

University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

---

Community and Regional Planning Program:  
Student Projects and Theses

Community and Regional Planning Program

---

2012

## Creation of a GIS Based Model for Determining the Suitability of Implementing Green Infrastructure: In The Town Of Berlin Maryland

Ronald A & W Marney

University of Nebraska - Lincoln, ronald@huskers.unl.edu

Follow this and additional works at: [https://digitalcommons.unl.edu/arch\\_crp\\_theses](https://digitalcommons.unl.edu/arch_crp_theses)



Part of the [Urban, Community and Regional Planning Commons](#)

---

Marney, Ronald A & W, "Creation of a GIS Based Model for Determining the Suitability of Implementing Green Infrastructure: In The Town Of Berlin Maryland" (2012). *Community and Regional Planning Program: Student Projects and Theses*. 14.

[https://digitalcommons.unl.edu/arch\\_crp\\_theses/14](https://digitalcommons.unl.edu/arch_crp_theses/14)

This Article is brought to you for free and open access by the Community and Regional Planning Program at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Community and Regional Planning Program: Student Projects and Theses by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

**Creation of a GIS Based Model for Determining the Suitability of Implementing Green  
Infrastructure: In The Town Of Berlin Maryland**

By

Ronald Marney

A Thesis

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Community and Regional Planning

Major: Community and Regional Planning

Under the Supervision of Professor Yunwoo Nam

Lincoln, Nebraska

May, 2012

**Creation of a GIS Based Model for Determining the Suitability of Implementing Green  
Infrastructure: In The Town Of Berlin Maryland**

Ronald Marney, M.C.R.P.

University of Nebraska, 2012

Advisor: Yunwoo Nam

This project is entitled "Incorporation of Green Infrastructure Into Comprehensive Storm Water Management and the Effective Utilization of LiDAR: In the Town of Berlin ". The goal of this research was the creation of a Geographic Information System (GIS) based model for determining the suitability / feasibility of green infrastructure implementation, as defined by this study, within the study area. This model was only applicable for the identified elements or tools under green infrastructure as defined by this study. This enabled clear and concise definitions and more readily identified the criteria and their parameters. The scope of the model's applicability is limited to municipal level or larger scales with the data and nature of the analysis being unsuited for site level analysis. The model was successful in determining the areas of probable suitability for green infrastructure implementation. It was found that the study area on average had a medium to high potential for green infrastructure implementation. The model and its resulting products led to implications for better incorporation of green infrastructure into planning. The model also represented an excellent tool for education of the general public on green infrastructure, its concepts, implementation, and potential for debunking myths on its drawbacks. The model also allowed easier adaptation for the municipality and for other similar communities wishing to implement comparable policies.

## Table of Contents

<b>Chapter 1: Introduction.....</b>	<b>5</b>
1.1 Establishing Need & Relevance	5
1.2 Objective of Research	7
1.3 Research Statement	9
1.4 Contents of Thesis	9
<b>Chapter 2: Identification and Review of Key Topics and Concepts..</b>	<b>11</b>
2.1 Identifying the Study Area the Town of Berlin in Detail	11
2.2 Suitability Study Descriptions and Comparisons	18
2.3 Feasibility Vs. Suitability and the Flaws of Current Feasibility Studies	29
2.4 Storm Water Management Descriptions and Identification of Systems	34
2.5 Green Infrastructure it's Definition, Tools, Methods, and Relevance	36
2.6 LIDAR it's Definition, Components, and Products	43
<b>Chapter 3: Methodology.....</b>	<b>54</b>
3.1 Data Collection	54
3.2 Data Formatting	55
3.3 Selection of the Criteria	55
3.4 Conducting the Analysis	62
<b>Chapter 4: Analysis.....</b>	<b>65</b>
4.1 Establishing Parameters	65
4.2 Ranking the Criteria	67

4.3 Weighting the Criteria	68
4.4 The Model	69
<b>Chapter 5: Results</b> .....	72
5.1 Maps and Their Descriptions	72
<b>Chapter 6: Conclusion</b> .....	86
6.1 Conclusion and Implications	86
6.2 Limitations of the Study & Possible Future Research	88
<b>Bibliography</b> .....	92

## Chapter 1

### Introduction:

#### 1.1 Establishing Need & Relevance

Natural hazard mitigation has been a part of society throughout history. These hazards are still a threat to the world's population, so much so that an estimated one million people die of natural disasters each year (Randolph, 2004). The United States Government spent 39 billion dollars in disaster assistance from 1990 to 2002 (Randolph, 2004). Flooding in particular is an area of concern for the United States. Flooding is our Nation's number one natural disaster and fully one quarter of all flood claims come from areas of low or moderate flood risk (FEMA, 2007). With flooding and its mitigation having such a prominent position research and new strategies for handling these disasters are of extreme importance.

The study area for the project is the Town of Berlin Maryland. The town is located in Worcester County on Maryland's eastern shore. The study area is extremely flat coastal plain and is susceptible to flooding. Flooding particularly due to large rain events is a major concern. The Town of Berlin has experienced flooding in the Bottle Branch, Hudson Branch, and Kitts Branch watersheds for years and flooded streets and neighborhoods are a relatively common occurrence (Army Corps of Engineers, 2007). Maryland as a whole faces the potential of \$8.12 Billion in damages in the event of a 100-Year Flood (Maryland Department of Environment, 2005). According to the Maryland Department of Environment Worcester County has the highest vulnerability to flooding in the State (Maryland Department of

Environment, 2005). Flooding is also a risk beyond established FEMA 100 year floodplains (FEMA, 2007). The town also has significant historic value and plays a role in the area's tourism. The risk of flooding and the town's historic value combine to make the issue of storm water management extremely important.

The other major factor affecting the area is its proximity to environmentally sensitive water bodies and areas that are protected by State and Federal laws. All runoff in the town of Berlin either drains into a protected coastal bay or the protected Chesapeake Bay. Maryland's coastal bays are managed by the Maryland Coastal Bays Foundation and consist of the Isle of Wight, Assawoman, Sinepuxent, Newport and Chincoteague Bays (Maryland Coastal Bays program, 2012; EPA, 2011). They also include the 23 creeks and tributaries that feed the bays, which is Berlin's connection to these sensitive environments (EPA, 2011). The total area covered under the program is 175 square miles (EPA, 2011). One of the main concerns for these sensitive lands under this program is excessive nitrates and other pollutants from runoff (EPA, 2011). The Chesapeake Bay similarly managed by the Chesapeake Bay Foundation as well as relevant State and Federal programs (Chesapeake Bay Foundation, 2011). The Chesapeake also faces similar pollution issues but do to the size and location of the bay also faces Combined Sewer Overflows [CSO's] (Chesapeake Bay Foundation, 2011). Urbanization anywhere increases the variety and amount of pollutants carried into water bodies across the United States. These pollutants come from the land conversion in urban and suburban areas, because these conversions result in more impervious surface and thus less natural filtration and infiltration of water (EPA, 2011). This means the

inclusion of efforts to reduce pollution and runoff are necessary in the study area and are issues faced by all communities.

The Town of Berlin is further at risk due to its size. Berlin is classified as a rural town. The United States Census Bureau classifies all places with populations under 2,500 as rural and all places above as urban. The smaller a community's population, the less human and monetary capital it will have available to put to use. No rural community like Berlin or of comparable size and nature would be able to provide the level of services such as public transportation, grounds keeping, etc. seen in larger municipalities such as New York City. This small size is reflected in their level of influence and the care given to them. The small stature of a town means it has little clout to effect change or garner attention in larger political arenas. So while extensive research and concern is applied to cities or larger regions or counties little of the necessary site level work or research needed for meaningful understanding and planning of towns is nonexistent due to an out of sight out of mind attitude. These specific and stringent issues and needs readily establish the necessity and relevance of the research.

### 1.2 Objective of Research

In order to address the issues discussed the use of green infrastructure is needed. Green infrastructure is not new as a concept or practice. Suitability and feasibility studies are also not a new concept but the methods applied to them for this topic differs greatly from those in this research. Current suitability studies, such as those covered in this study: the State of Maryland, Kent County Delaware, Central



New York, and Omaha Nebraska, vary in methods and criteria. Current feasibility studies, such as those covered in this study: River Dee, City of Camden, and Bridgeport & New Haven, seem to not address actual technical or structural necessities of green infrastructure but rather address perception, public and private opinion, and cost benefit analyses. This has been an issue across many fields recently where feasibility studies are not addressing actual technical feasibility (Pincock, 2004). What this means for this research is that there is a gap in addressing aspects of feasibility such as if a project or concept is capable of being implemented based on its physical needs. What is unique about this thesis is that rather than focusing on the traditional criteria an additional criterion (depth to ground water) has been added into the model based on the technical requirements of the identified green infrastructure tools, seen on page 38, found in research.

The goal of this research is to create a Geographic Information System (GIS) based model for determining the suitability or technical/ scientific feasibility of green infrastructure implementation as defined by this study. Green infrastructure has been defined as systems that mimic natural processes in order to infiltrate, evaporate, and/or reuse storm water (Environmental Science and Forestry, 2012). This will identify where the defined green infrastructure elements will work based on technical requirements. In terms of scope of the applied criterion the emphasis is on technical requirements but also on a modest level incorporates perception and other social factors through the land-use and public versus private land criteria. While social aspects are considered they are not central to the scope of this study. This comparative lack of social elements or criteria within the study is a limiting

factor but the nature of the model enables their possible inclusion or consideration in future research.

It was also the goal of the study to provide a basis or framework for other municipalities to do similar changes or upgrades to their storm water management / infrastructure. The model will be applied in the Town of Berlin, Maryland. While the intended scale of the model and study was the municipal level it can be applied to larger areas. The scope of the model's applicability is limited to municipal level or larger scales though. This is because with the type and quality of the data and by the nature of the analysis the model is unsuited for site level analysis.

### 1.3 Research Statement

This research has developed a GIS based model for determining the suitability of green infrastructure based on the traditional criteria of soil, slope, proximity to buildings as well as the unique criterion of depth to round water along with land use and private versus public property.

### 1.4 Contents of Thesis

This research paper is broken into six chapters each with it's own subsections. The first chapter is the introduction. This will provide the background and the hard facts and definitions for the basis of the analysis. The introduction sets up the basis for the study including the research statement and establishment of relevance and need for the research. The second chapter is Identification and Review of Key Topics and Concepts. The subsections for the chapter are Identifying the Study Area the Town of Berlin in Detail, Suitability Study Descriptions and Comparisons, Feasibility Vs. Suitability and the Flaws of Current Feasibility Studies,

Storm Water Management Descriptions and Identification of Systems, Green Infrastructure it's Definition, Tools, Methods, and Relevance, and LIDAR it's Definition, Components, and Products. These will define and review the topics providing the knowledge base for the rest of the study. Chapter three is the methodology. The subsections for the chapter are Data Collection, Data Formatting, and Conducting the Analysis. This chapter covered the specifics of how the study was conducted. Chapter four is the analysis. The subsections are Establishing Parameters, Ranking the Criteria, Weighting the Criteria, and The Model. This chapter shows the actual analysis and described it as well. Chapter five is Results. This chapter presented and described the map products. Chapter six is the conclusion and is the final chapter. It covers the summation of the research, its weaknesses, and possible future research. The final portion of the thesis is the bibliography citing all used sources.

## Chapter 2

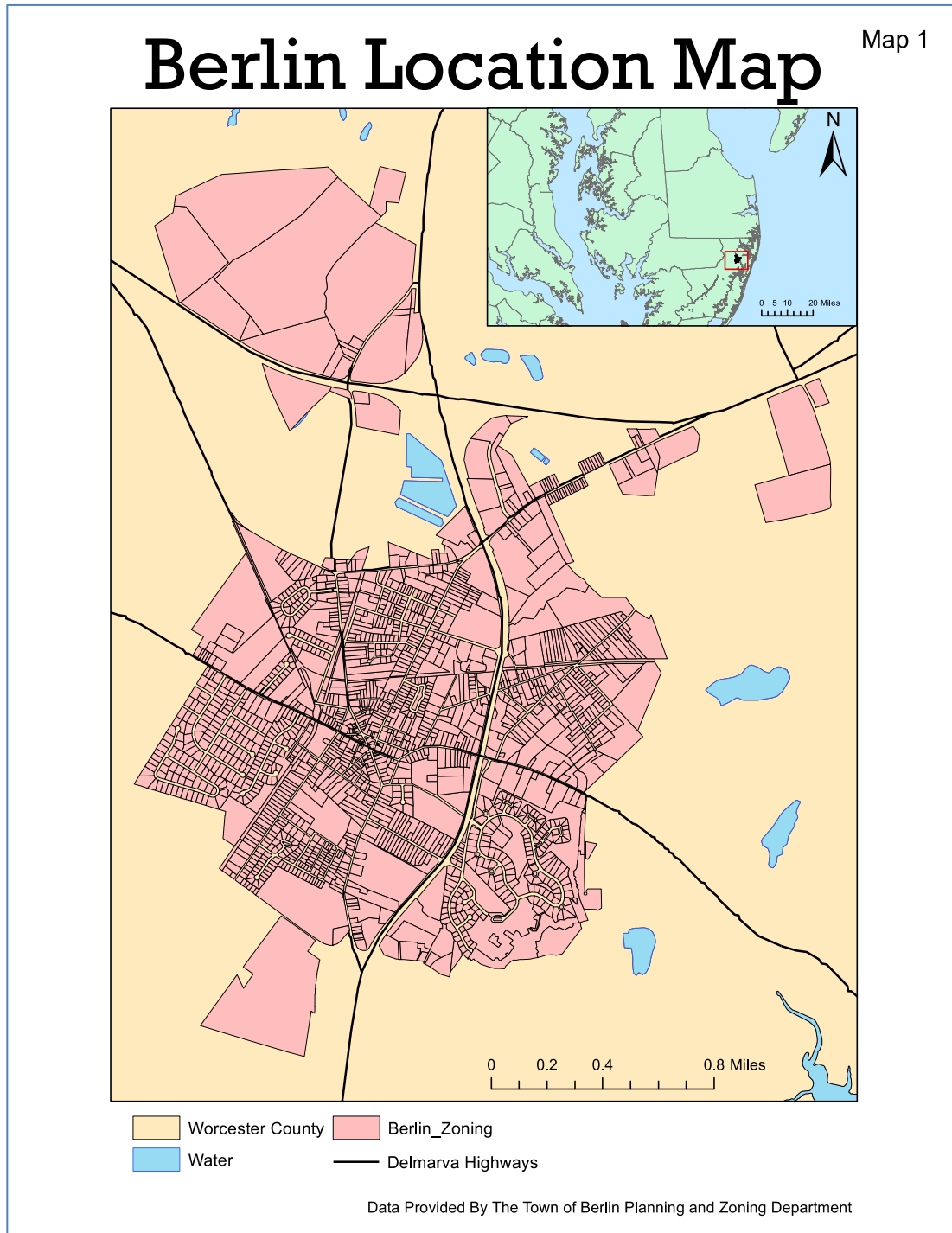
### Identification and Review of Key Topics and Concepts:

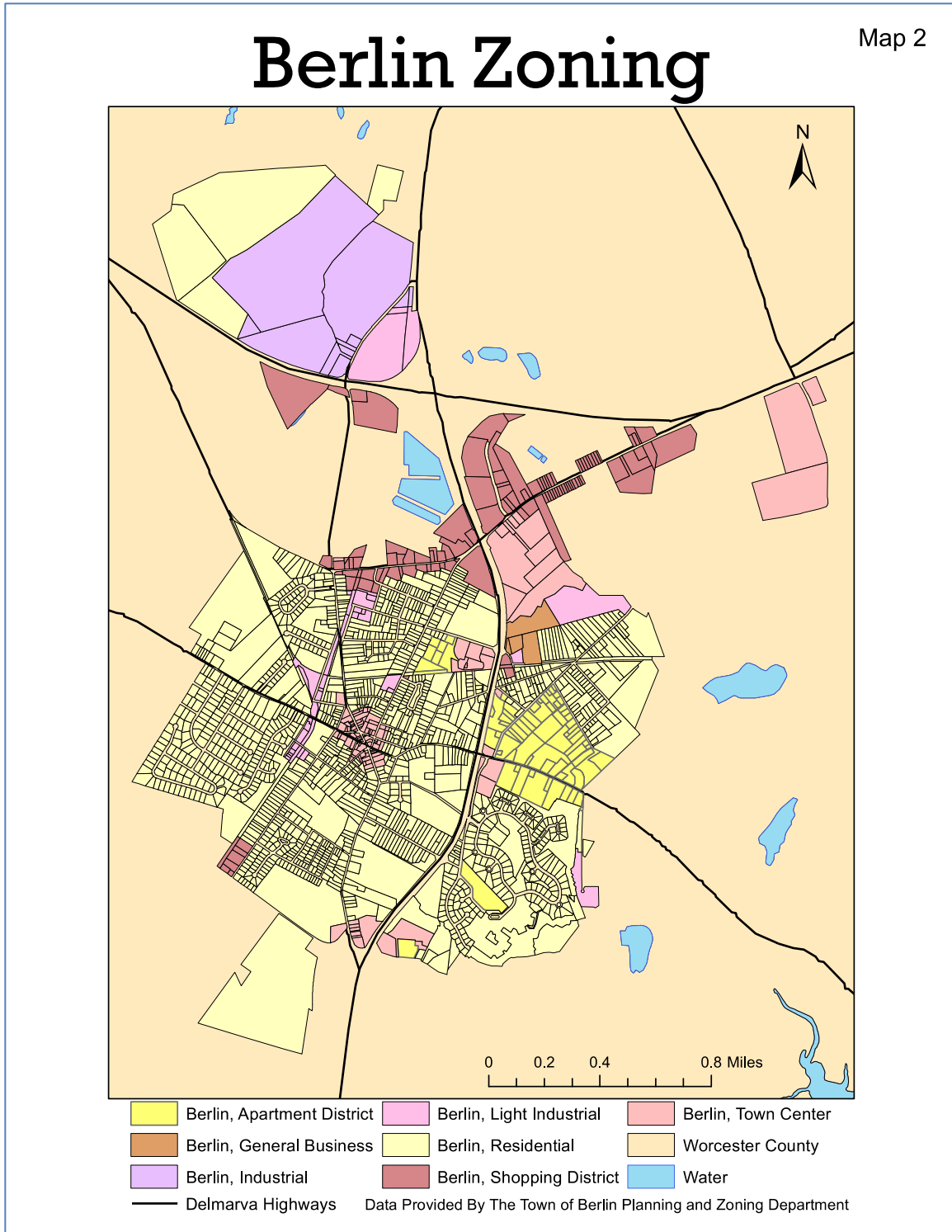
In research a strong knowledge base is necessary to carry out any effective analysis or reach a meaningful conclusion. To this end for this study a brief definition and review of the pertinent topics has been done. The topics covered are done in separate sections of which there are five. These are Storm Water Management, Green Infrastructure, Feasibility Studies, LiDAR, and The Town of Berlin. This portion of the thesis provided the fundamental knowledge and forms the base for the rest of the study.

#### 2.1 Identifying the Study Area the Town of Berlin in Detail

The study area for the project is the Town of Berlin Maryland. The town of Berlin is located in Worcester County, Maryland on what is referred to as the lower Eastern Shore. The study area and it's location is easily delineated in the Location Map (Map 1) bellow. The town has significant historic value and plays a role in the area's tourism. This historic tourism is the major component to the town's economy; coupled with some service-based industries, light industrial, and agriculture. Berlin's zoning consists of Apartments, General Business, Industrial, Light Industrial, Residential, and Town Center, which can be seen in the Town Zoning Map (Map 2) bellow. Of the town's housing 86.4 % is occupied leaving only 13.6 vacant (Cubit, 2012). This vacancy while high does not detract from the physical character of the town since the passing of various maintenance ordinances controlling lawn care and

management of vacant properties. With the physical aspects of Berlin covered the human / demographic may be examined.





