POTENTIALS FOR IMPLEMENTATION OF GREEN INFRASTRUCTURE IN LITTLE FERRY, NEW JERSEY

by

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ABSTRACT OF THE THESIS

POTENTIALS FOR IMPLEMENTATION OF GREEN INFRASTRUCTURE IN LITTLE FERRY, NEW JERSEY

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Thesis Director:

Dr. Qizhong Guo

Due to urbanization, there has been a rapid expansion in the developing cities, due to which there has been a large increase in the impervious surface area through the expansion of parking lots, roadways and other built up structures which resulted in altered natural water flows, reduced groundwater recharge, increased surface temperatures, and also have impacted water quality. Green infrastructure mimics natural systems to lessen these impacts and have a numerous environmental, social and economic benefits. The main objective of this thesis is to develop strategies for implementing green infrastructure on a municipal scale. Three different potentials were considered for analysis. First potential focuses on implementing green infrastructure for the entire municipality whereas the second potential focuses on implementing green infrastructure only in the area under 100-year flood zone. As a part of assessing the third potential a GIS suitability model is developed by integrating three key factors of green infrastructure suitability: soil type, land cover and tree canopy, and for the third potential green infrastructure techniques are implemented only in the highly suitable area from the model. Cost analysis is done for these three potentials for implementing different green infrastructure techniques like green roof, rain garden, bio swales, vegetation filter strips, planter box, permeable parking, permeable sidewalk and permeable driveway. Cost analysis is performed for a 50-year time horizon using a software package. Also the maximum surface run-off that will be captured by the used green infrastructure techniques is calculated for all the three potentials using the software package. This analysis hopes to provide technical support for practitioners and community planners for implementation of green infrastructure at municipal scale.

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This project would not have been possible without the support and encouragement of many people who generously contributed their time and knowledge.

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1. Introduction

Urbanization has increased the amount of impervious surface across the United States. Impervious surface lessens the infiltration of stormwater into the ground, by which the surface run-off increases. High volumes of run-off can erode stream banks, cause localized flooding, and contributes to sewer overflows. Also in urban areas rainfall run-off as stormwater is the major carrier for nonpoint sources of pollution which impacts the water quality of waterways to which this run-off is directed through sewers. Storm water from street surfaces is often contaminated with car oil, dust and the feces of animals and soil and sediment run-off from construction sites and in industrial areas often contains more toxicants and chemicals (Green and Gray Infrastructure Research, USEPA website).

1.1. Green infrastructure:

Green infrastructure is a general name given to an approach using environmentally friendly techniques to manage stormwater. Green infrastructure refers to sustainable pollution reduction practices that also provide other ecosystem services such as reduced greenhouse gas emissions and increased flood control. Green infrastructure either retains stormwater run-off or redirects water into the ground where plants and soil will naturally filter the water (Green and Gray Infrastructure Research, USEPA website).

Green infrastructure has become an integral part in the innovative designs which focus towards stormwater management, climatic variability, and community development. EPA has conducted research ranging from soil analysis to best-placement modeling for effective implementation of green infrastructure. Under EPA researchers have developed a tool called the National Stormwater Calculator (NSC) to help city planners, developers, and property owners assess how green infrastructure can be used to reduce rainwater runoff before it becomes a problem. The easy-to-use NSC estimates the annual amount and frequency of stormwater run-off from a specific site based on historical rainfall data, land cover, soil conditions (Green Infrastructure Fact Sheet, USEPA website).Whereas this thesis focuses on strategies for implementing green infrastructure on a municipal scale.

1.2. Little Ferry:

The Study area, Little Ferry is a Borough in Bergen County in New Jersey. Little ferry is located at 40°50′40″N 74°02′10″W (40.844332,-74.036164). According to the United States Census Bureau, the Borough has a total area of 1.703 square miles, of which, 0.277 square miles accounts for water and 1.476 square miles is land. As of 2010 census the Borough's population was 10,626 with 4,439 households and 2,370 families residing in the Borough (United States Census Bureau 2010). The map showing the boundary of Little Ferry is shown in Figure 1.

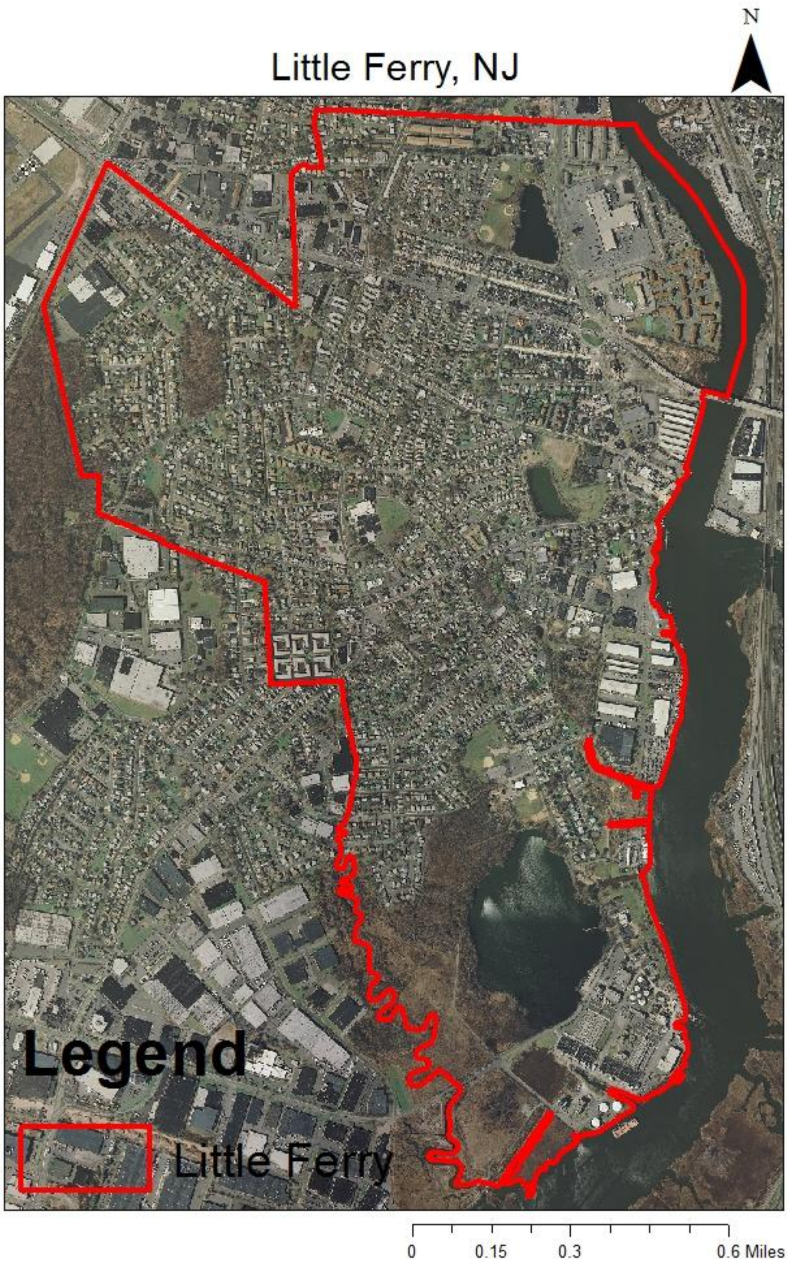

Figure 1. Map showing the boundary of Little Ferry, NJ

Flooding is a regular concern in the Little Ferry Borough. Little Ferry is extremely low lying with little or no relief. Little Ferry drainage system is characterized by a shallow, low slope pipe networks that direct run-off to three pump stations which pump water into the Hackensack River. Typically these pumps are effective and prevent major flooding. Localized street flooding occurs but is short lived.

The direct run-off which is being pumped into the Hackensack River is vulnerable to many non-point sources of pollution such as pathogens and bacteria from human and animal waste, chemicals and heavy metals from industries and gas and oil from roads. Implementation of green infrastructure in Little Ferry will not only reduce the pollution of run-off, but also reduces or removes localized flooding caused by the run-off. The land use classification of Little Ferry is shown in Figure 2.

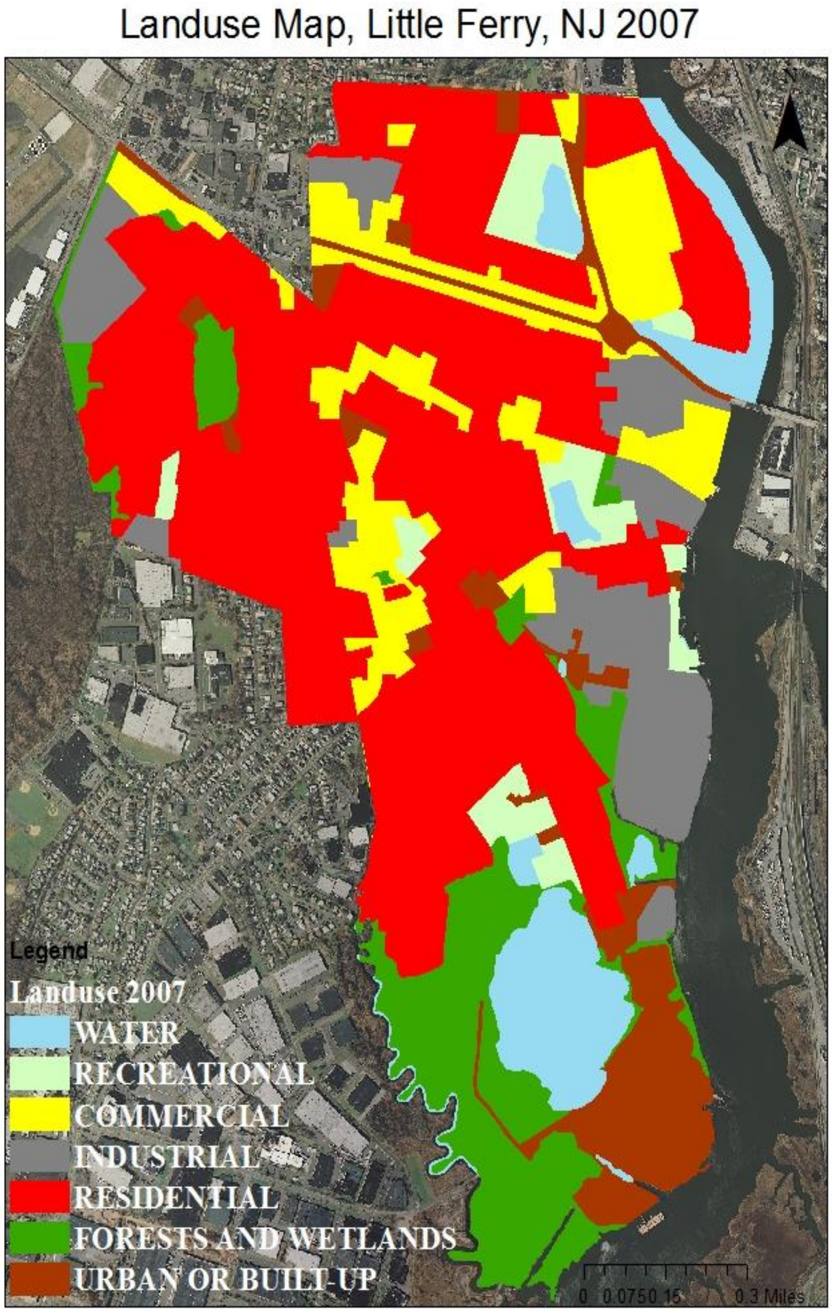

Figure 2. Map showing the land use classification in Little Ferry, NJ

1.3. Key terms :

Green Infrastructure: an approach which uses natural hydrological structures to manage stormwater by which environment and community benefits. To create healthier urban environments, green infrastructure uses vegetation, soil and natural ways to intercept stormwater. At municipal scale green infrastructure refers to the patchwork of natural areas that provide natural habitat, reduced flooding, cleaner water and cleaner air.

Stormwater management: involves the control of “run-off” from precipitation for reducing flooding, downstream erosion and water quality degradation.

Surface run-off: is generated when rain hits saturated or impervious ground and begins to flow overland downhill (USGS website).

Geographic Information System (GIS): “an organized collection of computer hardware, software, geographical data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information” (Redlands, CA: Environmental System Research Institute, 1990).

Shapefile: stores nontopological geometry and attribute information for the spatial features in a data set. Geometry for a feature is stored as a shape comprising a set of vector coordinates (ESRI White Paper, July 1998).

Raster data: consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information, such as temperature. Rasters generally are digital aerial photographs, imagery from satellite, digital pictures, or even scanned maps (ArcGIS 9.2 Desktop Help).

FEMA Preliminary work maps: are created for certain New Jersey/ New York communities and are an interim product created by FEMA in the development of preliminary Flood Insurance Rate Maps (FIRMs). The preliminary work maps are intended to help the communities and property owners to understand the current flood risk and likely flood insurance requirements in the future.

Modelbuilder: is a tool in ArcGIS which is used not only to create, but also edit, and manage models. A model is a workflow which string together sequences of geoprocessing tools, using output of one tool into another tool as input (ArcGIS Help 10.1).

Weighted overlay analysis: is the most used approach for overlay analysis to solve multicriteria problems such as site selection and suitability models.

2. Literature review:

2.1. Green infrastructure:

Green Infrastructure is one of the approaches to handle the flooding problem. Green Infrastructure is building with nature for solving urban and climatic challenges. The main components in this approach are storm water management, less heat stress, climate adaptation, more biodiversity, better air quality, clean water and healthy soils, and sustainable energy production.

A range of green infrastructure elements can be woven throughout a watershed, from smaller scale elements which can be integrated into sites to larger scale elements that span entire watershed. Green infrastructure elements considered in this thesis are limited to green roof, rain garden, permeable pavement, permeable parking, permeable sidewalk, swales, vegetative filter strips and planter box.

2.1.1. Green roof:

Green roofs are roofs covered with living plants as shown in Figure 3. Although historical and archeological evidence suggests that green roofs have been built for more than three thousand years, their use has always been limited by the technical challenges of low-slope waterproofing. Green roofs have been made practical with the recent developments of lightweight thin-profile green roofs and advancements in membrane waterproofing technologies. Although green roofs are more expensive compared to bare roofs, they offer significant long-term economic and environmental advantages which justify their higher initial cost. Green roofs reduce stormwater run-off significantly by retaining half to three-quarters of annual rainfall and retarding the run-off of most of the remainder. Moreover, green roofs are not only visually attractive but also are energy efficient. The thermal mass of the soil reduces heat gain and loss by averaging temperature extremes which helps in reducing urban heat island effect. Also by shielding the waterproofing from the sun and reducing temperature fluctuations, synthetic membranes can last for more than fifty years (Green Roof handbook, Conservation Technology, Inc.).

While designing new systems or converting existing roofs to green roofs, adequate capacity and easy access to gutters, downspouts, underdrains and other components of the roof's drainage system must be provided. With a combination of sound design and regular inspection and maintenance, clogging of underdrains can be prevented. To address the drainage system malfunctioning and for the rainfalls exceeding the systems design storm, overflows must be provided. Generally the slope (horizontal to vertical) of the roof can vary between 12:1 and 4:1. By providing proper erosion protection measures steeper roofs can be used. Relatively flat roofs require underdrain layer, while the steeper roofs can drain by gravity. Type of vegetation used should be based on the access and maintenance requirements and secondary uses of specific roof areas. Except for intermittent watering and fertilization, a meadow-like planting of perennial plants can require minimal maintenance (New Jersey Best Management Practices Manual, February 2004).

