Strategies for Flood Risk Reduction for Vulnerable Coastal Populations along Hackensack River at Little Ferry and Moonachie

FINAL REPORT

Submitted to

New Jersey Governor's Office of Recovery and Rebuilding
and
New Jersey Department of Environmental Protection

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Executive Summary

Flooding is a regular concern in both Little Ferry and Moonachie along the tidal Hackensack River. Although the storm surge from Hurricane Sandy highlighted their vulnerability to an extreme event, smaller more frequent events regularly occur and impact residents, commerce and the area's transportation infrastructure. This study addressed improvements to the stormwater drainage system for storm events that are limited to a storm surge that reaches the vertical extent of the protective berms surrounding the area. The proposed flood remedies take into account both the scale of the remedy itself as well as the event. The scales investigated are 1.) Municipal which includes use of new infrastructure or upgrades to existing infrastructure to protect areas from flooding that occurs fairly regularly (about yearly); and 2.) Block and lot which includes individual projects conceptualized to protect smaller areas such as chronically flooded roadways, intersections, and public spaces. That also includes the use of stormwater green infrastructure and preventative maintenance to ensure the flood impacts are minimized.

At the municipal scale, the recommendations from this study include:

1. Cleaning and dredging of open trenches present in Moonachie.
2. Implementation of green infrastructure to reduce the source contribution of runoff.
3. Mapping and simulation of existing drainage systems.
4. Maintenance and upgrade to the existing tide gate structures.
5. Creation of new surface storages in Little Ferry and Moonachie.
6. Expansion of existing storm water detention capabilities of Willow Lake in Little Ferry.

At the block and lot scale, the recommendations include:

- Proper maintenance of the existing stormwater drainage system. Periodic cleaning and maintenance of storm grates, etc.
- Installation of check valves at the outlet of all storm water pipes to impede tidal waters.
- Redesigning of open trenches as vegetated swales to increase infiltration. Expansion and conversion of open trenches to wetlands or bioretention structures.
- Reduction of impervious surface at Route 46 corridor.
- Raising of important transportation infrastructure.
- Implementation of stormwater green or blue infrastructure projects.

Five projects at specific locations are recommended as well:

(1) Expansion of open ditches in Moonachie and Little Ferry and Carlstadt towns.
(2) Implementation of green infrastructure strategies along Moonachie Road.
(3) Installation of Pervious Pavement in the Burger King Parking Lot.
(4) Rehabilitation of Trenches on State Street.
(5) Tree removal from drainage system.

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Strategies for addressing flood impacts in Little Ferry and Moonachie

1. Approach to Developing Flood Mitigation Strategy and Measures

The Rutgers University Flood Mitigation Study Team, in collaboration with Montclair State University and Monmouth University, headed by Principal Investigator, Dr. Qizhong (George) Guo developed a framework to facilitate the assessment of flood risk to communities and facilitate the selection of flood mitigation measures for these communities, see Figure 1 below.

The Rutgers University Flood Mitigation Study Team also developed a menu of flood risk-reduction functions and their associated measures. Figure 2 is a schematic showing the application of various flood mitigation measures and Table 1 provides a listing of each function and its associated measures.

The strategy development framework includes the consideration of (a) all three sources of the threat (the flood water), local rainwater, upstream riverine flow, and downstream coastal water; (b) various levels (recurrence intervals) of the threat and their future changes; (c) types and extents of the exposure/vulnerability including various types of land use and infrastructure; (d) regional, municipal, and neighborhood/block/lot scales of solutions; (e) types of possible flood mitigation measures, (f) functions of possible flood mitigation measures, and (g) costs, benefits, environmental impacts, waterfront accessibility and synergy of the proposed solutions. The types of the measures considered include: maintenance/repair vs. new construction, mobile/adaptable vs. fixed, green/nature-based vs. grey, non-structural (policy, regulation, etc.) vs. structural, micro-grid vs. large-grid powered, innovative vs. conventional, preventative vs. protective, retroactive vs. anticipatory, and short-term vs. long-term. The functions of the measures considered include: (1) rainfall interception, (2) storage, (3) conveyance, (4) upstream flow reduction, (5) diversion, (6) deceleration, (7) tide barrier, (8) pumping, (9) surge barrier, (10) mobile barrier, (11) elevation, and (12) avoidance. Implementation of the flood mitigation measures will help the communities achieve the resilience.

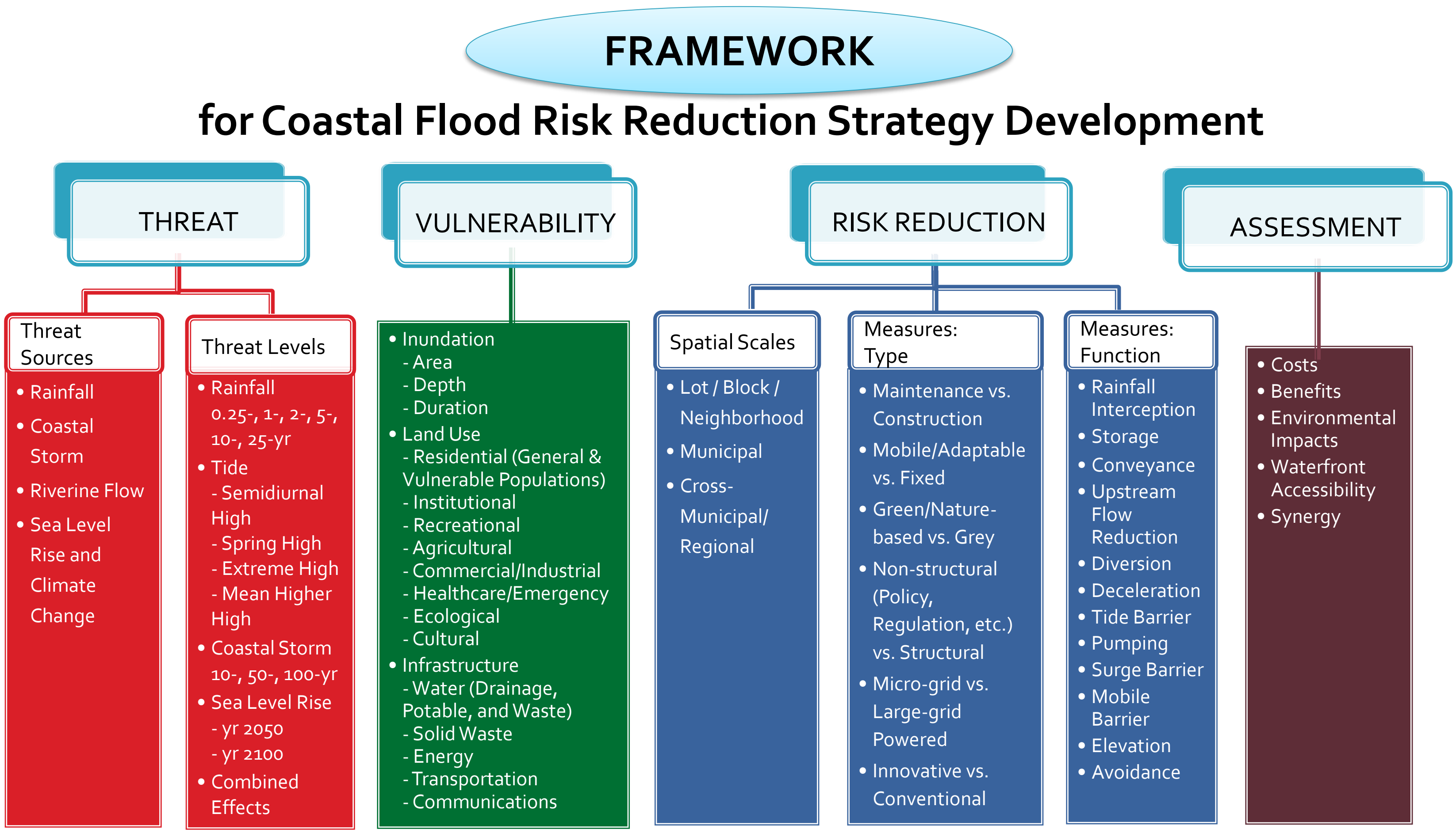

Figure 1: Framework for Flood Risk Reduction Strategy Development

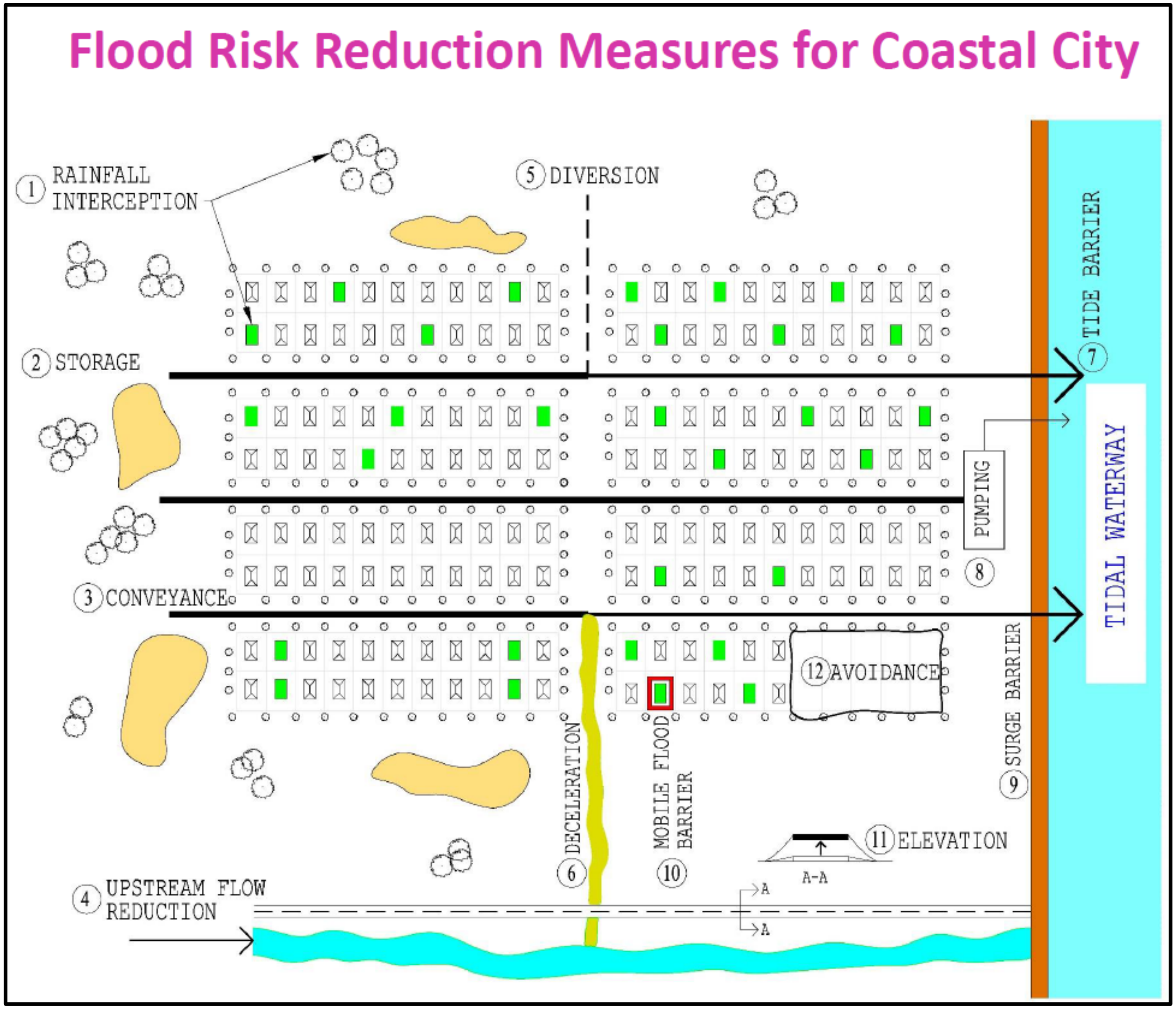

Figure 2: Flood Risk Reduction Measures

Table 1: Flood Mitigation Functions and Associated Measures

FUNCTIONS AND MEASURES

RAINFALL INTERCEPTION	STORAGE	CONVEYANCE	UPSTREAM FLOW REDUCTION	DIVERSION	FLOW DECELERATION	TIDE BARRIER	PUMPING	SURGE BARRIER	MOBILE FLOOD BARRIER	ELEVATION	AVOIDANCE
INCREASE VEGETATION	RETENTION	SEWER	DAM	NEW SEWER	VEGETATED SWALE	FLAP GATE	PUMPING STATION	NEW LEVEE	MOVABLE FLOOD WALL	ELEVATE BUILDING	BUYOUT
GREEN ROOF	DETENTION	CHANNEL	WATERSHED MANAGEMENT	BYPASS FORCE MAIN*	ARTIFICIAL WETLANDS	SLUICE GATE	EMERGENCY POWER	SEAWALL	FLOOD GATE	ELEVATED ROAD	EVACUATION
BIOSWALE	INFILTRATION	DREDGING				HEADWALL	WIND PUMP	TEMPORARY SEAWALL	INFLATABLE BARRIER		WARNING
VEGETATED FILTER STRIP	EXPANSION	COMBINED SEWER SEPARATION					RAIN PUMP*	ELEVATING LEVEE			RISK EDUCATION
POROUS PAVING	CONSTRUCTED WETLANDS	CULVERT SIZE					WAVE PUMP*	NEW DUNES			
RAIN GARDEN	LAKE EXPANSION	DEBRIS REMOVAL					CURRENT PUMP*	BEACH NOURISHMENT			
PLANTER BOX		DE-SNAGGING						ARTIFICIAL WETLANDS			
RAIN BARREL		STRAIGHTENING						SHEETING BULKHEAD			
SOIL AMENDMENT		SEWER FLUSHING						CONCRETE BULKHEAD			
VERTICAL WALL								REPAIR LEVEE			
								VEGETATED LEVEE			
								BREAKWATER			
								IN-WATER BARRIER			
								RESTORED WETLANDS			
								LIVING SHORELINE			
								FLOATING BARRIER			
								EXTENDABLE FLOOD PANEL*			
								CAUSEWAY WITH OPERABLE FLOOD GATE*			

*Newly proposed.