Berlin has ample human capital for a town of its size. According to the 2010 Census Berlin has a population of 4,485 people. The populations age break down

was reported as follows 15.1 % under the age of ten, 12.4 % ages 10-19, 12.1 %ages 20-29, 12.5 % ages 30-39, 13 % ages 40-49, 12.2 % ages 50-59, 9.4 % ages 60-69, and 13.4 ages 70 and over (Cubit, 2012). Berlin contains a relatively even distribution for its population's ages. Race was found to have a less even distribution with 66.5 % of the population being white, 23.2 % black, and the remaining 10.3 % being a mix of other races (Cubit, 2012). While the town's current attributes are significant to the research a majority of Berlin's since of place, cultural identity, and intrinsic value are tied to its history, because of this it is necessary to briefly review this important aspect of the town.

The Town of Berlin has a rich history reaching back 331 years. The majority of the town is built on a tract of land called Burley (Hammond, 2008). Burley was 300 acres of land out of 1,350 acres, which was deeded, to Colonel William Stevens by King Charles II on June 22<sup>nd</sup>, 1677 (Taylor, 2007). The 300 acres then known as Burley was in turn assigned to William Tomkins and was patented July 12<sup>th</sup>, 1683 (Taylor, 2007). The inn in Burley gave the area its name , which was eventually shortened to Burlun and with time obtained the modern pronunciation of Berlin (Hammond, 2008).

Berlin was incorporated as a town by the State of Maryland in 1868 (Taylor, 2007). The newly incorporated Town of Berlin's first Mayor was Dr. John Pitts. Through the remainder of the 17<sup>th</sup> century after the patenting of Burley and into the 18<sup>th</sup> century the Berlin along with most of the surrounding area was primarily agricultural with farms and plantations in abundance (Taylor, 2007). The Town's inn and location made it a popular (Taylor, 2007). This status as a crossroads gained

the Town a railroad station in the 19<sup>th</sup> century (Taylor, 2007). With this tie in to the rail way the town became a rail junction for the North - South line, the Breakwater, Frankford, Worcester Rail Road, and the East - West line, the Wicomico and Pocomoke Rail Road (Taylor, 2007). The laying of the railroads transformed Berlin into "the hub" of Worcester County (Hammond, 2008). With the railroad tie in the town became a shipping center for the area and served to export the areas agricultural products and to import produced goods (Taylor, 2007). This economic growth facilitated the developed Berlin's downtown from a few sparse buildings into a "true Main Street" (Hammond, 2008). Berlin's downtown area suffered three devastating fires in 1895, 1902 and 1904 (Taylor, 2007). The first fire in 1859 was so devastating that the entire downtown was burned to the ground facilitating the mandate that all buildings within town limits be built of stone or brick.

Berlin's place as "the hub" of Worcester County continued into the 20<sup>th</sup> century until the arrival of the modern era and the automobile. Berlin was passed by when Route 50 was built in 1945 (Hammond, 2008). This resulted in a severe economic down turn and by the 1970's only three stores remained open in the downtown area (Hammond, 2008). Fortunately the abandoned historic buildings where not torn down but simply covered up with tin siding (Hammond, 2008). During the 1980's a local grass roots movement began to restore the historic center of Berlin (Hammond, 2008). The restoration was highly successful and changed the towns focus from agriculture to a vibrant historical tourism industry (Hammond, 2008). Berlin's recover went so well that it garnered national attention with Hollywood movies such as Runaway Bride [1999] being filmed in town (Town of



Berlin Planning Department, 2010). The town area was also listed in the National Register of Historic Places (Town of Berlin Planning Department, 2010). Berlin was designated as a “Main Street Community” and an “Arts and Entertainment District” by the State by the State of Maryland (Town of Berlin Planning Department, 2010). This brings the town to its current condition of a historic tourist hub filled with art, antiques, and hosting large family oriented venues.

Berlin's current conditions and past have been summarized it is essential to review existing pertinent research conducted on the Town of Berlin. There has only been a single report conducted regarding the town's storm water and none regarding green infrastructure directly. The storm water study was conducted by the Army Corps of Engineers and was titled “*STORMWATER SYSTEM IMPROVEMENT STUDY FOR THE TOWN OF BERLIN, WORCESTER COUNTY, MARYLAND*”.

The main purpose behind the Army Corps study was to evaluate the factors and conditions contributing to the flooding problems experienced by the Town of Berlin (Army Corps of Engineers, 2007). The study was completed as a technical level investigation and conducted a comprehensive investigation into specific causes of flooding for the town (Army Corps of Engineers, 2007). This study had been conducted in three phases. The first phase was the mapping and assessment of Berlin's existing MS4 infrastructure (Army Corps of Engineers, 2007). The results from this were contained in a separate report made to the town of Berlin in 2005 (Army Corps of Engineers, 2007). The first phase was the bases for the second and third phases, which comprised the bulk of the study.

The second phase of the study was the storm water modeling, analysis, and problem identification (Army Corps of Engineers, 2007). This phase was done in a two-step process. The first step was the modeling and analysis, which was accomplished using (USACE) Hydrologic Modeling System (HEC-HMS), USACE River Analysis System (HEC-RAS), and StormCAD by Haestad (Army Corps of Engineers, 2007). The data for this came from the results of the first phase and data collected from the town or remote sensing. Data collected included land use derived from aerial photography and drainage basins determined from grading plans from the town with gaps filled with LiDAR (Army Corps of Engineers, 2007). This study had an intensive engineering perspective and relied heavily on the modeling software and statistical calculations such as rational runoff coefficients. From the results and base modeling of step one the second step of identification of problem areas was done (Army Corps of Engineers, 2007). The problem areas identified in the modeling were cross referenced with the experiences of Berlin staff for accuracy then divided into high, medium, and low priorities based on the severity of flooding and the severity of its impacts or potential severity of impacts on surrounding properties. With the problem areas identified the study moved into its third and final phase.

The third and final phase was the development of alternatives and improvement plan (Army Corps of Engineers, 2007). This was also a two-step process. With the first step being the development of alternatives and the second the evaluation of the alternative and improvement plan (Army Corps of Engineers, 2007). There were two alternatives developed for each problem area. The first was based solely on infrastructure improvements such as outfall elevation, flow

diversion, and inlet replacement (Army Corps of Engineers, 2007). The second incorporated retrofits of Best Management Practices (BMP) consisting of either use of detention ponds to reduce flow into the system, constructed wetlands at outfalls to hold and clean water, or use of under ground cisterns to again hold more water (Army Corps of Engineers, 2007). It is important to note that these are significantly different from the green infrastructure tools defined earlier in the thesis. The primary concern and motivation for the selection of these BPM's is to hold water and reduce flow into the system on a large scale. These are not used or applied in the same manner as the green infrastructure in described earlier though the two systems used in concert would complement each other. Finally with alternative defined the final step of alternative selection and the improvement plan took place. The Army Corps Engineers using their best judgment did this selection and subsequent plan (Army Corps of Engineers, 2007). The final decisions were given at the end of the study. The goal of this study would not be to usurp this study or its methods but to fill the gaps it left and to build on this existing research and implement them in concert.

## 2.2 Suitability Study Descriptions and Comparisons

There are predominantly two models for determining suitability through use of GIS (NC Center for Geographic Information and Analysis, 2005). These can vary through their methods of weighting criteria but are rooted in their fundamental basis for analysis. The fundamental basis for a suitability study emerges from needs and goals of the study and thus the type of data model used. There are two data

models used in GIS; these are Raster and Vector (NC Center for Geographic Information and Analysis, 2005). Vector data can be represented as points, lines or polygons (NC Center for Geographic Information and Analysis, 2005). Raster Data is a grid of cells / pixels (NC Center for Geographic Information and Analysis, 2005). Vector data can contain multiple attributes while a raster cell will contain only one (NC Center for Geographic Information and Analysis, 2005). In terms of suitability modeling both utilize overlays, which originated in this type of application from McHarg's study *Design with Nature* (McHarg, 1967). Raster based models tend to be more efficient because the weighted overlay can be applied to several layers at once as opposed to two at a time with vector (NC Center for Geographic Information and Analysis, 2005). Raster however can lose or distort information depending on its resolution, which is its cell size (NC Center for Geographic Information and Analysis, 2005). Due to this issue vector is more common when working with specific features such as structures while raster is more commonly applied to land cover (NC Center for Geographic Information and Analysis, 2005). Due the factors being considered and the intended application in urbanized areas the use of vector based data and overlays was chosen.

The Maryland Green Infrastructure and Kent County conducted suitability / scientific feasibility studies. Their goals, definitions, and scale and thus data selection were very similar. Green infrastructure for both studies was the distribution of natural features in the landscape (The Conservation Fund, 2006) (Weber, 2006). Based on this definition the goals were set primarily with the intention of ecological preservation, restoration, and the benefits associated with

them (The Conservation Fund, 2006) (Weber, 2006). This also required a large-scale approach hence the State and County level study areas seen. All of this is starkly different from that which is done for this study. This study's green infrastructure is systems that mimic natural processes in order to infiltrate, evaporate, and/or reuse storm water (Environmental Science and Forestry, 2012). The different definitions resulted in different goals. Maryland and Kent County want to protect and restore ecological resources and their functions while this model aims to determine the suitability of the green infrastructure tools identified on page 30.

The products produced from these two studies were green infrastructure hubs and corridors (The Conservation Fund, 2006; Webber, 2006). In the Maryland study the hubs were created through a series of GIS functions including the overlay of desired inputs such as forest and critical habitat, which were merged and then clipped based on specified criteria (Weber, 2006). The corridors were also based on similar data to the hubs and were broken into three ecotypes, terrestrial, wetland, and aquatic (Weber, 2006). The corridors were created using least cost path analysis (Weber, 2006). The products and associated models also differed from this thesis, which produced a GIS based model and the associated map products.

The study conducted in Kent County, DE did not include a model but the analysis description followed the same principles as the Maryland study even siting it within the text. While the general outlines are the same Kent County relied exclusively on raster data models and analysis (The Conservation Fund, 2006). The study utilized a 10-Meter cell (The Conservation Fund, 2006). This use of raster data is another key difference between Kent County's study and what was done in this

research, which utilized vector and raster data. Values were assigned to cells based on ecotype as well with the chosen types being forest, wetland, and aquatic system (The Conservation Fund, 2006). Additional values were applied to areas adjacent to protected lands and designated *Livable Delaware Green Infrastructure* (The Conservation Fund, 2006). Kent County not only identified their areas of green infrastructure but also applied a weighting and value system to them. Scores were based on the assigned suitability with high suitability surfaces assigned a value of 9, while the lowest scores were assigned a value of 1 (The Conservation Fund, 2006). The surfaces or raster layers were then combined to create a composite suitability surface, which included a core green infrastructure surface that utilized a weight of 1/3 for each of the tree ecotypes: core forests, core wetlands, and core aquatic systems (The Conservation Fund, 2006). Its important to note that the green infrastructure feasibility / suitability was part of a larger project, which included parks and working landscapes that were all integrated at later stages after being separately evaluated. The ranking system for Kent County was included below. This ranking system was applied in the thesis ranking system.

Table 1: SUITABILITY SURFACE TABLE

SURFACE	HIGH SUITABILITY	MEDIUM SUITABILITY	LOW SUITABILITY
Forests	Core Forest Area	Hub outside core, mature non-hub forest	Non-forest
Wetlands	Core Wetland Area	Non-core unmodified wetland	Modified wetland, non-wetland
Aquatic Core	Aquatic Area Riparian	unchannelized Riparian along ditch	non-riparian
Livable Delaware	Inside GI Boundary	N/A	Outside GI Boundary
Proximity	Within 100m of Protected land	Between 100-800m	>800m from protected land

(Source) The Conservation Fund. (2006, June). *Rapid Assessment of Green Infrastructure*. Retrieved Feb 18, 2012, from Kent County, Delaware: [http://www.conservationfund.org/delaware/kent\\_county](http://www.conservationfund.org/delaware/kent_county)

These studies differ greatly from that which is outlined in this thesis but retain the same core methodology. The green infrastructure definitions and goals differ most starkly with this study. These, as stated above and as was reviewed in the green infrastructure portion of the paper, focus on green infrastructure as a means of ecological protection and recovery with added benefits to human society. This resulted in data selection including protected lands, critical habitat, etc. This thesis is based more in structural applications of green infrastructure again as reviewed in the green infrastructure section. This required data selection based on the structural needs of the selected green infrastructure tools such as slope and soil type. While these differences exist the basic methodology for the overlay analysis in Maryland and Kent County originating from McHarg's study *Design with Nature* are utilized in this study as well (McHarg, 1967). The ranking of factors or criteria seen in Kent will be applied in Berlin for this study but will be further modified based on

additional studies to reflect the desires and needs of this study. The goals and general models from the above models represent the predominance of GIS based suitability / feasibility studies for green infrastructure. These cases are also important because they are within the region of the study area for this research and provided not only examples of applied GIS based models for comparison but also gave additional insight into similar efforts and the background of the region.

The next study models reviewed were Central New York and Omaha, Nebraska. The goals and green infrastructure definition and purpose were much similar to that of this study. Both the State of New York and Omaha applied green infrastructure with the goal of storm water management with ecological and other functions being the secondary or added benefit to implementation. This resulted in green infrastructure tools or practices more in line with those defined for this study within the green infrastructure section on page 30. This in turn resulted in data and criteria selections similar to this study. All the studies again have the basis for their methodology entrenched in the overlay model developed by McHarg (McHarg, 1967).

The suitability study in New York was titled *Green Infrastructure Planning for Improved Storm water Management in Central New York* (Central New York Regional Planning & Development Board, 2012). The suitability analysis conducted for Central New York was used to validate viability of 18 specified storm water practices for the area (Central New York Regional Planning & Development Board, 2012). The geographic suitability factors or criteria applied in the study were hydrologic soil group, slope, land-use, proximity to roads, and wetland and



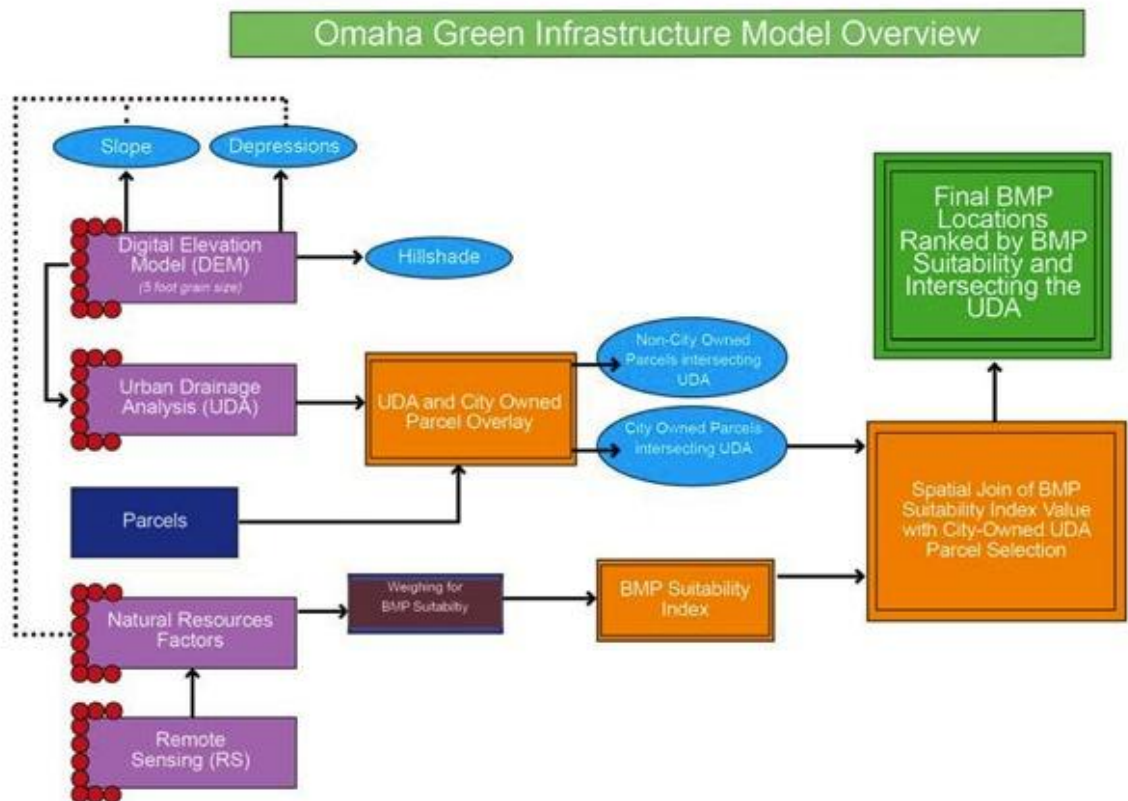
floodplain presence (Central New York Regional Planning & Development Board, 2012). These criteria are very similar to those used in this study with three overlapping and two differing. The criteria established for the study were placed in ranked raster layers. Ranked values of 0 to 5 were used, with 0 representing the least suitable, and 5 representing the most suitable (Central New York Regional Planning & Development Board, 2012). Once the established layers were ranked, they were given a weighted suitability by multiplying the ranked value by the established weight (Central New York Regional Planning & Development Board, 2012). The application of ranking and weighting is also used applied in this model with the ranking based on the Kent County study and the weighting based in part on this Central New York study. The weighting for Central New York's model was based reasoning, and nothing else, which was given, such as soils weight being based on its control of infiltration and thus function of green infrastructure (Central New York Regional Planning & Development Board, 2012). While a proper methodology or justification beyond the reasoning given for the model's weighting is lacking the weights are justified with logic by the research and are along with other applicable studies the basis for weighting in this thesis's model. The final product for the suitability study was created when the layers were combined together to obtain a numerical value for the suitability of the storm water practice for each cell in the completed suitability grid (Central New York Regional Planning & Development Board, 2012).

The suitability study for the City of Omaha was titled Green Solutions Guidance For The City Of Omaha CSO Long Term Control Plan (City of Omaha, 2009).

The study was done using a GIS based model similar to the other studies above. While similar it is better defined and is the closest of the studies to the model produced in this thesis. The model was done in five tasks. This listing of tasks was also applied for this thesis but differs based on the differing criteria. The first task was the creation of a DEM of the entire City, which was then used to develop associated products including urban hydrology and catchments, slope, hillshade, and existing depressional storage areas (City of Omaha, 2009). Task 2 was the classification and rank of land cover type using the Landsat cover classification (City of Omaha, 2009). Task 3 was development of a Green Solutions suitability index, which used the Landsat cover classification results as well as available natural resources data (City of Omaha, 2009). A ranked and weighted system was developed by associating factors to represent the “quality of individual” resources within a category and then multiplying them with weights to rank the criteria used (City of Omaha, 2009). The parcels found to have higher numbers were qualified as highly suitable and those found to have low numbers had a low suitability (City of Omaha, 2009). Beyond this no real description or even listing of the rankings/weights was provided in the document or found else-ware. Task 4 was the creation of an Urban Drainage Analysis [UDA] (City of Omaha, 2009). This UDA developed an urban hydrology and parcel analysis model to identify locations that currently intercept and/or were adjacent to overland flow paths (City of Omaha, 2009). Task 5 created the final product by creating a ranked green infrastructure analysis through the joining of the BMP suitability index to the UDA where parcels intersected each other from the two analyses (City of Omaha, 2009). Due to lack of information on the

weighting little consideration of this aspect of Omaha's analysis was given for this study instead Omaha is used as a basis for the GIS model, which was used in this research. The Model created for Omaha can be seen below.

Figure 1: Omaha Green Infrastructure Model



(Source) City of Omaha. (2009). *Long Term Control Plan for the Omaha Combined Sewer Overflow Control Program*. City of Omaha.

