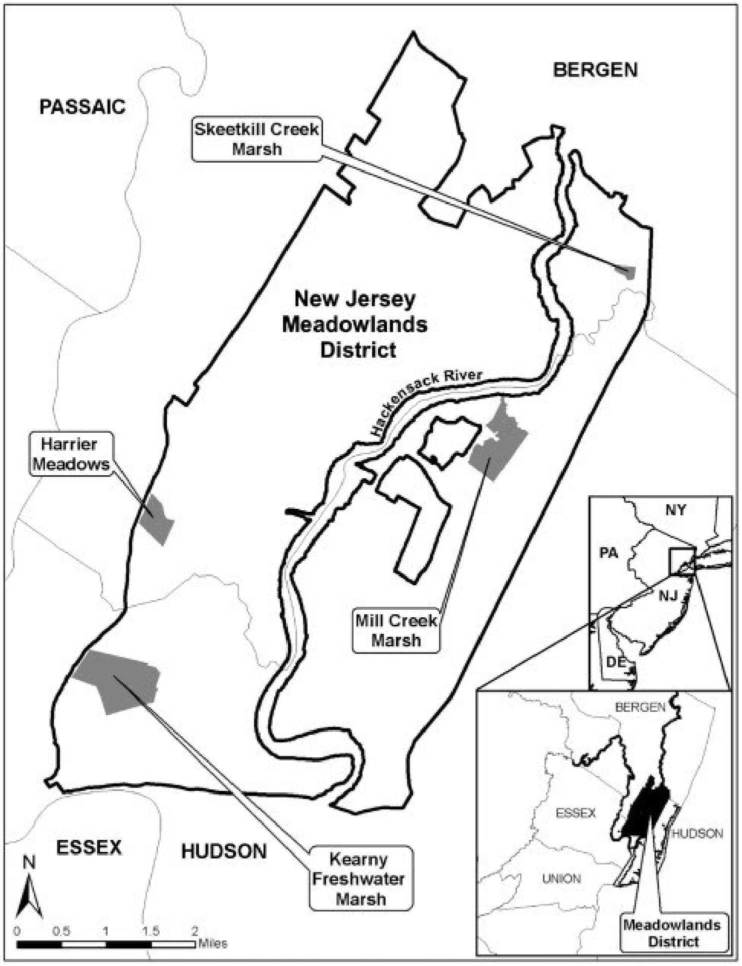


Figure 23. Map of the contaminant sites in the Meadowlands District.

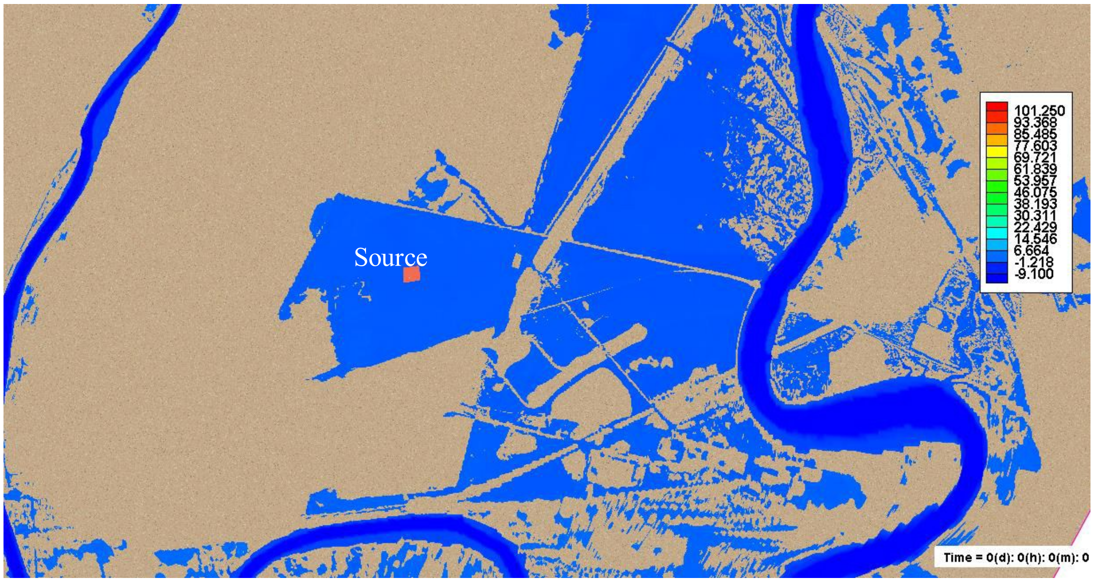


Figure 24. The contaminant source location in the numerical mesh.

This study applied CCHE2D-Chem, an integrated model developed by NCCHE, to simulate pollutant migration profiles under two hypothetical scenarios. The contaminants are assumed to be released in the site of the Kearny freshwater marsh (Fig. 22 and Fig. 23) when the storm surge waters of Hurricane Sandy inundate this area. In the two cases, one is assumed with a high flux rate and the other with a slow flux rate. The flow fields computed by CCHE2D-Coast are used as input flow conditions for simulation of contaminant migration. The simulation conditions and results are briefly discussed below.

To demonstrate the potential heavy metal migration from marshland to flood water, the pollutant source location in the numerical grid is shown in Fig. 24. The mobility of heavy metals are affected by many factors including the chemical forms and properties, soil organic content, the quantity and type of soil binding sites, soil ion strength, pH, temperature, the concentration of complexing anions (organic and inorganic), and competing cations in soil solution. All these factors are site specific and need extensive investigations to accurately interpret. An approximation was used to estimate the range of the migration rate of arsenic (As) from the marshland to the floodwater. There were studies (Solomon et al. 1990, Smedley and Kinniburgh 2002, USEPA 2005, Dubey et al. 2007, Zhu et al. 2011) showing Arsenic leaching from CCA-treated woody debris to the floodwater and sediments after Hurricane Katrina. Measured As concentration in sediment right after Hurricane Katrina ranged from 1-100 ppm (µg/kg). For that specific case, the leaching rate was estimated at 0.1 mg/s from soil to the overlying floodwater during the inundation period. In our case, we assume that the As contaminant is assumed to leach through flood waters due to rising of surge tide in Hurricane Sandy in 2012. Two scenarios of the leaching were simulated: one with a high leaching rate of 0.1 mg/s (Scenario 1) and the other with a slow leaching rate of 0.001 mg/s (Scenario 2). For this short period of inundation, chemical decay is assumed negligible.

The simulations were calculated using CCHE2D-Chem model (Zhu, et al. 2012, Jia et al. 2013). It is a two-dimensional depth-averaged model to simulate chemical fate and transport with the input of simulated flow fields. Based on mass balance and fate processes, the model solves the transport equations of contaminant in water, within bed sediments and the interaction between water and sediments through adsorption partition. Users can specify single or multiple pollution sources/sinks. The general fate processes include volatilization, photolysis, hydrolysis, and biodegradation. For the simulation of contaminant release, the flow fields of the surge tide were already computed and stored into a dataset. The computation of the leaching started at 0000 UTC, 10/29/2012. It continued for three days, till 0000 UTC, 11/1/2012. The time step for simulation of leaching was 10 sec. After three-day leaching during the period of inundation by Sandy, the As concentration distributions in water at 0000 UTC 11/1/2012 are shown in Fig. 25 (Scenario 1) and (Scenario 2). It can be seen that the As distribution patterns are similar for both scenarios. Scenario 1 with high leaching rate resulted in a peak concentration level of 0.22 ppb compared with 0.0022 ppb in Scenario 2. There is no violation of the drinking water quality standard for As of 10 ppb (10 µg/L). The distribution patterns are determined by the hydraulic conditions. The area near the marsh was flooded and then quite isolated from the other flooded area. As a result, the leached As remained in the isolated area after inundation for both scenarios.

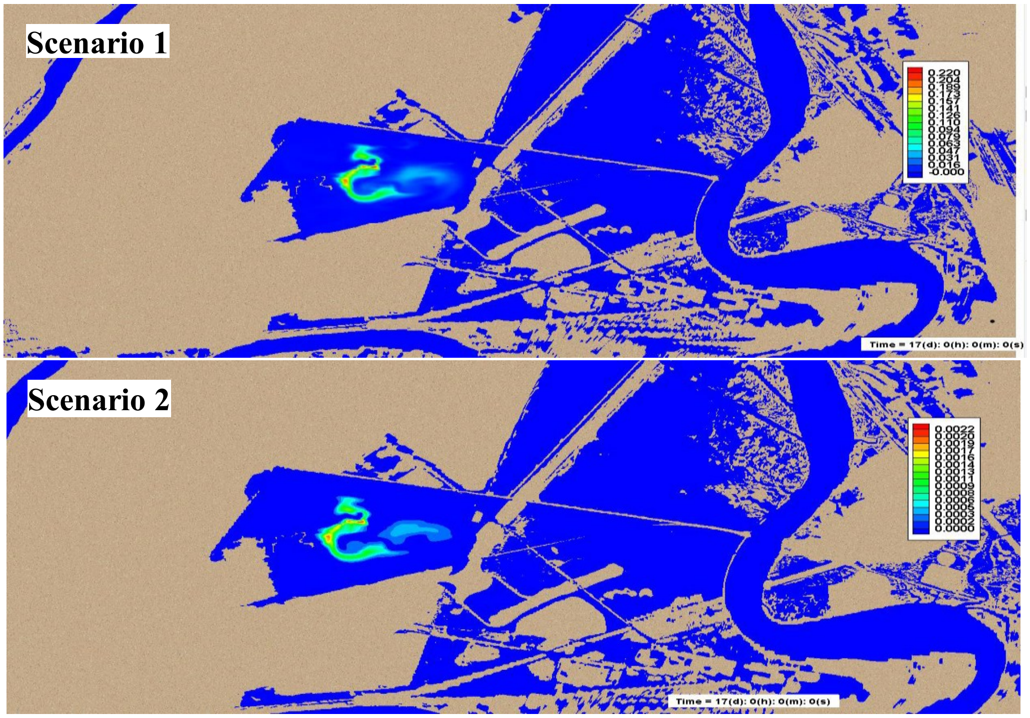


Figure 25. Arsenic concentration distribution in water at Day 17 of migration.