2. Introduction to Flooding in Little Ferry and Moonachie

2.1 Flooding Problems

In the past three years, two major events have occurred that have not only severely impacted low lying areas in Northern New Jersey, but also highlighted the varied degree of impact resulting from storm origin and character. An area particularly hard hit was a section of the Hackensack Meadowlands that includes the municipalities of Moonachie and Little Ferry (Figure 3). The two storms were Hurricane Irene in July 2011 and Hurricane Sandy in October 2012. The former of these storms was characterized by large rainfall depth (>8 inches) along with an abnormally high antecedent soil moisture that resulted in extreme flooding throughout inland New Jersey, while the latter was characterized by relatively low rainfall (~2.5 inches in Meadowlands), but the highest storm surge measurements ever recorded in several locations throughout the NYNJ Harbor complex.

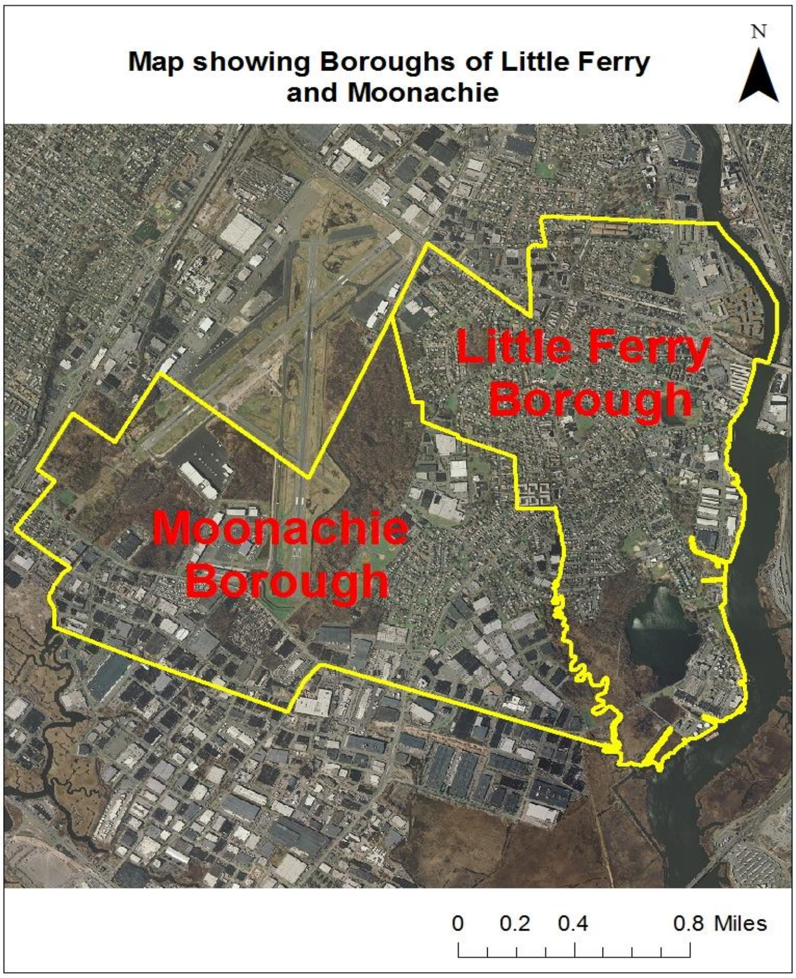

Figure 3: Site Location Map

The impact of these storms was felt in the study area, however through communication with town officials and review of flooding reports it is quite apparent that the storm surge related to Hurricane Sandy was far more damaging than the rainfall associated with Irene. Flood protection infrastructure was completely overwhelmed as the 8.5 feet high storm surge overtopped the 5 feet high berm at multiple locations (Artigas 2013). The situation was exacerbated by power outages that disabled pump stations. The result was upland flooding that lasted far longer than it should have, at least 5 days after the surge had receded (Figure 4.)

Figure 4: Main St., Little Ferry. This area remained flooded for 5 days following Sandy because Main Street and Willow Lake pump station were without power and there is no gravity drainage. (Photo from NOAA flyover November 1, 2012.)

Flooding is a regular concern in both of these communities and although the storm surge from Hurricane Sandy highlighted their vulnerability to an extreme event, smaller more frequent events regularly occur and impact residents, commerce and the area's transportation infrastructure. This report will address improvements to the storm water drainage system for storm events that are limited to a storm surge that reaches the vertical extent of the protective berms surrounding the area. Although it will not address increased protection from a storm surge, the altered drainage characteristics (associated with increased elevation of the downstream receiving water) will be addressed when discussing storm water drainage.

2.2 Drainage System

Moonachie and Little Ferry are extremely low lying with little or no relief. As a result the storm water drainage systems are extremely shallow with a minimal slope. The Moonachie drainage system directs water by gravity to either Hackensack River or Berry's Creek through existing drainage ditches such as the East Riser, West Riser and Losen Slote (Figures 5 to 10). These drainage ditches are protected from surge via existing tide gates. The Losen Slote tide gate is equipped with pumps (Figure 7.) capable of draining runoff despite elevated downstream water elevations (high tide and storm surge less than berm height).

The Little Ferry drainage system is characterized by a shallow, low slope pipe network that directs runoff to one of three pump stations. Typically these pumps stations are effective and prevent major flooding. Localized street flooding occurs but is typically short lived. The pump stations were cut off from the power grid and failed to function after Hurricane Sandy, with the exception of the Losen Slote tide gate pumps which are equipped with a diesel backup generator. The municipality has expressed their desire to increase their resiliency by installing backup generators capable of running each of the pump stations.

Surface drainage in Moonachie is directed through a collection system consisting of open trenches and pipes which drain into the downstream tide gate. The gate closes during high tide restricting upland flow from the receiving water and opens during low tide to allow upland areas to drain. Walsh and Miskewitz (2013) indicate that large increases in the downstream elevation will impact tide gate function and may result in upland flooding even without a surge that overtops the protective berm. In addition to storm surges, sea level rise will result in higher downstream water elevations which may exacerbate the impact of storm surges.

2.3 Flood Inundations in the Area of Study

Water inundation depths for Little Ferry and Moonachie Flood under (a)10-year coastal flood, (b) 50-year coastal flood, (c) 100-year coastal flood, and (d) 500-year coastal flood are shown in Figure 11.

The average inundation depths and flood volumes in Little Ferry and Moonachie under different coastal flood recurrence intervals are shown in Table 2.

2.4 Water Protection Level of Existing Berms

The Meadowlands Environmental Research Institute (MERI) estimates the storm surge protection elevation for Little Ferry and Moonachie to be 5 feet on average and less in some areas, referred to as ‘soft edges’. MERI’s determination of this value comes from 2009 topographical data, where elevations were derived using LiDAR data. Seepage is likely to occur through these soft edges at the mean higher high water level (MHHW) and in some cases as the tides have been observed working their way backwards through existing stormwater drainage infrastructure.

Since the average water inundation depth for the 10-year storm is 5 feet (Table 2), the existing berms (the soft edges) are expected to be only able to protect the coastal storm of the recurrence interval less than 10 years.