Figure 3. Example of green roof implementation (Source-science.howstuffworks.com)

2.1.2. Rain garden:

A rain garden is a garden which takes rainfall and stormwater run-off. Amount of rainfall or stormwater run-off entering the garden plays a crucial role in its design and plant selection. A rain garden is designed to withstand the extremes of moisture and concentrations of nutrients which are most commonly found in stormwater run-off. Rain gardens slow the stormwater as it travels downhill providing more time for water to infiltrate in the garden (Roger Bannerman and Ellen Considine, 2003).

Figure 4. Image showing rain garden (Source – raindogdesigns.com)

Looking like an attractive garden on the surface, rain garden may support habitat for birds and butterflies. Figure 4 shows an image of a rain garden. How it gets its water and what happens to the water as it enters the garden is what it makes it a rain garden. Processes which mimic natural hydrological actions of a forest occur below the ground. The garden acts like a small bioretention cell in which rainwater is cleaned and reduced in volume once it enters the rain garden. Not only the sediments, but nitrogen and phosphorus in stormwater run-off are also reduced by the action of plants and growing media. Plants with deep fibrous roots are more suitable and have many advantages when planted in a rain garden. Such plants provide the most cleaning and filtration benefits to the environment. Multiple rain gardens over an area will have cumulative effect on both the volume and quality of stormwater run-off (Rain Garden Design Template: Low Impact Development center).

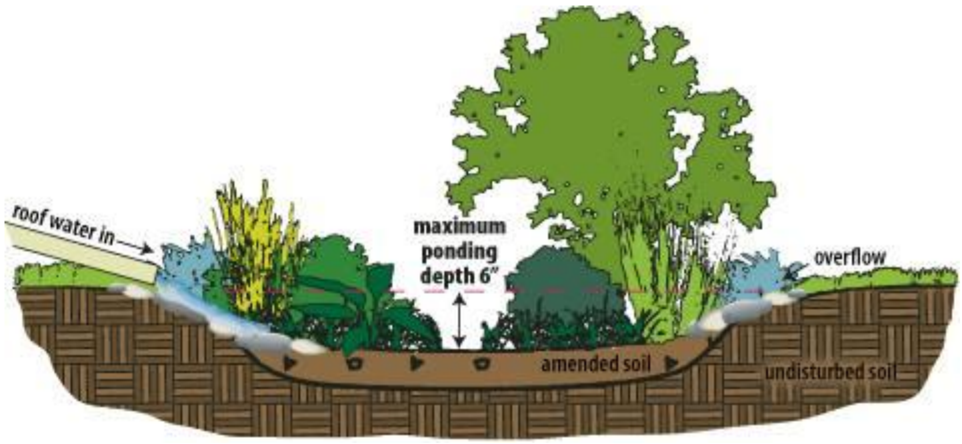

Figure 5. Cross-section of a rain garden (Source – oeconline.org)

Rain gardens should not exceed 300 square feet and the contributing impervious area should not exceed 4,000 square feet. Figure 5 shows typical cross section of a rain garden. A general recommendation is to size a rain garden with 6 inch ponding depth to approximately 6% of the contributing area (Low Impact Development Best management Practices: Long Beach Development Services).

2.1.3. Swales:

Swales are broad, shallow channels designed to promote infiltration, filter pollutants and sediments and to slow runoff in the process of conveying runoff. Figure 6 shows a swale implemented on the side of a roadway. Not only providing environmentally superior alternative to gutter conveyance systems, swales also promote infiltration and treatment of stormwater run-off. Vegetation with a dense and diverse selection of native, water resistant plants with high pollutant removal potential are suitable for planting in swales.

Figure 6. Image showing an installed swale (Source – ecosrq.com)

Swales constructed with an underlying 12 to 24 inches of aggregate provide significant volume reduction and also reduce the stormwater conveyance rate. A major concern while designing a swale is to make certain that excessive storm water, slope, type of vegetation and other factors will not combine to generate erosive flows, which exceed the swale capabilities. Dense, low growing native vegetation that is water resistant, salt and draught tolerant, and provide substantial pollutant removal are suitable for swales. 1 to 6 % longitudinal slope and a side slope ranging between 3:1 to 5:1 is best suitable for swale. A bottom width of 2 to 8 feet is best suited for a swale. Figure 7 shows a cross-sectional view of a swale. Generally a swale should be designed to convey a 10-year storm with 6 inches of free board and to generate non-erosive velocities up to the 10-year storm (Pennsylvania Stormwater Best Management Practices Manual-December 2006).

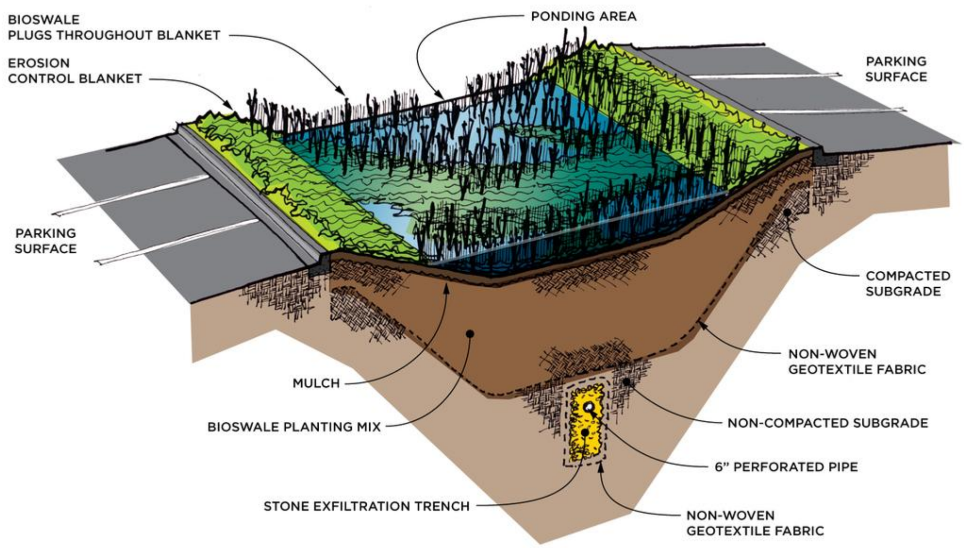

Figure 7. Cross-sectional view of a swale (Source – archinect.com)

2.1.4. Vegetative filter strips:

Vegetative filter strips (shown in Figure 8) are bands of vegetation planted not only to reduce surface run-off but also remove sediment and nutrients from run-off. Vegetative filter strips reduce the velocity of surface run-off by which there is a decrease in the sediment transport capacity and induces sediment deposition. By filtering solid particles from run-off, vegetative filter strips reduce nutrients and sediments.

Factors like flow rate, density and height of vegetation, width of strip, slope of the filter bed and incoming sediment and nutrient load will account for effectiveness of the vegetative filter strip. Grasses and dense vegetation offer high resistance to shallow overland flow and decrease the velocity of overland flow immediately upslope of and within the filter causing significant time for the stormwater run-off to infiltrate and also decreases the sediment transport capacity (Dillaha, Sherrard & Lee, 1986). Width of vegetative filter strip is a largely judgmental factor which depends on land use and management across the strip, strip vegetation, land slope above the strip, length of slope above the strip, slope across the strip and anticipated degree of strip maintenance. For effective sediment removal, the strips width will vary from a few feet to several hundred feet. A minimum width of 12 feet is recommended for herbaceous vegetative strips (Stormwater Best Management Practices, Boston Water and Sewer Commission, January 2013).

Figure 8. Vegetative filter strip beside a roadway (Source – austintexas.gov)

2.1.5. Permeable paving systems:

Permeable pavers are paved areas which produce less stormwater run-off compared to traditional paved areas. The reduction in run-off is achieved primarily through the infiltration of rain falling on the area either through the paving material itself or through void spaces between individual paving blocks known as pavers. Permeable paving systems are used to reduce the imperviousness of firm surfaces such as patio, driveways, walkways, parking areas, sidewalks, and fire lanes to reduce surface runoff and increasing infiltration. Permeable pavers can also be used as inlets and outlets for infiltration trenches. Permeable pavers effectively reduce the peak surface run-off rates and improve the ground water recharge characteristics of developed site. Figures 9, 10 and 11 shows permeable sidewalk, permeable parking and permeable driveway.

Permeable pavers should work well on most residential sites where paved surfaces such as driveways, patios and parking areas for commercial sites. Sites with slope greater than 3 percent may not be suitable for implementation of permeable pavers. Permeable pavements should not be implemented within 10 feet from foundation of a building unless an approved impermeable liner is installed to prevent infiltration under these facilities. Infiltration of the soil in the site must be approximately 0.5 inch per hour, and the depth to groundwater from the bedrock should be at least 5 vertical feet. An underdrain system should be installed in sites with characteristics that do not permit infiltration. The use of surface (i.e. vehicles, foot traffic, and recreation), site conditions, and maintenance requirements should be considered during the design process. Though the cost for implementing permeable pavers is more compared to the traditional pavers, the advantages overshadow the high cost (New Jersey Best Management Practices Manual, February 2004).



Figure 9. Permeable sidewalk-source-naturalpathlandscaping.com(Top left); Figure 10. Permeable parking-source-ralieghnc.com(Top right); Figure 11. Permeable driveway-source-dailysightline.com(Bottom)

2.1.6. Planter box:

Planter boxes (shown in Figure 12) are bioretention measures which are contained within impermeable wooden or concrete structures with an under-drain to remove excess water entering the box. Boxes are filled with gravel on the bottom, planting soil media, and vegetation. As the stormwater passes through the planting soil, pollutants present are filtered by the soils and plants.

Planting soil should be at least 2 feet deep. Planting soils must contain no more than 30 percent compost (Low Impact Development Best management Practices: Long Beach Development Services). Planters should not be installed on elevated platforms, decks or porches without necessary arrangements. Planter box should not be implemented on uneven or sloped surfaces. Planters should undergo annual plant and soil maintenance to ensure optimum filtration, storage and drainage capabilities (Stormwater Best Management Practices, Boston Water and Sewer Commission, January 2013).

Figure 12. Example of Planter box (Source – calfinder.com)

2.2.Flood Zones:

Different flood zones present in Little Ferry area are Zone AE, Shaded Zone X and Unshaded Zone X. Zone AE are areas which have a probability of 1% to get flooded every year (also referred as “100 – year floodplain). Flood water elevations above the sea level are established for this zone. Properties in Zone AE are considered to be at a high risk of flooding under National Flood Insurance Program (NFIP).

Shaded X Zone is areas that have 0.2% probability of flooding every year (also known as 500-year floodplain). Properties in Shaded X Zone are considered to be at moderate risk of flooding under NFIP.

Unshaded X zone are areas which are above 0.2% flood elevation and properties in this zone are considered to be at a low risk of flooding by NFIP (FIRM floodplain mapping FAQ – Dane County Planning and Development).

Figure 13 shows the flood zones present in Little Ferry, NJ.

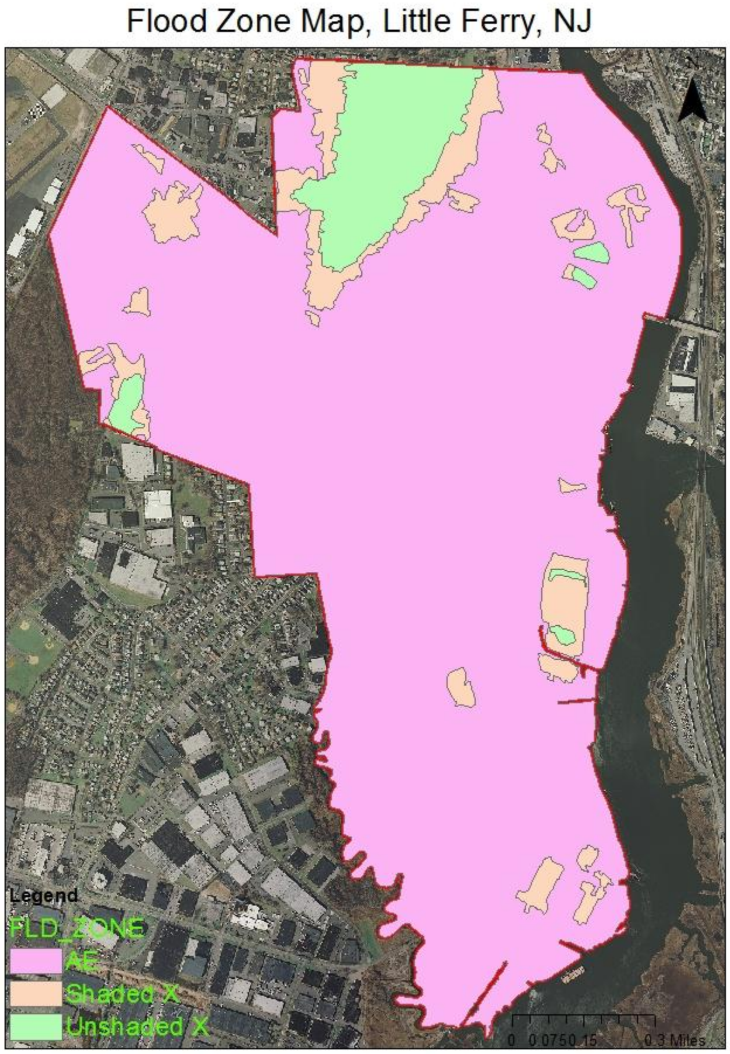

Figure 13. Map showing the different flood zones in Little Ferry, NJ.

2.3.Green infrastructure optimization tool:

A software was developed to calculate the total cost (capital, maintenance and replacement) of implementing the green infrastructures as a part of a State-funded project. Unlike other software packages available, the developed software is capable of finding 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 14 shows the tool used for finding the costs.