The simulation above showed that the impact of leaching from Kearney Marsh as a result of Sandy was acceptable (<10 ppb). However, this a preliminary look at the contamination issue in the study area. Further investigation is needed for its application.

4. EVALUATION OF ALTERNATIVE SOLUTIONS

It should be stressed that the latest State of New Jersey, Department of Community Affairs Amendment to its Superstorm Sandy-related action plan (15), which calls for more buy-outs and raising the elevations of a number of homes would change the situation on the ground, in terms of risks associated with different storm scenarios, from the situation prior to Sandy, to that ex-post of the RREM and other Hazard Mitigation Program components. The figures presented herein would need to be adjusted once the abovementioned action plans are consummated.

4.1. Cost Estimates: Assumptions and Development

The cost estimates for various alternatives include the following categories:

A- Capital Costs:

- 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 Wetlands
- Installing 40’ Long Sheet Piles. 12’ of the length will be elevated and 28’ will be below ground
- Keeping the waterways navigable
- Movable gates on roads and railroads
- Tide Gates wherever the walls are crossing a water stream
- Pump Stations to pump out the collected water
- Overhead and Profit
- Design

B- Annual maintenance and repair cost

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

C. Other cost: Periodic maintenance (e.g. the pumps)

D. Replacement of Pumping Stations every 20 years: It is assumed that 50% of the pumping station costs is related to mechanical equipment that is replaced every 20 years

E. Total Estimated Life Span: Besides the mechanical equipment in the pumping stations, the benefit/cost analysis model assumes a 70 year life span, at which time, it is assumed that the non-mechanical portions of each alternative have a remaining residual value shown in F below.

F. Remaining Residual Capital Value: This is assumed to be at 20% of the initial capital costs minus all mechanical costs associated with pumping stations.

The development of cost estimates for various alternatives under consideration is detailed in Appendices A1 through A5.

4.2. Benefit Evaluation: Data Sources and Estimation Technique

The FEMA's HAZUS-MH Hurricane Model represents an advance in the state of the art over most hurricane loss prediction models, in that it estimates wind induced loads, building response, damage, and then loss, rather than simply using historical loss data to model loss as a function of wind speed Vickery et al., (2006).

Although hydrodynamic models, e.g., FEMA's HAZUS-MH, are used extensively to quantify the physical hazard of hurricane storm surge, the connection between the physical hazard and its effects on the built environment has not been well addressed. Assessment of hurricane damage has traditionally been conducted through field reconnaissance deployments where damage information is captured and cataloged. The increasing availability of high resolution satellite and aerial imagery in the last few years has led to damage assessments that rely on remotely sensed information. Friedland (2009) evaluated suitability of using remote sensing in assessing residential building damage from hurricane storm surge at the neighborhood and per-building levels is investigated using visual analysis of damage indicators.

Identification, assessment, and documentation of flood related damage, and a review of flood mitigation and repair work was needed by the NJIT FMERC team to better understand the full extent of current conditions. This was accomplished by contacting FEMA, and town officials to review their available data. In addition faculty reconnaissance teams visited flood affected areas of Hackensack, Moonachie, and Little Ferry to identify, assess, and document storm related damage to both the infrastructure and buildings. The field documentation data was used to inform and educate the public and town officials about the current state of affairs in the study area and identify, and prioritize flood repair/mitigation work that still needs to be done.

Municipality	Little Ferry Borough	Moonachie Borough	South Hackensack Township	Teterboro Borough	Hackensack City	Carlstadt Borough	East Rutherford Borough
County	Bergen	Bergen	Bergen	Bergen	Bergen	Bergen	Bergen
Area in ACRES	1,070.23	1,114.88	476.3	714.53	2,779.44	2,690.10	2,588.81
Area in SQ_MILES	1.67	1.74	0.74	1.11	4.34	4.2	4.04
Population - 2010	10,626	2,708	2,378	67	43,010	6,127	8,913
Population - 2000	10,800	2,754	2,249	18	42,677	5,917	8,716
No. of residences damaged							
Total Homes with Damages	1036 Minor: 0; Major: 609; Severe: 427	560 Minor: 8; Major: 331; Severe: 221	24 Minor: 24; Major: 0; Severe: 0	0	80 Minor: 0; Major: 51; Severe: 29	1 Minor: 0; Major: 1; Severe: 0	24 Minor: 0; Major: 24; Severe: 0
Total Rentals with Damages	489 Minor: 135; Major: 211; Severe: 143	114 Minor: 32; Major: 54; Severe: 28	0	0	101 Minor: 44; Major: 22; Severe: 35	0	09 Minor: 2; Major: 01; Severe: 06
Businesses Impacted	488	378	379	0	3,791	807	690

(Table 9: Partial) Post-Sandy Demographic and Damage baseline information for Impacted Communities in Study Area (cross-referenced damage and statistical/demographical information)

Municipality	Rutherford Borough	Ridgefield	Secaucus Town	North Bergen Township	Kearny Town	Newark City	Harrison Town
County	Bergen	Bergen	Hudson	Hudosn	Hudosn	Essex	Hudosn
Area in ACRES	1,849.68		4,196.61	3,383.58	6,520.11	16,777.86	848.34
Area in SQ_MILES	2.89		6.55	5.28	10.18	26.21	1.32
Population - 2010	18,061	11,032	16,264	60,773	40,684	277,140	13,620
Population - 2000	18,110		15,931	58,092	40,513	273,546	14,424
No. of residences damaged							
Total Homes with Damages	111 Minor: 96; Major: 12; Severe: 03	45 Minor: 44; Major: 1; Severe: 0	302 Minor: 233; Major: 46; Severe: 23	52 Minor: 01; Major: 42; Severe: 09	96 Minor: 0; Major: 41; Severe: 55	266 Minor: 0; Major: 221; Severe: 45	100 Minor: 0; Major: 40; Severe: 60
Total Rentals with Damages	7 Minor: 2; Major: 04; Severe: 01	2 Minor: 2; Major: 0; Severe: 0	49 Minor: 20; Major: 24; Severe: 5	10 Minor: 07; Major: 01; Severe: 02	35 Minor: 7; Major: 19; Severe: 9	185 Minor: 135; Major: 30; Severe: 20	57 Minor: 7; Major: 18; Severe: 32
Businesses Impacted	1094	697	1,390	1765	1,484	10,522	536

Table 9 (ctd.): Post-Sandy Demographic and Damage baseline information for Impacted Communities in Study Area

Research related to the towns and boroughs most affected in the study area, and likely to be protected by the range of structural alternatives under consideration, was performed in order to identify the number of structures and businesses impacted. Results of this research, which cross-references 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, are shown in Table 9 above.

Hazus was run in the FMERC computer laboratory using the post-Sandy flood map depth results provided by FEMA and corroborated by the FMERC flood simulation results. The outputs of the Hazus runs are being refined with additional asset inventory information and will be presented in a future updated Release of this Final Report. It was therefore decided to perform an estimation of the damages using more recent surveys of existing assets and damage activity recorded post-Sandy. A detailed benefit-cost analysis model was therefore developed by the FMERC team, in order to more accurately reflect the estimates for benefits from various alternatives under consideration.

4.3. Benefit-Cost Analysis and Risk Analysis

The benefit-cost analysis (BCA) model developed by FMERC follows the updated BCA guidelines released by the Corps of Engineers. In particular, it analyzes the benefits from a given alternative/project, by comparing the "Without Project" baseline scenario to the "With Project" scenario. Benefits related to the implementation of a given project are calculated as the reduction in damages and economic losses from protected areas that are not subject to flooding under such alternative. In other words, benefits from a given alternative are derived from the summation of damages and economic losses under the "Without Project" conditions in the areas where flood damage would be prevented by the alternative at hand.

