ABSTRACT

Title of Document:	A SCENARIO PLANNING APPROACH FOR SCHOOL GREEN ROOFS TO ACHIEVE STORMWATER MANAGEMENT BENEFITS: A CASE STUDY OF BRIER'S MILL RUN SUBWATERSHED
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In 2010, the United States Environmental Protection Agency (EPA) determined the Total Maximum Daily Load (TMDL), a "pollution diet", for the Chesapeake Bay watershed for six states (New York, Pennsylvania, Delaware, Maryland, West Virginia, Virginia) and the District of Columbia. The EPA required responsible agencies to develop statewide Phase I Watershed Implementation Plans (WIPs) to support the implementation for TMDLs. Previous planning efforts included the development of Subwatershed Action Plans (SWAPs), which provided a baseline of conditions, proposed tools for achieving TMDL reductions, and visions for the subwatersheds.

In 2012, the Phase II WIP process was developed to refine Phase I plans at the county level, including more local details about a variety of green infrastructure interventions to optimize nutrient and sediment load reductions. While green roofs were considered an important tool in the SWAP plans, they were not included in Prince George's County's Phase II WIP plans. Recently, Prince George's County has implemented a new green roof incentive policy. In

light of this new policy, this research explores how green roofs might contribute to reducing TMDLs. The research uses Brier's Mill Run Subwatershed as a case study to demonstrate the benefits of both the incentives and the green roof as a tool in the SWAP plan.

The objective of this research is first to document the specific role of green roofs in stormwater management in Brier's Mill Run Subwatershed. Secondly, the thesis provides three metrics to measure and compare the stormwater management benefits of each proposed educational institutional green roof in the research site. The third goal is to use a scenario approach to achieve school green roofs benefits that contribute to the stormwater management goals of the subwatershed.

A SCENARIO PLANNING APPROACH FOR SCHOOL GREEN ROOFS TO ACHIEVE STORMWATER MANAGEMENT BENEFITS: A CASE STUDY OF BRIER'S MILL RUN SUBWATERSHED

By

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Thesis submitted to the Faculty of the Graduate School of the
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Acronyms

AWS	Anacostia Watershed Society
BMPs	Best Management Practices
CSS	Combined Sewer System
CWA	Clean Water Act
DDOE	District of Columbia Department of the Environment
EPA	United States Environmental Protection Agency (EPA)
ESD	Environmental Site Design
LEED	Leadership in Environmental and Energy Design
MS4	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
SITES	Sustainable Sites Initiative
SWAPs	Subwatershed Action Plans
TMDL	Total Maximum Daily Load
USGBC	the U.S. Green Building Council
WIPs	Watershed Implementation Plans

Introduction

This thesis explores how a comprehensive approach to green roof planning and design can be developed in a selected subwatershed to achieve stormwater management and educational benefits. Stormwater management regulations and policies ranging from federal to county have been implemented nation-wide to target pollution reduction goals. Green roofs, as one of many green infrastructure tools, have been widely incorporated in state and county stormwater management policies and design methods. Green roofs, an increasingly used green infrastructure tool, have primarily been designed and planned one-by-one and not systematically. This thesis explores how a more comprehensive approach might provide planning and design flexibility to county and water decision-makers in applying the appropriate green infrastructure tools to provide the most benefits. The author also uses a scenario approach to create a range of development situations in the research site. A scenario approach can provide decision-makers a variety of master plans based on different development assumptions.

In addition to exploring a more comprehensive approach using scenarios, the thesis also explores the intersection between stormwater benefits and educational benefits. The application of green roofs to institutional settings is growing and opportunities exist for green roofs to provide multiple benefits.

In 2010, the United States Environmental Protection Agency (EPA) determined the Total Maximum Daily Load (TMDL), a "pollution diet", for the Chesapeake Bay watershed for six states (New York, Pennsylvania, Delaware, Maryland, West Virginia, Virginia) and the District of Columbia. EPA required responsible agencies to develop statewide Phase I Watershed Implementation Plans (WIPs) to support the implementation for TMDLs. Previous planning efforts included the development of Subwatershed Action Plans (SWAPs), which provided a baseline of conditions, proposed tools for achieving TMDL reductions, and visions for the subwatersheds.

In 2012, the Phase II WIP process was developed to refine Phase I plans at the county level, including more local details about a variety of green infrastructure interventions to optimize nutrient and sediment load reductions. While green roofs were considered an important tool in the SWAP plans, they were not included in Prince George's County's Phase II WIP plans. Recently, Prince George's County has implemented a new green roof incentive policy. In light of this new policy, this research explores how green roofs might contribute to reducing TMDLs. The research uses Brier's Mill Run Subwatershed as a case study to demonstrate the benefits of both the incentives and the green roof as a tool in the SWAP plan. Using this design tool, the research will be centered on these possible questions:

1. What is the specific role of green roofs in stormwater management in Brier's Mill Run Subwatershed?

2. What are the stormwater management benefits of each proposed selected educational green roof in Brier's Mill Run Subwatershed?

3. How can using scenario planning in the use of school green roofs contribute to the stormwater management goals of Brier's Mill Run Subwatershed?

The thesis is organized into the following six chapters. The first chapter provides an introduction and the literature review for stormwater management and green roofs benefits. The literature review provides relevant information that is applied to Brier's Mill Run Subwatershed case study. The second chapter documents the inventory and analysis of the watershed and the creation of a proposed 2040 land use plan. The inventory and analysis is critical to understand the comprehensive nature of the Brier's Mill Run Subwatershed. Furthermore a proposed 2040 land use plan and the planning assumptions are important in laying the groundwork for the development of the scenarios. The third chapter documents the site inventory and site analysis for eight educational institutional green roofs selected in Brier's Mill Run Subwatershed. Each school building and property is assessed by three metrics to demonstrate its stormwater management benefits. The benefits analysis can provide school principals a more comprehensive idea of how a particular green roof can help with the campus environment and help further make a more informed decision about applying green roofs on their school buildings. This chapter also provides suggestions for other stormwater management tools that can be applied based on the unique site conditions. The fourth chapter demonstrates how school green roofs, using scenarios to provide a comprehensive approach, can contribute to the stormwater management requirement of Brier's Mill Run Subwatershed. can The scenarios are intended to provide a tool that water decision-makers can use to choose between green roofs among the other green infrastructure tools and among land use types (e.g. educational, commercial, residential) to mitigate stormwater runoff required by local governments. The fifth chapter illustrates potential green roof educational applications. The design suggestions can help educators better use green roofs as a study tool in teaching and learning. The final chapter contains a summary. The author then provides conclusions and limitations to the application of this research project.

Chapter 1: Literature Review

The literature review is organized into four broad categories: 1) a brief overview of stormwater management and an introduction to green roofs, 2) stormwater regulation and policy with a focus on green roofs, 3) a survey of the benefits of green roofs, and, 4) documentation of selected three precedent studies with the focus on green roofs in educational settings. The review of the stormwater management will focus on the current regulations and policy, in particular Maryland regulations. The third section will document the benefits of green roofs and will build a solid understanding of the environmental, social, and economic benefits of green roofs. The fourth section on educational applications will provide a background and necessity of expanding designs tools beyond their environment benefits.

1.1 Green Roofs' Role in Stormwater Management

The following stormwater management section of the literature review is organized into three sections. The first section reviews the formation of stormwater in cities. The second section explores the problems and impacts of stormwater on natural water system and people. The third section covers an introduction of green roofs, its role in urban stormwater management and the current industry development.

1.1.1 Stormwater in Cities

Stormwater is rainwater and melted snow that runs off streets, lawns, and other sites (EPA

2012b). Before development, the land with permeable surface cover could easily intercept rainfall. In natural process, when stormwater is absorbed into the ground, it is filtered by vegetation and soil and ultimately replenishes groundwater aquifers or discharge to larger surface water bodies (Schueler 1995). In contrast, after development, impervious surfaces such as pavement and roofs prevent precipitation from naturally soaking into the ground and rainwater no longer infiltrates (Figure 1). Instead, the water could potentially drain into engineered storm water or sewer systems (EPA 2012b).

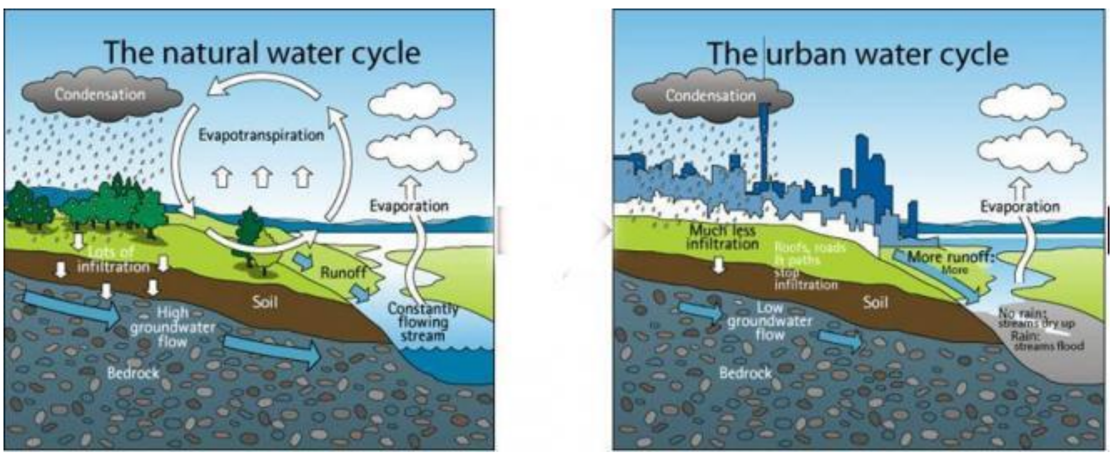


Figure 1: Natural Water Cycle and Urban Water Cycle

(Source: Modified from http://www.sswm.info/category/implementation-tools/wastewater-collection/hardware/surface-runoff/stormwater-management)

1.1.2 Stormwater Impacts

Impact on Water Systems

Urbanization changes how water naturally travels through the watershed. With natural vegetation cover, about 50% of rainfall infiltrates into the ground, 40% evaporates or is transpired through plants (i.e., evapotranspiration), and only about 10% actually runs off the surface (EPA 2003). After development, runoff is generated due to stormwater that does not percolate into built impervious surfaces (e.g., paved streets, parking lots, and building rooftops). As runoff flows over the land, it accumulates quickly and can concentrates as channel flow, and eventually flow directly into a drainage system and finally into rivers or water bodies (Roehr and Kong 2010). In this situation, evapotranspiration by plants is largely removed, and runoff increases. In urban environments with 75% to 100% impervious area, more than half of rainfall becomes runoff, and infiltration is less than 1/3 when compared with pre-development (Figure 2).

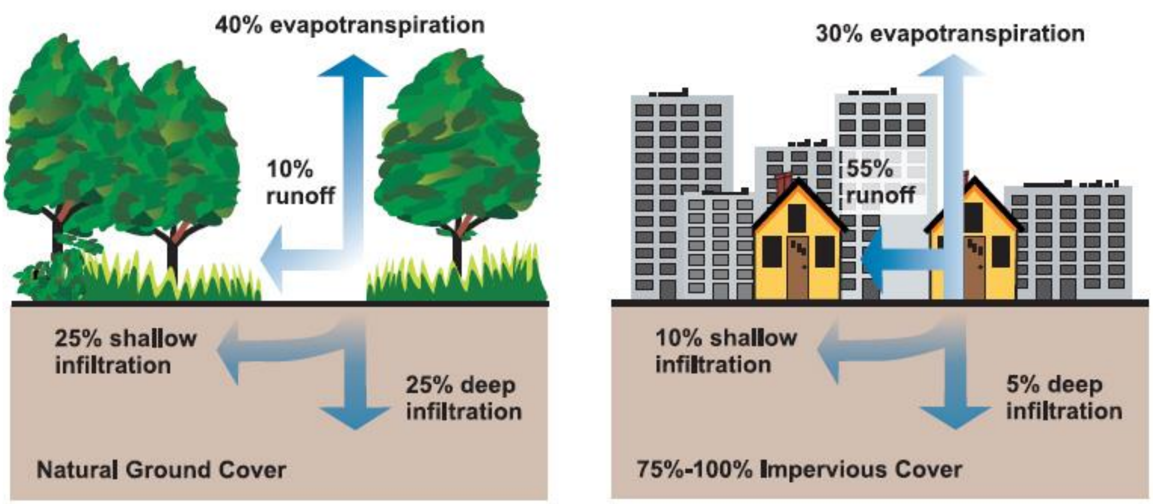


Figure 2: Natural Water Infiltration and Urban Water Infiltration

(Source: EPA. 2003. Protecting Water Quality from Urban Runoff.)

The increased runoff and reduced infiltration could also influence attached water bodies. The additional runoff contributes to increased stream flows, which leads to a rapid flow increases. With decreased stormwater infiltration, less water is available to recharge into the streams resulting in lower stream base flow levels between rainfall events. As a result, much of the water now enters the stream all at once. Environmental problems occur including downstream flooding, stream bank erosion, increased turbidity, habitat destruction, combined sewer overflows in older cities, infrastructure damage, and contaminated streams, rivers and coastal water (EPA 2012b).

Impacts on People

Stormwater runoff can also effect local populations from several aspects. One problem caused by stormwater runoff is impact of water availability due to lowering of the water table. Water leaves the natural system by running off all the impervious surfaces and not entering the water table; this lowers the base flow of streams, which can result in local water shortages (Ferguson et al 2003).The increased stormwater volume also increases the risk of city flooding. For example, when it rains, the growing volume of water in the creek can crack an exposed sewer line. Street’s storm drains can clog and send waves cascading into structures. At the same time, floods carry a high cost to both property owners and taxpayers, who subsidize emergency aid as well as federal flood insurance.

In addition to increasing runoff volume in the landscape, expanded urbanization also impacts stormwater quality. Increased rainwater and snowmelt flowing across impermeable surfaces such as concrete, asphalt, rooftops, as well as urban lawn areas and construction sites, carries contaminants such as road salt, fertilizers, pesticides, heavy metals, oils, nutrients, bacteria, and total suspended solids (Roehr and Kong 2010), all of which affect the health of waterways and surrounding lands. As runoff flows through impervious areas, it accumulates debris, chemicals, sediment or other pollutants that can adversely affect water quality if the runoff is discharged untreated (EPA 2012b).

1.1.3 Introduction of Green Roofs

Green roofs, also called vegetated roof cover, use engineered growing media, drought tolerant plants, and specialized roofing materials installed on existing and proposed structures (Peck et al. 1999). They typically contain a layer of growing medium, planted over a waterproofing membrane, which might also include a root barrier, drainage and irrigation system (Figure 3).

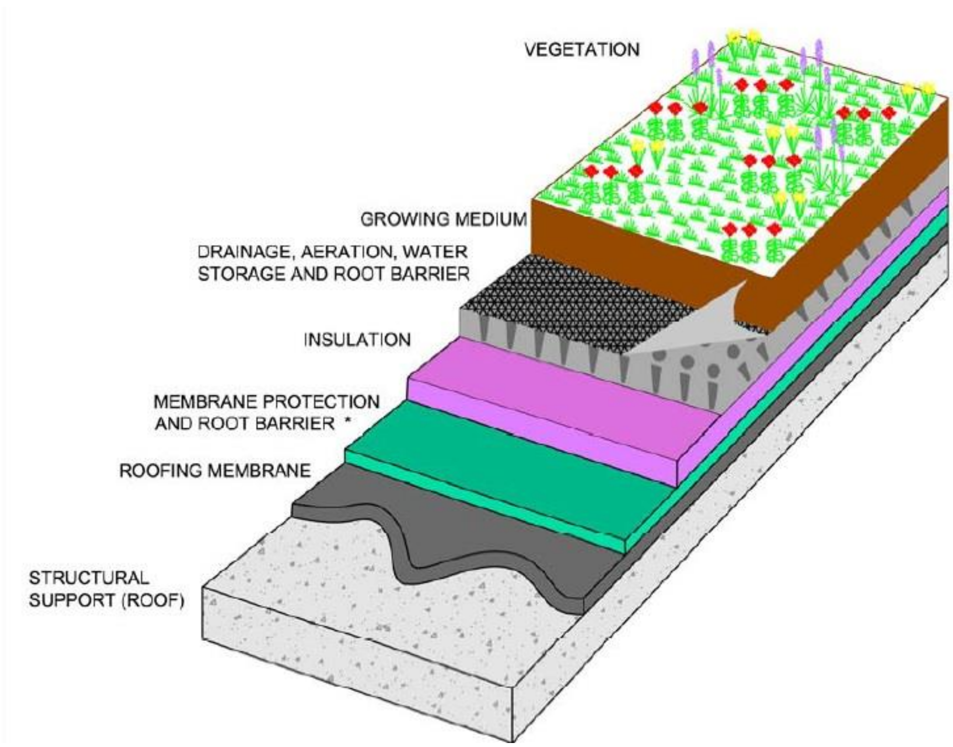


Figure 3: Typical Green Roof Structure Layers

(Source: MDE. 2009; Figure 5.2, page 5.44**)**

During recent decades, green roofs have been playing a more important role as a design and construction tool for structural stormwater control, which are defined as "constructed stormwater management facilities designed to treat stormwater runoff and/or mitigate the effects of increased stormwater runoff peak rate, volume, and velocity due to urbanization" (Atlantic Regional Commission 2001). There are three types of green roofs depending on the depth of planting medium and maintenance needs. The characteristics (Table 1) of the three categories of green roofs can be summarized in the following table (GRHC 2006):

Table 1: Green Roof Type and Characteristics

Characteristic	EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
Growing Medium Depth	6” or less	25% above or below 6”	More than 6”
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully Saturated Weight	Low 10-35 lb/ ft^2 (170.9 - 1,464.7 kg/m^2)	Varies 35-50 lb/ ft^2 (170.9 - 1,464.7 kg/m^2)	High 35-300 lb/ft^2 (170.9 - 1,464.7 kg/m^2)
Plant Diversity	Low	Greater	Greatest
Cost	Low	Varies	High
Maintenance	Minimal	Varies	Varies, but is generally high

1.1.4 Green Roofs as a Stormwater Management tool

With urbanization, the increase in stormwater volume affects the physical characteristics of urban streams (Bhaduri et al. 2000). In the past, stormwater management focused on conveyances to route stormwater runoff from urban centers directly into nearby rivers, streams, and lakes. Engineering solutions – often for flood control – include armoring stream banks with concrete or riprap, straightening channels, and stream piping (Dunne and Leopold, 1978). As a result, the built environment is often implicated as a causal agent in degradation of stream ecosystems near urban centers (Booth and Jackson 1997). At the same time, impervious surface cover adversely affects stream ecosystems due to the reduction of soil infiltration (Arnold and Gibbons 1996). Nonstructural controls primarily encompass better site design practices.