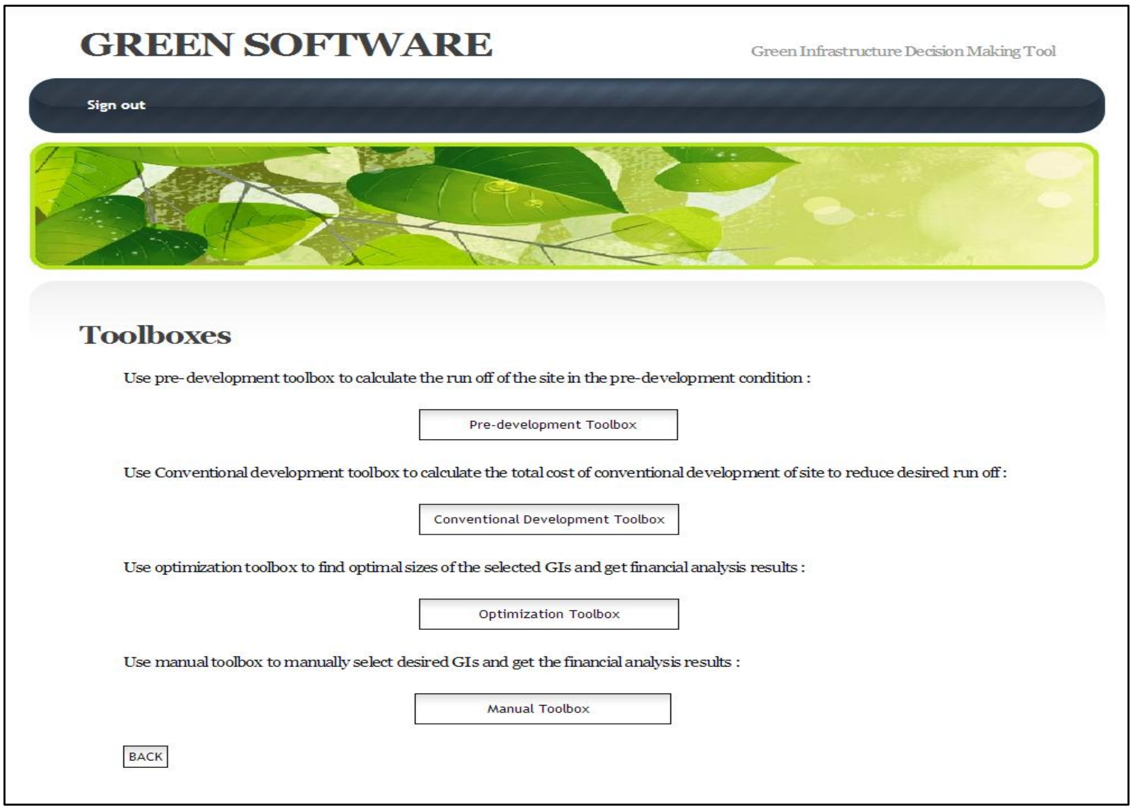

Figure 14. Layout of optimization software used

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. Default values of porosity and depths are given in Table 1.

Table 1. Table showing the porosity and depth of green infrastructure elements used in the software

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	0.35

porosity	
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 2. Long lifetime of green infrastructure types is considered.

Table 2. Table showing the unit costs, annual maintenance costs and life time for green infrastructure elements used in the software

Green Infrastructure type	**Capital cost ($/ft^2)**	**Yearly maintenance cost ($/ft^2)**	**Life time (Years)**
Permeable sidewalk,	6.65	0.17	50

driveway and parking (Asphalt)			
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

3. Methodology:

3.1. Data collection and formatting:

All the data used in the research was straightforward and was downloaded from various free online sources.

The boundary for Little Ferry was obtained from the New Jersey Department of Environment Protection website. The boundary of Little Ferry used was from the New Jersey municipal coast boundary shapefile downloaded from NJDEP website. The land use data for year 2007 shapefile for Hackensack watershed area is also obtained from NJDEP website and is clipped for Little Ferry boundary.

Orthophoto's for Little Ferry were obtained from New Jersey Geographic Information Network website. The 2007 orthoimagery is the latest version available in NJGIN website.

Road network data was obtained from New Jersey Department of Transportation (NJDOT) website. From the New Jersey road network map and road network for Little Ferry area is clipped in ArcGIS.

100-year flood zone data was obtained from the FEMA website. Preliminary work maps are available for the Bergen County. The Little Ferry data is clipped from the Bergen County shapefile.

For suitability model, the soil data required was downloaded from United States Department of Agriculture (USDA) website. Soil shapefile and tabular data is obtained from the USDA's Natural Resources Conservation Service Soil Survey data gateway. The tabular data is added to the shapefile in ArcGIS. Both the land cover and Tree Canopy data were obtained from USGS's Landsat 7 ETM+, National Land Cover (NLCD) 2006 and 2001 from National Map Viewer interface.

3.2. Suitability model:

As a part of research a GIS suitability model was developed to find suitable areas for green infrastructure implementation. For the GIS suitability analysis, three key factors (soils, land cover and tree canopy) for green infrastructure implementation were considered. The model has the possibility of creating a tool which will enable the community planners and localities to identify suitable areas for green infrastructure implementation. In order to develop a replicable model, all the data utilized in this model is freely accessible at a national scale. This enables the model to be used in various localities throughout the United States.

3.2.1. Establishing parameters:

The parameters considered for the suitability model are soil type, land cover and tree canopy. Soil type is a key criterion in the implementation of green infrastructure. Soil is made up of three particle sizes, which are sand, silt and clay. Among these, sand is the largest particle with particle size of 0.05 to 2 mm diameter, whereas silt is intermediate with particle sizes ranging from 0.05 to 0.002 mm and clay is the smallest at less than 0.002mm. Soils have different textures and thus different infiltration rates based on the percentages of sand, silt and clay particles in the soil. Soil texture is graded into 14 texture classes. Examples include clay, sandy clay, loam, silty clay loam, sandy loam and sand. The soils present in Little Ferry are mostly types of Udorthents and sandy loam.

Tree canopy is another criterion considered in the analysis. In order to better capture the present environmental conditions, tree canopy is used as a criterion. Land cover is the last criterion used in the analysis. Land cover gives us information on both built and environmental conditions present in the area.

3.2.2. Ranking the criteria:

This subsection describes how the ranking of data for the model is done. Ranking will break each criterion into three ranks High, Medium and Low. Ranking of High equates a value of 3, Medium equated to 2 and Low equates to 1. “Creating a Replicable GIS Suitability Model for Stormwater Management & the Urban Heat Island Effect in Dallas, Texas” provided a basis for how to rank the criteria’s selected in this model.

Before ranking the soils, to the shapefile of soil data, tabular data which has the description of the soils type is to be added in GIS. Soils which have slopes of 0-1% or exceeding 8% are ranked 1, due to drainage issues caused by rapid runoff or lack of water flow. Sandy (or sandy-loam) will be given a 3 ranking (highly suitable), loamy a 2, and clay a 1 (low suitable). Urban land is given a rank of 3, because it is an area which would benefit from increased permeability, and water is excluded from the analysis by giving a value of 0.

Table 3. Table showing the rank given to different soil type present in Little Ferry, NJ

Description	**Rank**
Water	0
Urban land	3
Udorthents, wet substratum, 0 to 8 percent slopes	2
Udorthents, wet substratum-Urban land complex	3
Transquaking mucky peat, 0 to 1 percent slopes, very frequently flooded	1
Riverhead sandy loam, 8 to 15 percent slopes	1
Dunellen-Urban land complex, 8 to 15 percent slopes	1
Dunellen-Urban land complex, 3 to 8 percent slopes	3

Tree canopy data comes in raster tiles. The raster data is ranked based on the percentage of tree canopy. Areas with 0-40% tree canopy are given a rank of 3 (high suitability), with areas between 41-70% tree canopy are ranked 2 (moderately suitable) and areas with 71-100% tree canopy are ranked with 1 (less suitable).

Land cover data also comes in raster tiles. 7 different types of land cover classifications are present in Little Ferry. These are ranked in accordance to both most suitable and area that would benefit from green infrastructure implementation. Areas which are highly developed, with 50-100% impervious area are ranked as 3, and areas with less developed land and have 20-49% impervious area are given a rank of 2. All the natural lands, less developed lands and agricultural lands are given a rank of 1. Open water is given a value of 0.

Table 4. Table showing different land cover types present in Little Ferry and their ranks

Land Cover type	Rank given
Open Water	0
Developed, Open Space	1
Developed, Low Intensity	2
Developed, Medium Intensity	3
Developed, High Intensity	3
Woody Wetlands	1
Emergent Herbaceous Wetlands	1

3.2.3. Weighting the criteria:

After identifying and ranking the three criterions for the analysis, appropriate weights are given to each criterion for the analysis. For this model, soils is given higher weight compared to tree canopy and land cover as the type of soil in the area influences greatly whether green infrastructure implementation is possible or not. 40% of the weight is given to soils. Both the land cover and tree canopy are given equal weight (30% each) in the influence as these both criterion focuses mainly on the need for implementation of green infrastructure.

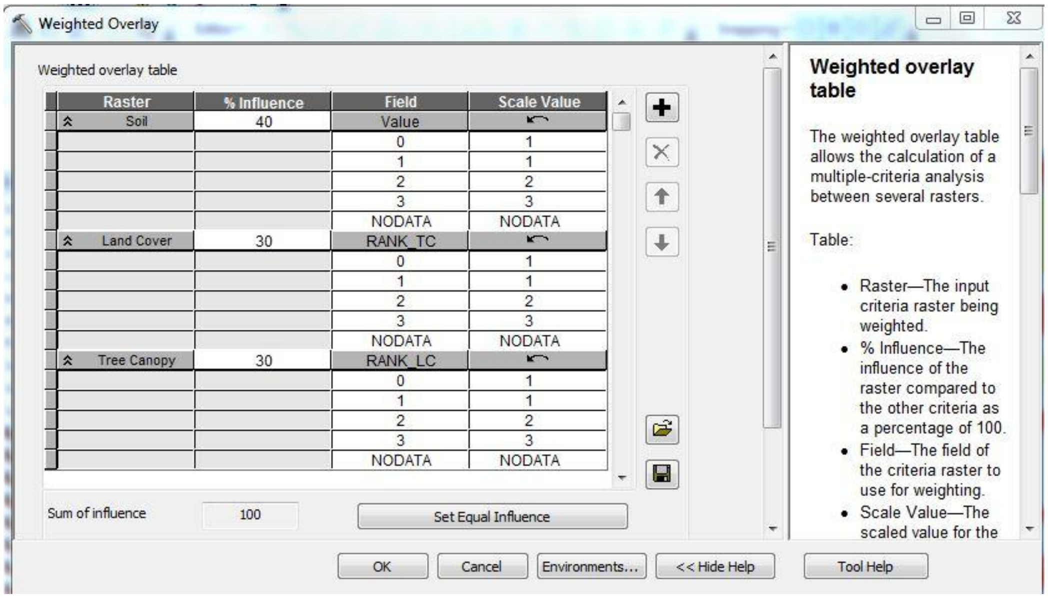

Figure 15. Snapshot of the weighted overlay tool where the weights are set to the criterion

3.2.4. Model:

After ranking all the criterions, several steps are required to execute the model in ArcGIS model builder. To perform weighted overlay analysis, all the data must be in raster format. Land cover and tree canopy data comes directly in raster format. But the soils data is shapefile. This data has to convert into vector data using conversion tool in ArcToolbox. Once the polygon data is converted into raster data, it is ready to be used for the weighted overlay analysis.

The model is created in ArcCatoalogue. All the existing and converted raster data are added into the model where the weighted overlay tools are applied. Main difference between weighted overlay analysis and weighted sum analysis is that weighted overlay analysis tool only enables an integer raster. Moreover only the output from weighted overlay analysis can be converted back into vector shapefile which is necessary to perform the cost analysis. Hence the weighted overlay analysis is used instead of weighted sum analysis in this model.

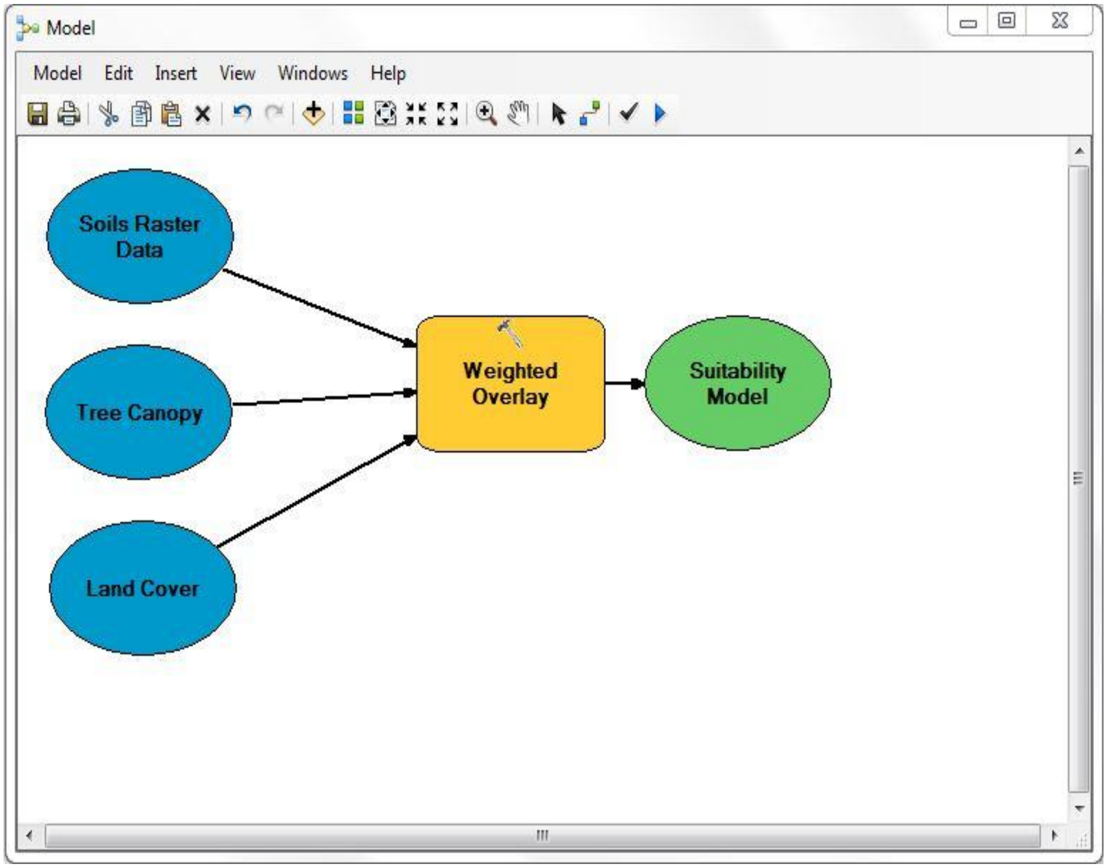

Figure 16. Snapshot of the model generated in model builder using ArcGIS

Each raster cell in the output will have had the equation in Figure 17. The equation works fairly simple. The final score or suitability of a location is represented by Y and W stands for the weight of the criterion. The individual criterion ranked is denoted by C with subscript of (i) and (i) stands for the number. In this model (i) would be 1-3 since three criteria is used. The sigma means the sum of, in this case it is the sum of each ranked criteria multiplied by its weight. The subscript of I = 1 the first criterion and N is the number of criterion. In this model N = 3.

$$Y = \sum_{i=1}^{N} (WC_i)$$

Figure 17. Formula used in weighted overlay analysis

4. Analysis:

4.1. Calculating areas for implementing green infrastructure elements:

This section focuses on how the maximum areas to implement each of the green infrastructure elements are calculated. The areas are calculated from the data generated from ArcGIS and some sensible assumptions made from the literature review focusing on design standards for green infrastructure elements. Detailed explanation for generating the maximum area of implementing the eight elements used in this thesis is described below.

4.1.1. Roof area:

For finding the maximum roof area, a new empty shapefile with polygon features is created in ArcGIS. New polygons are created to all the visible roofs in the orthophotos as shown in the Figure 20. This way all the roofs in Little Ferry are marked. From this shapefile, depending on the scale of implementation the file is clipped to the required scale.

