

**GIS-Base Suitability Analysis and Planning of Green Infrastructure:  
A Case of the PPCOD, Capitol Hill**

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A thesis  
submitted in partial fulfillment of the  
requirements for the degree of

Master of Landscape Architecture

University of Washington

2016

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Program Authorized to Offer Degree:

Landscape Architecture

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## **Abstract**

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The combination of the population growth in cities and climate change at a global scale continually requires developed approaches and strategies for our built environments. In the city of Seattle, which is one of the fastest growing cities in population and of the most intense cities in urban heat islands in the U.S., Capitol Hill is a representative neighborhood for these issue, having the highest population density in the city. Also, the Pike/Pine Conservation Overlay District (PPCOD) is a central historic district in Capitol Hill, which is facing intensive pressure of redevelopment. With this background, this thesis starts form recognizing the three pronounced issues in Capitol Hill –lack of green space, stormwater management, and urban heat islands– and addresses that efficiently applied green infrastructure planning, grounded on a specific analysis, can contribute to mitigating the issues and projecting the better neighborhood.

This thesis has a key concept and a key methodology. The key concept is green infrastructure (GI). It is generally accepted with two dimensions: GI as a conceptual meaning of green networks and GI as a practical meaning of stormwater management. Suitability Analysis is a methodology of this thesis. It is an GIS-based overlay method to support the decision-making process by identifying the most and least suitable location for given purposes. In this research, suitability analysis mainly deals with the site's issues by integrating six selected criteria, but also tries to fill gaps between the different definitions of GI.

This research has two major goals. First, by conducting suitability analysis, it will provide the most suitable suggestions of GI for Capitol Hill to improve its built and natural environment. Second, by using suitability analysis, this research will try to fill gaps between the concepts of GI and the practices of GI.

## **Acknowledgements**

I would like to offer my sincere gratitude to my committee, Professor Jeffrey Hou and Professor Manish Chalana, for their expert suggestions, support and patience throughout my thesis. Jeffrey especially inspired me to come up with the thesis's key concepts and helped me wade through my ideas for entire process. Manish provided me with direction, and his class gave me a lot of inspiration for establishing the topic at the first stage of this thesis. Their intellectual contributions were invaluable, and I am more than lucky to have an opportunity to work under their guidance.

Thanks so much to Eunjee Oh for taking care of every aspect of my life outside this thesis. Lastly, I must thank my beloved parents, who always support me. Also I would like to express special gratitude to my father for being the most important mentor of my entire life.

Note: The maps are of good resolution, but not entirely legible in a b/w print out. Please review this thesis on screen, or a color print out will reveal more details.

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# **Chapter 1. Introduction**

## **1.1. Thesis Statement**

Since the Great Recession, many American cities have experienced intensive growth. Many urban areas have been under pressures of new development becoming much denser and more complex. Even though cities have come to provide advanced urban services, such as well-organized urban forms, highways and water supplies, thus making cities more convenient with the development, we have observed that a wide array of urban problems have been markedly exposed on the surface. The problems include loss of biodiversity, air and water pollution, stormwater runoff, urban heat islands, and exponential population growth, which negatively affects both nature and cities themselves. Meanwhile, global climate change has gradually accelerated the problems to be more pronounced by accumulated impacts.

The city of Seattle is the fastest growing city in the U.S. (Balk, 2014). Currently, with a population of more than 660,000 (City of Seattle, n.d.), the city is one of the nation's largest and most diverse in terms of population, economic activity, and transportation options (Puget Sound Regional Council[PSRC], 2013). For decades, with following the trends, the city has converted rural and agriculture lands to urban gray infrastructure, such as parking lots, roads, and buildings. These land conversions have impinged on urban ecosystems, and yet at the same time increased demands for new strategies to aim for a better environment. "Seattle's Comprehensive Plan," "Seattle Green Factor," and "2013 Climate Action Plan" are the city's actions in response to the demands. Now, we need more environmentally focused study, policy and stewardship for our built environment; how we are proactive and reactive to the contemporary conditions will be a key challenge to envision a better Seattle.

Capitol Hill, as a center for that growth, taking into account the highest population density in Seattle (PSRC, 2013), has much responsibility for the aforementioned issues. Currently, many development projects are under progress or recently completed, such as the Capitol Hill Light Rail Station which opened in March, 2016, that are making the neighborhood's system streamlined but much denser and more complex. The Pike/Pine Conservation Overlay District (PPCOD) is an important conservative district, which originated from the city's first auto-row development in the early 20<sup>th</sup> century, and is located at the center of Capitol Hill. But currently, due to the overall growth of the neighborhood, it is facing intensive pressure of redevelopment which is threatening its historic and cultural characters. In regard to its cultural assets and the central location, the district could be a symbol of the negative face of current development-oriented issues in Capitol Hill.

This thesis was started from recognizing the pronounced issues in Capitol Hill. Even though the neighborhood has produced several envisioning plans, including "Capitol Hill EcoDistrict," the environmental issues at a global scale and the rapid growth at a regional scale continually require developed studies and strategies. This thesis ultimately aims to contribute to better approaches for the fastest growing neighborhood in Seattle. Through a widely accepted, environmental concept –green infrastructure (GI)– and a methodology to support decision-making process –suitability analysis–, this thesis will show how GI is effectively applied to the neighborhood by conducting suitability analysis, and how the outcomes are related to mitigating the current issues.

The key concept of this study, green infrastructure (GI), is generally accepted with two dimensions. First, as a conceptual meaning, which is a primary definition by the President's Council on Sustainable Development, GI refers to green networks. This definition aims to

provide environmental connections between green spaces to enforce its ecological functions in both rural and urban areas. The second concept of GI specifically and narrowly focuses on systems and practices for stormwater management. To alleviate the contemporary pronounced issues of stormwater runoff, this definition addresses that the original concept can be extended and specified by comprehensive practices of stormwater management (Wise, 2008).

Suitability analysis is an overlay method to support the decision-making process by identifying the most and least suitable location for specific purposes. In this research, suitability analysis not only deals with the two related but different concepts of GI but also is intended to fill gaps between them. By using a modeling tool, ModelBuilder, of ArcGIS with publicly accessible GIS data from governmental websites, such as KCGIS Center<sup>1</sup> and WAGDA<sup>2</sup>, and Landsat 7 data, this research will generate several visual outcomes of the analysis to represent the most suitable locations of GI networks and GI practices in Capitol Hill. Further, based on the outcomes, a suggestion in planning dimension on the PPCOD will be created to show a link between analysis (methodology) and application (practices).

In sum, this research has two major goals. First, by conducting suitability analysis, it will provide the most suitable suggestions of GI for Capitol Hill to improve its built and natural environment. Second, by using suitability analysis, this research will try to fill gaps between the concepts of GI and the practices of GI.

To address the two goals in a logical organization, the study is comprised with seven chapters. The outline of each chapter is described as following:

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<sup>1</sup> King County GIS Center: <http://www.kingcounty.gov/operations/GIS.aspx>

<sup>2</sup> Washington State Geospatial Data Archive: <https://wagda.lib.washington.edu/>

## 1.2. Thesis Structure

**Chapter 2** reports concepts and practices of green infrastructure, introduces a methodology of this research, suitability analysis, and explores four related case studies to show current states of application of the methodology. Based on two commonly accepted, different definitions of GI, this chapter argues that there is evident uncertainty and ambivalence –gaps between concepts and practices– in current scholarships of GI by referencing several literatures. Then, it explicates suitability analysis –an overlay process– as methodology that can fill the gaps in planning dimensions. Four case studies do not only show practical applications of suitability analysis but also provide important references, such as criteria establishment and reasoning for weighting, to guide the detailed process of this research.

**Chapter 3** discusses what issues the sites of this research, the Pike/Pine Conservation Overlay District and Capitol Hill, face. By exploring the site with two different approaches, built environment and green/natural environment, this chapter concludes that there are three major, pronounced issues in Capitol Hill: a lack of green spaces caused by the rapid development; demands for better stormwater management related to its sewage systems, topography, and precipitation; and urban heat islands issues that result from the rapid growth and global warming. This chapter arguably addresses that the suitability analysis of this study should be associated with or grounded on the three issues.

**Chapter 4**, as a methodology chapter, explains the overall process of suitability analysis of this study: how the data are collected from a variety of accessible GIS data resources, how the criteria, selected data for the analysis, are established, what reasoning process (scenario development) is created for ranking and weighting the criteria, and how the overlay process is

conducted by using ArcGIS are clarified in details in this chapter. This chapter will play the most significant part in this thesis for readers to understand logics and technical grounds.

**Chapter 5** is divided into two sections. In the first section, it visualizes six criteria, including slope degree, flow accumulation, soil infiltration, surface temperature, population density, and parcel use. Each criterion is reformatted in response to suitability of GI practices and is closely explained in terms of the site issues, mentioned in Chapter 3. The second section is a comprehensive discussion of the outcomes of suitability analysis. The different results of the GIS-based suitability model under the scenarios developed are compared and examined. The outputs of this process directly connect to the conclusion of this research.

**Chapter 6** suggests a draft planning based on the result shown in the previous chapter. The suggestion is created in order to show what GI practices can be implemented on the PPCOD. This suggestion mainly represents how the methodology –suitability analysis– can be applied on the ground based on the planning scaled data analysis.

**Chapter 7** summarizes the results and draws a conclusion of this thesis. This chapter discusses implication of suitability analysis in terms improving urban areas. Also, it shows the limitations and challenges of this research, and discusses further research.

## **Chapter 2. Literature Review**

This chapter provides background scholarships to support this research as well as acts as a primary step to establish methodology of suitability analysis used in this study. Through exploring related literatures and scholarships, it helps shape an understanding of what this study addresses and aims to research on. This chapter can be divided into three parts: Chapter 2.1 and 2.2 explicitly describe green infrastructure, questioning how the concept is understood and applied, and what functions of green infrastructure we can expect from planning. Chapter 2.3, as a transition to the following sections, briefly describes deficiency of today's green infrastructure planning. Chapter 2.4 and 2.5 explore suitability analysis as one of the alternatives to the deficiency. They are mainly about methodology that clarifies what degree of success has been achieved and how it has been applied to different cases.

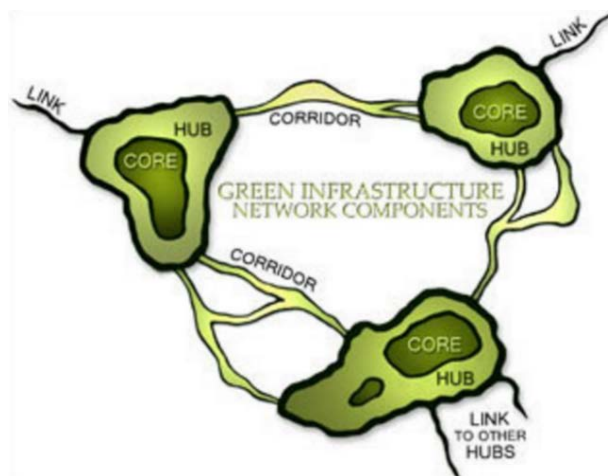
### **2.1. Concepts of Green Infrastructure**

#### ***Green Infrastructure as Green Network***

The term, “Green Infrastructure” (GI), was first introduced into a mainstream planning practice in May 1999 by the President’s Council on Sustainable Development (PCSD) and was identified as one of several key strategies for an achievement of sustainability. The council defined GI as “a network of open space, airsheds, watersheds, woodlands, wildlife habitat, parks, and other natural areas that provides many vital services that sustain life and enrich the quality of life” (PCSD, 1999). Since that time, the concept of GI has contributed to knowledges to better understand cities’ sustainability by providing a practical meaning of social, economic, and environmental benefits (Pankhurst, 2012; LaGro et al., 2014). GI has also played an important

role in allowing our built environment to benefit from ecological and working landscape by addressing that healthy landscapes are essentially involved in human health, vitality and quality of life (Mell, 2010; Allen, 2012).

With this worldwide emergence of GI, there have been numerous research and discourses to explicitly develop the concept of GI in response to a wide array of actions occurring in contemporary built environment (Young et al., 2014). Mostly, definitions of GI align with the overarching original concept by the PCSD, stated above (Allen, 2012). Mark A. Benedict and Edward T. McMahon (2006) broadened this definition by approaching GI as two aspects, ‘noun’ and ‘adjective,’ in a book, *Green Infrastructure: Linking Landscapes and Communities*. As a noun, GI refers to “an interconnected green space network that is planned and managed for its natural resources values...” and as an adjective, they described it as “a process that promotes a systemic and strategic approach to land conversion...for nature and people” (Benedict & McMahon, 2006). Another definition, promulgated by England’s Planning Policy Statement 12, is also closely accompanied with the original concept, defining GI as “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



**Figure 1 Conceptual Diagram of Green Infrastructure as Green Network**  
Source: <http://calumetstewardship.org/smart-growth>

communities” (Department for Communities and Local Government, 2008). Figure 1 illustrates the concept of GI as a green network.

### ***Green Infrastructure as Stormwater Management***

Recently, several publications have projected a second concept of GI which narrowly and specifically focused on stormwater management. With regards to the quality of water –including rivers, streams, lakes and estuaries– which is sensitively affected from development and urbanization, the second definition addresses that the original concept of GI can be extended and specified by comprehensive practices of stormwater management (Wise, 2008). United States Environmental Protection Agency (EPA, 2015) refers to GI as “a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits... green infrastructure reduces and treats stormwater at its source ...” highlighting runoff reduction and flood mitigation. Also, Center for Neighborhood Technology and American Rivers (CNT & American Rivers, 2012) noted that “Green infrastructure is an approach to water management that uses natural systems”.

This concept is widely named as Green Stormwater Infrastructure (GSI). It is an emerging approach of urban greening in the United States and other countries which have outdated combined sewer systems that are subject to overflow during heavy rain (Kondo et al., 2015). With the specified definition and purpose, GSI approaches are largely applied on a small scale and in conjunction with new development and redevelopment projects (Kondo et al., 2015).

Although both GI approaches have successfully become widespread as a critical means of delivering sustainable development, uncertainty about what GI and its scope are, what values it brings, and how it can be achieved on the ground still remain (Mell, 2010; Pankhurst, 2012). Due to the uncertainty in information and methodology, decision-making of GI planning has lacked recognition of the benefits that GI provides communities (CNT, 2010). The purpose of this research is to fill the gaps between methodology of GI and the planning process, and it is explored in more depth in the following chapters. Commonly accepted definitions of GI can be classified into the two major aspects (Figure 2), which are allied with qualities that the suitability analysis of this research addresses.

|                              | Source   | Definition  |
|------------------------------|--|---|
| <b>Green Network</b>         | President's Council on Sustainable Development, 1999       | A network of open space, airsheds, watersheds, woodlands, wildlife habitat, parks, and other natural areas that provides many vital services that sustain life and enrich the quality of life.  |
|                              | Mark A. Benedict and Edward T. McMahon, 2006               | An Interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife.   |
|                              | Planning Policy Statement 12 (England), 2008               | 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.   |
|                              | Natural England, 2008                                      | A strategically planned and managed network of green spaces and other environmental features vital to the sustainability of any urban area.   |
| <b>Stormwater Management</b> | Clean Water American Alliance, 2010                        | Green infrastructure systems and practices use or mimic natural processes to infiltrate, evapotranspire, or reuse stormwater and runoff on the site where it is generated.  |
|                              | Center for Neighborhood Technology & American Rivers, 2012 | Green infrastructure is an approach to water management that uses natural systems—or engineered systems that mimic natural processes—to reduce water pollution and flooding, enhance overall environmental quality and provide utility services.  |
|                              | United States Environmental Protection Agency, 2015        | Green infrastructure is a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits. While single-purpose gray stormwater infrastructure—conventional piped drainage and water treatment systems—is designed to move urban stormwater away from the built environment, green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits. |

*Figure 2 Commonly accepted definitions of green infrastructure*

## 2.2. Practices of Green Infrastructure

The concepts of GI, which have been explored so far, give clues for this study to figure out what key qualities we can expect from GI planning. Clearly, with the GI planning process, cities are able to increase interaction with the natural system through functionally connected green spaces as well as to yield a variety of benefits from efficiently managed stormwater systems. Now, to get into detail, this section examines how these concepts are applied on the ground.

EPA introduces eleven types of practices on their website<sup>3</sup>: downspout disconnection, rainwater harvesting, rain gardens, planter boxes, bioswales, permeable pavements, green streets and alleys, green parking, green roofs, urban tree canopy and land conservation. Among these eleven, this research covers four practices –rain gardens, bioswales, permeable pavement (covering green parking), and green roofs— which are widely accepted as representative tools for GI and suitably implemented on open space areas, such as Right-of-Way, parking lots, rest areas and roofs spaces, at neighborhood scale. Also these selected practices directly affect holding volumes of stormwater without heavy structural installation.

### *Technical Requirements*

Rain garden: A rain garden is a functional landscape area constructed to collect, absorb and filter stormwater runoff from driveways, roof tops and other hard surfaces (Hinman, 2013). In bowl-shaped area planted with native



**Figure 3 Rain Garden**  
Source: <http://bolincreek.org>

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<sup>3</sup> Environmental Protection Agency. (2015, November). What is Green Infrastructure? Retrieved January 18, 2016, from EPA: <http://www.epa.gov/green-infrastructure/what-green-infrastructure>

vegetation, it allows water to slowly soak into the ground (City of South Portland, n.d.). Since impervious surfaces in developed areas, like asphalt and concrete, and the removal of vegetation result in an increase in stormwater runoff, this functional landscape is widely accepted as an essential and versatile tool to treat runoff (Northern Virginia Soil and Water Conservation District[NVSWCD], 2009). In order to build a functionally efficient rain garden, there are several technical requirements to be considered. First, since the additional water soaking into the ground on steep slope can cause unwanted runoff or sometimes landslides, in general, rain gardens should be installed on gentle slopes of which degree is less than 10% and no greater than 15% (NVSWCD, 2009; Hinman, 2013). Soil infiltration rates are also an important factor. Soils with high infiltration rates are desirable because they can filter a large volume of stormwater quickly (NVSWCD, 2009). Besides these requirements mentioned, ground water tables should be low, the location should be at least 10 feet from structures, and precipitation and other environmental factors are required to be considered, when locating a rain garden.

Bioswale: A bioswale is a vegetated stormwater conveyance system that provides an alternative to, or enhancement of, traditional stormwater piping with treating water quality and attenuating flooding potential (Natural Resources Conservation Service[NRSC], 2005; Clark & Acomb, 2008). In most cities where the built environment of buildings, streets, and sidewalks are hard and impervious, when it rains, the water cannot be absorbed into the ground the way it would in natural areas (NYC DEP, n.d.). Also, in old cities which have a combined sewage system, since combined sewer overflows (CSO) events frequently occur, reducing runoff is a necessity (Nielsen et al., 2008). This infiltration system, as an alternative to the existing sewage system,



*Figure 4 Swale on Yale, Capitol Hill  
Source: Seattle Public Utilities*

allows cities to absorb low flows or carry runoff into storm sewer inlets or directly to surface water (NRCS, 2005). As linear features, bioswales are usually well suited to parking lot islands, road medians, landscape buffs to treat stormwater as well as enhance landscape aesthetics (Figure 4) (NRCS, 2005; EPA, 2015).

This infiltration practice is generally affected by soil type, groundwater table, size of the area services, imperviousness, and slope degree (Clark & Acomb, 2008). If slopes are very flat or steep, the functions will be impractical, and therefore slope degree should be no greater than 5% (Clark & Acomb, 2008). Also, likewise with rain gardens, soil infiltration should be great in that the objectives of this practice are infiltrating storm flows (NRCS, 2005). Lastly, bioswales should be located in areas where groundwater tables are not high enough to prevent groundwater reaching the bottom of the swales (Clark & Acomb, 2008).