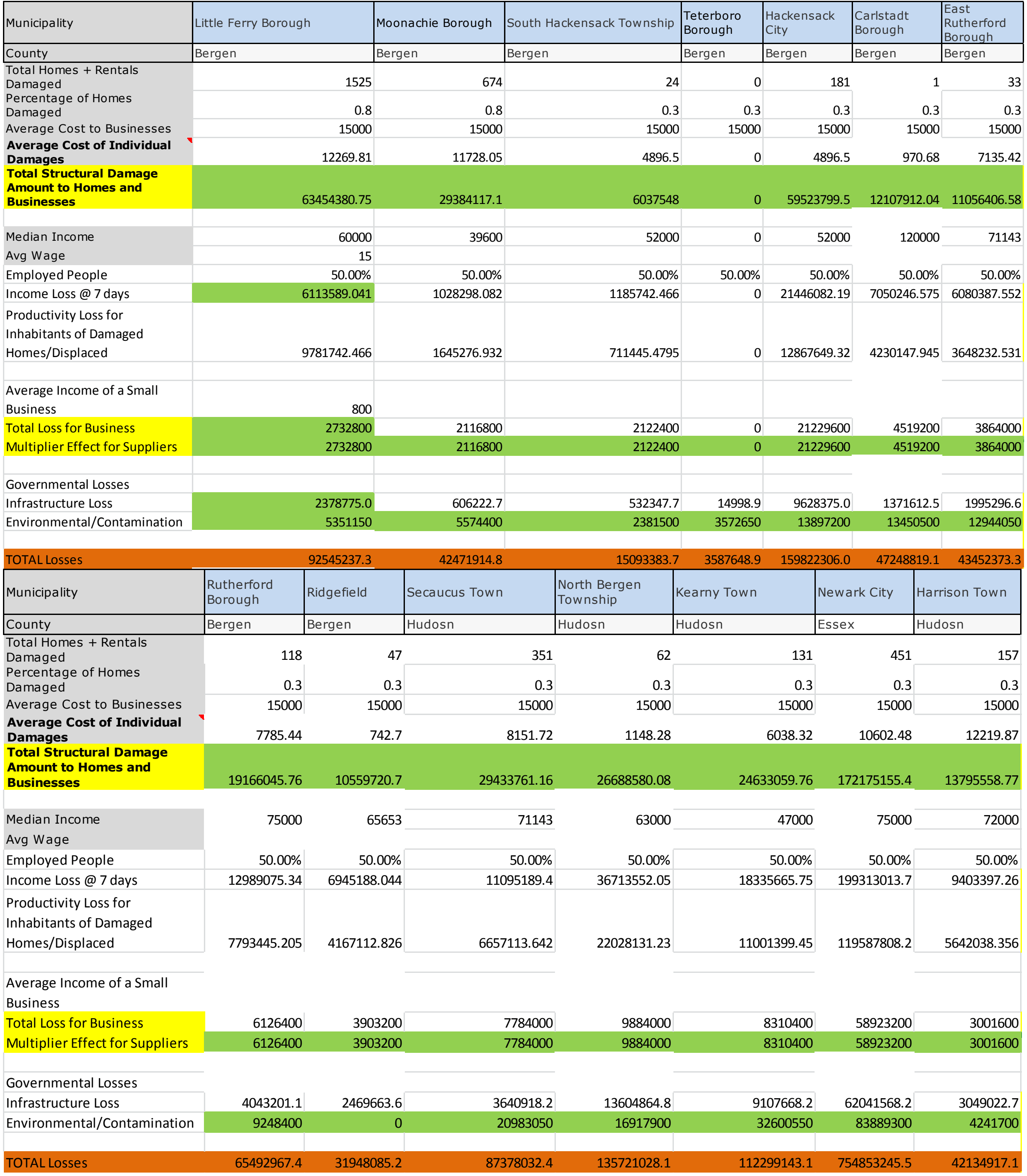
Categories of model damages in areas at risk are listed and evaluated in Table 10. They include:

1- Structural Damages to Homes (Owned and Rented), based on severity of damages reported after Sandy in different communities for both residential categories.
2- Structural Damages to Businesses, using the number of impacted businesses.
3- Income Loss for residents of Impacted Communities for 7 days.
4- Income Loss for Residents of Damaged Homes for an additional 2 weeks.
5- Income Loss to Businesses Impacted, and their supplier base.
6- Infrastructure Loss Damages, based on a State-wide per capita estimate
7- Environmental Contamination Estimate, based on a per acre contamination cost.

The total damages and economic losses incurred from a Sandy-type event can be estimated by summing up the above categories for every Borough, Town and City in the impact zone. This value represents the de facto benefits from a protection alternative that would shield the community from flood damage. In order to calculate the benefits from a given protection alternative, this value is added across protected communities under any given alternative.

An additional benefit from each alternative is the Induced benefits from construction work, due to the wage content and the multiplier effect from recycling wages through the supplier chain. A life cycle cost analysis was performed for each of the 4 structural alternatives, and is shown in Appendix B2. The Net Present value 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 damages and economic losses from protected communities, as well as the induced benefits from large-scale infrastructure projects. The Benefit-Cost Ratios for Various Alternatives were computed, under 4 scenarios with decreasing probability of one to four Sandy-like events during the 70 year time horizon. Even if only one event were to occur, all 4 alternatives would be justifiable, with the Arc Wall achieving the highest Benefit-Cost Ratio of 1.97 (one event) followed by Wall Middle, which achieves a Benefit-Cost Ratio of 1.4 (one event) (Table 11).
It is worth noting that, as 100 year flood maps have been updated as a result of Sandy, the probability of one Sandy event occurring over a 70 year time horizon can be estimated at almost

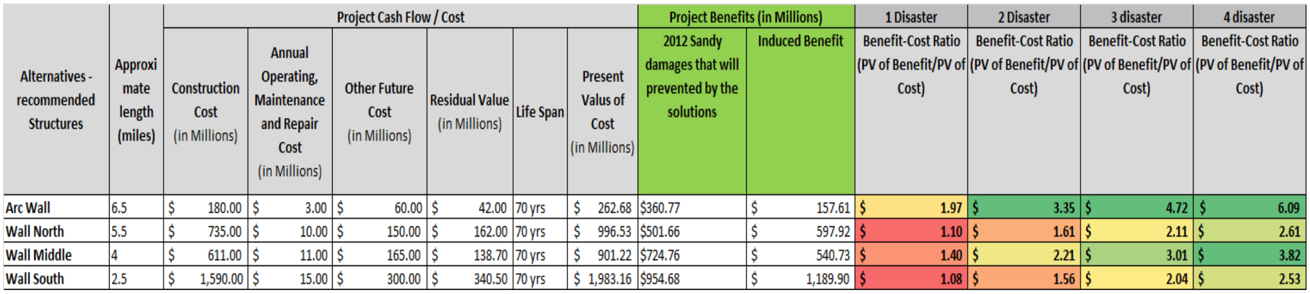
a 50%, as Probability (No Storm) = $(0.99)^{70}$=0.495. Hence the probability of at least one Sandy/100 yr Storm during the 70 year time horizon would be equal to 0.505. Considering the issue of climate change and sea level rise with many extreme forecasts of sea level rise, the assumption is made in this study that at least one Sandy type event will take place within the 70 year time horizon.



Municipality	Little Ferry Borough	Moonachie Borough	South Hackensack Township	Teterboro Borough	Hackensack City	Carlstadt Borough	East Rutherford Borough
County	Bergen	Bergen	Bergen	Bergen	Bergen	Bergen	Bergen
Total Homes + Rentals Damaged	1525	674	24	0	181	1	33
Percentage of Homes Damaged	0.8	0.8	0.3	0.3	0.3	0.3	0.3
Average Cost to Businesses	15000	15000	15000	15000	15000	15000	15000
Average Cost of Individual Damages	12269.81	11728.05	4896.5	0	4896.5	970.68	7135.42
Total Structural Damage Amount to Homes and Businesses	63454380.75	29384117.1	6037548	0	59523799.5	12107912.04	11056406.58
Median Income	60000	39600	52000	0	52000	120000	71143
Avg Wage	15						
Employed People	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%
Income Loss @ 7 days	6113589.041	1028298.082	1185742.466	0	21446082.19	7050246.575	6080387.552
Productivity Loss for Inhabitants of Damaged Homes/Displaced	9781742.466	1645276.932	711445.4795	0	12867649.32	4230147.945	3648232.531
Average Income of a Small Business	800						
Total Loss for Business	2732800	2116800	2122400	0	21229600	4519200	3864000
Multiplier Effect for Suppliers	2732800	2116800	2122400	0	21229600	4519200	3864000
Governmental Losses							
Infrastructure Loss	2378775.0	606222.7	532347.7	14998.9	9628375.0	1371612.5	1995296.6
Environmental/Contamination	5351150	5574400	2381500	3572650	13897200	13450500	12944050
TOTAL Losses	92545237.3	42471914.8	15093383.7	3587648.9	159822306.0	47248819.1	43452373.3

Municipality	Rutherford Borough	Ridgefield	Secaucus Town	North Bergen Township	Kearny Town	Newark City	Harrison Town
County	Bergen	Bergen	Hudosn	Hudosn	Hudosn	Essex	Hudosn
Total Homes + Rentals Damaged	118	47	351	62	131	451	157
Percentage of Homes Damaged	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Average Cost to Businesses	15000	15000	15000	15000	15000	15000	15000
Average Cost of Individual Damages	7785.44	742.7	8151.72	1148.28	6038.32	10602.48	12219.87
Total Structural Damage Amount to Homes and Businesses	19166045.76	10559720.7	29433761.16	26688580.08	24633059.76	172175155.4	13795558.77
Median Income	75000	65653	71143	63000	47000	75000	72000
Avg Wage							
Employed People	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%
Income Loss @ 7 days	12989075.34	6945188.044	11095189.4	36713552.05	18335665.75	199313013.7	9403397.26
Productivity Loss for Inhabitants of Damaged Homes/Displaced	7793445.205	4167112.826	6657113.642	22028131.23	11001399.45	119587808.2	5642038.356
Average Income of a Small Business							
Total Loss for Business	6126400	3903200	7784000	9884000	8310400	58923200	3001600
Multiplier Effect for Suppliers	6126400	3903200	7784000	9884000	8310400	58923200	3001600
Governmental Losses							
Infrastructure Loss	4043201.1	2469663.6	3640918.2	13604864.8	9107668.2	62041568.2	3049022.7
Environmental/Contamination	9248400	0	20983050	16917900	32600550	83889300	4241700
TOTAL Losses	65492967.4	31948085.2	87378032.4	135721028.1	112299143.1	754853245.5	42134917.1