To implement green roof, a roof needs typically 25 to 100 more load than the conventional roof. New roofs, whether made of concrete, steel, or wood can be designed to support green roofs with a minimal additional expenses. But to implement green roofs to existing roofs a costly structural reinforcing is needed. Hence only 20 percent of the total roof area is considered to be applicable for implementation of green roof. The runoff generated from the remaining roofs will be captured by directing the runoff to either a rain garden or planter box.

For implementing a rain garden, runoff from 40 percent of the remaining roof area is considered. Since there are restrictions such as rain gardens cannot be installed within 10 feet from the foundation of the structure, should be at least 3 feet from public sidewalks, should be at least 10 feet away from property lines, this assumption is made. The area of rain garden is assumed as 6 percent (for water quality treatment) of the contributing roof area with reference from Low Impact Development (LID) Best Management Practices (BMP) Design Manual by Long Beach Development Services.

The remaining runoff from 40 percent of the roofs is captured by planter box. The size of planter box is calculated with reference to the table in figure 19 from Low Impact Development (LID) Best Management Practices (BMP) Design Manual by Long Beach Development Services.

Table 5. Table showing the required total planter surface area for given roof area

Roof Area Contributing to Planter Boxes (sq. ft.)	Total Surface Area of Planters (sq.ft.)
500-1000	32
1001-1500	52
1501-2000	108
2001-2500	168

This table is for planter boxes designed for a depth of 2.5 feet for prepared soil depth of which 0.5 feet is for free board. Since in the analysis, 1 foot deep prepared soil is used, the area surface of planter from the table is doubled.

The mean of all the roof areas in Little Ferry is 1,752 square feet, the area for planter box is taken as 216 square feet for 1,752 square feet area of roof (double of 108 square feet as 1,752 square feet is in the range of 1,501 – 2,000 square feet).

Figure 18. Zoomed image showing how the roof area is marked

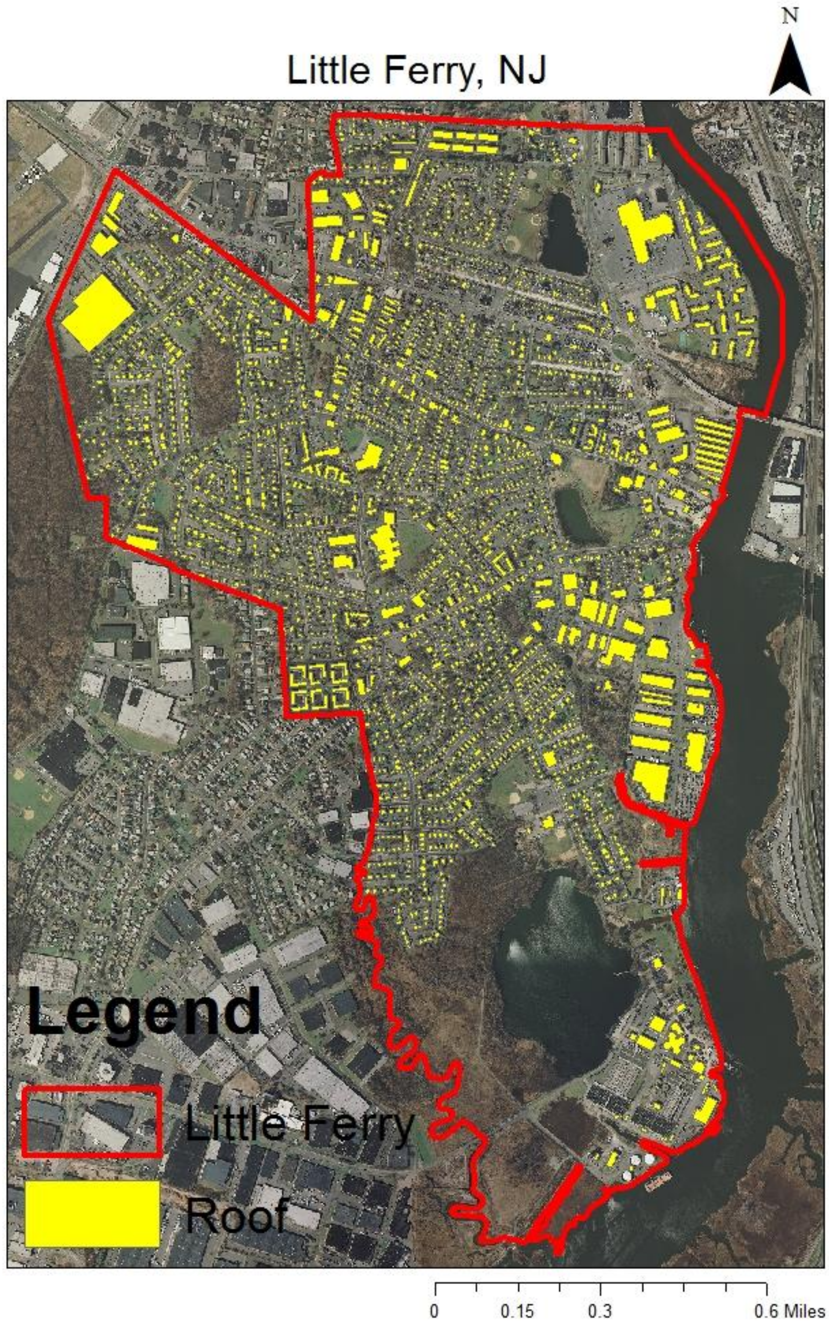

Figure 19. Map showing all the roof area marked in Little Ferry, NJ

4.1.2. Permeable driveways:

Similar to the procedure followed for roofs, a new shapefile with polygon features is created with marking all the driveways visible in the images are marked. The entire private road which connects a structure or a group of structures to the main motorway is considered as the driveway in this analysis.

Figure 20. Image showing marked driveways

4.1.3. Permeable parking:

All the parking lots in commercial, industrial and high density residential units are marked in a new shapefile created. Most of the parking lots in commercial and industrial will be subjected to higher load than the maximum load which pervious pavers can resist. But for the analysis all the parking lots are considered to be suitable to implement permeable pavers.

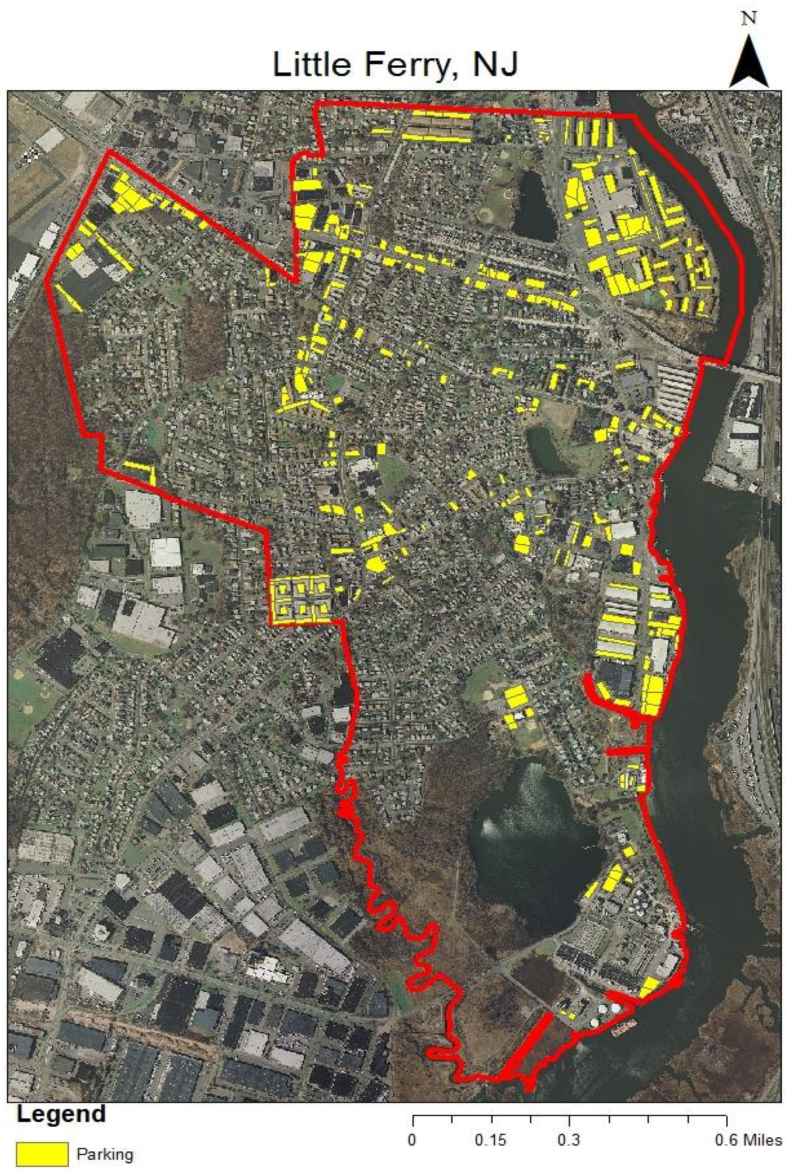

Figure 21. Map showing all the marked parking lots in Little Ferry, NJ

4.1.4. Permeable sidewalk:

For finding the maximum area in which permeable sidewalk can be implemented, a new shapefile with line features is to be created. Lines are to be marked through the length of the sidewalk present in Little Ferry. The width of the sidewalk is taken as 5 feet uniformly for all the sidewalks in the town.