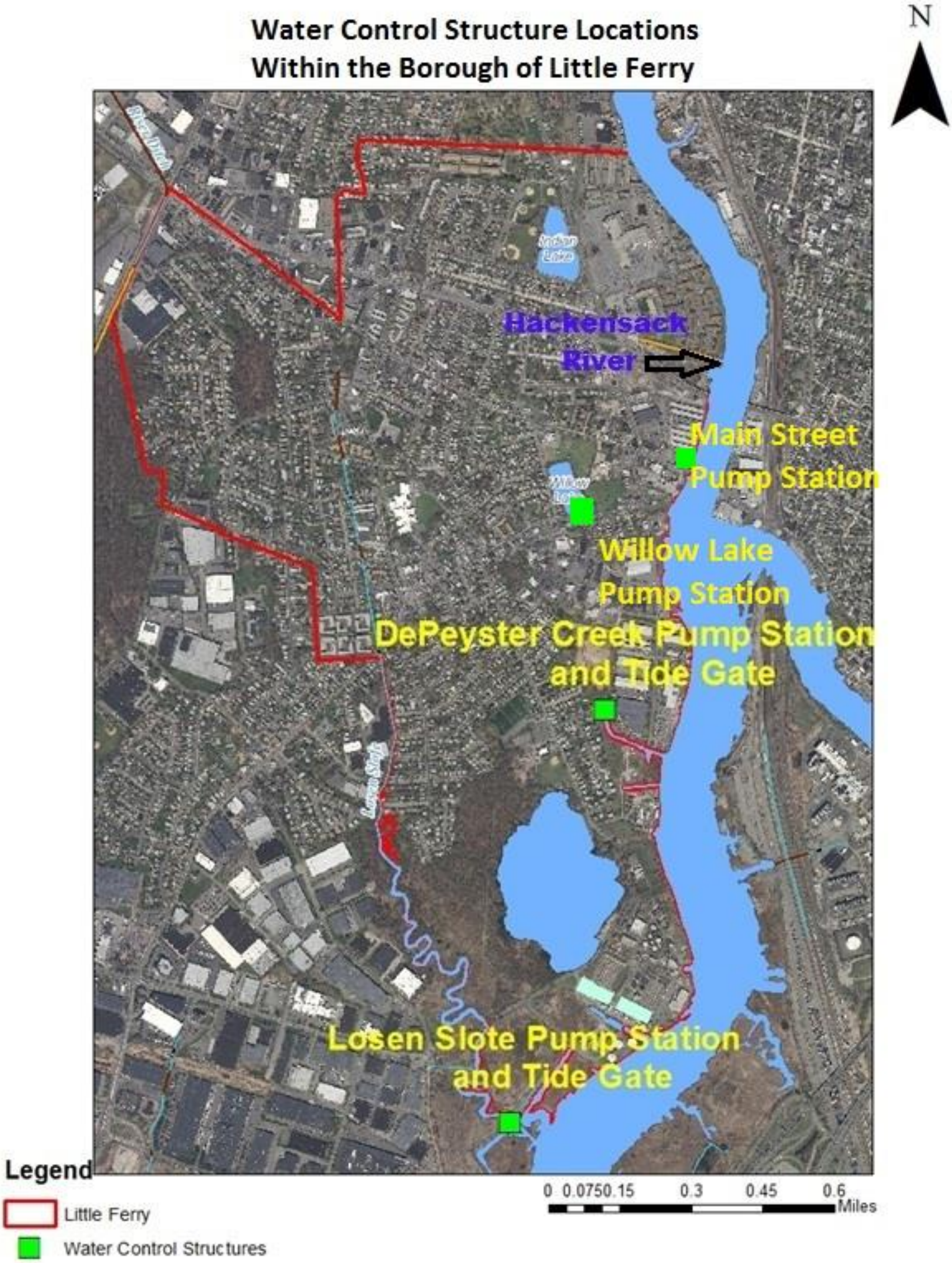

Figure 5: Image showing water control structures in Little Ferry

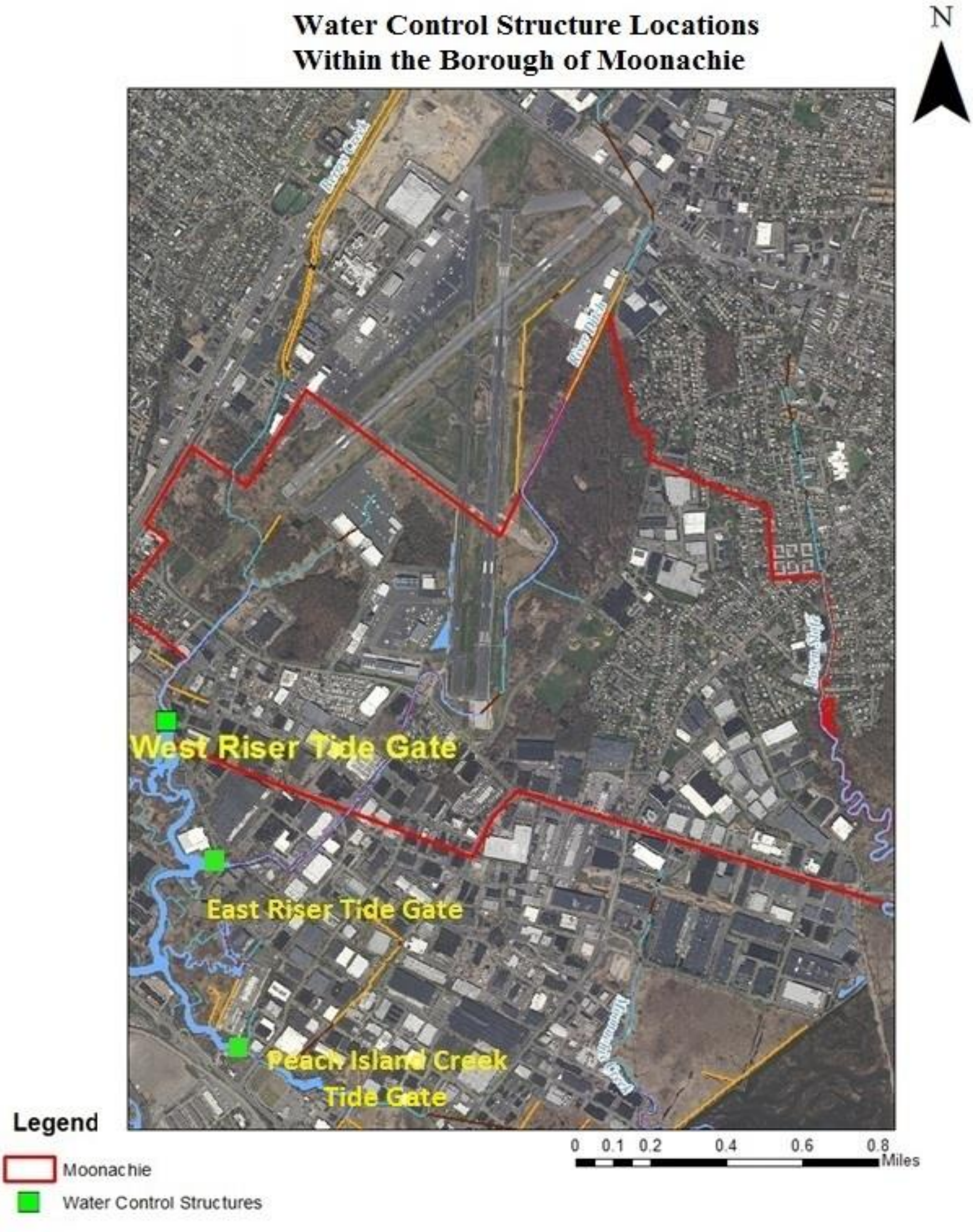

Figure 6: Image showing water control structures in Moonachie

Figure 7: Losen Slote Tide Gate is equipped with high volume pumps, and a diesel generator backup power supply

Figure 8: View of trash racks at intake structure, Losen Slote tide gate


Figure 9: Four timber tide gates, West riser tide gate.


Figure 10: View of trash racks at intake structure, East Riser tide gate

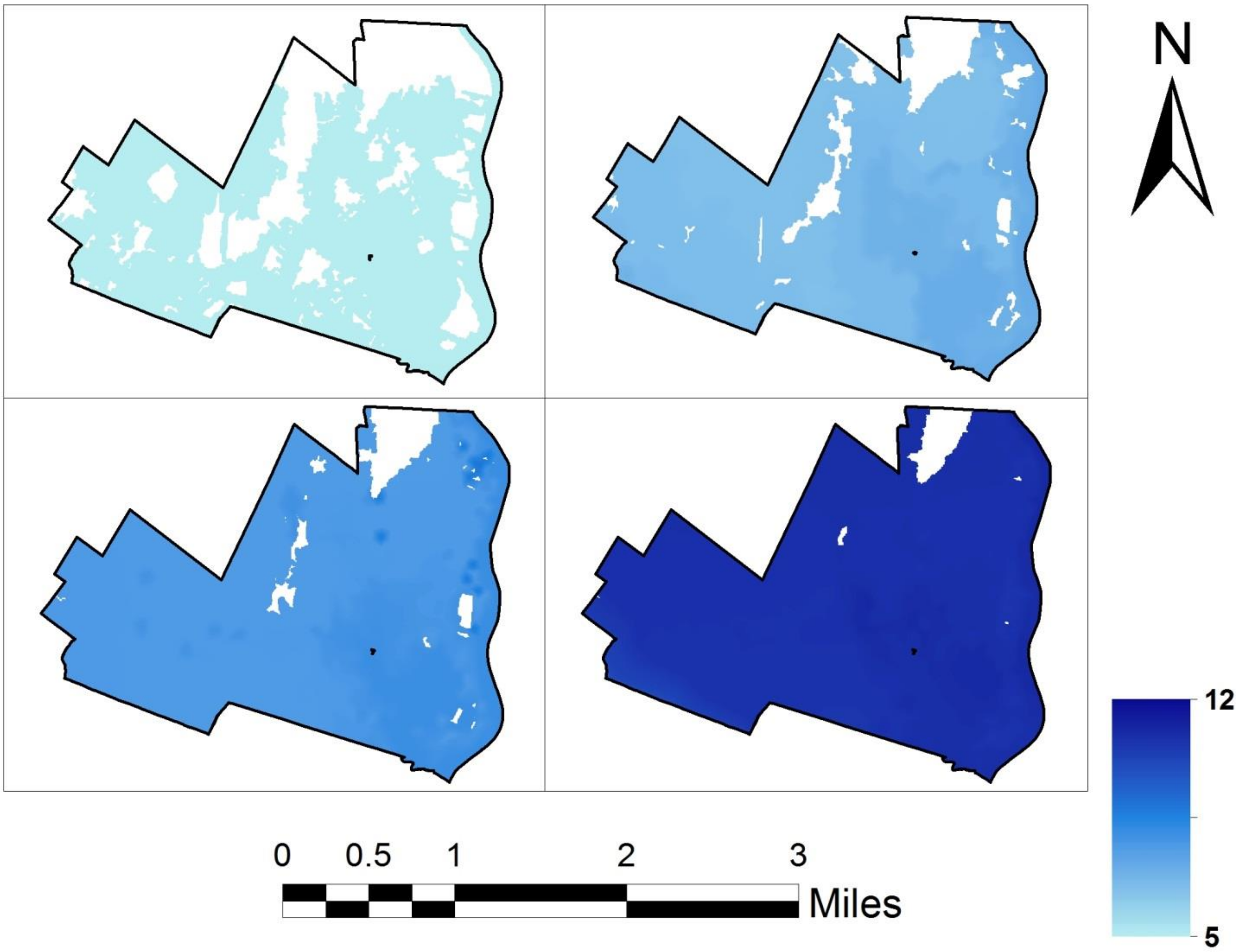

Figure 11: Inundation depths (in feet) in Little Ferry and Moonachie under (a)10-year coastal flood, (b) 50-year coastal flood, (c) 100-year coastal flood, and (d) 500-year coastal flood (Source: FEMA Map Service Center)

Table 2: Average Inundation depths and flood volumes in Little Ferry and Moonachie under different coastal flood recurrence intervals

Coastal Flood Return Period	**Average Inudation Depth (ft)**	**Volume (ft^3)**
10-year	5	34,597,1875
50-year	6.6	526,629,375
100-year	7.7	643,186,875
500-year	10.8	935,458,750

2.5 Critical infrastructure in Little Ferry and Moonachie

Identification of Critical Infrastructure was solicited from the two municipalities. Little Ferry provided researchers with a Critical Facilities list, which was used in determining critical infrastructure from building map layers in GIS (Table 3). Moonachie did not provide a Critical Facilities list. Critical infrastructure for Moonachie (Table 4) was therefore selected based on best professional judgment and the types of Critical Facilities provided by Little Ferry. The locations of the critical infrastructure are shown in Figure 12.

Table 3: List of Critical Facilities in Little Ferry (excluding pump stations)

Facility Name	Location	Building Elevation (ft)	Area (ft^2)
Bergen County Utilities Authority	24 EMPIRE BLVD	16.1	84
Bergen County Utilities Authority	MEHRHOF RD (FT OF)	Multiple Buildings >20	
Early Learner's Child Care	201-211 REDNECK AVE	20.6	32978
Little Ferry Nursery School	164 LIBERTY ST	17.0	2875
Little Ferry VFW	100 MAIN ST	14.3	5330
Washington School	123 LIBERTY ST	40.7	20656
Recycling Center Little Ferry/ DPW	179 MEHRHOF RD	21.2	9985
Recycling Center Little Ferry/ DPW	179 MEHRHOF RD	27.8	1440
Washington School	123 LIBERTY ST	18.7	1161
Little Ferry Public Library	239 LIBERTY ST		8579
Little Ferry Boro Hall	217 LIBERTY ST	34.9	15792
Memorial School Little Ferry	130 LIBERTY ST	19.4	85927
SCIENTIFIC DESIGN CO INC	49 INDUSTRIAL AVE	22.1	26901
St. Margaret of Cortona	39 CHAMBERLIN AVE	13.9	972
Fire House Storage	50 MAPLE ST	16.2	1200
Fire House	22 MARSHALL AVE	29.3	3135
Little Ferry Public Safety Building & Senior Center	95 MAIN ST	26.7	10455
Little Ferry Public Safety Building & Senior Center	95 MAIN ST	16.6	490
Little Ferry Hook & Ladder Co. No. 1	124 MAIN ST	18.6	4257

Table 4: List of Critical Facilities in Moonachie

Facility Name	Location	Building Elevation (ft)	Area (ft^2)
Moonachie DPW	7 WILLOW ST	19.9	4222
Pump Station	CAESAR PL	14.5	435
Robert L. Craig School	20 WEST PARK ST	17.4	60962
Moonachie Senior Citizen and Civic Center	MOONACHIE RD	12.6	589
Moonachie Boro Hall	70 MOONACHIE RD	15.7	7937
Moonachie Boro Hall	70 MOONACHIE RD	15.7	408
Moonachie Fire Department (Hose Co. # 2)	MOONACHIE RD	29.6	6227
Moonachie First Aid Squad	116 MOONACHIE RD	14.7	2859
Moonachie Senior Citizen and Civic Center	MOONACHIE RD	14.6	6547

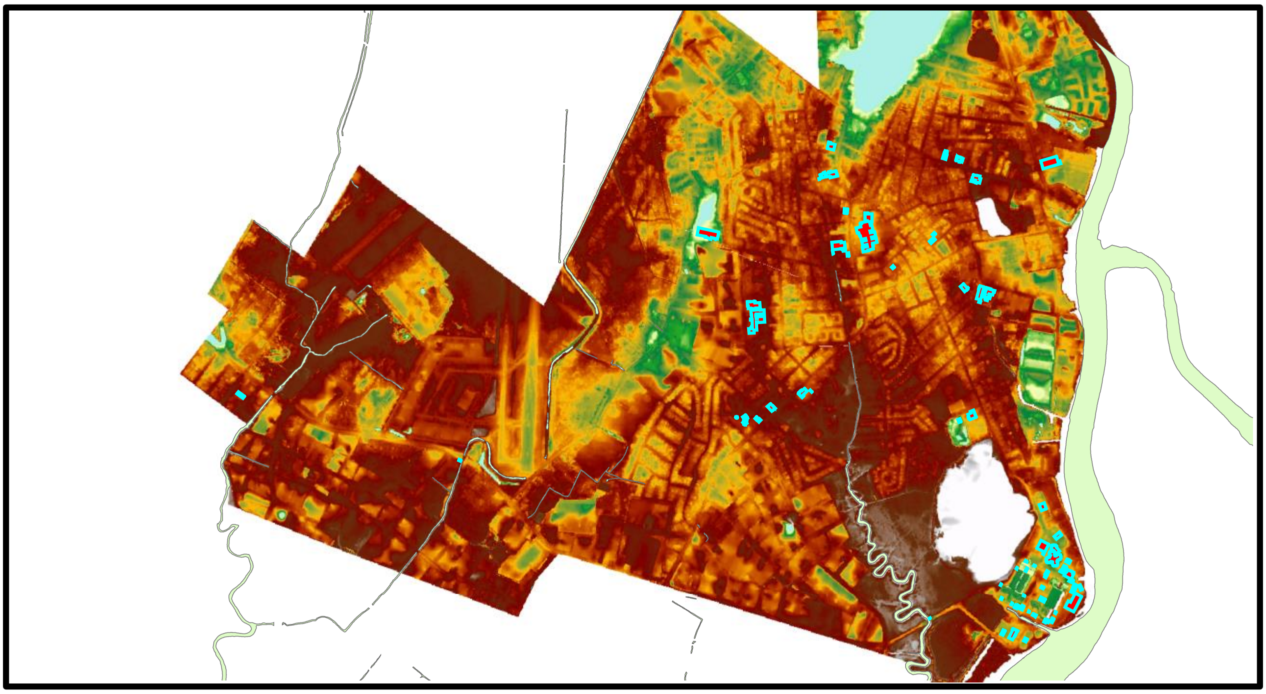

Figure 12: Locations of Critical Facilities (highlighted) in Moonachie and Little Ferry with DEM basemap.

Since the building elevation of these critical facilities is higher than the 500-year flood level (10.8 ft), this infrastructure is not affected by flooding of recurrence intervals less than 500-years.