Table 10 (ctd.): Categories and Estimates of Damages and Economic Losses for Impacted Communities in Study Area



Alternatives - recommended Structures	Approximate length (miles)	Project Cash Flow / Cost						Project Benefits (in Millions)		1 Disaster	2 Disaster	3 disaster	4 disaster
		Construction Cost (in Millions)	Annual Operating, Maintenance and Repair Cost (in Millions)	Other Future Cost (in Millions)	Residual Value (in Millions)	Life Span	Present Valus of Cost (in Millions)	2012 Sandy damages that will prevented by the solutions	Induced Benefit	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)
Arc Wall	6.5	$ 180.00	$ 3.00	$ 60.00	$ 42.00	70 yrs	$ 262.68	$360.77	$ 157.61	$ 1.97	$ 3.35	$ 4.72	$ 6.09
Wall North	5.5	$ 735.00	$ 10.00	$ 150.00	$ 162.00	70 yrs	$ 996.53	$501.66	$ 597.92	$ 1.10	$ 1.61	$ 2.11	$ 2.61
Wall Middle	4	$ 611.00	$ 11.00	$ 165.00	$ 138.70	70 yrs	$ 901.22	$724.76	$ 540.73	$ 1.40	$ 2.21	$ 3.01	$ 3.82
Wall South	2.5	$ 1,590.00	$ 15.00	$ 300.00	$ 340.50	70 yrs	$ 1,983.16	$954.68	$ 1,189.90	$ 1.08	$ 1.56	$ 2.04	$ 2.53

Table 11: Summary of Benefits and Costs for Various Alternatives Under 1 (highly likely) to 4 Events (Less Likely) in Planning Horizon

Additionally, the simulation of the performance of these alternatives under various assumptions of sea level rise, provides a clear picture of the "protection" performance of these alternatives.

For example, as seen in Figure 26, under a Sandy scenario with no Sea level Rise by 2100, the Arc Wall, the Middle Wall and the North Wall provide a "safe" alternative as the maximum surface elevation remains significantly below the wall heights. However, the Southern walls, including the Wall South solution (Kearny), and the Wall 78, are close to overtopping.

Under a moderate Sea Level Rise scenario (9.6 inches), as seen in Figure 27, a Sandy scenario with Sea level Rise of 9.6 in by 2100, the Arc Wall represents the "safest" alternative as the maximum surface elevation remains significantly below the wall height. However, the Middle Wall and the North Wall are almost full or close to overtopping while the Southern walls, including the Wall South solution (Kearny), and the Wall 78, would be overtopped.

Under a High Sea Level Rise scenario (37.6 inches), as seen in Figure 28, a Sandy scenario with Sea level Rise of 37.6 in by 2100, the Arc Wall still represents the "safest" alternative as the maximum surface elevation remains below the wall height. However, the Middle Wall and the North Wall as well as the Southern walls, including the Wall South solution (Kearny), and the Wall 78, would be overtopped.