Green roofs can reduce decrease both the speed and quantity of water runoff during precipitation and improve water quality (Mentens et al 2006). Most importantly, it is a new and essential approach to decrease impervious surfaces in built areas. The environmental issues raised from impervious areas include overload of stormwater management and treatment facilities and potential floods due to heavy precipitation.

1.1.5 Green Roof Industry and Development

Regarding the above risks of urban stormwater and the potential benefits of green roofs, green roofs are ideal for urban stormwater management because they make use of existing roof space and prevent runoff before it leaves the site (Oberndorfer et al 2007). "The green roof industry grew by 115 percent over the course of 2011, up significantly from 28.5 per cent growth recorded in 2010" (Figure 4, Peck 2012) In total, the projects reported represent 870 projects, 4,577,935 square feet installed in 2011, up from the 713 projects, 4,341,394 square feet reported installed in 2010 (Figure 4) (GRHC, 2012). North America's green roof industry has grown rapidly in recent years (Figure 4).

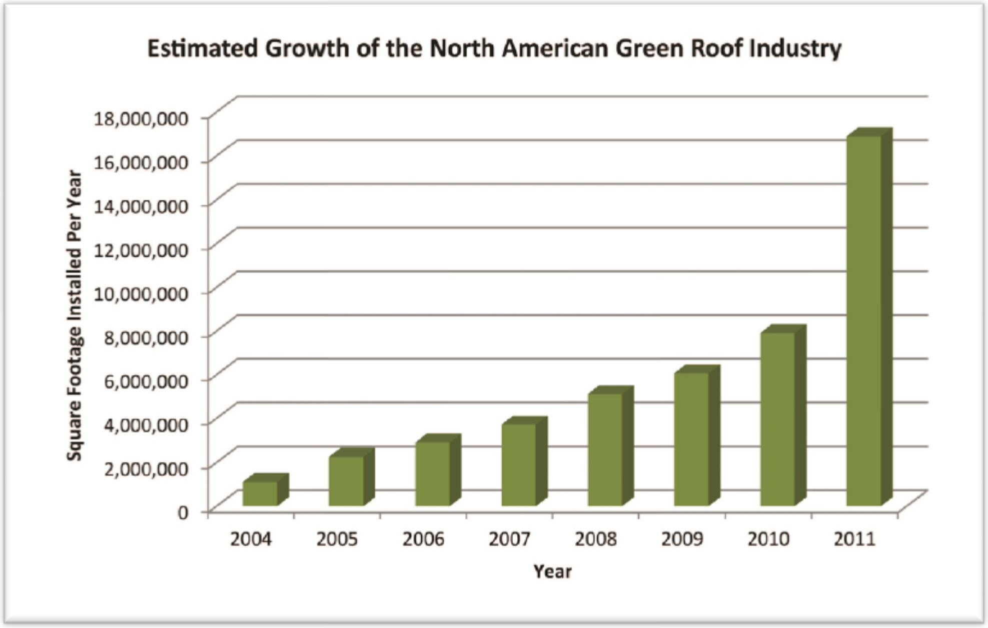


Figure 4: 2011 North American Green Roof Industry Growths

(Source: Peck 2012, p.3)

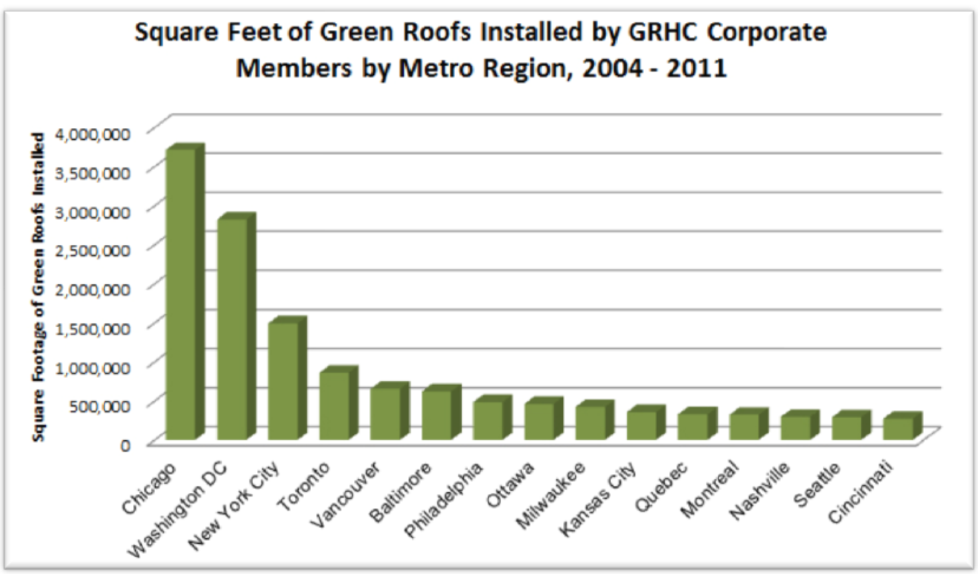


Figure 5: 2011 Green Roof Installed in North America

(Source: Peck 2012, p. 5)

For example, a green roof boom in Washington, DC has vaulted it into first place (Figure 5), bolstered by some very large projects like St. Elizabeth's West Campus (Figure 6). Under the rapid development of green roof industry and the promotion varies agencies and non-profit organizations, at the end of 2008, a total of about 75 green roof projects (of over 1,000 square feet each) have been completed in DC (DDOE 2011). The total green roof coverage for all of these 75 projects is approximately 350,000 square feet.

Figure 6: Coast Guard Headquarters Green Roof Illustration

(Source:http://coastguard.dodlive.mil/2011/04/new-coast-guard-headquarters-to-incorporate-sustainable-design/cghq-green-roof/)

According to the 2011 Annual Green Roof Industry Survey, Washington DC came to the second on the list, containing 501,402 square foot (Figure 5). Green roof has become a popular design element for big cities and has also become a marketing tool for its ecological, social and financial benefits. (Deutsch et al. 2005) pointed out that under a reasonable development, the target green roof coverage in D.C could be set as 20 years/ 20% coverage/ 20 million square feet (Figure 7).

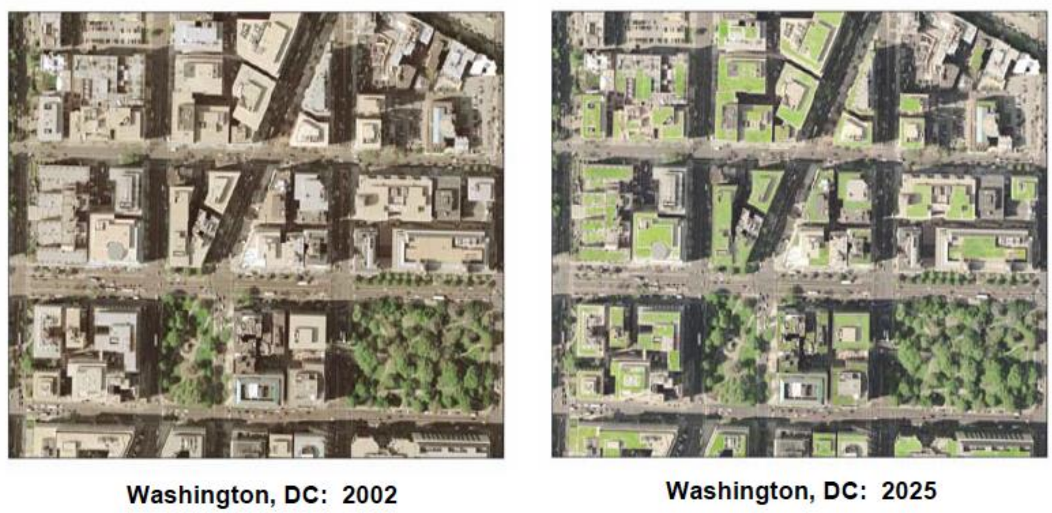


Figure 7: Green Roof Projection of Washington D.C.

(Source: Deutsch et al. 2005, p. 2-1)

1.2 Stormwater and Green Roof Regulation and Policy

The following stormwater and green roofs management regulation and policy section of the literature review is organized into three sections. The first section reviews three federal stormwater regulations from Clean Water Act (CWA). The second section explores the stormwater management and green roof policies in the State of Maryland and Prince George’s County. The third section covers national wide green roof incentive programs with a more detailed documentation of programs in the District of Columbia, the City of Chicago and Portland, Oregon.

1.2.1 Total Maximum Daily Load (TMDL)

Since 1972, Section 303(d) of the federal Clean Water Act (CWA) has required states to identify the maximum amount of pollution that water bodies can hold and still meet water quality standards. This maximum amount of pollution is called a Total Maximum Daily Load (TMDL) (EPA 2012c). TMDLs may apply to both point and nonpoint sources of pollution. In 1996, the EPA pointed out that certain sections of the Virginia portion of the Chesapeake Bay were insufficient to fully support aquatic life. All of the upper Chesapeake Bay tidal water segments were recorded as not meeting standards for phosphorus, nitrogen, and sediments (MDE 2010). Green roofs controls can be incorporated into TMDL control plans to reduce pollutant loads in water bodies impacted by stormwater runoff.

In 2000, the Chesapeake 2000 Agreement was developed to identify the actions needed to achieve water quality standards. Much progress has been accomplished, but the pollution reduction goals have not been achieved (Prince George's County 2011). As a result, in 2010, EPA led a process to develop TMDLs for Chesapeake Bay for six states (New York, Pennsylvania, Delaware, Maryland, West Virginia, Virginia) and the District of Columbia

(EPA 2012d). EPA assign the year 2017 to meet 60% of the needed implementation and 2025 as the deadline for achieving final target reduction loads (Prince George's County 2011). Maryland's strategy was more aggressive and it established earlier deadlines than the EPA to reach nutrient and sediment reductions. Maryland committed to achieve the final target loads by 2020 (Prince George's County 2011).

1.2.2 National Pollutant Discharge Elimination System (NPDES) Permit

To enforce TMDLs from point sources, water quality-based effluent limitations (WQBELs) must be established and implemented with discharge permits (EPA 2012c). The National Pollutant Discharge Elimination System (NPDES) permit program is authorized in section 402 of the CWA. The initial permit focused on publicly owned treatment works (POTWs) and industrial wastewater issued in 1970s -1980s. The Water Quality Act of 1987 (1987 WQA) extended the permit to include stormwater discharges from Municipal Separate Storm Sewer Systems (MS4) and industrial sources (EPA 2012c). The MS4 NPDES permits require regulated municipalities to utilize Best Management Practices (BMPs) to reduce pollutants to the "Maximum Extent Practicable. (EPA 2012c)" As of 2001, more than 400,000 facilities were subject to NPDES permit requirements (EPA 2001). Green roofs, as one of the BMPs, can be implemented to prevent pollution and reduce contaminates in municipal sewer systems.

NPDES permits must be reissued every five years (EPA 2011). The current NPDES permit for Maryland was issued on October 7, 2011. In section 4.1.1, the permit states stormwater management should "achieve on-site retention of 1.2 inches of stormwater from a 24-hour storm with a 72-hour antecedent dry period through evapotranspiration, infiltration and/or stormwater harvesting and use for all development greater than or equal to 5,000 square feet (EPA 2011)".

1.2.3 Nonpoint Source Management Program

Additionally, the 1987 amendments created the Nonpoint Source Management Program in CWA section 319. This section requires states to identify waterways which cannot meet water quality standards without control of nonpoint source pollution (Carter and Fowler 2007). Section 319 also establishes grant money for states, territories and tribes to supports a wide variety of improvement activities including "technical assistance, financial assistance, education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects" (EPA 2012d). For Fiscal Years 2012, the program grant fund was $164.5 million (EPA 2012e). From 2002-2006, twelve green roofs projects in Tennessee, North Carolina, Michigan, Washington DC, Iowa, Idaho, Illinois and Oregon received grant funds (Carter and Jackson 2007).

1.2.4 State of Maryland

In addition to the federal regulations, EPA required the Bay states to developed statewide Phase I Watershed Implementation Plan (WIP) to support the reasonable assurance of implementation for TMDLs (Prince George's County 2011). The goal of the WIP is to determine the target loads to be achieved by various pollution source sectors in different geographic areas. In line with this aggressive implementation date, Maryland planned to reach 70% of the Final Target by 2017 (Prince George's County 2011), which is reflected in this Phase I WIP. In 2012, the Phase II WIP was developed to refine the Phase I plan at the county level, which included more details about where and how nutrient and sediment loads can be reduced to clean the Bay (Prince George's County 2011). In urban stormwater sector, the goal of Prince George’s County is to achieve conditions specified in the anticipated new municipal separate storm sewer system (MS4) permits by Best Management Practice (BMP) and practice. County’s Best Management Practice Decision Support System (BMPDSS), which is a BMP modeling, selection, and placement decision support system applicable at various scales, can determine the optimal placement for BMPs in the County to optimize load reduction.

In addition, the main goal of Maryland’s stormwater management program is to sustain after development, as nearly as possible, the predevelopment runoff characteristics (MDE 2009). A comprehensive design strategy, known as Environmental Site Design (ESD) was provided to capture and treat runoff relying on integrating site design, natural hydrology, and smaller controls (MDE 2009). Green roofs are demonstrated in the ESD manual as alternative surfaces that can replace conventional materials as well as a protective covering of planting media and vegetation (MDE 2009).

1.2.4 Prince George's County

In June 19th 2012, Prince George's County passed Bill CB-40, which was the establishment of Stormwater Management Retrofit Program (Prince George's County, 2012a). The program will provide rebates for private owners to build green infrastructure intervention on their properties. Green roofs are included in this bill and are proposed to have rebate of $10 per square feet. Other techniques included in this program are urban tree canopy, rain barrels, cisterns, rain gardens, permeable pavement, and pavement removal.

1.2.5 Nation-Wide Stormwater Policy and Green Roof Incentives

Under encouragement of the federal government, municipal and community green roof incentives have been carried out to promote new green roof projects. As of December 2011, the "Various LEED initiatives including legislation, executive orders, resolutions, ordinances, policies, and incentives are found in 45 states, including 442 localities (384 cities/towns and 58 counties), in 34 state governments, 14 federal agencies or departments, numerous public school jurisdictions and institutions of higher education across the United States (USGBC 2011).

According to the research conducted between February and September 2009, the following figure exhibits the location of the green roof incentives, both green roof specific and broader green building incentives found across the United States (Shepard 2010). In total, there are around 90 green roof incentives implemented across the nation. Specific programs are found in Portland, New York, Chicago, Washington D.C and other cites/towns across the nation (Figure 8).