3. Flood Mitigation Strategies

In this report flood remedies will be described that take into account both the scale of the remedy itself as well as the event. The scales to be discussed are 1.) Municipal, this includes the use of new infrastructure or upgrades to existing infrastructure to protect areas from flooding that occurs fairly regularly (~yearly); 2.) Block and lot, these include individual projects that will be conceptualized to protect individual areas such as chronically flooded roadways, intersections, public spaces. These will include the use of green infrastructure and preventative maintenance to ensure that flood impacts are minimized. Note that the flood protection at the regional scale and for the storms of long recurrence intervals (e.g., 100 years) will be addressed in a concurrent study conducted by New Jersey Institute of Technology.

3.1 Municipal Scale

The first strategies to be presented will address flood impacts on a municipal scale. These will require large scale implementation plans that address existing or proposed drainage and would require the support of the individual municipalities. The strategies to be discussed include:

1. Cleaning and dredging of open trenches present in the study area. Open trenches present in Moonachie drain into either Hackensack River or Berry's Creek.
2. Green Infrastructure. Implementation of green infrastructure to reduce the source contribution of runoff. These include municipality wide implementation of infiltration (pervious pavement) and retention (wetlands and green/blue roofs) technologies.
3. Mapping and simulation of existing drainage systems. The Drainage Systems were designed and built piece-meal with little or no documentation. It is unknown where many of the pipes originate or drain to. As a result the actual capacity of the system is unknown, and targeted improvements are not possible.
4. Maintenance and Upgrade to the existing tide gate structures. Many of the gates are old and their function may be impaired. Addition of pumping capability may reduce upland flooding and expand the protective capabilities of the tide gate.
5. Creation of new surface storages. There are potential areas in both towns that can be utilized as surface storages for stormwater runoff.
6. Expansion of existing storm water detention capabilities of Willow Lake in Little Ferry. Willow Lake is located in the center of Little Ferry and is bordered on its east side by open space. Conversion of this open space to wetland / storm water storage will increase the drainage capacity of the Little Ferry storm water drainage system and thus reduce the level of street flooding upstream.

3.1.1 Cleaning of open trenches in Little Ferry and Moonachie

Open trenches in Moonachie direct water by gravity to Hackensack River or Berry's Creek. Many of these open trenches are filled with sediments and are not functioning to their full capacity. The solution for this is to dredge these trenches so that the trenches can be used to their full capacity. There is a total of 22 miles of open trenches in Moonachie. The total cost for cleaning the open trenches in Moonachie area would cost $4.3 million (estimated by the borough official). Cleaning cost approximately $200,000 per mile. This cost estimate includes removal, hazardous material testing and disposal of the sediments.

3.1.2 Stormwater Green Infrastructure

The development of green flood prevention infrastructure includes the implementation of hydrologic features to manage water and provide environmental and community benefits. It is proposed in the study area to reduce the storm water inputs to the drainage system. The feasibility of implementing green infrastructure to absorb a portion of the surface water runoff has been assessed for this study. Table 5 summarizes the problem, our approach and source of flood water. A description of the Green Infrastructure implementation software is included in Appendix A.

Table 5: Problem and solution description

Problem to solve	Reduce surface flood water inlet to the drainage system
Approach	Removal of runoff by using optimal combinations of green infrastructures
Source of flood water	Rainfall only (1 year and 2 year return periods)

One option is to evaluate the implementation of stormwater green infrastructure over the area of entire town. In this study, the areas only in the 100-year flood zone are considered in the calculations.

Potential sites were identified using land use maps. Only the areas characterized as commercial, industrial, residential, athletic fields, urban lands and built up lands are taken into consideration for green infrastructure implementation.

(Table 6). The costs for removing one inch of runoff are estimated and shown in Tables 7 to 10.

Table 6: Little Ferry and Moonachie data

	Rainfall amount(1-Year Storm) (in)	Runoff from 1 year storm (in)	Total area (sq.ft)	Area in 100 year flood zone (sq.ft)	Excluded area (sq.ft)	Area used for analysis (sq.ft)	Percentage of area in the town
Little Ferry	2.8	2.00	43409578	40561183	16256959	24304224	56
Moonachie	2.8	2.01	48521311	47606853	41013243	6593610	14

1) Little Ferry

- Maximum runoff capture: 1.2 inch
- Cost to remove 1.2 inch of runoff (10 year horizon) = $ 97,699,717
- Cost to remove 1.2 inch of runoff (50 year horizon) = $ 109,174,939

Table 7: Optimal combination of green infrastructure and associated cost to remove 1 inch of runoff

	Optimal area (ft^2) for 1 inch runoff removal	Maximum potential area (ft^2)
Green roof	2290803	3694242
Swales	692670	692670
Planter box	36942	36942
Vegetated filter strips	692670	692670
Permeable sidewalk	646249	646249
Permeable driveway	785026	785026
Permeable parking	235994	235994
Rain garden	184712	184712
Total cost ($) – 10 year	74,580,412	
Total cost ($) – 50 year	84,135,445	

Table 8: Comparison of costs of green and gray infrastructures

Time Horizon	Gray Infrastructure Cost ($)	Gray Infrastructure /Green Infrastructure cost
10 year	55830610	0.74
50 year	75958822	0.9

2) Moonachie

- Maximum runoff capture: 1.2 inch
- Cost to remove 1.2 inch of runoff (10 year horizon) = $ 26,505,469
- Cost to remove 1.2 inch of runoff (50 year horizon) = $ 29,618,635

Table 9: Optimal combination of green infrastructure and associated cost to remove 1 inch of runoff

	Optimal area (ft^2) for 1 inch runoff removal	Maximum potential area (ft^2)
Green roof	621486	1002228
Swales	187918	187918
Planter box	10022	10022
Vegetated filter strips	187918	187918
Permeable sidewalk	646248	175324
Permeable driveway	212974	212974
Permeable parking	64023	64023
Rain garden	50110	50110
Total cost ($) – 10 year	20,233,322	
Total cost ($) – 50 year	22,825,550	

Table 10: Comparison of costs of green and gray infrastructures

Time Horizon	Gray Infrastructure Cost ($)	Gray Infrastructure /Green Infrastructure cost
10 year	17701398	0.87
50 year	23313138	1.02

3.1.3 Mapping and simulation of the existing drainage systems

Flood mitigation for runoff events requires a receiving water body that has the capacity to receive surface drainage, and a collection system that facilitates the conveyance of water to it. In Little Ferry and Moonachie these conveyance systems are present; however there are no comprehensive system-wide maps or plans. As development has occurred in these municipalities, individual property owners have installed proper storm water drainage systems. However, they have no knowledge of the sewer conditions or capacity downstream (Figure 13). As a result, the system may lack the capacity to properly drain the area.

Figure 13: Headwall in Moonachie with three drainage pipes of unknown origin

The storm water drainage systems route water to either Berry's Creek or the Hackensack River. In Moonachie and the southern end of Little Ferry, drainage occurs through tide gate structures while in the rest of Little Ferry water is routed to collection areas where it is transferred to the receiving water by one of three pump stations. During precipitation events the ability of the system to properly drain upland areas is dependent upon the capacity of the pipes/trenches that make up the drainage system and the elevation head of the receiving water. Limited historical information on the collection systems of Moonachie is available (Figure 14.), however it is incomplete and does not cover the entire drainage area. It is therefore proposed to complete mapping and numerical simulations of the drainage system to determine the actual capacity of the system. This will enable calculation of the system capacity.

The tasks to be completed during this proposal will be a field investigation completed with the assistance of the Public Works Departments of the Little Ferry and Moonachie municipalities to develop comprehensive GIS based storm sewer maps and a modeling effort that will construct system-wide SWMM models. It is anticipated that the field survey could be completed over a six month period. The information to be collected during this survey includes:

1. Location of all manholes, catchbasins, trenches, and headwalls (Completed using GPS)
2. Measurement of all pipe sizes, construction material, and inverts
3. Measurement of the inlet and outlet elevation of all open trenches
4. Development of a comprehensive sewer plan in Arc GIS.

Once the field investigation is complete, the newly developed sewer maps will be used to develop a system wide sewer drainage model using the USEPA's Storm Water Management Model (SWMM). This model will enable simulation of drainage conditions under various rainfall and tidal scenarios. The model will have the capability to simulate gravity drainage as well as logic-based subroutines that will enable simulation of the functions of the various pump stations. Once developed these models can then be used to predict the locations at which the capacity of the system is insufficient to facilitate drainage as well as assess the impact of proposed system upgrades. Ultimately the sewer maps and models can be used as a management tool by the municipalities to better manage their systems, and reduce the incidence of flooding.

A preliminary cost estimate for this investigation and modeling project is $150,000.

Figure 14: Existing drainage system details for Moonachie, (red-open trenches, blue-gravity mains)

3.1.4 Maintenance and Upgrade to the existing tide gate structures

The existing tide gate structures in the area are typically old and may require maintenance or upgrade. The West Riser Tide Gate has been damaged and in need of replacement for several years (Figure 15.).

Figure 15: A hole in the West Riser Tide Gate below the waterline is shown.

The result of this is flooding at high tides in the storm sewers upstream from this gate (during spring tides with no storm surge), characterized by flow up through catch basins onto the street.

Recent communication from the NJ Meadowlands Authority has confirmed that a plan is in place to construct a new tide gate at this site in the spring/summer of 2014 at a contracted cost of $1.1 million. While this failure is extreme, it took several years for the problem to be addressed. The East Riser tide gate that protects the area is seemingly in better condition however, it too requires preventative maintenance and at minimum it requires trash removal. The trash removal is especially important for flap gates as trash may block the closure of the gate and facilitate propagation of the tide upland. The cost for preventative maintenance and trash removal is minimal and should be included in the operating expenses of the agency or municipality that manages these structures.

The Losen Slote tide gate was built in 1921 to protect the residential areas in Little Ferry and Moonachie. It was replaced in 1999 with a gate with pumps and a backup generator. This enables drainage to the Hackensack River regardless of the tidal condition. It provides protection to the upland areas provided the water level in the Hackensack does not rise above the height of the protective berm. At least three other tide gates in the area could benefit from a similar system; these include the East Riser, West Riser and the Peach Island Tide Gates. The cost for this upgrade would require a study to determine the required flow rate and how the system could be incorporated onto existing gate or if a new gate would be required. The reconstruction of the Losen Slote Tide Gate and Pumping Station was completed for a total of $2 million in 1999.

3.1.5 Creation of new surface storages

Locations for potential detention basins/mitigation wetlands were identified using New Jersey Department of Environmental Protection 2007 Land Use and Land Cover Maps. Candidate areas were characterized by land use/land cover types of deciduous forest, wetlands, and recreational fields. A total of 24 locations in the study area are marked in Figure 16.

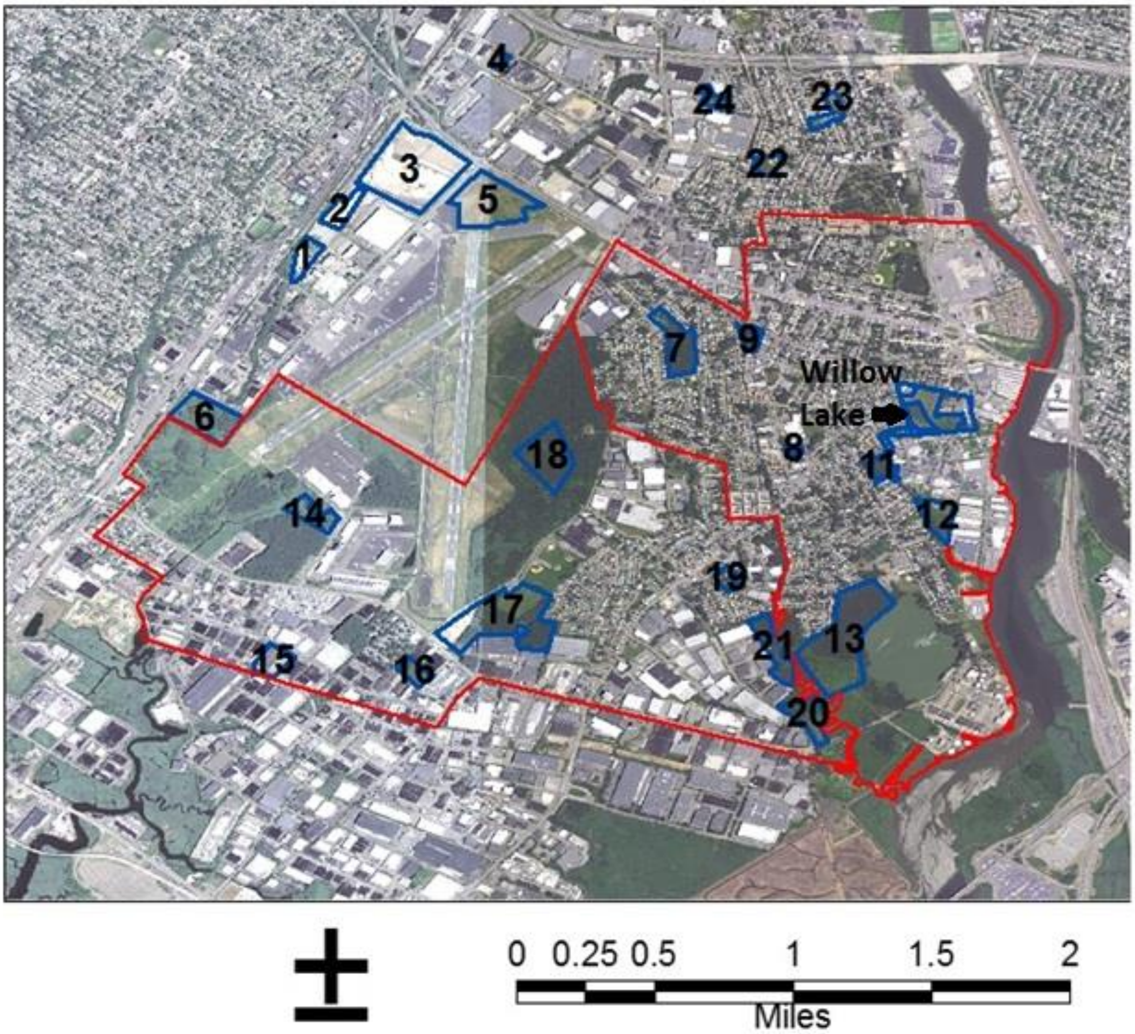

Figure 16: The location of the proposed drainage basins (in blue) that could be used to reduce flooding in Moonachie and Little Ferry (town borders in red). The numbers correspond with the basins listed in Table 11.