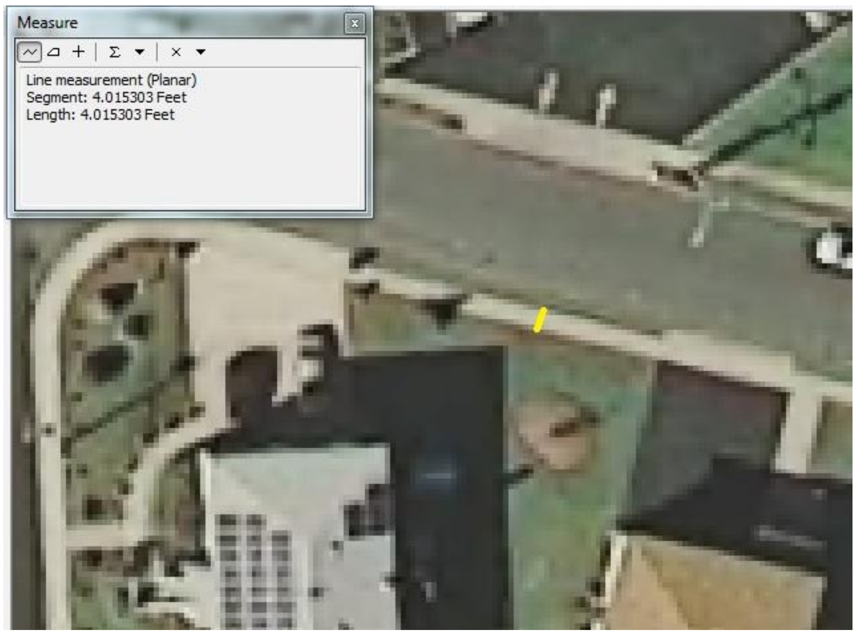

Figure 22. Image showing 4 feet wide sidewalk in Little Ferry, NJ

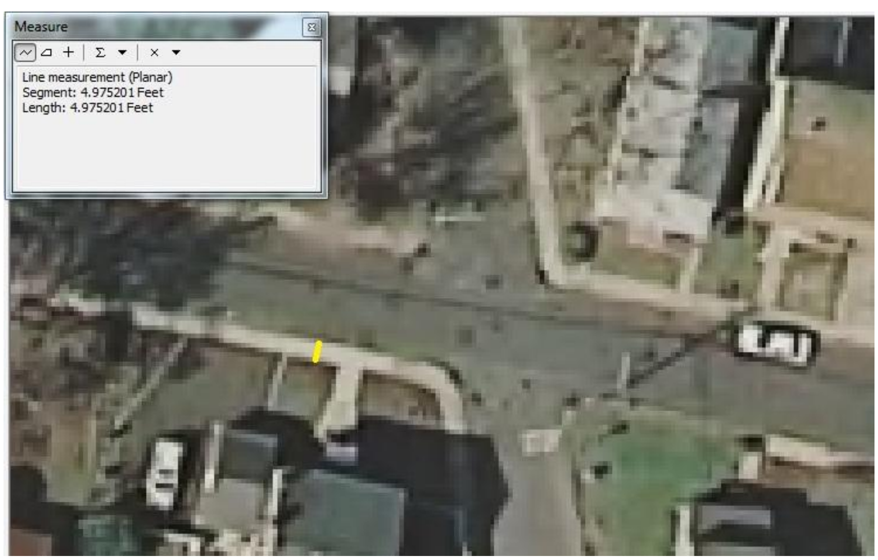

Figure 23. Image showing 5 feet wide sidewalk in Little Ferry, NJ

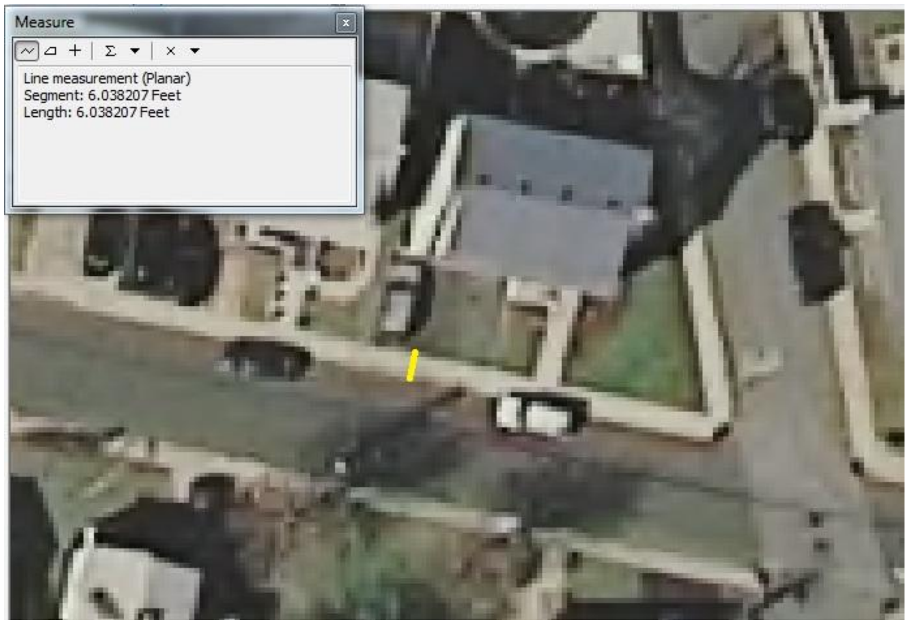

Figure 24. Image showing 6 feet wide sidewalk in Little Ferry, NJ

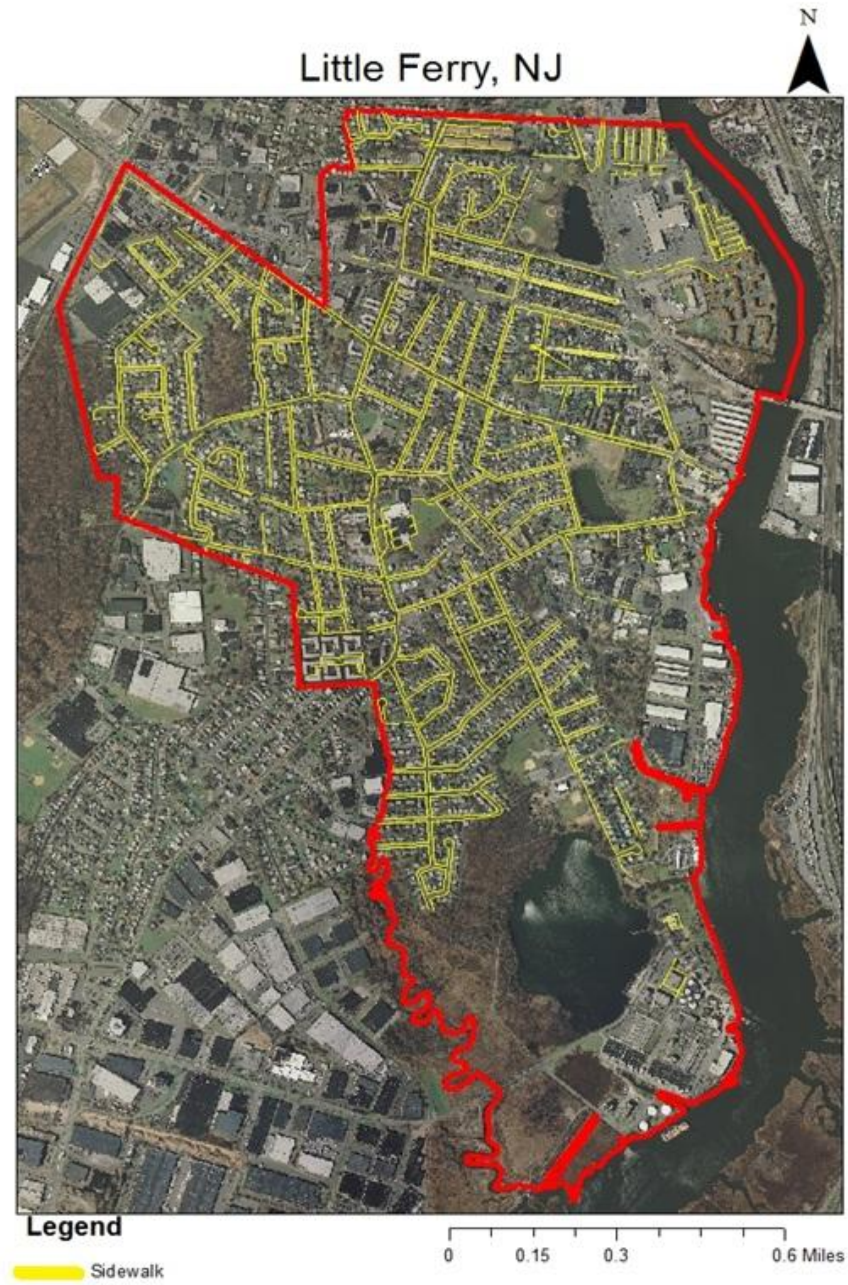

Figure 25. Map showing all the sidewalks present in Little Ferry, NJ

4.1.5. Swales and vegetative filter strips:

From the road network map of Little Ferry, the total length of road ways is calculated. Swales and vegetative filter strips (in this analysis) serve the same function of removing runoff from roadways. Hence only one of the both elements will only be placed at a location. Also assumption is made that these elements are applied on only one side of the roadway and all the runoff is diverted to that element. From the total length of roadways, 80 percent of lengths of roadways swales will be implemented. The bottom width of the swale is taken as 4 feet. As the depth is taken as 1 foot in the optimization tool, the total width of the swale will be 10 feet (assuming a side slope of 1:3 vertical to horizontal).

For vegetative filter strips, the remaining 20 percent length of the roadway is considered. This 20 percent of the roads accounts for the parts of roadways which have enough space beside the roadway for implementing 40 feet wide vegetative filter strips.

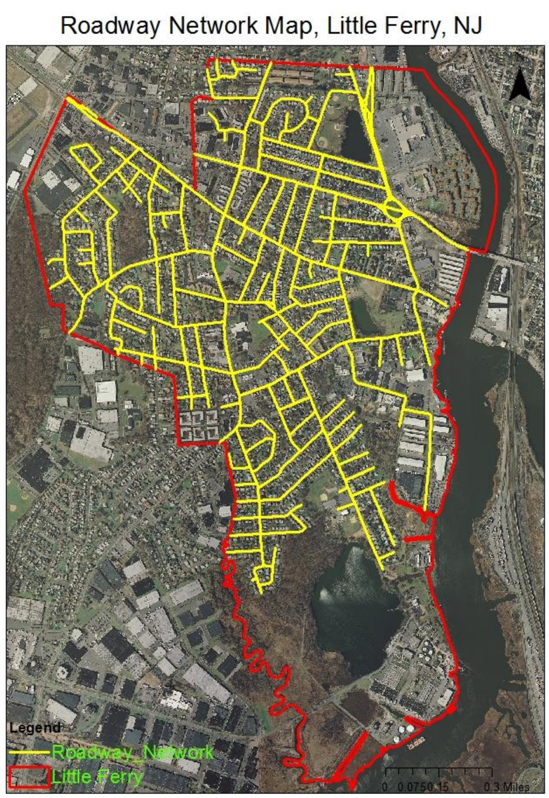

Figure 26. Map showing roadway network in Little Ferry, NJ

With this data and assumptions made the areas for implementation of the considered green infrastructure elements is calculated for all the three potentials considered.

4.2.Potential 1:

For potential 1, areas for implementation of green infrastructure are calculated for the whole Borough of Little Ferry. Detailed calculations for all the elements are provided in the Appendix A.

Total area considered for the analysis = 43360489 square feet.

Table 6. Table showing the maximum area for implementation of each green infrastructure element considered for potential 1

Green infrastructure element	Estimated maximum area available (square feet)
Green roof	1,219,612
Swales	961,136
Planter box	300,726
Vegetation filter strips	961,136
Permeable sidewalk	936,840
Permeable driveway	826,402
Permeable parking	2,814,905
Rain garden	146,353

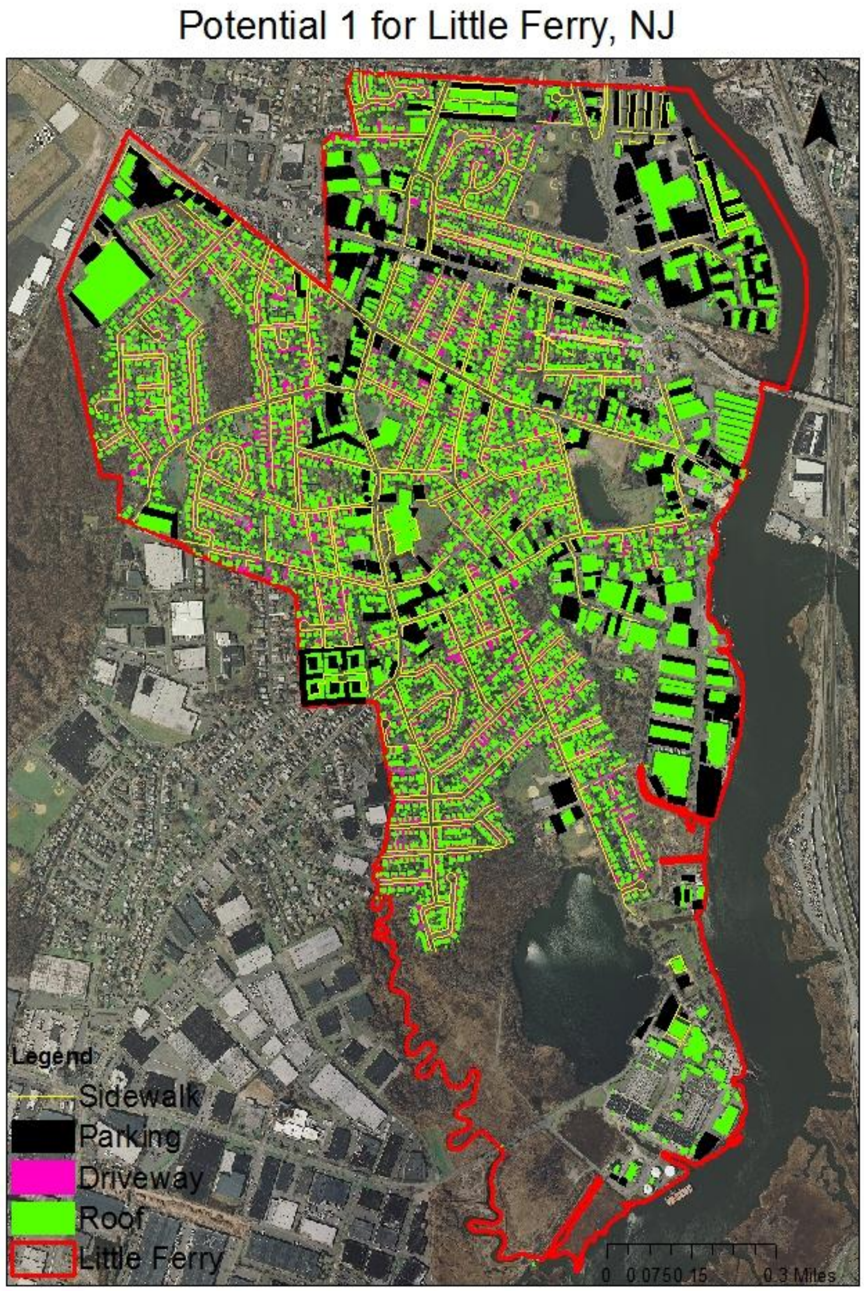

Figure 27. Map showing all the possible areas for implementation of green infrastructure in Little Ferry, NJ for potential 1

4.3.Potential 2:

As potential 2, only the area in Borough of Little Ferry which is in the 100 year flood zone is considered. All the shapefiles created are clipped with the 100 year flood zone boundary and the calculations for the areas for implementing the green infrastructure elements are performed.

Total area considered for analysis = 37302234 square feet.

Table 7. Table showing the maximum area for implementation of each green infrastructure element considered for potential 2

Green infrastructure elements	Estimated maximum area available (sq. ft)
Green roof	999,651
Swales	826,000
Planter box	246,489
Vegetation filter strips	826,000
Permeable sidewalk	788,620
Permeable driveway	712,294
Permeable parking	2,297,704
Rain garden	119,958