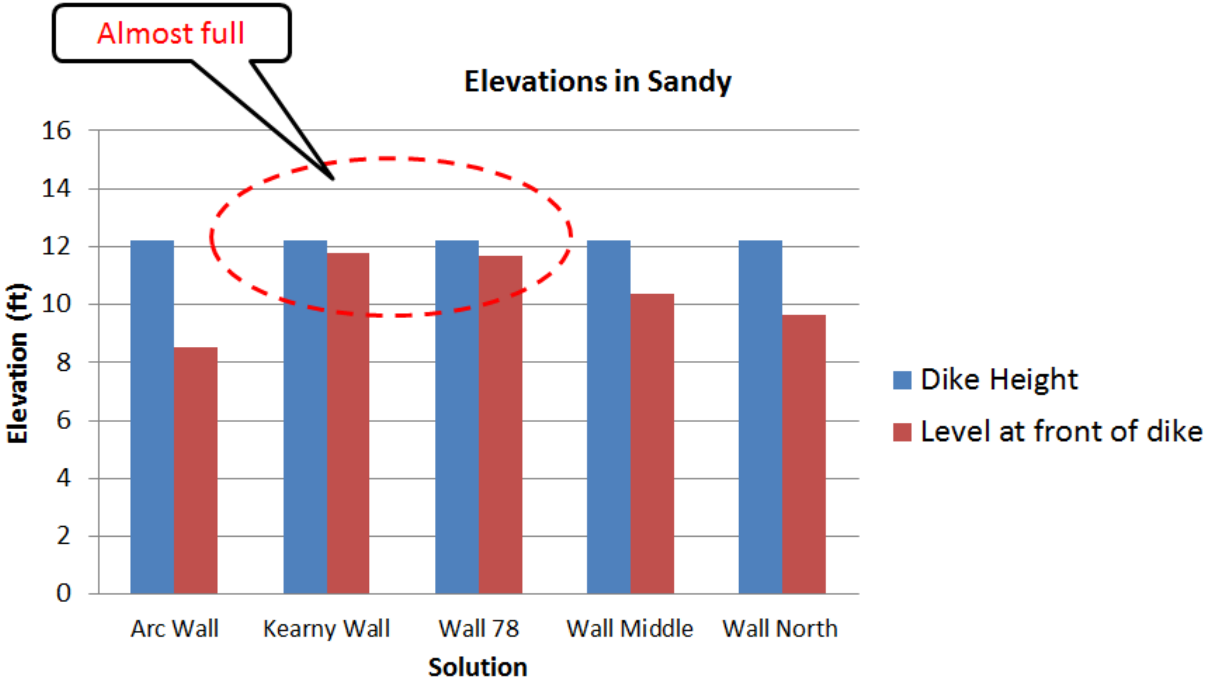


Figure 26. Maximum Water Surface Elevations at Front of Structures, SLR=0

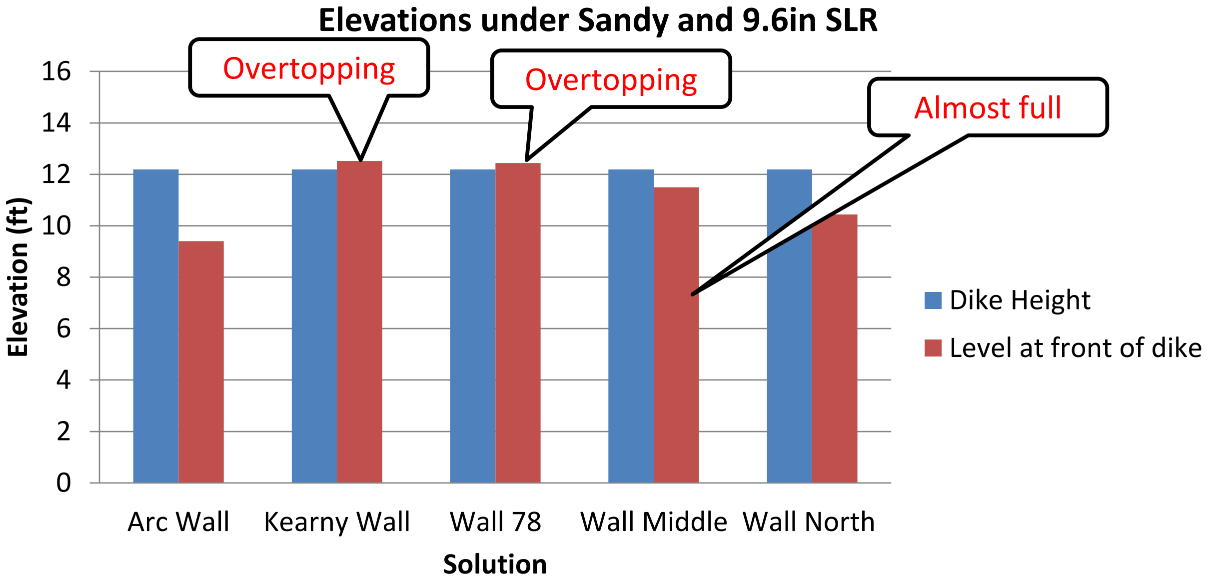


Figure 27. Maximum Water Surface Elevations at Front of Structures, SLR=9.6 in

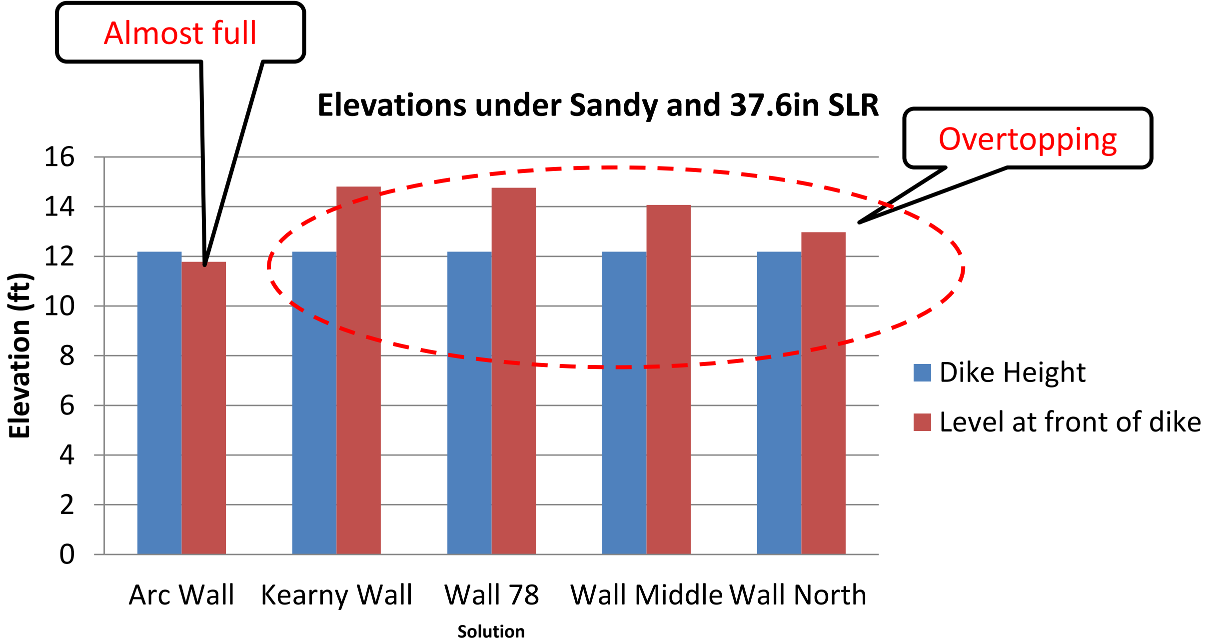


Figure 28. Maximum Water Surface Elevations at Front of Structures, SLR=37.6 in

5. SUMMARY, CONCLUSIONS, SHORT-TERM AND LONG-TERM STRATEGY RECOMMENDATIONS

In this Flood Mitigation Engineering Resource Center (FMERC) project, a multi-disciplinary team was formed and went to work to create an integrated capability for the analysis of multi-dimensional flood hazards and the review and ranking of cost-effective protection and mitigation alternatives. This capability was developed and applied to a study area, consisting of some of the most affected low-lying areas in the Hackensack/Meadowlands region.

The problems encountered by the Boroughs of Little Ferry and Moonachie and the City of Hackensack were reviewed, within the local municipal context and the broader contexts of the New Jersey Meadowlands Commission and Bergen County, and with important input and collaboration with the New Jersey Department of Environmental Protection, in order to understand the local and regional components of some of the key mitigation solutions. The surveys of major constituents and public officials made it possible for the FMERC to understand some of the complexities of the flooding problems in the study area, and recommend short-term solutions, which can yield both local and regional dividends.

The short-term recommended measures include a range of measures listed in Table 6, and further detailed in Sections 3.4.1 through 3.4.4. They includes various measures identified by the affected communities to construct, repair, and upgrade storm drainage elements including dredging of drainage channels, cleaning of inlets and piping, culvert maintenance or replacement, rebuilding berms, upgrading pump stations and tidal gates, and providing resilient power systems. It is strongly recommended that these be implemented immediately with Post-Sandy emergency funding.

The FMERC also developed a comprehensive suite of GIS-enabled analytical capabilities, which were applied to first develop, with significant data acquisition and integration effort across a number of agencies such as USACE, FEMA, NJDEP, HUD and others, a well calibrated Sandy hydrodynamic model. As a result, this model can now be used to analyze flood protection options for any flood-prone vulnerable area, and simulate the performance of a range of structural and non-structural solutions for both flooding and possible contamination impacts, and can be put to beneficial use by the State of New Jersey and the Nation.

The FMERC developed preliminary designs for four key structural solutions (flood barriers), along with their cost estimates. These solutions achieve increasingly wider areas of protection around the study area, and are designed to bring adequate protection against Storm surge and fluvial events.

An economic analysis and Benefit-Cost Analysis (BCA) model allowed the evaluation of benefits achieved from the protection achieved against a potentially recurrent Sandy-like event. The BCA of the 4 key structural alternatives confirms that the structural alternative that achieves the highest Benefit-Cost Ratio is the Arc Wall. Additionally, the Arc Wall achieves the highest robustness, against an increased Sea Level Rise Scenario, and can possibly be adjusted in a protection solution for more complex events such as a combined Oradell dam breach and Storm event.

As described in Table 5, this "optimal" solution (Arc Wall) involves construction of a 6.5-mile wall (top Elev. +10 ft) to provide substantial relief from chronic flooding of streams, ditches, and the Hackensack River during heavy rainfall events. The Arc Wall will also provide a moderate degree of protection against storm surges (for example, area tidal gages during Sandy peaked at Elev. ~+9.5 ft). Given the moderate cost and strong benefit-cost ratio, it is recommended that governmental partnerships be formed now to identify funding sources to accomplish the work.

The NJIT FMERC Team lists 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. Additionally, as mentioned earlier and shown in Figures 26, 27 and 28, the Arc Wall is the least risky with regard to the uncertainty in the exposure to sea level rise, as it is able to provide storm surge protection under a high sea level rise scenario of 37.6 inches.

Within the range of long-term solutions delineated in Table 5, the Middle Wall achieves the next highest Benefit-Cost Ratio. However, given that other regional solutions might achieve a broader protection coverage, it is recommended that further analysis of broader protection solutions be undertaken beyond the Hackensack. These holistic solutions can be analyzed by the FMERC Team, using our integrated data model, which combines our storm simulation modeling with economic analysis models for optimal decision-making under uncertainty. In concert with NJDEP and the GORR, the FMERC can coordinate with the USACE the analysis of a range of portfolios of alternatives that can achieve maximum protection for the State of New Jersey and neighboring areas with significant exposure to future storm flood risk.

Areas of opportunities and challenges in the study area include the required improvements to the municipal and regional drainage networks, particularly as they relate to the design and management of waterways and ditches, pumping practices and regional watershed-level solutions to the chronic flooding problems experienced by the affected communities in the study area.

6. REFERENCES

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7. APPENDICES

A- Cost Estimate Templates for Alternative Structural Measures
B- Lifecycle Cost Analysis and Benefit-Cost Model Templates for Structural Protection Alternatives
C- Hydrodynamic Modeling, Data Sources, Acquisition, Development of Sandy Model and Simulation of Performance of Protection Alternatives
D- Pollution Prevention Analysis during Sandy's Hurricane and Flooding
E- Oradell Dam Break Simulation Analysis
F- Assessment of the Condition State of Existing Tide Gates, Pump Stations and Berms in Little Ferry, Moonachie and Hackensack

Appendix A1
Calculation of Benefit/Cost Ratio for ARC Wall (R2)

Capital Recovery Factor @ 4 % for 50 years = **0.0466**

Cost in 2014 = $ 180 M
A = ($ 180,000,000) * (0.0466)
A = $ 8,388,000

Estimated Annual maintenance & Repair & Operation = **$ 3 M**

Total Annual Cost (C): $ 8,388,000 + $ 3,000,000
C = **$ 11,388,000**

The 1993 U.S. Army Corps of Engineers report listed "Saved Damage Annual," which is the benefits as **$ 35,543,000**

Assuming that further development and asset appreciation increased such damage annuals by 50%, a multiplier factor of (**1.5**) is applied to the benefits estimate:

B = $ 35,543,000 * 1.5
B = $ 53,314,500

This results in a Benefit-Cost Ratio of:

B /C = ($ 53,314,500) / ($ 11,388,000) = 4.7

⇨ **B / C = 4.7 (using the USACE BCA calculation described in the USACE report (4), with adjustment for land development changes)**

Appendix A2 - Cost Estimate

Alignments : R2 - Arc Wall

Total Length (ft)	Total Cost (M$)
34,000	180.8

Lable	Item	Quantity	Unit	Unit Cost	Total Item cost	Remarks
1	SSPD	9,400	Lft	4,500	42,300,000	
2	SSPS	12,600	Lft	2,000	25,200,000	
3	RB	11,300	Lft	1,000	11,300,000	
4	Movable Road Gate	6	Gate	2,000,000	12,000,000	
5	Tidal gate	3	Gate		50,000,000	2-200' (30'R; 60'R) ==> 2*10M = 20M
						1-200' (160'R) ==> 1*30m = 30 m

Sub-Total Cost	140,800,000
Pump Stations Cost	40,000,000
Total in Place cost	180,800,000
Annual Cost	**3,000,000**

Project Elements :

Design
Right of way acquisition
Mobilization
Clear and Grub
Utility Relocation
Wetland Mitigation
Maintenance & protection of Traffic
Access Roads
Road Raisings
Steel Sheet Pile Wall/ Burm
Drainage Penetrations- Duckbill Valves
Drainage Ditches
O&P
Annual Services: Periodic Operation & Maintenance, Repair of gates & Pumps, ….