The Mean High Higher Water (MHHW) and Mean High Water Spring (MHWS) levels for Little Ferry and Moonachie via Losen Slote were estimated using tidal datum from Mill Creek Tide Gauge (Meadowlands Environmental Research Institute). The Mill Creek Tide Gauge is just over 1 mile downstream from the Losen Slote Tide Gate near the Hackensack Meadowlands Conservation and Wildlife Area. For the Mill Creek tidal datums, the predicted MHHW and MHWS are 2.87 ft and 3.01 ft respectively (NAVD88).

In Table 11, the basin area is the size of the detention area, while the drainage area is the size of land (i.e., watershed) that drains to the basin in question. For the storage volumes, two possible bottom elevations of the basins were calculated using the mean higher high water (conservatively estimated to be 3 feet above sea level) as well as the sea level (0 ft NAVD88) for an optimistic level. These elevations represent the deepest the basins could be constructed without them filling with groundwater, which would defeat their purpose.

Table 11: The basin characteristics shown in the map in Figure 13.

Drainage Basin #	Basin Area (ft^2)	Drainage Area (hectares)	Drainage Area (sq. ft)	Elevation (ft above sea level)	Storage volume (ft^3) with MHHW as base	Storage volume (ft^3) with sea level as base
1	185394	301.3	32431229	11.8	1637815	2193997
2	194408	212.4	22860178	11.8	1717447	2300671
3	1467688	198.8	21401989	10.2	10597412	15000476
4	822430	2.3	245370	17.8	12131961	14599251
5	822430	182.5	19640907	10.8	6380741	8848031
6	538146	53.3	5740318	10.2	3885672	5500110
7	414714	9.8	1055393	16.1	5448347	6692489
8	29328	3.7	395567	12.4	274867	362851
9	102070	6.0	650233	10.2	736994	1043204
Willow Lake current (#10)	467348	16.4	1763840	11.8	4128664	5530708
Willow Lake grassy areas	499180	16.7	1800440	14.0	5483952	6981492
Willow Lake entire block	780068	16.7	1800440	14.0	8569765	10909969
Willow Lake connected greenways	995139	103.4	11133600	14.0	10932517	13917934
11	116240	1.3	134578	10.8	901836	1250556
12	263590	9.7	1038795	11.3	2186827	2977597
13	1403560	156.8	16880717	5.4	3339350	7550030
14	214064	3.0	324243	6.5	739600	1381792
15	216476	18.5	1990721	3.8	165699	815127
16	131946	12.8	1382075	7.5	597831	993669
17	1207000	24.0	2580723	11.8	10662928	14283928
18	576132	24.3	2618407	9.7	3850037	5578433
19	96851	49.6	5339179	7.5	438820	729373
20	300860	4.8	517318	2.2	--------	647354
21	325942	9.8	1053852	2.2	--------	701323
22	114829	6.7	721810	23.7	2373341	2717828
23	148723	8.8	949869	26.9	3553885	4000054
24	107977	7.2	770338	31.2	3044882	3368813

Table 12 shows the costs estimated for creating the new surface storages. The unit cost ($35 per cubic yard of excavation) used is a part of Appendix B – Unit Cost Tables.

Table 12: Table showing the costs for all the basins proposed

Drainage Basin #	Cost for expansion (MHHW as base)	Cost for expansion (Sea level as base)
1	$ 2120970	$ 2841226
2	$ 2224093	$ 2979368
3	$ 13723648	$ 19425616
4	$ 15710889	$ 18906030
5	$ 8263059	$ 11458200
6	$ 5031945	$ 7122642
7	$ 7055609	$ 8666773
8	$ 355952	$ 469892
9	$ 954407	$ 1350949
Willow Lake current (#10)	$ 5346619	$ 7162266
Willow Lake grassy areas	$ 7101717	$ 9041032
Willow Lake entire block	$ 11097845	$ 14128409
Willow Lake connected greenways	$ 14157609	$ 18023724
11	$ 1167877	$ 1619470
12	$ 2831940	$ 3855988
13	$ 116877251	$ 9777288
14	$ 25886001	$ 1789420
15	$ 214580	$ 1055589
16	$ 774191	$ 1286801
17	$ 13808491	$ 18497686
18	$ 4985797	$ 7224070
19	$ 568271	$ 944538
20	-----------------	$ 838323
21	-----------------	$ 908213
22	$ 3073476	$ 3519587
23	$ 4602281	$ 5180069
24	$ 3943122	$ 4362612

Note: Basins 4, 8, 9, 11, 12, 14, 18, 22, 23, and 24 are perfect locations to convert into surface storage because of their elevation.
Basins 1, 2, 3, 5 and 6 are good spots, but these locations are under Teterboro Airport authorities.
Basins 19, 18, 15, 16, 20 and 21 must be investigated further.

Since the depth of groundwater table at the proposed sites is not available, the depth of basins is taken as 5 feet and the calculations are done accordingly. The calculation results are shown in Table 13.

Table 13: Table showing the costs for basin depth of 5 feet

Drainage Basin #	Basin Area (ft^2)	Drainage Area (hectares)	Drainage Area (sq. ft)	Elevation (ft asl)	Storage volume (ft^3)	Rainfall captured by basin (inch)	Cost($)
1	185394	301.3	32431229	11.8	926970	0.95	1205061
2	194408	212.4	22860178	11.8	972040	1.2	1263652
3	1467688	198.8	21401989	10.2	7338440	4.9	9539972
4	822430	2.3	245370	17.8	4112150	202	5345795
5	822430	182.5	19640907	10.8	4112150	3.25	5345795
6	538146	53.3	5740318	10.2	2690730	6.7	3497949
7	414714	9.8	1055393	16.1	2073570	25	2695641
8	29328	3.7	395567	12.4	146640	5.7	190630
9	102070	6.0	650233	10.2	510350	10.3	663455
Willow Lake current (#10)	467348	16.4	1763840	11.8	2336740	17	3037762
Willow Lake grassy areas	499180	16.7	1800440	14.0	2495900	17.85	3244670
Willow Lake entire block	780068	16.7	1800440	14.0	3900340	27.2	5070442
Willow Lake connected greenways	995139	103.4	11133600	14.0	4975695	6.75	6468403
11	116240	1.3	134578	10.8	581200	53.9	755560
12	263590	9.7	1038795	11.3	1317950	16.4	1713335
13	1403560	156.8	16880717	5.4	7017800	5.9	9123140
14	214064	3.0	324243	6.5	1070320	41.1	1391416
15	216476	18.5	1990721	3.8	--------	-------	-------
16	131946	12.8	1382075	7.5	659730	6.8	857649
17	1207000	24.0	2580723	11.8	6035000	29.75	7845500
18	576132	24.3	2618407	9.7	2880660	15.15	3744858
19	96851	49.6	5339179	7.5	484255	1.8	629531
20	300860	4.8	517318	2.2	--------	---------	--------
21	325942	9.8	1053852	2.2	--------	---------	--------
22	114829	6.7	721810	23.7	574145	11.3	746388
23	148723	8.8	949869	26.9	743615	10.8	966699
24	107977	7.2	770338	31.2	539885	9.7	701850

3.1.6 Expansion of existing storm water detention capabilities at the Willow Lake in Little Ferry

Figure 17: Image showing Willow Lake in Little Ferry

The current area of Willow Lake (Figure 17) is 130,000 ft^2. Different options to potentially expand the lake are discussed here. Each expansion is discussed sequentially, with each step growing in area.

The first expansion discussed is enlarging Willow Lake into the adjacent green areas (Figure 18). The existing green areas include trees and grass lawns, and would minimize the number of structures to be displaced. The projected costs associated with this expansion as well as all additional potential expansion scenarios are presented in Table 14.

Figure 18. The potentian expansion into adjacent green areas (blue outline)

The second option would require the removal of several structures and infrastructure such as parking lots (Figure. 19).

Figure 19: The potential expansion into the entire block

The third option (Figure. 20) is expansion of the second expansion option into the adjacent block to the south and the adjoining areas that are either lower in elevation, currently undeveloped, or both.

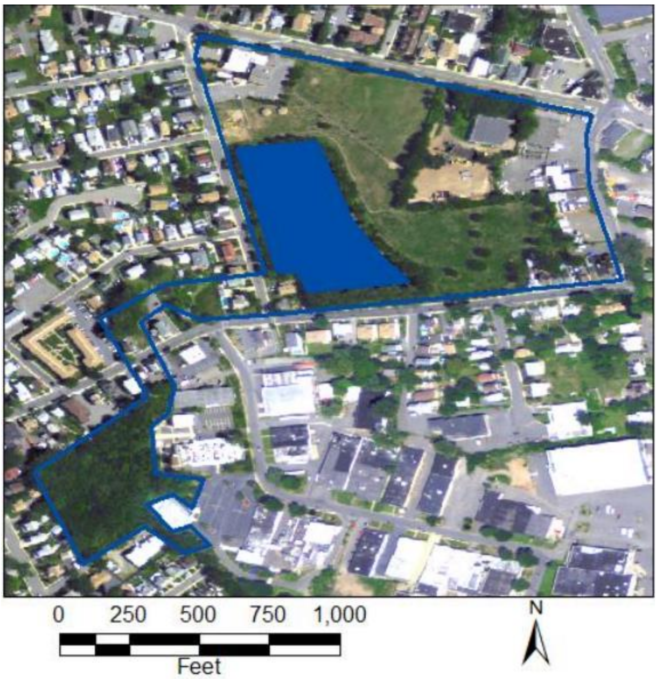

Figure 20: The potential expansion into the adjacent block shown in blue boundary

Table 14: Table showing the costs for various options for expansion of Willow Lake

	Storage with MHHW as base	Storage with sea level as base
Willow lake current	$ 5346619	$ 7162266
Willow lake grassy areas	$ 7101717	$ 9041032
Willow lake entire block	$ 11097845	$ 14128409
Willow lake with connected greenways	$ 14157609	$ 18023724

3.2 Block and Lot Scale

The block and lot scale flood protection strategies will address projects to be completed on individual properties and provide protection to small areas. These are the easiest and potentially most effective strategies. This is due to the fact that while larger scale projects will provide protection for extreme losses during huge events such as Hurricane Sandy, a storm of that magnitude may not occur for another hundred years, while it is a given fact that small scale flooding will occur and impact society in this area regularly.

The flood mitigation strategies on this scale are primarily engineering practices that will make sure that existing storm water infrastructure is functioning and enhance its effectiveness by reducing the stress upon it.

- Proper maintenance of the existing storm water drainage system (Clogged pipes do not drain). Individual items that should be standard operating procedures for municipalities include:

    - Periodic cleaning and maintenance of storm grates, etc.
    - Installation of check valves at the outlet of all storm water pipes to tidal waters. While the high tide may inhibit drainage, at least no addition water from downstream will encroach on the upland areas. In addition, high tide has a limited temporal extent, even if the upland doesn't drain immediately, it will in short order.

- Open trenches are an integral part of the drainage system in this area. These trenches are often clogged with sediment. Municipalities are hesitant to clean them due to potential contaminants. In addition, these trenches require maintenance and clearing of vegetation that has grown in the trench.
    - Trenches could be redesigned as vegetated swale to increase infiltration.
    - Trenches are often adjacent to large impervious surface (i.e. Parking lots, roofs, etc.) trenches could be expanded and converted to wetlands or bioretention structures to reduce flow to receiving waters and expand the storage of the system.

- Implementation of Green or Blue infrastructure projects. Typically green infrastructure aims to infiltrate or retain storm water to reduce flow in drainage systems. In this area where groundwater is shallow, a reduction of the peak flow or a spreading of the peak would provide a great deal of protection because of the relatively short travel distance to the receiving waters.

- Reduction of impervious surface. The Rt 46 corridor is lined with commercial development, these areas could benefit from green infrastructure including grassed detention basins, pervious pavement in the parking lots, and green/blue roofs.

- Raising of important transportation infrastructure. Small scale flooding in this area often occurs in low lying intersections or roadways. These areas could be raised and infiltration galleries installed beneath them to provide temporary storage.