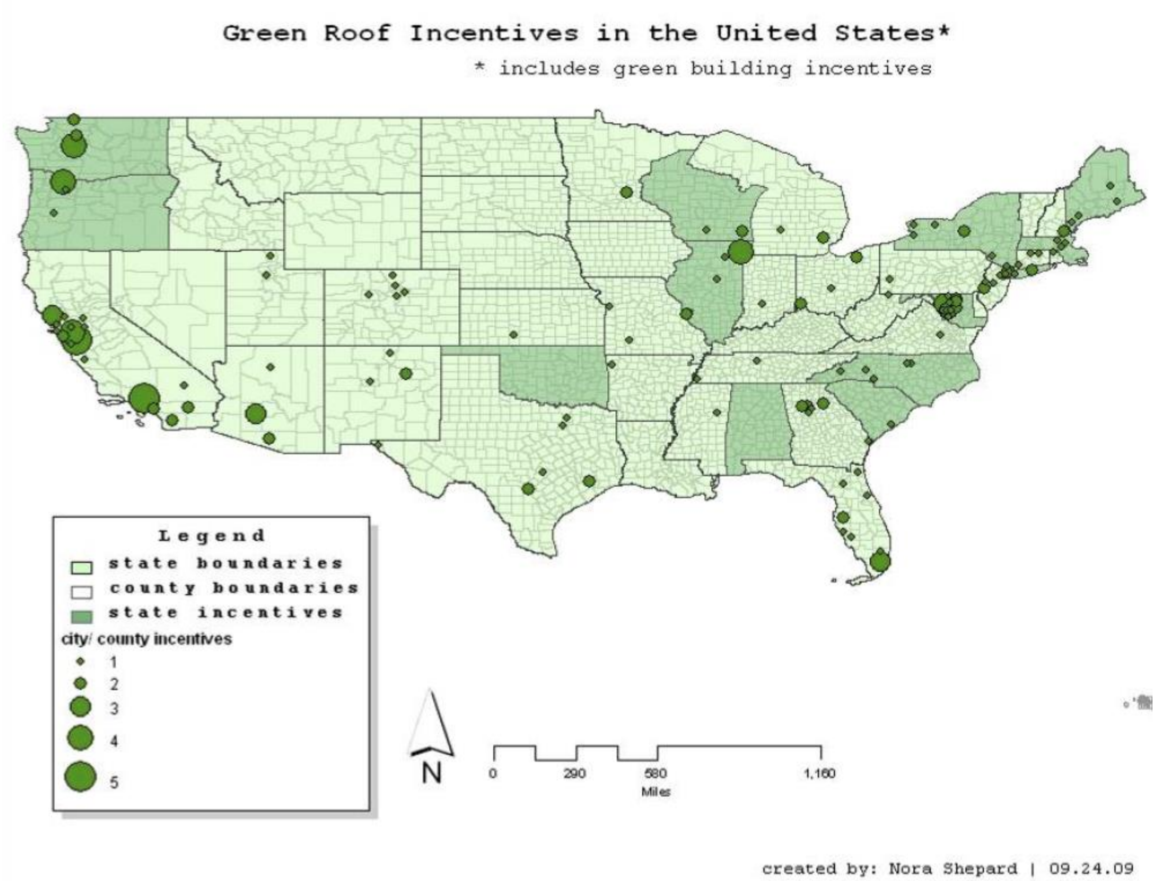


Figure 8: Green Building and Green Roof Incentives in America

(Source: Shepard 2010, p.16)

1.2.6 Stormwater Policy and Green Roofs in Washington D.C.

Current Permit

Effective on October 6, 2011, EPA approved the new performance standards for controlling urban stormwater runoff in Washington, D.C (EPA 2012e). The District's renewed Municipal Separate Storm Sewer System (MS4) permit requires sustainable stormwater management techniques including green roofs, tree planting, and retaining rainfall on-site from redevelopment projects. The permit (EPA 2012e) requires the District to take sustainable steps promoting green infrastructure including:

· Requiring a minimum of 350,000 square feet of green roofs on District properties;

· Retaining 1.2 inches of stormwater on-site from a 24-hour storm for all development projects of at least 5,000 square feet;

Stormwater Fee

The District of Columbia Department of the Environment (DDOE) is responsible for managing stormwater pollution in the District (DDOE 2010). It is also in charge of the commercial and residential property owners' stormwater fee based on the amount of impervious surface within the property (DDOE 2010). The stormwater fee includes the cost to manage and treat pollution in stormwater runoff (DDOE 2010). The stormwater fees for DDOE are based on the Equivalent Residential Unit (ERU), which is defined as 1,000 square feet of impervious area on a property (DDOE 2011). Effective November 1, 2010 the DDOE charged $2.67 per month for one ERU. This fee was included in the customer's monthly water and sewer bill (DDOE 2011) (Table 2).

Table 2: 2012 Single Family Residences Costs for DDOE Stormwater Fee

Impervious Area (Square Feet)	ERU	ERU Rate	Monthly Cost	Yearly Cost
100-600	0.6	$2.67	$1.60	$19.2
700-2,000	1	$2.67	$2.67	$32.04
2,100-3,000	2.4	$2.67	$6.41	$76.92
3,100-7,000	3.8	$2.67	$10.15	$121.8
7,100-11,000	8.6	$2.67	$22.96	$275.52
11,100 and more	13.5	$2.67	$36.05	$432.6

(Data is obtained from DDOE 2011)

For all other properties, including businesses and large multi-family properties, the stormwater fee is charged for a rate of $2.67 per month for each 1,000 square feet of impervious area, reduced to the nearest 100 square feet (DDOE 2011).

Impervious Area Charge

The new Clean Rivers Impervious Area Charge (IAC) is used to distribute the cost of maintaining storm sewers and protecting area waterways based on a property's contribution of rainwater to the District's sewer system (DC Water 2011). Owners of large properties like office buildings, shopping centers and parking lots will be charged more than owners of modest residential dwellings based on the property impervious area (DC Water 2011). DC Water's IAC is expected to greatly increase as the tunnel building progresses. In 2010, DC Water was charging $2.20 per ERU. In 2011, the fee was $3.45, however estimates given in March 2011, expected the IAC to increase to $6.19 per ERU for the 2012 billing year with increases of up to $23.76 per ERU by 2018. The actual fee for 2012 ended up being $6.64 (DC Water 2011) (Table 3).

Table 3: 2012 Monthly and Yearly Costs for DC Water Impervious Area Charge

Impervious Area (Square Feet)	ERU	ERU Rate	Monthly Cost	Yearly Cost
100-600	0.6	$6.64	$3.98	$47.76
700-2,000	1	$6.64	$6.64	$79.68
2,100-3,000	2.4	$6.64	$15.94	$191.28
3,100-7,000	3.8	$6.64	$25.23	$302.76
7,100-11,000	8.6	$6.64	$57.10	$685.2
11,100 and more	13.5	$6.64	$89.64	$1,075.68

(Data is obtained from DC Water 2011)

Green Roof Incentives in Washington D.C.

Stormwater Fee Discount: River Smart Rewards Program

A stormwater fee discount is based on the area of impervious surface on the property and when the amount of impervious surface is reduced, the municipality reduces the fee (EPA 2009). DDOE is currently developing a stormwater fee discount program called River Smart Rewards. The program will provide users to receive up to a 55% discount off the stormwater fee to property owners who install BMPs to manage and reduce stormwater runoff (DDOE 2011). The program aims to provide an incentive for property owners to implement BMP's.

Green Roof Rebate

For 2011-2012, DDOE Green Roof Rebate Program provides a rebate of $5 per square foot to qualified recipients through the Anacostia Watershed Society (AWS) (AWS 2012). The program is eligible for green roofs on existing buildings as well as newly constructed projects of any size that go beyond the stormwater management permit requirements (Shepard 2010). This direct financial policy can help overcome the barrier of adopting new technology and encourage of new green roof construction (Carter and Fowler 2007).

greeNEr Program

The greeNEr program (Shepard 2010) was founded by non-profit organization, DC Greenworks, from augmented DDOE's rebate program with a Neighborhood Investment Fund (NIF) Target Area Grant Project from Office of the Deputy Mayor for Planning and Economic Development. GreeNEr was aimed to make available private economic benefits to green roof construction along the commercial corridor of H Street Northeast. The program offers a total of combined subsidy of 12 dollars for each square foot of green roof installed.

1.2.7 Green Roof Program in Chicago, Illinois

Green Permit Program

Chicago's Green Permit Program, created by Chicago Department of Construction and Permits, offers developers a fast track for permit submission for projects that meet predetermined green building criteria (City of Chicago 2010). Green roofs are included if they are proposed in the building design. There are two types of incentives. The first one is that developers can receive a 15 to 45 day turn-around for building permits that implement green building practices, which reduces permitting time to as little as six weeks (Table 4) (EDAW 2008). The more green features incorporated into the project, the more time reduction is granted for the project. This time saving can translate into significant financial savings because the earlier construction starts contribute to earlier leasing, sales, and less loan interests (EDAW 2008). In conjunction with the shortened timeline, the second incentive provides a direct financial benefit in reduced permit fees. Additionally, some of the expedited permit requirements exceed the Green Building Matrix requirements for green roofs, to further incentivize added green roof square footage throughout the city (Shepard 2010).

In summary, this program consists of an accelerated time frame for green projects to receive building permits as well as reduced permit application fees. Instead of typical several months long time that is required to receive certain construction permits, Chicago created condensed timelines for projects with innovative, sustainable building technologies to make green building more attractive to developers (Shepard 2010). As is shown in the following table, projects with green roofs are able to obtain more benefits from the Green Permit Program.

Table 4: Chicago Green Permit Program

Project Type	**Benefit Tier I**	**Benefit Tier II**
Requirements	**Expedited Permit (< 30 days)**	**Expedited Permit (< 30 days) Consultant Review Fee Paid Up to**
Residential	LEED® Certified/Silver + 2 MI	Chicago Green Home ** + 2-3 MI
Institutional	LEED® Certified + 2 MI	LEED® Silver + 2 MI
Industrial	Not Applicable	LEED® Certified + EnergyStar Roof + 1 MI
Retail	LEED® Silver + Energy Star Roof + 2 MI	LEED® Silver + 25% Green Roof + 2 MI
Office	LEED® Silver + 50% Green Roof +	LEED® Silver + 75% Green

Green Roof Grant Program

The Chicago Green Roof Grant Program was implemented in 2005. The program funds were received from a settlement agreement with Commonwealth Edison, the City's electric utility provider (Shepard 2010). The grant was created to increase public awareness of green roofs as a tool to help address the rising temperatures in Chicago's urban core and stormwater management challenges. It also provides $5,000 grant per project for residential and small commercial buildings fewer than 10,000 square feet. Over the four funding cycles of the program, Chicago's Department of the Environment received 209 applications and received the highest numbers in the first year (Shepard 2010). As of 2009, a total of 69 green roof projects were funded and 18,000 square feet of vegetated roofs have been installed through the program (Shepard 2010).

Mayor's GreenWorks Awards

Businesses want to be recognized as environmentally responsible and a good corporate citizen. The GreenWorks Awards program by Chicago, Illinois is a good example of a municipal green building award program. The City offers bi-annual awards to recognize individual and groups with outstanding green buildings. The awards are given in three categories for residential projects, commercial projects and student proposals from college and university students. The program provides free positive publicity to encourage other projects to build green projects. Awards encourage people and businesses to continue to innovate and improve their bottom line and the triple bottom line of sustainability, accounting for social, environmental and economic health of the community (Shepard 2010).

1.2.7 Green Roof Program in Portland, Oregon

EcoRoof Grants – Grey to Green Initiative

Portland's Ecoroof Grant Program is part of the Grey to Green Initiative to implement green infrastructure, such as green roofs to help urban stormwater runoff reduction. It was implemented at the end of 2008 and provides $5.00 per square foot grants for ecoroof projects in Portland. The incentive could also be combined with other incentives in the city like the green roof FAR (floor area ratio) bonus. The grant only supports ecoroofs with low profile less than 6 inches of growing medium. For the past 10 years the public outreach and advocacy has created a culture around ecoroofs and their benefits and aided in the success of the grant program to date. The projects were roughly split between new and retrofit projects. Ecoroofs must meet a list of prescriptive requirements and may not be completed on or before the specific application deadline, but may be in progress. Currently, 56 applications were received and 54 were funded. There are 9.41 acres of green roofs in Portland and is projected to add another 43 acres within the next five years (Shepard 2010).

EcoRoof FAR

In Portland, Oregon there are a number of added building amenities that may receive a FAR (Floor Area Ratio) bonus if incorporated into development projects. As one of the most affordable public amenities, the ecoroof is the second most highly used (Shepard

2010). It is capable to earn a bonus of 3 additional square feet of area for every 1 square foot of vegetated green roof space incorporated into a project in certain areas of the city. As of November 2008, 260,000 square feet of ecoroofs have earned the FAR bonus which led to an additional 600,000 square feet of developable space (Johnson 2007).

EcoRoof FAR program encourages developers to build more green roofs on their properties indirectly. Added permitted space means more money for developers. More space also contributes to additional units or floors that can be sold and rented for additional money. The allowance of more square feet or greater height for green building techniques or amenities helps developers to incorporate the innovative sustainable building elements (Shepard 2010. As a result, developers are offered for additional permitted buildable space.

1.3 Benefits of Green Roofs

This section discusses the benefits of green roofs. The first section reviews the environmental benefits of green roofs, particularly in stormwater management. The second section documents green roofs' role in economic development. The third part records social benefits of green roofs.

1.3.1 Environmental Benefits

1.3.1.1 Stormwater Management

As mentioned above, green roofs have become a widely used on-site stormwater management practice both in previous built-up areas and new developments in Washington D.C. Several field studies in North America indicate that green roofs provide substantial stormwater management benefits by reducing runoff volumes (Deutsch et al 2007); controlling peak flows, altering the timing of flows, improving the water quality and decreasing the risk of flooding (Berndtsson 2010). Green roofs offer significant advantages over other source controls methods. First of all, green roofs can be installed in dense urban areas where space for structural practices is not available. Secondly, they function well in areas where tight soils may limit the effectiveness of infiltration technologies, such as rain gardens and permeable pavements.

Previous researches in both Europe and U.S. have supported that green roofs have a performance benefits for stormwater quantity control. In southern Sweden, research has demonstrated that an extensive green roof with 1.2in substrate depth retained 49% of the annual rainfall (Berndtsson et al. 2006). Michigan State University research demonstrated that after 83 rainfall events, 61% of the precipitation was retained by an extensive green roof with 1in deep media and a 0.3in thick water retention layer (Van Woert, et al., 2005).

Penn State University research demonstrated that precipitation retention of seven rainfall events in the fall of 2002 ranged from approximately 25%-100% for the experimental green roofs (DeNardo, et al. 2005; Beattie and Berghage 2004). It can be seen as clear as crystal that green roofs have been tested widely for their stormwater retention ability.

Along with the quantity analysis, associated water quality assessment also indicated that green roofs could reduce water pollutants like phosphate, phosphorus and heavy metals. The ASLA Headquarters Green Roof Monitor Project demonstrated the COD (chemical oxygen demand), phosphate, total phosphorus, total suspended solids, and total dissolved solids all increased by significant amounts over rainwater (Glass 2007). In addition, a significant amount of nitrogen reduction in stormwater runoff from the green roof can be expected (Glass 2007). As the runoff water is drained into the sewer system and then tributary rivers, there would be less nitrogen flow into the surrounding watersheds.

1.3.1.2 Urban Heat Island Effect

The urban heat island effect is the collective effect of heat storage by manmade surfaces that absorb solar radiation. It causes temperatures to rise up to 10 degrees Fahrenheit in cities when compared to surrounding rural areas (EPA 2007). The second environmental benefit that green roof offer is to reduce the amount of thermal energy that is contributed to the urban heat island through vegetation and its evapotranspiration. During this natural process, water is released to the atmosphere as a result of evaporation from the soil and transpiration by plants (USGS 2005). As a result, evapotranspiration on green roofs acts as a passive cooling system that allows a green roof to keep its building at a lower temperature than the traditional roof. During dry periods, absorption and reflection of solar energy by plant materials also contributes to the cooling effect. At the same time, air quality is improved significantly through the absorption of carbon dioxide (one of the major source of greenhouse gas that contributes to global warming and climate change) and the release of oxygen. CNT (2010) estimated that green roofs in D.C can save 0.1–0.2 million kWh of electricity and 1.7–2.1 billion Btu of gas per year.

1.3.1.3 Provide Wildlife Habitat

Depending on soil depth and composition, and choice of plant materials, green roofs can be designed to create wildlife habitat. The recreation of native habitats with local material and sensitive design can help mitigate loss of wildlife habitat in urban areas for some species (Brenneisen 2006). Among DC's twelve showcase green roofs, facility maintenance staff have noticed butterflies and bees in summer, and found several bird nests established too. With the expansion of green roofs in DC, more and more individual pieces of green roofs will connect as a network to create more urban wildlife habitat.

1.3.2 Economical Benefits

1.3.2.1 Energy Efficiency

The insulating nature of green roofs can significantly reduce the amount of energy needed for heating and cooling a building, thereby reducing building operating costs (Saiz 2006). The economic benefits of green roof have been verified quantitatively in many cities (e.g., Chicago, Portland, Toronto, Vancouver, etc.). Potential benefits have been estimated in dollar value in countries/cities like Singapore and Hong Kong. In the previous quantitative cost-benefit analysis, the following benefits are taken into consideration: reduction in grey infrastructure needs, reduction in health investment due to air quality improvement, reduction in energy consumption, and relief of urgency of climate changes and global warming.

The economic benefits of existing green roof in Washington DC is around $0.1-$0.2 million per year (Buckley 2012). These benefits comes from government expenditure savings from water treatment needs, stormwater grey infrastructure needs, energy consumption, air quality and greenhouse emission improvement, and noise pollution management. CNT (2010) published a quantitative analysis and valuation of quantifies benefits of the following areas have been posted: economic benefits from reduced stormwater runoff, reduced energy use, reduced criteria pollutant, and reduced atmospheric carbon dioxide.

1.3.2.2 LEED Credits and SITES Points

In October 2007, Maryland adopted the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) and required LEED Silver rate building standard for all government funded new construction and major renovations. Green roofs have the potential to earn LEED credits to help meet the rating. These points could come from credits relating to stormwater management, water-efficient landscaping, energy and atmosphere, and reducing the urban heat island effect. A total of 3-15 possible points could be applied to LEED Credits. Kahn (2009) have shown that LEED and Energy Star have a positive impact on rental and sales price, there is a potential that retrofit old roofs by green ones could achieve the same effects. The Sustainable Sites Initiative (SITES) is an interdisciplinary effort to create guidelines and performance benchmarks for sustainable land design, construction and maintenance (USBG 2009). Similar to LEED Credits, green roofs can help earn many SITES Points.