**Permeable Pavement:** Permeable pavements allow stormwater runoff to filter through voids in the pavement surface into underlying soil where it is stored or infiltrated (Chesapeake Stormwater Network[CSN], 2013; City of Mercer Island, n.d.). They are generally suited for open space areas such as landscape areas, parking lots, sidewalks, bike path and rest areas (Caltrans, 2016). Although there are a variety of available pavement materials, including pervious concrete and porous asphalt, so that the specific designs vary, all permeable pavements have a similar structure (CSN, 2013). The pavements are subject to many specific technical requirements. In this section, I introduce three of them that are the most related to the suitability analysis, conducted in this study. First, there should be enough available space. Since one function of permeable pavement is to combine detention/infiltration and pavement, land for detention



**Figure 5 Permeable Pavement**  
Source: <http://nacto.org/>

facilities should be available. This is particularly important in urban areas in that land prices are high (Minnesota Pollution Control Agency[MPCA], 2016). Second, slope should be gentle which is not greater than 5% (SPU, n.d.). Steep slope impinges on the stormwater storage capacity of pavement (MPCA, 2016). Last, soil infiltration rates should be high, and especially areas dominated by HGS A or B soils<sup>4</sup> are preferred as primary locations (MPCA, 2016).

Green roof: Green roofs, also called eco-roofs and roof gardens, are vegetated roof surfaces that typically involve waterproofing and drainage materials and a growing medium to support plants (CSN, 2013). Green roofs are a layered system of roofing, which is intended to retain stormwater on the roof surface before it is conveyed into the local sewer system (CSN, 2013). Currently, the roofs are widely considered an effective Green Stormwater Infrastructure (GSI) tool that provides many ecosystems services, including stormwater management, increased carbon sequestration, urban heat island mitigation, and increased local biodiversity (McIntosh, 2010). Since the vegetated roofs are installed on the top surface of buildings or structures, differently from other practices, physiographic conditions, such as slope degree and soil types of the site, are not important factors for installation. Rather, costs, uses and size of a building, structure of a roof, vegetation selection, accessibility, and maintenance are generally regarded as considerations (Paladino and Company, 2006; McIntosh, 2010).



*Figure 6 Green Roof, Ballard*  
*Source: Author, 2015*

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<sup>4</sup> In Hydrologic Soil Groups (HSG), A group of soils (Sand, loamy sand, or sandy loam) and B group of soils (Silt loam or loam), which have high infiltration rates, are generally considered the best soil groups for all types of infiltration practices.

### **2.3. Gap between Concepts and Practices**

Green infrastructure, by its very nature, occupies an amplified position in built environment, combining ecological and social values within planning to simultaneously provide ecosystem services (Young et al., 2014). Amidst current urban patterns, the importance of understanding landscape forms and functions are gradually more emphasized. GI planning therefore should target to enhance the linkage between ‘traditional’ or existing urban services and ecological processes (Schäffler & Swilling, 2013). By doing so, GI can ensure the effectiveness of on-the-ground applications by shifting the urban green linkage into mainstream planning (Schäffler & Swilling, 2013).

However, in spite of much research that examines GI, Mell (2008) indicates that “only a small number have attempted to link the theory with the practices.” He adds “the development of conceptual ideas into practices is an important area that researchers have to address” (Mell, 2008). “What is needed now is for this work to be taken further by researchers, policy makers and practitioners into issue specific areas such as climate change or urban regeneration” (Mell, 2008). In this regard, in GI planning, unambiguous methodology to fill the gap between concepts and practices is necessary and should address specific urban issues. McDonald et al. (2005) observe that the GI approach has its root in planning and scientific analysis; they argue the GI design should be created by conducting suitability analysis or similar methods to gauge a range of resource values (McDonald et al., 2005). This research mainly aims to suggest a methodology –suitability analysis– to apply GI to a particular urban area which has patent issues as well as potentials.

## **2.4. Suitability Analysis: filling the gap**

### *Overview of Suitability Analysis*

Suitability analysis is a well-known method among urban planners, landscape architects and environmental managers for informed decision-making to identify the most and least propitious locations for specific given purposes (Steiner et al., 2000; Collins et al., 2001; Liu et al., 2014). Specifically, this method enables planners and analysts to evaluate the interactions among three types of factors: location, development actions, and environmental elements (Collins et al., 2001). The evolution of GIS technology has greatly fueled the development of this method, allowing a wide array of uses in planning practices such as environmental impact reviews, agricultural land assessment, and land-use plans (Collins et al., 2001; Liu et al., 2014). Also, publicly accessible data on governmental and institutional websites, such as United States Geological Survey(USGS), Census, KCGIS Center, and WAGDA, have significantly contributed to the development of this type of data analysis.

Since the outcome of suitability analysis can be accomplished quickly by combining multiple raster layers, the method may look simple on the surface (Carr & Zwick, 2007). It requires, however, a complex understanding of the site's issues, characteristics of the data to be combined, rules for the overlay process, strategies for ranking and weighting the raster layers, and the development of goals and objectives that guide the analysis (Carr & Zwick, 2007).

In history, the advancement of suitability analysis has a strong tradition with in planning practices (Miller et al., 1998). Early approaches for suitability analysis were evolved from Warren Manning and Charles Elliot's "sunprints" overlay process –the overlay of transparent sheets on a window– in 1912 (Carr & Zwick, 2007; Liu et al., 2014). They used soil and

vegetation data with topography simultaneously in order to visualize recommendations in a site's circulation routes and lands uses (Collins et al., 2001). The most significant methodological advance was the development of the ecological inventory process by Ian McHarg, described in his publication, *Design with Nature* (1969) (Collins et al., 2001; Liu et al., 2014; Carr & Zwick, 2007). He developed the overlay techniques by proposing a manual overlay cartographic procedure using vector data, which has been generally accepted as a precursor of today's standard suitability analysis (Malczewski, 2004).

### ***Method of Suitability Analysis***

With the great advancement in the field of computer mapping technology, the development of geographic information systems (GIS) has been used in a vast array of applications, mostly associated with the environment and resources (Goodchild, 2003). This full-fledged technology has enabled planners to input, store, manipulate, analyze and display a set of spatial and attribute data as well as create new data through the automated overlay processes (Malczewski, 2004). As suitability analysis gains more popularity and diverse disciplines become involved, arguably, it is regarded as one of the most fundamental and widely used types of GIS analysis (Collins et al., 2001; Malczewski, 2004).

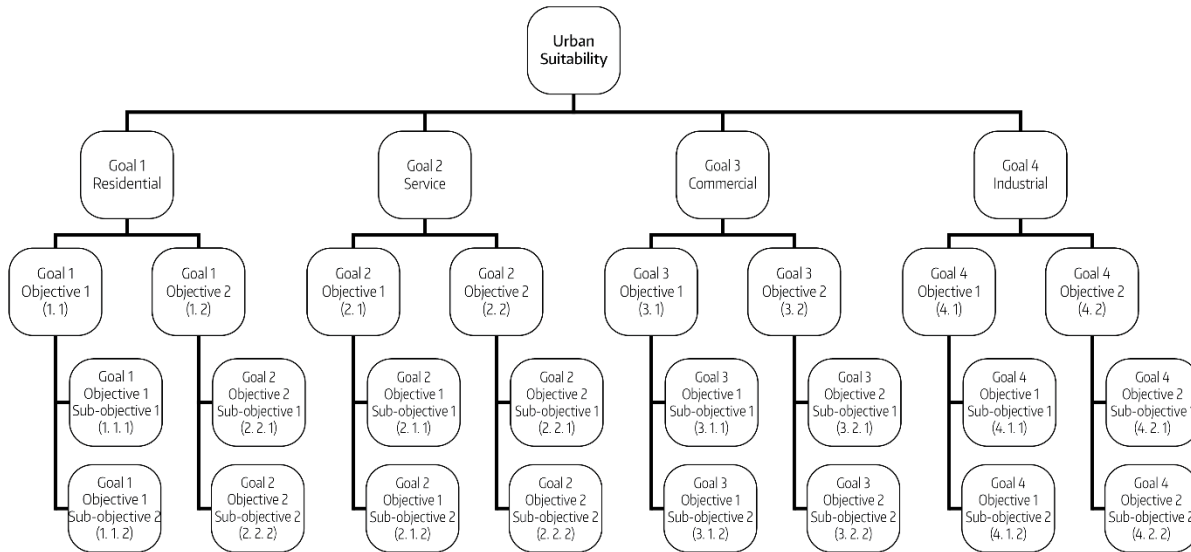
The methods of suitability analysis vary with regard to its specific goals and purposes. Currently there are various systems and models, such as MCDM<sup>5</sup>, GWRAPPS<sup>6</sup> and LUCIS Model<sup>7</sup>, that indicate the development and application of the methodologies. As aforementioned, each model has different process in detail regarding its given purposes, but the process of these

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<sup>5</sup> Multiple Criteria Decision Making

<sup>6</sup> GIS-based Water Resources and Agricultural Permitting and Planning System

<sup>7</sup> The Land Use Conflict Identification Strategy, developed by the University of Florida's Department of Urban and Regional Planning.



**Figure 7 Example of Urban Suitability Toolbox**  
 Source: Carr & Zwick, 2007

methodologies can be largely described in five steps: 1) identify goals and site's issues; 2) collect data and establish criteria; 3) rank and weight criteria; 4) integrate and analyze data by using geographic information systems (GIS); 5) evaluate outputs (Miller et al., 1998; Marney, 2012; ESRI, n.d.).

This study basically follows these five steps. It begins with understanding the site context to guide the goals of this research, and ends with assessing the final products to make suggestions. Each step as methodology is well explicated in depth in the methodology chapter, Chapter 4. In addition, Figure 7 above illustrates a hierarchical structure of suitability analysis, created by Carr and Zwick (2007), which aligns with that of this study,

## 2.5. Case Study: application of suitability analysis

Four cases selected mainly provide direction to this research in terms of better understanding of the applicable process of suitability analysis. Since all four cases deal with

green infrastructure or specifically stormwater issues in urban areas, thus creating comparable analyzing processes, different criteria they used and ways to rank and weight the criteria act as significant references for this study which deals with a similar purpose. Commonly, the four cases have lack of explanation of how they place different weights on criteria, which would decrease the reliability of their results. As to this issue, this research put much effort on developing the weighting process, which is discussed in Chapter 4. The question of this lacking logic is well stated in the first case study.

### ***Green Infrastructure Suitability Pilot Study, Greater New Haven***

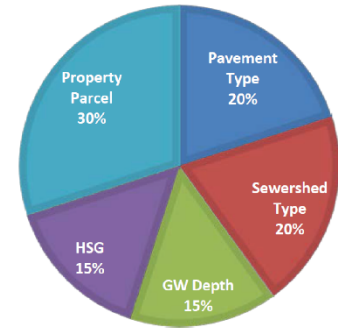
The study of suitability analysis in the city of New Haven, *Green Infrastructure Suitability Pilot Study*, was conducted by CH2M HILL, an engineering company, for Greater New Haven Water Pollution Control Authority. Like many other cities in the U.S., the hydraulic conditions in the city suffered from frequent CSO events due to the old sewer system, a combined sewer system (CH2M HILL, 2014). To identify suitable areas for implementation of GI for CSO reduction, the general process, described in the above section, was applied to the study (CH2M HILL, 2014). Five criteria were selected for the overlay process which include soil type (HSG), groundwater depth, pavement type, parcel use, and sewer system, and they were ranked in five degrees, from 1 representing the lowest suitable to 5 representing the highest suitable (CH2M HILL, 2014). Once ranked, the established GI raster layers were weighted against one another to determine the overall suitability for GI implementation (CH2M HILL, 2014) (Figure 8). Then the outcomes were produced by the overlay process that multiplies the ranked value by the given weight. The ranking and weighting were established based on reasoning, such as residential parcel being ranked the lowest due to difficulties in collaborating with other property owners, and pavement type being highly weighted to highlight the possibility

**Ranking Criteria for Site Conditions**

| GI Implementation Suitability Criteria |                       |                     |                       |              |                            |
|--|-----------------------|---------------------|-----------------------|--------------|----------------------------|
| Ranking Score                          | 1                     | 2                   | 3                     | 4            | 5                          |
| Hydrologic Soil Group                  | D                     | C                   | not rated             | B            | A                          |
| Depth to Groundwater (feet)            | < 1                   | 1 - 2               | 2 - 4                 | 4 - 6        | > 6                        |
| Pavement Type                          | Driveway              | Private Parking Lot | Non-paved/other       | Road         | Public Parking Lot         |
| Parcel                                 | Residential           | -                   | Commercial/Industrial | Exempt/other | Public/Planned Development |
| Sewershed Type                         | Separated/non-sewered | -                   | Partially Separated   | -            | Combined                   |

**Criteria Weighting Distribution**

HSG = Hydrologic Soil Group; GW = Groundwater



**Figure 8 Ranking and Weighting of Green Infrastructure Suitability Pilot Study**  
Source: CH2M HILL, 2014

of constructing porous pavement on public parking lots (CH2M HILL, 2014). This case shows a well-organized study showing application of GI planning. An accurate methodology to explain the weighting process, however, was not provided; this study thus may become unreliable when it comes to such a question, which should be clearly answered when creating the final outcomes by combining raster layers: what calculating or reasoning methods were behind ‘parcel’ having an exact 30% of weight while pavement type was given 20% of weight?

***Green Infrastructure Planning for Improved Stormwater Management in Central New York, Central New York***

The second case was titled *Green Infrastructure Planning for Improved Stormwater Management in Central New York*, led by Central New York Regional Planning & Development Board (CNY RPDB, 2012). The suitability analysis was conducted in order to certify the vitality of specific stormwater practices and to graphically illustrate the factors affecting the decision-making process of GI planning in a given area (CNY RPDB, 2012). Rather than a detailed technical process, this case has more meaning in that it provides specifications of why and how the criteria were established. While the purpose is quite similar with the above and following cases, the criteria applied slightly differ. The criteria taken into consideration are hydrologic soil

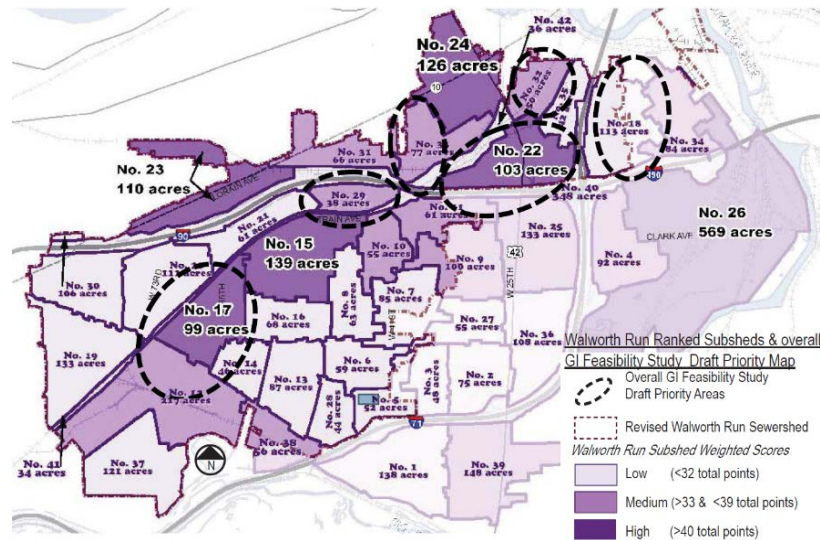
group, slope, land use, proximity to roads, presence of wetlands and floodplains, and given a value of 0 to 5 (CNY RPDB, 2012). In comparison with the study above, proximity to road and presence of wetlands and floodplains were added, addressing how much the distance of a practice from a public roadway highly affects maintenance and how it is preferable to avoid locating GI practices near wetlands or in floodplain areas (CNY RPDB, 2012). Among the seven criteria, soil group and land use were considered the most deciding factors in relation to the technical requirements and maintenance issues, given weight of 0.3 and of 0.25, out of 1, for each (CNY RPDB, 2012).

### ***Walworth Run Green Infrastructure Feasibility Study, Walworth Run***

Not simply aiming to implement GI practices effectively on a given area, this study, titled *Walworth Run Green Infrastructure Feasibility Study*, has a relatively distinct and specific purpose, when compared with other studies: regenerating an urban area in which the rate of vacant lands is increasing (Northeast Ohio Regional Sewer District[NORSRD], 2011). This study was grounded on the assumption that “if properly planned and implemented could provide open space for residents, water quality benefits to Lake Erie, and means to attract reinvestment” (NORSRD, 2011). It mainly focused on clarifying opportunities of redevelopment by benefiting from GI (NORSRD, 2011), and therefore surely criteria selected were quite different from other cases. The criteria<sup>8</sup> are redevelopment coordination, vacant properties, impervious areas, public lands adjacent to vacant properties, minority and poverty, and soils. It should be pointed out that minority and poverty was newly considered as one of criteria in that this study aimed to regenerate underserved urban communities (NORSRD, 2011). The study area was divided into

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<sup>8</sup> The study used ‘Inventory Category’ instead of ‘Criteria.’



**Figure 9 Overlay Result of Walworth Run Green Infrastructure Feasibility Study**  
 Source: NORSD, 2001

forty-two subsheds, and each criterion was ranked with 1(low) to 3 (high) score (NORSD, 2011). Then different multiplier numbers ranged from 1 to 5, as a weight, were placed on each criterion (NORSD, 2011). Redevelopment coordination and vacant properties were considered the most important for the goals –urban regeneration–, and thus were given the highest multiplier of five (NORSD, 2011). For instance, in regard of two criteria of redevelopment weighted coordination (a multiplier of five) and minority and poverty (a multiplier of one), if a subshed area has multiple projects to be constructed within five years (three score) and simultaneously has both poverty rate above 13% and minority rate above 33% (one score), sixteen score<sup>9</sup> is placed on the area. Like this method, all scores from each criterion were merged into each subshed by ArcGIS which conclusively illustrated the feasibility of GI (Figure 9).

### ***Green Infrastructure Planning in the Greater Chattanooga, Chattanooga***

This study, named as *Green Infrastructure Planning in the Greater Chattanooga, TN Area*, does not deal with urban areas but a suburban area. But this is a notable case in that it

<sup>9</sup> 16 = 5(a multiplier of redevelopment coordination) \* 3(score) + 1(a multiplier of minority and poverty) \* 1(score)

focused on the first concept of GI –green network–, thus providing a different approach from others. The major goals of this case is to identify linkages between green hubs and corridors and to spur sustainable development by using GIS technologies (Oakley et al., 2010). To identify the suitable networks, four datasets –elevation, slope, land cover, and proximity to transportation infrastructure (roads and railroads)– were equally considered. Through overlay process, the study produced a habitat suitability model which indicates the suitable location of green corridors, and several corridors to connect two major wetland hubs were then suggested.