Table 2: Suitability Studies Model Comparison

	Location	Maryland	Kent County	Central New York	Omaha Nebraska	Berlin Maryland
Model Base	All Models have the same basis in utilization of overlays but differ in base data type used.					
Raster		X	X	X	X	X
Vector		X			X	X

Table 3: Suitability Studies Criteria Comparison

Location	Criteria						
	Soil	Slope	Proximity	Depth to Groundwater	Public Vs Private Land	Land Use	Other
Maryland							X
Kent County							X
Central New York	X	X	X			X	X
Omaha		X	X		X	X	X
Berlin	X	X	X	X	X	X	

The suitability studies done in Omaha and Central New York closely resemble this model. Both the State of New York and Omaha applied green infrastructure with the goal of storm water management. This resulted in green

infrastructure elements and model criteria along the same lines as those seen in this model. Omaha's model is more concerned with retention of storm water than Central New Yorks or this thesis. Due to this Omaha included their UDA analysis, which is not seen in this research or New York's. Both incorporated slope, which is used in this research's model. Soils are seen in almost every model except Omaha's, which substituted soils data in its BMP's portion of the study for Landsat coverage and it's classifications to determine permeability and amounts of impervious surfaces. Proximity to structures is discussed but not applied in the show studies, its inclusion in this model is due to recommendations seen in installation guides for the various green infrastructure tools seen in the above green infrastructure section. Depth to ground water is another aspect of this model, which was discussed in other research but not applied. Kent County looked into issues involving depth to ground water due to concerns with possible contamination of ground water through infiltration. This concern was dismissed in the Kent County study due to what the research deemed more important and through looking at risks versus rewards. The concept of depth to ground water as a criterion has been given little credence in other models and research. This is likely because depending on your area it usually is not an issue of concern or as in Kent County the goals of the study left it a secondary concern. The use of depth to ground water in this research model emerged through several points. The research showed this area to be a gap but still an area of concern. Its inclusion was determined through requirements seen in installation guides for various green infrastructure tools, concerns expressed but not addressed in other research, and finally due to the need for it within the chosen

study area. Berlin is within the shallowest aquifer in the State of Maryland meaning depth to ground water is of greater concern than in various other portions of the state and easily more important than other portions of the Country such as Omaha where depth to ground water is much greater.

### 2.3 Feasibility Vs. Suitability and the Flaws of Current Feasibility Studies

In order to compare existing feasibility studies with this thesis and identify their differences the term must first be defined. For purposes of this study a feasibility study is defined as a study based on test work and analysis, which presents enough information to determine whether or not the project should be advanced to the final construction stage (Pincock, 2004). This definition basically means that a feasibility study determines if project or concept can be implemented based on requirements. This is significant because with this thesis more technical definitions for green infrastructure determined that a more technical feasibility study or a suitability was necessary. As with defining green infrastructure other research has applied the term feasibility study in a broader and ultimately differently intentioned method.

One example of an existing feasibility study for green infrastructure is the River Dee study conducted in July 2009. The River Dee is located between North East Wales and West Cheshire, England (Marrs, 2009). The goal of this feasibility study was the development or delivery of a green infrastructure strategy for the River Dee area through policy review and stakeholder consultation of the various relevant “partners” (Marrs, 2009). This goal immediately shows that this is not an

approach that would be as technical in nature as is defined for this study. A simple break down of the study's contents shows that they identified the "partners" for green infrastructure, which are the relevant parties that may want to implement green infrastructure, the study area, defined green infrastructure as "*Green infrastructure is a network of multi-functional green space, both new and existing, both rural and urban, which supports the natural and ecological processes and is integral to the health and quality of life of sustainable communities*", and introduced the topic and its place in the River Dee. The methodology was not to look at specific green infrastructure tools and determine if they were actually feasible to implement based on their technical requirements. It instead analyzed planning and policy aspects of green infrastructure and how they would be applied to this watershed, which includes two nations and various stakeholders. The type of research applied to the River Dee is an essential and important step in planning and is significant as a study. It has however also proven to be completely different from that intended in this thesis for the Town of Berlin.

The City of Camden, New Jersey has also had a feasibility study conducted. It was done in November of 2011 (Rutgers, 2011). The goal and methodology of this feasibility study was relatively similar to that of the River Dee feasibility study. The goal of this feasibility study was to create a pilot program for a community-based initiative implementing green infrastructure projects throughout the City of Camden (Rutgers, 2011). This again differs greatly from the defined objective of a feasibility study set above and for the goal of this thesis as a whole. The first step of this feasibility study was the standard definition of the problems faced by Camden and

identification of green infrastructure, which for Camden was defined as “*an array of products, technologies, and practices that use natural systems – or engineered systems that mimic natural processes – to enhance overall environmental quality and provide infrastructure services*” (Rutgers, 2011). While this definition is much closer to that set forth in this research the Camden feasibility study did not apply it or the tools it represents in the same technical manner as this thesis. The rest of the methodology consisted of the establishment of the Camden Smart Initiative, methods for engaging the public, outlining of education and training programs, and the use of demonstration projects (Rutgers, 2011). All of these played an important role for the City of Camden but are significantly different from that which was planned for Berlin. Camden’s feasibility study essentially focused on planning initiatives to garner public support and understanding for green infrastructure (Rutgers, 2011). The closest it comes to the technical analysis for this thesis is the definitions for green infrastructure tools and the demonstration projects. The tools defined are by in large the same as those chosen for Berlin but their technical requirements are not identified they only defined the terms (Rutgers, 2011). The demonstrations while showcasing the tools needs through example does not actually identify where to apply the green infrastructure tools only how to install and maintain them (Rutgers, 2011). Again this feasibility study was useful to the City of Camden as was the River Dee study for its area but as with the River Dee this feasibility study has shown significant differences with this research.

The final feasibility study example is Bridgeport and New Haven, Connecticut. Both cities had CSS’s and their associated issues. The goal and



methodology of this feasibility study was relatively similar to that of the other two feasibility studies. The goal of the study was to develop a plan with green infrastructure to address issues related to CSOs, sewer backups, and street flooding within both of these cities. Green infrastructure was defined as this study the use of natural processes and storm water reuse to manage runoff in combined sewer areas. The simplified methodology for this study was the creation of a policy based framework for implementation, the conduction of a cost-benefit analysis to determine feasibility, and consideration of the effect green infrastructure implementation could have on job creation in the cities. This study like the other focuses on planning policies and public opinion and out reach but has the added facet of a cost benefit analysis for its feasibility. The cost benefit analysis is an important and technical process or determining feasibility but does not resemble the analysis intended for Berlin. This study also identifies and defines green infrastructure tools but like the Camden study only defines them. This is another excellent study but does not have the same methods of analysis as this study.

Table 4: Feasibility Study Comparison

Study	Goal	Methods/Components	Scale
River Dee	Development or delivery of a green infrastructure strategy	Policy review and stakeholder consultation	Region
City of Camden, New Jersey	Create a pilot program for a community-based initiative implementing green infrastructure projects throughout the City of Camden	Establishment of the Camden Smart Initiative, methods for engaging the public, outlining of education and training programs, and the use of demonstration projects	City
Bridgeport and New Haven, Connecticut	Develop a plan with green infrastructure to address issues related to CSOs, sewer backups, and street flooding	Creation of a policy based framework for implementation, the conduction of a cost-benefit analysis to determine feasibility, and consideration of the effect green infrastructure implementation could have on job creation in the cities	City
Town of Berlin, Maryland	Develop a GIS based Model for determining Green Infrastructure Suitability	Create and Apply a GIS based model based on the criteria of soil, slope, depth to groundwater, and proximity to buildings	Town

The comparisons above show that while the concept of a feasibility study is nothing new for green infrastructure there is a gap in the approach and methods for

the existing research. Current feasibility studies focus on feasibility in terms of finances, policy, and public opinion. These are major factors in determining feasibility for these types of projects but do not meet the technical needs for the type of study done in this thesis. This means the model created for this research has the characteristics of a scientific feasibility study or suitability analysis and ignores the other factors focused on in other feasibility studies as seen above. This thesis based on the technical requirements for the defined green infrastructure elements has created and applied a GIS based model for determining feasibility/suitability. This as was strived for in all aspects of the research aims for a better-defined and more technical methodology and overall more precise study.

#### 2.4 Storm Water Management Descriptions and Identification of Systems

The first step in any research is the proper definition of key terms and concepts. This thesis directly deals with issues regarding storm water management. Storm water is defined as surface runoff due to a storm event such as rain, snow, etc. (EPA, 2003). Storm water management is efforts to control or mitigate any adverse effects from storm water runoff (EPA, 2003). With storm water and its management defined an overview of the topic can be conducted.

There are two main types of storm water systems combined storm and sanitary sewer systems [CSS] and separate storm sewer systems [MS4] (EPA, 2000). Each is what it says. A combined system is just that, a system in which both storm water and sewage are managed in a single system of pipes (EPA, 1994). Combined sewer systems are in use in roughly 772 communities (EPA, 2008). These CSS serve around 40 million people (EPA, 2008). Most municipalities with CSS, and by default

Combined Sewer Overflows (CSO's), are located in the Northeast and Great Lakes regions, and the Pacific Northwest because these are the older areas of the country where communities were built before MS4's (EPA, 2008). The City of Chicago is one example of a municipality served by a CSS (EPA, 2010). Since the cost, as is the case for most municipalities, is prohibitively high to switch to a MS4 is making due with various improvements and new policies such as the inclusion of green infrastructure (EPA, 2010). This combined system is the original model for storm water but the issue of CSO's necessitated the creation and switch to a new model.

This new model was the MS4. Again this system is its name's sake a system of two separate pipes one for storm water another for sewer (EPA, 2000). This system being newer and having advantages to CSS's is the more common system (EPA, 2000). An example of a municipality with a MS4 is the City of New Castle, Indiana (City of New Castle, 2010). The MS4 was of particular interest to this research for two reasons. The first is as stated above that it is the more common system the second is that this is system in use in the Town of Berlin, Maryland where the research is applied. This system emerged to eliminate CSO's. It has however still transferred a great deal of pollution. MS4's gather runoff a nonpoint source pollutant and discharge them directly into waterways at outfalls (EPA, 2000). With CSS's still in use and MS4's having their own issues storm water systems and management have continued to evolve.

The goal of all storm water systems has traditionally been to remove the water as quickly as possible from municipalities. This has led to various issues including runoff pollution and overflow events in combined storm sewer systems.

The Environmental Protection Agency has implemented various requirements to manage these issues, which have been taken up by municipalities. The main tool for this and the one most often referred to for compliance is the National Pollutant Discharge Elimination System [NPDES]. The NPDES started in 1990 and is part of the Code of Federal Regulations [CFR] (EPA, 2011). It is primarily used to manage storm water and issues arising from it; the regulations of which are in CFR Title 40 (EPA, 2011). The NPDES essentially regulates pollution from MS4 and from CSO's, which occur in high rainfall events (EPA, 2011). Phases one and two of the NPDES cover MS4's and their regulations (EPA, 2000). Phase one regulates medium to large MS4's, which covers municipalities of 100,000 or more (EPA, 2000). Phase two handles all other MS4's, which are designated as small (EPA, 2000). This program is enforced through a permitting process (EPA, 2011). This permitting process crosses over with the CSO Control Program to manage CSS's and the issue of CSO's (EPA, 1994). This regulation through the NPDES permitting is one of the main driving forces behind the inclusion of green infrastructure in municipal storm water management. This is an important fact since it is the primary purpose of green infrastructure in general and for purposes of this research to manage these issues.

### 2.5 Green Infrastructure it's Definition, Tools, Methods, and Relevance

Green infrastructure has many meanings and definitions. The most common definition or thought process applied to green infrastructure is strategically planned and managed networks of natural lands, working landscapes and other open spaces that conserve ecosystem values and functions and provide associated benefits to human populations (The Conservation Fund, 2012). Under this definition everything

from parks and trees to infrastructure such as porous pavers are considered green infrastructure. This is a comparatively broad definition. This broadness can be useful and this is what the State of Maryland applies in an adaptive form; “A statewide network of protected areas representative of Maryland’s natural and cultural landscape” (Sheladia, 1988). For purposes of this study green infrastructure is defined as systems that mimic natural processes in order to infiltrate, evaporate, and/or reuse storm water (Environmental Science and Forestry, 2012). Green infrastructure under this definition uses soils, topography, and vegetation in a way that minimizes the impacts of anthropogenic or human disturbance and maintains the pre-development hydrology and water quality of urban environments (Environmental Science and Forestry, 2012). This is a more sterile and utilitarian definition but it is also more clear and concise, which was paramount for the effective and efficient conduction of the research.

With the topic of green infrastructure defined it is important to define the types of tools this definition would refer to. This research will cover rain gardens, filter strips, bio-swales, permeable pavers, and bio-retention ponds. These are the anticipated green infrastructure tools for this research. Their structural requirements shall also be addressed. This is not a full account of all tools, which would possibly fall under the definition of green infrastructure set above but is those to which the study will refer. Other green infrastructure tools, which meet the project’s established definition but are not covered, include tools such as green roofs and green walls. These are structural green infrastructure implements but do not directly integrate into municipal storm water gray infrastructure.

A rain garden is a shallow planted depression designed to retain or detain storm water before it is infiltrated or discharged downstream (Clark, 2008). There are structural requirements for rain gardens in order for them to function well and not have adverse effects. Rain gardens must be at least 10 feet from a structure to minimize risks of water damage to foundations (Cudahy, 2010). They should be 25 feet from a septic system to ensure no conflict with roots from trees and other plants (Cudahy, 2010). The depth to ground water in an area must exceed two feet (Szatko, 2012). The maximum depth of the rain garden itself is determined by the rate of infiltration but should not exceed one-foot (Cudahy, 2010). Rain Gardens also require a gentle slope of around eight percent, which equates to a one-foot elevation drop for every twelve feet (Cudahy, 2010). Filter strips are uniformly graded, vegetated areas of land that remove pollutants from run-off through filtration and infiltration (Army Core of Engineers, 2009). They are placed in between impervious surfaces to filter water before it infiltrates, drains to a storm water system, or is discharged (Army Core of Engineers, 2009). They have little requirements other than the space to place them. A bio-swale is a long vegetation lined depression with gently sloped sides used to slow water flow and increase infiltration (Cudahy, 2010). They are generally used to convey runoff from one location to another. A bio-swale is often used in conjunction with rain gardens, bio-retention ponds, and other similar features (Cudahy, 2010). These like filter strips have little structural requirements. Porous pavers are any alternative to impervious asphalt, which allow infiltration (Army Core of Engineers, 2009). Again there are few technical needs for this tool. Bio-retention ponds are similar to rain gardens and the two are often used

interchangeably (Clark, 2008). It is however an incorrect assumption to say that they are not different and distinct features. Rain gardens slowly to ground water and have a spill way for overflows in large rain events (Clark, 2008). A bio retention pond still infiltrates with some going to ground water however most is funneled to an inlet in the ground and there is another elevated inlet to directly send water away in high rain fall events (Szatko, 2012). The purpose of both tools is to slow flow and filter runoff but a bio retention pond is directly linked to traditional infrastructure. The similarities in use and purpose for rain gardens and bio-retention ponds extend to their design. They require the same slope, depth, and depth to ground water (Szatko, 2012). All the green infrastructure tools above contain an element of infiltration to them; as such it requires a relatively permeable soil type. Sandy loam is an ideal soil type but various others work (Szatko, 2012). A rule of thumb is to try and have the clay levels at below 30 percent (Cudahy, 2010). There are methods of improving the rate of infiltration if this is not naturally achieved. The above are the types of green infrastructure referred to in the case of the study for application in the Town of Berlin.

Green infrastructure while having grown in scope and importance is not a new concept. The term green infrastructure was coined in Florida in 1994 in a report to the governor on land conservation strategies (Firehock, 2010). The report was intended to reflect the notion that natural systems are equally, if not more important, components of our infrastructure (Firehock, 2010). In other words natural / working landscapes are equally as important as traditional or gray infrastructure. The concept of green infrastructure with time has become more



defined. It has also come to span or encompass many fields of study.

Green infrastructure has been implemented in various places across the United States. There are limiting factors to this though; with most implementation happening at city, county, or regional levels little has been done for smaller municipalities. There are also variations in technique, methodology, tools used, and as stated above in the definition of green infrastructure itself. Alachua County is located in Florida and contains the city of Gainesville and The University of Florida. Here green infrastructure was incorporated into Alachua's Comprehensive Plan and Land Development Code, which were implemented in 2005 and 2006 (EPA, 2010). This was one program utilized green infrastructure through a variety of methods. The type, tools, and use of green infrastructure were determined by the definition of green infrastructure, which was that of a strategic landscape approach to the conservation of open space (EPA, 2010).

The use of green infrastructure was encouraged in Alachua through development requirements. Requirements included 75-foot buffer around all streams, maintenance of 50 percent of strategic ecosystems (defined by the county), and conservation of 20 percent of tree cover (EPA, 2010). A main tool for conservation of open space was cluster zoning. This required that any development of 25 units or more to cluster said units and conserve a minimum of 50 percent of the preexisting open space (EPA, 2010). Various codes were amended as well. The standard width for pavement was reduced to 18-22 feet (EPA, 2010). The requirement of a comprehensive storm water management plan was also

established (EPA, 2010). While all of Alachua's green infrastructure efforts were effective and are important tools they are too large scale and dissimilar by comparison to what would be wanted for this project. These are more along the lines of general smart growth tools already seen in Maryland not the specific structural green infrastructure intended for Berlin. The closest to the structural green infrastructure this program came to was alterations to its own codes, which still only focused on gray infrastructure.

The city of Chicago is a forerunner in green infrastructure. Their use of green infrastructure has been managed and implemented through six programs. The program most directly impacting green infrastructure was the 2008 storm water management ordinance (EPA, 2010). This required that any new or redevelopment must handle the first half-inch of rain on site or reduce the previous impervious area by 15 percent (EPA, 2010). The green streets program sought to encourage more public and private tree planting within the city (EPA, 2010). The main goal of this was a reduction in the city's urban heat island effect but also benefited storm water as well by reducing runoff volumes through interception and evapotranspiration (EPA, 2010). The city had a green roof grant program in effect to fund the conversion to green roofs, which has since been discontinued due to the recent economic down turn (EPA, 2010). The sustainable streetscapes plan in Chicago most closely resembles the intent for green infrastructure in Berlin. It takes a select number of arterials such as Route 41 and incorporates vegetated swales and treatment ponds (EPA, 2010). These are features that are effective in not only improving water quality but reduce the flow and volume of runoff. Finally is

Chicago's green permit program, which started in 2005 (EPA, 2010). This was an incentive based program offering expedited permitting and other benefits in exchange for development integrating green infrastructure elements (EPA, 2010). These green infrastructure elements are incorporated into a strategic landscape approach in order to serve the needs and goals of a major city.

The definition / type of green infrastructure in Chicago more closely resembles that set forth for this study. There are distinct differences though. There is still a significant difference in scale and while actual structural tools such as porous pavers are used there is still a clear regional strategic landscape approach. This is due to the scale of the issue in Chicago as well as the city's goals. Rather than conservation of open space as in Alachua County and many cases Chicago has been reclaiming open / green space and taking advantage of its associated benefits.

The City of Seattle is another city in the vanguard of green infrastructure. The driving forces behind their inclusion of green infrastructure where storm water management and most importantly protection of the areas ecology. This is significant because while the scale of Seattle and its issues differs with that of the Town of Berlin they have these two key needs or concerns in common. Both are located in environmental sensitive and significant watersheds and both face concerns with managing storm water.

The inclusion of green infrastructure has taken place in the storm water code for the city, which is managed by the Seattle Public Utilities [SPU] (EPA, 2010). There are three facets to these updates. The first is new and redevelopment, which

is required to include green infrastructure or pay a fee in exchange for exemption (EPA, 2010). The codes updated for this include source control, storm water grading and drainage control, flow control, etc. (EPA, 2010). Second are the roads updates. In this Seattle is retrofitting the public right-of-way to reduce the runoff flow going directly into sensitive habitat (EPA, 2010). The final portion addresses private lands by having created the Rainwise Incentives Program, which uses educational materials and low cost incentives, such as guides, workshops and discounted utilities in order to encourage private land owners to utilize green infrastructure (EPA, 2010).