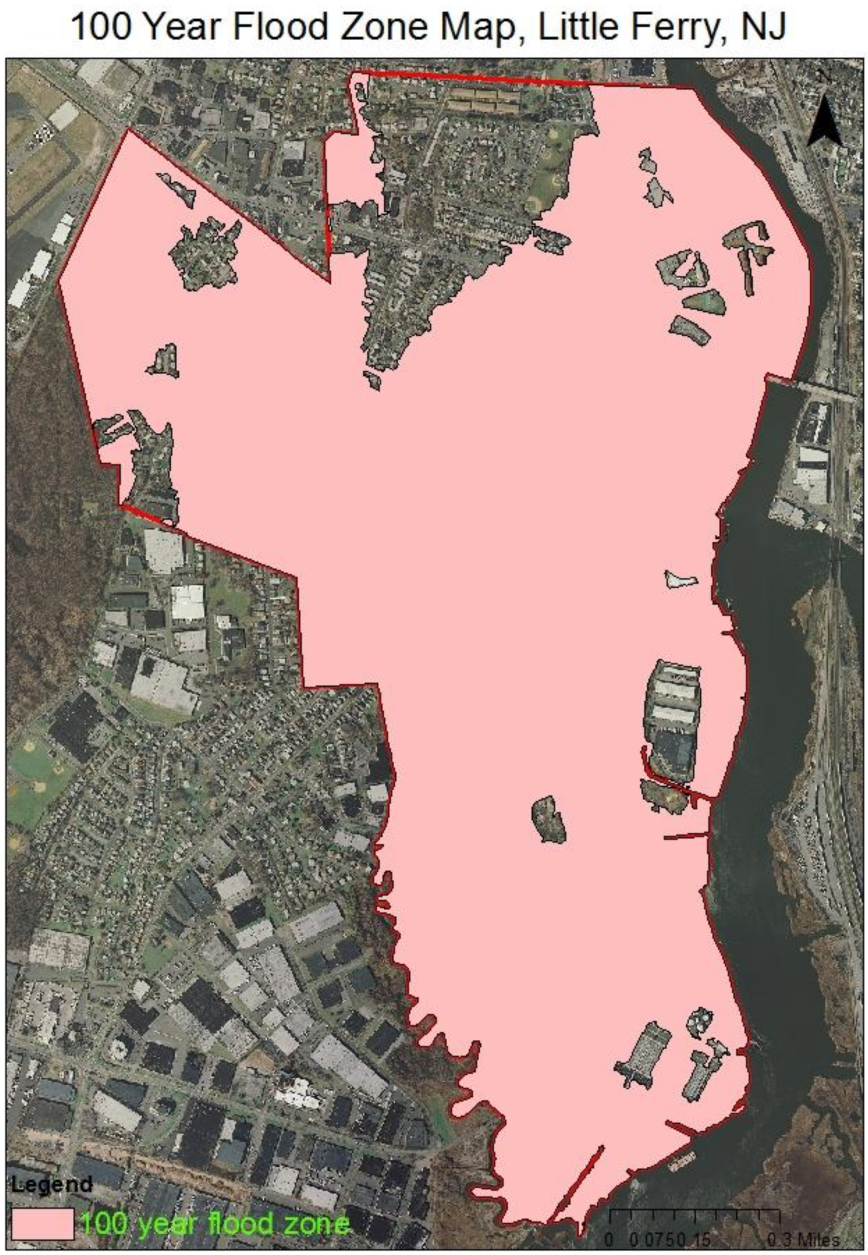

Figure 28. Map showing the 100 year flood zone for Little Ferry, NJ

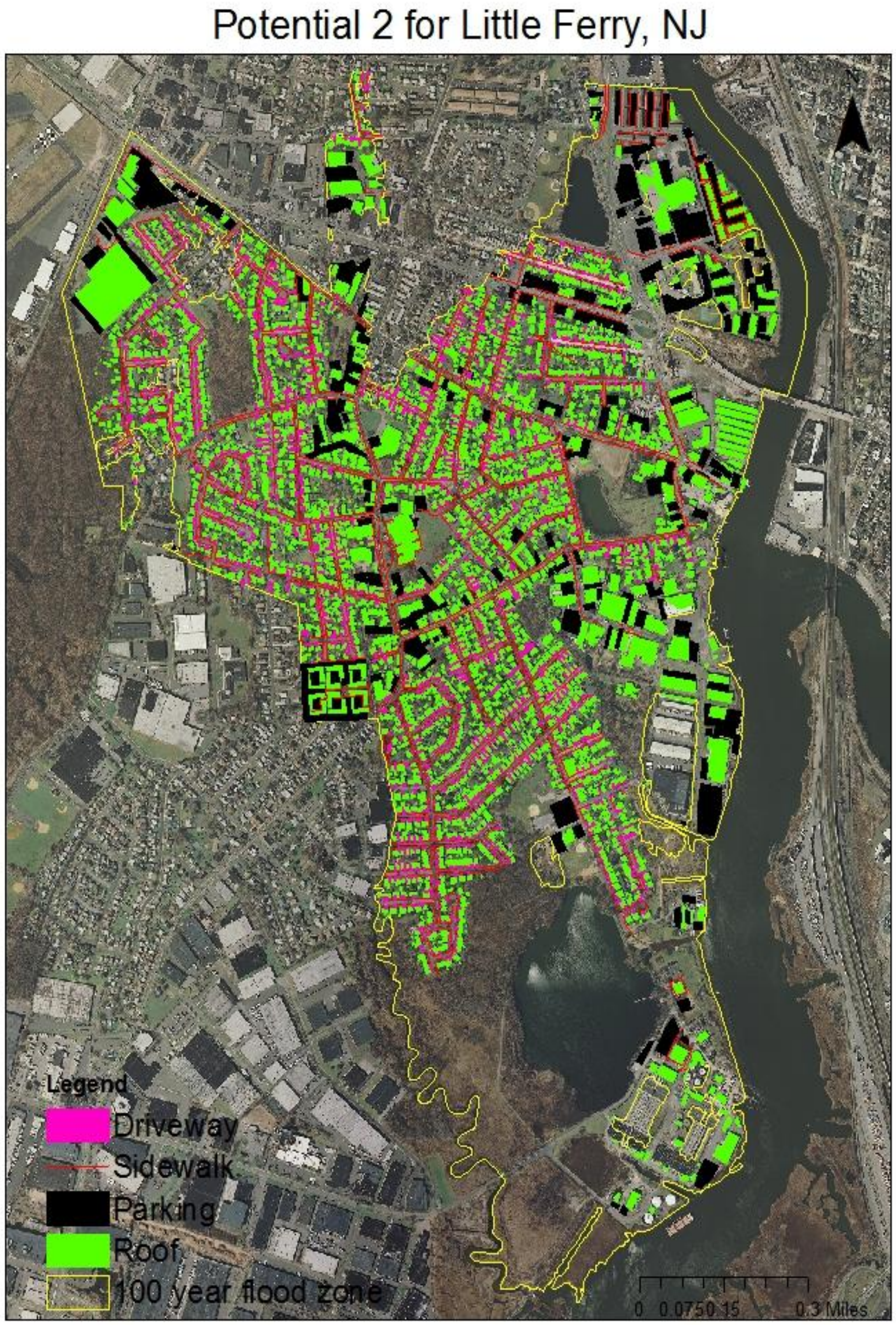

Figure 29. Map showing all the possible areas for implementation of green infrastructure in Little Ferry, NJ for potential 2

4.4.Potential 3:

In this case, the areas for implementing green infrastructure elements are calculated only in the most suitable zone obtained from the suitability model. For doing this, the raster output obtained from the suitability model is converted into vector data. From this vector data a new layer with only polygons for most suitable zone is created in ArcGIS. Then the shapefiles created are clipped in ArcGIS with the most suitable zone layer created and the calculations for finding the maximum areas for implementing green infrastructure elements are done.

Total Area used in the analysis = 16809245 square feet.

Table 8. Table showing the maximum area for implementation of each green infrastructure element considered for potential 3

Green infrastructure elements	Estimated maximum area available (sq. ft)
Green roof	703,814
Swales	424,312
Planter box	173,543
Vegetation filter strips	424,312
Permeable sidewalk	391,375
Permeable driveway	232,393
Permeable parking	2,413,158
Rain garden	84,457

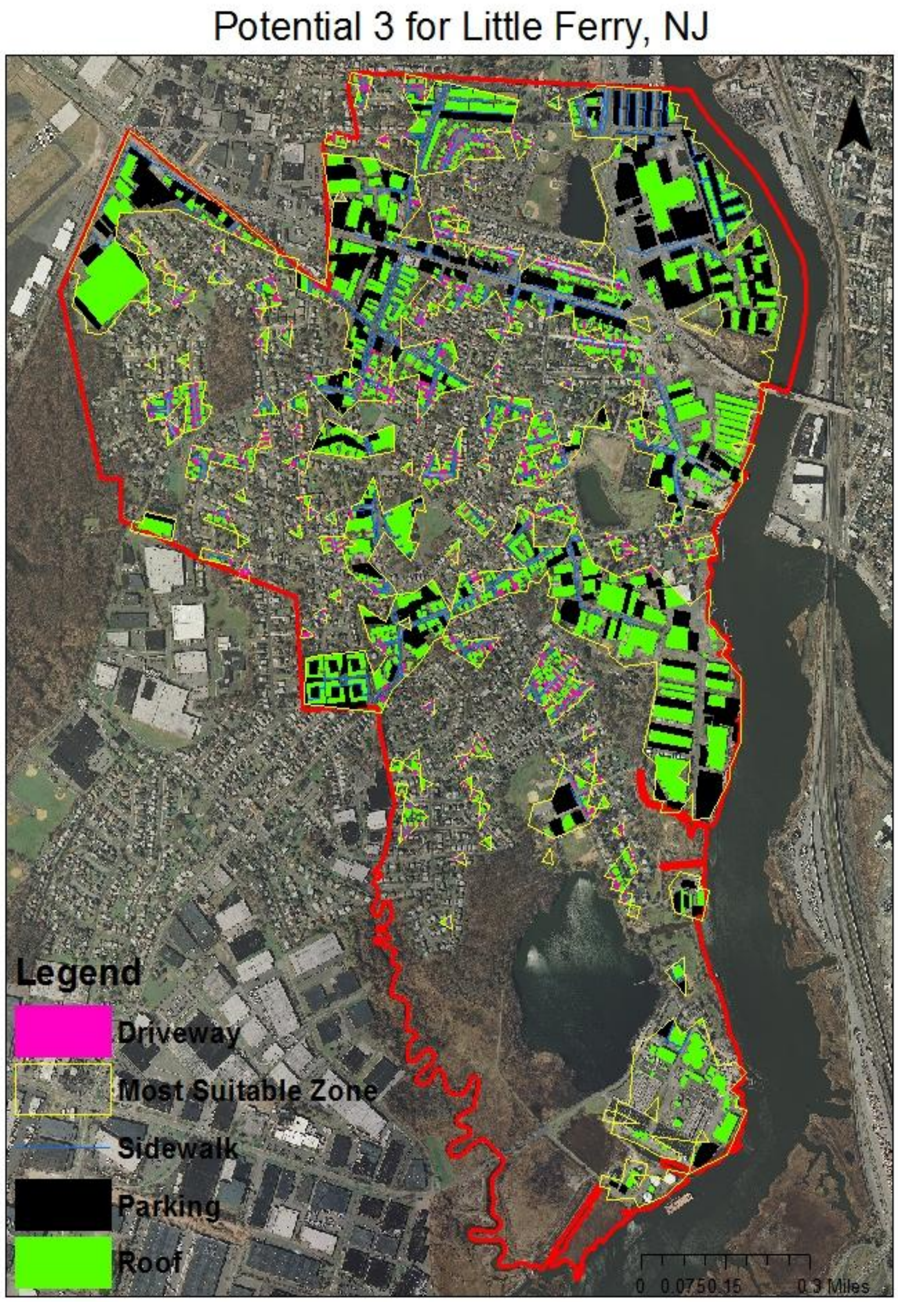

Figure 30. Map showing all the possible areas for implementation of green infrastructure elements in most suitable zone from the model

4.5. Analysis using low cost green infrastructure elements

Analysis is done for all the three potentials by using only relatively lower cost green infrastructure elements among the eight elements considered in the research. Costly elements are replaced by relatively cheaper elements which perform the same function. From Table 2 it can be observed that the green roof is the costliest element among the eight elements considered. Instead of using green roof, only rain garden and planter box are used to remove the run-off from the roof. Run-off from 50 percent of the total roof area is used for implementing rain garden and the other 50 percent is captured by planter box.

The other element which can be replaced is permeable parking. If all the parking lots are converted to permeable parking lots, the total cost will be high. Rain gardens can be used as a substitute for permeable parking. Rain garden can be used instead of permeable parking if all the run-off from the parking lot is diverted towards the rain garden. In this analysis only 50 percent of the total parking area is used for permeable parking and the other 50 percent of total parking area is used to drain into a rain garden.

The areas for implementing green infrastructure elements for all the three potentials using this analysis are given in the Table 9.

Table 9. Table showing the areas for implementing only low cost green infrastructure elements

	Estimated areas available in potential 1 (sq. ft)	Estimated areas available in potential 2 (sq. ft)	Estimated areas available in potential 3 (sq. ft)
Green roof	0	0	0
Swales	961136	826000	424312
Planter box	375907	308111	216928
Vegetation filter strips	961136	826000	424312
Permeable sidewalk	936840	788620	391375

Permeable driveway	826402	712294	232393
Permeable parking	1407452	1148852	1206579
Rain garden	267388	218878	177965

5. Results and discussions:

All the outcomes starting from the ranked maps, model, and the cost analysis for all three potentials are presented in this section.

5.1. Results for the model created:

For the model, criterions considered are ranked according to their suitability for green infrastructure.

Image shows all the different types of soil present in the Little Ferry.

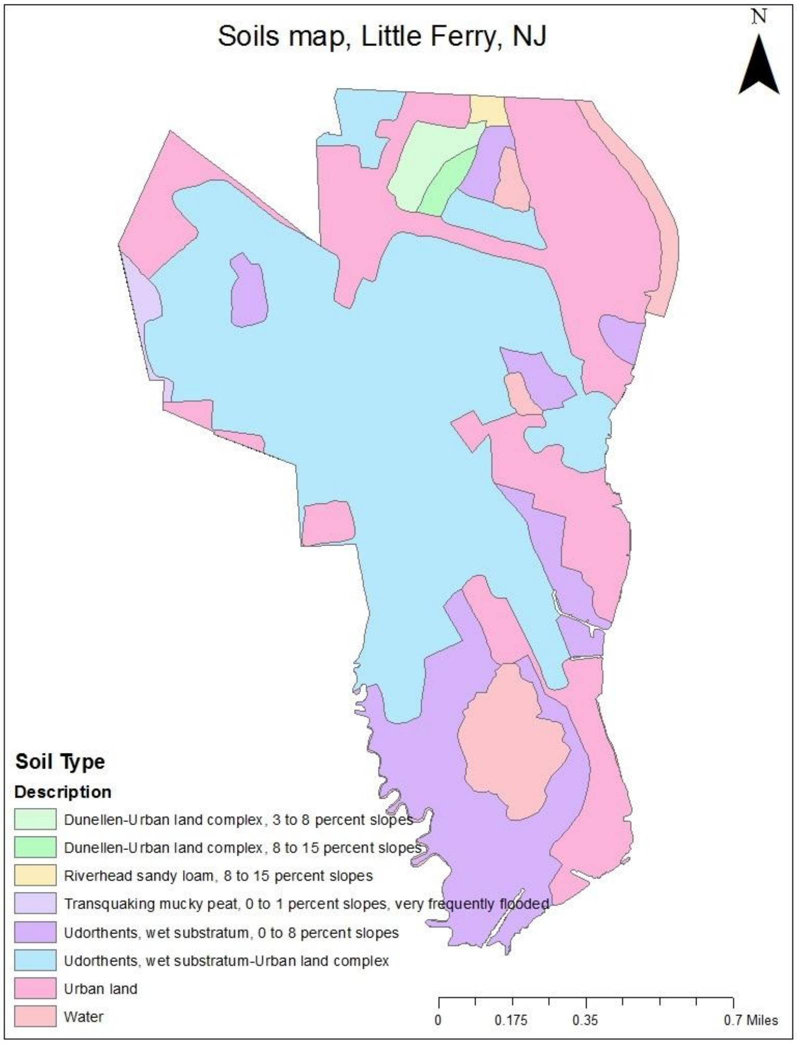

Figure 31. Map showing different types of soils present in Little Ferry, NJ

Ranks are given to each soil type based on their suitability for implementing green infrastructure. Higher rank is given to most suitable type and water is given a rank of 0.

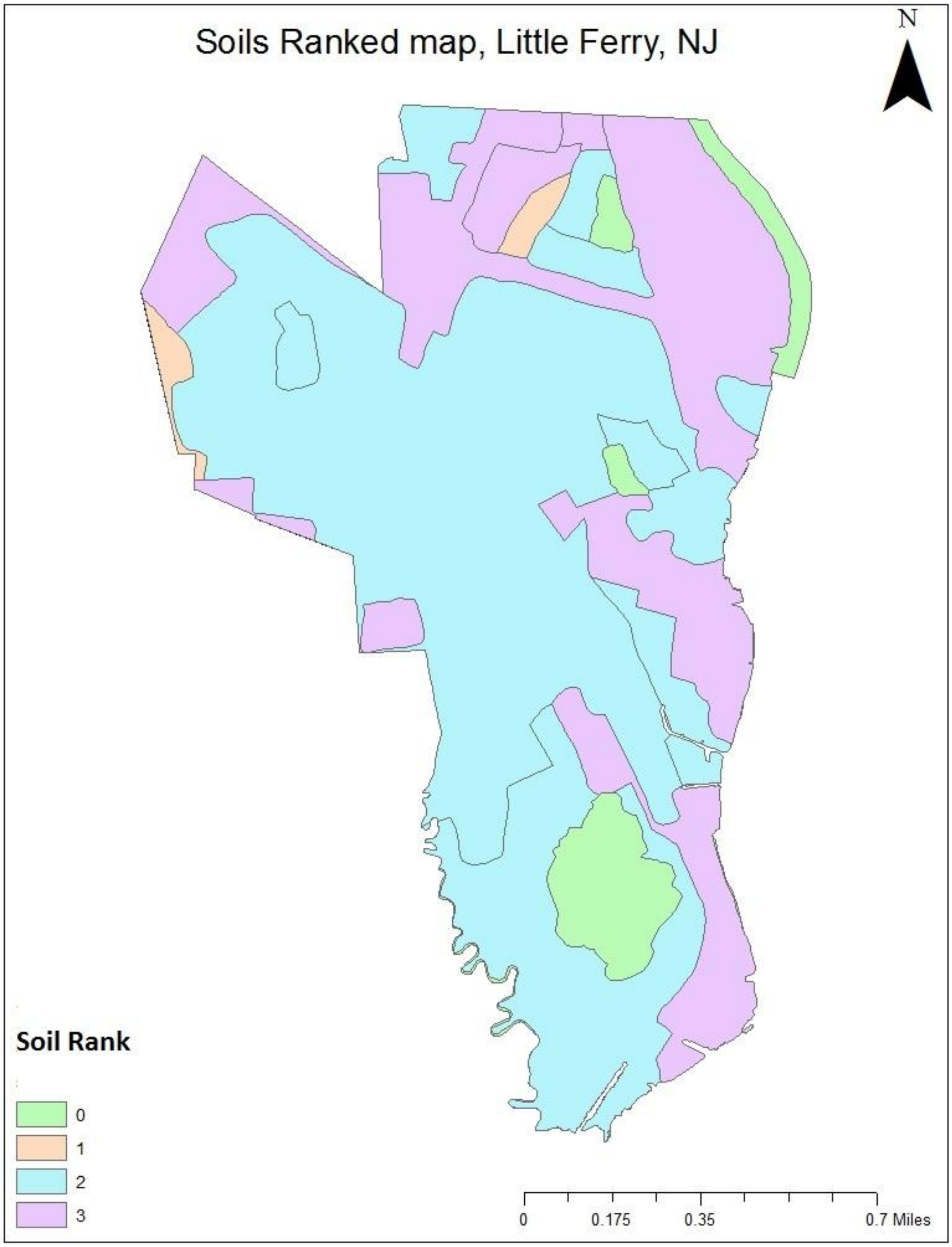

Figure 32. Map showing the soils ranked according to their suitability

Land cover map shows the type of land cover present in the area. Image below shows the different types of land cover present in Little Ferry.