### *Discussion*

The four case studies reviewed so far provide methodological ideas as well as technical specifications which played a critical role to establish this study’s methodology. One clear idea from reviewing the cases is that data selected for the overlay process should be thoroughly related to site issues and should support specific goals. Although commonly aiming at better green infrastructure, criteria should differ according to one’s goals, Also, the weighting process which directly affects the outcomes should be clearly explained, such as the grounds on why parcel is given 20% weight, as mentioned in the first case section. This research puts more effort on elucidating the reasoning process of establishing criteria and ranking/weighting criteria in order to increase the reliability of this thesis’ outcomes. While this research largely follows the general process of suitability analysis, a new weighting method is proposed, which is described in Chapter 5. Lastly, based on the criteria used in the four cases, I assume that the data selected, as criteria, can be categorized into four categories: topography, hydrology, existing infrastructure, and socio-economy (Figure 10). These categories would cover natural aspects of

GI as well as social and developmental aspects. These are also applied to setting the criteria of this study.

|                  |   |                            |
|------------------|---|----------------------------|
| Great New Haven  | ● | Parcel Use                 |
|                  | ● | Depth of Groundwater       |
|                  | ● | Hydrologic Soil Group      |
|                  | ● | Sewer Type                 |
|                  | ● | Pavement Type              |
| Central New York | ● | Hydrologic Soil Group      |
|                  | ● | Land Use                   |
|                  | ● | Slope                      |
|                  | ● | Proximity to Raod          |
|                  | ● | Presence of Wetlands       |
|                  | ● | Presence of Floodplains    |
| Chattanooga      | ● | Elevation                  |
|                  | ● | Slope                      |
|                  | ● | Proximity to Raod          |
|                  | ● | Land Cover (perviousness)  |
| Walworth Run     | ● | Redevelopment Coordination |
|                  | ● | Vacant Property            |
|                  | ● | Impervious Area            |
|                  | ● | Public Land                |
|                  | ● | Minority and Poverty       |
|                  | ● | Soil Type                  |

Topography
  Hydrology
  Infrasturcture
  Socio-economic

*Figure 10 Categories of Criteria used in Case Studies*

### Chapter 3. Site Context

With the growing popularity of central neighborhoods in cities across the United States, many urban areas are facing intensive pressures of new development (Chalana, 2015). Cities are becoming denser and more complex which frequently causes a wide range of urban issues, such as environmental degradation, gentrification, and inadequate urban services. Capitol Hill, located east of downtown Seattle, is one such neighborhood for that growth (Sarko, 2014; Chalana, 2015). Although there are many citywide efforts to alleviate the issues, such as “Seattle Green Factor” for enforcing green practices, “Seattle 2035 Comprehensive Plan” for envisioning the ideal future city, and “Climate Action Plan” for becoming carbon neutral, the area is being rapidly developed, requiring better regulation and management.

The Pike/Place Conservation Overlay District (PPCOD) is located at the central area of Capitol Hill (Figure 11) and currently being threatened by urbanization; the development disrupts the district’s historic fabric and characters which originated in the early 1910s development of auto-row (Chalana, 2015). Many things have changed in the PPCOD in recent

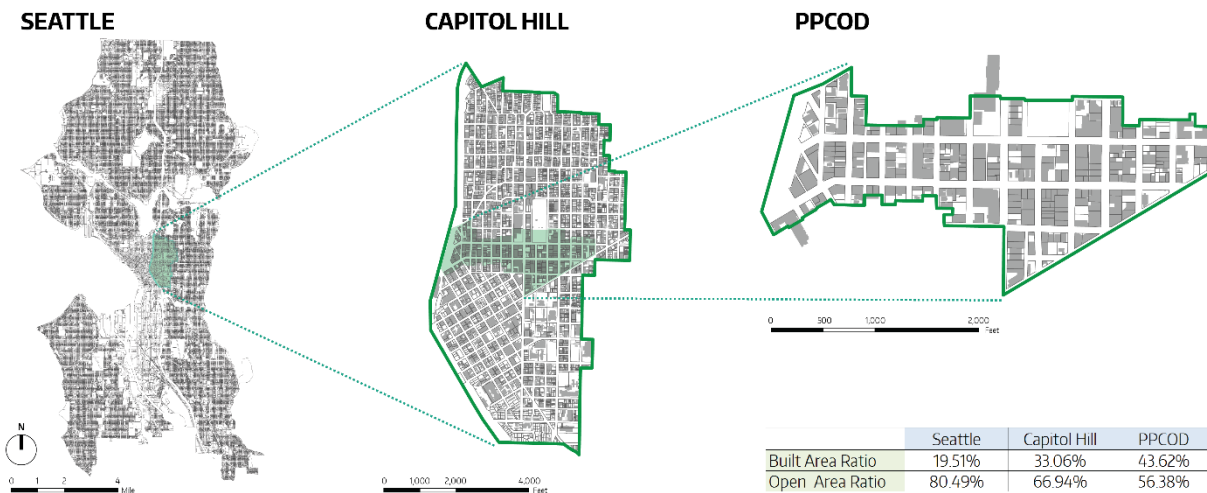


Figure 11 Location and Building Density of Capitol Hill and the PPCOD

years. Currently, there are twenty-four redevelopment projects on progress, including seven applied projects, twelve approved, and five newly constructed, transforming the area to being upscale, higher and denser (Figure 12).

Within the context of these developmental issues, the “Capitol Hill EcoDistrict” plan, by Capitol Hill Housing and GGLO (2012), provides important guidance for improving sustainability. By approaching the neighborhood with a comprehensive perspective of communities, infrastructures, and natural resources, the plan envisions a sustainable neighborhood in the fullest sense of the word. It mainly aims to enhance community health and affordability through behavior change, building design, and infrastructure investments for the most populated urban village in Seattle, dealing with eight performance areas including water, habitat, culture, energy, materials, transportation, health, and equity (Bullitt Center, 2013; Captiol Hill EcoDeistrict, n.d.).



**Figure 12 PPCOD Current Development Map**  
Source: <https://www.seattleinprogress.com>

According to the plan report, Capitol Hill has excellent assets for supporting a sustainable water system, including city support for water conservation and a safe water supply, but the full benefits of stormwater are not realized (GGLO, 2012). Given that Seattle is famous for its rainfall and lakes, better utilizing the water resources and managing the stormwater runoff will act as a central strategy to achieve the neighborhood sustainability.

As stated in Chapter 1, the major goal of this study is to suggest a suitable guidance of green infrastructure (GI) planning in order to ameliorate the urban issues. In this regard, it would be an imperative step to have a clear understanding of what issues the area is facing and what potentials it has in relation to GI. This chapter explores the site's context of built environment and green/natural environment which will play a significant role to establish criteria of the suitability analysis (described in Chapter 5).

### **3.1. Built Environment**

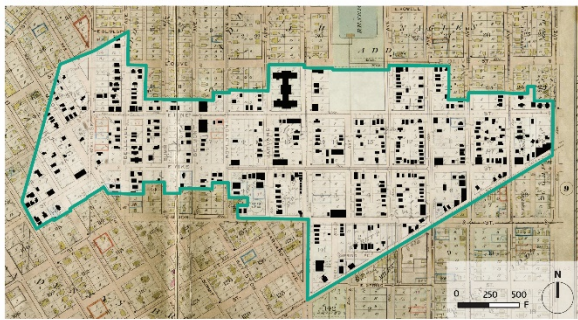
#### *Development of Capitol Hill*

Capitol Hill has been undergoing rapid transformation. The earliest major development in the neighborhood was initiated by the first automobile dealership on Pike street in 1909, which became the largest concentration of auto dealerships (Dorpat, 2009). Many of the old buildings, that were once auto shops, storage buildings, and showrooms, are still standing in the Pike/Pine neighborhood forming its historic values. After the Interstate-5 was opened in the 1960s, the neighborhood area began to change rapidly as many large constructions took place replacing the

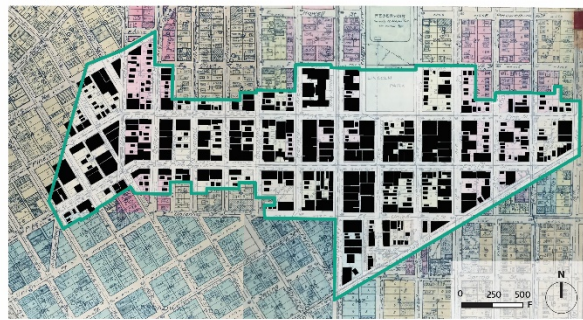
small buildings. Today, Capitol Hill is the largest regional growth center in the city<sup>10</sup> (PSRC, 2013). With a number of significant developments, such as Capitol Hill Light Rail Station, the area is predicted to continue to increase its density and compactness.

The percentage of built area in the PPCOD has continually increased since the auto-row development at the beginning of the 20<sup>th</sup> century. Figure 13 shows the overtime changes in built area ratio, from approximately 8.15% in 1905 to 43.62% in 2015, which was created by calculating building area of historical maps<sup>11</sup> and aerial photos by using AutoCAD and ArcGIS. Also, Figure 11 depicts the density increases by zooming into the central area, PPCOD. Both

**PPCOD in 1905: Before the Auto-Row Development**  
**Built Area Ratio: 8.15%**



**PPCOD in 1928: Peak of the Auto-Row Development**  
**Built Area Ratio: 33.32%**



**PPCOD in 1961: After the Construction of I-5**  
**Built Area Ratio: 37.90%**



**PPCOD in 2015: Mixed use Community**  
**Built Area Ratio: 43.62%**



**Figure 13 Overtime Changes in Built Area of the PPCOD**  
 1928 and 1961 maps are parts of the productions of URBDP 508 class (*Urban Design & Historic Preservation Specialty Studio*) in 2015 at the University of Washington.

<sup>10</sup> The city of Seattle designates six regional growth centers—Downtown, Capitol Hill (First Hill/Capitol Hill), Northgate, South Lake Union, Uptown Queen Anne, and the University Community—to accept significant planned population and employment growth (PSRC, 2013).

<sup>11</sup> Baist's Real Estate Atlas of Surveys of Seattle (maps from Seattle Public Library and UW Suzzallo Library)

figures show that the population growth and increasing developmental activities have caused an issue of a lack of open space<sup>12</sup>.

### *Demography*

According to the 2010 U.S. Census Bureau, Capitol Hill has a population of 36,502 residents, which is the largest number among Seattle's neighborhoods, and it has grown by 1,920 over the past 10 years (PSRC, 2013). As the most rapidly growing neighborhood in the city, the total population is mostly constituted of working age residents. The age of residents is predominantly 18-32 (53%), followed by 35-64 (32%), with the small number of youth (5%) and seniors (10%) (PSRC, 2013). In terms of race, Capitol Hill has less diversity<sup>13</sup> with 71.3 % of the residents being white and 28.7% non-white residents including 11.6% Asian and 8.1% black (Figure 14).

Capitol Hill also has the highest population density in the city. Whereas the average population per acre of Seattle is 11.4, that of Capitol Hill is 39.9, which is much higher than that of downtown (27.8) (PSRC, 2013; Seattle DPD, 2011). The population density is described in detail in Figure 30 in Chapter 5. This particular demographic context of Capitol Hill has required a variety of urban services, such as developed communities, robust local business, mixed use buildings, decent street network, and enough green spaces, which would be necessary for the related activities occurring in this neighborhood.

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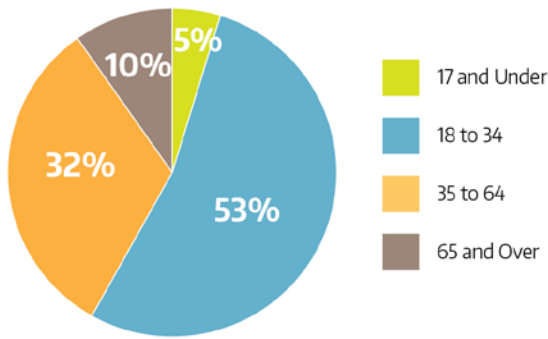
<sup>12</sup> The lack of open/green space was also indicated in Capitol Hill Neighborhood Plan (Capitol Hill Neighborhood Planning Committee, 1998). The plan envisioned the area as a new mixed-use cultural and commercial complex; and to respond to the demand of this change, it suggested to create a new park on the Lincoln Reservoir and the Bobby Morns Playfield, which is currently the Cal Anderson Park.

<sup>13</sup> The average percentage of White in Seattle is 69.5% (City of Seattle, n.d.).

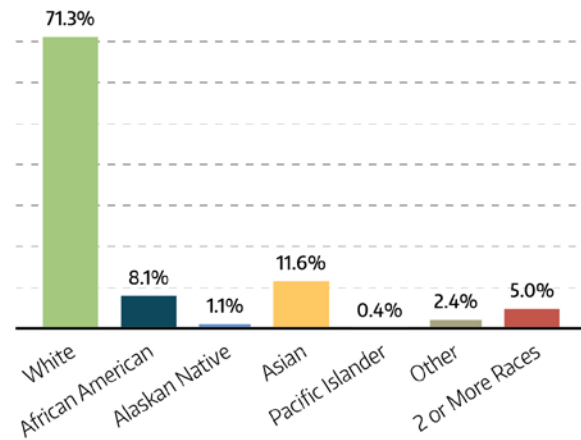
**Population and Population Change**

|                      | Population | % of City | Population Change (2000-2010) | % of City |
|----------------------|------------|-----------|-------------------------------|-----------|
| Downtown             | 25,920     | 4.26%     | 6,117                         | 13.51%    |
| Capitol Hill         | 36,502     | 6.00%     | 1,920                         | 4.24%     |
| Northgate            | 7,049      | 1.16%     | 740                           | 1.63%     |
| South Lake Union     | 4,234      | 0.70%     | 1,911                         | 4.22%     |
| University Community | 23,198     | 3.81%     | 3,265                         | 7.21%     |
| Uptown               | 7,641      | 1.26%     | 2,242                         | 4.95%     |
| Seattle              | 608,660    | 100%      | 45,286                        | 100.00%   |

**Age of Residents** (36,502 residents)



**Racial Composition** (36,502 residents)

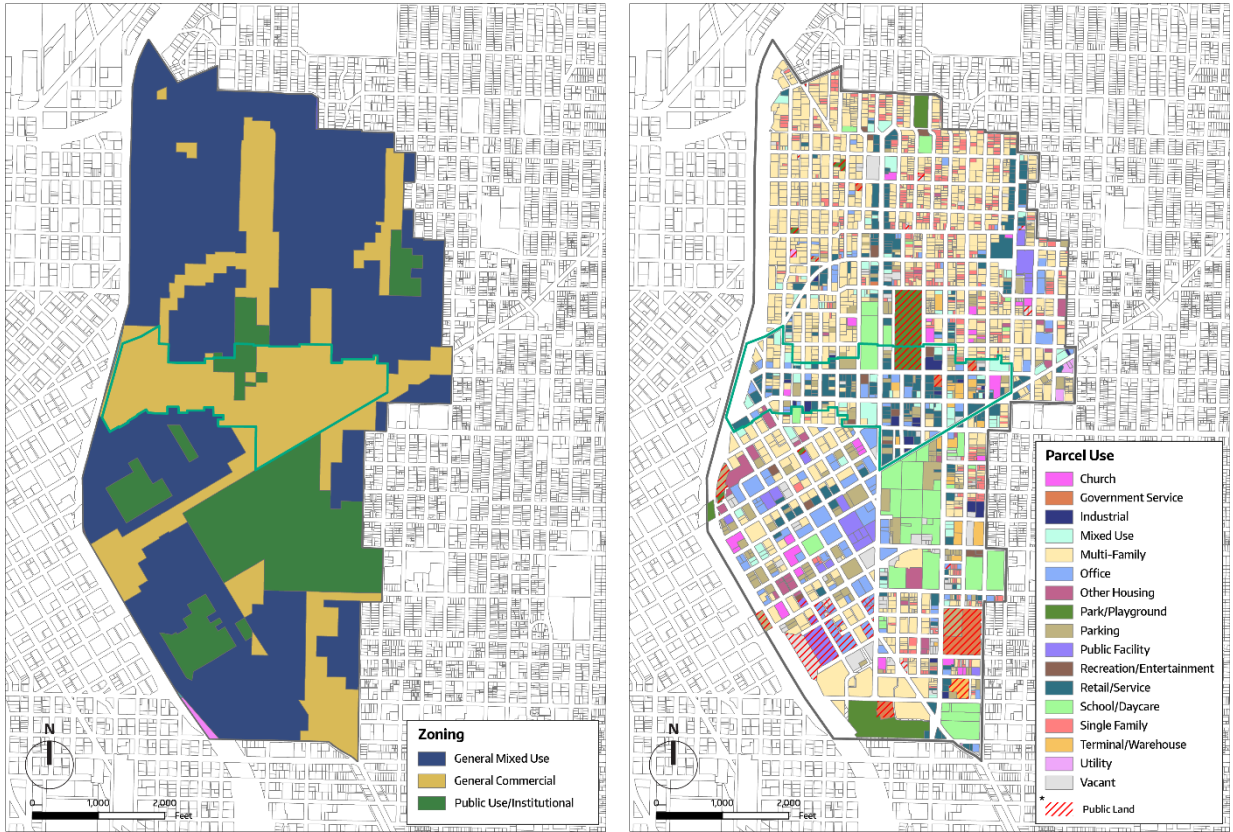


*Figure 14 Capitol Hill Demography Data*  
 Source: U.S. Census Bureau, 2010

**Zoning and Parcel Use**

The city of Seattle designated three zonings for the Capitol Hill neighborhood. General mixed-use accounts for 55.8% in total area, followed by general commercial (27.7%) and public use/institutional (16.2%), which reflect its bustling business activities predominantly associated with employment-related use. Given that over a half of the parcels are used for residential uses<sup>14</sup>, most buildings in the neighborhood are constituted of mixed-use apartments, covering both its growing population and business. Fifty parcels (43.41 acres) are public property –including

<sup>14</sup> 1359 parcels are used for multi-family housing, 356 are for single family housing and 31 are for other housing of total 2690 parcels.

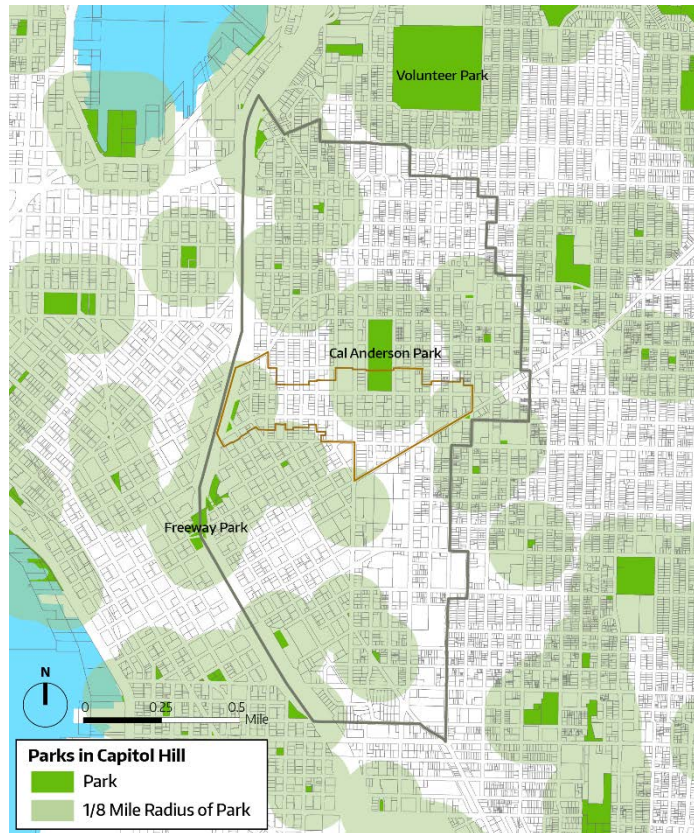


**Figure 15 Zoning and Parcel Use**  
 Source: King County GIS Data and modified by author

government services, parks, and schools— which the practices of green infrastructure are more easily applied or efficiently managed rather than private property (Figure 15).

***Lack of Open Space***

As mentioned above, since the beginning of auto-row development, the open space ratio has gradually and markedly decreased. This issue is attributed to its developmental history that the primary uses of this neighborhood were not residential or human-oriented but majorly commercial/industrial and car-oriented. Capitol Hill Neighborhood Planning Committee (CHNPC, 1998) already addressed this issue and decided to create the Cal Anderson Park, located at the center of Capitol Hill (Figure 16), by covering the Lincoln Reservoir and



*Figure 16 Park Buffer in Capitol Hill*

converting the Bobby Morns Playfield to a public green space. Even if the Cal Anderson Park plays many roles, such as providing breathing room for environmental and social activities within the neighborhood, when it comes to the apparent increase in the number of both residents and commuters in this mixed-use area, there is a large lacking in quality and quantity of green spaces (Fucoloro, 2015).