Legend:

Single Sheet Pile Deep - SSPD ==> 40' PZ 27 - 32' in / 8' out
Single Sheet Pile Short - SSPS ==> 20' PZ 27 - 17' in / 3' out
Douple Sheet Pile w/lightweight Fill - DSPLW
Concrete T-Wall with Pile Support - CTW
New Embankment - NE
Tidal Gate with Pile Support - TG
Navigation Tidal Gate with Pile Support - NGT
Raised Berm - RB
Raised Berm High (RBH) (+12)
Existing RR Embankment - ERRE

Appendix A2 - Quantity Take-Off

Alignments : **R2 - Arc Wall**

Lable #	Start Station	End Station	Length (ft)	Wall Type	Elev.Top Wall (ft)	Elev. Top Bedrock(ft)	Ground Condition	Remarks
1	0	3,000	3000	SSPS (50%), RB (50%)	8	-100	Roadway Embankment	Paterson Plank
2	3,000	3,200	200	TG	8	-90	Berry's Creek- Tidal Gate	
3	3,200	8,000	4800	SSPS (50%), RB (50%) or ERRE	8	-50	Roadway Embankment	Paterson Plank
4	8,000	8,200	200	SSPS	8	-20	Roadway Embankment	Marsh
5	8,200	8,300	100	Movable Gate	8	-20	Roadway Crossing	Washingtion Ave-Moonachie
6	8,300	10,000	1700	SSPD	8	-30	Marsh	
7	10,000	10,100	100	Tidal Gate	8	-30	Creeek-Sky Harbor Terminal	
8	10,100	13,000	2900	SSPD	8	-60	Marsh	
9	13,000	13,200	200	Tidal Gate	8	-60	Moonachie Creek	
10	13,200	18,000	4800	SSPD	8	-60	Marsh	
11	18,000	18,100	100	Tidal Gate	8	-60	Loosen Slote - Creek/ Empire Blve	
12	18,100	21,000	2900	SSPS (50%), RB (50%)	8	-80	Marsh to Merioitti Road	
13	21,000	28,000	7000	SSPS (50%), RB (50%)/ Raodway Crossings	8	-60	Developed Water Front	
14	28,000	34,000	6000	SSPS (50%), RB (50%)	8	-60	Developed Water Front	

Project Elements :

Design
Right of way acquisition
Mobilization
Clear and Grub
Utility Relocation
Wetland Mitigation
Maintenance & protection of Traffic
Access Roads
Road Raisings
Steel Sheet Pile Wall/ Burm
Drainage Penetrations- Duckbill Valves
Drainage Ditches
O&P
Annual Services: Periodic Operation & Maintenance, Repair of gates & Pumps, ….

Legend:

Single Sheet Pile Deep - SSPD ==> 40' PZ 27 - 32' in / 8' out
Single Sheet Pile Short - SSPS ==> 20' PZ 27 - 17' in / 3' out
Douple Sheet Pile w/lightweight Fill - DSPLW
Concrete T-Wall with Pile Support - CTW
New Embankment - NE
Tidal Gate with Pile Support - TG
Navigation Tidal Gate with Pile Support - NGT
Raised Berm - RB
Raised Berm High (RBH) (+12)
Existing RR Embankment - ERRE

Appendix A3 - Cost Estimate

Alignments : **Barrier Wall North**

Total Length (ft)	Total Cost (M$)
28,500	735.6

Lable	Item	Quantity	Unit	Unit Cost	Total Item cost	Remarks
1	SSPS	2,100	ft	2,000	4,200,000	
2	SSPD	890	ft	4,500	4,005,000	
3	Movable Road Gate	13	Gate	2,000,000	26,000,000	
4	1-RR Gate	1	RR Gate	10,000,000	10,000,000	
5	Tidal gate	4	T-Gate	22,500,000	90,000,000	1-200' (180'R) ==> 40m
						1-200' (50'R) ==> 30m
						1-100' (50'R) ==> 2*10m
6	Concrete Walls	300	ft	10,000	3,000,000	
7	Road Embankment Modification (RB)	1,210	ft	1,000	1,210,000	
8	Road Embankmend Modification (RBH)	15,720	ft	3,000	47,160,000	
9	Navigation Tidal barrier (Hackensack River)	1,500	ft	300,000	450,000,000	

Sub-Total Cost	635,575,000
Pump Stations Cost	100,000,000
Total in Place cost	735,575,000
Annual Cost	**10,000,000**

Project Elements :

Design
Right of way acquisition
Mobilization
Clear and Grub
Utility Relocation
Wetland Mitigation
Maintenance & protection of Traffic
Access Roads
Road Raisings
Steel Sheet Pile Wall/ Burm
Drainage Penetrations- Duckbill Valves
Drainage Ditches
O&P
Annual Services: Periodic Operation & Maintenance, Repair of gates & Pumps, ….

Legend:

Single Sheet Pile Deep - SSPD ==> 40' PZ 27 - 28' in / 12' out
Single Sheet Pile Short - SSPS ==> 20' PZ 27 - 17' in / 3' out
Douple Sheet Pile w/lightweight Fill - DSPLW
Concrete T-Wall with Pile Support - CTW
New Embankment - NE
Tidal Gate with Pile Support - TG
Navigation Tidal Gate with Pile Support - NGT
Raised Berm - RB
Raised Berm High (RBH) (+12)
Existing RR Embankment - ERRE

Appendix A3 - Quantity Take-Off

Alignments : Barrier Wall North

Lable	Start Station	End Station	Length (ft)	Wall Type	Elev.Top Wall (ft)	Elev. Top Bedrock(ft)	Ground Condition	Remarks
1	0	2800	2800	SSPS (20%), RB (20%)	12	-200	Roadway Embankment	Road - Rt 3
2	2800	3000	200	Tidal Gate	12	-180	Berry's Creek- Tidal Gate	
3	3000	3100	100	Movable Gate	12	-178	Sherton Plz Drive	
4	3100	5100	2000	SSPS (20%), RB (20%)	12	-100	Roadway Embankment	
5	5100	5400	300	Gates	12	-80	Roadway Embankment	M.Sport Complex Road
6	5400	6800	1400	SSPS (10%), RB (10%)	12	-70	Roadway Embankment	
7	6800	7100	300	Gates	12	-70	Roadway Embankment	M.Sport Complex Road
8	7100	8200	1100	SSPS (10%), RB (10%)	12	-40	Roadway Embankment	
9	8200	8600	400	Movable Gate/Conc.Wall	12	-20	Washington Ave-Razyps- Gates	
10	8600	9500	900	SSPS (50%), SSPD (50%)	12	-20	Roadway Embankment	
11	9500	9800	300	CTW	12	-20	NJTP.95	
12	9800	12000	2200	SSPS (20%),SSPD (20%), RBH (60%)	12	-50	Roadway Embankment	
13	12000	12100	100	Tidal Gate	12	-40	Tidal	
14	12100	12500	400	RBH	12	-40	Roadway Embankment	
15	12500	12600	100	Movable Gate	12	-40	Roadway Embankment	Ex Paterson Plaza
16	12600	14500	1900	RBH	12	-40	Roadway Embankment	
17	14500	14600	100	Tidal Gate	12	-50	Creeek-Sky Harbor Terminal	
18	14600	15500	900	RBH	12	-50	Roadway Embank-Turnpike	
19	15500	15700	200	Tidal Gate	12	-50	Moonachie Creek	
20	15700	21000	5300	RBH	12	-70	Roadway Embank-Turnpike	
21	21000	22500	1500	Navigation Tidal Gate	12	-80	Hackensack River Crossing	
22	22500	24800	2300	RBH	12	-80	Roadway Embank-Turnpike	
23	24800	24900	100	Movable Gate	12	-100	Roadway Crossing	
24	24900	28500	3600	RBH	12	-100	Marsh	

Project Elements :

- Design
- Right of way acquisition
- Mobilization
- Clear and Grub
- Utility Relocation
- Wetland Mitigation
- Maintenance & protection of Traffic
- Access Roads
- Road Raisings
- Steel Sheet Pile Wall/ Burm
- Drainage Penetrations- Duckbill Valves
- Drainage Ditches
- O&P
- Annual Services: Periodic Operation & Maintenance, Repair of gates & Pumps, ….

Legend:

Single Sheet Pile Deep - SSPD ==> 40' PZ 27 - 28' in / 12' out
Single Sheet Pile Short - SSPS ==> 20' PZ 27 - 14' in / 3' out
Douple Sheet Pile w/lightweight Fill - DSPLW
Concrete T-Wall with Pile Support - CTW
New Embankment - NE
Tidal Gate with Pile Support - TG
Navigation Tidal Gate with Pile Support - NGT
Raised Berm - RB
Raised Berm High (RBH) (+12)
Existing RR Embankment - ERRE

Appendix A - 4 - Cost Estimate

Alignments : Barrier Wall Middle

Total Length (ft)	Total Cost (M$)
19,600	643

Lable	Item	Quantity	Unit	Unit Cost	Total Item cost	Remarks
1	SSPS	2,320	ft	2,000	4,640,000	
2	SSPD	1,150	ft	4,500	5,175,000	
3	RB	1,470	ft	1,000	1,470,000	
4	Movable Road Gate	6	Gate	2,000,000	12,000,000	
5	Cross Road Raise	5	Raise	1,000,000	5,000,000	
6	RR Gate	1	Gate	10,000,000	10,000,000	
7	Tidal gate	1	Gate	40,000,000	40,000,000	
8	Concrete Walls	300	ft	10,000	3,000,000	
9	Tidal barrier (Hackensack River)	1,500	ft	280,000	420,000,000	
		(50'R)				

Sub-Total Cost	501,285,000
Pump Stations Cost	110,000,000
Total in Place cost	611,285,000
Annual Cost	**11,000,000**

Project Elements :

Design
Right of way acquisition
Mobilization
Clear and Grub
Utility Relocation
Wetland Mitigation
Maintenance & protection of Traffic
Access Roads
Road Raisings
Steel Sheet Pile Wall/ Burm
Drainage Penetrations- Duckbill Valves
Drainage Ditches
O&P
Annual Services: Periodic Operation & Maintenance, Repair of gates & Pumps, ….