1.3.3 Social Benefits

1.3.3.1 Aesthetic Value and New Amenity Spaces

In addition to the ecological value, green roofs provide social and cultural services to improve human and neighborhood quality of life. First of all, the increased greenery on rooftops increases the aesthetic value of the building and the neighborhoods. The positive impact of green roofs on aesthetics can be reflected in the well-observed relationship between urban greening and property value. People are willing to pay more to live in places with more green (Wachtel 2007). Secondly, green roofs provide additional recreation space in dense urban cities. In my visit to the ASLA green roof, I was told that both staff and visitors would like to go up at their green roofs in warm weather and may spend several hours on the rooftop reading books or chat with friends. Several green roofs along Potomac River provide a special view of the cities' famous architectures like the Capital Hill and the National Cathedral. It is not hard to imagine that these green roofs could become the "park in the sky" under proper safety control.

Moreover, green infrastructure including green roofs can make communities better places to work and live through its effect on 'community cohesion'—improving the networks of formal and informal relationships among community members that foster a nurturing and mutually supportive human environment (Sullivan 2004). This community integrity would also provide a great public education opportunity. Family and friends get together to acknowledge more about water issues, climate changes and have some hands-on experience with the plants.

1.3.3.2 Reducing Noise

Last but not least, vegetation has the added benefit of reducing noise pollution. In big urban cities like Washington D.C, Planes, trains and roadway noise are significant and could become a health risk. A Canadian research institution for the Advancement of Green Roof Technology measured the sound transmission loss increased 5–13 decibels in low- and mid-frequency ranges, and 2–8 decibels in the high frequency range than conventional roofs (CNT and Hodgson 2008). All above merits of green roofs are valuable to personal and community healthy development.

1.3.3.3 Educational Opportunities

In addition to the ecological value, green roofs provide educational opportunities for students to learn various subjects including plant science, wildlife habitat, water cycle, hands-on experiences and so on (Louv 2008). It is a new trend to teach students the “change agent” skills required for positive societal changes instead of just producing analytical thinkers (Rowe 2002). Interactive programs with institutional green roofs can combine environmental knowledge, life-science topics with real nature connections. There are increasing numbers of schools that are pursing green roofs in order to use the roof area as an educational tool. The following two precedents provide a brief overview of schools that have specifically utilized their green roof as both in-class and extra-curriculum educational tool.

1.4 Institutional Green Roof Precedent Studies

This section documents three precedent studies of green roofs in educational settings. The first is Bronx Design and Construction Academy in New York City. The second is Calhoun School in New York City. The last one is Cumberland Hall in the University of Maryland, College Park.

1.4.1 Bronx Design and Construction Academy, New York City

Bronx Design & Construction Academy built the first approved public city school green roof (Figure 9) in New York City. The green roof was established during 2010 as part of the school's sustainable initiative. The project received a grant help from the City Gardens Club and the New York State Department of Environmental Conservation. Besides sedum planting layer, the green roof also has rainwater harvesting system and solar panel.

A science teacher, Nathaniel Wight, who is the co-founder of Bronx Design, runs the science club, which is engaged in researching the green roof stormwater management and energy saving benefits. Together with Mr. Wight, the students planted the roof in sedum and other crops. They also built rainwater harvesters and solar-powered irrigation and transformed it into a naturally cooled showcase of urban farming technology (BDCA 2012). The green roof is used for the 9th grade ecology class and Green Science Club to discuss environmentally sustainable issues. Students collaborate with professors and graduate students from Columbia University's Green Roof Consortium to study water quality and quantify the benefits of green roofs by monitoring of ambient temperature, ambient relative humidity, and solar insolation (BDCA 2012). The students have been involved in local and regional conferences and competitions to present and share their study results.

Figure 9: Bronx Design and Construction Academy Green Roof

(Source: Photo by BDCA Sustainability http://bxdca.org/our_pages/sustainability.jsp Reproduced by permission of Bronx Design and Construction Academy)

1.4.2 Calhoun School, New York City

Open in May 2005, Calhoun's Green Roof Learning Center was the first eco-friendly green roof in New York City dedicated to educational study. The green roof was built as part of a four-story addition to the School's main building. This semi-intensive green roof is used for the school’s lunch program, which students and chefs work together to promote nutrition and healthy eating habits (Figure 10). The space is also used for courses including environmental science, plant biology, and math. Recently, Center officials are discussing plans to build a weather station, solar panels and telescope to advance classes and studies. Besides science program, the outdoor space has also been the site for art installation, receptions and an inspirational place for writing classes.

The Green Roof offers multiple environmental benefits in stormwater management, energy saving, greenhouse gas relief and wildlife habitat improvement. It reduces stormwater runoff (reportedly by 40 percent--or an average of almost 26,000 gallons of water every year). The vegetation functions as a insulate layer to reduce heating and cooling needs, help filter the air by absorbing carbon dioxide and giving off oxygen, and provides a food source for wildlife (Calhoun School 2012). The school website also includes green roof design and content knowledge pages for public education for anyone who is also interested in similar projects.

Figure 10: Calhoun School Green Roof

(Source: Photo by the Calhoun School Green Roof http://www.calhoun.org/green_roof Reproduced by permission of Calhoun School)

1.4.3 Cumberland Hall, University of Maryland

University of Maryland's first green roof on Cumberland Hall (Figure 11 and 12), which is south of Eppley Recreation Center, and is also the largest planted roof on campus. Cumberland Hall is a co-ed residential hall housing close to 500 students in a variety of room types and also houses a College Park Scholars Living-Learning Center.

According to the University's Department of Environmental Safety, the green roof project was chosen "as a way to promote environmental stewardship and sustainability in the University's construction practices" (UMD 2010). The green roof was installed in 2008 to replace a 20 year old roof. This extensive green roof utilizes 15 types of plants including native species like Sedum album, Talinum calycinum, and Sedum spurium. Total roof area is about 13,000 square feet with about 8,000 square feet comprising the green roof (the remaining portion of the roof is reflective stone ballast and membrane roofing which also aids in cooling the building).

Figure 11: University of Maryland Cumberland Hall Green Roof

(Source: University of Maryland Cumberland Hall, http://www.sustainability.umd.edu)

Figure 12: University of Maryland Cumberland Hall Green Roof

(Source: University of Maryland Cumberland Hall, http://www.sustainability.umd.edu)

According to the University Department of Environmental Safety Report, the university spent $350,000 on the Cumberland green roof, which was roughly 35 percent more than a standard roof. The average maintenance fee of the green roof is $1,500 annually. While the initial cost more than a traditional roof, the premium paid for the Cumberland hall green roof will have an estimated payback period of seven years (UMD 2010). Therefore, over the 30-40 year lifespan of the green roof, it will save 10% - 30%, or between $35,000 and $105,000, over the cost of a conventional roof.

The purpose of chapters 2, 3, 4 and 5 is to document the steps that were undertaken for the planning and design application. These steps include 1) documentation of the inventory and analyses of Brier Mill's Run Subwatershed, 2) creation of a 2040 Land Use Master Plan, 3) analysis and calculation water benefits of eight selected schools in the watershed, 4) the creations of four scenarios using the rankings from step 3, and last, 5) a suggestions about educational criteria in the use of a green roof.

Chapter 2: Brier Mill's Run Subwatershed 2040 Land Use Master Plan

This chapter documents Brier Mill's Run inventory and provides a land use plan for 2040. The chapter is organized into four parts. The first part documents the methods used in this chapter. The second part documents the abiotic, biotic and cultural inventories in Brier's Mill Run Subwatershed. The third part) describes the proposed Brier's Mill Run 2040 land use master plan.

2.1 Methods

This chapter documents selected abiotic, biotic and cultural inventory and analysis of Brier's Mill Run Subwatershed. All GIS data came from Maryland-National Capital Park and Planning Commission (MNCPPC). The materials provided include shape-files of 5 feet contours, buildings, land-use, hydrography, demographics, property, town boundaries and etc. The Brier Mill's Run Environmental Baseline Conditions and Restoration Report was also an important resources for the inventories listed below (Metropolitan Washington Council of Governments, 2009). First, inventory maps were created from GIS to demonstrate the current natural and cultural conditions in the study area. Soil hydrology data for each school was downloaded from United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) web soil survey. Second, the demographic projection data is from Maryland Department of Planning.

Population projection table was generated to illustrate the demographic trend. Last, an estimated land use plan for 2040 was created in GIS by editor tool.

2.2 Context

Brier Mill's Run, (also known as Brier's Ditch), is a free-flowing tributary of the Northeast Branch of the Anacostia River (Figure 13); the stream joins the Northeast Branch at the confluence with Still Creek in Riverdale Park, Maryland (COE, 2009). The entire subwatershed is located entirely within the Coastal Plain physiographic province. It is generally surrounded by Good Luck Road to the north and west, Annapolis Road (MD Route 450) to the east, and Veterans Parkway (MD Route 410) to the south (Figure 14). Brier's Ditch subwatershed is approximately 2,653 acres (4.1 mi2) in size and located within Prince George's County. At 6,448 people/ mi^2, it is the most densely populated major Anacostia subwatershed (Metropolitan Washington Council of Governments 2009) (Figure 14).

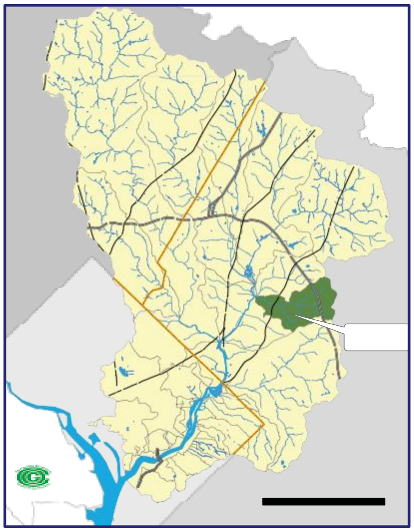


Figure 13: Site Context of Brier's Mill Run Subwatershed

(Source: Metropolitan Washington Council of Governments 2009, p1)

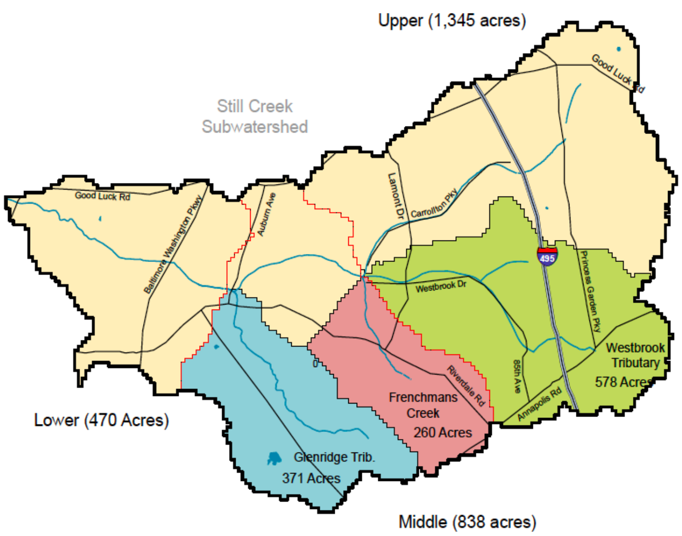


Figure 14: Brier’s Mill Run Subwatershed

(Source: Metropolitan Washington Council of Governments 2009, p2)

2.3 Inventory

2.3.1 Hydrology

Brier's Mill Run (Figure 15) is designated a Use I stream (i.e., suitable for water recreation and support of aquatic life) by the Maryland Department of the Environment (MDE) (Metropolitan Washington Council of Governments 2009). Three out of five of the County's Brier Ditch Index of Biotic Integrity (IBI) main stem and tributary sampling stations were rated as having non-supporting physical aquatic habitat conditions present, with the remainder exhibiting supporting conditions (Metropolitan Washington Council of Governments 2009).

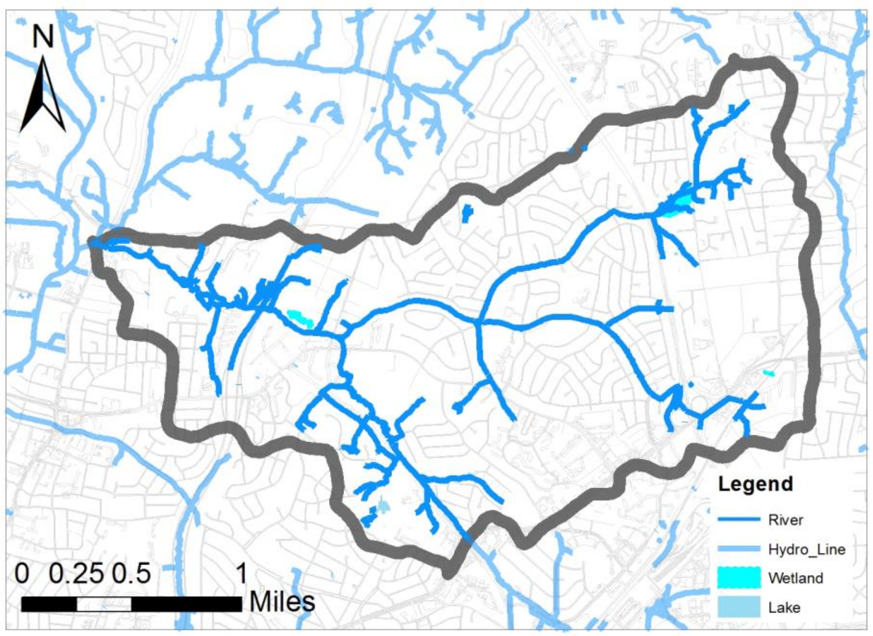


Figure 15: Site Hydrology

2.3.2 Topography

Elevations in the Brier's Mill Run Subwatershed range from 212 feet at the Patuxent

River watershed divide to 28 feet at the confluence with the Northeast Branch. With an average gradient of 0.5 percent over 3.4 miles of its main stem length, Brier Ditch flows from through predominantly single family residential land use areas (Figure 16).

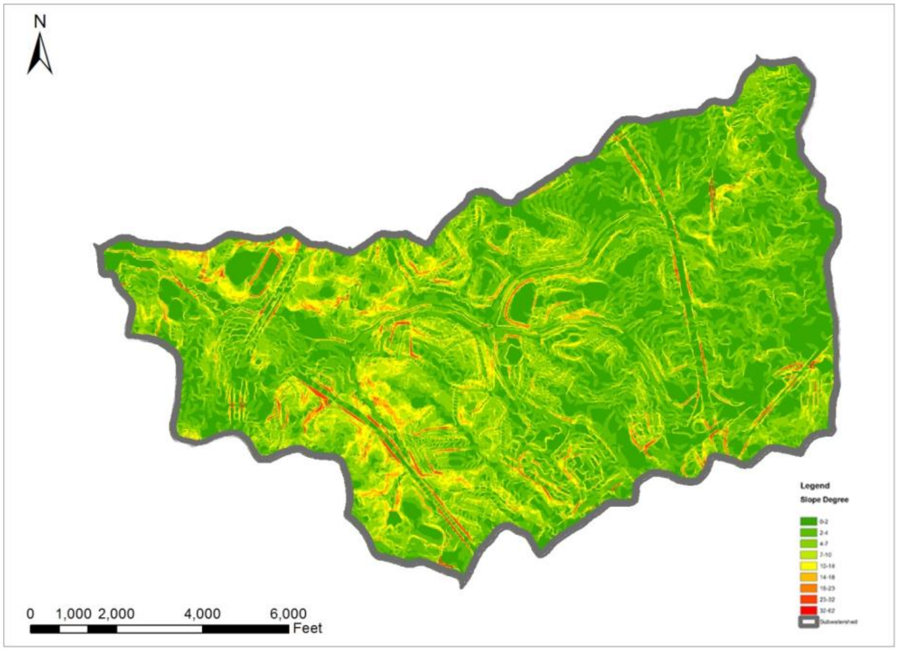


Figure 16: Site Topography

2.3.3 Soil Hydrology

Hydrologic groups were designated by the Natural Resources Conservation Service (NRCS) which are based on measured rainfall, runoff, and infiltration data (USDA NRCS 2007). Details about each hydrologic group are noted in Appendix 3. The lower and middle parts of the subwatershed are covered by hydrologic B and C group soils. The upper land is covered mostly by hydrologic C group soil. Notably, hydrologic D group soil is largely found around stream banks (Figure 17).

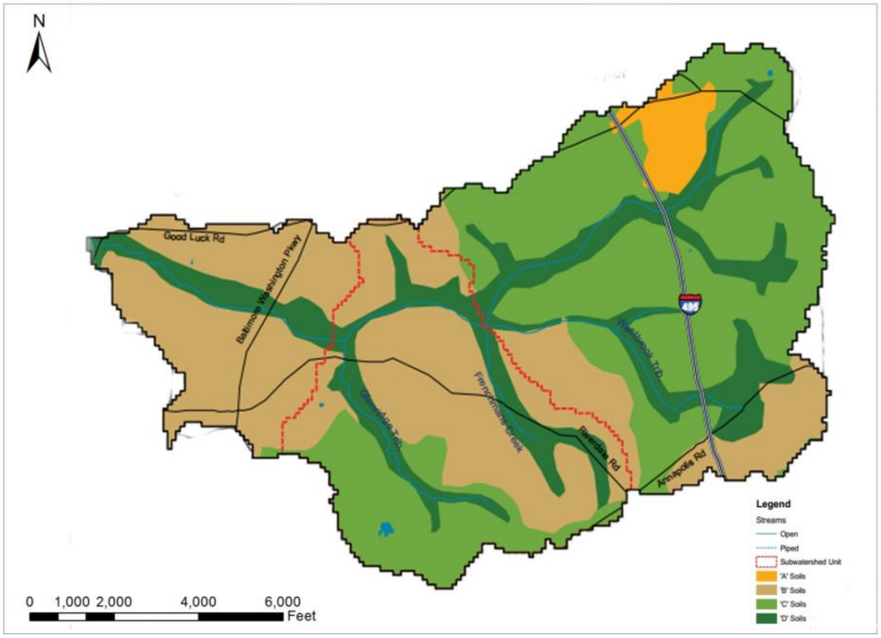


Figure 17: Site Soil Hydrology

(Source: Metropolitan Washington Council of Governments 2009, p8)

2.3.4 Forest Cover (1936-2000)

The historic forest cover in 1936 was 2.6 mi^2, which is account for 63% of the total site. However, with more human activities, the forest cover has dropped to 1.2 mi^2, which is equal to 28.9% of the whole area. The decrease in forest cover is largely due to human related development activities with the process of urbanization (Figure 18 and 19).