### **3.2. Natural/Green Environment**

#### *Climate and Topography*

The city of Seattle is located between Puget Sound and Lake Washington. Water flows into Puget Sound from Lake Washington and shapes Lake Washington Ship Canal and Lake

Union, which is situated north of Capitol Hill. Due to this geophysical condition, Seattle's climate is classified as an oceanic climate which makes the city experience high rainfall and mostly cloudy days. With the bounty of oceans, lakes and rainfalls, the city is known as having abundant water assets.

Capitol Hill literally lies on a steep hill, which is one of seven hills<sup>15</sup> constituting the city. The highest elevation is over 450 feet forming several steepest streets in the city such as East Roy Street whose slope degree is 26% (Seattle Department of Transportation, n.d.). By slope analysis using ArcGIS, the mean of slope degree of Capitol Hill appears 7.32% which is approximately 2% higher than that of Seattle (Figure 18). Although neither ground water or stream exists within the boundary of Capitol Hill, considering its rainy climate, vicinity to the substantial water resources including Lake Union, and steep slopes taking a weighty responsibility of stormwater runoff, well-balanced water infrastructure is essential to utilize and manage the water legacy.

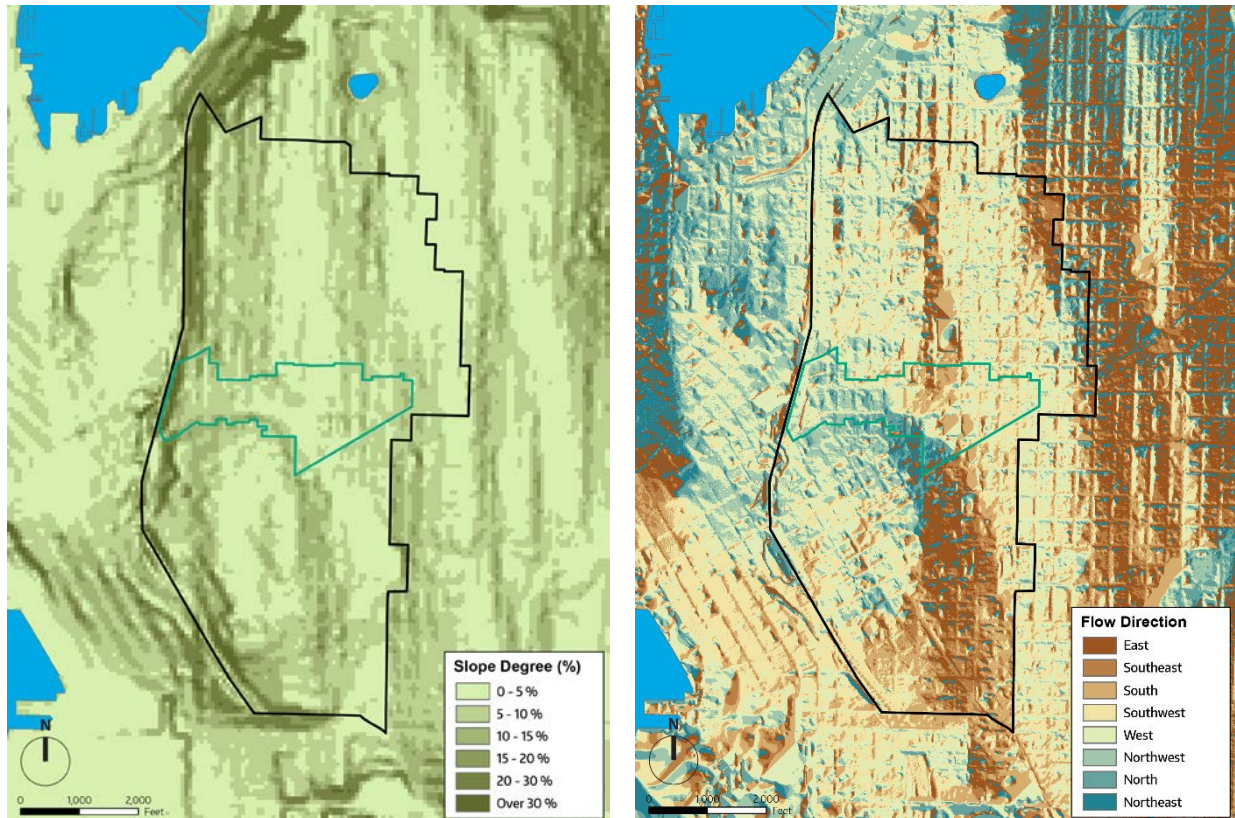
### ***Stormwater Management***

Therefore, better stormwater management has been one of the most important aims of Capitol Hill (SPU, 2012). Also, many of Seattle's roads, parking areas, and building stocks were originally developed without understanding the importance of stormwater management because it was not widely understood at the time (SPU, 2015). Figure 18 shows flow direction analysis which indicates that surface water on Capitol Hill mainly drains into two destinations: Lake Union and Elliot Bay. Stormwater on the upper Capitol Hill, including the partial PPCOD, is treated by Swale on Yale that is located on four blocks on Yale Avenue North and Pontius

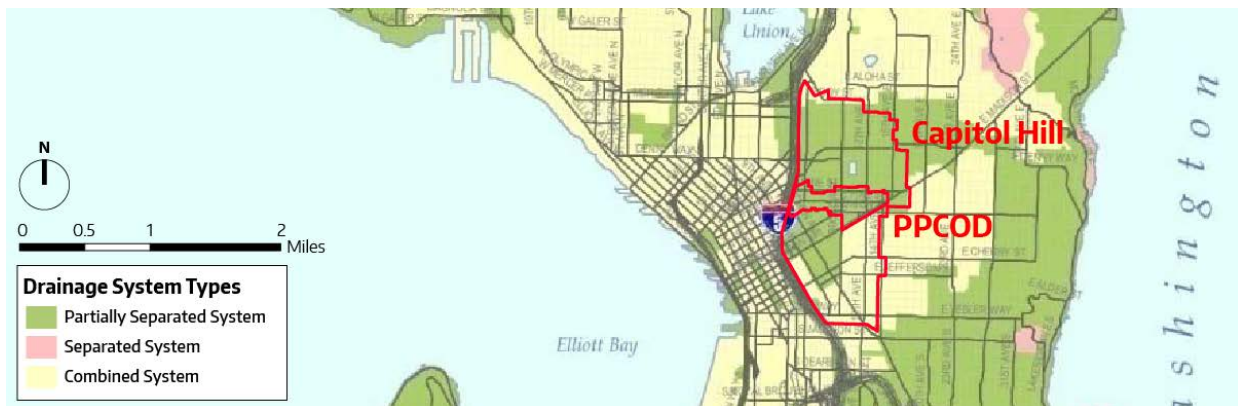
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<sup>15</sup> Unofficially the seven hills include First Hill, Yesler Hill, Renton Hill, Denny Hill, Capitol Hill, Queen Ann Hill and Beacon Hill.

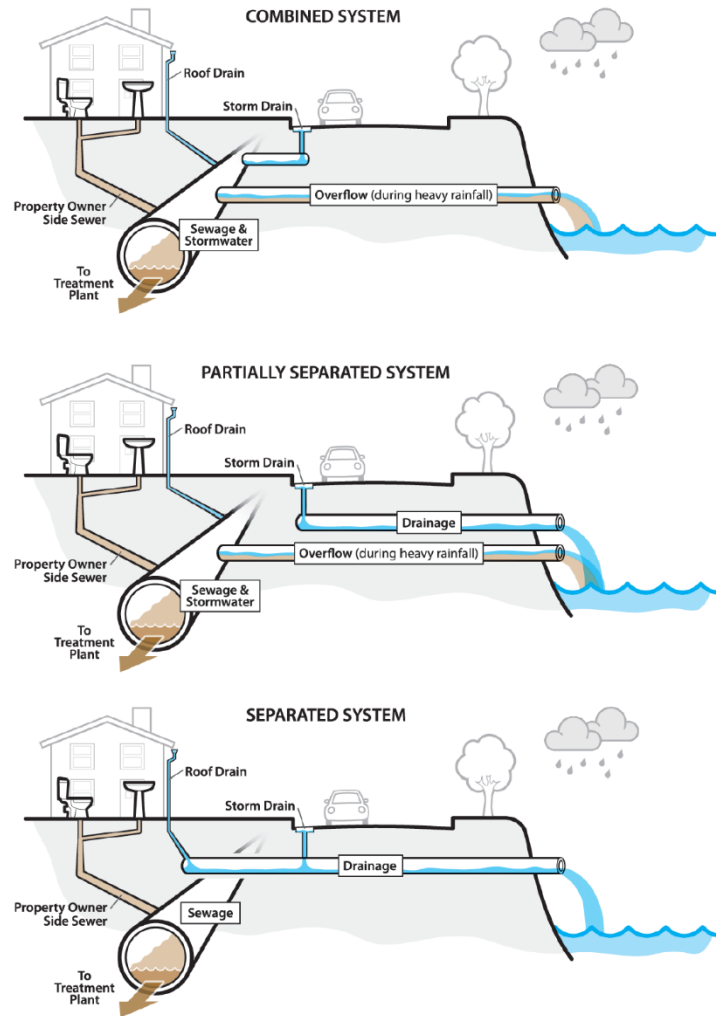
Avenue North being managed with the partially separated sewer system (MS4). But stormwater on lower Capitol Hill, including the rest of the PPCOD, would need more adequate water management to prevent combined sewer overflows (CSO), flooding, or back-ups when raining heavily in regard to the combined system which is the dominantly installation (Figure 17 and Figure 19).



**Figure 18 Slope Degree and Flow Direction**



**Figure 17 Drainage Systems of Seattle**  
 Source: Seattle Public Utilities and modified by author



*Figure 19 Types of Drainage Systems  
Source: Seattle Public Utilities*

### ***Urban Heat Island (UHI)***

As cities developed, the ground was replaced with impervious covers of concrete, asphalt, and shingled roofs which can get much hotter in the sunlight than open and vegetated areas, causing surface temperature in the city to become hotter (Kenward, et al., 2014). The combination of the development and global warming would have urban temperature much hotter. This phenomenon of hotter temperature in cities than their surroundings is known as an urban heat island (UHI) (EPA, 2015).



### 3.3. Discussion

Site contexts of Capitol Hill's built environment and natural/green environment discussed so far guide to capture three major issues for this research. As aforementioned in Chapter 1, the major aims of this study is to provide a suitability guidance for Capitol Hill's green infrastructure planning as well as suggest a draft plan for the PPCOD. This thesis will show how urban green infrastructure can be planned for dense and growing urban neighborhood in the following chapters; and Capitol Hill including the PPCOD is an excellent case to examine. Also, regarding that the roles of green infrastructure are to provide cost-effective and resilient approaches in order to manage urban green issues (EPA, 2015), the suitability data should be grounded on the current or potential phenomena the site faces.

First, more green or open spaces should be provided when it comes to its unprecedented population growth and development. The incremental urban density of the neighborhood, including floor area ratio (FAR), gross and net density, and employment density, has degraded its capacity of urban ecological functions and green activities of the residents. The more green spaces we can provide, the better environment the neighborhood may have; however, we should consider which area has better suitability in terms of overall efficiency and demands.

The second issue is the stormwater management. Rainy climate, steep topography, and the non-ideal sewage systems require better management to utilize water and reduce runoff. Although Capitol Hill has an excellent water supply, almost zero sewer overflows, and city support for water conservation, the neighborhood could do much better (GGLO, 2012).

Lastly, urbanization has caused a huge difference in temperature between urban and rural areas. Seattle's temperature is ranked as the tenth hottest in the nation, but the number of

developments occurring in the city is expected to increase more. Capitol Hill has a responsibility of this urban heat island phenomenon as the most rapidly growing neighborhood. Since the development would be not stoppable for the time being, providing adequate green infrastructure can be an answer to this issue.

## Chapter 4. Methodology

Suitability analysis emphasizes the effectiveness of decision-making process and links a variety of urban components to specific purposes, such as regenerating urban spaces, enhancing green functions, or increasing sustainability. Suitability analysis therefore can be defined as a multi-disciplinary tool, requiring ecological, social, physical, and landscaping understanding (Liu et al., 2014). While database and spatial information are the kernel of the process, suitability analysis is more than a GIS-based procedure (Malczewski, 2004). It essentially involves identifying opportunities of given sites and of social and environmental relationships (Liu et al., 2014).

As discussed in Chapter 2, the process of suitability analysis largely follows five steps: 1) identify goals and site's issues; 2) collect data and establish criteria; 3) rank and weight criteria; 4) integrate and analyze data by using geographic information systems (GIS); 5) evaluate outputs. The identification of site's issues and opportunities acts as critical guidance to establish criteria which are selected data to be input for the overlay calculation. Malczewski (2004) particularly underlines processing of spatial data (reformatting data) because the data for suitability analysis are typically derived from different mediums (e.g. scanned and digitized maps) and stored in different formats (e.g. raster and vector data). All data should be transformed to the same co-ordinate system and be adjusted to the same spatial resolution or scale (Malczewski, 2004).

Even with the similar process and the quickly accomplishable outputs by a GIS function that automatically integrates multiple layers of data (Malczewski, 2004; Carr & Zwick, 2007), the reasoning for weight process must vary because the weight indicates "relative importance" of each criterion (Malczewski, 2004) in regard of given purposes and concerns of studies. As

criticized in Chapter 2, however, many case studies do not devote much of space to explaining the reasoning but rather put much effort to explicating formulas of the overlay calculation, or sometimes omit the reasoning.

This chapter explains the overall process of suitability analysis in detail conducted in this research. From data collection and data reformatting to criteria establishment, and from weight reasoning to GIS model creation, each step is explicitly described in the following to support reliability of the outputs of the analysis.

## **4.1. Data Collection**

Publicly accessible data have contributed to the widespread of GIS technology. This research also was developed by relying on the open data sources. Shape files from the King County GIS Center (KCGIS Center) account for the majority of data for this study. They include District Boundaries, Parcel, Property, Park in King County, 2010 Consolidated Demographics, and others which are mapped in Chapters 3 and 5, establishing the essential knowledge of Capitol Hill. Since KCGIS Center has periodically updated the database, suitability analysis of this research was conducted with the most up-to-date data collected in March and April, 2016. Washington State Geospatial Data Archive (WAGDA) and City of Seattle<sup>17</sup> have also provided important data including Contour (2 foot), Building Outlines and Drainage Systems. Since several data such as soil infiltration have not been provided as shape files but PDF formats, those were manually traced and stored as vector data in ArcMap. Lastly, surface temperature data, which represents the UHI issues, were downloaded from Global Land Cover Facility as raster

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<sup>17</sup> Data.seattle.gov and Seattle Public Utilities

data (GeoTIFF format), and the data are mapped in Chapter 5. Raster data from the Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+) were used, and Band 6.2 (thermal infrared) was selected for this study based on the Landsat bands guidance by United States Geological Survey (USGS, 2015).

## **4.2. Criteria Establishment**

As repeatedly mentioned so far, criteria establishment should be much emphasized in that criteria must reflect the purposes of studies comprehensively and must be differentiated by their issues or opportunities. While, for example, the case study of Walworth Run, stated in Chapter 2, selects ‘minority and poverty’ as one of the criteria to reflect its major goal that regenerates a declined urban area through GI, the criteria of the case of Central New York does not include minority but selects ‘presence of floodplains’ because the case puts emphasis on flooding control and water quality management.

In this research, the process of criteria establishment was done by considering three standards: 1) three issues –lack of green space, better stormwater management, and UHI– in Capitol Hill, 2) four criterial classifications –topography, hydrology, infrastructure and socio-economy– from case study, 3) data availability.

The first criterion is slope degree. Slope degree is a critical factor for most types of stormwater management and GI practices to determine the capacity to treat runoff (CNY RPDB, 2012). Also, it is important data to illustrate the hilly topography of Capitol Hill. The second criterion is flow accumulation. In the four cases studied, depth to groundwater or proximity to wetlands is considered to cope with existing water resources for appropriate GI installation.

However, within the Capitol Hill area, since stream or groundwater does not exist and the steep slope may cause runoff by accumulating stormwater on the surface, flow accumulation was selected as a criterion to cover its hydrological context. Soil infiltration was chosen as the third criterion. Commonly, rather than the infiltration, soil (Hydrologic Soil Group) is selected, and the data are acquired through USDA's Web Soil Survey. But due to the lack of data for the Seattle area, Infiltration Potential Conceptual Level Planning Map from City of Seattle (2009) was used as an alternative to soil data in order to indicate the runoff potential. The fourth criterion is surface temperature, which is a key criterion of UHI issues. This criterion illustrates the actual hot spots where adequate green functions are indeed required. Population density is the fifth criterion which represents the rapid growth of Capitol Hill as well as demands for green spaces. The data was selected based on a fundamental assumption that more people need more open/green spaces. The final selection is parcel use (land use). This criterion takes into account of the growing pattern of the current development and the ease of implementation or management of GI practices (CNY RPDB, 2012; Marney, 2012).

Through incorporating the three standards mentioned above, these six criteria lead into important consideration of how much responsibility each criterion accounts for with regard to GI suitability. The next section mainly discusses the reasoning of weight.

### **4.3. Rank and Weight**

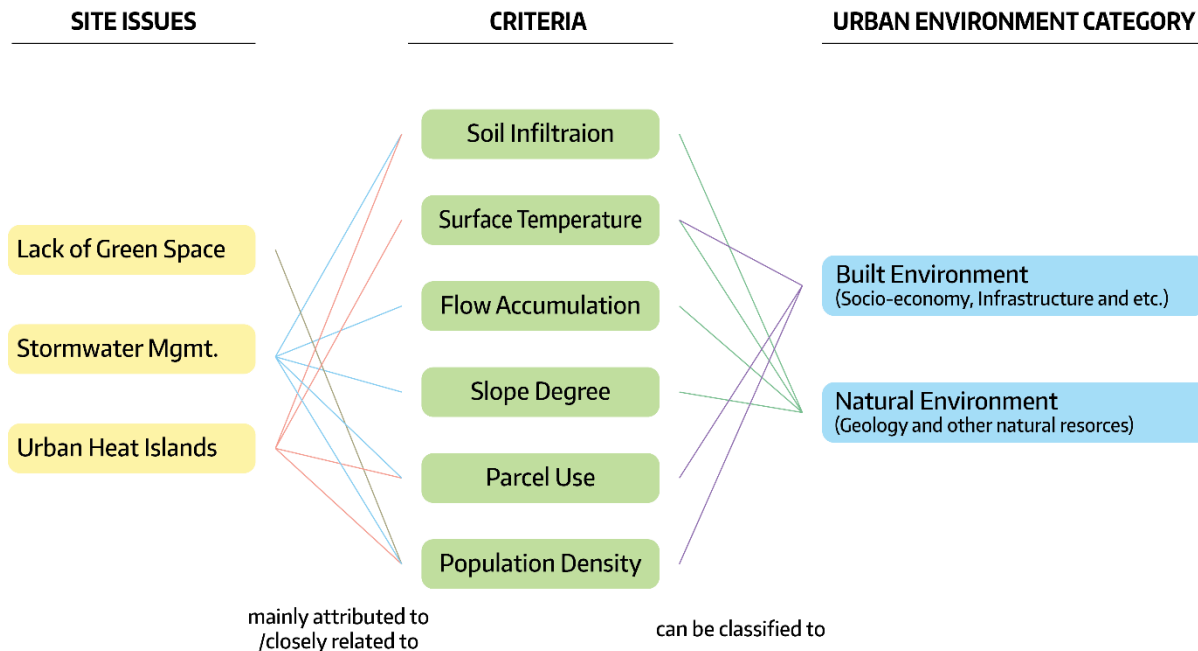
For each of the criteria, the data were ranked with five degrees, from one being the least suitability to five being the most suitable. Case studies and technical requirements for the four selected GI practices discussed in Chapter 2 acted as significant guidance to establish this

ranking system. For example, considering that the required slope degrees for both bioswale and permeable pavement are no greater than 5%, and if slopes are very flat, the functions are impractical (Clark & Acomb, 2008; SPU, n.d.), and therefore, the rank of the most suitability for a criterion of slope degree was assigned as 3% to 5%. In this way, each criterion has specified grounds for the ranking, which is described in detail in Chapter 5, Data Analysis, with illustrated maps.