Legend:

Single Sheet Pile Deep - SSPD ==> 40' PZ 27 - 28' in / 12' out
Single Sheet Pile Short - SSPS ==> 20' PZ 27 - 17' in / 3' out
Douple Sheet Pile w/lightweight Fill - DSPLW
Concrete T-Wall with Pile Support - CTW
New Embankment - NE
Tidal Gate with Pile Support - TG
Navigation Tidal Gate with Pile Support - NGT
Raised Berm - RB
Raised Berm High (RBH) (+12)
Existing RR Embankment - ERRE

Appendix A - 4 - Quantity Take-Off

Alignments : Barrier Wall Middle

Lable	Start Station	End Station	Length (ft)	Wall Type	Elev.Top Wall (ft)	Elev. Top Bedrock(ft)	Ground Condition	Remarks
1	0	2800	2800	SSPS (20%), RB (20%)	12	-200	Roadway Embankment	Road - Rt 3
2	2800	3000	200	Tidal Gate	12	-180	Berry's Creek- Tidal Gate	
3	3000	3100	100	Movable Gate	12	-178	Roadway Embankment	
4	3100	5100	2000	SSPS (20%), RB (20%)	12	-100	Roadway Embankment	
5	5100	5400	300	Gates	12	-80	Roadway Embankment	M.Sport Complex Road
6	5400	6800	1400	SSPS (10%), RB (10%)	12	-70	Roadway Embankment	
7	6800	7100	300	Gates	12	-70	Roadway Embankment	M.Sport Complex Road
8	7100	8200	1100	SSPS (10%), RB (10%)	12	-40	Roadway Embankment	
9	8200	8600	400	Movable Gate/Conc.Wall	12	-20	Washington Ave-Ramps- Gates	
10	8600	9500	900	SSPS (50%), SSPD (50%)	12	-20	Roadway Embankment	
11	9500	9800	300	CTW	12	-20	NJTP.95	
12	9800	10300	500	SSPD	12	-50	Roadway Embankment	
13	10300	11800	1500	Navigation Tidal Gate	12	-70	Navigation Tidal Barrior-Hackensack River	
14	11800	12400	600	SSPD (33%), SSPS (33%)	12	-70	Concrete Wall on Piles	
15	12400		3300				Ground Above Elevation +12	
16	12400	17000	4600	SSPS (10%)	12	-40	Numerous roads/ Ramp crossing	
17	17000	19600	2600	RB / Roads (10%)	12	-150	Roadway Embankment	

Project Elements :

Design
Right of way acquisition
Mobilization
Clear and Grub
Utility Relocation
Wetland Mitigation
Maintenance & protection of Traffic
Access Roads
Road Raisings
Steel Sheet Pile Wall/ Burm
Drainage Penetrations- Duckbill Valves
Drainage Ditches
O&P
Annual Services: Periodic Operation & Maintenance, Repair of gates & Pumps

Legend:

Single Sheet Pile Deep - SSPD ==> 40' PZ 27 - 28' in / 12' out
Single Sheet Pile Short - SSPS ==> 20' PZ 27 - 17' in / 3' out
Douple Sheet Pile w/lightweight Fill - DSPLW
Concrete T-Wall with Pile Support - CTW
New Embankment - NE
Tidal Gate with Pile Support - TG
Navigation Tidal Gate with Pile Support - NGT
Raised Berm - RB
Raised Berm High (RBH) (+12)
Existing RR Embankment - ERRE

Appendix A - 5 - Cost Estimate

Alignments : Barrier Wall South (Kearny Point)

Total Length (ft)	Total Cost (M$)
12,300	1,591.50

Lable	Item	Quantity	Unit	Unit Cost	Total Item cost	Remarks
1	SSPD	3,000	ft	4,500	13,500,000	
2	SSPS	1,000	ft	2,000	2,000,000	
3	Movable Road Gate	8	Gate	2,000,000	16,000,000	
4	Concrete Walls	1,000	ft	10,000	10,000,000	
5	Tidal barrier (Hackensack River)	2,500	ft	350,000	875,000,000	
6	Tidal barrier (Passaic River)	1,500	ft	350,000	525,000,000	

Sub-Total Cost	1,441,500,000
Pump Stations Cost	150,000,000
Total in Placo cost	1,591,500,000
Annual Cost	**15,000,000**

Project Elements :

Design
Right of way acquisition
Mobilization
Clear and Grub
Utility Relocation
Wetland Mitigation
Maintenance & protection of Traffic
Access Roads
Road Raisings
Steel Sheet Pile Wall/ Burm
Drainage Penetrations- Duckbill Valves
Drainage Ditches
O&P
Annual Services: Periodic Operation & Maintenance, Repair of gates & Pumps, ….

Legend:

Single Sheet Pile Deep - SSPD ==> 40' PZ 27 - 28' in / 12' out
Single Sheet Pile Short - SSPS ==> 20' PZ 27 - 17' in / 3' out
Douple Sheet Pile w/lightweight Fill - DSPLW
Concrete T-Wall with Pile Support - CTW
New Embankment - NE
Tidal Gate with Pile Support - TG
Navigation Tidal Gate with Pile Support - NGT
Raised Berm - RB
Raised Berm High (RBH) (+12)
Existing RR Embankment - ERRE

Appendix B1: Life Cycle Cost Analysis of Structural Protection Alternatives

	Arc Wall				APPENDIX B1 Lifecycle Cost Analysis	Wall North				
Years	Construction Cost	Annual Maintenance and Repair Cos	Pump Station Replacement Cost	Residual Valu	Total	Construction Cost	Annual Maintenance and Repair Co	Pump Station Replacement Cost	Residual Value	Total
0	$180,000,000.00				$180,000,000.00	$735,000,000.00				$735,000,000.00
1		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
2		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
3		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
4		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
5		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
6		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
7		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
8		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
9		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
10		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
11		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
12		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
13		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
14		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
15		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
16		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
17		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
18		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
19		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
20		$3,000,000.00	$20,000,000.00		$23,000,000.00		$10,000,000.00	$50,000,000.00		$60,000,000.00
21		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
22		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
23		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
24		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
25		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
26		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
27		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
28		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
29		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
30		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
31		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
32		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
33		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
34		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
35		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
36		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
37		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
38		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
39		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
40		$3,000,000.00	$20,000,000.00		$23,000,000.00		$10,000,000.00	$50,000,000.00		$60,000,000.00
41		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
42		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
43		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
44		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
45		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
46		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
47		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
48		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
49		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
50		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
51		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
52		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
53		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
54		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
55		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
56		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
57		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
58		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
59		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
60		$3,000,000.00	$20,000,000.00		$23,000,000.00		$10,000,000.00	$50,000,000.00		$60,000,000.00
61		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
62		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
63		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
64		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
65		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
66		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
67		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
68		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
69		$3,000,000.00			$3,000,000.00		$10,000,000.00			$10,000,000.00
70		$3,000,000.00		$ (42,000,000.00)	-$39,000,000.00		$10,000,000.00		$ (162,000,000.00)	-$152,000,000.00
Total	**$180,000,000.00**	**$210,000,000.00**	**$60,000,000.00**	**-$42,000,000.00**		**$735,000,000.00**	**$700,000,000.00**	**$150,000,000.00**	**-$162,000,000.00**	
Assume Rate of Return		4%								
NPV	$262,681,057.94					$996,528,426.46				