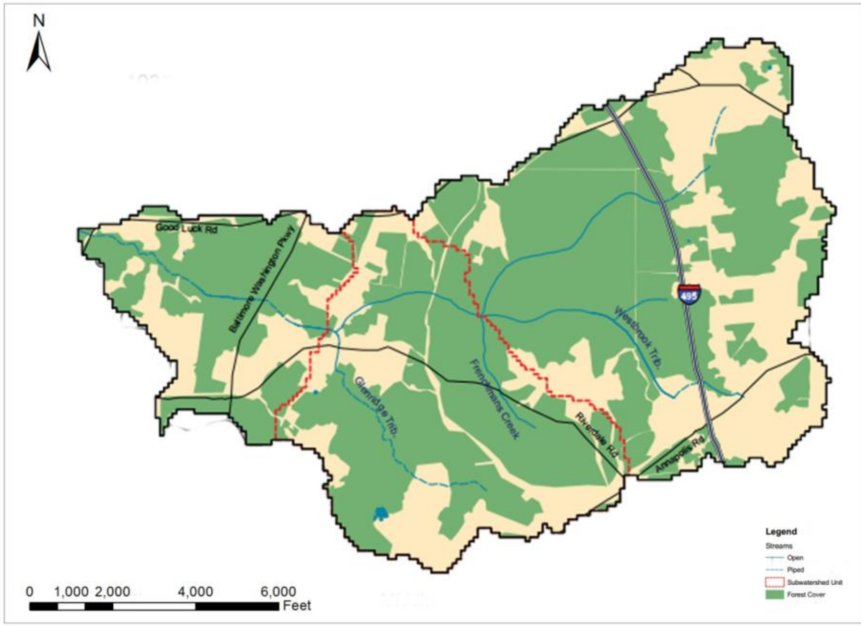


Figure 18: Forest Cover in 1936

(Source: Metropolitan Washington Council of Governments 2009, p13)

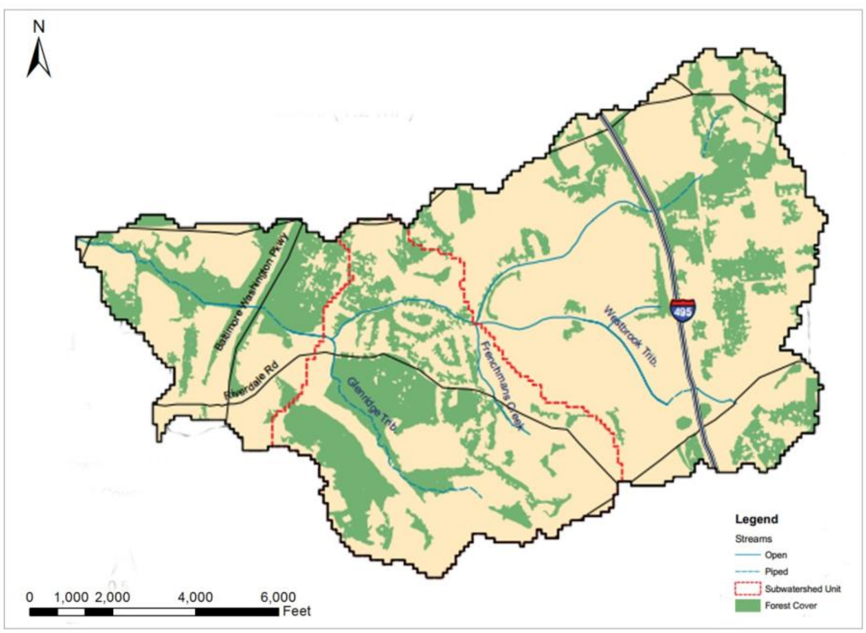


Figure 19: Forest Cover in 2000

(Source: Metropolitan Washington Council of Governments 2009, p13)

2.3.5 Land Use

The three largest land uses by area in the Brier Ditch subwatershed are: 1) medium density, single family residential, 2) institutional, open space and parkland and 3) high density residential apartments. There are currently approximately 4,551 single family homes in the subwatershed (Figure 20).

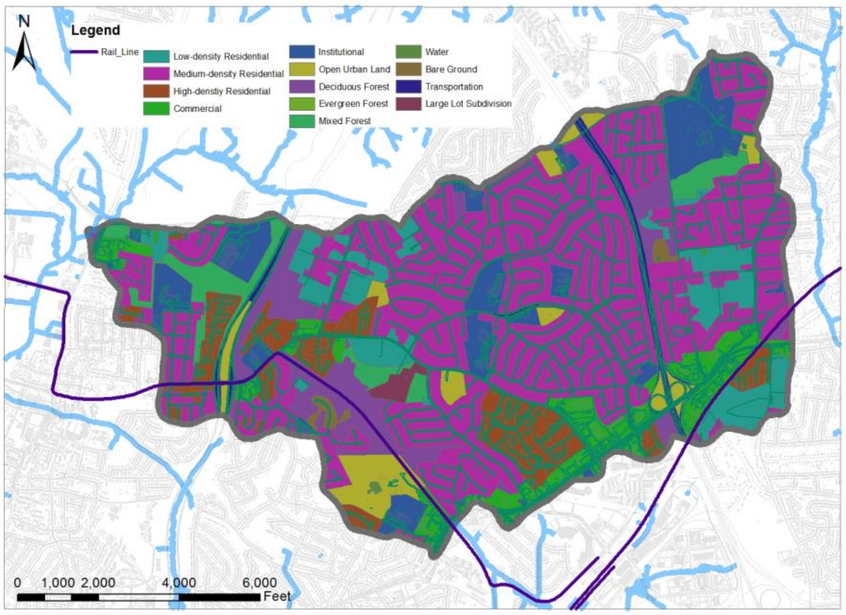


Figure 20: Site Land Use

2.3.6 Schools

There are ten schools and one library located in the study area. Two of them (Lanham Christian School and Washington Bible College) are private properties. An-Nur Academy does not drain into Brier's Mill Run Subwatershed (Figure 21).

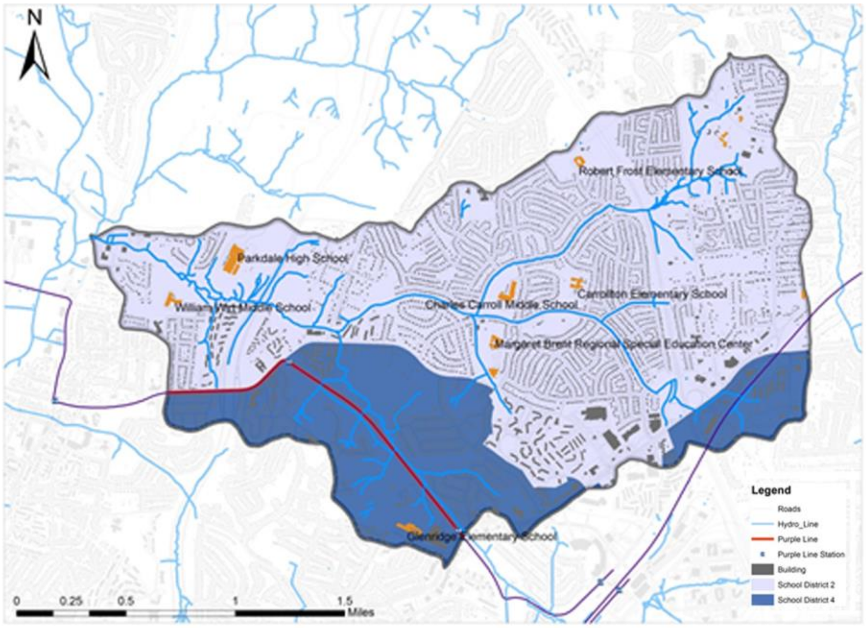


Figure 21: Suitable Potential Green Roof Institutional Properties

2.3.7 Commercial

There are current seven large shopping centers within the subwatershed. Three of them are currently located closely to the proposed purple line station. The commercial buildings have flat roof area (Figure 22).

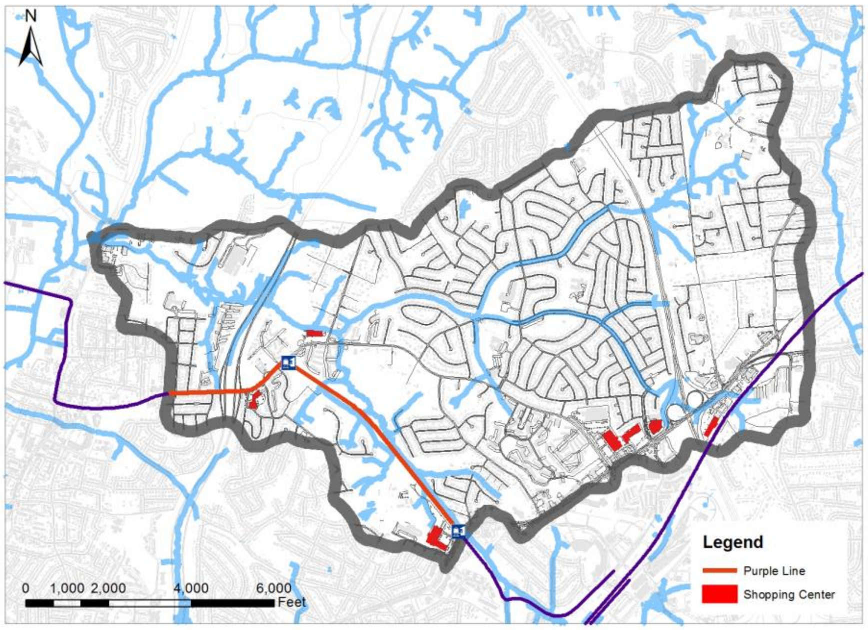


Figure 22: Site Commercial Buildings

2.3.8 Transportation

The major roads in the subwatershed are Good Luck Road that bound the subwatershed on the north, Annapolis Road (MD Route 450) to the east, and Veterans Parkway (MD Route 410). There are also two proposed purple line stations that will cross the site (Figure 23).

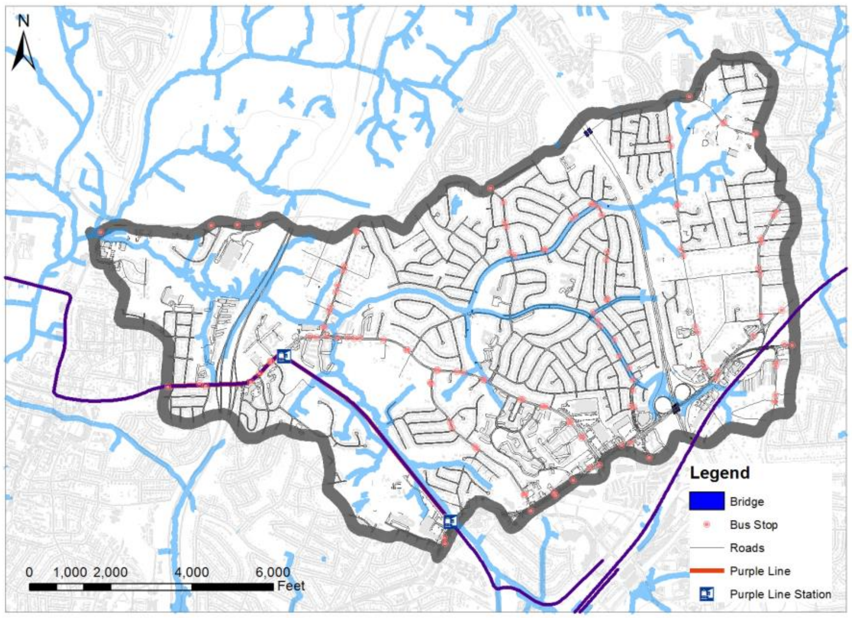


Figure 23: Site Transportation

2.3.9 Impervious Surface

The entire subwatershed is approximately 2,653 acres (4.1 mi^2) and 29% of it is covered by impervious surface. Within the impervious area, 236 acres (31%) are roof surface including 18.8 acres on institutional properties (Metropolitan Washington Council of Governments 2009) (Figure 24 and 25). Only approximately 25 acres of those impervious surfaces are currently controlled by eight BMPs (COE 2009).

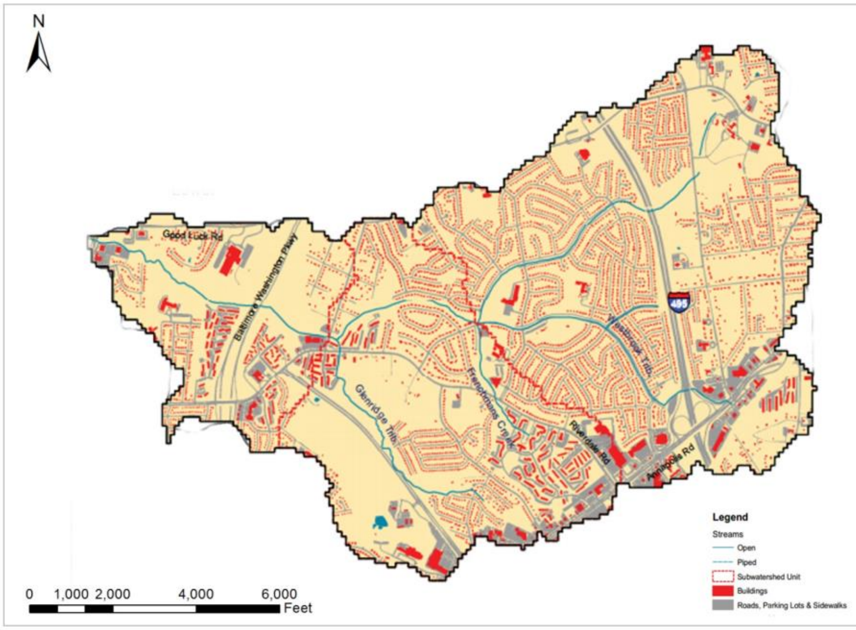


Figure 24: Site Impervious Area

(Source: Metropolitan Washington Council of Governments 2009, p5)

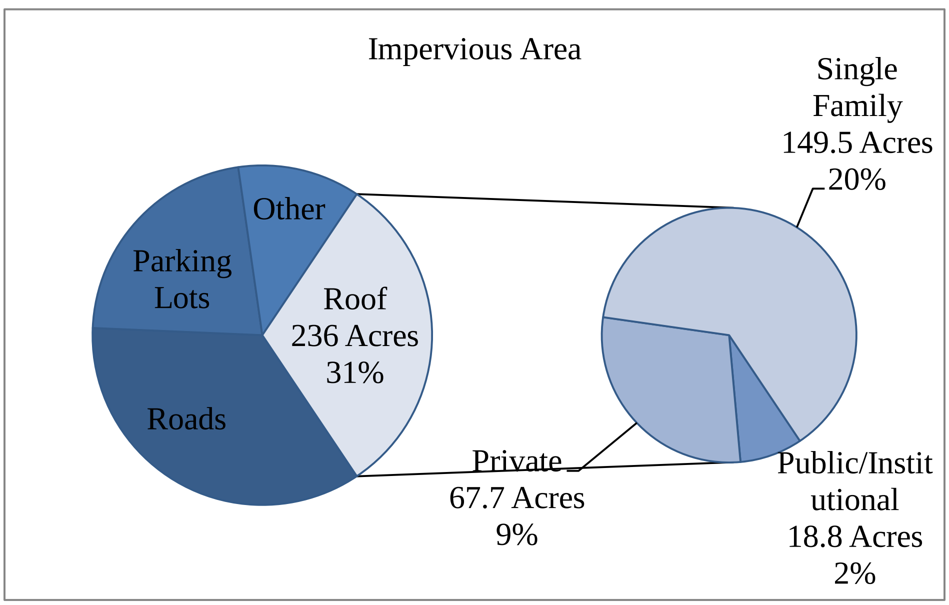


Figure 25: Impervious Area Composition in Brier's Mill Run Subwatershed

(Data Derived from COE 2009)

2.3.10 Current Stormwater Control

Brier’s Mill Run Subwatershed has the fewest number of stormwater management controls, is one of the most densely populated and is the most channelized subwatershed within the Maryland portion of the Anacostia. The total area controlled is 25.1 acres (0.94%) with 8 BMPs (Metropolitan Washington Council of Governments 2009). Not surprisingly, far more stormwater retrofitting and stream restoration efforts are needed to restore the subwatershed (Metropolitan Washington Council of Governments 2009). Planned future projects include, but are not limited to: stormwater management focusing on the employment of low impact development (LID) and ESD, wetland creation, aquatic and terrestrial habitat restoration, fish barrier modification/removal, invasive plant management, trash reduction and potentially additional fish reintroduction (Metropolitan Washington Council of Governments 2009).

2.4 Land Use Plan for 2040

2.4.1 Purple Line

The Purple Line (Figure 26) is a proposed 16-mile light rail line extending from Bethesda in Montgomery County to New Carrollton in Prince George's County. There are two station purposed (Riverdale East Pines and Annapolis Road) in Brier’s Mill Run Subwatershed. Maryland Transportation Administration provided future planning recommendation of pedestrian path, bike lanes and trails.