The process of weighting is a critical step that directly links to the given issues and purposes. The higher weight is placed on a criterion, the more importance is regarded for GI suitability. Each numeric weight relatively varies with 1, 1.5 and 2; but when combined as percentage, the sum of all the six weights should be calculated as 100%.

This research put much endeavor to develop the sound reasoning for assigning the weight. Since this study was fundamentally started from recognizing the three pronounced issues in Capitol Hill, the weighting should be associated with the issues and act as logical backing to support this thesis' outcomes. Figure 21 shows the correlation between the issues, criteria, and urban environment category. Each site issue is linked to criteria regarding its own attribution or relationship, and each criteria is linked to different classification of built or natural environment. For instance, as seen in Figure 21, UHI issues are 'mainly attributed to' soil infiltration (soil moisture), parcel use and population density, and 'closely related to' surface temperature rather than other two left criteria. These four criteria connected 'can be classified to' different urban categories.

Based on this relationship, four scenarios were developed to demonstrate the 'relative importance,' dealing with the three issues (Figure 22). The first scenario (S1) is named "Equal Consideration," which gives an equal weight of 1 to all six criteria. Therefore, when considering



*Figure 21 Weight Reasoning: Correlation between Site Issues, Criteria, and Urban Environment Classification*

the total weight as percentage out of 100, each weight of 1 is converted to approximately 17% (16.66...%). Second, the third and fourth scenarios are more strategically developed. The second scenario (S2) focuses on the first issue, lack of green spaces. As pronounced in Chapter 3, the lack of green space in Capitol Hill is mainly associated with the rapid development, which results in the current high population density. Also, since this issue can be classified as a built-environmental issue rather than a natural-environmental one, a criterion of population density is therefore regarded ‘more importance’ and given double weight, which is 29% (28.57...%) out of 100%; on the other hand, other criteria are given one weight, 14% (14.28...%). The third scenario (S3) copes with stormwater management. The stormwater issues are generally attributed to such factors including soil infiltration, flow accumulation, and slope degree, and also related to parcel use and population density (regarding the amount of water use). These issues are more vulnerable to natural environment such as rainfall and geology rather than built environment given that Capitol Hill has provided well-managed water services (GGLO, 2012). With this

## SCENARIO DEVELOPMENT

- S1 **Equal Consideration(Weight)**
- S2 **Weight on Lack of Green Space**  
The rapid increase in urban density brings more demands for GI. More people need more green spaces, which can be classified to built environment rather than natural one.  
 Weight 2 on Population Density
- S3 **Weight on Stormwater Management**  
Capitol Hill has well-manged water services, which would mean the stormwater issues are mainaly attributed to natural factors, such as topography and precipitation  
 Weight 2 on Soil Infiltration, Flow Accumulatoin, and Slope Degree; 1.5 on Parcel Use and Population Density
- S4 **Weight on UHI Issues**  
UHI is primarily attributed to the globla climate change, but density, lack of green space and land use also account for the major causes.  
 Weight 2 on Surface Temperature, Parcel Use and Population Density; 1.5 on Soil Infiltration (soil moisture)

|           |        | Soil Infiltration | Surface Temperature | Flow Accumulation | Slope Degree | Parcel Use | Population Density | Sum  |
|-----------|--------|-------------------|---------------------|-------------------|--------------|------------|--------------------|------|
| <b>S1</b> | Weight | 1                 | 1                   | 1                 | 1            | 1          | 1                  | 6    |
|           | %      | 17%               | 17%                 | 17%               | 17%          | 17%        | 17%                | 100% |
| <b>S2</b> | Weight | 1                 | 1                   | 1                 | 1            | 1          | 2                  | 7    |
|           | %      | 14%               | 14%                 | 14%               | 14%          | 14%        | 29%                | 100% |
| <b>S3</b> | Weight | 2                 | 1                   | 2                 | 2            | 1.5        | 1.5                | 10   |
|           | %      | 20%               | 10%                 | 20%               | 20%          | 15%        | 15%                | 100% |
| <b>S4</b> | Weight | 1.5               | 2                   | 1                 | 1            | 2          | 2                  | 9.5  |
|           | %      | 16%               | 21%                 | 11%               | 11%          | 21%        | 21%                | 100% |

*Figure 22 Weight Reasoning: Scenario Development*

reasoning, weight of 2 (20%) is placed on three criteria –soil infiltration, flow accumulation and slope degree– which are connected to both the right side in the Figure 22, ‘stormwater management,’ and the left side, ‘natural environment.’ Weight of 1.5 (15%) is placed on parcel use and population density, which are connected to only ‘stormwater management.’ Another criterion, surface temperature, is not entirely related to this issue, thus given 1 weight (10 %). The last scenario (S4) is about UHI, which can be classified as issues of built environment. As described above, flow accumulation, parcel use, and population density are given weight of 2 (21%), and soil infiltration that is classified as natural environment is assigned with weight of 1.5 (16%). Weight of 1 (11%) was placed on other two criteria.

### 4.3. Creation of Overlay Model

The output of suitability analysis was produced through the Weighted Overlay tool in ArcMap. Since the criteria layers are in different numbering systems with different range, before overlaying all the layers, each criterion should be reclassified into one numbering scale (ESRI, n.d.). In this research, as stated above, the scale is 1 to 5, with 5 being the most suitable; the criteria ranked are converted to this numbering scale. Then, each of the reclassified criteria is multiplied by the each assigned weight –relative importance– and summed together to produce one raster map of GI suitability. This calculation process is described in a formula below (Figure 23):  $c$  indicates a reclassified numeric cell value of a criterion layer, and  $w$  is the assigned weight for each criterion. For instance, when it comes to Scenario 3 (Figure 22), if one cell is ranked and reclassified as 5 in the soil infiltration layer (weight of 20%), 2 in the surface temperature layer (weight of 10%), 4 in the flow accumulation layer (weight of 20%), 5 in the slope degree layer (weight of 20%), 4 in the parcel use layer (weight of 15%), and 1 in the population density layer (weight of 15%), the numeric output of the cell is  $3.15^{18}$ , which connotes ‘High Suitability.’

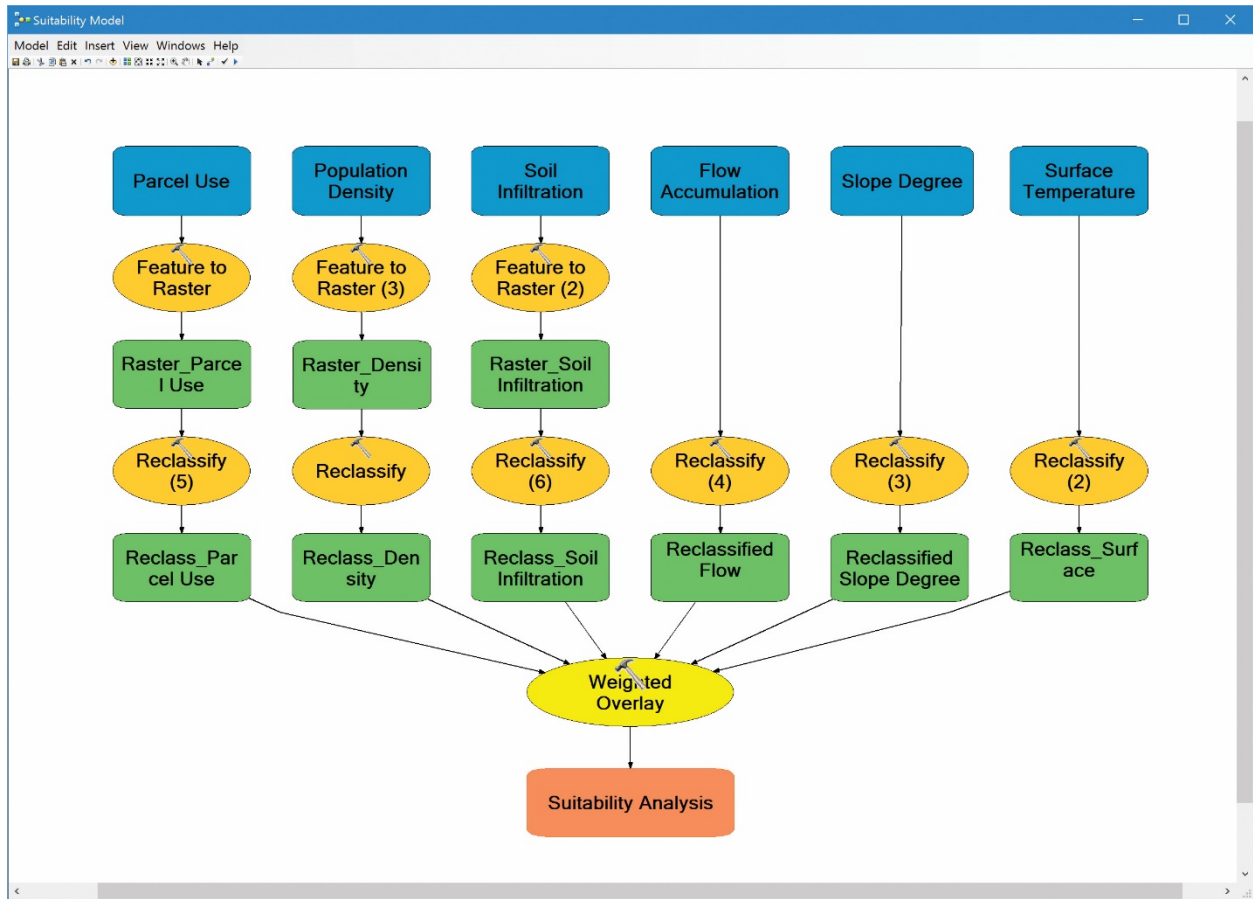
ModelBuilder in ArcMap allows these whole procedures of overlay analysis to be conducted by one simple action, and also help shape illustration of the process. Figure 24 is the screenshot of the created suitability analysis model which was actually used in this study. As illustrated, parcel use, population density, and soil infiltration data were firstly transformed into

$$S = \sum_{i=1}^6 c_i w_i$$

|     |                 |     |                       |
|-----|-----------------|-----|-----------------------|
| $C$ | : criteria data | $W$ | : weight              |
| $S$ | : 4 to 5        | =   | Very High Suitability |
|     | 3 to 4          | =   | High Suitability      |
|     | 2 to 3          | =   | Medium Suitability    |
|     | 1 to 2          | =   | Low Suitability       |
|     | 0 to 1          | =   | Very Low Suitability  |

Figure 23 formula of the Overlay Process

<sup>18</sup> $3.15 = 5(0.2) + 2(0.1) + 4(0.2) + 5(0.2) + 4(0.15) + 1(0.15)$



*Figure 24 GIS Model of Suitability Analysis*

raster data, and then all data were reclassified into the same numeric scale, 1 to 5. Then, six reclassified data were multiplied by the different, designated weight and converged into one map through the Weighted Overlay tool. The outputs of this model with the four different scenarios are shown and interpreted in the following chapter.

## Chapter 5. Suitability Analysis

### 5.1. Criteria Analysis

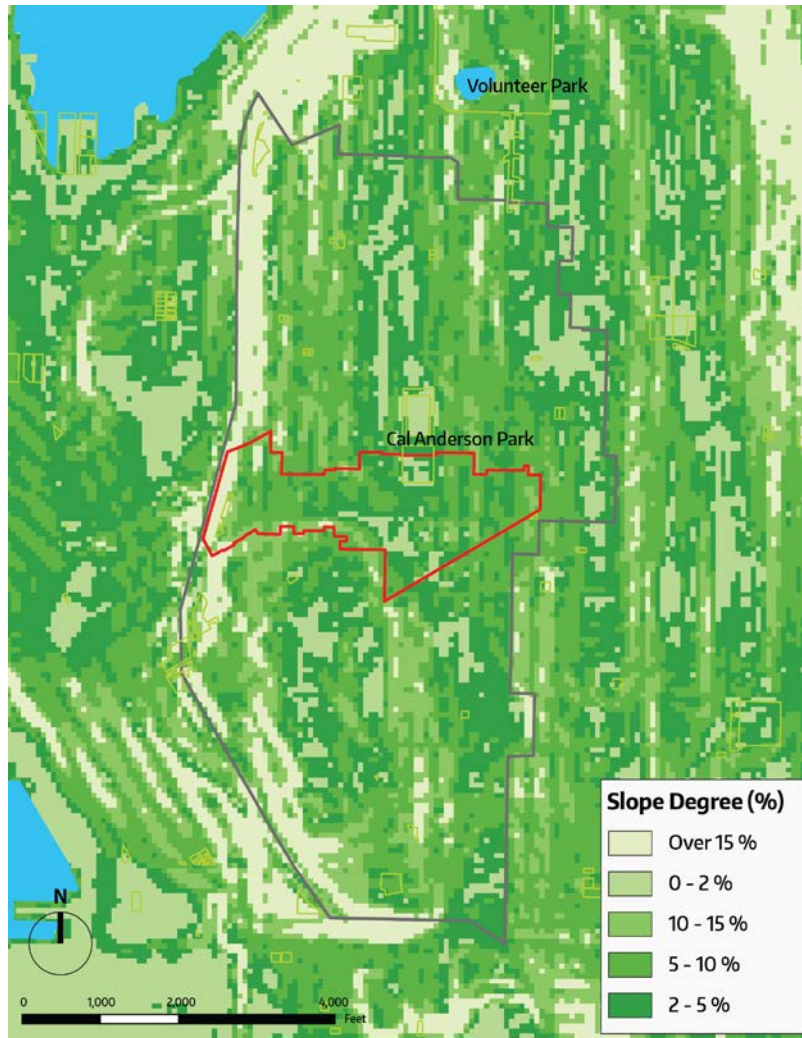
This section visualizes the products of the six criteria analysis –slope degree, flow accumulation, soil infiltration, surface temperature, population density, and parcel use– and describes them in detail with regards to GI concepts and practices. The criteria were established based on three considerations of the site issues, case studies, and data availability; among them, the site issues were considered as the priority since they project the key grounds of why GI and what types of GI are required.

Each criterion was simply mapped by inputting data provided or visually analyzed by the Spatial Analysis tools in ArcMap, and then ranked. The ranking was mainly accomplished by regarding technical requirements of GI practices, mentioned in Chapter 2. Several criteria such as surface temperature and flow accumulation were ranked by equal distribution of data within the site area because there are not designated requirements or preferences of the GI implementation of these criteria.

The following describes the technical process of the criteria analysis and its meaning in the site issues. Also, the figure below shows the sources of each data.

| Criteria            | Data Format  | Data Source               |
|---------------------|--------------|---------------------------|
| Slope Degree        | Shape File   | WAGDA, 2012               |
| Flow Accumulation   | Shape File   | WAGDA, 2012               |
| Soil Infiltration   | PDF File     | City of Seattle, 2009     |
| Surface Temperature | GeoTIFF File | USGS Landsat 7 ETM+, 2006 |
| Population Density  | Shape File   | KCGIS Center, 2015        |
| Parcel Use          | Shape File   | KCGIS Center, 2014        |

*Figure 25 Lists of Criteria and Data Sources*



*Figure 26 Sloe Degree*

### *Slope Degree*

Slope degree is a critical factor in determining the functions of GI practices. It significantly affects stormwater capacity and flow as well as soil erosion potentials. Also, it acts as a key indicator in visualizing the hilly topography of Capitol Hill. With these data, it become clear which space is relatively suitable for GI implementation. As stated in the previous chapters, if the slopes are too flat or too steep, the functions will be impractical. The required degree for both permeable pavements and bioswales is less than 5 % and that for rain gardens should be

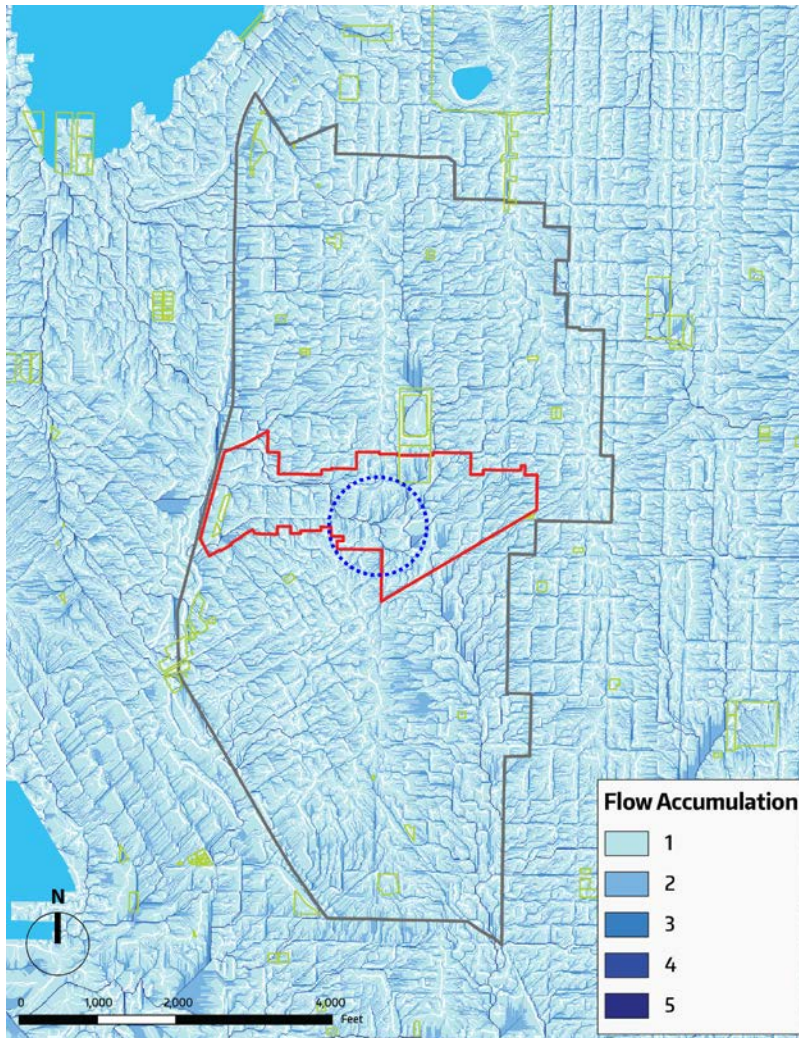
gentle, less than 10 % and no greater than 15 % (Clark & Acomb, 2008; NVSWCD, 2009; Hinman, 2013; SPU, n.d.). Since the implementation of green roofs is influenced by conditions of rooftop surfaces rather than slopes of topography, by considering the required slope degree of permeable pavements, bioswales, and rain gardens, 2 to 5 % of the degree was ranked as the most suitable and over 15 % was ranked as the least suitable. 0 to 2 % was ranked as the second least slope degree because it can be considered too flat.

The map of slope degree, Figure 26, was created by using 2-foot contour data from the WAGDA. This reclassified map illustrates different visualizations with the slope degree map (Figure 18) shown in Chapter 2, newly identifying that the central area of the PPCOD, below the Cal Anderson Park, can be a proper location for GI practices. Also, it may indicate a potential of green corridors across Capitol Hill to connect the Cal Anderson Park and the Volunteer Park.