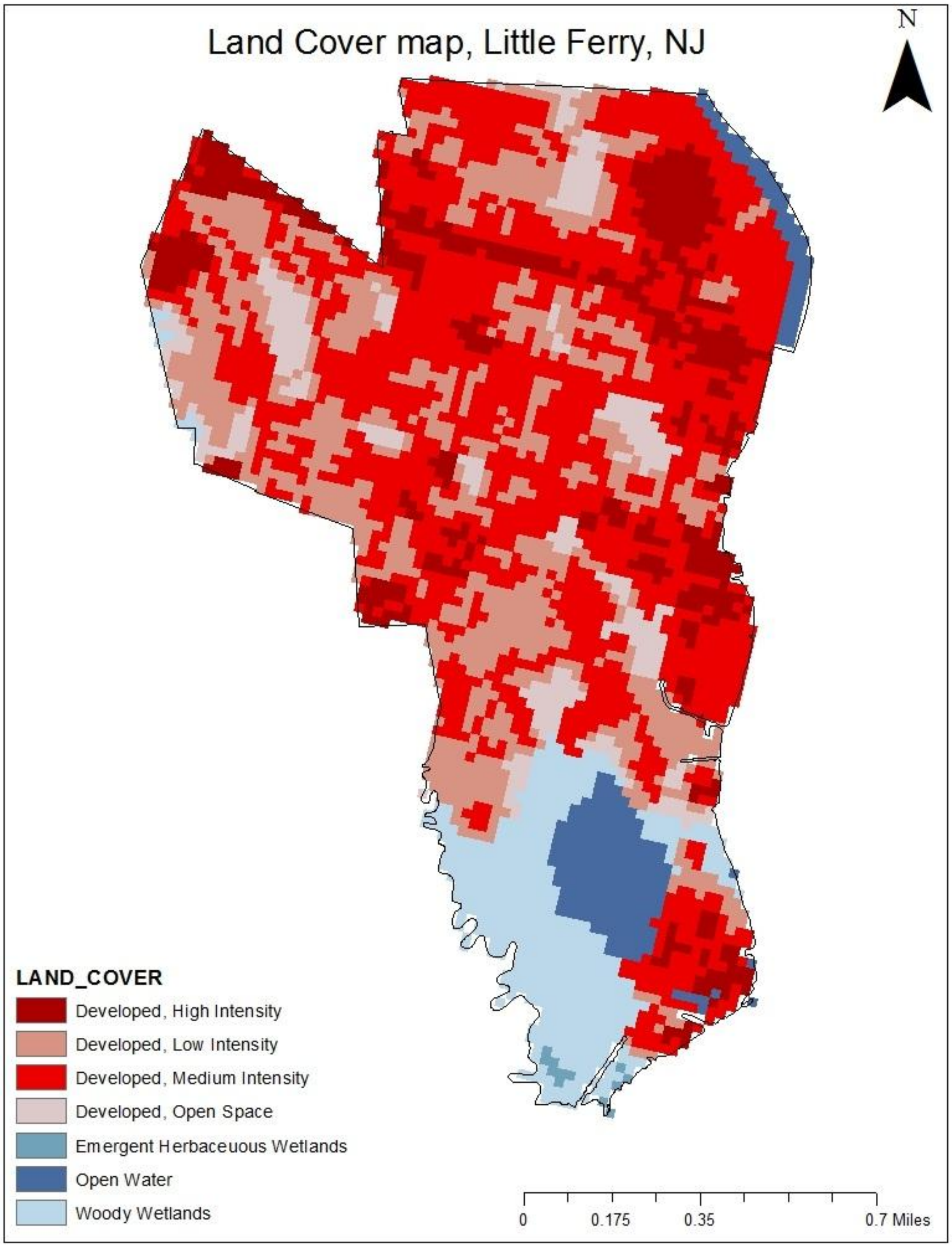

Figure 33. Map showing the land cover types present in Little Ferry, NJ

The seven classifications are ranked in the same way soils are ranked, giving higher rank for most suitable types. Water is given a rank of 0. The image below shows the ranked map for land cover.

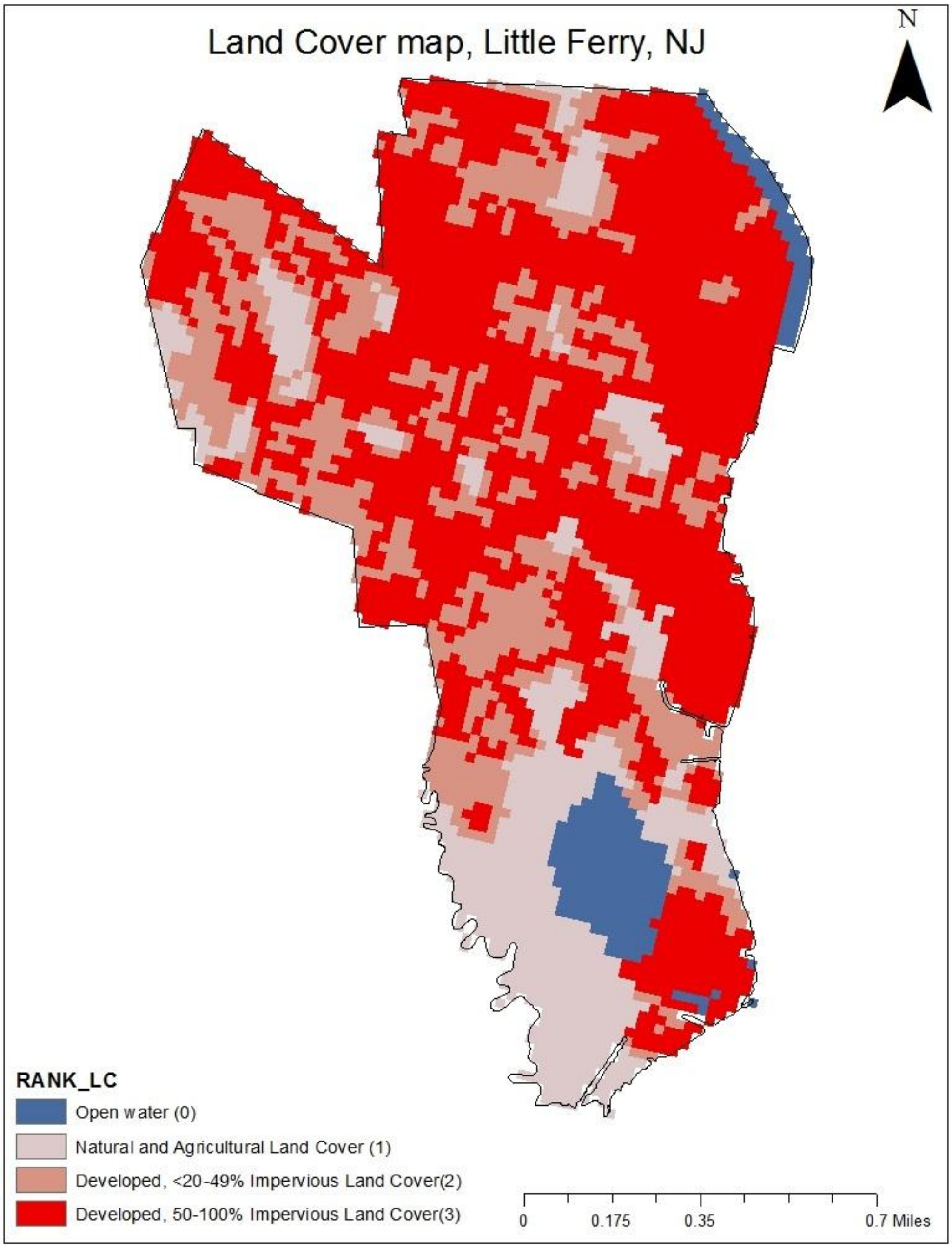

Figure 34. Map showing the land cover type ranked according to their suitability

Tree canopy map displays the percentage of tree canopy present in the area. The image below shows the percentage of tree canopy present in Little Ferry.

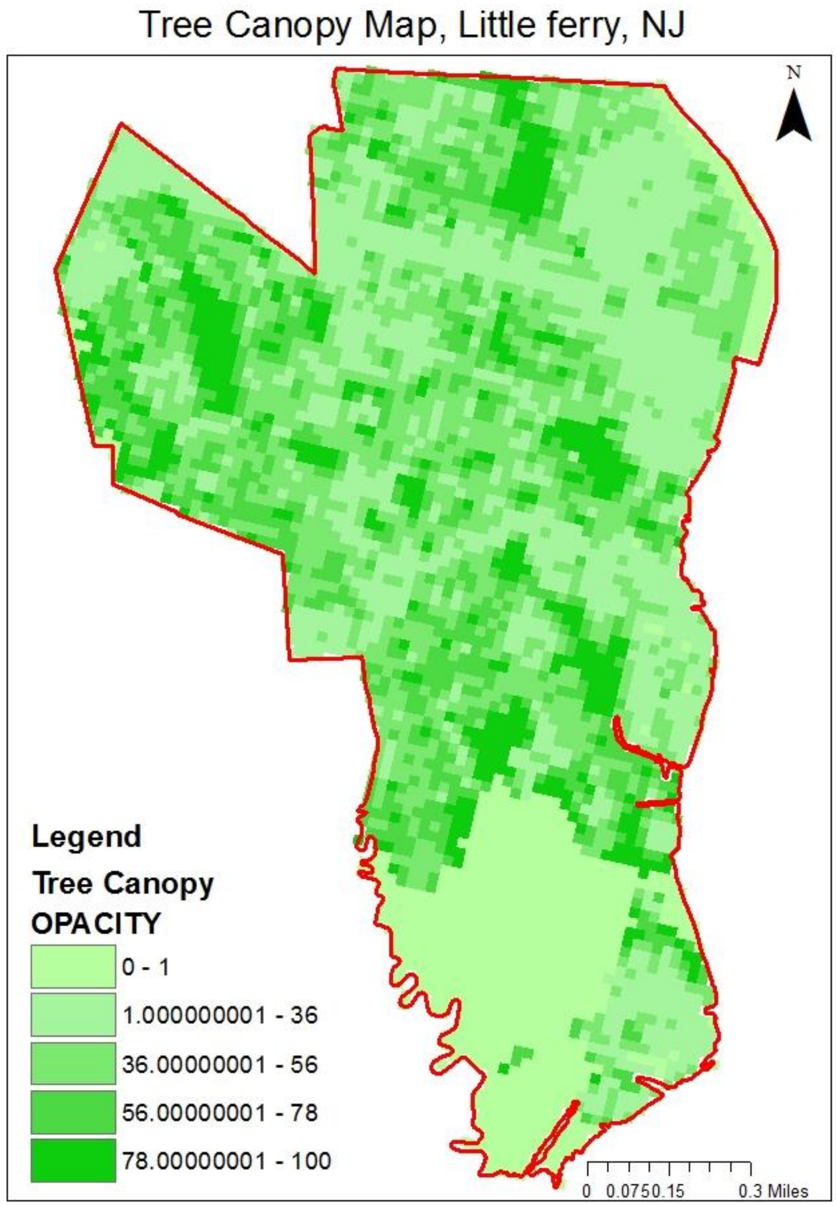

Figure 35. Map showing the tree canopy percentage in Little Ferry, NJ

Tree canopy map is ranked according to the percentage of tree canopy. Areas with less tree canopy are given a higher rank and areas with more tree canopy are ranked low.

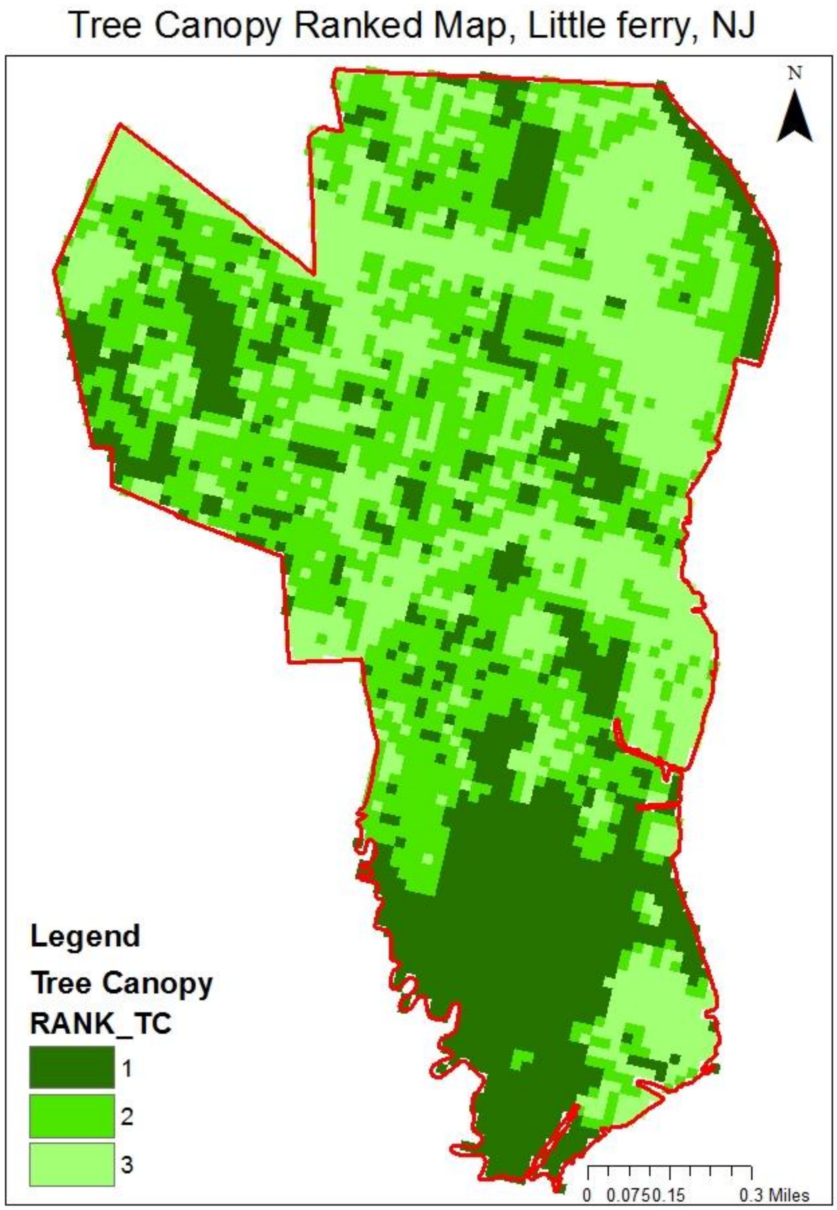

Figure 36. Map showing tree canopy ranked according to their suitability

After the model is created and executed, areas with high, medium and low suitability are obtained. The map below shows the high, moderate and low suitable areas in Little Ferry.