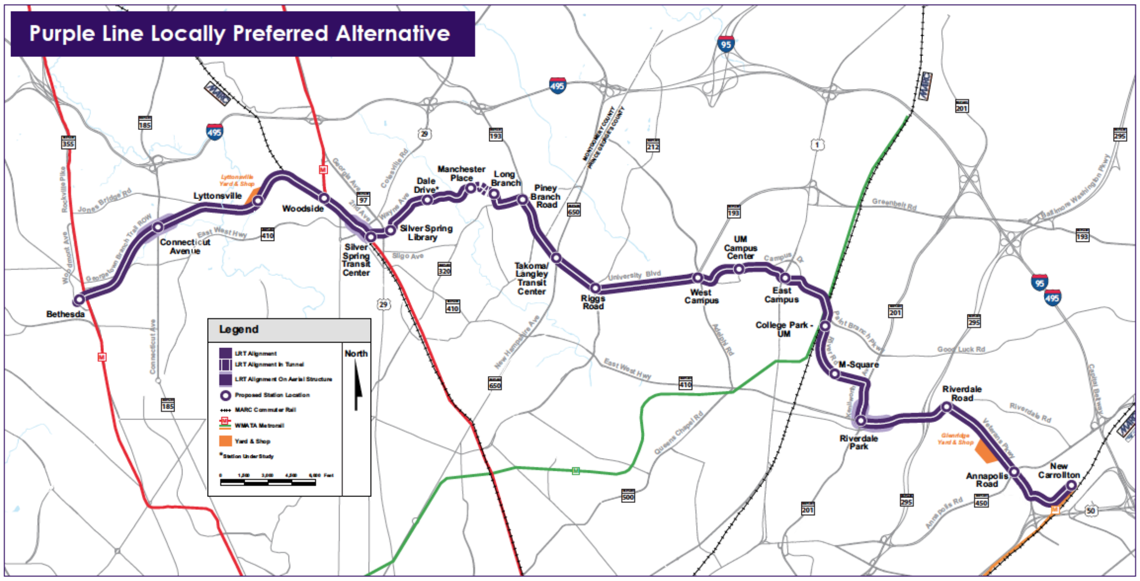


Figure 26: Proposed Purple Line Locally Stations

(Source: Maryland Department of Transportation)

2.4.2 Demographic

Currently, single families are dominated in the area. During the last 30 years, the population increased from 665,071 in 1980 to 863,420 in 2010. According to Maryland Department of Planning population in Prince George's County is estimated to increase to 962,850 in 2040 (Figure 27). The Brier's Mill Run Subwatershed is completely located in Prince George's County. Therefore, it is reasonable to assume that residents in the study area will also increase by 2040. In particular, communities are estimated to grow more than the county average rate due to newly established mass transportation. With new metro station, an increasing of multi-family properties and mix-use buildings are highly expected.

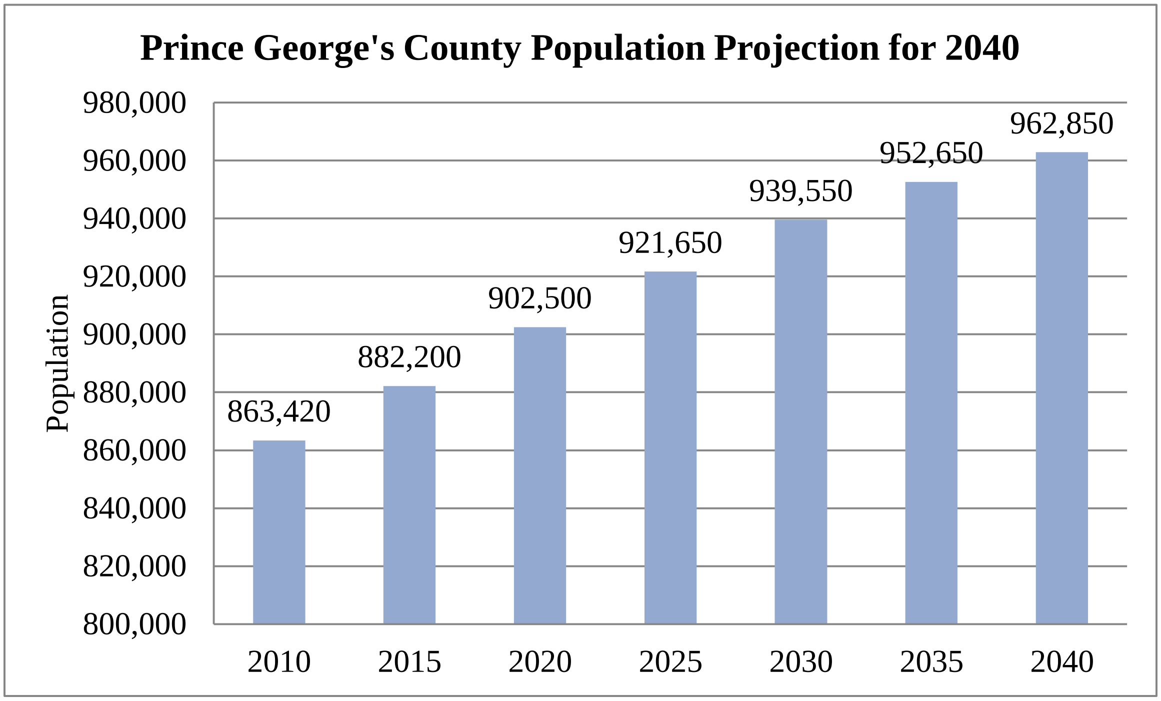


Figure 27: Prince George’s County Population Projection for 2040.

(Data was obtained from Maryland Department of Planning)

2.4.3 Proposed Land Use in 2040

Based on the purple line planning alignment proposal and population projection, it is reasonable to assume that the population in Brier’s Mill Run Subwatershed will increase in 2040 (Figure 28). To accommodate more residents, there is proposed residential densification surrounding the proposed purple line stations.

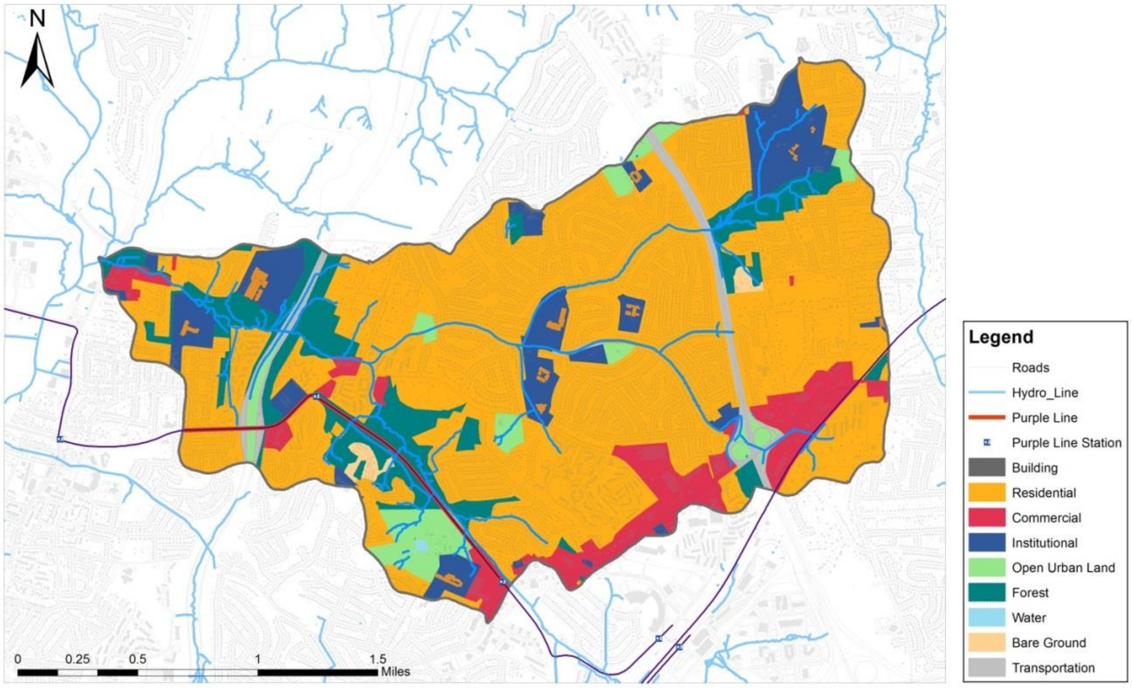


Figure 28: Proposed Land Use for 2040

Chapter 3: Individual School Green Roof Stormwater Management Benefits

This chapter is organized into four sections to analyze and calculate individual school green roof benefits. The first section introduces methods applied in this chapter. The second section calculates individual green roof annual rainwater retention volume. The third section includes the calculations of proposed green roof runoff rate under the State of Maryland ESD requirement. The fourth section creates a feasibility rank to compare individual green roof's overall role within the subwatershed.

3.1 Method

In order to evaluate the stormwater benefit, certain criterion and parameters need to be selected and established to quantify the potential benefits of the educational institutional green roofs. In the SWAP plan, a WTM model was used to calculate the pollution reduction. However, this model is limited to land use level and is not able to measure the potential stormwater control benefits variance between proposed institutional green roofs. Therefore, this chapter provides three metrics to evaluate proposed school green roofs. The first is annual runoff storage volume in gallon. The second is runoff retention rate based on Maryland State ESD requirement. The third is feasibility rank of the eight proposed green roofs.

Data Collection

The data collection for the research was straightforward. All data came from MNCPPC. The materials provided included shape-files of soils, buildings, land-use, hydrography, demographics, property, and town boundaries among others. These data was particularly important for the accurate hydrologic modeling for the scenario master plan model.

The data format was based on the Maryland State Geographic Information Committee guidelines. The committee established standardization of projection, datum and unit for data exchange by Maryland State Government Agencies. The purpose is to maintain compliance with Maryland State standards.

3.2 Annual Runoff Retention Volume

The purpose of this section is to calculate individual green roof's role in annual runoff storage volume. The results reflex the direct amount of how many gallons of rainwater a particular green roof can retain during a year.

3.2.1 Calculation Steps

Calculation Steps and examples are noted in Appendix 6.

3.2.2 Results

Table 5 documents the calculation results from the steps above for individual schools in Brier's Mill Run Subwatershed. Parkdale High School occupies the largest site area and also has the biggest potential area for green roof installation (Figure 29). Table 6 documents the annual amount rainwater storage in proposed green roofs.

Table 5: Available School Roof Area

	Total Roof Area (Acre)	50% Roof Area (Acre)	63% Roof Area (Acre)	75% Roof Area (Acre)
William Wirt Middle School	1.30	0.65	0.81	0.97
Glenridge Elementary School	1.76	0.88	1.10	1.32
Parkdale High School	4.67	2.34	2.92	3.5
Charles Carroll Middle School	2.12	1.06	1.32	1.59
Margaret Regional Special	1.20	0.60	0.75	0.90
Carrollton Elementary School	1.28	0.64	0.80	0.96
Robert Frost Elementary School	0.88	0.44	0.55	0.66
New Carrollton Branch Library	0.75	0.37	0.47	0.56
Total	13.95	6.97	8.72	10.46

Table 6: Potential Green Roof Retention Volume

	50% Roof Area (gallon)	63% Roof Area (gallon)	75% Roof Area (gallon)
William Wirt Middle School	493325.3	614759.6	736196.5
Glenridge Elementary School	575411.2	719264.0	863116.8
Parkdale High School	1530065.6	1909314.4	2288563.2
Charles Carroll Middle School	693106.4	863116.8	1039662.4
Margaret Regional Special	392358.4	490406.6	588487.2
Carrollton Elementary School	418480.2	523099.9	627720.8
Robert Frost Elementary School	287705.0	359631.4	431557.8
New Carrollton Branch Library	241934.0	307321.3	366170.0

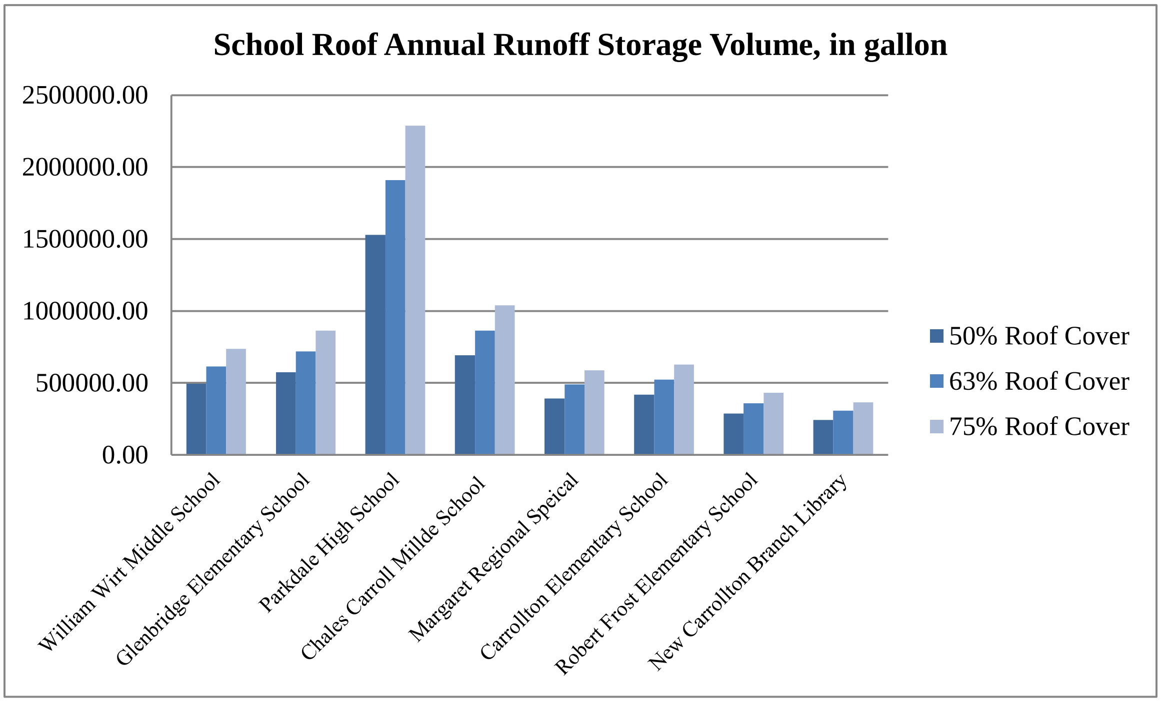


Figure 29: School Roof Annual Runoff Storage Volume

3.3 Runoff Retention Rate under State ESD Requirement

The purpose of this section to calculate individual school green roof stormwater storage benefits under the State ESD requirements for restoration projects. According to Maryland Department of Natural Resource (MD DNR), the goal of current stormwater management is to modify the developed runoff characteristics of a project in such a way that the property hydrology emulates “woods in good condition”. This is accomplished through the use of ESD practices (including green roofs), and requires the computation of an ESD target volume.

3.3.1 Calculation Steps

Calculation Steps and examples are noted in Appendix 6.

3.3.2 Results

Table 7: Individual School Green Roof ESD Requirements Calculation Results

School Name	%I	P_E	ESD_V (cf)	R_2
William Wirt Middle School	38	1.8”	24913.3	14%
Glenridge Elementary School	29	1.2”	16379.8	19%
Parkdale High School	43	1.8”	81388.1	15%
Charles Carroll Middle School	33	1.6”	25591.6	19%
Margaret Regional Special	29	1.6”	18614.2	15%
Carrollton Elementary School	30	1.6”	16640.3	18%
Robert Frost Elementary School	56	2.0”	24782.3	10%
New Carrollton Branch Library	23	1.2”	5294.5	25%

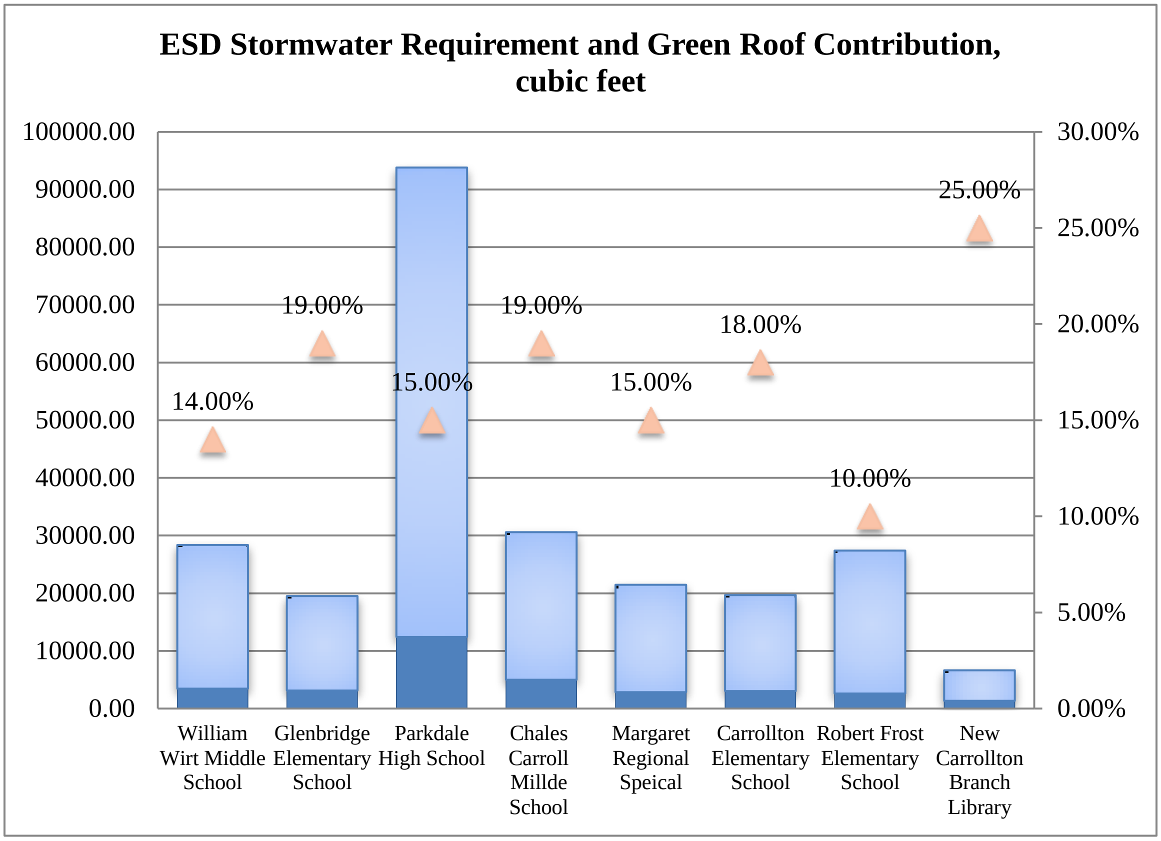


Figure 30: ESD Stormwater Requirements and Green Roof Contribution

3.4 Feasibility Rank

Besides the above two measures, the following section provides specific site green roof feasibility focusing on stormwater management benefits.