### ***Flow Accumulation***

Figure 27 delineates drainage networks in Capitol Hill in terms of where stormwater is mainly accumulated on the surface following the topography and therefore which space mostly faces the pressure of runoff. Since there are not considerable elements for GI within the neighborhood, such as streams and groundwater, flow accumulation was selected as a criterion to cover the hydrological conditions.

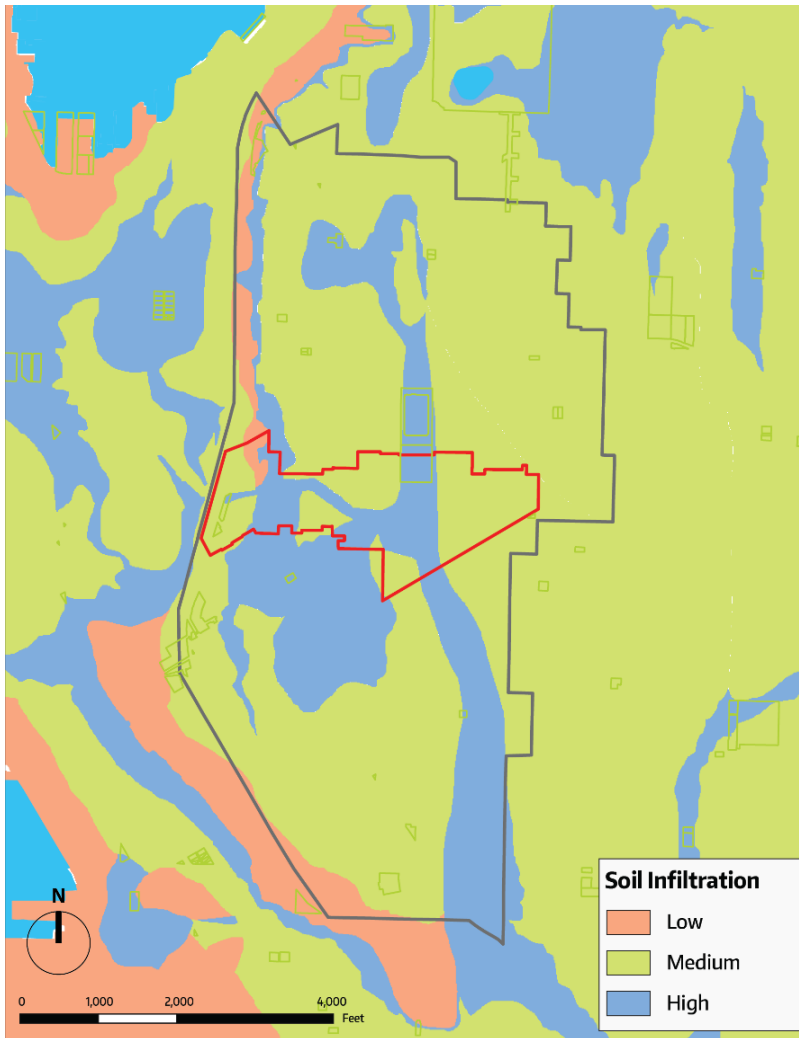
This hydrological analysis was accomplished through the Hydrology tool in ArcMap by using the 2-foot contour data that is used in the slope analysis. Additionally, since the first output of the flow accumulation analysis was plainly blurry due to the lack of hydrological factors in the study area, for better visualization, all data were exaggerated by Rater Calculator, applying log10 to each value.



*Figure 27 Flow Accumulation*

The ranking was established by equal intervals of data within the study area –1 indicating the lowest accumulation and 5 indicating the highest accumulation– because there is limitation to convert the flow accumulation into the numeric data of stormwater volume and not enough technical guidance of GI practices related to this criterion. With this criterion that shows relative pressure of stormwater, by locating the appropriate GI practices, unintended runoff can be alleviated.

The result of flow accumulation analysis describes that there are some vulnerable spots for stormwater accumulation within the PPCOD. Specifically, the areas below the Cal Anderson



*Figure 28 Soil Infiltration*

Park along the East Pike Street (blue dotted circle on Figure 27) can be pointed out as the location where adequate GI practices are needed to prevent potential runoff.

***Soil Infiltration***

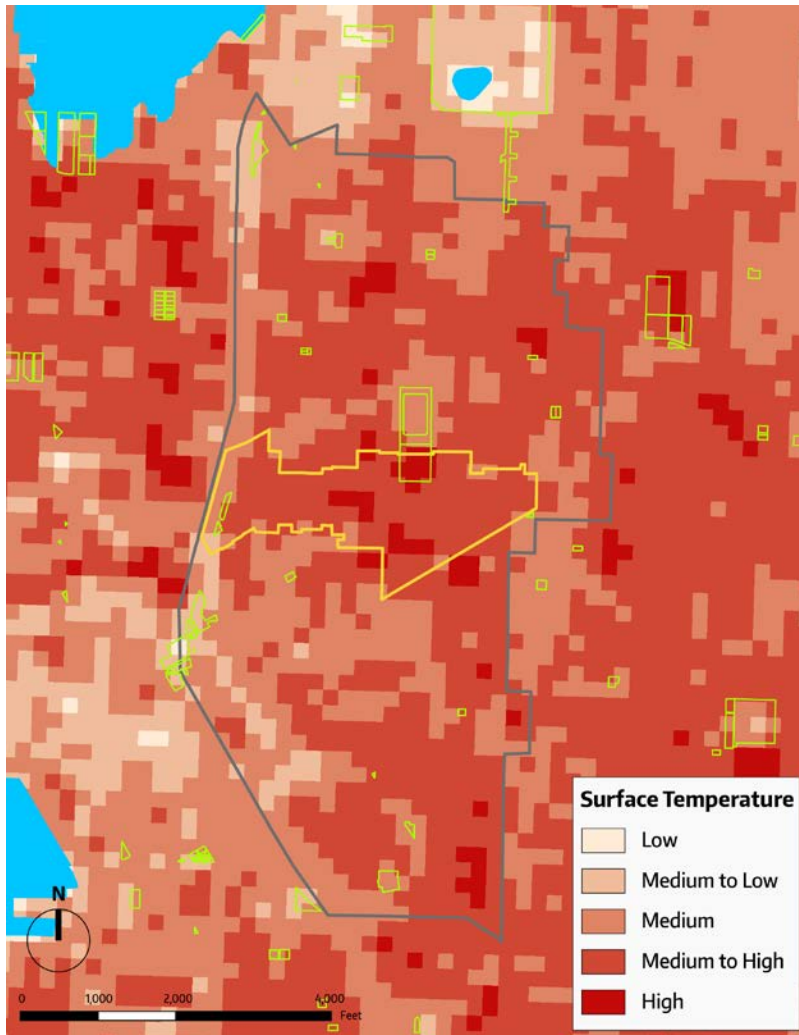
The map of soil infiltration, Figure 28, represent the areas where stormwater infiltrates sufficiently or not, based on the cumulated geological conditions over time (City of Seattle, 2009). It delineates while most of area in Capitol Hill is moderate for GI, there is a huge linear area at the center of Capitol Hill in which GI practices can function efficiently with high infiltration rates.

As mentioned in Chapter 4, soil Infiltration is an alternative criterion to the soil type (Hydrologic Soil Group) which is generally chosen in other precedent studies. Due to the unavailability of soil data for the Seattle area, the map was reproduced in ArcMap by tracing Infiltration Potential Conceptual Level Planning Map acquired from the City of Seattle (2009). Therefore, the ranking for this criterion inevitably followed three degrees which has been done in the original map with Low being 1 as the least suitability, Medium being 3 as moderate suitability and High being 5 as the most suitability. There can be inaccuracy in this data as the original sources do not allow looking at the specific rates of infiltration; however, given the primary purpose of the Hydrologic Soil Groups that determines a soil's associated runoff curve number (NRCS, 2009), this map would represent the runoff vulnerability directly by showing the relative infiltration rates.

### *Surface Temperature*

Given a fact that the city of Seattle is the tenth most intense city in UHI across the United States (Kenward, et al., 2014), identifying the hot spots within Capitol Hill would be an important step to benefit from GI implementation in terms of subduing the increased temperature. The data of surface temperature indicate which spaces are currently impacted by UHI.

As stated, the temperature data were obtained from Global Land Cover Facility as GeoTIFF image data which were collected by the Landsat 7 satellite (Landsat 7 ETM+). Also, among the eight bands available, Band 6 (6.2) was selected of which data are generally used for thermal mapping and estimated soil moisture (USGS, 2015). However, on this data format, with regard to the ranking process, there are several limitations: First, since the temperature data are stored as digital numbers with a range between 0 and 255, not as temperature degrees, the actual



*Figure 29 Surface Temperature*

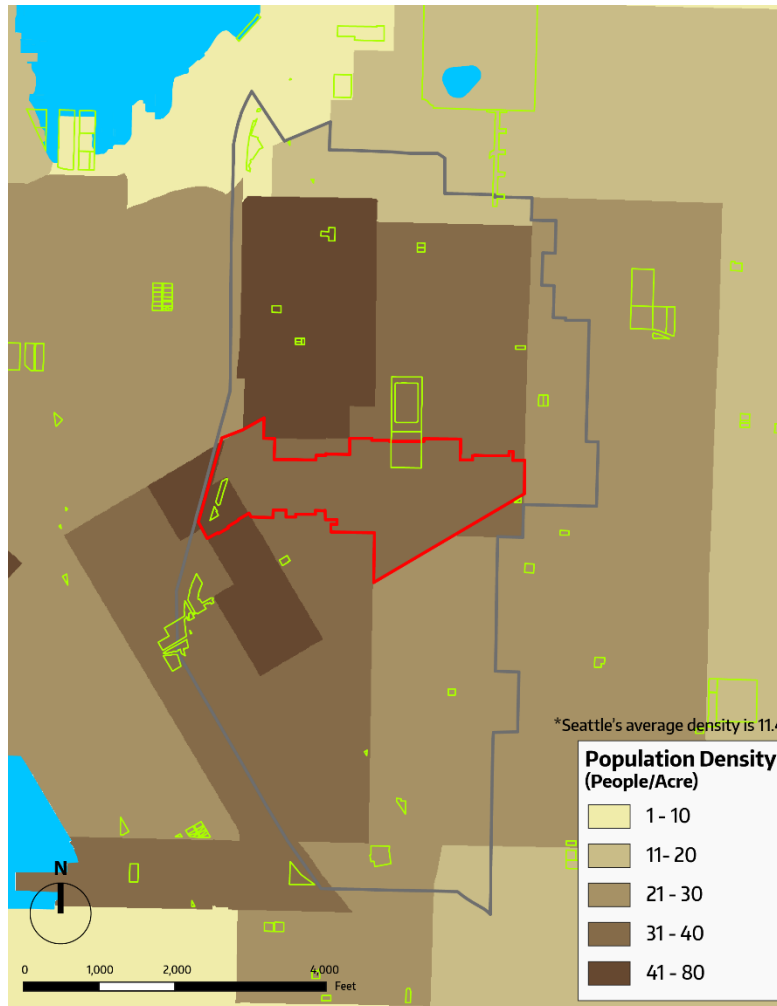
temperature in the neighborhood was not visualized<sup>19</sup>. Thus, from the surface temperature map (Figure 29), numeric intensity of UHI cannot be specified. Second, the image data are comprised of a spatial resolution of 60 meters (about 197 feet), which cause lack of accuracy of data in terms of cell size. Lastly, the changes by seasons or times of heat are not described which can be important by specifically articulating the current UHI phenomena in Capitol Hill.

<sup>19</sup> Although there is a way to convert the digital numbers to Kelvin by using a two-step calibration process (digital numbers to radiance values, and then to degrees Kelvin) (The Yale Center for Earth Observation, 2010), since this process deviates from the topic of this thesis, the primary numeric values were used for the suitability analysis.

Albeit these limitations, this map provides relative intensity of heat, showing most of the PPCOD is under medium to high temperature. The map can be interpreted as more or better approaches of GI are needed where the higher surface temperature is spotted. Additionally, the reclassifying and ranking data were done by equal distribution of data within the site boundary similar to the flow accumulations analysis.

### ***Population Density***

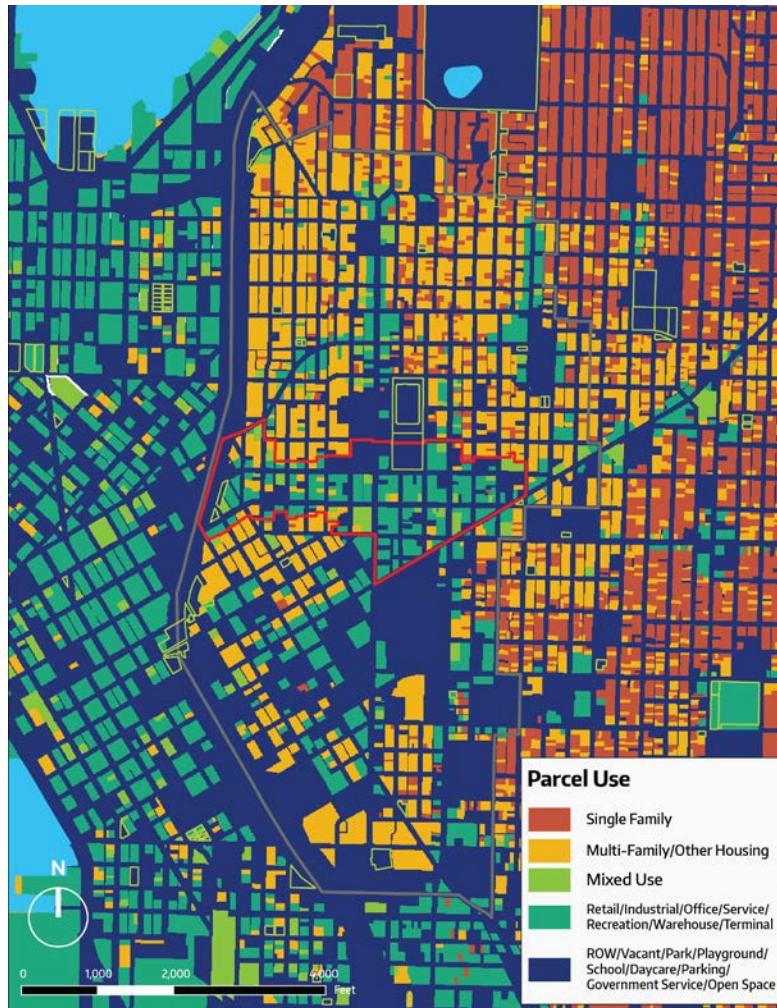
Population density is closely associated with the most pronounced issue in Capitol Hill, the rapid growth. The fact that the neighborhood has the highest density in Seattle clearly indicates the intense pressures for redevelopment on Capitol Hill. Through the population density analysis (Figure 30), the average population per acre of Capitol Hill appeared as 39.9 (population per acre), which is much higher than both that of Seattle, 11.4, and Seattle downtown, 27.8 (Seattle DPD, 2011). In terms of GI, these data also involve the demands for enough green spaces and functions and the amount of water uses, which leads to the ranking that the highest population density received is 5 (the most suitability). Also, since the original population data are bound by blocks used for the 2010 Census, distribution of these data by equal intervals within the site boundary for the ranking was not available. Thus, instead, a specific interval of 10 was used to represent the density conditions in Capitol Hill.



*Figure 30 Population Density*

### *Parcel Use*

The specified parcel use of the area in which a GI practice is to be placed significantly affect its suitability (CNY RPDB, 2012). This criterion is closely related to the ease of implementation or management. For example, some stormwater practices may be undesirable in a property of single family housing due to its installation costs and because they sometimes cause the presence of pests including mosquitoes (CNY RPDB, 2012). Also, public properties such as right-of-way, parks and schools and vacant properties can be considered as the most suitable areas, since locating GI practices at such areas are more beneficial to the neighborhood in terms of mitigating the common, environmental issues, but there can be possible difficulties in



*Figure 31 Parcel Use*

collaborating with private landowners with regard to GI implementation. (CH2M HILL, 2014). The ranking of this criterion was done with this reasoning; public parcels and related parcels were ranked as the most suitable, parcels for commercial and industrial uses were ranked as the second most suitable, and parcels of single families were ranked as the least suitable.

The map of parcel use (Figure 31) was created out by reclassification of parcel data from KCGIS Center. It identifies that commercial parcels constitute most of the PPCOD, implying the district is relatively suitable for applying GI and also has more opportunities along right-of-ways as green corridors where adequate bioswales can be located.

## 5.2. Results of Suitability Analysis

The four scenarios, which have different ways of weighting respectively, resulted in the four productions of suitability analysis. To clarify the differences among them, each scenario was named as: 'Equal Consideration,' 'Green Space-focused Consideration,' 'Stormwater-focused Consideration,' 'UHI-focused Consideration.' Following the process discussed in the previous chapter, all the data ranked and the different weights assigned were inputted into the GIS-based model. The four results (Figures 32, 33, 34, and 35) identify the most and the least suitable spaces for GI implementation with regard to the three major issues –lack of green space, stormwater management, and urban heat islands– of the Capitol Hill neighborhood. Specifically, among the six criteria, the analysis of slope degree, soil infiltration and parcel use refers to where GI practices can be applied suitably in terms of runoff control and management issues (Figures 26, 28, and 31); and the analysis of flow accumulation, surface temperature, and population density points out the vulnerable locations of the three issues (Figures 27, 29, and 30). Therefore, the results of suitability analysis in this study provide visualized grounds of not only the locations that GI can function practically but also the locations that GI is needed.

The first scenario, 'Equal Consideration,' which applies the weight values equally – weight of 1 (approximate 17% each)– shows the balanced result in both effectiveness and necessity. This scenario assumes that any of issues in Capitol Hill will be not distinctively severe, and three issues thus can be considered equally. The process with the formula discussed in Chapter 4, which all numeric data were ranked into five degrees, multiplied by 0.17 and summed into one map (Figure 32). As described on the map, the areas shown in red indicate the least suitable locations and the areas in green mean the most suitable locations for GI to be implemented. The result, showing green in most of the areas within the PPCOD, supports the

primary argument of this research that the PPCOD needs more and better GI practices to mitigate the three issues, and also addresses that GI practices can be located with high efficiency. Specifically, the area below the Cal Anderson Park along the 10<sup>th</sup> and 11<sup>th</sup> Avenue appears as more important in green practices, which is described and developed in more depth in the following chapter as a suggestion. Beside the PPCOD, the result also shows a possibility that many right-of-ways in Capitol Hill can play an important role to connect green functions to be located.

The second scenario, ‘Green Space-focused Consideration,’ mainly emphasizes an issue of lack of green space. If the current developmental pattern is not subdued, planning for Capitol Hill may need to be focused on meeting the increasing demands for green space. Under this scenario, more weight was placed on the development-related criteria. Based on the weight reasoning, explained in Chapter 4, a criterion of population density was given double weight, 29% (28.57...%), and five other criteria received weight of 1(14.28...%). The second scenario shows the different result from the first one (Figure 33). Much more areas in this result represent high suitability (green areas) than those in the first one, which is attributed to the great density in Capitol Hill. This result supports a fundamental notion that higher population needs more green spaces and services. Also, it shows that almost all areas of the PPCOD are highly suitable for GI when the district plans to provide more green spaces.

Suitability Analysis under the third scenario, named ‘Stormwater-focused Consideration,’ resulted in Figure 34. It illustrates the suitable locations of GI implementation when Capitol Hill sets the runoff issues as a priority to mitigate in their planning process. Under this scenario, the three criteria which are most closely associated with this issue –soil infiltration, flow accumulation and slope degree– were given weight of 2. Parcel use and population density were

given weight of 1.5, and weight of 1 was placed on surface temperature. Interestingly, the result shows that while areas in green are relatively shrunk, areas in red increase in comparison with other results. This may be supportive of the fact that there have been the neighborhood's overtime efforts to manage stormwater (SPU, 2012), and thus, stormwater issues are not severe as much as the green space and UHI issues.