Seattle in its needs and definitions of the issue focus on a strategic landscape approach in order to better address their primary concern of protecting aquatic biota and creek channels as well as improving overall water quality (EPA, 2010). The main focus in Berlin would be on the benefits for storm water management with the ecological benefits being a much-appreciated bonus. Due to this focus the study for Berlin will use only structural green infrastructure as defined earlier in this section, as opposed to the mix of structural and landscape based tools seen in Seattle.

## 2.6 LIDAR it's Definition, Components, and Products

In any research accuracy and precision are key to ensuring validity. This is particularly true of research involving mapping or any type of spatial element. For many planners or researchers we rely on mapping or other spatial referencing material to illustrate points or to aide in visualizing problems and other aspects of

situations. This means the production and analysis of data through programs like Arcmap but where does this data come from. Other than digitized reference maps or geocoding the primary source for mapping data comes from remote sensing.

Remote sensing is the process by which spatial parameters or characteristics are determined through remote interpretation of the electromagnetic spectrum (Schmugge, 2002). There are two forms of remote sensing active and passive.

Passive remote sensing views the naturally reflected or emitted energies of the world (Campbell, 2007). Active remote sensing emits some form of electromagnetic energy and analyzes what is reflected (Campbell, 2007). Examples of remote sensing systems include various satellite systems such as Landsat and aerial photography.

However a new system / technology has emerged that is highly accurate and has been increasingly more available. This emerging system is called LiDAR.

With remote sensing the accuracy and precision of a system are paramount. With the importance of accuracy LiDAR has begun to take the forefront in the field. Many of these systems are limited in their accuracy especially in terms of vertical accuracy in terrain mapping. Traditional remote sensing systems are usually accurate to within three to five meters. LiDAR is far superior with its vertical accuracy placed at around fifteen centimeters. This is a major improvement in accuracy and allows for terrain mapping of areas such as coastal plains where the vertical / elevation change varies by a foot or so if not inches. So the power behind LiDAR is the increased level of accuracy in most terrain and the opening up of accurate mapping of other terrains with less variation. With this increase in

prominence and use there is an increased need for knowledge and understanding of LiDAR.

When broaching the subject we must first define LiDAR. LiDAR is an acronym for Light Detection and Ranging. Modern LiDAR in remote sensing originates from NASA efforts with airborne prototypes back in the 1970's (Shuckman, 2010). Stuttgart University in the mid 1980's proved the high geometric accuracy of a laser profiler system taking the next step in establishing LiDAR (Shuckman, 2010). The next major development in LiDAR systems was the development of better GPS units and IMU systems (Shuckman, 2010). Rapid development of GPS and IMU systems occurred in the 1990's, which led to the development of new airborne kinematic GPS systems (Shuckman, 2010). It was also at this time in the 1990's that the GPS satellite constellation reached full configuration and was finally able to provide the coverage needed for widespread operations with GPS technology (Shuckman, 2010). High-accuracy IMU systems became available as certain military missile guidance systems were declassified during this same period allowing for accurate monitoring of an aircraft's acceleration, roll, pitch, and yaw (Shuckman, 2010).

With all this advancement in technologies LiDAR had become an established method for collecting very dense and accurate elevation values but with this level of data came difficulties with processing it. The demand for the LiDAR rapidly accelerated beyond the ability of processing programs such as CAD and Arcmap GIS software to efficiently process such volumes of data (Schmugge, 2002). In the early 2000's rapid improvements in data processing systems and supporting IT architecture occurred allowing for the processing ability required to handle the

terabytes of data produced through LiDAR (Shuckman, 2010). Since acquiring the ability to easily process LiDAR this thirty-year-old technology has become a highly utilized and prominent tool in mapping and terrain analysis.

LiDAR systems have four main components. These four parts to a LiDAR system are the laser scanner, the GPS, the IMU, and the computer processor. The laser scanner component can be subdivided into three key sub-components; these are the opto - mechanical scanner, the ranging unit, and the control-processing unit (Shuckman, 2010). The opto - mechanical scanner is the device that actually generates the laser pulses (Shuckman, 2010). The laser pulses are fed to the next subcomponent the ranging unit. Inside the ranging unit the laser pulses are reflected off a mirror, which is either rotating or scanning (Shuckman, 2010). The ranging unit then transmits the laser pulse to the target. The ranging unit also acts as the receiver as the laser pulses are reflected back from the target (Shuckman, 2010). Finally the information from the laser pulse including its travel time and angle/direction is sent to the control-processing unit (Shuckman, 2010).

There are two types of lasers components used in LiDAR systems profiling and imaging (Campbell, 2007). The profiling laser faces directly down beneath the aircraft focusing on this single region and producing data in strips (Campbell, 2007). LiDAR laser imaging is basically a laser scanner. The profiler laser system is from the earliest days of LiDAR while the scanner is relatively new coming into existence toward the 1990's after all the necessary technologies were created (Campbell, 2007). The mirror portion of the ranging unit scans the laser pulses and / or lines across a swath of land (Campbell, 2007). This system puts out between two

thousand and thirty three thousand laser pulses per second (Campbell, 2007). This instead of producing a strip of data points creates a data cloud. There are multiple types of imaging LiDAR systems. The imaging LiDAR is distinguished by the area covered by the instrument that is also known as its “footprint” (Campbell, 2007). An imaging LiDAR system that is designed to have a small footprint is known as a discrete return LiDAR (Campbell, 2007). A system that has a larger footprint is called a waveform LiDAR (Campbell, 2007). How these imaging LiDAR systems generate their data also distinguishes them. The discrete return LiDAR rely on laser pulses and produce point clouds (Campbell, 2007). The waveform LiDAR uses continuous wave lasers or a continuous line of light (Campbell, 2007).

The next of the main components of a LiDAR system is the IMU. An IMU is an acronym for an inertial measurement and works by sensing motion including the type, rate, and the direction of that motion through the use of a combination of accelerometers and gyroscopes (Farlex, 2010). The data collected from these sensors allows a computer to track a craft's position, using a method known as dead reckoning (Farlex, 2010). This works hand in hand with another of the main components of a LiDAR system the GPS. GPS is another acronym this one standing for global positioning system. LiDAR systems however must be very accurate all while in motion this requires a special type of GPS known as a kinematic GPS. Real time A kinematic GPS works in real time and instead of relying only on triangulation as in common GPS receivers it has a position location process in which it uses not only the signals received the receiver as reference but also those from a reference station (Althos, 2009). This system allows for the unit to provide real time accuracy



below 5 cm (Althos, 2009). The kinematic GPS combined with the inertial measuring unit allow for the final component the computer processor to account for any motion of the aircraft its acceleration and provide accurate location information. The computer processor takes the information from the other LiDAR components to create the basic LiDAR data or output.

With LiDAR properly defined and its history and components gone over the next thing to be addressed are the products of LiDAR. There are various products that can be produced from LiDAR data. These products are produced through the use of a geographic information system [GIS] such as Arcmap, which is the industry standard. These LiDAR products from GIS analysis are DSM, DTM, DEM, TIN, Contour Lines, Hill-shading, etc. A DSM is a digital surface model, which takes the LiDAR data and creates a full model of the surface including vegetation, buildings, and any other objects (Garrity, 2004). A DTM or digital terrain model is the same as a surface model but excludes everything but the actual terrain and are a more accurate version of the DEM (Garrity, 2004). DEMs are digital elevation models and consist of a series of terrain elevations for positions on the grounds, which are spaced at regular horizontal intervals (USGS, 2001). A TIN or triangulated irregular network is another model for terrain mapping and is made up of adjacent irregular triangles that do not overlap (NDEP, 2004). The triangles of a TIN computed from irregularly spaced points with x/y coordinates and z-values, which are often superior to some other derived from mass points because the exact location of each ground point sample is preserved in a TIN (NDEP, 2004). Contour lines are lines of continuous elevation and are another elevation product that can be created from

LiDAR (USGS, 2006). Hill-shading also known as shaded relief is a technique that can be applied to LiDAR data where a lighting effect is added onto the base level elevation data. Shaded relief is done in order to provide a clearer picture of the topography because the process mimics the sun's effects of illumination, shading and shadowing on hills and other terrain features (USGS, 2009). With this wide variety of products that can be produced from LiDAR it is a technology that has an equally varied amount of applications in studies.

Next to be reviewed are the actual application of LiDAR. LiDAR can be used in a variety of ways and applied to many fields of study. LiDAR can and has been applied in everything from basic cartography to environmental planning and conservation. Thus far all descriptions of LiDAR have limited or relegated it to terrain mapping. While terrain mapping in and of itself can be useful for a variety of things but it is not all the technology is capable of. An example of a less common application of LiDAR would be for environmental resource inventory and measurement. LIDAR has emerged as the standard technology for collecting high-resolution geospatial data for terrain mapping even over vegetated areas. Despite this wide usage the natural resource management community has been slower to appreciate the capability of LIDAR and acknowledge its potential in the field (Reutebuch, 2005). LiDAR simultaneously collects both high-resolution terrain and bio-spatial data however the data on vegetation is being underutilized and / or is being largely ignored in terms of the potential applications of LIDAR towards vegetation mapping and inventorying (Reutebuch, 2005). In recent years the accuracy and value of LIDAR derived bio-spatial forest structure data has been

gaining notice and momentum in Canada and Europe (Reutebuch, 2005). The 3D forest structure data can be applied in a variety of ways in terms of forest inventory and monitoring through things such as large-scale LIDAR measurements of height, volume, stocking, and basal area in forested areas (Reutebuch, 2005). Studies utilizing this have been relying on LIDAR point densities ranging from 0.1 to 10 points per square meter (Reutebuch, 2005). Although more common in Europe and Canada the interest in the use of LIDAR for large-scale resource inventory applications is growing within the United States as the knowledge of it becomes more common place. The ability to accurately map this bio-spatial data is important for conservation efforts and as a way of maximizing the use and effectiveness of LiDAR.

Some of the more common applications of LiDAR are the various form of terrain mapping the technology can be applied to. Terrain mapping is the most common application for LiDAR. A majority of products produced from LiDAR are terrain models so it makes sense that it would take the forefront in terms of application of LiDAR. The prominence of terrain applications of LiDAR stems from the extremely high level of vertical accuracy seen in LiDAR data. The quality of LiDAR and its ability to show elevation in such high resolution means it is a better alternative for basic terrain mapping and the only real option in areas where the vertical variation is limited. An example of LiDAR applied in a low relief area would be the USGS's mapping of Sussex county Delaware. Delaware is on the Atlantic Coastal Plain and its elevation variance is low enough to make other analysis methods much less effective. The main application of the LiDAR mapping of Sussex

County was for the production of better quality flood plain mapping for the Federal Emergency Management Agency [FEMA] (USGS, 2008). This use of LiDAR for terrain mapping can be applied to many other things as well. Another low relief area often mapped is wetlands. Accurate wetland mapping is a pivotal part in restoration and protection efforts applied to the features. Wetland inventorying with LiDAR for preservation efforts has been applied in the San Francisco bay area (Athearn, 2010). The goal of the program in San Francisco is to protect the salt marshes and the species of animals dependent on them (Athearn, 2010). The San Francisco bay area has lost around 79 percent of its marshland due to development so it is a significant issue and one in which LiDAR is uniquely useful and effective in its application because of the superior accuracy of the technology and ease of access (Athearn, 2010). LiDAR all in all is the superior tool and preferred tool for high-resolution terrain mapping.

LiDAR's ability to accurately map terrain is not limited to the surface. LiDAR is also frequently used in bathymetric mapping particularly in coastal regions. The use of LiDAR expands into bathymetry by changing the type of laser light used from the red light into blue – green light, which is capable of penetrating water.

Bathymetric LiDAR data is particularly useful in coastal engineering endeavors.

LiDAR's usefulness in this field is significant enough that in 1994 the US Army Corps of Engineers completed development of the Scanning Hydrographic Operational Airborne LiDAR Survey [SHOALS] system (Irish, 1998). This system has mapped over 2000 km squared of coastal water along the United States (Irish, 1998). LiDAR can also be applied beyond terrain bathymetry and branch into other areas such as

monitoring. Monitoring of fisheries has been difficult and there is a real need for quantitative data if sustainable models are to be developed. Most methods for achieving this simply aren't practical or are not accurate enough to be useful (Gauldie, 1996). LiDAR is believed to be accurate enough and available to monitor both fish and their environment (Gauldie, 1996). Applying LiDAR in this way would provide a sufficient database to sustain predictive models of local fish abundance and thus promote sustainability (Gauldie, 1996). In all LiDAR has a variety of applications across many field and applications both in and out of water or typical circumstance.

Accuracy and precision are key to research and for the success of many programs; this requires remote sensing. Active remote sensing systems like LiDAR are ideal but LiDAR is superior to other methods in terms of accuracy. LiDAR is a relatively old or older technology having been developed in the 1960's but as the technology developed it has only recently emerging as an affordable and viable technology for widespread application (Shuckman, 2010). LiDAR is a complex technological system of a series of components. The core components of a LiDAR system are the laser scanner, the GPS, the IMU, and the computer processor (Campbell, 2007). Despite its complexity LiDAR has emerged as the prominent tool applied to any research or problem with a type of spatial element. This is because research, and issues with spatial elements require visualization and LiDAR provides high – resolution mapping and visualization when applied. LiDAR has a variety of products produced from it such as DSM, DTM, DEM, TIN, etc. With the range of products produced from LiDAR coupled with its accuracy and quantity of data

LiDAR is found applied in many field of study and scenarios. Terrain mapping appears to be the most common application of LiDAR. It is also applied in bathymetric mapping as well as more recently in various environmental resource management and inventorying strategies. LiDAR is a technology, which is versatile enough for a variety of applications and has taken the forefront in some fields and in the future will continue to expand into others.

## **Chapter 3**

### **Methodology**

#### 3.1 Data Collection

The data collection for the research was relatively straightforward. All data came from one of two sources. These sources are The Town of Berlin Planning Department, and The Eastern Shore Regional GIS Cooperative (ESRGC). The Town of Berlin has provided the majority of the data for the research. The materials provided are shape-files detailing the Town including Zoning, Land-Use, Utilities, Transportation, Economics, Demographics, Critical Areas, Property, Protected Lands, Storm Surge, Base Files; such as town boundaries, county boundaries, etc., Soils, Sensitive Areas, Hydrography, and the Town's Historic District. These data when mapped will form the core of the knowledge of the Town. The ESRGC has provided the LiDAR and aerial photography. This data was particularly important for the accurate terrain modeling for the feasibility/suitability model. The LiDAR is the latest available and is of high quality. The company Terrapoint produced the LiDAR for the Maryland DNR and Federal Emergency Management Administration (FEMA). A visual qualitative assessment was performed to ensure data completeness and bare earth data cleanliness. There is no void or missing data in the LiDAR. This means the bare earth surface is of good quality and that the data passes vertical and horizontal accuracy specifications. The accuracy was calculated for the LiDAR data as a Root Square Mean Error [RMSE]. The horizontal RMSE is

3.28 feet. The vertical RMES is .31 foot or 9.25 centimeters. This high accuracy ensures the reliability of the research as a whole.

### 3.2 Data Formatting

The data formatting and or standardizing was based on the Maryland State Geographic Information Committee requirements and/or regulations. This committee established a standard on a single Datum, Projection and Unit for exchange of data between State government agencies and for distribution of data through the Technology Toolbox™ program. The Datum established was the North American Datum [NAD] of 1983. The projection they approved was the Maryland State Plane Projection. The Maryland State Plane "projection" is actually a coordinate system that is based on the Lambert Conformal Conic projection using the GRS 1980 Ellipsoid. The Units set down by the committee are not as certain. The Annotated Code of Maryland requires the use of meters, however as a practical matter, no one uses meters to report survey results. Due to this both meters and the more commonly used feet are acceptable. The Datum and Projection used in all data for this thesis are those set forth by the committee and the Units are in the more commonly used feet. All this is done to maintain compliance with Maryland State standards.

### 3.3 Selection of the Criteria

Selection of the criteria for the study and model was a significant endeavor. Available existing models and research largely dictated this portion of the research. The main focus was the technical needs of the established green infrastructure tools defined on page 38. Other significant factors were focused on as well. Various



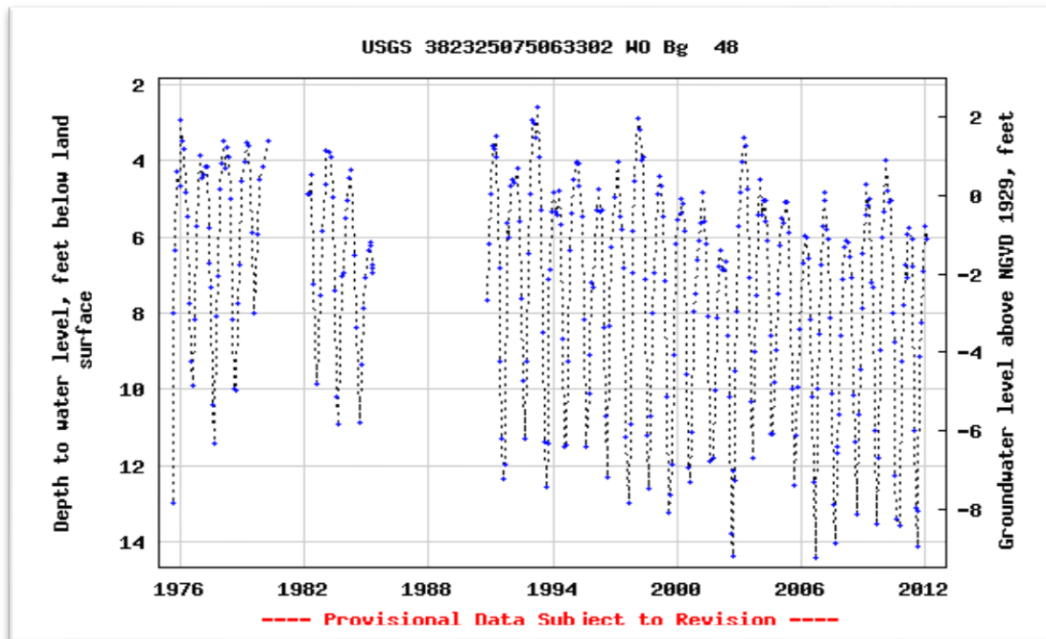
criteria were considered but only a select few were chosen and incorporated into the model.

To start with the chosen criteria and the reasons behind their selection shall be identified. The first group of criteria are those chosen based on structural / technical requirements of the established green infrastructure tools defined on page 38. The first criterion selected was soil. This was chosen because it is a very common element found in other research and models. Not only is soil a commonly used element but it also is virtually always given significant weight as in the Central New York suitability model (Central New York Regional Planning & Development Board, 2012). The criterion of slope as with soil is a reoccurring element seen in the literature and is consistently given a higher weight in modeling. This is because soil and slope significantly impact the functionality of green infrastructure. The concept of proximity while less common is still seen. It is more often applied in terms of proximity to wetland or floodplains (Central New York Regional Planning & Development Board, 2012). The Central New York suitability model used proximity to roads as a criterion. This study's model applied proximity to buildings. This was done because as stated above it is a more common and thus legitimate criteria. The other major reason behind the selection of this criterion was that it also was a significant factor addressed in installation guides for the various green infrastructure tools, which state that a minimum distance from structure foundations is needed to prevent possible damage (Cudahy, 2010).