3.4.1 Calculation Steps

3.4.1.1 Criteria Selection

The selection of the criteria for the model is mainly focused on two requirements. The first is the runoff retention rate of potential green roofs. The second criterion is an estimation of the stormwater infiltration conditions after the stormwater has left the green roof. Slope, can impact water infiltration rate, flat landform can infiltrate more water than steep slopes. In general we can also assume that the stepper the slope the less chance for infiltration during an event. Thus a flatter site is considered less important to have a green roof, which obtains a lower score, since a flatter area of the site has the potential to provide for infiltration after the stormwater leave the roof area. A second criterion is the distance to nearest river. The criteria can theoretically impact water infiltration after leaving the roof. A longer distance is considered less important to have a green roof, which obtains a lower score. Like the slope criteria, it is assumed that a longer distance would provide greater opportunities for infiltration.

3.4.1.2 Criteria Data

Table 8: Runoff Retention Rate

	Rate (63% coverage)
William Wirt Middle School	14
Glenridge Elementary School	19
Parkdale High School	15
Charles Carroll Middle School	19
Margaret Regional Special	15
Carrollton Elementary School	18
Robert Frost Elementary School	10
New Carrollton Branch Library	25

Slope Degree

The slope degree analysis is processed from ArcGIS by data from zonal statistics. The tool can be found in GIS→ Spatial Analysis → zonal → zonal statistics → mean slope within school property.

Table 9: Slope Degree

	Slope Degree
William Wirt Middle School	4.21
Glenridge Elementary School	2.5
Parkdale High School	2.72
Charles Carroll Middle School	5.5
Margaret Regional Special	4.95
Carrollton Elementary School	2.62
Robert Frost Elementary School	2.23
New Carrollton Branch Library	5.25

Table 10: Distance to Nearest River

	Distance (feet)
William Wirt Middle School	400.21
Glenridge Elementary School	240.48
Parkdale High School	269.20
Charles Carroll Middle School	365.00
Margaret Regional Special	300.00
Carrollton Elementary School	573.30
Robert Frost Elementary School	1148.80
New Carrollton Branch Library	73.90

3.4.1.3 Data Normalization

Three metrics are normalized to compare the potential rank of green roofs. The method of normalization is to set the most suitable data to a score of 100 and the least suitable data to 0. The rest data is scaled between the score of 0 and 100. In the "Distance to Nearest River", the Robert Frost Elementary School is considered as an out layer and is also assigned with a score of 0.

Table 11: Runoff Retention Rate Normalization Results

	Rate (63% coverage)	Normalization
William Wirt Middle School	14	26.67
Glenridge Elementary School	19	60.00
Parkdale High School	15	33.33
Charles Carroll Middle School	19	60.00
Margaret Regional Special	15	33.33
Carrollton Elementary School	18	53.33
Robert Frost Elementary School	10	0
New Carrollton Branch Library	25	100

Table 12: Slope Degree Normalization Results

	Slope Degree	Normalization
William Wirt Middle School	4.21	60.55
Glenridge Elementary School	2.5	8.26
Parkdale High School	2.72	14.98
Charles Carroll Middle School	5.5	100
Margaret Regional Special	4.95	83.18
Carrollton Elementary School	2.62	11.93
Robert Frost Elementary School	2.23	0.00
New Carrollton Branch Library	5.25	92.35

Table 13: Distance to Nearest River Normalization

	Distance (feet)	Normalization

William Wirt Middle School	400.21	34.74
Glenridge Elementary School	240.48	66.68
Parkdale High School	269.20	60.94
Charles Carroll Middle School	365.00	41.78
Margaret Regional Special	300.00	54.78
Carrollton Elementary School	573.30	0
Robert Frost Elementary School	1148.80	0
New Carrollton Branch Library	73.90	100

3.4.2 Results

In summary, the score of three metrics are added to come to the final rank of green roofs. New Carrollton Branch Library ranks first among the 8 institutional properties and Robert Frost Elementary School ranks the last (Table 14).

Table 14: Data Normalization Rank

	Rate	Slope	Distance	Total	Rank
William Wirt Middle School	26.67	60.55	34.74	121.96	5
Glenridge Elementary School	60.00	8.26	66.68	134.94	4
Parkdale High School	33.33	14.98	60.94	109.26	6
Charles Carroll Middle School	60.00	100	41.78	201.78	2
Margaret Regional Special	33.33	83.18	54.78	171.29	3
Carrollton Elementary School	53.33	11.93	0.00	65.26	7
Robert Frost Elementary School	0.00	0.00	0.00	0	8
New Carrollton Branch Library	100	92.35	100	292.35	1

Chapter 4: Scenario Planning

This chapter is organized into two sections to analyze school green roofs' stormwater management benefits in Brier's Mill Run Subwatershed. The first section introduces methods applied. The second section includes the plans and analysis for four school green roof scenarios for Brier's Mill Run Subwatershed in 2040.

4.1 Methods

4.1.1 Brief Introduction of Scenario Planning

Traditional planning is often based upon the idea that the application of professional expertise to achieve well-defined goals will guarantee efficient and effective future management result (Peterson 2003). However, such assumptions often fail to consider the variety of local conditions or the uncertainty of novel conditions that result in unexpected situations (Scott 1998). Herbert Kahn first developed scenarios in response to the difficulty of creating accurate forecasts in the U.S. military (Kahn & Wiener 1967). Scenario planning is a strategic planning method that can make flexible long-term plans. Instead of focusing on the prediction of a single outcome, it takes important future uncertainties into an integrated thinking (Peterson 2003).

4.1.2 SWAP Scenario Plan

In SWAP, scenario planning was used to investigate the potential of the homeowner BMPs to control stormwater runoff generated by residential homes within the subwatershed. Six scenarios of various combinations of the five BMPs (green roofs, rain barrels, rain gardens, downspout disconnects and reduced sidewalk and driveway impervious pavements) were evaluated. Pollution reduction efficiencies were estimated by WTM, which indicated that green roof could remove 45% of Nitrogen, 45% of phosphorus and 80% of Total Suspended Sediments (TSS) (COE, 2011). The plan also evaluated the percent reduction of pollutants estimated for homeowner BMPs control scenarios and acreage controlled. Estimated results suggested that a large amount of pollutants could be controlled if homeowner stormwater controls were implemented over a large portion of the subwatershed (Table 15). COE concluded that public awareness and participation needed to be increased, so that all the citizens of the subwatershed are working together toward the common goal. Governmental efforts were suggested to encourage public BMPs constructions through significant outreach, coordination, technical assistance, and funding to extensively apply a homeowner's stormwater management control program (COE 2011).

Table 15: Percent Reduction of Pollutants Estimated for Homeowner Scenarios and Acreage Controlled

Scenario	**N**	**P**	**TSS**	**Impervious Acreage Controlled**	**Percent of Residential Impervious Acreage Controlled**
1	1%	1%	1%	19.4	6.4%

2	3%	3%	4%	47.8	15.7%
3	6%	6%	9%	95.7	31.3%
4	14%	14%	24%	261.3	85.6%
5	16%	16%	21%	227.4	74.5%
6	10%	10%	15%	52.7	50.0%

(Data is obtained from COE 2011, Table 3.11, p53)

In the SWAP, nine acres of green roofs were planned as one the stormwater control tools. According to the COE, the nine acres was estimated from total institutional roof area. That is to say, school roofs tend to have a higher chance of green roof installation. On the other hand, single-family home roofs are consider less favorable to green roofs. Therefore, land use plays an important role to achieve the COE's goal of green roofs in Brier's Mill Run Subwatershed. Along with Prince George's County's incentive CB-40, in this research, scenario planning is appropriately used to determine green roof application for 2040 of Brier's Mill Run Subwatershed and also design green roof master plan for 2040 of Brier's Mill Run Subwatershed. Various scenarios of green roof by land use combination will be studied evaluated to provide municipality government a general idea, in order to meet their goals, what are the options of green roof locations and what are the stormwater control benefits for each scenario.

4.1.3 Four Scenarios

In the SWAP plan, an evaluation by the WTM was performed to investigate the potential of the homeowner BMPs to control the stormwater inputs produced by residential homes within the subwatershed. BMPs used in the evaluation are green roofs, rain barrels, rain gardens, and downspout disconnects, and practices that directly applied to sidewalks and driveways. Six scenarios of various combinations of the five BMPs were evaluated, in which green roofs were estimated for 1% (control), 5%, and 10% of the total impervious control area (Figure 22). Because of sloped surface and expensive initial cost, green roofs have limited installation on single families (Getter et al. 2007).

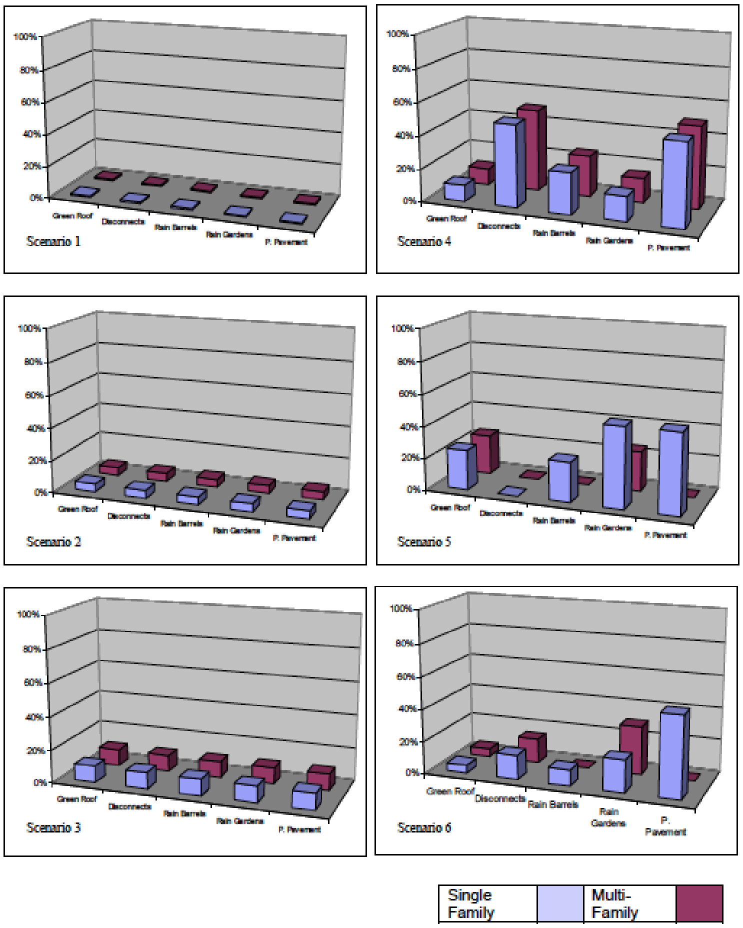


Figure 22: SWAP Scenario Planning of five BMPs in Stormwater Management (Source: COE 2011, p51)

In the proposed scenarios for this program (Table 16), the same numbers as the SWAP are used in master plan. Also, in the proposed restoration, nine acres of projected green roofs are the sum the total school roof areas. With implementation of the newly carried out green roof incentive program, the research explores four scenarios of green roof master plan. The drivers of green roofs installation include public property (schools), private non-single families (including projected new multi-family buildings and commercials), and single families. I also provide an additional scenario where the nine acres of green roofs identified in the SWAP plan is increased one third to twelve acres. The purpose of the additional scenario can be considered as a reference in case the state or county would like to increase the current stormwater management goal trough additional green roof interventions.

Table 16: Four Scenarios of Green Roof Master Plan

	Public (school)		Private (non-Single Family)		Single Family	
Scenario 1 (9 acres)	100%	9	0	0	0	0
Scenario 2 (9 acres)	80%	7.2	10%	0.9	10%	0.9
Scenario 3 (9 acres)	60%	5.4	25%	2.25	15%	1.35
Scenario 4 (12 acres)	75%	9	15%	1.8	10%	1.2

1) There are total of nine acres of green roofs projected for 2040. In this scenario, majority school roofs are covered. The green roof master plan includes 9 acres in schools. When school green roofs do not meet the nine acres, private and single family roofs will be taken into account.

2) There are total of nine acres of green roofs projected for 2040. In this scenario, the incentive program encourages private properties green roofs. The green roof master plan

includes 7.2 acres in schools, 0.9 acres in private non-single family and 0.9 acres in single families.

3) There are total of nine acres of green roofs projected for 2040. In this scenario, majority private roofs are covered. The green roof master plan includes 1.8 acres in schools, 2.25 acres in private non-single family and 1.35 acres in single families.

4) Encouraged by the new incentive program, there are total of twelve acres of green roofs projected for 2040 (one third more than SWAP projection). In this scenario, all school roofs are covered. The green roof master plan includes 9 acres in schools, 1.8 acres in private non-single family and 1.2 acres in single families.

4.2 Scenario Results

4.2.1 Scenario 1

In scenario one, 100% (9 acres) of proposed green roofs are distributed on institutional properties. Depends on the green roof coverage rate, there are three sub-scenarios:

Table 17: Scenario One

% Roof Cover	Total Acreage	Meet the 9 acres goal?
50%	6.97	NO
63%	8.72	NO
75%	10.46	YES

4.2.1.1 50% Roof Cover

Table 18: Scenario 1A

Scenario		Institutional	Commercial	Residential
1A1	Acreage	6.97	2.03	0
	Building	8	2	0
1A2	Acreage	6.97	0	2.03
	Building	8	0	50
1A3	Acreage	6.97	2	0.53
	Building	8	1	15

4.2.1.2 63% Roof Cover

Table 19: Scenario 1B

Scenario		Institutional	Commercial	Residential
1B1	Acreage	8.72	0.27	0
	Building	8	1	0
1B2	Acreage	8.72	0	0.27
	Building	8	0	7
1B3	Acreage	8.72	0.2	0.07
	Building	8	1	2

4.2.1.3 75% Roof Cover

Table 20: Scenario 1C

Scenario		Institutional	Commercial	Residential
1C	Acreage	9	0	0
	Building	8	0	0

4.2.2 Scenario 2

In scenario two, 80% (7.2 acres) of proposed green roofs are distributed on institutional properties. Depends on the green roof coverage rate, there are three sub-scenarios:

Table 21: Scenario Two

% Roof Cover	Total Acreage	Meet the 7.2 acres goal?
50%	6.97	NO
63%	8.72	YES
75%	10.46	YES

4.2.2.1 50% Roof Cover

Table 22: Scenario 2A

Scenario		Institutional	Commercial	Residential
2A1	Acreage	6.97	2.03	0
	Building	8	2	0
2A2	Acreage	6.97	0	2.03
	Building	8	0	20
2A3	Acreage	6.97	1.03	1
	Building	8	1	25

4.2.2.2 63% Roof Cover

Table 23: Scenario 2B

Scenario		Institutional	Commercial	Residential
2B1	Acreage	7.2	1.8	0
	Building	7	2	0
2B2	Acreage	7.2	0	1.8
	Building	7	0	45

2B3	Acreage	7.2	0.9	0.9
	Building	7	1	23

4.2.2.3 75% Roof Cover

Table 24: Scenario 2C

Scenario		Institutional	Commercial	Residential
2C1	Acreage	7.2	1.8	0
	Building	6	2	0
2C2	Acreage	7.2	0	1.8
	Building	6	0	45
2C3	Acreage	7.2	0.9	0.9
	Building	6	1	5

4.2.3 Scenario 3

In scenario three, 60% (5.4 acres) of proposed green roofs are distributed on institutional properties. Depends on the green roof coverage rate, there are three sub-scenarios:

Table 25: Scenario Three

% Roof Cover	Total Acreage	Meet the 5.4 acres goal?
50%	6.97	YES
63%	8.72	YES
75%	10.46	YES

4.2.3.1 50% Roof Cover

Table 26: Scenario 3A

Scenario		Institutional	Commercial	Residential
3A1	Acreage	5.4	3.6	0

	Building	6	3	0
3A2	Acreage	5.4	0	3.6
	Building	6	0	90
3A3	Acreage	5.4	2.25	1.35
	Building	6	2	34