Conversely, the fourth scenario which focuses on the UHI issues results in the greatest green areas on the map (Figure 35) among the four results. This scenario, 'UHI-focused Consideration,' majorly aims to mitigate the UHI issues based on an assumption that Capitol Hill will face more intensive UHI due to climate changes. UHI mainly influenced by global climate changes, but specifically the phenomena are identified as surface temperature and are associated with urban density and use, and amount of soil moisture. Following the weight reasoning process discussed in Chapter 4, different weights were assigned –21% was applied to surface temperature, parcel use, and population density respectively, 16% was applied to soil infiltration, and 11% was applied to both flow accumulation and slope degree-. This result evidently addresses that Capitol Hill has been urbanized in negative ways with great density, human-oriented land use, and high temperature. Also, when compared with the results of the first and their scenario (Figure 32 and Figure 34), it also shows that when the built-environmental factors are considered with greater weight, there are more potential demands for GI.

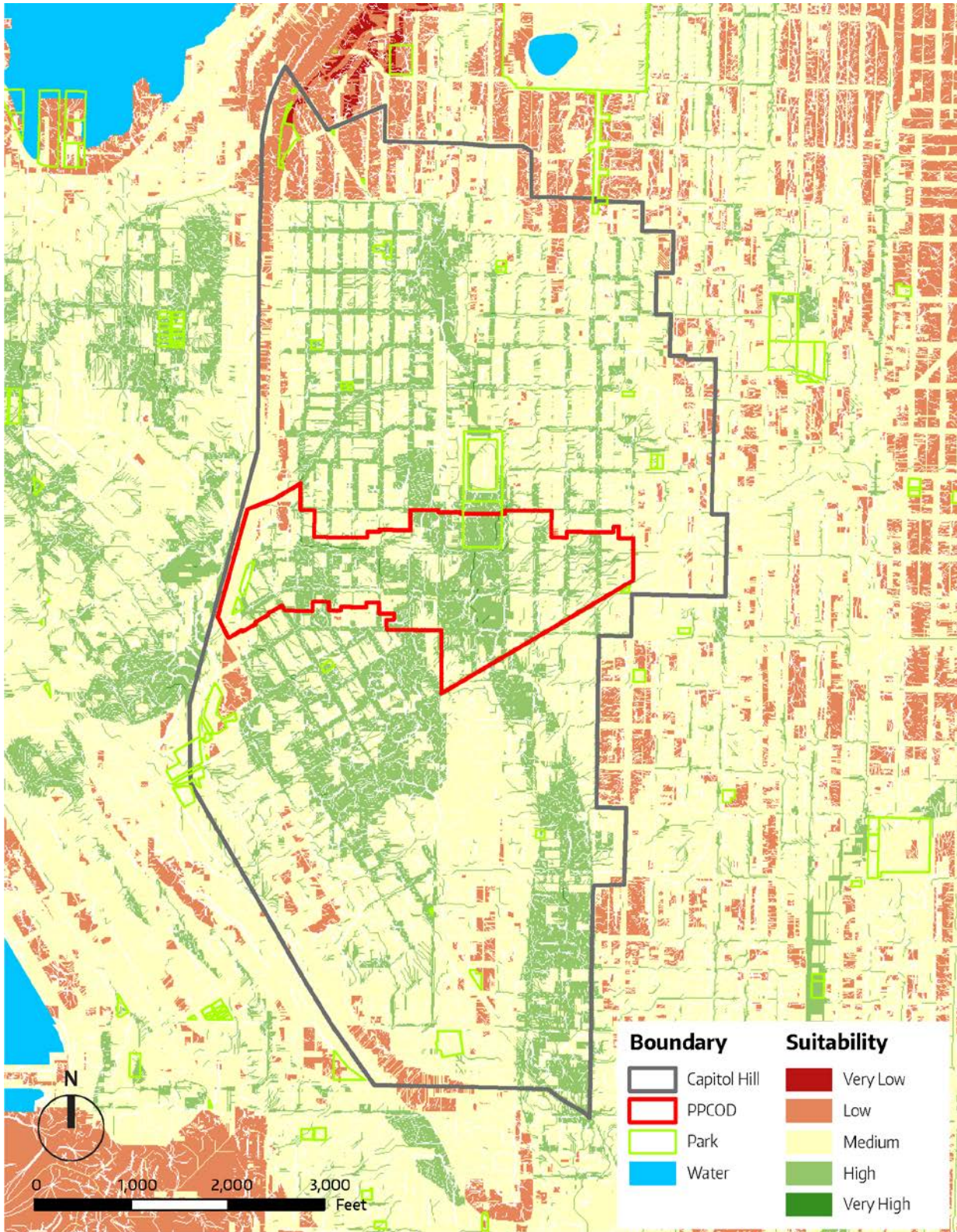


Figure 32 Suitability Analysis under the Scenario 1, 'Equal Consideration'

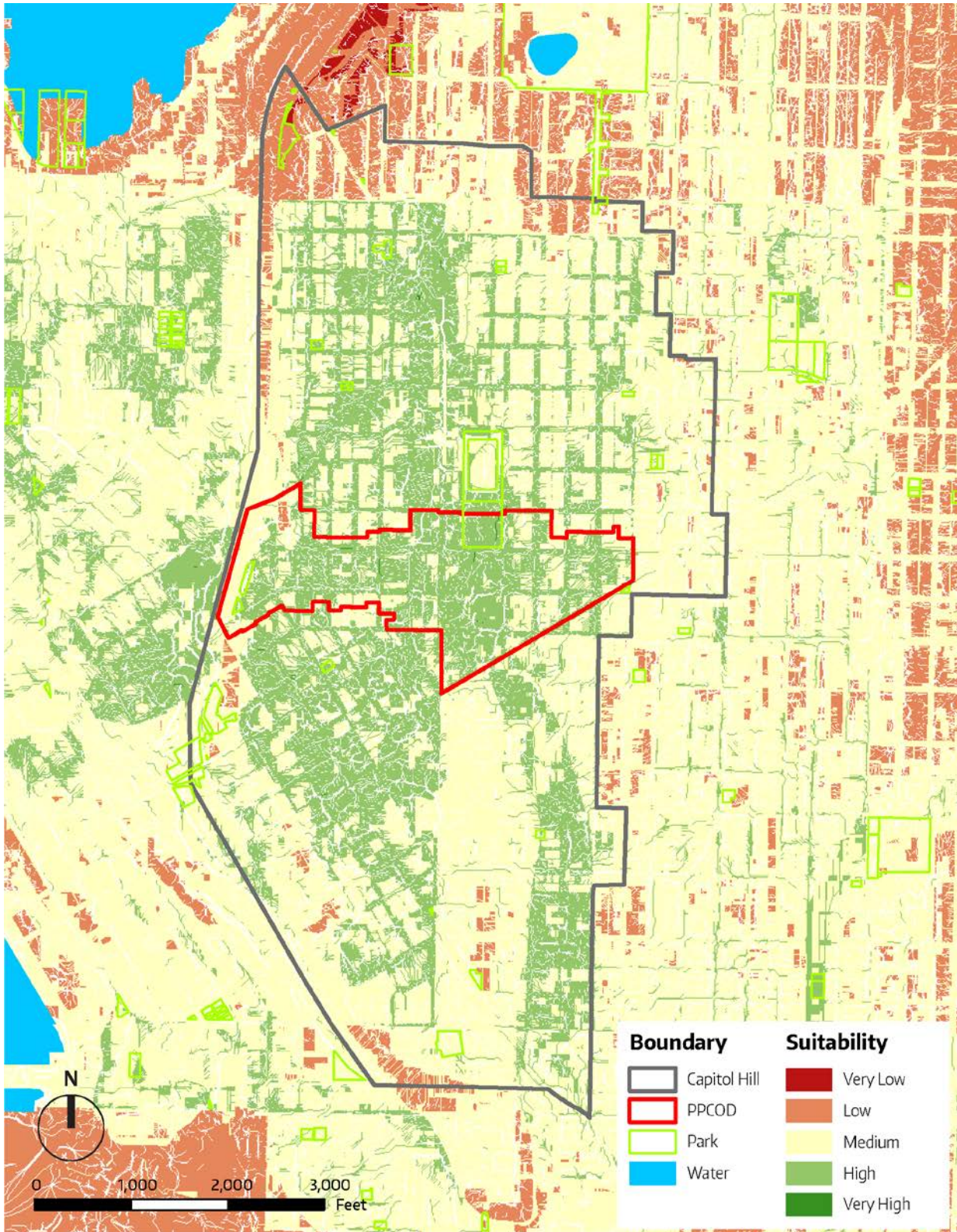


Figure 33 Suitability Analysis under the Scenario 2, 'Green Space-focused Consideration'

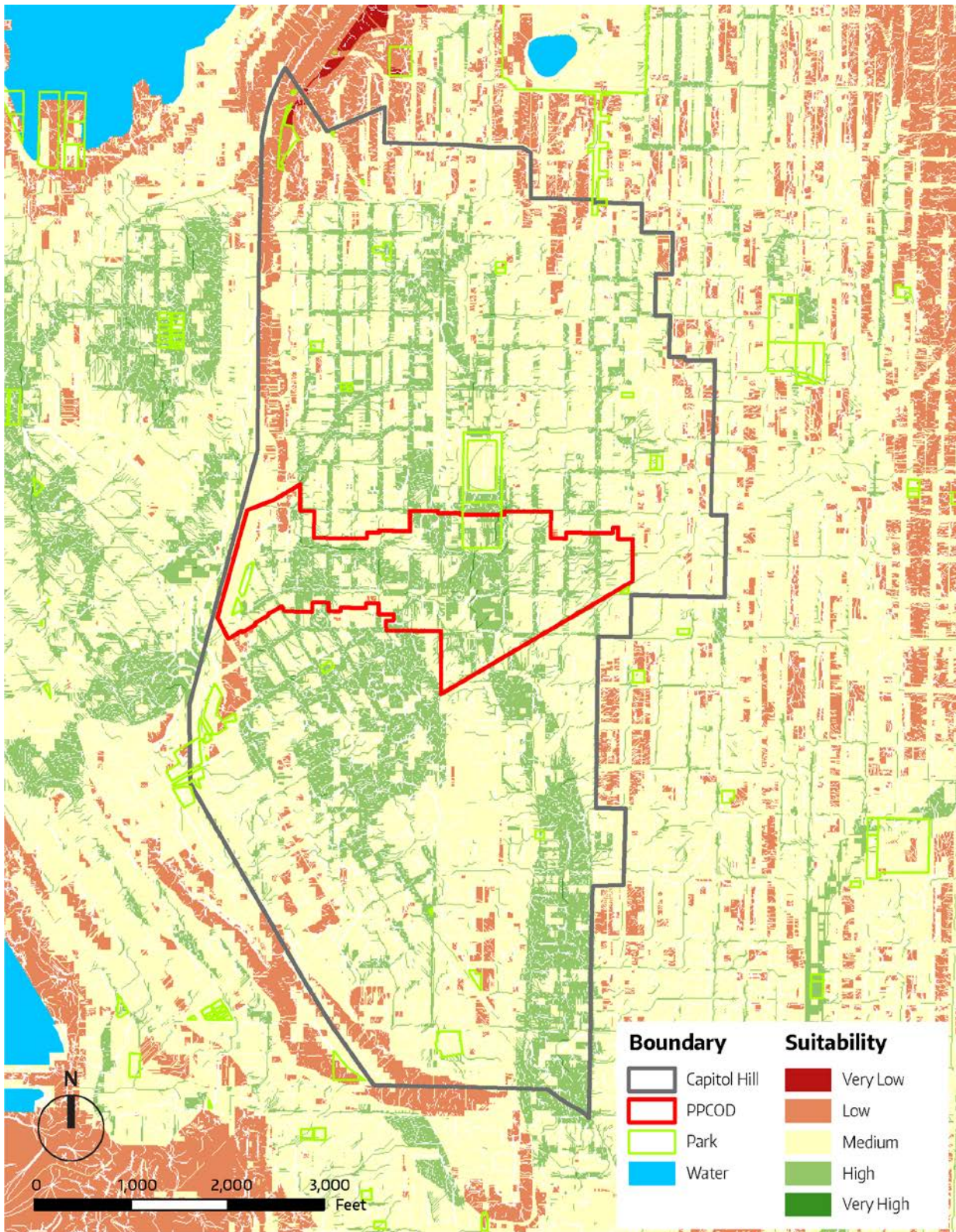


Figure 34 Suitability Analysis under the Scenario 3, 'Stormwater-focused Consideration'

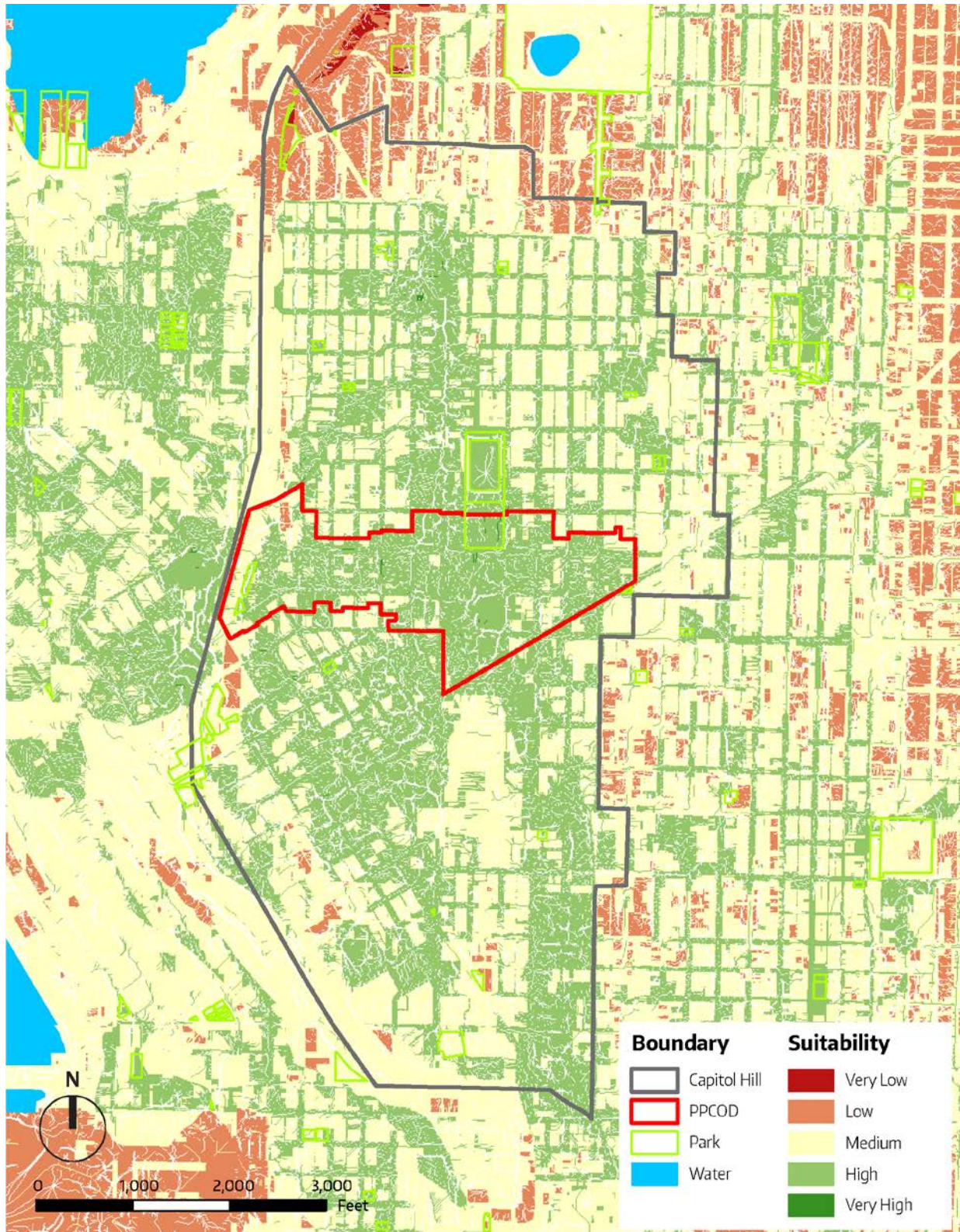


Figure 35 Suitability Analysis under the Scenario 4, 'UHI-focused Consideration'

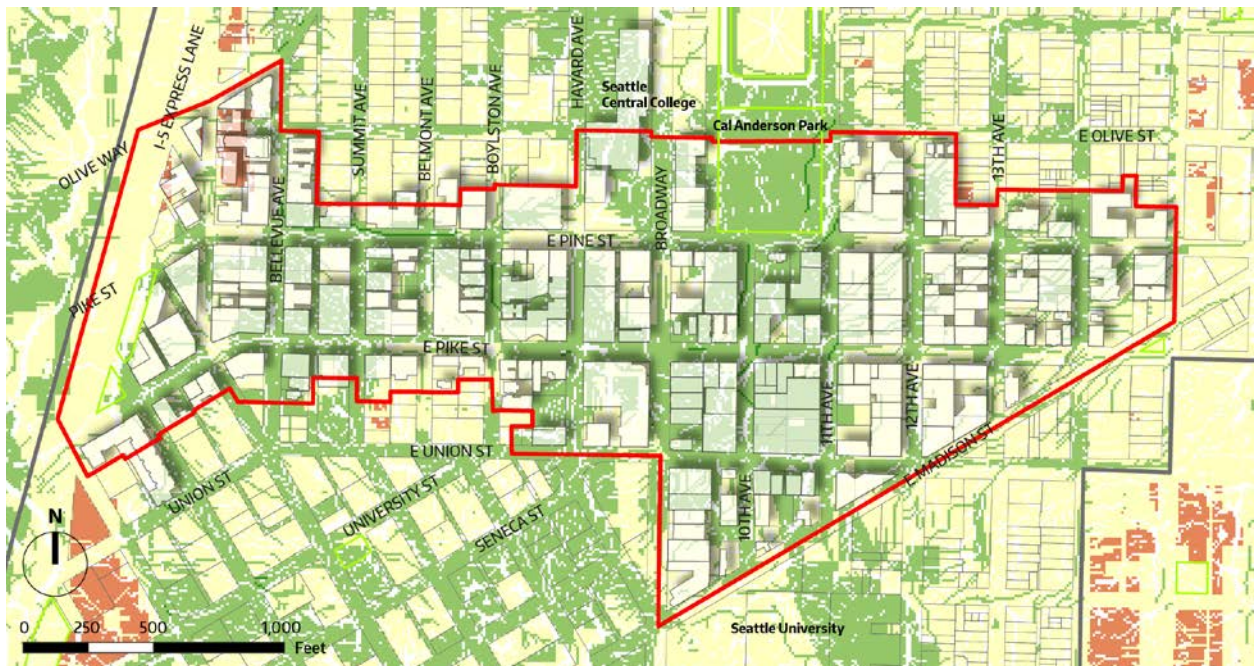
## **Chapter 6. Recommendation**

This chapter is mainly intended to suggest a springboard for filling gaps between analysis (methodology) and practices. Based on the result of suitability analyses under Scenario 1, 'Equal Consideration,' which places equal weight on the six criteria, this chapter tries to show how the four selected GI practices –rain garden, bioswale, green roof, and permeable pavement– can be located suitably, balancing the effectiveness of and demands for GI. The reason why the first scenario was selected for the recommendation is that since the three issues are basically grounded on uncertain and unpredictable factors –climate change and urbanization–, the equal consideration can be regarded as the most plausible scenario among the four scenarios. In order to prevent the recommendation being biased, the first scenario was chosen for GI implementation.