The final criterion based on structural requirements was depth to ground water and is the most important for the model. This is the unique criterion applied

only in this model. It was selected based on the needs of the green infrastructure tools and the unique requirements / features of the study area. Features such as rain gardens require a depth to ground water exceeding two feet (Szatko, 2012; Cudahy, 2010). This because while the maximum depth of the rain garden itself is determined by the rate of infiltration they do not exceed one-foot in depth (Cudahy, 2010). With a maximum depth set of one foot a layer of soil for actual infiltration is necessary otherwise the environmental benefits generally seen are lessened or negated and the functionality of the installed green infrastructure is compromised (Cudahy, 2010). Thus an additional foot of soil is needed between the ground water and the bottom of the installed green infrastructure tool (Szatko, 2012; Cudahy, 2010). This is particularly important in the study area and any similar location. The Town of Berlin is located above the Pocomoke Aquifer, which is within the Yorktown formation (Town of Berlin Planning Department, 2010). The Pocomoke aquifer is the shallowest aquifer within the Chesapeake group (Town of Berlin Planning Department, 2010). Over the years the depth to ground water has come close to this cut off but has not past it. This is easily seen in Graph 1 bellow, which covers the various depths to ground water measured from the USGS monitoring well (USGS, 2012). This shallowness posed an issue of concern for this research and because of this was included as a criterion in the model.

Graph 1: USGS Depth to Ground Water Measurements



(Source) USGS. (2012, Jan 25). *Groundwater Levels for Worcester County*. Retrieved Feb 12, 2012, from National Water Information System: Web Interface:  
[http://nwis.waterdata.usgs.gov/nwis/gwlevels?site\\_no=382325075063302&agency\\_cd=USGS&format=html](http://nwis.waterdata.usgs.gov/nwis/gwlevels?site_no=382325075063302&agency_cd=USGS&format=html)

The inclusion of non-structural based suitability criterion was done to enhance the model and give the suitability study a more firm standing. There were two non-structural based criterion these were public versus private land and land use. Public versus private was chosen because it significantly impacts the ease of implementation. Publicly owned land in ideally located terrain is easily and efficiently applied with green infrastructure. Privately owned land while not necessarily difficult poses the serious risk of being so. If a private landowner does not wish to implement a green infrastructure tool then there is an added level of cost and difficulty in implementation. This concept is taken from the City of Omaha suitability model, which also takes this criterion into account. The other non-structural criterion of land use is a basis for incorporation public perception into the

model. As stated above private landowners pose a possible obstacle to implementation. This criterion breaks that down further by looking at the context of a given area. An example of this would be conflict arising in residential areas due to the public perception that the green infrastructure tools will result in more mosquitos. It is important to take public perception into account. This criterion while seen in various models is largely based on the Central New York study discussed in the literature.

With the incorporated criteria accounted for it is necessary to explain why various other possible criteria were excluded. Perhaps the most obvious and significant criterion excluded was impervious surfaces. Impervious surfaces impact surface flow and are a common element of suitability models. On a cursory glance it appears that this was not addressed at all, however this was not the case. In order to address impervious surfaces, which would be a factor preventing implementation of the outlined green infrastructure they were excluded from the study area. This is most easily seen in Map 6 Proximity to Buildings. The included criterion of proximity to buildings is based on the standard that the green infrastructure tools identified on page 38 must be at least 10 feet from a structure to minimize risks of water damage to foundations (Cudahy, 2010). With this in mind the building footprints and thus the impervious surface they represent are excluded from the model. Also excluded are the municipality's streets. Due to the age of the town and the design of the streets they are not wide enough to have any of the tools installed in medians except on the highways of Routes 50 and 113, which already have vegetated medians installed. Since the green infrastructure tools cannot be installed

in medians or the roads themselves all roads were removed just as the buildings were. Again viewing the zoomed in portion of Map 6 is the easiest means to view this. While this does not account for 100% of impervious surfaces with roads and buildings excluded an overwhelming percentage of impervious surfaces in the study area are accounted for.

Vegetation is another significant criterion that was excluded. Looking at the type of vegetation would be a possible factor because by virtue of what is growing in an area, you gain insight into the environment in which it is growing. In other words the inclusion of vegetation and looking at the types of vegetation would enable the model to determine if an area is constantly wet, dry, has shallow soils, level of human influence, etc. These are important and relevant factors to consider but in the end they essentially only establish the hydric soils of a location. With soils already a criterion it is not necessary to rehash them in another form. It still held the potential that you could garner a better understanding of human alterations to the soil such as changed soil types or increased compaction. Despite that it was excluded because the most promising aspect of vegetation, its insight into soil alterations would make the most sense in a field assessment application rather than GIS. This is because the scale of a GIS based model would have made it difficult to obtain the more valuable detailed data and with broad vegetation types such as wetlands, forest, prairies, etc. that could be more easily obtained and incorporated they are essentially a mute point with soils already accounted for.

There are various other criteria that appear in other models such as presence of floodplains. This was seen in many models. In particular it was applied in the

Central New York suitability study, which not only is the closest model to this study's but also is the most recent found in the literature. Despite this it was excluded. This was done because floodplain presence or absence had no real meaningful impact. The identified green infrastructure tools are not intended to treat a 100-year flood event. That having been said few things are. Function wise all the tools would work relatively well regardless of being in a floodplain except in extreme rain events for which they could never handle (Central New York Regional Planning & Development Board, 2012). This criterion was applied in the Central New York model and was also said to be "not particularly meaningful" on page 15 of that study. With the literature blatantly stating that it is not a useful criterion floodplain presence was excluded.

There are various others that can be excluded when the definition of green infrastructure and thus basis for the model is changed. This was seen in the Maryland State and Kent County Delaware models. Those studies used the most common definition or thought applied to green infrastructure, which is that green infrastructure is strategically planned and managed networks of natural lands, working landscapes and other open spaces that conserve ecosystem values and functions and provide associated benefits to human populations (The Conservation Fund, 2012). Under this definition everything from parks and trees to critical habitats were applied in the models. Due to the difference in definition and thus overall goals of the models these criteria are not relevant for this study and its model.

### 3.4 Conducting the Analysis

Analysis for the thesis was conducted through use of Arc GIS software. The three components in particular that were utilized are ArcMap, and ArcCatalogue. ArcScene was used for all 3D analysis. Creation of the Geodatabase will be done in ArcCatalogue. The geodatabase will enable the conversion of shapefiles into the more compact and usable file geodatabase. A geodatabase is a spatial database with certain schemes designed to store, query and manipulate geographic information. The decision to use a geodatabase had several advantages to the use of shapefiles. A geodatabase enabled the organization of all relevant geospatial data of different subjects in a single file (Jacques, 2003). This provided convenience, ease of access, and superior indexing (Jacques, 2003). There were other advantages including the automatic calculation of spatial parameters such as length, area, and perimeter (Jacques, 2003). All the data from the project was placed in a geodatabase.

There are three types of geodatabases; these are personal geodatabases, file geodatabases, and ArcSDE geodatabases (ESRI, 2010). Personal geodatabases have a 2 GB limitation on storage capacity, because of this they were unsuitable for this research due to its use of LiDAR, which produces high-volume datasets (ESRI, 2010). ArcSDE geodatabases have no capacity limit but are basically designed for commercial or professional level data management (ESRI, 2010). This made it more complex than was needed for use in this study. The file geodatabase is in the “goldilocks zone” having a balance in storage capacity and structure complexity, because of this and the nature of this research project this was the database that was used (ESRI, 2010).

ArcCatalogue was also where the model was constructed. The GIS based feasibility/ suitability model was the goal of the study. The model took the established criteria for the green infrastructure and determined where they were present in the town. These parameters were soil type, slope, depth to ground water, proximity to structures, public versus private land, and land-use. After the criteria are established and ranked with their basic maps in ArcMap all relevant layers will be placed in the model. The model contains the main analysis, which is a weighted overlay and weighted sum.

A majority of the mapping and all of the analysis will be done in ArcMap. The analysis conducted in the ArcMap software will be done in two steps. The first was the selection of the desired attributes from the base data. This included the appropriate soil type, slope, depth to ground water, proximity to structures, public versus private land, and land-use. The soil types were selected using the select by attributes function and then placed in their own layer. The slope was calculated using the LiDAR and the surface analysis tool found under Extensions > Spatial Analyst > Analysis concepts > Surface analysis. The areas with the appropriate slope will be selected and placed in their own layer. The depth to ground water was determined from USGS monitoring wells. Again the areas meeting the criteria set forth will be selected. Finally a series of ten-foot buffers were placed around all structures using the buffer tool. The public versus private land and land use classifications will be taken from the town land-use / zoning data through a series of basic queries. These ranked or formatted criteria were placed in a series of maps in the Results section and provided the basis for the model.



With the criteria properly ranked or formatted the second step of the ArcMap analysis was done. The criteria were converted to raster with the LiDAR raster attributes providing the basis for all the other criteria's conversion. The converted and existing raster data was taken into ArcCatalogue where it was incorporated into the model. The final product of the model was then brought into ArcMap. This final product was all locations within the study area that are feasible locations for green infrastructure based on the model's established parameters / criteria.

## Chapter 4

### Analysis

#### 4.1 Establishing Parameters

The unique parameter that was established for this feasibility study was depth to ground water. The Town of Berlin is located above the Pocomoke Aquifer, which is within the Yorktown formation (Town of Berlin Planning Department, 2010). The Pocomoke aquifer is the shallowest aquifer within the Chesapeake group (Town of Berlin Planning Department, 2010). This shallowness posed an issue of concern for this research. The designated minimum depth is two feet, which means that in order for an area to qualify based on this criteria it must have presently and historically a depth of more than two feet before reaching ground water. The data from this portion of the analysis came from a USGS monitoring well. Data for individual locations within Berlin town limits was unavailable and unfeasible to collect. Due to this limitation the USGS monitoring well, which was applied to the ground water levels for the county was used. The well used has been collecting data since 1975. The last depth to ground water measurement from the monitoring well was taken January 25<sup>th</sup> of 2012. The needed depth to ground water is set at greater than two feet. This gives room for installation of features such as rain gardens and allows for infiltration.

Soil type is another of they key criterion used. Soil is made up of three particle sizes, which are sand, silt, and clay. Sand is the largest particle at 0.05 to 2 mm diameter; silt is intermediate and is 0.05 to 0.002 mm; and clay is the smallest

at less than 0.002 mm. Soils have different textures and thus different infiltration rates based on the proportions of sand, silt, or clay particles in the soil (Earth Partnership for Schools, 2000). Soil texture is graded into 14 texture classes or types total (Earth Partnership for Schools, 2000). Examples include sand, sandy loam, silty clay loam, loam, sandy clay, or clay (Earth Partnership for Schools, 2000). The excepted soil types for this study will be those with the lower proportions of clay with the ideal soil being sandy loam.

Slope is also a key criterion used. It is frequently used in these types of studies. The parameters for slope are eight percent or lower, which equates to a one-foot change in elevation for every 12 feet. The ideal percent slope will be in the middle of the above range. This ensures that the area is not too steep or shallow for the green infrastructure to function.

The parameter of proximity to structures is used to protect property. Proximity to structures was a significant factor addressed in installation guides for the various green infrastructure tools. Since all green infrastructure utilizes infiltration a ten foot buffer from all buildings will be in place to prevent possible damage to foundations. With this criterion in place unintended damages can be averted.

The criteria of Public vs Private land and land-use provided additional scope the model moving beyond just structural factors to incorporation of social factors. Publicly owned land in ideally located terrain is easily and efficiently applied with green infrastructure. Privately owned land while not necessarily difficult poses the

serious risk of being so. If a private landowner does not wish to implement a green infrastructure tool then there is an added level of cost and difficulty in implementation. With this in mind public land received a higher ranking than private land. The criterion of land use is a basis for incorporation public perception into the model. As stated above private landowners pose a possible obstacle to implementation. This criterion breaks that down further by looking at the context of a given area. An example of this would be conflict arising in residential areas due to the public perception that the green infrastructure tools will result in more mosquitos. With this concept in mind Commercial areas were given the highest ranking and residential the lowest. It was important to take public perception into account.

#### 4.2 Ranking the Criteria

This subsection in detail describes the ranking for the model and for each criterion. This ranking will break each criterion into three ranks High, Medium, and Low. A ranking of High equates to a value of 3. A ranking of Medium equates to a value of 2. A ranking of Low equates to a value of 1. The basis for this ranking system is largely from the Kent County Delaware study, which is seen and discussed on Page 22 and can be viewed in Table 1. Each criterions ranking are based on the established parameters written above in subsection 4.1. The full ranking system for the whole model is shown in Table 5.

Table 5: Ranking of the Criteria

Rank →	High	Medium	Low
Criteria	3	2	1
Soil	Sandy/ Sandy-Loam	Loams / Soils With High Silt	Loams / Soils With High Clay
Slope	4.9-2 %	8-5 %	1.9-0 %
Depth to Ground Water	≥ 5 Ft	4.9-2 Ft	1.9-0 Ft
Proximity to Structures	≥ 15 Ft	10-14.9 Ft	9.9-0 Ft
Public/Private	Public	N/A	Private
Land-Use	Commercial	Industrial	Residential

#### 4.3 Weighting the Criteria

This subsection describes the weighting of each criterion as applied in the model. The weighting is out of one, which means each criteria was given a numerical weight of less than one with all the weights when combined adding up to one. The higher the number the more weight and thus importance or emphasis applied to the criterion. Each criterion's weight comes from observed instances of occurrence and given weights seen in the literature. The weighting scheme and applied weights were primarily based on the Suitability study conducted in Central New York but other literature impacted objective decision for each weight. The Central New York study was the most recent having been completed this January and is one of those, which most closely resembles this model and study. This is discussed on pages 23-24. The available literature was combined with personal opinion to determine the weighting for each criterion. This was a sound basis for the weighting and made sense but it would have been preferable for each weight to have statistical backing which was feasible to due time constraints. The literature applied in the decision process for the weighting is best viewed in the Suitability Study Comparison Table 2

(Table 3). Table 3 shows which study applied which criteria. The criteria of Depth to Ground Water and Proximity to Structures are primarily based on structural requirements found in installation guides but are also covered in Table 3. The full-applied weighting system can be viewed in table 6.

Table 6: Weighting of the Criteria

Criteria	Soil	Slope	Depth to Ground Water	Proximity to Structures	Public / Private	Land-Use
Weight	.25	.25	.1	.1	.15	.15

#### 4.4 The Model

This subsection reviews the model and the weighted overlay conducted within it. The model was created in ArcCatalogue. The converted and existing raster data of the criteria were taken into ArcCatalogue and incorporated into the model at which point the weighted overlay and sum tools are applied. The difference between the weighted overlay tool and the weighted sum tool is that the weighted sum tool allows for floating point values whereas the weighted overlay tool only enables an integer raster. The weighted overlay can be navigated to in the toolbox in ArcCatalogue and ArcMap through the following path Extensions > Spatial Analyst > Spatial Analyst functional reference > Overlay (Spatial Analyst). The weighted sum can be navigated to in the toolbox in ArcCatalogue and ArcMap through the following path Extensions > Spatial Analyst > Spatial Analyst functional reference > Sum (Spatial Analyst). The model can be seen below in Figure 4.

As stated above the overlay analysis incorporates all the rasterized criteria within the model. Each raster cell in the outputs will have had the equation in Figure

3 below applied to it. The equation works fairly simply. Y stands for the final score or the suitability of a location. W is the weight for a criterion. C with the subscript of (i) is the individual criterion ranked and labeled with a number with (i) standing for the number. In this case (i) would be 1-6 since there are six total criteria. 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 indicates the starting point which is the first criterion. The superscript of N just means number but stands for the end point. In this model the end point is the sixth criterion but should anyone applying the equation wish to add or remove criteria that would change hence the use of the variable N. The full equation (Figure 2) and a table (Table 7) combining rank and weight for the criteria is available below.

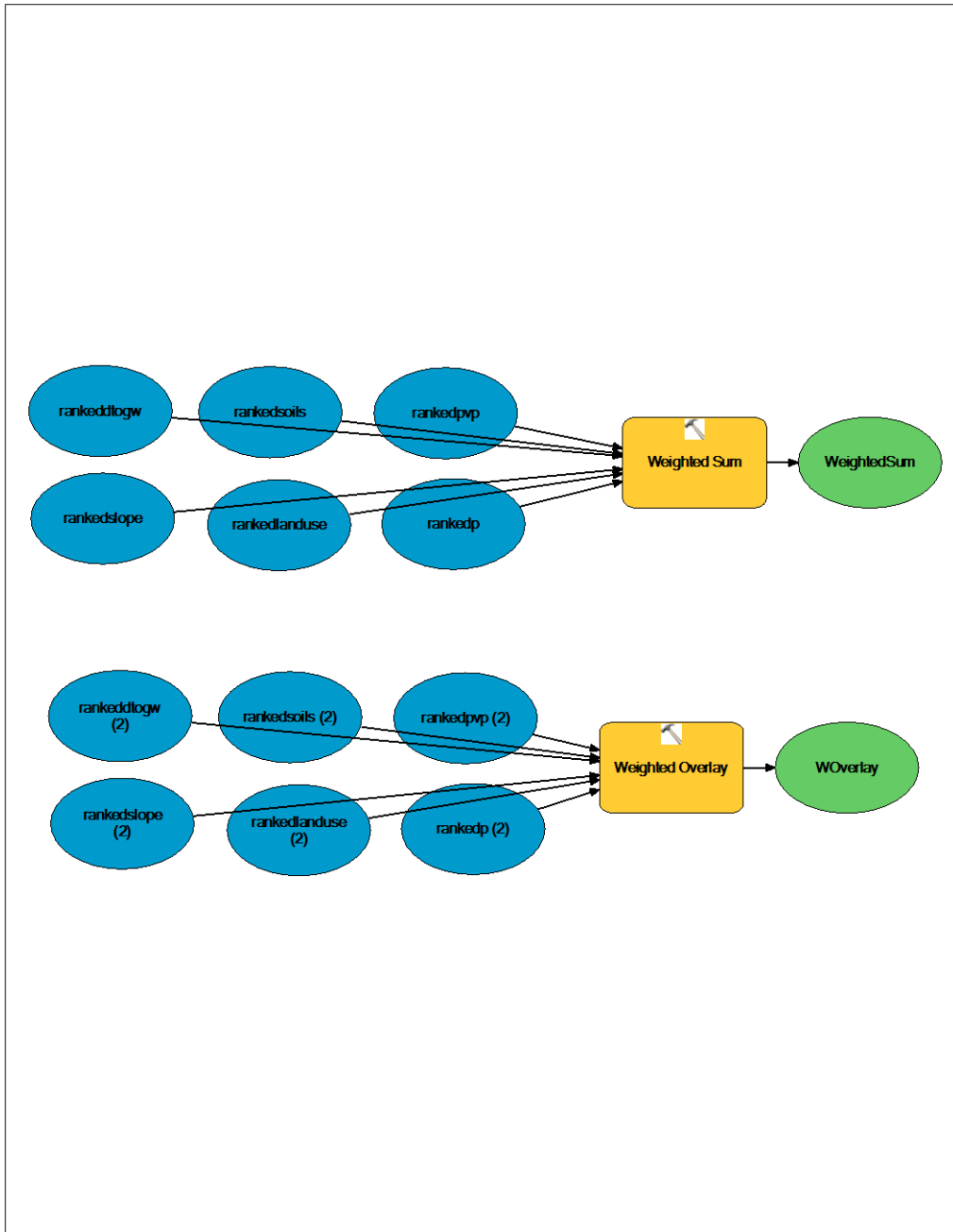
Figure 2: The Equation

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

Table 7: Combined Ranks and Weighting

Weight	Rank →	High	Medium	Low
	Criteria	3	2	1
.25	Soil	Sandy/ Sandy-Loam	Loams / Soils With High Silt	Loams / Soils With High Clay
.25	Slope	3.1-6 %	6.1-8 %	3-0 %
.1	Depth to Ground Water	≥ 5 Ft	4.9-2 Ft	1.9-0 Ft
.1	Proximity to Structures	≥ 15 Ft	10-14.9 Ft	9.9-0 Ft
.15	Public/Private	Public	N/A	Private
.15	Land-Use	Commercial	Industrial	Residential