	Wall Middle				APPENDIX B1 Lifecycle Cost Analysis	Wall South				
Years	Construction Cost	Annual Maintenance and Repair Cost	Pump Station Replacement Cost	Residual Value	Total	Construction Co	Annual Maintenance and Repair Cost	Pump Station Replacement Cost	Residual Value	Total
0	$611,000,000.00				$611,000,000.00	$1,590,000,000.00				$1,590,000,000.00
1		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
2		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
3		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
4		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
5		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
6		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
7		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
8		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
9		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
10		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
11		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
12		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
13		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
14		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
15		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
16		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
17		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
18		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
19		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
20		$11,000,000.00	$55,000,000.00		$66,000,000.00		$15,000,000.00	$75,000,000.00		$90,000,000.00
21		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
22		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
23		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
24		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
25		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
26		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
27		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
28		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
29		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
30		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
31		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
32		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
33		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
34		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
35		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
36		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
37		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
38		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
39		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
40		$11,000,000.00	$55,000,000.00		$66,000,000.00		$15,000,000.00	$75,000,000.00		$90,000,000.00
41		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
42		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
43		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
44		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
45		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
46		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
47		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
48		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
49		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
50		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
51		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
52		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
53		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
54		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
55		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
56		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
57		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
58		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
59		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
60		$11,000,000.00	$55,000,000.00		$66,000,000.00		$15,000,000.00	$150,000,000.00		$165,000,000.00
61		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
62		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
63		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
64		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
65		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
66		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
67		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
68		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
69		$11,000,000.00			$11,000,000.00		$15,000,000.00			$15,000,000.00
70		$11,000,000.00		$ (138,700,000.00)	-$127,700,000.00		$15,000,000.00		$ (340,500,000.00)	-$325,500,000.00
Total	**$611,000,000.00**	**$770,000,000.00**	**$165,000,000.00**	**-$138,700,000.00**		**$1,590,000,000.00**	**$1,050,000,000.00**	**$300,000,000.00**	**-$340,500,000.00**	
Assume Rate of Return										
NPV	$901,217,935.44					$1,983,160,778.19				

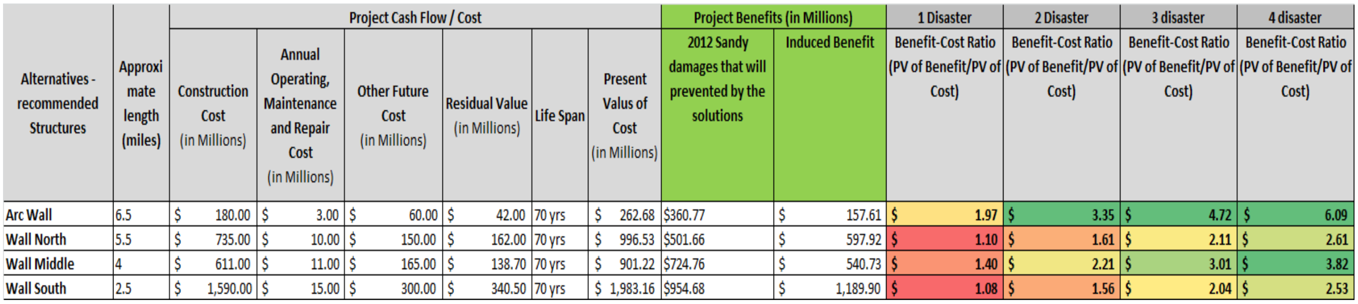
Appendix B2: Benefits (Damages and Economic Loss Avoidance) Model for Impacted Communities

Municipality	Little Ferry Borough	Moonachie Borough	South Hackensack Township	Teterboro Borough	Hackensack City	Carlstadt Borough	East Rutherford Borough
County	Bergen	Bergen	Bergen	Bergen	Bergen	Bergen	Bergen
Total Homes + Rentals Damaged	1525	674	24	0	181	1	33
Percentage of Homes Damaged	0.8	0.8	0.3	0.3	0.3	0.3	0.3
Average Cost to Businesses	15000	15000	15000	15000	15000	15000	15000
Average Cost of Individual Damages	12269.81	11728.05	4896.5	0	4896.5	970.68	7135.42
Total Structural Damage Amount to Homes and Businesses	63454380.75	29384117.1	6037548	0	59523799.5	12107912.04	11056406.58
Median Income	60000	39600	52000	0	52000	120000	71143
Avg Wage	15						
Employed People	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%
Income Loss @ 7 days	6113589.041	1028298.082	1185742.466	0	21446082.19	7050246.575	6080387.552
Productivity Loss for Inhabitants of Damaged Homes/Displaced	9781742.466	1645276.932	711445.4795	0	12867649.32	4230147.945	3648232.531
Average Income of a Small Business	800						
Total Loss for Business	2732800	2116800	2122400	0	21229600	4519200	3864000
Multiplier Effect for Suppliers	2732800	2116800	2122400	0	21229600	4519200	3864000
Governmental Losses							
Infrastructure Loss	2378775.0	606222.7	532347.7	14998.9	9628375.0	1371612.5	1995296.6
Environmental/Contamination	5351150	5574400	2381500	3572650	13897200	13450500	12944050
TOTAL Losses	92545237.3	42471914.8	15093383.7	3587648.9	159822306.0	47248819.1	43452373.3

Municipality	Rutherford Borough	Ridgefield	Secaucus Town	North Bergen Township	Kearny Town	Newark City	Harrison Town
County	Bergen	Bergen	Hudosn	Hudosn	Hudosn	Essex	Hudosn
Total Homes + Rentals Damaged	118	47	351	62	131	451	157
Percentage of Homes Damaged	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Average Cost to Businesses	15000	15000	15000	15000	15000	15000	15000
Average Cost of Individual Damages	7785.44	742.7	8151.72	1148.28	6038.32	10602.48	12219.87
Total Structural Damage Amount to Homes and Businesses	19166045.76	10559720.7	29433761.16	26688580.08	24633059.76	172175155.4	13795558.77
Median Income	75000	65653	71143	63000	47000	75000	72000
Avg Wage							
Employed People	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%
Income Loss @ 7 days	12989075.34	6945188.044	11095189.4	36713552.05	18335665.75	199313013.7	9403397.26
Productivity Loss for Inhabitants of Damaged Homes/Displaced	7793445.205	4167112.826	6657113.642	22028131.23	11001399.45	119587808.2	5642038.356
Average Income of a Small Business							
Total Loss for Business	6126400	3903200	7784000	9884000	8310400	58923200	3001600
Multiplier Effect for Suppliers	6126400	3903200	7784000	9884000	8310400	58923200	3001600
Governmental Losses							
Infrastructure Loss	4043201.1	2469663.6	3640918.2	13604864.8	9107668.2	62041568.2	3049022.7
Environmental/Contamination	9248400	0	20983050	16917900	32600550	83889300	4241700
TOTAL Losses	65492967.4	31948085.2	87378032.4	135721028.1	112299143.1	754853245.5	42134917.1

Appendix B3: Benefit-Cost Ratio Computations under various Storm frequencies

Alternatives - recommended structure	Approximate length	Immediate Protected Areas	Major Water Crossing	Protected Areas	Present Valus of Cost (in Millions)	Project Benefits (in Millions)		1 Disaster	2 Disaster	3 disaster	4 disaster
						2012 Sandy damages that will prevented by the solutions	Induced Benefit (30% of Construction Cost in Wages)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)
Arc Wall	6.5	1. Carlstadt 2. Moonachie 3. Little Ferry 4. Teterboro 5. South Hackensack 6. Hackensack	Berry's Creek	17.4 sq miles	$ 262.68	$360.77	$ 157.61	$ **1.97**	$ **3.35**	$ **4.72**	$ **6.09**
Wall North	5.5	1. Carlstadt 2. Moonachie 3. Little Ferry 4. Teterboro 5. South Hackensack 6. East Rutherford 7. Rutherford	Hackensack River and Berry's Creek	11.3 sq miles	$ 996.53	$501.66	$ 597.92	$ **1.10**	$ **1.61**	$ **2.11**	$ **2.61**
Wall Middle	4	1. Carlstadt 2. Moonachie 3. Little Ferry 4. Teterboro 5. South Hackensack 6. East Rutherford 7. Rutherford 8. Part of Secaucus 9. Part of North Bergen	Hackensack River and Berry's Creek	18.9 sq miles	$ 901.22	$724.76	$ 540.73	$ **1.40**	$ **2.21**	$ **3.01**	$ **3.82**
Wall South	2.5	1. Kearny 2. Areas above Kearny Point 3. Harrison 4. East of Newark	Hackensack River and Passaic River	38.1 sq miles	$ 1,983.16	$954.68	$ 1,189.90	$ **1.08**	$ **1.56**	$ **2.04**	$ **2.53**



Alternatives - recommended Structures	Approximate length (miles)	Project Cash Flow / Cost						Project Benefits (in Millions)		1 Disaster	2 Disaster	3 disaster	4 disaster
		Construction Cost (in Millions)	Annual Operating, Maintenance and Repair Cost (in Millions)	Other Future Cost (in Millions)	Residual Value (in Millions)	Life Span	Present Valus of Cost (in Millions)	2012 Sandy damages that will prevented by the solutions	Induced Benefit	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)	Benefit-Cost Ratio (PV of Benefit/PV of Cost)
Arc Wall	6.5	$ 180.00	$ 3.00	$ 60.00	$ 42.00	70 yrs	$ 262.68	$360.77	$ 157.61	$ **1.97**	$ **3.35**	$ **4.72**	$ **6.09**
Wall North	5.5	$ 735.00	$ 10.00	$ 150.00	$ 162.00	70 yrs	$ 996.53	$501.66	$ 597.92	$ **1.10**	$ **1.61**	$ **2.11**	$ **2.61**
Wall Middle	4	$ 611.00	$ 11.00	$ 165.00	$ 138.70	70 yrs	$ 901.22	$724.76	$ 540.73	$ **1.40**	$ **2.21**	$ **3.01**	$ **3.82**
Wall South	2.5	$ 1,590.00	$ 15.00	$ 300.00	$ 340.50	70 yrs	$ 1,983.16	$954.68	$ 1,189.90	$ **1.08**	$ **1.56**	$ **2.04**	$ **2.53**