The recommendation provides possible ways to benefit from GI mainly by mitigating the three major issues for the area specific –PPCDO– at a planning scale. Besides the six criteria, for this suggestion of locating the GI practices properly, several socio-cultural contexts were considered to support the feasibility of planning. However, it should be highlighted that, in the real world, a wide array of factors, such as policy, stakeholders, urban forms, and cost, significantly affect the implementation of GI practices; therefore, the suggestion should be regarded only as a draft recommendation for the tuned use of suitability analysis for GI planning rather than as a specific technical guidance.

## 6.1. Green Infrastructure Recommendation for the PPCOD

Figure 36 is a cropped result of the Scenario 1, equal consideration, which focused on the PPCOD and of which the recent building outlines were then overlaid. As stated in the previous chapter, the area below the Cal Anderson Park shows high suitability for GI implementation containing the most suitable spaces (linear dark green along 10<sup>th</sup> Avenue). Spaces on East Pine Street between Summit Avenue and Boylston Avenue appear the most suitable. Since the PPCOD is rapidly being developed with over twenty projects currently underway (Figure 12 in Chapter 3), losing its neighborhood character (Chalana, 2015), it is important for the GI implementation to be involved in the current social context. This is because the objectives of GI should not be limited to mitigating environmental issues but include improving social livability (CNT, 2010). A series of maps shown in Figure 37 and Figure 38 describes several social contexts including bike lanes, tree canopy, historical buildings, and cultural and social assets<sup>20</sup>.



*Figure 36 Result of Suitability Analysis under Scenario 1, zoomed into the PPCOD*

<sup>20</sup> It should be mentioned that the six maps were reproduced based on the productions of URBDP 508 class in 2015 at the University of Washington.

These maps do not take into account of all sociocultural facets of the PPCOD, but can be importantly referenced for deciding the actual locations of the GI practices. For example,

- **Bioswales** are better placed along pedestrian streets or bike lanes rather than usual right-of-ways for providing closer user-oriented experiences.
- Existing parking lots shown as high suitability can be considered the best locations for **permeable pavement**.
- **Rain gardens** can be adjacent to or included in social spots, such as plazas.
- Buildings which provide social functions, such as new apartments (private community) or commercials, can be best suited for **Roof gardens**.

Foremost, however, it should be reminded that the suggested implementation was fundamentally grounded on the result of suitability analysis to satisfy demands for and increase efficiency of GI.

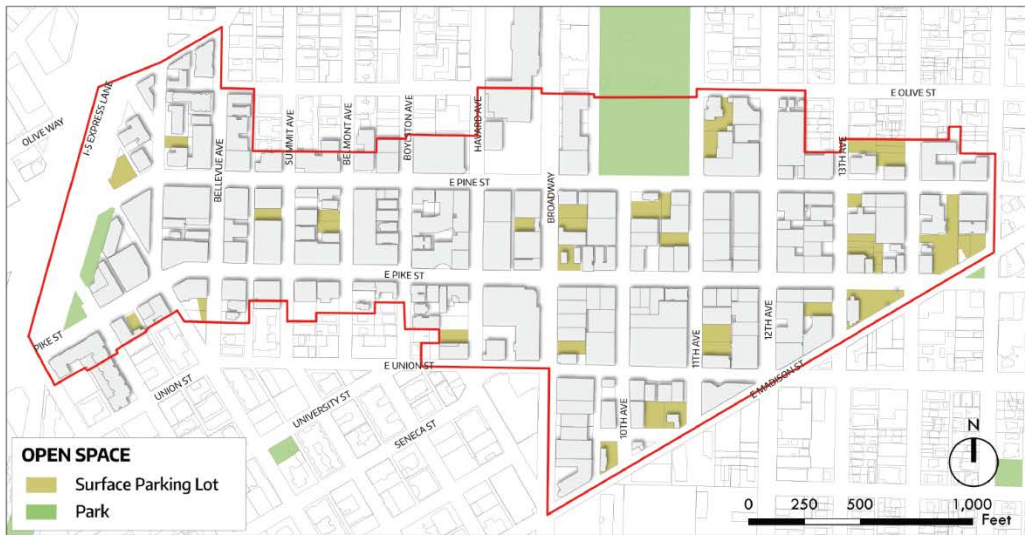
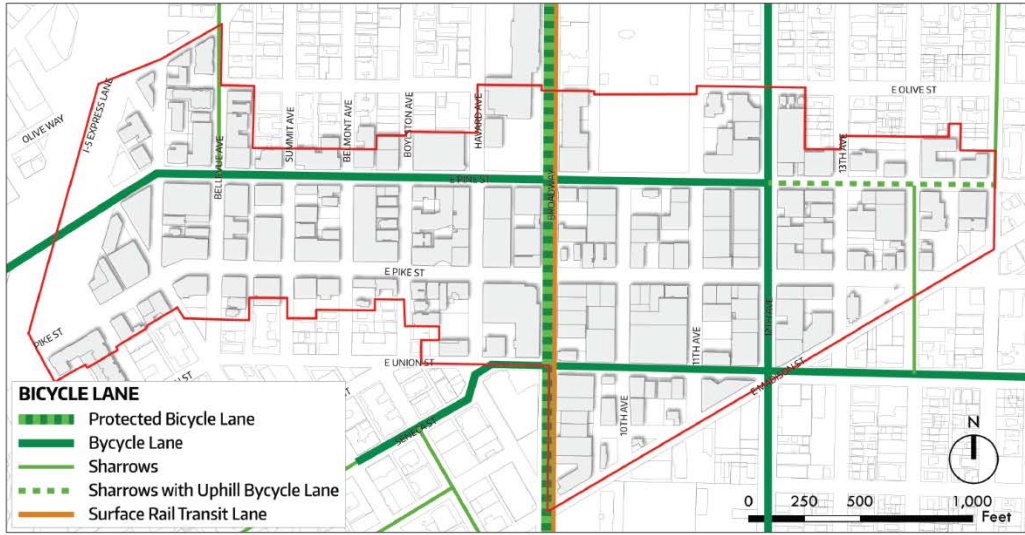


Figure 37 Sociocultural Contexts of the PPCOD (1)

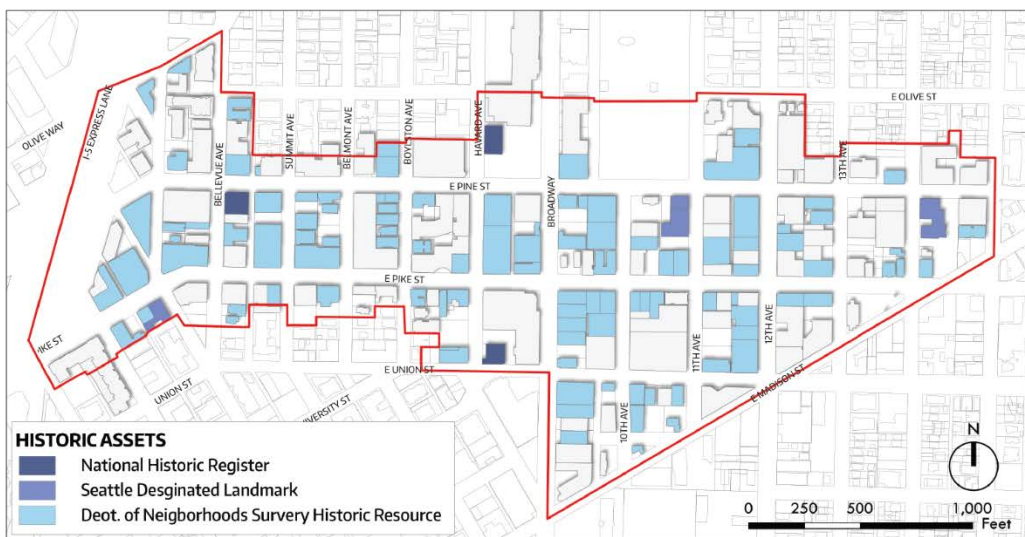
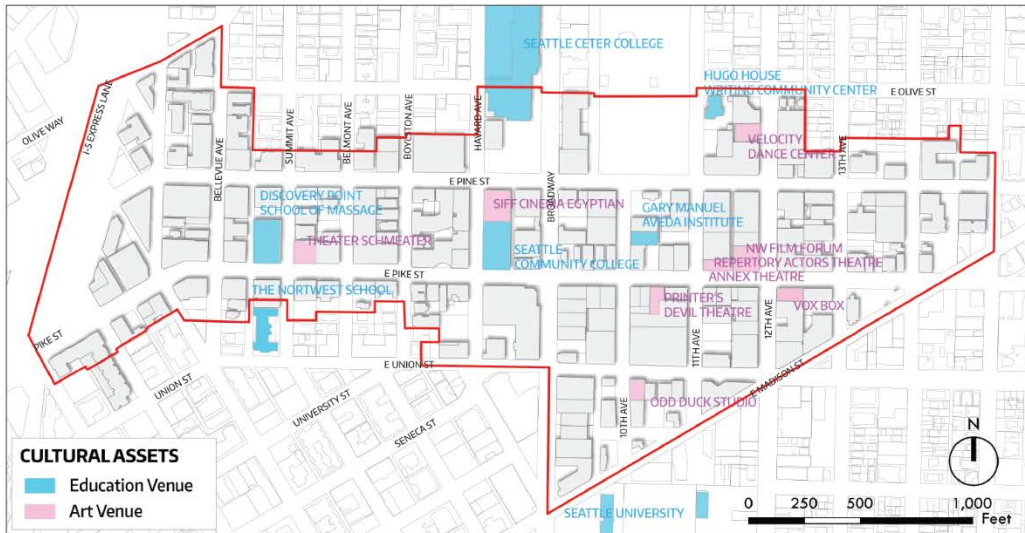
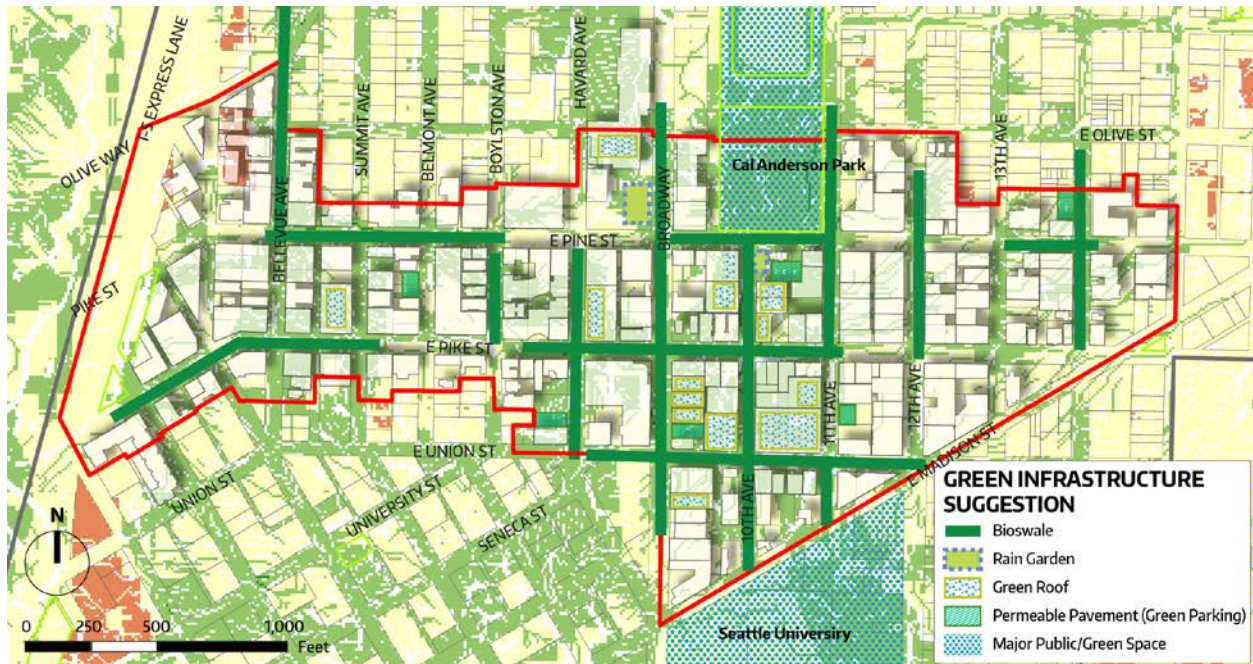


Figure 38 Sociocultural Contexts of the PPCOD (2)



*Figure 39 Green Infrastructure Suggestion on the PPCOD*

Figure 39 is a planning recommendation, created with integrated consideration of the contexts shown in Figure 37 and the result of suitability analysis, for the four selected GI practices to be located suitably. 10<sup>th</sup> Avenue and 11<sup>th</sup> Avenue are suggested as a main GI corridor where all the selected GI practices can be implemented along the avenues and where the two major public spaces –Cal Anderson Park and Seattle University– can be linked. Most of spaces in both avenues are identified as high suitable; and many restaurants, cafés and several historical buildings are functioning as social, gathering spaces. In this regard, the proposed GI practices on 10<sup>th</sup> Avenue and 11<sup>th</sup> Avenue can play an important role at the center of the PPCOD in not only mitigating the three issues but also nourishing social activities. Also, East Union Street and 11<sup>th</sup> Avenue within the district can be suggested as green streets with bioswales incorporating bike lanes that cross through the district. Rain gardens are suggested to be located on the existing open spaces, such as a plaza below Seattle Center College, to enrich their community characters. Permeable pavements are proposed on the parking lots which appear as high suitability (Figure 36).

As aforementioned, this suggestion is mainly intended to show the use of suitability analysis for GI planning, and thus, it does not fully guarantee its feasibility. Currently, in Capitol Hill, several GI practices, such as Swale on the Yale and several green streets with planters, are functioning, but capturing the suitability of GI can be a necessary process to improve efficiency of implementation before moving into the design or planning stage. Figure 40 shows examples of implementation of GI practices on the PPCOD, including bioswale on 10<sup>th</sup> Avenue and East Union Street, and a rain garden on an open space below the Cal Anderson Park, which may help shape envisioning how the recommendation could be applied to the ground.



*Figure 40 Vignettes of Implementations of GI Practices on the PPCOD*

## **Chapter 7. Conclusion**

### **7.1. Implication of Suitability Analysis**

Suitability analysis was conducted through a series of steps with sound knowledge to validate the purposes of this research. From exploring the scholarship of green infrastructure to developing a GIS model, this thesis tries to examine the broad scope of implication of suitability analysis. Especially, the scholarship, studied in Chapter 2, identifies the overarching purpose of this research –addressing a linkage between analysis and application– by presenting the disciplinary gaps in current, widely accepted GI definitions. With regard to this purpose, this research proposes a specified methodology of suitability analysis which was developed for Capitol Hill, where GI related issues have been significantly exposed on the surface. Site analyses, shown in Chapters 3 and 5, provide a comprehensive knowledge of the site and demonstrate the pronounced three issues in the neighborhood: lack of green space, stormwater management, and UHI. These processes led this research into more specified, primary goals.

The primary goals of this thesis is to develop an applicable methodology that can contribute to mitigating the issues of Capitol Hill and guiding the neighborhood into a better environment. Since this research copes with the particular issues of Capitol Hill, even if it largely follows the general process of suitability analysis, this study developed its own methodology optimized for the site. In other words, since the method development was fundamentally grounded on Capitol Hill, the six criteria establishment, and the ranking and weighting reasoning with four scenarios, discussed in Chapter 4, are distinct contributions of this thesis from other precedent studies. For tailoring the general methodology best suited to the neighborhood, this thesis suggested six criteria, which are closely connected to the three issues, and four scenarios

which cover each issue. Furthermore, this research provides a planning recommendation on the more specific site, the PPCOD, in order to show how the developed methodology can be applied to the ground.

The results of suitability analysis provide valuable information in implementation of the GI planning on Capitol Hill. The visualized overlay results identify the best locations of GI to increase efficiency of and satisfy needs for GI. Each scenario resulted in quite different areas in high suitability, specifically implying that the neighborhood needs more and better GI when pursuing an improvement of development-oriented issues, such as lack of green space. A majority of areas in the PPCOD appears high suitability in all four scenarios, which support the primary argument that the district is being threatened by intensive pressure for redevelopment. On the flip side, they also address a strong possibility that the PPCOD can be improved with proper implementation of GI. As an effective alternative to planning practice, this thesis hopes the suitability analysis from comprehensive analysis will benefit the local community.

Another noteworthy implication of suitability analysis of this research is applicability to other urban areas which likely pursue other approaches of GI. Although this thesis suggests the specified methodology to Capitol Hill's context, the suitability analysis model with the proposed reasoning process –logic in criteria selection and weighting–, which has been emphasized, can be applicable and replicable in other cases. Different sites bring about different criteria and scenarios. Although Capitol Hill seeks amelioration of green spaces, stormwater and UHI, other sites may have different aims such as remedy of urban blight (a case of Walworth Run) or creation of green corridors for sustainable development (a case of Chattanooga). However, the reasoning of how criteria are logically connected to each other and how the weights are assigned

to criteria based on the scenario development, discussed in Chapter 4, can provide a supportive tool that identifies areas most suited to GI, and guide better site planning.

## **7.2. Limitations and Next Step**

The GIS-based suitability analysis and planning of GI in this research was conducted in a logical process with comprehensive understanding of the site issues, and has a pivotal meaning in that it can play an important and supportive role in the decision-making process for the better neighborhoods. However, there are several limitations that should be considered. Specifically, data unavailability, limited scope of GI practices, and technical issues demonstrate the limited reliability of the results when applying to real world planning practice.

Foremost, lack of data caused several challenges in both criteria establishment and criteria analysis. As discussed in Chapters 5, the flow accumulation and the soil infiltration were selected as alternatives to stream data (or ground water) and hydrologic soil group data respectively. Even if the flow accumulation well represent the hydrological conditions of stormwater pressure on the surface, since this data originated from the contour data, some implied information is inevitably overlapped with the slope degree. Also, since the original resource of soil infiltration is a PDF file from the City of Seattle which already ranked the data into three degrees, this data could not be manipulated to follow the five degrees, causing data gaps in both ranking and weighting process. Another limitation is apparent on the surface temperature. Given that it is from a satellite infrared image, the data does not represent the accurate conditions of the Capitol Hill. The cell size, 60 meter by 60 meter, and data values, ranging between 0 and 255, in the GeoTIFF image, are not relatively compatible to the overlay

process. Also, for better understanding of the thermal conditions, data associated with seasons or times during the day would be required.

This thesis limited GI practices into four –bioswale, rain garden, green roof, and permeable pavement– in order to cover the technical requirements. The reclassification of data was grounded on these requirements –such as the required degree for both permeable pavements and bioswales is less than 5 %– but it cannot be said that the six criteria fully reflect the four practices. The detailed requirements for each practice fairly differ, and the implementation of GI practices are subject to many other related factors, including stakeholders, policy, and cost. Therefore, even if the results show the most suitability on specific spaces, it does not directly mean the spaces are actually available now for the GI implementation. To overcome this limitation, a draft planning was suggested in the previous chapter considering several sociocultural contexts, but as aforementioned, it is a recommendation based on the results rather than a practical design or a technical guidance.

Despite these limitations, this thesis provides useful insight to support a comprehensive understanding of GI planning, through the integrated data analysis, focused on the urban area facing rapid urban growth. The example of Capitol Hill is not limited to Seattle but can be extended to other cities across the United States experiencing urbanization. This thesis mainly demonstrates suitability analysis that identifies the best location for GI implementation can contribute to better approaches for improving our built environment. As next steps, additional research should be conducted by considering sophisticated factors of urban areas and by applying the suggested methodology to other sites where better GI approaches are needed. Again, the combination of climate changes at a global scale and urbanization at a regional scale require planners and landscape architects to creatively mitigate the issues that we are facing, and

suitability analysis is expected to play an important, supportive tool in decision making process in conjunction with policy.

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