Figure 3: The Model





## Chapter 5

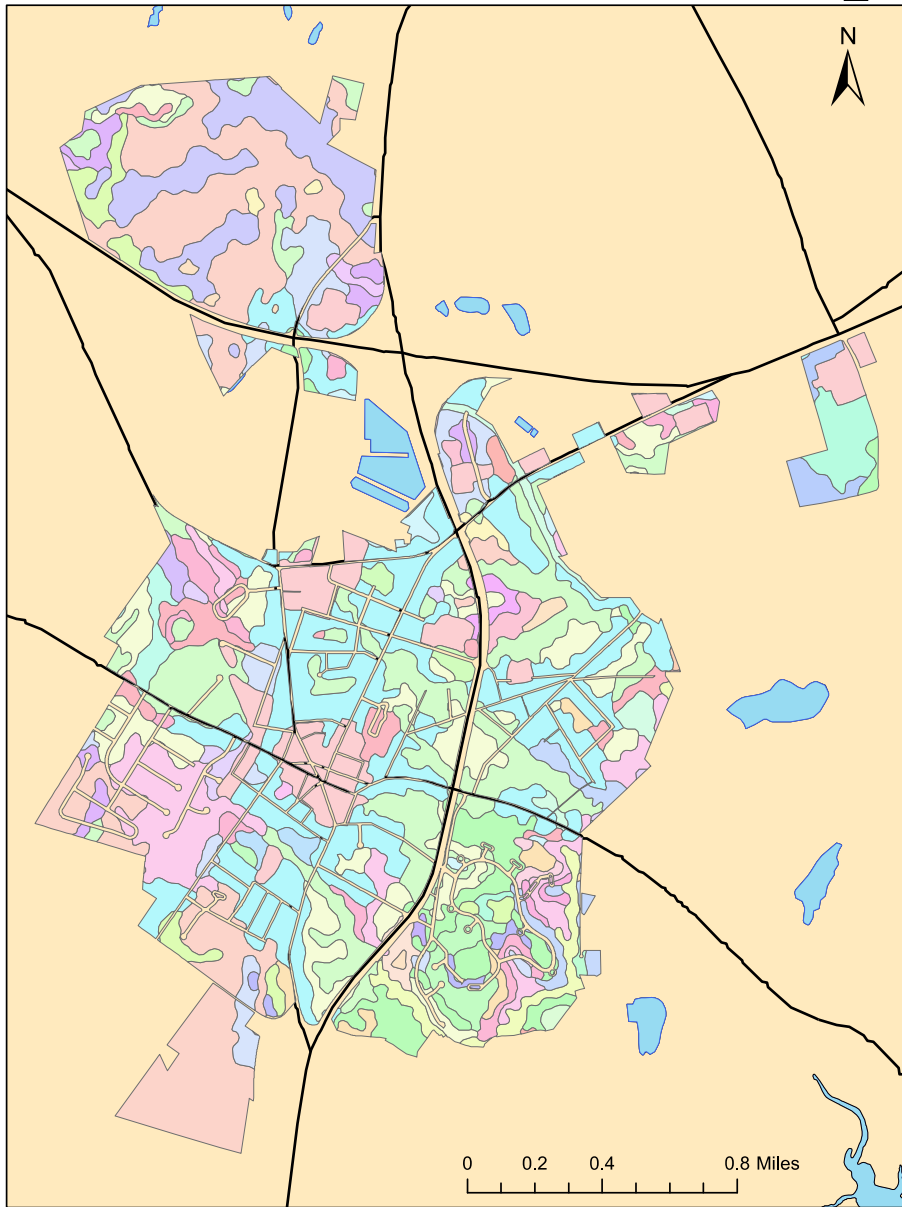
### Results

#### 5.1 Maps and Their Descriptions

This subsection contains the entire contents of results from the research consisting of the various map products created by and in association with the model. Each map has been described in detail and its relevance made evident. All maps following in this section are numbered in conjunction with the mapping done previously in the study. This was a significant portion of the research as a whole since it contains all tangible results.

The first maps to be produced under this section were Maps 3 and 4. These maps covered the criterion of soil. Map three was done to operate as a base map for the criteria. This was only done for this criterion and only because it illustrated the significance of ranking soil and the level of difficulty involved in the undertaking. Map three contains all of the Town of Berlin's soil types. There were dozens of individual soil types present in the town, so many in fact that they could not be effectively included without obscuring the map or being separately listed. Each soil type was identified via the USGS website and placed in the appropriate generalized type used in the ranking. This resulted in the creation of Map 4, which contains the ranked soil types. This was all done based on the ranking visible in Tables 5 and 7. It is also based around the established parameters discussed above. Map four enables ease of viewing for this particular criterion and was necessary as a visualization to show readers the criterion ranked and the locations of each ranked soil type.

# Berlin Soils Base Map Map 3

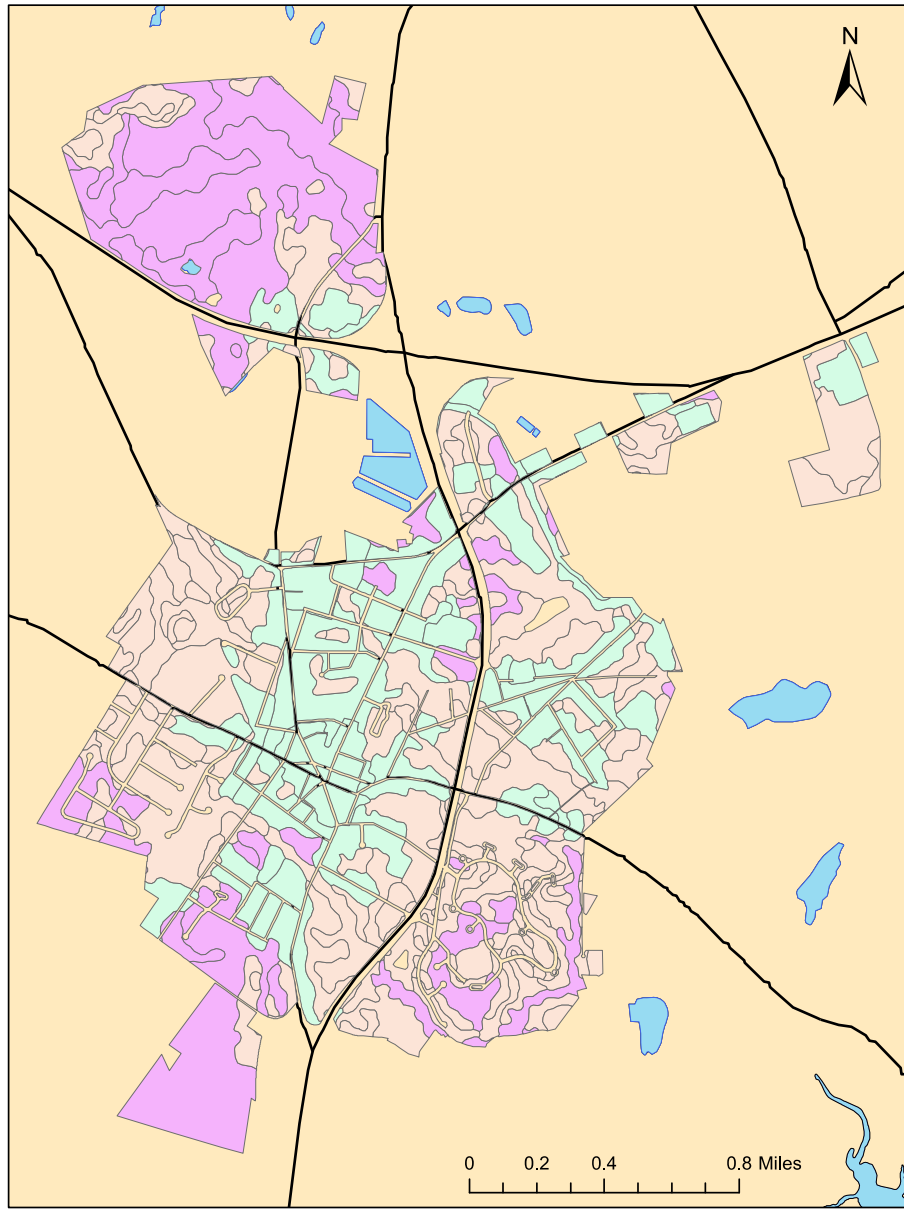


- Worcester County
- Water
- Delmarva Highways

Data Provided By The Town of Berlin Planning and Zoning Department

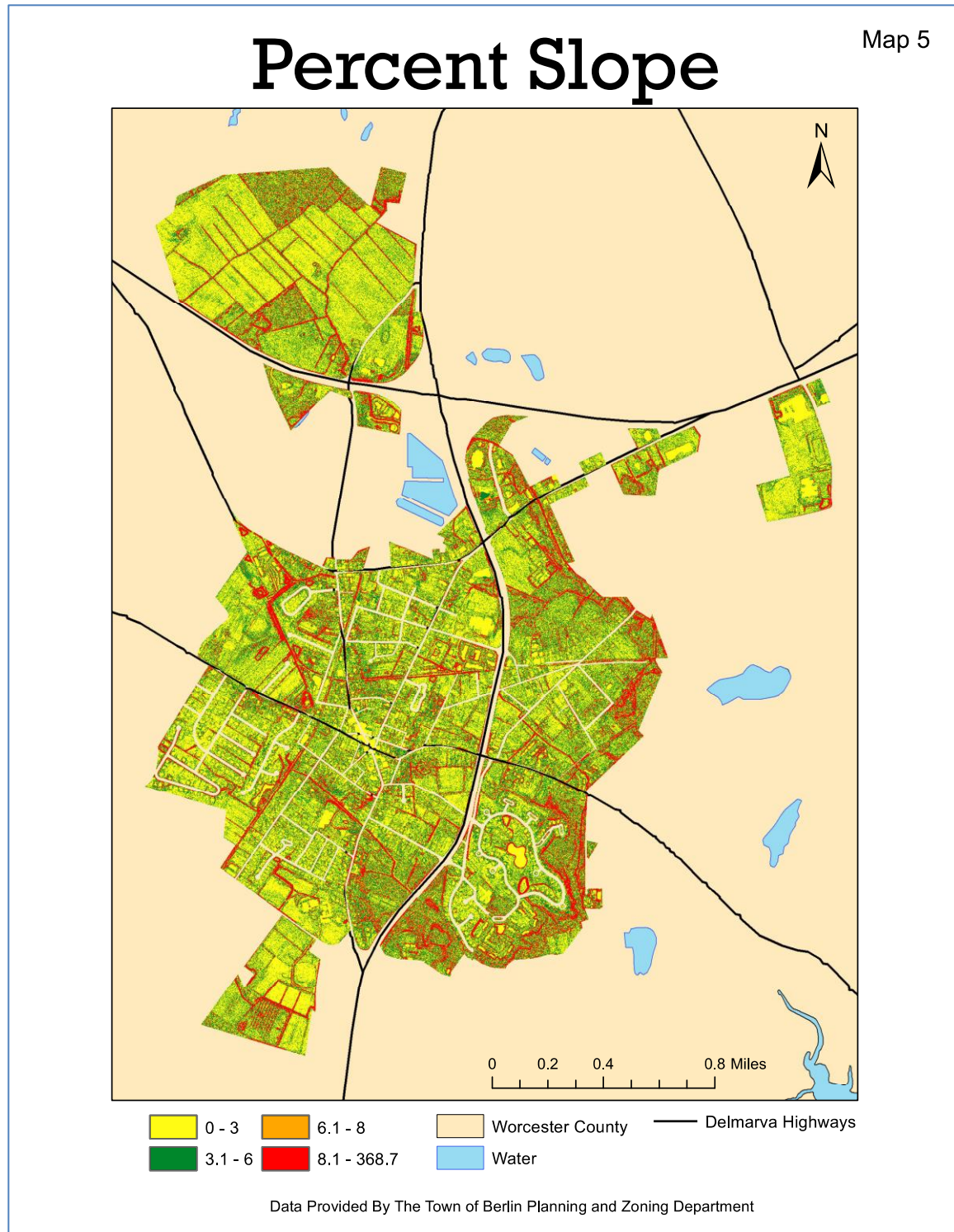
# Berlin Soils Ranked

Map 4



**Berlin Soils 2005**    Medium    Worcester County    Delmarva Highways  
 High    Low    Water

Data Provided By The Town of Berlin Planning and Zoning Department

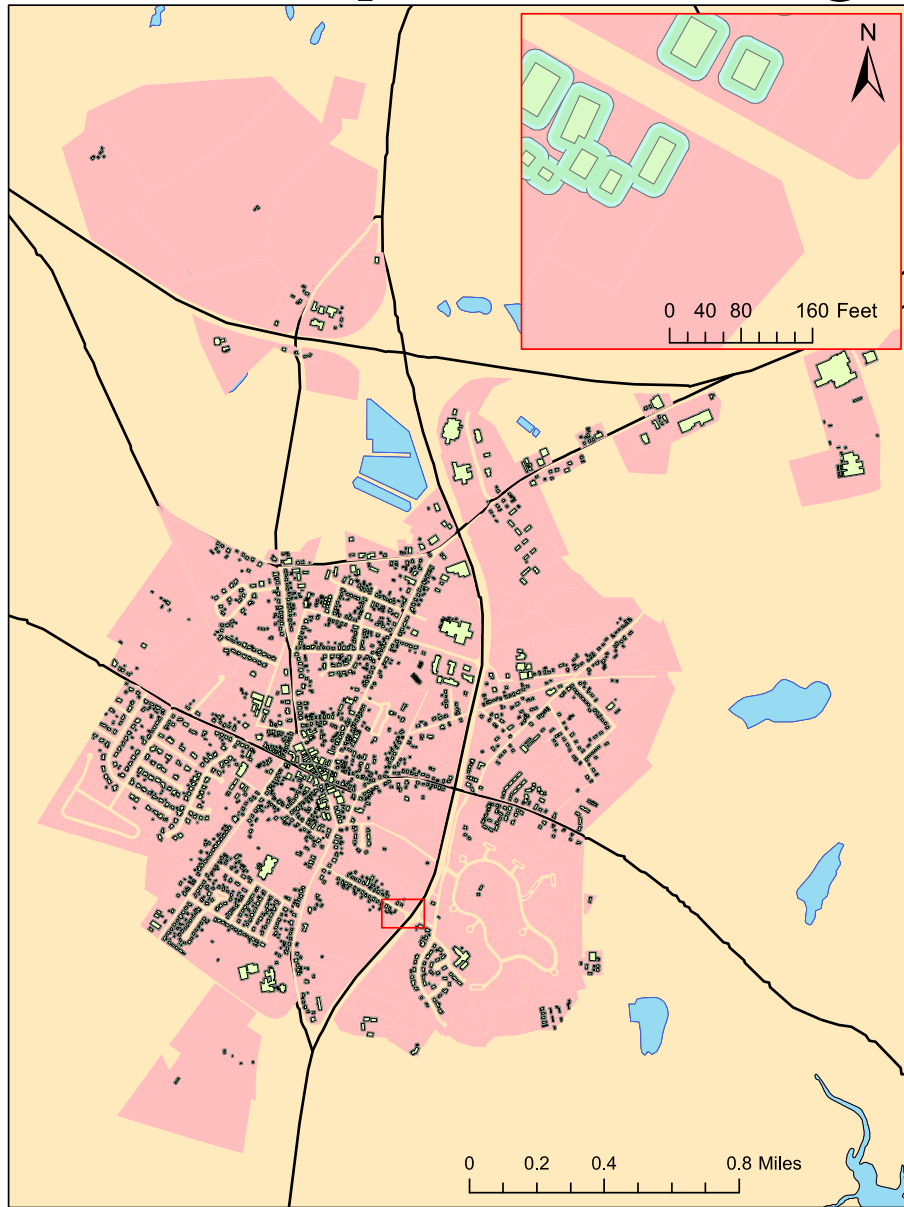


Much as with the ranked soil the ranked slope map, Map 5 above, was created out the established parameters and from subsection 4.1 and the rankings

seen in Tables 5 and 7. Rather than having a less intelligible base map for slope utilizing floating point values only a ranked map was created. This was easily accomplished in the properties function of the raster set in ArcMap, which changed it to the ranked form seen above. This was then reclassified into the basic ranked integer raster used in the model. Map 5 enables ease of viewing for this particular criterion and was necessary as a visualization to show readers the criterion ranked and the locations of each ranked percent slope range.

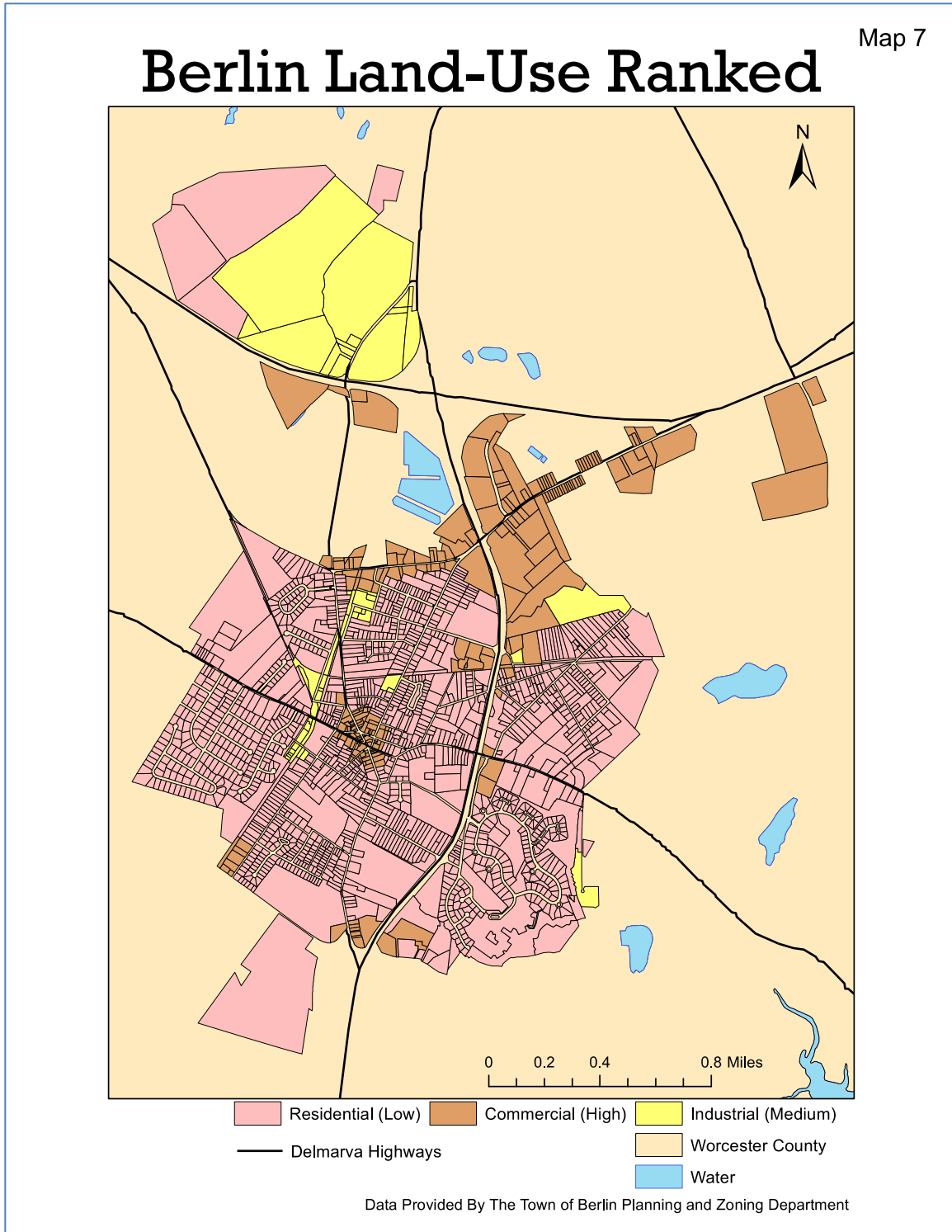
The parameter of proximity to structures was mapped in Map 6 below. Proximity to structures was a significant factor addressed in installation guides for the various green infrastructure tools. Since all green infrastructure utilizes infiltration a ten foot buffer from all buildings will be in place to prevent possible damage to foundations. This was done through a series of buffers. A buffer for 0-10 feet, 10-15 feet, and >15 feet. Map 5 enables ease of viewing for this particular criterion and was necessary as a visualization to show readers the criterion ranked and the locations of each ranked buffer or distance. With this criterion in place unintended damages can be averted.