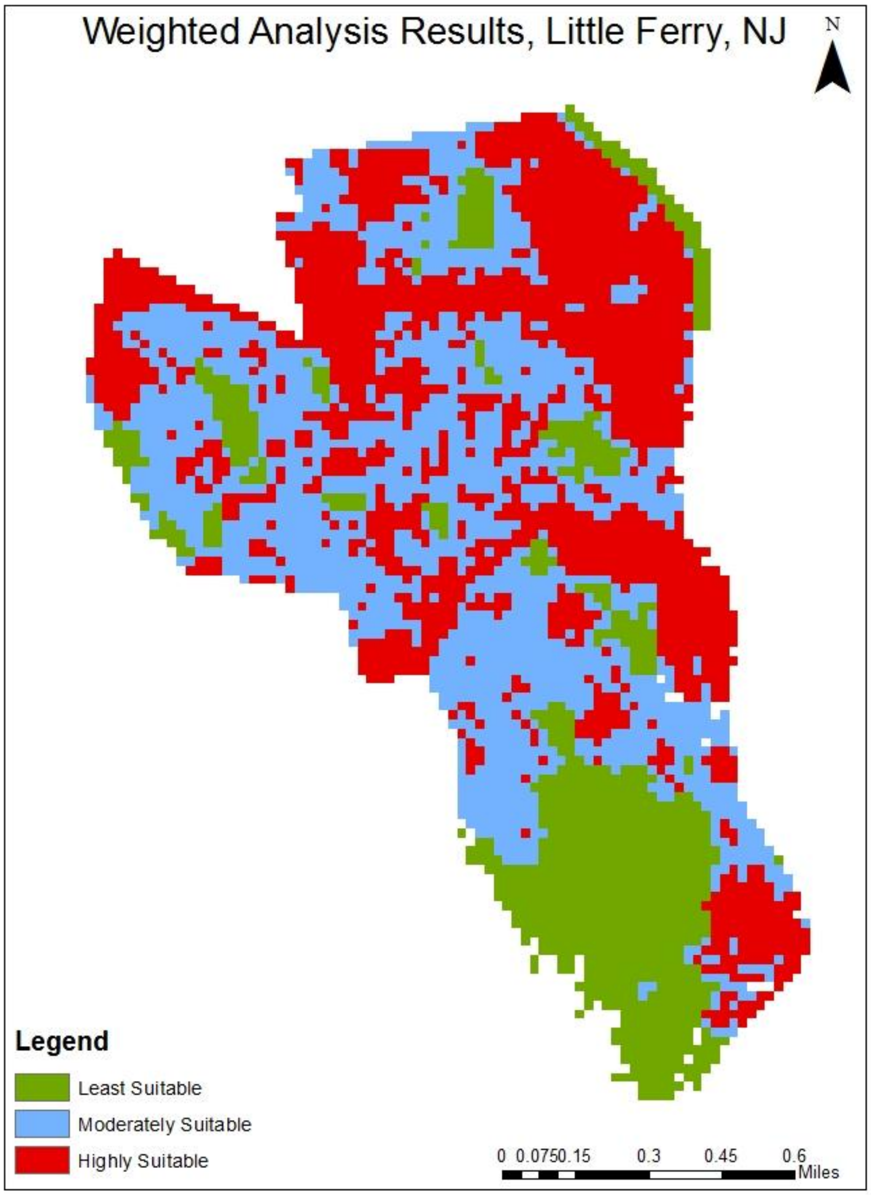

Figure 37. Map showing the results from the suitability model in raster format

The results obtained from the model are in raster format. For collecting the data for cost analysis, the raster file is concerted into vector data in ArcGIS. Below image shows the vector format of the results of model.

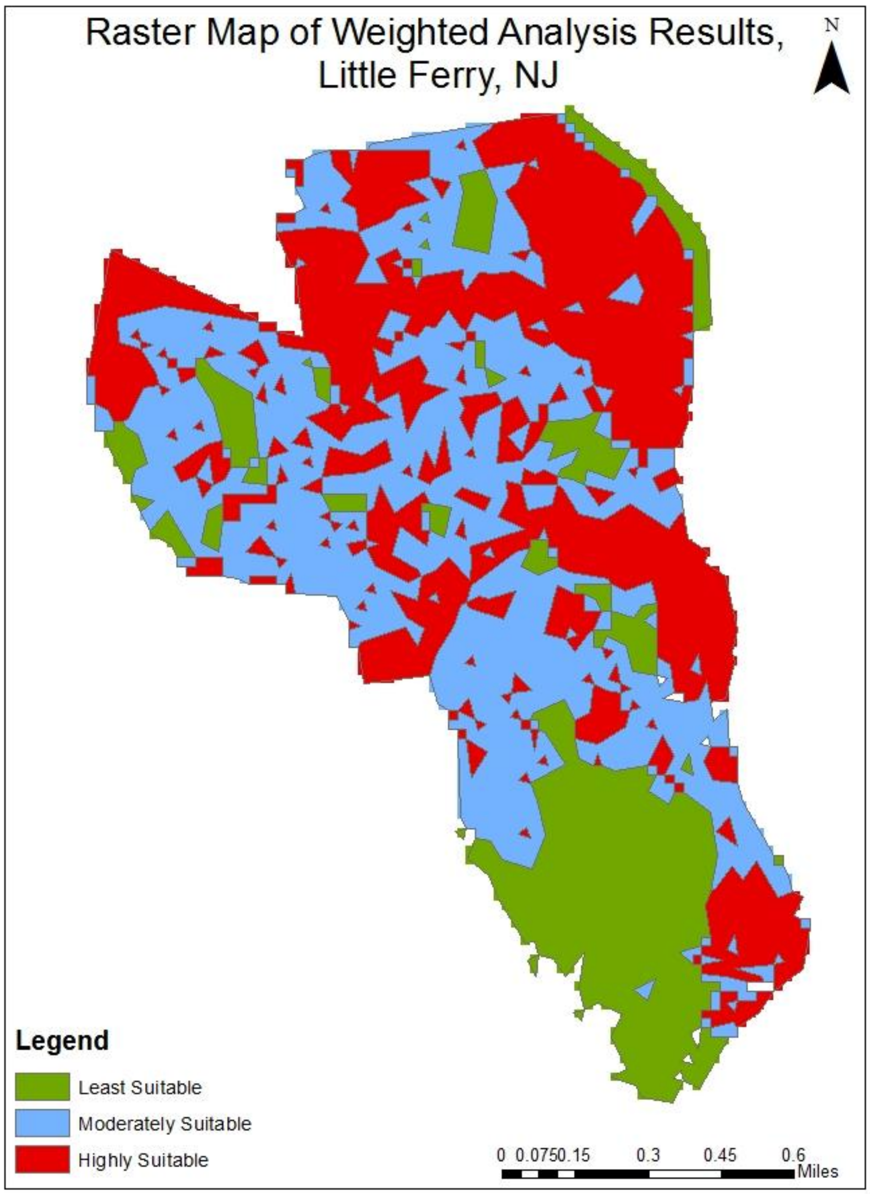

Figure 38. Map showing the vector format of the results from the suitability model

The results from the model give us the least suitable, moderately suitable and highly suitable areas where green infrastructure elements can be implemented. Most of the area in least suitable area is either water bodies or forests and wetlands present in Little Ferry. Moderately suitable area is comprised mostly of low density housing units and less developed lands whereas the most suitable area has high density and medium density residential units, commercial and industrial areas. The most suitable area is 39 percent of the total area of Little Ferry.

5.2. Results for the cost analysis considering all the green infrastructure elements

The costs for implementation of green infrastructure and the run-off that can be captured for all the three potentials are given in the Table 10.

Table 10. Table showing the results from analysis for the three potentials

	Potential 1	Potential 2	Potential 3
Total Area used for analysis (square feet)	43,360,489	37,302,234	16,809,245
Total Cost ($)	100,490,000	83,520,000	59,265,000
Runoff removal (inches)	0.834	0.808	1.275
Volume of Run-off removal(cubic feet)	3,013,553	2,511,683	1,785,982

The individual costs for all the elements considered are given in the Table 11 for all the potentials.

Table 11. Table showing the costs for implementing each element for all the three potentials

Green infrastructure element	Potential 1	Potential 2	Potential 3
Permeable Sidewalk	9,289,000	7,819,000	3,881,000
Permeable Parking	27,911,000	22,783,000	23,927,000
Permeable Driveway	8,194,000	7,063,000	2,304,000

Swale	16,620,000	14,283,000	7,337,000
Planter Box	6,824,000	5,594,000	3,938,000
Rain Garden	2,526,000	2,070,000	1,458,000
Green Roof	26,299,000	21,478,000	15,172,000
Vegetative Filter Strip	2,827,000	2,430,000	1,248,000
Total ($)	100,490,000	83,520,000	59,265,000

The results from the analysis gives the costs for implementation of green infrastructure for the three potentials considered. The cost for potential 3, which is implementing green infrastructure in the best suitable zone from the suitability model, is almost 60% of the first potential which is implementing green infrastructure for the whole town. As the cost for implementing green infrastructure in the whole town is almost around 100 million dollars, it is relatively tough for a municipality to invest such huge amounts at a time. Hence, the implementation of these green infrastructure strategies can be done in different stages. Starting with implementing the green infrastructure elements in the areas under potential 3 or in the areas which get flooded frequently, and then expanding it to areas in 100 year flood zone, and then to the remaining areas in the town.

The run-off removal is the total amount of run-off captured by the green infrastructure elements when implemented. It not only depends on the areas of the green infrastructure elements but also depends on the total area under the potential. The high run-off removal in potential 3 is because of less area under the potential.

5.3. Results for the analysis done using low cost green infrastructure elements

From the results above (Table 9) it can be observed that permeable parking and green roof together account for almost 50 percent of the total cost. A separate analysis is done by replacing costly green infrastructure elements with less cost elements which can serve the same function. The results for this analysis are showed in Tables 12 and 13.

Table 12. Table showing total costs and run-off removal for the three potentials

	Potential 1	Potential 2	Potential 3
Total Area used for analysis (square feet)	43,360,489	37,302,234	16,809,245
Total Cost ($)	63,862,000	53,758,000	34,680,000
Runoff removal (inches)	0.617	0.603	0.866
Volume of Run-off removal(cubic feet)	2,229,451	1,874,437	1,213,067

Table 13. Table showing the costs for implementing low cost green infrastructure elements for all the three potentials

Green infrastructure element	Potential 1	Potential 2	Potential 3
Permeable Sidewalk	9,289,000	7,819,000	3,881,000
Permeable Parking	13,955,000	11,391,000	11,964,000
Permeable Driveway	8,194,000	7,068,000	2,304,000
Swale	16,452,000	14,280,000	7,288,000
Planter Box	8,530,000	6,992,000	4,923,000
Rain Garden	4,615,000	3,778,000	3,072,000
Green Roof	0	0	0
Vegetative Filter Strip	2,827,000	2,430,000	1,248,000
Total ($)	63,862,000	53,758,000	34,680,000

A significant reduction in the total costs can be observed when green roofs and permeable parking is replaced by less costly elements. But the maximum amount of runoff that can be removed is reduced by doing so.

Comparison of total costs and run-off removal for these two scenarios for all the three potentials is given in the Table 14.

Table 14. Table showing the costs and run-off reduction for all the three potentials for implementing all the elements and only low cost elements instead of green roof and permeable parking

	Potential 1	Potential 2	Potential 3
Total cost for implementing all the GI elements ($)	100,490,000	83,520,000	59,265,000
Total cost for implementing low cost elements instead of green roof and permeable parking ($)	63,862,000	53,758,000	34,680,000
Runoff reduction by implementing all the GI elements (inches)	0.834	0.808	1.275
Runoff reduction by implementing low cost elements instead of green roof and permeable parking (inches)	0.617	0.603	0.866

Based on the deciding factors like cost or run-off removal, a municipality can achieve a significant reduction in run-off by implementing some or all of these green infrastructure elements in a municipal scale. Municipalities which have more localized flooding even for small rainfall events and municipalities with combined sewer system where there is a chance for run-off to combine with sewer waste should focus on maximum run-off removal. For municipalities which have flooding problems only during heavy rainfall events can opt for low cost green infrastructure elements. If all the new developments across the United States include green infrastructure in their design, not only flooding problems will be reduced but also the natural hydrologic features will not be disturbed.

6. Conclusions

The primary purpose of this thesis is to create a practical methodology for implementing green infrastructure on a municipal scale. This thesis gives an insight into the techniques which can be implemented on a large scale over a municipality. This research helps in finding the areas where some of the green infrastructure elements can be implemented and also helps in finding the costs associated in implementing them.

The model developed as a part of potential 3 will serve as a key tool for finding the areas which are most suitable for implementing green infrastructure elements in a municipality. Though the model uses only some of the key criteria for green infrastructure implementation, it provides an insight for the practitioners, planners and the residents an insight on the suitable locations for green infrastructure implementation in their municipality.

Also the benefit of applying these green infrastructure elements is given in the form of run-off removal. The total volume of run-off reduced over the total area can be calculated with this data which will help the community planners and designers in designing any flood control structures in the municipality.

Overall, this thesis helps in deciding the types of green infrastructure elements to be implemented based on the limitations of budget, the amount of run-off removal required to reduce flooding or the area available for implementing green infrastructure elements.

7. Scope for future work

The scope for future work mostly lies with the development of the model. In the suitability model developed only soil type, land cover and tree canopy were used. Several other important factors like ground water level, proximity from the foundation of structures, public owned or privately owned land, etc., will make an important criterion in suitability model. Also socio-economic factors like minority and poverty status, emerging issues of climatic variability like urban heat island effect can also be incorporated to the model. Due to limitations in data acquisition, time, resources, etc., these factors could not be incorporated into the model developed in this research. The model can be made more comprehensive with incorporating these factors as criterion for the model.

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Appendix A – Sample Calculations

Calculations done to find areas under potential 1 for implementation of green infrastructure elements:

Green roof = Total roof area * 20% (only 20 percent of total roof area is used for green roof)

= 6098060 sq. feet * 0.2

= 1219612 sq. feet

Rain Garden = Total roof area * 40% (run-off from 40 percent of the roof area is used) * 6% (6 percent of the contributing roof area is the size of rain garden)

= 6098060 * 0.4 * 0.06

= 146353 sq. feet

Planter Box = Total roof area * 40% (run-off from 40 percent of the roof area is used) * 216/1752 (area of planter box is 216 sq. feet for every 1752 sq. feet of roof area)

= 6098060 * 0.4 * 216/1752

= 300726 sq. feet

Permeable Driveways = Total area of permeable driveways present in the study area

= 826402 sq. feet

Permeable parking = Total area of parking lots present in the study area

= 2814905 sq. feet

Permeable Sidewalk = Total length of sidewalk present in study area * 5 Feet (assumed uniform width of sidewalk)

= 187368 * 5

= 936840 sq. feet

Swale = Length of road network * 80% (swales are installed by the side of only 80 percent of the road

network) * 10 feet (width of the swale considered)

= 120142 * 0.8 * 10

= 961136 sq. feet

Vegetative filter strip = Total length of road network * 20% (vegetative filter strips are installed by the side of only 20 percent of the road network) * 40 feet (width of vegetative filter strip considered)

= 120142 * 0.2 * 40

= 961136 sq. feet