Proposed Projects:

(1) Expansion of open ditches in Moonachie and Little Ferry and Carlstadt towns

All the open ditches in the towns of Little Ferry and Moonachie have been identified (Figure 21) and will be expanded to increase storage during storm events, this is especially important during high tide when tide gates are closed and these trenches do not drain. The increase in the capacity of these trenches is calculated based upon the increased cross section due to widening and deepening of the trenches and the length or trenches present (Table 15). The total length of the open ditches present in the study area is 91,855 feet. The total areas that drain to these trenches is 88,558,437 square feet.

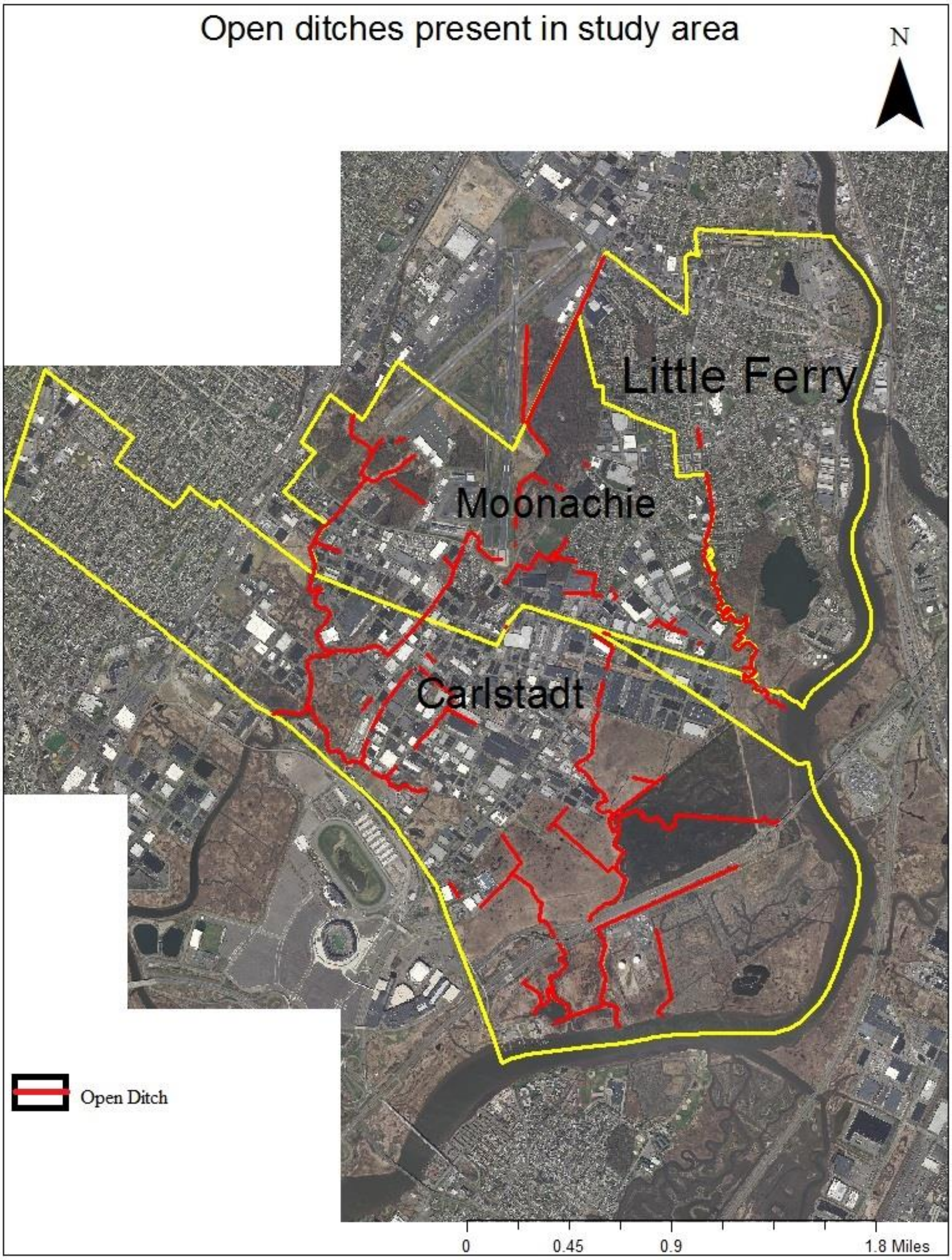

Figure 21: Image showing open ditches in study area

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Table 15: Storage Volumes of Open Ditches and Expansion Costs

	Actual depth (ft)	New Depth (ft)	Actual width (ft)	New width (ft)	Increased Volume(Cubic Ft)	Cost
Total	3	5	12	15	5,970,575	$774,000
Little Ferry	3	5	12	15	277,286	$35,946
Moonachie	3	5	12	15	2,351,934	$304,895
Carlstadt	3	5	12	15	3,341,355	$433,159

The increased width and depth of the open ditches can store an additional 5,970,575 cubic feet of water. This accounts for 0.8 inches of rainfall over the drainage area which drains into these ditches.

(2) Implementation of green infrastructure strategies along Moonachie Road

An open and unused yard lies behind the Presbyterian Church on Moonachie Rd., adjacent to a parking / loading / unloading lot (Figure 22). Stagnant water is often sitting in the open trenches surrounding these lots. In order to take advantage of the trenches to reduce runoff during storm events, increased pervious cover and wider trenches are proposed.

Figure 22: Image showing the proposed area

The parking lot has four small entrances and a barrier island, creating an obstacle for vehicular movement through the lot. Improving the vehicle patterns through the lot would also decrease the use for impermeable pavement. One way to improve the parking lot efficiency would be to eliminate the extra entrances, leaving only the eastern-most entrance. As a result, all vehicles will be using the same entrance, and the northwestern strip of the parking lot serves no purpose. The parallel open trench can be widened accordingly. To make this change possible, the barrier must also be adjusted, allowing a truck to enter at the only entrance, and drive straight through to the loading zone at the southern side of the parking lot. These changes would give the parking lot and truck loading zone a better flow of vehicles, as well as allow for a widened trench along the sides of the lot. The increased water capacity will be available in future flood events. The cost to implement this project is estimated to be approximately $ 18,000.

(3) <u>Installation of Pervious Pavement in the Burger King Parking Lot</u>

Pervious pavement allows rainfall to infiltrate rather than contributing to runoff. The parking lot of Burger King on Moonachie Road (Figure 23) is a good candidate to install pervious pavement, because of its strategic location and its low vehicle loads. An open trench lies along the side of the parking lot. The trench is undersized to carry the runoff that drains to it. Pervious pavement would reduce runoff to the trench. Parking lots are especially useful for permeable pavement because vehicles typically move at low speeds, causing less stress on the pavement.

Figure 23: Image showing the parking lot

Project Description:

- Total area of the drainage area = 44,775 sq. ft.
- Area where porous parking can be implemented = 19,875 sq. ft.
- Rainfall which can be trapped by implementing porous parking = 1.1 in.
- Cost for changing the existing parking lot to porous parking lot is $154800.

(4) <u>Rehabilitation of Trenches on State Street</u>

The open trenches between the factories on State St. are in poor condition; trash and debris clog much of the drainage system (Figure 24). Litter poses more than an eyesore; it reduces the capacity of the drainage system and can clog the downstream pipes and tidal structures, impairing their function. This may result in reduced flood protection.

Figure 24: Trash in an open ditch in Moonachie Area

The cost for trash removal is minimal and should be included in the operating expenses of the agency or municipality that manages these structures. These trenches have trash piled above the level of the underground pipes, so no water is flowing downstream as the system is designed. The trash can present a chemical hazard as well as a physical one. The trash may contain contaminants that will ultimately affect the water quality. The sites must be tested for disposal to ensure high water quality. Cost for trash removal in this site will be $42,000 which also includes the disposal of the sediments.

(5) <u>Tree removal from drainage system</u>

Trees present another maintenance issue in the open trenches. Trees have naturally rooted inside and along the open trenches. These trees prevent flow along the trench. A solution for this is to remove the trees present in the open trench. Due to the environmental benefits associated with trees, replacement trees should be planted in open spaces. The total cost for this project will be $37,500 (Table 16).

Table 16. Cost for removing from trenches and planting a new tree at other site for Moonachie area

No. of Trees	Cost for removing one tree	Cost for planting one tree	Total Cost
75	$150	$350	$37,500

References

Artigas, Francisco (2013). Water Level Observations during Super Storm Sandy, a presentation given in January, Meadowlands Environmental Research Institute, Lyndhurst, NJ.

Artigas, Francisco J. and Chun, Soon Ae (2013). Hackensack Meadowlands tide gates inspection report – The New Jersey Meadowlands Commission, Lyndhurst, NJ.

Chun, Soon Ae, Artigas, Francisco (2013). Tide Gate Sensor Network as a Forensic Tool: Establishing Facts during Superstorm Sandy. International Conference on Digital Government Research, Université Laval, Quebec City, Quebec, Canada, June 17-20.

Walsh, S. and Miskewitz, R. (2013). "Impact of seal level on tide gate function." Journal of Environmental Science and Health, Part A, Vol. 48, pp. 453-463.

RELATED REPORTS AND PUBLICATIONS

Guo, Qizhong, Bertrand Byrne, Jie Gong, Raghav Krishnamoorthy, and Henry Mayer, 2014. Strategies for Flood Risk Reduction for Vulnerable Coastal Populations along Arthur Kill at Elizabeth, Linden, Rahway, Carteret and Woodbridge. Rutgers, The State University of New Jersey, August.

Guo, Qizhong, Yunjie Li, Michael J. Kennish, Norbert P. Psuty, Richard G. Lathrop Jr., James L. Trimble, 2014. Strategies for Flood Risk Reduction for Vulnerable Coastal Populations around Barnegat Bay. Rutgers, The State University of New Jersey, August.

Guo, Qizhong, David Bushek, Richard G. Lathrop Jr., Junghoon Kim, Bertrand Byrne, James L. Trimble, 2014. Strategies for Flood Risk Reduction for Vulnerable Coastal Populations around Delaware Bay. Rutgers, The State University of New Jersey, August.

Guo, Qizhong, Robert Miskewitz, Eleni Athanasopoulou, Kaveh Gharyeh, Jun Zhao, 2014. Strategies for Flood Risk Reduction for Vulnerable Coastal Populations along Hudson River at Hoboken and Jersey City. Rutgers, The State University of New Jersey, August.

Guo, Q. and Correa, C. A., 2013. "The Impacts of Green Infrastructure on Flood Level Reduction for the Raritan River: Modeling Assessment." Proceedings of the ASCE/EWRI World Environmental & Water Resources Congress, Cincinnati, Ohio, May 19-23.

Guo, Q., Kantor, P., Roberts, F., and Robinson, D., 2012. Risk Analysis for Flood Mitigation on the Raritan, Final Report, CCICADA - Command, Control, and Interoperability Center for Advanced Data Analysis, Submitted to Federal Emergency Management Agency via Rutgers Bloustein Planning School, April 30.

Appendices

Appendix 1-Stormwater Green Infrastructure Methodology

Green Infrastructure Deployment: Introduction and Methodology

By Qizhong Guo, Kaveh Gharyeh, and Manoj Raavi

1) Green Infrastructure

Green Infrastructure or Blue-green infrastructure is a network providing the "ingredients" for solving urban and climatic challenges by building with nature. The main components of this approach include storm water management, climate adaptation, less heat stress, more biodiversity, food production, better air quality, sustainable energy production, clean water and healthy soils, as well as the more anthropocentric functions such as increased quality of life through recreation and providing shade and shelter in and around towns and cities. Figure 1 shows several green infrastructures that are commonly implemented in different locations.

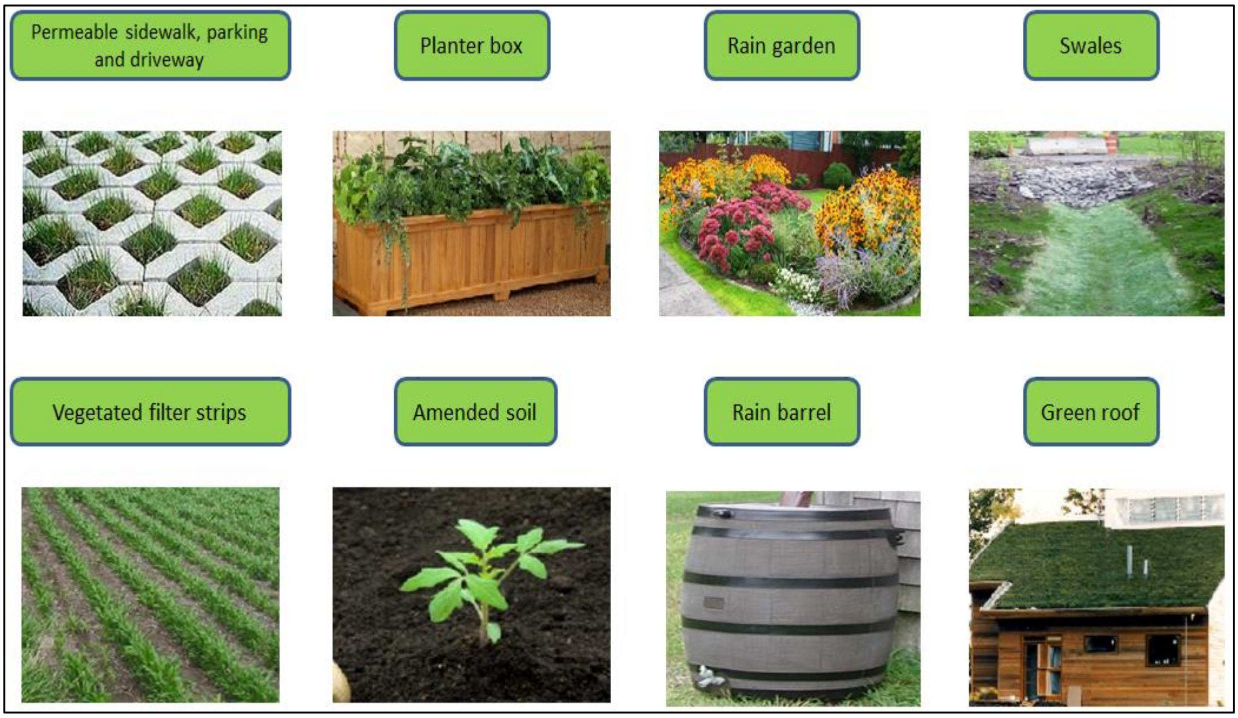

Figure 3 : Green Infrastructure types

US Department of Environmental Protection (DEP) is conducting a comprehensive research to quantify non-stormwater benefits of green infrastructure deployment [1]. For instance, City of Hoboken, New Jersey, is conducting a green infrastructure strategic plan to develop place–based stormwater management and flood control strategies and identify implementable climate adaptation action steps. More details of the Hoboken Green Infrastructure Strategic plan is available on [2]. There are other ongoing green infrastructure projects in a number of cities all around the U.S such as Philadelphia, New York City, San Francisco, Chicago, Seattle and St. Louis. More details of these projects are available on [3], [4], [5], [6], [7] and [8] respectively.