# Proximity to Buildings Map 6



- 0-10 Ft Buffer
- >15 Ft
- Worcester County
- Delmarva Highways
- 10-15 Ft Buffer
- Berlin Buildings
- Water

Data Provided By The Town of Berlin Planning and Zoning Department



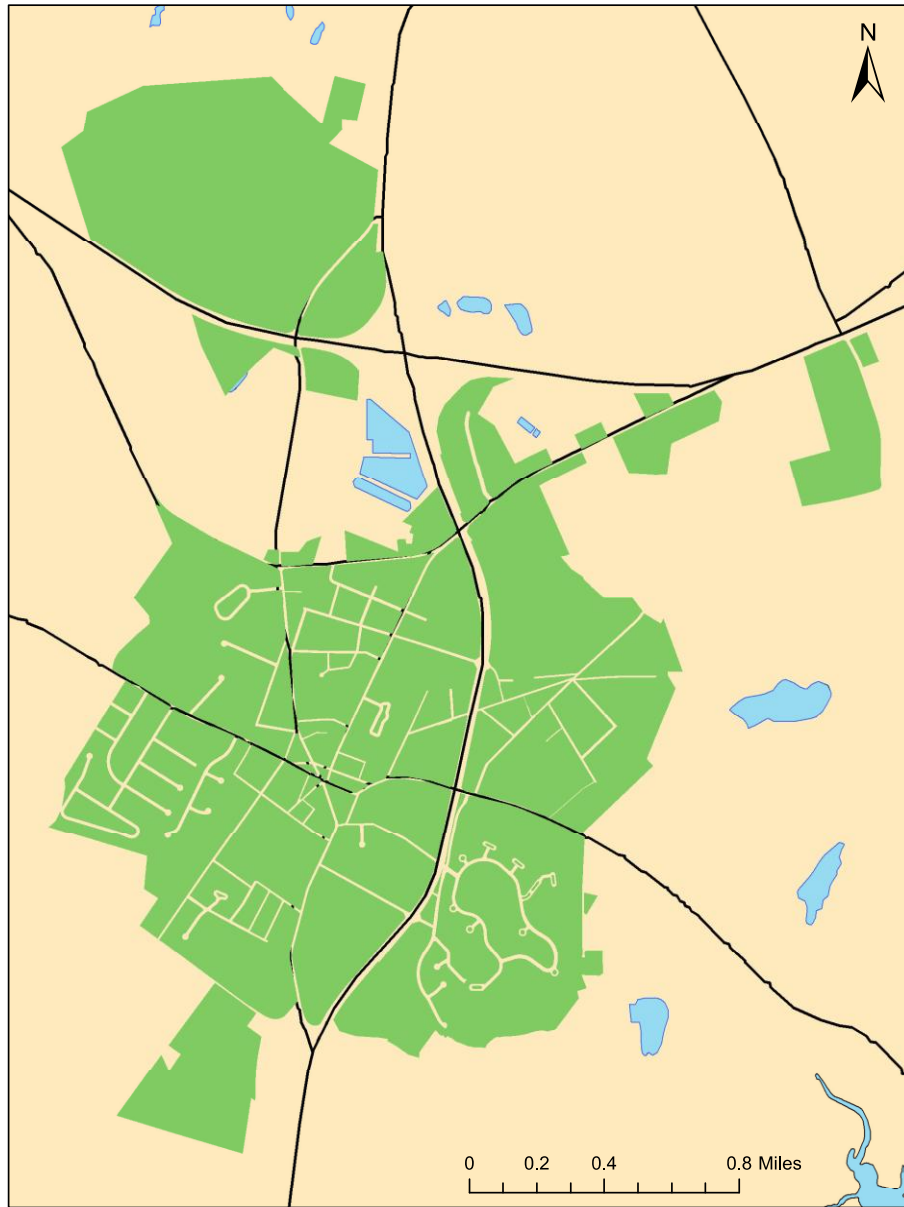
Map 7 seen above contains the ranked land use criterion. This map was created out the established parameters and from subsection 4.1 and the rankings

seen in Tables 5 and 7. No base map was created for this as with every criterion besides soil though a basis can be seen in Map 2, which contains the town's zoning. This was easily accomplished in the properties function of the data set in ArcMap, which changed it to the ranked form seen above. This was then converted into the basic ranked integer raster used in the model. Map 7 enables ease of viewing for this particular criterion and was necessary as a visualization to show readers the criterion ranked and the locations of each ranked land use.

Map 8 seen below contains the ranked land use criterion. This map was created out the established parameters and from subsection 4.1 and the rankings seen in Tables 5 and 7. Based on the nature of the data no base map was necessary for this criterion. The designated minimum depth is two feet, which means that in order for an area to qualify based on this criteria it must have presently and historically a depth of more than two feet before reaching ground water. The data from this portion of the analysis came from a USGS monitoring well. Data for individual locations within Berlin town limits was unavailable and unfeasible to collect. Due to this limitation the USGS monitoring well, which was applied to the ground water levels for the county was used. Though limited in this application with additional tie and resources this criterion could be greatly expanded on and thus much more valuable warranting a greater weight in analysis. Map 8 enables ease of viewing for this particular criterion and was necessary as a visualization to show readers the criterion ranked.



# Ranked Depth to Ground Water Map 8



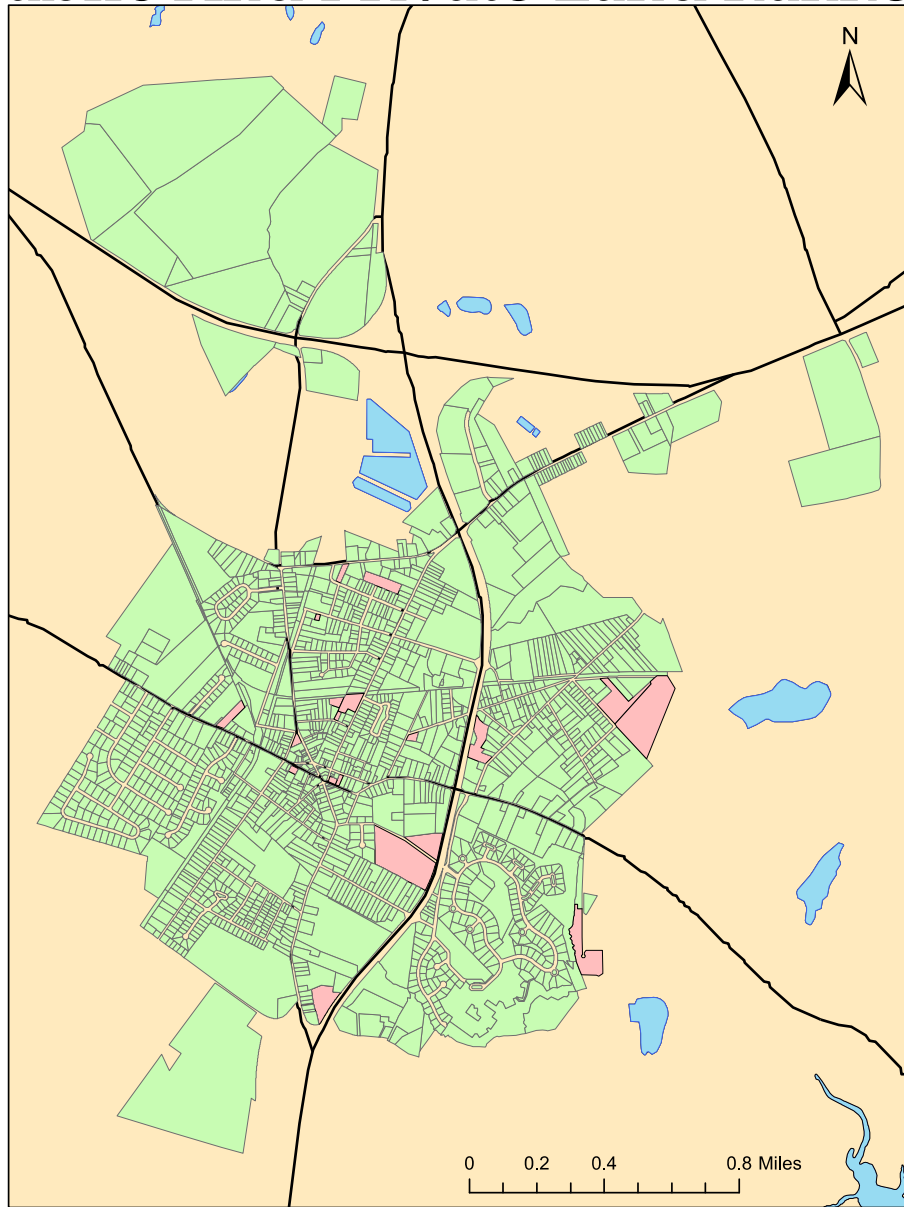
- Worcester County
- Medium (2)
- Water
- Delmarva Highways

Data Provided By The Town of Berlin Planning and Zoning Department

Map 9 seen below contains the ranked public versus private land. This map was created out the established parameters and from subsection 4.1 and the rankings seen in Tables 5 and 7. No base map was created for this as with every criterion besides soil though a basis can be seen in Map 2, which contains the town's zoning. This map was created with land use data and cross-referenced land ownership data from GIS parcel centroids containing the pertinent data. Publicly owned land in ideally located terrain is easily and efficiently applied with green infrastructure. Privately owned land while not necessarily difficult poses the serious risk of being so. With this in mind public land received a higher ranking than private land. Map 9 enables ease of viewing for this particular criterion and was necessary as a visualization to show readers the criterion ranked and the locations of the public and private land.

Map 9

# Public And Private Land Ranked

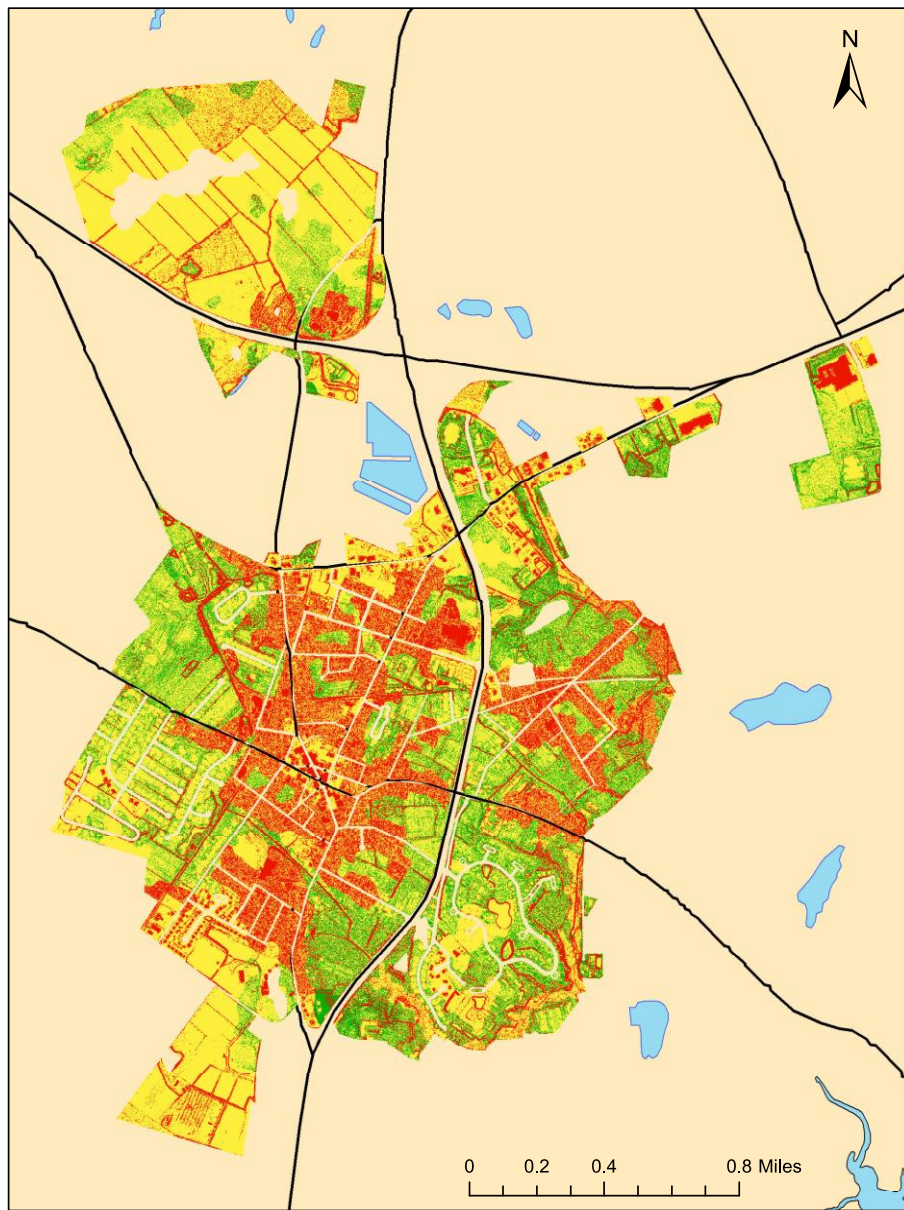


- 1 — Delmarva Highways
- 3
- Worcester County
- Water

Data Provided By The Town of Berlin Planning and Zoning Department

# Weighted Overlay Analysis

Map 10



- Low (1)
- High (3)
- Worcester County
- Medium (2)
- Delmarva Highways
- Water

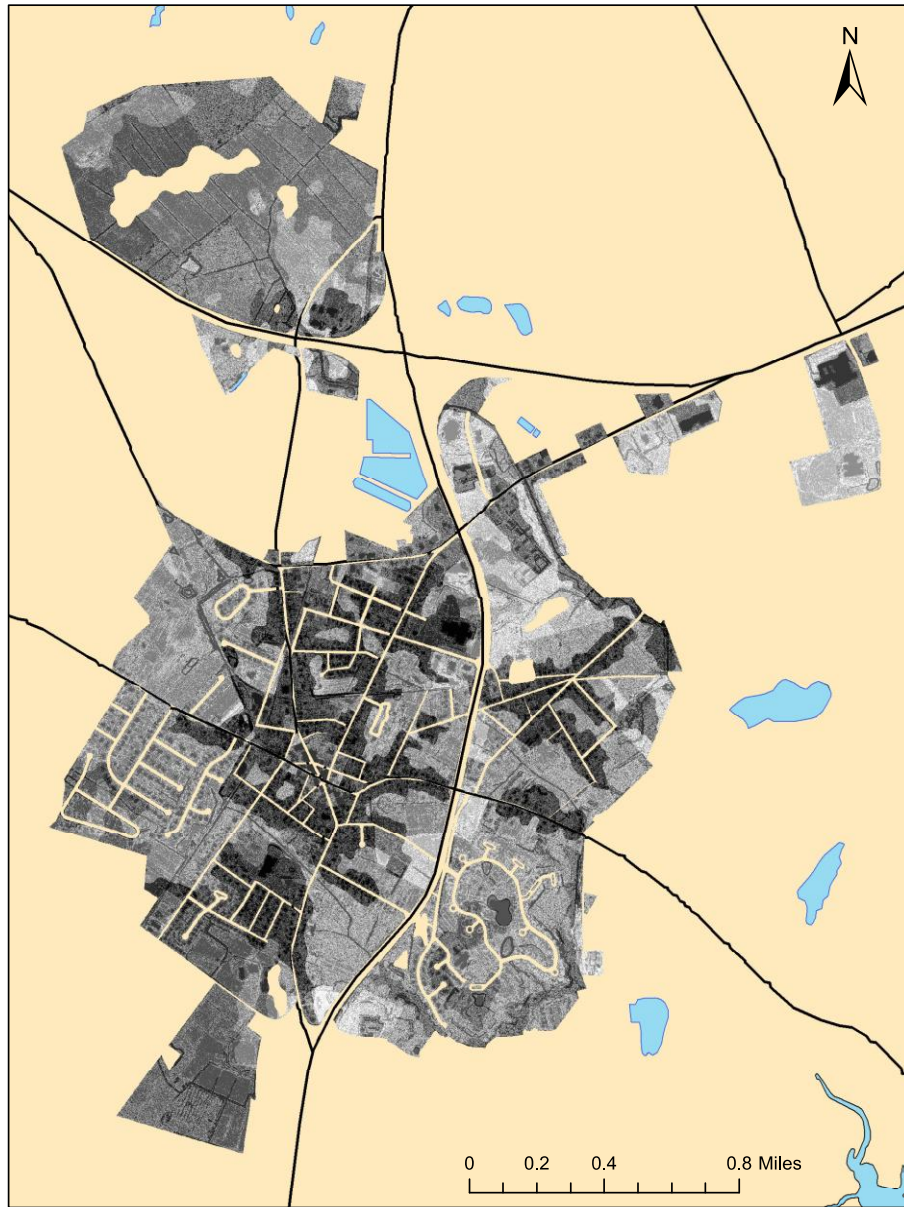
Data Provided By The Town of Berlin Planning and Zoning Department

Map 10 seen above contains one of the main analyses done by this study. This map was created out of the established parameters from subsection 4.1 and

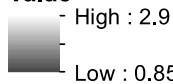
Table 7 and its accompanying Figures 2 and 3. The weighted overlay tool only enables an integer raster. The weighted overlay can be navigated to in the toolbox in ArcCatalogue and ArcMap through the following path Extensions > Spatial Analyst > Spatial Analyst functional reference > Overlay (Spatial Analyst). This resulted in the above map after the weighting from Tables 6 and 7 and equation from Figure 2 were applied. The model can be seen in Figure 3. The overlay analysis incorporates all the rasterized criteria within the model. Each raster cell in the outputs will have had the equation in Figure 2 applied to it. This map provides a ranked suitability for green infrastructure in the study area. It was immensely helpful as visualization by enabling easy prioritization of areas or locations.

Map 11 seen below contains the other main analysis done by this study. This map was created out of the established parameters from subsection 4.1 and Table 7 and its accompanying Figures 2 and 3. The weighted sum tool allows for floating point values. The weighted sum can be navigated to in the toolbox in ArcCatalogue and ArcMap through the following path Extensions > Spatial Analyst > Spatial Analyst functional reference > Sum (Spatial Analyst). This resulted in the below map after the weighting from Tables 6 and 7 and equation from Figure 2 were applied. The model can be seen in Figure 3. The weighted sum analysis incorporates all the rasterized criteria within the model. Each raster cell in the outputs will have had the equation in Figure 2 applied to it. This map provides a floating-point value map for green infrastructure in the study area. It was immensely helpful as visualization by enabling detailed location of suitable locations not available in the weighted overlay.

# Weighted Sum Analysis



**WSum Value**



- Delmarva Highways
- Worcester County
- Water

Data Provided By The Town of Berlin Planning and Zoning Department

## Chapter 6

### Conclusion

#### 6.1 Conclusion and Implications

In all this study has done a considerable amount of research. Various pertinent topics were defined and addressed in detail; the second chapter was where this was done. It consisted of the subsections of Identifying the Study Area of the Town of Berlin in Detail, Suitability Study Descriptions and Comparisons, Feasibility Vs. Suitability and the Flaws of Current Feasibility Studies, Storm Water Management Descriptions and Identification of Systems, Green Infrastructure it's Definition, Tools, Methods, and Relevance, and LIDAR it's Definition, Components, and Products. This provided the review of the topics and gave the the knowledge base for the rest of the study. From there the actual study is defined in the methodology. The subsections for the chapter consisted of Data Collection, Data Formatting, and Conducting the Analysis. With methods in place the analysis was conducted. The subsections for this were Establishing Parameters, Ranking the Criteria, Weighting the Criteria, and The Model. This showed the actual analysis in detail. Finally were the results of all this effort; a functional model and the map products produced by it and in conjunction with it.

The model function exactly as intended and provided and excellent view of the areas best suited for green infrastructure. A majority of the Town of Berlin based on the model shows a medium range of potential for implementation of green infrastructure. There were comparatively few places of low suitability with these being mostly clustered in the east portion of the town. This can be seen in

maps 10 and 11. Also noticeable is a slight clustering of high suitability cells in the western half of town, which was also visible in the maps. The weighted overlay map as a visualization enabled easy prioritization of areas or locations for location of green infrastructure. The weighted sum map provided detailed locations of individual cells or suitable locations not available in the weighted overlay. These combined gave rise to the above locations of suitability and enable the reaching of a fairly simple conclusion. This conclusion was that the town of Berlin as a whole is suitable for the implementation of green infrastructure and should in practice apply it more.

The conclusion reached has planning implications for the Town of Berlin. With the suitable locations in the Town Identified not only in a prioritized manner as seen in the weighted overlay but on an individual basis in the weighted sum map various practices could be implemented with this detailed knowledge. Using the weighted overlay an incentive based program could easily be implemented within the town in order to garner more interest in the implementation of green infrastructure. This as with suitability would be tiered with the areas of highest suitability having the most incentives to implement the green infrastructure tools. The model and the information contained within it and the study as a whole could be used to provide education of the benefits and to provide reasoning and logic behind the program and green infrastructure in general. This more than anything is the most important implication of the research. Increasing education and understanding of the topic is pivotal if true change were to occur. With this in mind various levels of plans could be implemented.



A strategic plan for green infrastructure developing goals and objectives for the concept and its place within the community could be done. From the strategic plan individual neighborhood plans could be created in order to provide focus and detailed guidance to specific areas of the town. The development of a neighborhood plan would also enable ease of focus on the areas of highest suitability. Both the neighborhood and strategic plans would fall under the town's comprehensive plan and would provide meaningful and directed effort towards meeting municipal goals as well as the goals of improved environment and increased emphasis on green infrastructure seen in the State as a whole. A major area of concern for anything done would be funding but this is a misplaced worry there are various funding opportunities available. The EPA has an entire page dedicated to identifying grants for issues such as this (EPA, 2012). There are also always various grants and funding opportunities available at the State level. All this combined with the conclusion reached through the study creates the hope that this model and green infrastructure as a whole will lead to positive changes and improved policy based on sound research.

#### 6.2 Limitations in the Study and Possible Future Research

This research was conducted in a sound manner and has a reliable basis. Despite this as with all research there are various limitations such as data acquisition, time, finance, etc. Limitations inevitably occur in research. There were limitations apparent in the study simply create the opportunity for improvement in future research. These limitations occurred in the data collection for the depth to ground water and the basis for the weighting.

The depth to ground water was restricted by data availability. As seen in Map 8 the criterion res perfectly uniform across the entire town. This is because there was only a single data source available. The data from this portion of the analysis came from a USGS monitoring well. The well used has been collecting data since 1975. So while an extensive history was available more detailed information was not available. The town does have four wells used for municipal water but again the depth to ground water information was not unobtainable. Collection of this data for individual locations within Berlin town limits was unavailable and unfeasible to collect. These limitations resulted in the uniform application of the criterion. This did not and does not harm its validity however. As stated above more detailed information existed even if it was not possible to collect it for the study. It also opens more possibilities in future research. If this model was applied at the county level in Worcester County Maryland which has the same needs and difficulties as the towns with it like Berlin then the criterion of Depth to groundwater could be viewed in much greater detail since there would be ample more USGS wells with easily accessed data available. So while imperfect in this study it is an excellent criterion with ample potential for future applications.

Scope was also a limiting factor. Scope in terms of the criteria was limited due to the limited inclusion of social factors. . In terms of scope of the applied criterion the emphasis is on technical requirements but also on a modest level incorporates perception and other social factors through the land-use and public versus private land criteria. While social aspects are considered they are not central to the scope of this study. This comparative lack of social elements or criteria within

the study is a limiting factor but the nature of the model enables their possible inclusion or consideration in future research.

Scope in terms of scale was also limited. While the intended scale of the model and study was the municipal level it could be applied to larger areas. The scope of the model's applicability is limited to municipal level or larger scales though. This is because with the type and quality of the data and by the nature of the analysis the model is unsuited for site level analysis. This means the model was excellent for initial mapping and general site selection but was unsuited for actual site level analysis. This may be addressed in future research through improved data and adjustment of the criteria.

Issues emerged in the basis for weighting as well. While all aspects of the model including the weighting have a strong basis in the literature the weighting does not have as sound of a backing as would have been preferable. The weighting emerged from the literature and from the Central New York study in particular. This study along with other literature was combined with personal opinion to determine the weighting for each criterion. This was a sound basis for the weighting and made sense but it would have been preferable for each weight to have statistical backing. Ideally for this study experts would have been polled on the weighting and each criterion's weight assigned from the mean value chosen by the experts. This would have added to the quality and legitimacy of the selected values. This was not done due to the constraints on time the surveying would have caused. Again while preferable it was not necessary and the model functioned admirably with its basis in the available literature. This as with depth to ground water rather than dragging

down the model provides important opportunity for future research and improvement. In future research the surveying could be applied or in the case of a municipality it would be prudent to additionally survey residents and thus incorporate the opinions into the model and selection process. These would both strengthen the model and benefit the individual applying it.

There are other possibilities for future research. Other possible future research could stem around the adding of criteria making the model more precise. What could be added and why would depend on the scale and nature of data available. If a full or more complete impervious surface inventory were available it would be a prime candidate for incorporation into the model regardless of scale. At larger scales such as at a county level would be more ideal for incorporation of a vegetation criterion as discussed on page 60 above. Also discussed on page 60 and page 61 is the presence of floodplains, which was used in the Central New York study. This means it may make more sense to incorporate the criteria on this level and thus would add an additional facet to the model. At these larger scales the presence of wetlands could be incorporated leading to better integration into the natural environment. So while this topic or concept is not new it is far from expended. This study has added to the concept and understanding of the suitability modeling process and exposed the opportunity for further development.

## Bibliography

- Althos. (2009). *Wireless Dictionary*. Retrieved December 5, 2010, from Wireless Dictionary:  
[http://www.wirelessdictionary.com/wireless\\_dictionary\\_gps\\_rtk\\_gps\\_definition.html](http://www.wirelessdictionary.com/wireless_dictionary_gps_rtk_gps_definition.html)
- Army Corps of Engineers. (2009). *Green Infrastructure Design*. Retrieved February 10, 2012, from City of Nashville:  
[http://www.nashville.gov/stormwater/docs/other/Green Infrastructure Design\\_final.pdf](http://www.nashville.gov/stormwater/docs/other/Green_Infrastructure_Design_final.pdf)
- Army Corps of Engineers. (2007). *Stormwater System Improvement Study For The Town Of Berlin, Worcester County, Maryland*. Baltimore: Army Corps of Engineers Baltimore District
- Athearn, N. D. (2010). Mapping Elevations of Tidal Wetland Restoration Sites in San Francisco Bay: Comparing Accuracy of Aerial Lidar with a Singlebeam Echosounder. *Journal of Coastal Research* Vol 26(2), 312-319.
- Campbell, J. B. (2007). *Introduction to Remote Sensing*. New York: The Guildford Press.
- Central New York Regional Planning & Development Board. (2012). *Green Infrastructure Planning for Improved Stormwater Management in Central New York*. Central New York Regional Planning & Development Board.
- Chesapeake Bay Foundation. (2011). *What We Do*. Retrieved February 12, 2012, from Chesapeake Bay Foundation: <http://www.cbf.org/page.aspx?pid=515>
- City of New Castle. (2010). *MS4 Public Notice - Storm Water Separation*. Retrieved February 11, 2012, from MS4 - Municipal Separate Storm Sewer System: <http://209.43.125.207/departments/division.php?fDD=14-76>
- City of Omaha. (2009). *Long Term Control Plan for the Omaha Combined Sewer Overflow Control Program*. City of Omaha.
- Clark, M. (2008). *Florida Field Guide to Low Impact Development*. Retrieved February 10, 2012, from University of Florida:  
[http://buildgreen.ufl.edu/Fact\\_sheet\\_Bioretention\\_Basins\\_Rain\\_Gardens.pdf](http://buildgreen.ufl.edu/Fact_sheet_Bioretention_Basins_Rain_Gardens.pdf)
- Cubit. (2012). *Berlin Town Census 2010 Data - Population*. Retrieved February 12, 2012, from Cubit Demographic Data:  
<http://www.cubitplanning.com/city/7124-berlin-town-census-2010-population>
- Cudahy, N. (2010). *Sustainable Landscapes*. Nebraska Department of Environmental Quality. City of Omaha.
- Earth Partnership for Schools. (2000). *Identifying Your Soil for Rain Gardens*. Retrieved February 12, 2012, from University of Wisconsin – Madison Arboretum:  
[http://uwarboretum.org/eps/research\\_act\\_classroom/rain\\_garden/2%20Perform%20Site%20Analysis/Identifying%20Soil%20for%20RG%202-3.pdf](http://uwarboretum.org/eps/research_act_classroom/rain_garden/2%20Perform%20Site%20Analysis/Identifying%20Soil%20for%20RG%202-3.pdf)
- Environmental Science and Forestry. (2012). *Green Infrastructure Initiative*. Retrieved Feb 2, 2012, from State University of New York College of Environmental Science and Forestry: <http://www.esf.edu/outreach/gi/>

- EPA. (2003). Clarification Of The Definition Of Storm Water Discharges Associated With Industrial Activity And Small Construction Activity. Denver, CO, United States.
- EPA. (1994). *Combined Sewer Overflow (CSO) Control Policy; Notice*. Retrieved February 11, 2012, from Environmental Protection Agency: <http://www.epa.gov/npdes/pubs/owm0111.pdf>
- EPA. (2008). *Combined Sewer Overflows Demographics*. Retrieved February 11, 2012, from Environmental Protection Agency: <http://cfpub.epa.gov/npdes/cso/demo.cfm>
- EPA a. (2010). *Environmental protection Agency*. Retrieved February 5, 2012, from EPA Office of Wetlands, Oceans and Watersheds: [http://www.epa.gov/owow/NPS/lid/gi\\_case\\_studies\\_2010.pdf](http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf)
- EPA b. (2010). *EPA Office of Wetlands, Oceans, and Watersheds*. Retrieved February 3, 2012, from Environmental Protection Agency: [http://www.epa.gov/owow/NPS/lid/gi\\_case\\_studies\\_2010.pdf](http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf)
- EPA. (2012). *Grant and Funding*. Retrieved April 14, 2012, from Environmental Protection Agency: [http://water.epa.gov/grants\\_funding/](http://water.epa.gov/grants_funding/)
- EPA a. (2011). *Maryland Coastal Bays - National Estuary Program*. Retrieved February 12, 2012, from Environmental Protection Agency: [http://www.epa.gov/reg3wapd/estuaries/md\\_coastal\\_bays.htm](http://www.epa.gov/reg3wapd/estuaries/md_coastal_bays.htm)
- EPA b. (2011). *National Pollutant Discharge Elimination System (NPDES)*. Retrieved February 11, 2012, from Environmental Protection Agency: [http://cfpub.epa.gov/npdes/npdesreg.cfm?program\\_id=45](http://cfpub.epa.gov/npdes/npdesreg.cfm?program_id=45)
- EPA c. (2011). *NPDES Permit Program Basics*. Retrieved February 11, 2012, from Environmental Protection Agency: [http://cfpub.epa.gov/npdes/home.cfm?program\\_id=45](http://cfpub.epa.gov/npdes/home.cfm?program_id=45)
- EPA d. (2011). *Polluted Runoff Fact Sheets*. Retrieved February 12, 2012, from Environmental Protection Agency: <http://water.epa.gov/polwaste/nps/urban.cfm>
- EPA. (2000). *Stormwater Phase II Final Rule*. Retrieved February 11, 2012, from Environmental Protection Agency: <http://www.epa.gov/npdes/pubs/fact2-0.pdf>
- ESRI. (2010). *ArcGIS Desktop Help*. Retrieved January 29th, 2012, from ESRI Support Center: [http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Types\\_of\\_geodatabases](http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Types_of_geodatabases)
- Farlex. (2010). *The Free Dictionary*. Retrieved December 5, 2010, from The Free Dictionary: <http://encyclopedia.thefreedictionary.com/Inertial+Measurement+Unit>
- FEMA a. (2007). *Flood Risks Across The Country*. *FEMA Library*. Retrieved April 10, 2011, from FEMA: <http://www.fema.gov/library/viewRecord.do?id=2830>

- FEMA b. (2007). *Flood Risks Across The Country*. Retrieved April 10, 2011, from National Flood Insurance Program.  
[www.floodsmart.gov/.../flood/.../FloodRisksAcrossCountry-11%2019](http://www.floodsmart.gov/.../flood/.../FloodRisksAcrossCountry-11%2019)
- Firehock, K. (2010). *A Short History of the Term Green Infrastructure and Selected Literature*. Retrieved February 3, 2012, from  
<http://www.gicinc.org/PDFs/GI%20History.pdf>
- Garrity, C. P. (2004). *Digital Cartographic Production Techniques Using Airborne Interferometric Synthetic Aperture Radar (IFSAR)*. Retrieved December 7, 2010, from USGS Publications:  
<http://pubs.usgs.gov/of/2004/1451/pdf/garrity.pdf>
- Gauldie, R. (1996). *LIDAR applications to fisheries monitoring problems*. Can. J. Fish. Aquatic Science, 1459-1468.
- Hammond, E. (2008). President of the Berlin Historical Commission & Taylor Museum. (R. Marney, Interviewer)
- Irish, J. L. (1998). *Coastal engineering applications of high-resolution lidar bathymetry*. Coastal Engineering, 47-71.
- Jacques, S. (2003). *ESRI Forum*. Retrieved January 29, 2012, from ESRI ArchGIS:  
<http://forums.esri.com/Thread.asp?c=93&f=985&t=104741>
- Marrs, C. (2009). *River Dee Green Infrastructure Feasibility Study*. Mercey Dee Alliance. Warrington: Genesis Centre.
- Maryland Coastal Bays Program. (2012). *Who We Are*. Retrieved February 12, 2012, from Maryland Coastal Bays Program:  
<http://www.mdcoastalbays.org/who-we-are>
- Maryland Department of Environment. (2005). *Environmental Matters*. Retrieved January 31, 2012, from Department of Environment:  
<http://www.mde.state.md.us/aboutmde/EnviroMatters/Documents/www.mde.state.md.us/assets/document/Enviromatters092005.pdf>
- McHarg, I. (1967). *Design with Nature*. Retrieved February 18, 2012, from  
[http://www.larch.umd.edu/classes/larc/L160/Lecture%20Presentations/Planned\\_Communities\\_11\\_3\\_08.pdf](http://www.larch.umd.edu/classes/larc/L160/Lecture%20Presentations/Planned_Communities_11_3_08.pdf)
- NC Center for Geographic Information and Analysis. (2005). *Land Suitability Analysis User Guide*. Retrieved February 18, 2012, from NC Division of Coastal Management: [http://dcm2.enr.state.nc.us/planning/user\\_guide\\_lsa2005.pdf](http://dcm2.enr.state.nc.us/planning/user_guide_lsa2005.pdf)
- NDEP, N. D. (2004). *Guidelines for Digital Elevation Data*. Retrieved December 7, 2010, from USGS Publications:  
[http://www.ndep.gov/NDEP\\_Elevation\\_Guidelines\\_Ver1\\_10May2004.pdf](http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf)
- Pincock, A. (2004). *Feasibility Study Does Not Mean Feasible*. Retrieved February 11, 2012, from Pincock Perspectives:  
<http://www.pincock.com/perspectives/Issue57-Feasibility-Study.pdf>
- Randolph, J. (2004). *Environmental Land-Use Planning and Management*. Washington DC: Island Press.
- Reutebuch, S. E. (2005). Light Detection and Ranging (LIDAR): An Emerging Tool for Multiple Resource Inventory. *Journal Forestry*, 286-292.
- Rutgers. (2011). *Community-Based Green Infrastructure For The City Of Camden*. New Jersey Agricultural Experiment Station. City of Camden.

- Schmugge, T. J. (2002). Remote Sensing in Hydrology. *Advances in Water Resources* , Pages 1367-1385.
- Sheladia, S. (1988). *Green Infrastructure Definitions*. Retrieved February 2, 2012, from EPA Office of Sustainable Ecosystems & Communities :  
[http://www.treelink.org/docs/GreenInf\\_def.PDF](http://www.treelink.org/docs/GreenInf_def.PDF)
- Shuckman, K. (2010). History of Lidar Development. The Pennsylvania State University, Pennsylvania, United States.
- Szatko, A. (2012). City of Omaha Employee: Interview on Green Infrastructure. (R. Marney, Interviewer)
- Taylor, S. (2007). *Images of America Berlin*. Mount Pleasant: Arcadia Publishing SC.
- The Conservation Fund. (2012). *Green Infrastructure* . Retrieved February 2, 2012, from The Conservation Fund: Green Infrastructure :  
<http://www.greeninfrastructure.net/content/definition-green-infrastructure>
- The Conservation Fund. (2006). *Rapid Assessment of Green Infrastructure*. Retrieved February 18, 2012, from Kent County, Delaware:  
[http://www.conservationfund.org/delaware/kent\\_county](http://www.conservationfund.org/delaware/kent_county)
- Town of Berlin Planning Department. (2010). *Comprehensive Plan*. Retrieved February 12, 2012, from Town of Berlin:  
<http://berlinmd.gov/content/docs/ADOPTEDCOMPPLAN061410.pdf>
- USGS. (2012). *Groundwater Levels for Worcester County*. Retrieved February 12, 2012, from National Water Information System: Web Interface:  
[http://nwis.waterdata.usgs.gov/nwis/gwlevels?site\\_no=382325075063302&agency\\_cd=USGS&format=html](http://nwis.waterdata.usgs.gov/nwis/gwlevels?site_no=382325075063302&agency_cd=USGS&format=html)
- USGS. (2009). *Hillshades*. Retrieved December 7, 2010, from USGS:  
<http://earthquake.usgs.gov/regional/nca/bayarea/hillshades.php>
- USGS. (2006). *Topographic Map Symbols*. Retrieved December 7, 2010, from USGS Publications:  
<http://egsc.usgs.gov/isb/pubs/booklets/symbols/topomapsymbols.pdf>
- USGS. (2008). *Use of Light Detection and Ranging (LiDAR) to Obtain High-Resolution Elevation Data for Sussex County, Delaware*. Retrieved December 7, 2010, from Fact Sheet , 1-6.
- USGS. (2001). *USGS Digital Elevation Model Information*. Retrieved December 7, 2010, from USGS: [http://rmmcweb.cr.usgs.gov/elevation/dpi\\_dem.html](http://rmmcweb.cr.usgs.gov/elevation/dpi_dem.html)
- Weber, T. (2006). *Maryland's Green Infrastructure Assessment: Development of a comprehensive approach to land conservation*. *Landscape and Urban Planning*, 77 (1-2), Pg 94-110.