Green infrastructure can reduce the volume of water going into combined systems during precipitation events by removing surface runoff, which may reduce number and volume of overflows. Green infrastructure can also slow the delivery of wet weather flows to sewer systems, helping to mitigate peak flows while providing filtration through soil for some portion of the release into the sewer system, thereby reducing pollutant loads. The implementation of green infrastructure practices may allow communities to downsize certain grey infrastructure components of their CSO control plans. This may provide some CSO communities with significant cost savings [9]. By implementing Green Infrastructure, need for piping, pumping and storage of stormwater could be reduced. In this project, the main reason to consider green infrastructures deployment is also to reduce the stormwater inflow to the drainage system by removing fraction of runoff. Table 1 summarizes the problem, our approach and source of floodwater.

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[1] NYC Environmental Protection website: http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_pilot_monitoring_results.shtml

[2] http://togethernorthjersey.com/?grid-portfolio=hoboken-green-infrastructure-strategic-plan

[3] http://www.phillywatersheds.org/whats_in_it_for_you/businesses/green-infrastructure-projects

[4] http://www.nyc.gov/html/dep/html/stormwater/green_infrastructure_slideshow.shtml

[5] http://sfwater.org/index.aspx?page=614

[6] http://www.seattle.gov/util/MyServices/DrainageSewer/Projects/GreenStormwaterInfrastructure/index.htm

[7] http://www.stlmsd.com/educationoutreach/msdgreeninitiatives

[8] http://www.epa.state.il.us/water/financial-assistance/igig.html

[9] http://water.epa.gov/infrastructure/greeninfrastructure/upload/EPA-Green-Infrastructure-Factsheet-2-061212-PJ.pdf

Table 1: Problem and solution description

Problem to solve	Reduce surface floodwater inlet to the drainage system
Approach	Removal of runoff by using optimal combinations of green infrastructures
Source of floodwater	Rainfall only (1 year and 2 year return periods)

2) Software developed

Online software is developed to calculate the total cost (capital, maintenance and replacement) of implementing the green infrastructures. Unlike available online softwares, the developed software is capable of fining out the most cost effective combination of different green infrastructures that can be implemented in any location. Spatial limitations for implementing any of the green infrastructure types are taken into consideration. Net Present Value (NPV) approach is used to calculate the total cost of implementing green infrastructure. Total cost includes the initial capital cost, maintenance cost and also replacement cost. Figure 2 shows a snap shot of a page of the developed software.

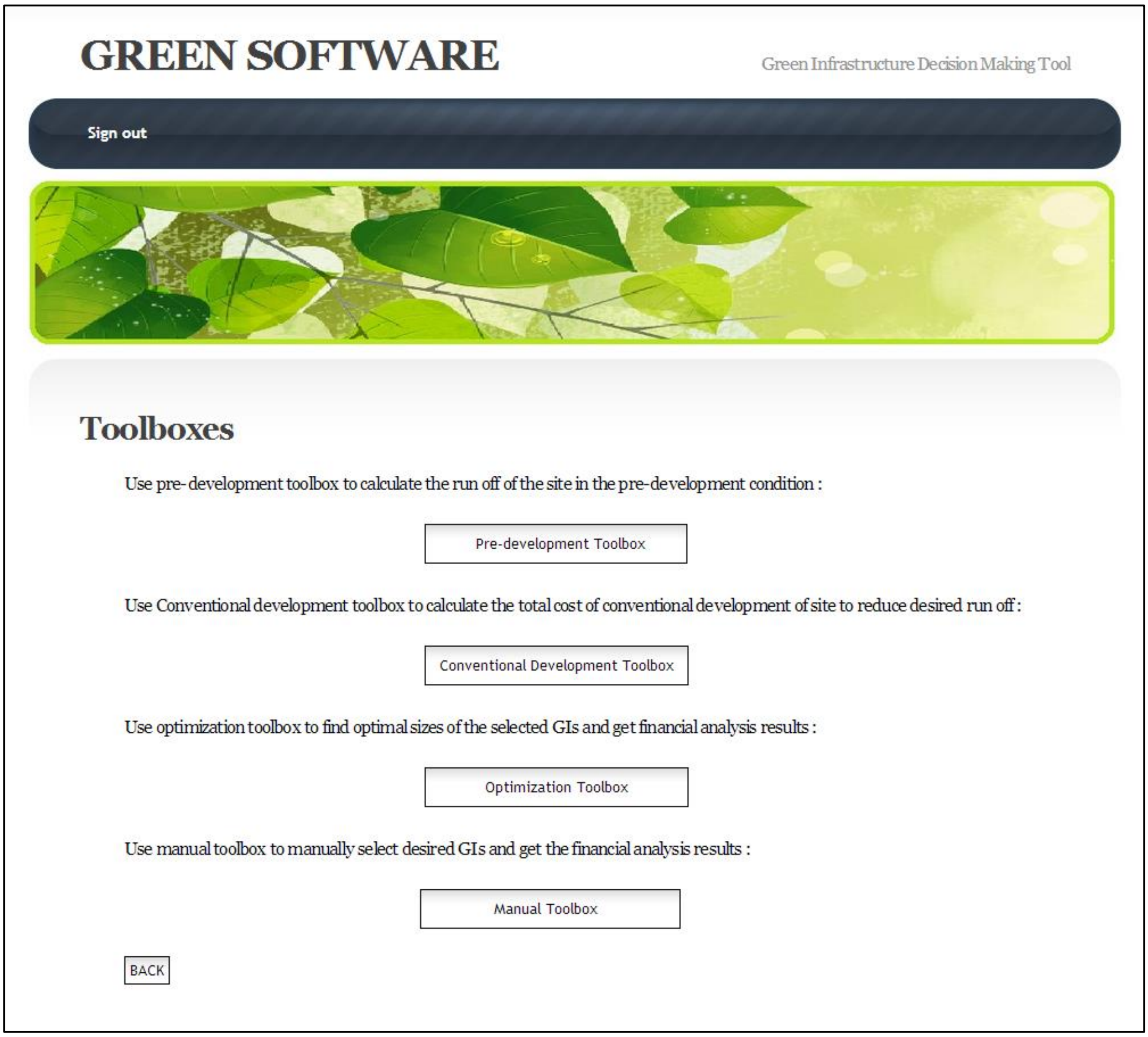

Figure 4 : Snapshot of the Green Software

The software interface is developed in JAVA, however the inside optimization engine is coded in MATLAB and then converted to JAVA packages.

3) Different sites spatial characteristics and limitations

In order to find out the total area of each site under research, GIS data is used. In addition the maximum area for implementing each of the green infrastructure types is found out via the following procedure for residential, industrial and commercial units.

3.1) Procedure

Step 1: Selection of Municipality

From the New Jersey state map of municipalities, select the municipalities required and make a layer from the selected municipality. Figure 2, shows a sample layer.

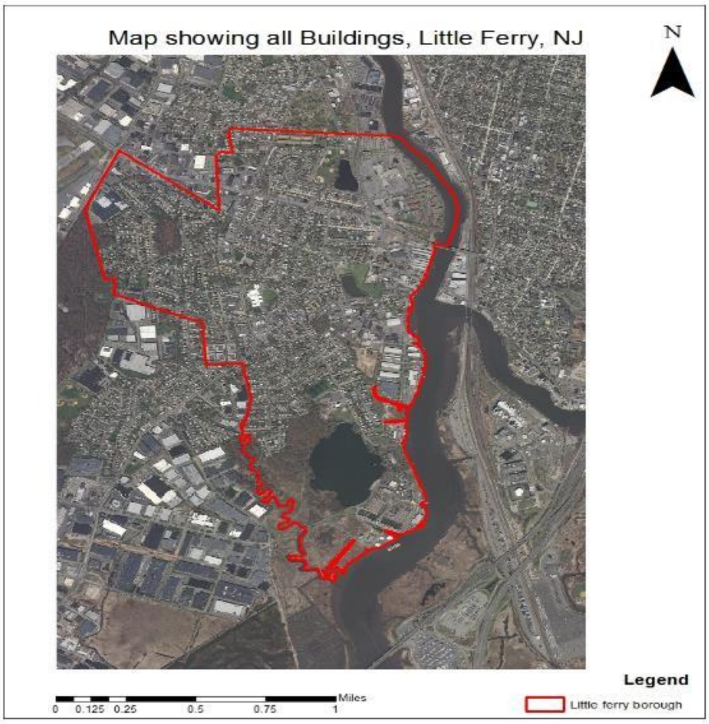

Figure 5 : Sample layer of a municipality

Step 2: Finding out maximum area to implement green roofs, permeable driveway and parking

For each type of residential units (i.e. low, medium and high density), three unique polygons are chosen. For each polygon the area of roof, parking and driveway are extracted. The average ratio of roofs, parking and driveway is multiplied to the total area of residential area of the municipality to find out the approximate total areas of roofs, parking and driveways. The same procedure repeats for the industrial and commercial sectors. For example, in order to find out the total area of roof, parking and driveway of the high density or multiple dwelling residential units in Hoboken, New Jersey, three sample polygons of high density residential units are selected. Table 2 shows the extracted information of the aforementioned polygons.

Table 2 : Extracted information for three selected polygons

	Total Area(ft^2)	Roof(ft^2)	Parking(ft^2)	Driveway(ft^2)
Polygon 1	216372	68388	18448	19041
Polygon 2	91164	29973	11780	9383
Polygon 3	119191	47149	14733	12434

Table 3 represents the ratio of roof, parking and driveway area to the total area for each polygon.

Table 3: Ratio of roof, parking and driveway in each polygon

	Percentage of roof area in polygon	Percentage of parking area in polygon	Percentage of driveway area in polygon
Polygon 1	31.6	8.5	8.8
Polygon 2	32.9	12.9	10.3
Polygon 3	39.5	12.3	10.4
Average	34.6	11.2	9.8

By using the average ratios and multiplying in the total high density residential units' area, the total area of roof, parking and driveway of this class of residential units are calculated as shown in Table 4.

Table 4: Hoboken high density residential units estimated roof, parking and driveway area

Roof(ft^2)	Parking(ft^2)	Driveway(ft^2)	Total area of high density residential units (ft^2)
6221824	2014001	1762250	17982151

Exactly the same procedure is carried out for industrial and commercial sectors of the municipality and the results are summed up to come up with the maximum spatial limitation to deploy each of the green infrastructures.

Step 3: Finding out maximum area to implement permeable roadway and sidewalk

By getting the map of NJ road networks and clipping it for the area of the required municipality, we can find the total length of the road network. From this we can find the length of the road where sidewalks is present. By multiplying the width of the side walk we can find the area of the pavement where we can apply permeable sidewalk.

The average width of the side walk for the major highway is calculated from the widths measured at several selected locations (by using the GIS measure tool). The average width was found to be 6ft on each side of the roadway. Considering the intersections of roadways, roadways with sidewalk on only one side and roadways without a sidewalk on both sides, only 50% of the total length of roadways in the town is used to calculate the area of sidewalk.

Step4: Finding out maximum area to implement rain gardens, swales, vegetated filter strips and planter box

For calculating the area of the site where rain gardens can be installed, we have assumed that the area of rain gardens will be 5% of the roof area. For calculating the area where vegetative swales and vegetative filter strips can be installed, we assumed a percentage of 80% of the length of sidewalk will be accessible for installing swales and remaining 20% will be used to install vegetated filter strip. For planter box implementation, we need to assume a percentage of area of the total roof area to find the area where the planter boxes can be installed. We assumed it to be 1% of total roof area.

4) Default values used in the software

In order to carry out the cost and the optimal combination calculations, the porosity and depth of each of green infrastructures are set to default values as shown in Table 5. However, values other than default values can simply be entered as inputs to the developed software.

Table 5: Default values for porosity and depth of green infrastructures

Permeable sidewalk depth (in)	12
Permeable sidewalk porosity	0.35
Permeable parking depth (in)	12
Permeable parking porosity	0.35
Permeable driveway depth (in)	12
Permeable driveway porosity	0.35
Bioswales depth (in)	12
Bioswales porosity	0.35
Green roof depth (in)	12
Green roof porosity	0.35
Planter box prepared soil depth (in)	12
Planter box aggregate soil depth (in)	12
Planter box prepared soil porosity	0.35
Planter box aggregate soil porosity	0.35
Rain garden prepared soil depth (in)	12
Rain garden aggregate soil depth (in)	12
Rain garden prepared soil porosity	0.35
Rain garden aggregate soil porosity	0.35
Vegetated filter strips depth (in)	12
Vegetated filter strips porosity	0.35

Unit capital and maintenance costs along with life time of each type of green infrastructure are also presented in table 6. Long lifetime of green infrastructure types is considered.

Table 6: Unit capital and maintenance costs and life time of each green infrastructure type

Green Infrastructure type	Capital cost ($/ft²)	Yearly maintenance cost ($/ft²)	Life time (Years)
Permeable sidewalk, driveway and parking (Asphalt)	6.65	0.17	50
Permeable sidewalk, driveway and parking (Cement)	7.70	0.16	50
Permeable sidewalk, driveway and parking (Gravel)	4.01	0.02	50
Bioswale	14.80	0.13	50
Planter Box	11	0.61	50
Rain Garden	9.4	0.41	50
Green Roof	18.76	0.15	50
Vegetated Filter Strip	1.6	0.07	50

Reference: [[10]]

As a part of analysis, green infrastructure cost is compared to the cost of gray infrastructure implementation to remove the same amount of runoff. The gray infrastructure cost includes onsite underground retention/detention system [[11]] cost, and required cost of standard roof, pavement, driveway and parking lot. In our methodology, we do not take into consideration the replacement cost of standard roof, pavement, driveway and parking lot to green infrastructure. In other words, we assume that we conduct a new development. Table 7 provides detailed information applied for gray infrastructure cost calculation.

Also note that some existing green infrastructure measures such as amended soil, rain barrels, and vertical walls are not included in the software. The software can be expanded to include these existing measures as well as the future emerging measures.

[10] http://greenvalues.cnt.org/national/cost_detail.php
[11] http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_runoff.pdf

Table 7: Detailed data required for Gray Infrastructure cost calculation

Infrastructure type	Capital cost	Yearly maintenance cost ($/ft^2)	Life time (Years)
Concrete Sidewalk	5.19 ($/ft^2)	0.029	80
Concrete Driveway	5.19 ($/ft^2)	0.029	80
Parking Lot	5.51 ($/ft^2)	0.15	30
Standard Roof	7.5 ($/ft^2)	0.05	30
onsite underground retention/detention system	11.55 ($/ft^3)	0.03	30

Appendix 2-Unit Cost Tables

Unit Cost Tables

Table 1 Unit Costs for Storm Surge Barrier

Measures	Unit & Unit	Reference
Levee	Clay levee: 4000 to 8000 $/linear foot	http://www.stronglevees.com/cost/
	T-walls: 14000 to 19000 $/linear foot	http://www.stronglevees.com/cost/
	Double wall levee: 5000 to 6000 $/linear foot	http://www.stronglevees.com/cost/
Levee raise	1) Levee raise with a floodwall (unit cost per linear foot) 1-foot raise: $37 1-to 3-foot raise: $120 Greater than 3-foot raise: $875 2) Levee raise by fill (unit cost per linear foot) 1-foot raise: $31 1-to 3-foot raise: $45 Greater than 3-foot raise: $87	http://www.papiopartnership.org/projects/damsite_15a_2_221441182.pdf
Sea Wall	300 $/linear foot	Contacted Jeff Patterson
	300 to 400$ per foot for walls 7' in height	Contacted Gary Kalke
Beach Nourishment	6.67 $ /cy @ 2011 @ Florida	Page 6 of : http://fsbpa.com/2012TechPresentations/AlBrowder.pdf
Bulkhead	3000 $/lf	Contacted : Tom Levy
Elevate Buildings	@New Jersey $ 60 per square feet	http://www.markofexcellence.com/house-lifting.html
Wetland Restoration	Very wide range	http://www.restorenhwetlands.com/pdf/finalreport/Appendix_E.pdf
Flood wall sheet pile	@2014 : 25 $/sf	http://www.icgov.org/site/CMSv2/Auto/construction/bid338/212201431318.pdf
Road elevation	~ 1.6 M$ per mile per foot elevation	http://marylandreporter.com/2013/08/01/rising-seas-5-800-miles-of-roads-at-risk-especially-in-shore-counties/
Removable Flood Wall	100$ per square feet	Contacted : Mr. Bryan Fryklund @ Flood Control America (FCA)

Table 2 Unit Costs for Mobile Flood Barrier

Measures	Cost & Unit	Reference
Muscle Wall	-2' Muscle Wall 50 $/LF excludes tax, installation, liner, sandbags, Muscle Wall accessories -4' Muscle Wall 99 $/LF excludes tax, installation, liner, sandbags, Muscle Wall accessories -8' Muscle Wall 525 $/LF excludes tax, installation, liner, sandbags, Muscle Wall accessories	Contacted Organic Industries Flood, LLC
Slide gate (12X6 ft^2)	@ 2014: 47,000 $ EA	http://www.icgov.org/site/CMSv2/Auto/construction/bid338/212201431318.pdf
Flood barrier (In water closure)	150,000 - 200,000 $/lf	http://www.eenews.net/stories/1059972561
Sand bag	Average cost of a pre-filled 50 lbs sandbag = $2.25	http://barriersystemsllc.com/make-money.php

Table 3 Unit Costs for Diversion

Measures	Unit & Unit	Reference
Sewer	PVC Sewer Pipe, 8 Inch Diameter: Unit: LF cost: $300 10/12 inch can be installed with a box, use $300-$350 per foot	Bid Tabulation for Horseshoe Bend Levee Improvements Project (Phase II) – Bidder : SCI Infrastructure, LLC

Table 4 Unit Costs for Tide Barrier

Measures	Cost & Unit	References
Flap gates	Diameter: 2 ft : $3,000 Diameter: 3 ft : $4,500 Diameter: 6 ft :$15,000	Contacted: hydro power company : http://www.hydrogate.com/sales-reps.aspx?S=NJ
	72" X 72" FLAP gate @ 2008 : 35,000 $	http://www.rcgov.org/pdfs/Public-Works/1736%20Levee%20Storm%20Sewer%20Flap%20Gates.pdf
	@2012 @CITY OF KENT : Flap Gate for 24 Inch Pipe 1 EA 5,200 Flap Gate for 8 Inch Pipe 1 EA 2,500 Flap Gate for 12 Inch Pipe 1 EA 3, 000 Flap Gate for 48 Inch Pipe 1 EA 9, 000	Bid Tabulation for Horseshoe Bend Levee Improvements Project (Phase II) – Bidder : SCI Infrastructure, LLC
	@ 2013 @ Kansas: Flap gate: 24" cost: 2500 EA Flap gate: 30" cost: 3000 EA	http://www.hutchgov.com/egov/docs/13831420807713.pdf
Sluice gate	Sluice gates, cast iron Hydraulic structures, 18" x 18", HD, self cont with crank, sluice Detail $ 7,764.89 / EA Hydraulic structures, 24" x 24", HD, self cont with crank, sluice Detail $ 10,011.41 / EA Hydraulic structures, 30" x 30", HD, self cont with crank, sluice Detail $ 11,828.56 / EA Hydraulic structures, 36" x 36", HD, self cont with crank, sluice Detail $ 13,627.37 / EA Hydraulic structures, 42" x 42", HD, self cont with crank, sluice Detail $ 16,221.16 / EA Hydraulic structures, 48" x 48", HD, self cont with crank, sluice Detail $ 19,026.87 / EA	http://www.allcostdata.info/browse.html/059110009

	Hydraulic structures, 54" x 54", HD, self cont with crank, sluice Detail $ 26,137.59 / EA Hydraulic structures, 60" x 60", HD, self cont with crank, sluice Detail $ 31,611.97 / EA Hydraulic structures, 66" x 66", HD, self cont with crank, sluice Detail $ 36,680.48 / EA Hydraulic structures, 72" x 72", HD, self cont with crank, sluice Detail $ 43,605.95 / EA Hydraulic structures, 78" x 78", HD, self cont with crank, sluice Detail $ 48,429.74 / EA Hydraulic structures, 84" x 84", HD, self cont with crank, sluice Detail $ 64,999.97 / EA Hydraulic structures, 90" x 90", HD, self cont with crank, sluice Detail $ 60,630.76 / EA Hydraulic structures, 96" x 96", HD, self cont with crank, sluice Detail $ 67,440.10 / EA Hydraulic structures, 108" x 108", HD, self cont with crank, Detail $ 87,380.36 / EA Hydraulic structures, 120" x 120", HD, self cont with crank, Detail $ 117,696.03 / EA Hydraulic structures, 132" x 132", HD, self cont with crank, Detail $ 168,117.06 / EA	

Table 5 Unit Costs for Pumping Station

Measures	Cost & Unit	References
Pump station	For stormwater, $C = 149055\ Q^{0.6907}$, where C = cost ($), Q = pump flow rate (cfs)	C-111 Spreader Canal Western Project Final Project Implementation Report (PIR) and Environmental Impact Statement (EIS) Final - January 2011: Appendix B - Cost Estimates http://www.evergladesplan.org/pm/projects/docs_29_c111_pir.aspx
	For wastewater, $ 750,000 at 0 – 0.99 MGD, $ 2M at 1.00 – 4.99 MGD, $ 5M at 5.00 – 9.99 MGD, $12.5M at 10.00 – 24.99 MGD, $ 22.5M at 25.00 – 49.00 MGD, $ 35M at 50.00 – 74.00 MGD, and $ 50M at 75.00 or larger MGD.	New Hampshire Department of Environmental Services - Water Division http://des.nh.gov/organization/divisions/water/wweb/documents/ar_appendix_g.pdf

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Table 6 Unit Costs for Conveyance

Measures	Cost & Unit		References
Culvert			
Size	material	Price	
12” x 10”	Steel	104	https://shop.mccoys.com/farm-ranch-yard/culverts/steel-culverts-and-accessories/steel-culverts
12” x 12”	Steel	124	
12” x 20”	Steel	199	
12” x 24”	Steel	246	
15” x 10”	Steel	155	

15” x 16”	Steel	204	
15” x 20”	Steel	289	
15” x 30”	Steel	385	
18” x 16”	Steel	249	
18” x 20”	Steel	335	
18” x 24”	Steel	369	
18” x 30”	Steel	469	
24” x 20”	Steel	395	
24” x 24”	Steel	475	
24” x 30”	Steel	599	
30” x 30”	Steel	749	
36” x 30”	Steel	949	
Dredging	Cost to design and build the spoil area, and dredge the material: $4.00 to $8.00 per cubic yard. Combined charge for mobilization and de-mobilization: $20,000 to $50,000. For preliminary cost estimates, use the average of the above costs.		http://www.dredgingspecialists.com/Dredging101.htm
	Hydraulic: 5-15 $/CY and Mechanical: 8-30 $/cy		http://www.epa.state.il.us/water/conservation/lake-notes/lake-dredging.pdf
Sewer	PVC Sewer Pipe, 8 Inch Diameter: Unit: LF cost: 300.00 $ 10/12 inch can be installed with a box, use $300-$350 per foot		Bid Tabulation for Horseshoe Bend Levee Improvements Project (Phase II) – Bidder : SCI Infrastructure, LLC

Table 7 Unit Costs for Rainfall Interception

Measures	Cost & Unit	Reference
Green Roof	15.75 ($ /sq ft)	http://greenvalues.cnt.org/national/cost_detail.php
Permeable pavement/ driveway/ parking (Material :Asphalt)	6.34 ($ /sq ft)	http://greenvalues.cnt.org/national/cost_detail.php
Permeable pavement/ driveway/ parking (Material :Asphalt)	6 ($ /sq ft)	http://greenvalues.cnt.org/national/cost_detail.php
Permeable pavement/ driveway/ parking (Material : Gravel)	4.32 ($ /sq ft)	http://greenvalues.cnt.org/national/cost_detail.php
Swales	15 ($ /sq ft)	http://greenvalues.cnt.org/national/cost_detail.php
Vegetated Filter Strips	1.45 ($ /sq ft)	http://greenvalues.cnt.org/national/cost_detail.php
Planter Box	8 ($ /sq ft)	http://greenvalues.cnt.org/national/cost_detail.php
Rain Garden	7 ($ /sq ft)	http://greenvalues.cnt.org/national/cost_detail.php
Amended Soil	30 ($ / CY)	http://greenvalues.cnt.org/national/cost_detail.php

Table 8 Unit Costs for Storage

Measures	Cost & Unit	Reference
Excavation	35 ($ / CY)	http://www.state.nj.us/transportation/business/procurement/ConstrServ/documents/BidTabs13454.pdf