4.2.3.2 63% Roof Cover

Table 27: Scenario 3B

Scenario		Institutional	Commercial	Residential
3B1	Acreage	5.4	3.6	0
	Building	5	3	0
3B2	Acreage	5.4	0	3.6
	Building	5	0	90
3B3	Acreage	5.4	2.25	1.35
	Building	5	1	34

4.2.3.3 75% Roof Cover

Table 28: Scenario 3C

Scenario		Institutional	Commercial	Residential
3C1	Acreage	5.4	3.6	0
	Building	4	3	0
3C2	Acreage	5.4	0	3.6
	Building	4	0	90
3C3	Acreage	5.4	2.25	1.35
	Building	4	1	34

4.2.4 Scenario 4

In scenario four, with the encouragement of incentive CB40, a total of twelve acres green roofs are planned for 2040. There is 75% (9 acres) of proposed green roofs are distributed on institutional properties. Depends on the green roof coverage rate, there are three sub-scenarios:

Table 29: Scenario Four

% Roof Cover	Total Acreage	Meet the 9 acres goal?
50%	6.97	NO
63%	8.72	NO
75%	10.46	YES

4.2.4.1 50% Roof Cover

Table 30: Scenario 4A

Scenario		Institutional	Commercial	Residential
4A1	Acreage	6.97	2.03	0
	Building	9	2	0
4A2	Acreage	6.97	0	2.03
	Building	9	0	20
4A3	Acreage	6.97	1.5	0.53
	Building	9	1	5

4.2.4.2 63% Roof Cover

Table 31: Scenario 4B

Scenario		Institutional	Commercial	Residential
4B1	Acreage	8.72	3.28	0

	Building	9	3	0
4B2	Acreage	8.72	0	3.28
	Building	9	0	82
4B3	Acreage	8.72	1.5	0.53
	Building	9	1	5

4.2.4.3 75% Roof Cover

Table 32: Scenario 4C

Scenario		Institutional	Commercial	Residential
4C1	Acreage	9	3	0
	Building	6	3	0
4C2	Acreage	9	0	3
	Building	6	0	75
4C3	Acreage	9	1.8	1.2
	Building	6	2	30

In summary, the four scenarios and the associated metrics provide a better understanding green roof's stormwater management potential role in Brier's Mill Run Subwatershed. In the original SWAP, there was a goal of nine acres of green roofs planned on the site. The scenario planning results demonstrate different green roofs land use compositions and buildings amounts that are needed to achieve the goals. Within each scenario, sub-scenarios are demonstrated that compare scenarios where one land use is maximized in comparison to another land use. Scenario planning offers policy makers a better method of how to realize the stormwater management visions and goals and, if needed, how to adapt to future conditions. Scenario four also provides planners and water decision-makers inspiration to think beyond the current goal and consider hoe green roofs can provide even greater benefits than originally planned.

Chapter 5: School Green Roofs Application

This chapter will document educational application of green roofs. The first section provides a summary of the Maryland Environmental Literacy initiatives. The second section summarizes the accessibility and site elements that can be included on school green roofs. The third section briefly describes some programs and activities that can be incorporated on the school green roofs.

5.1 Maryland Environmental Literacy Program

In 2011, Maryland developed an environmental literacy requirement as a condition of high school graduation. It is the first state in the nation that requires this standard for high school graduation. The State Board of Education ruled that “each local school system shall provide in public schools (Pre-K-12) a comprehensive, multi-disciplinary environmental education program infused within current curricular offerings and aligned with the Maryland Environmental Literacy Curriculum (MSDE 2011).” Instead of requiring a specific environmental course for students, each local school system is in charge to “shape its own environmental education program, which must align with Maryland Environmental Literacy Curriculum Standards (MAEOE 2011)”. There are eight state standards: Environmental Issues; Interactions of Earth's Systems; Flow of Matter and Energy; Populations, Communities and Ecosystems; Humans and Natural Resources; Environment and Health; Environment and Society; Sustainability (MSDE 2011). Through the newly established environmental literacy program, the State intends to help students to make decisions and take actions that can create and maintain an optimal relationship between themselves and the natural environment, and to preserve and protect the unique natural resources of Maryland, particularly those of the Chesapeake Bay and its watershed (MSDE 2011).

5.2 School Green Roof Application

5.2.1 Accessibility

Accessibility is the first and foremost to be considered in a school green roof design. One consideration is that green roofs could be accessible from inside the building. Students have full access to the green roof. The second one is that outdoor stair is built to get up the roof, where students gain access without entering the building. The third one is that students prepare green roof layers and plants on the ground level and then others will transport the green roofs up to the top of building, where students only have limited access to the green roof for the safety concern. For proposed new school building and green roofs, architectural design of roof accessibility can be incorporated before the building is built.

5.2.2 Site Elements

Site elements on the green roofs are also an important consideration to facilitate learning and education as well as safety and other considerations. Besides green roof plants, several design elements can be included in school green roofs. First of all, safety is always the most important consideration. Railings to protect students from falling off the roof are required. Secondly, pathways that help students and teachers circulate and walk around the roof are essential in activities. Thirdly, other site furniture include seating, signage, solar panels, planting beds and so forth can be added to make the green roof a better environment to stay and study. Larger siting and teaching areas to accommodate a class groups may also be important. However, more structures will add more weight of the roof, which leads to a higher cost to the green roof design, construction, and maintenance.

5.3 Program and Activities

5.3.1 Science Courses

Varies programs and activities can happen on a green roof. First of all, students can have all types of science courses including plant science class, chemistry class, biology class, earth system class and other scientific courses on the green roof. This outdoor living classroom can encourage students to investigate and analyze environmental issues ranging from small vegetation to the whole earth system. By exposed to the open air, students can master environmental knowledge beyond the paper textbooks. In addition, students can also collect real plants and growing media data and then transfer them to use models and computer programs to improve their understanding of for learning outcomes for specific science courses. Last, but not least, students can be grouped into teams to work on their scientific projects, which increases study efficiency as well as building a stronger confidence.

5.3.2 Human Subject Studies

Besides science classes, arts and humanities studies can also be facilitated on green roofs. Some schools can offer creative writing and drawing sessions on good weather days. Also, the roof top can be a good place to talk about local and world population issues, food and hungry, human impacts on natural system, human health and so forth. School green roofs could encourage students and teachers to explore issues beyond traditional in-door classrooms.

5.3.3 After School Clubs

Beyond classes, students can have garden clubs, environmental science club and after school science club on the roof to enrich extra-curriculum activities. The student organizations can extend what they learn from classes to more flexible subjects. They can plant vegetables and fruit at their leisure time as well as exploring the green roof stormwater, energy and economic benefits. The green roof offers more hands-on opportunities for after school activities.

5.3.4 Cooperation with Colleges and Universities

Last but not least, with University of Maryland nearby, there is a possibility to cooperate with college students in green roof and stormwater studies. With the help of college students, they can learn cutting-edge research and technology regarding green roof and green roof components. They can also learn to measure and analyze the environmental benefits of the green roofs to prepare themselves for future studies. This kind of outreach program can benefit the school and the community to support the educational environmental goals of the State.

In summary, under the new State Environmental Literacy Requirements, proposed green roofs can help students and schools achieve the goals as well as are better prepared for future studies. With proper design, various classes and programs can be facilitated on these green roofs to increase students' understanding in environmental issues on their campus setting. These educational benefits should be considered in future school green roofs design and planning in the watershed and the state.

Chapter 6: Summary and Conclusions

The objective of this research was, first, to document the specific role of green roofs in stormwater management in Brier's Mill Run Subwatershed. Secondly, the thesis provided three metrics to measure and further compare the stormwater management benefits of each proposed institutional green roof in the research subwatershed. The third goal used a scenario approach as a comprehensive method to provide options for green roofs on various land use types, including schools to contribute to the stormwater management goals of the subwatershed.

To achieve the above goals, the thesis was organized into six chapters. The first chapter provided an introduction and the general literature review of stormwater management and green roofs benefits. The second chapter documented the inventory and analysis of the watershed and the creation of a proposed 2040 land use plan. The inventory and analysis was critical in understanding the comprehensive nature of the Brier's Mill Run Subwatershed. Furthermore a proposed 2040 land use plan and the planning assumptions for the proposed land use plan were important in laying the groundwork for the development of the scenarios. The third chapter documented the design site and site analysis for the eight educational institutional green roofs selected in Brier's Mill Run Subwatershed. Each school was assessed by three metrics to demonstrate their respective stormwater management benefits. The benefits analysis can provide school principals and water decision-makers a more comprehensive idea of how a particular green roof can help with the campus environments and help them to make decision of applying green roofs on their school buildings. This chapter also provided suggestions about other stormwater management tools that could be applied based on the unique site conditions. The fourth chapter demonstrated scenarios where school green roofs can be prioritized along with commercial and residential properties contributing to the stormwater management requirements of Brier's Mill Run Subwatershed. The scenarios are intended to provide a tool that water decision-makers can use to choose between green roofs among the other green infrastructure tools to mitigate stormwater runoff required by local governments. The fifth chapter illustrated potential green roof educational applications. The design ideas can help educators better use green roofs as a study tool in teaching and learning. The final chapter contains a summary and conclusion.

Implications

In the third and fourth chapters, analysis and scenario results suggested the following implications. First, if using a standard of 50% green roof coverage for an individual school building, the eight existing schools cannot meet the nine acres of green roof targeted in the SWAP. Commercial and residential green roofs are necessary to achieve the overall subwatershed stormwater management goal illustrated in the SWAP. Secondly, while a bigger roof can retain more water, individual site efficiency depends on site conditions. For example, Parkdale High School's potential green roof could contain the most volume of stormwater runoff, but it only contributes to 15% of the ESD goal for its site as required by the new ESD regulations if redeveloped. Thus, some schools might be more suitable for green roofs than others. These should be prioritized if funding is limited. Fourth, ranking could and should be used and is important in policy decisions. The site conditions and potential stormwater management benefits vary for each specific institutional property; individual decisions should be taken into consideration in design and planning green roofs. Fifth, scenario approach results suggest that more green roofs can be accommodated than initially planned. For example in scenario 4, with eight schools and two commercial buildings with 50% green roof coverage, there could be twelve acres of green roofs developed in Brier's Mill Run Subwatershed. Thus it may be possible with proposed incentives to achieve greater green roof targets than originally planned. The proposed scenarios provide choices for water decision-makers as development choices might be made in the redevelopment of the subwatershed. The subwatershed, as a whole, has a larger capacity to take advantage of green roofs as a green infrastructure tool. Last, but not least, educational benefits matter and should be incorporated in school green roof site designs. With the new Maryland School Board

Environmental Literacy Graduation Requirements, green roofs could provide various environment learning opportunities on school properties.

This research also has some limitations. First of all, although green roofs can retain a certain amount of stormwater runoff, they do not provide infiltration benefits as other BMPs like rain gardens. Most water stored evaporates back to the atmosphere. More research and policy about how green roofs can be measured and incorporated into design and planning and policy is suggested. Second, the whole subwatershed is located within Prince George's County, which could vary on other sites. The results of this study may or may not be applicable to other settings, in particular where storm water controls are not as stringent. Thirdly, some of the methods used in this study have been approximated due to the limited scope of this research. As one example, the measurements of building to the nearest stream is a rough direct distance and is not exactly hydrological accurate. In addition, the school site characteristics in this research have been simplified to one catchment in the calculations. Where stormwater permits for development interventions were to occur, this might not be the case, and thus these results would not be as precise if there is more than one hydrologic soil groups.

In summary, with increasing stormwater management targets and environment literacy requirements, institutional green roofs can provide opportunities to address multiple problems that provide multiple benefits. This thesis has demonstrated the opportunities that exist on eight selected educational institutional buildings in the Brier's Mill Subwatershed. The thesis has also provided a comprehensive method of evaluating green roofs and provided a ranking of their stormwater benefits in relation to the site characteristics. In addition, the thesis also demonstrated the benefits of scenario planning by providing a broader number of decisions for planner's in measuring the outcomes of alternative futures. This may be of benefit in evaluating the ongoing success of green roof initiatives and green roof policy programs. The planning of future school green roofs should take both the individual site and the broader subwatershed into consideration. As a result, institutional green roofs can better contribute to stormwater management goals and provide outdoor study spaces that can contribute to environmental education goals.

Appendix

Appendix 1: USGBC LEED Credits Related to Green Roofs

The following criteria have possible credit points in the LEED rating system for green roofs.

Sustainable Sites – SSc5.2 Maximize Open Space
Sustainable Sites – SSc6.1 Stormwater Quantity
Sustainable Sites – SSc7.2Urban Heat Island Mitigation, Roof
Water Efficiency –WEc1 Water Efficient Landscaping
Materials & Resources –MRc4 Recycled Content
Materials & Resources –MRc5 Regional Materials
Innovation in Design (education etc.)

Appendix 2: ASLA SITE Points Related to Green Roofs

The following criteria have possible credit points in the SITE rating system for green roofs.

Site Design—Water

c3.2 Reduce potable water use for landscape irrigation by 75 percent or more from established baseline (2-5 Points)
c3.5 Manage stormwater on site (5-10 Points)
c3.6 Protect and enhance on-site water resources and receiving water quality (3-9 Points)
c3.7 Design rainwater/stormwater features to provide a landscape amenity (1-3 Points)

Site Design- Soil

c4.7 Use native plants (1-4 Points)
c4.10 use vegetation to minimize building heating requirements (2-4 Points)
c4.11 use vegetation to minimize building cooling requirements (2-5 Points)
c4.12 reduce urban heat island effects (3-5 Points)

Site Design-Material Selection

c5.5 use recycled content materials (2-4 Points)
c.5.7 use regional materials

Site Design—Human Health and Well-Being

c6.3 promote sustainability awareness and education
c6.6 provide opportunities for outdoor physical activity
c6.7 provide views of vegetation and quiet outdoor spaces for mental restoration
c6.8 provide outdoor spaces for social interaction
Monitoring and Innovation
c9.1 monitor performance of sustainable design practices (10 Points)

Appendix 3: Hydrologic Soil Groups

Source: USDA NRCS. 2007. "Hydrology National Engineering Handbook - Chapter 7 Hydrologic Soil Groups."
ftp://ftp.wcc.nrcs.usda.gov/wntsc/H&H/NEHhydrology/ch7.pdf

Group A—Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. The limits on the diagnostic physical characteristics of group A are as follows. The saturated hydraulic conductivity of all soil layers exceeds 40.0 micrometers per second (5.67 inches per hour). The depth to any water impermeable layer is greater than 50 centimeters (20 inches). The depth to the water table is greater than 60 centimeters (24 inches). Soils that are deeper than 100 centimeters (40 inches) to a water impermeable layer are in group A if the saturated hydraulic conductivity of all soil layers within 100 centimeters (40 inches) of the surface exceeds 10 micrometers per second (1.42 inches per hour).

Group B—Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. The limits on the diagnostic physical characteristics of group B are as follows. The saturated hydraulic conductivity in the least transmissive layer between the surface and 50 centimeters (20 inches) ranges from 10.0 micrometers per second (1.42 inches per hour) to 40.0 micrometers per second (5.67 inches per hour). The depth to any water impermeable layer is greater than 50 centimeters (20 inches). The depth to the water table is greater than 60 centimeters (24 inches). Soils deeper than 100 centimeters (40 inches) to a water impermeable layer or water table are in group B if the saturated hydraulic conductivity of all soil layers within 100 centimeters (40 inches) of the surface exceeds 4.0 micrometers per second (0.57 inches per hour) but is less than 10.0 micrometers per second (1.42 inches per hour).

Group C**—**Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. The limits on the diagnostic physical characteristics of group C are as follows. The saturated hydraulic conductivity in the least transmissive layer between the surface and 50 centimeters (20 inches) is between 1.0 micrometers per second (0.14 inches per hour) and 10.0 micrometers per second (1.42 inches per hour). The depth to any water impermeable

Group D—Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential. All soils with a depth to a water impermeable layer less than 50 centimeters **(**20 inches**)** and all soils with a water table within 60 centimeters **(**24 inches**)** of the surface are in this group, although some may have a dual classification, as described in the next section, if they can be adequately drained. The limits on the physical diagnostic characteristics of group D are as follows. For soils with a water impermeable layer at a depth between 50 centimeters and 100 centimeters **(**20 and 40 inches**)**, the saturated hydraulic conductivity in the least transmissive soil layer is less than or equal to 1.0 micrometers per second (0.14 inches per hour). For soils that are deeper than 100 centimeters **(**40 inches**)** to a restriction or water table, the saturated hydraulic conductivity of all soil layers within 100 centimeters **(**40 inches**)** of the surface is less than or equal to 0.40 micrometers per second (0.06 inches per hour).

Appendix 4: Runoff Curve Number Reduction used for ESD

(MDE 2009)

Hydrologic Soil Group A										
%I	**RCN***	**P_E = 1"**	**1.2"**	**1.4"**	**1.6"**	**1.8"**	**2.0"**	**2.2"**	**2.4"**	**2.6"**
0%	40									
5%	43									
10%	46									
15%	48	**38**								
20%	51	40	**38**	**38**						
25%	54	41	40	39						
30%	57	42	41	39	**38**					
35%	60	44	42	40	39					
40%	61	44	42	40	39					
45%	66	48	46	41	40					
50%	69	51	48	42	41	**38**				
55%	72	54	50	42	41	39				
60%	74	57	52	44	42	40	**38**			
65%	77	61	55	47	44	42	40			
70%	80	66	61	55	50	45	40			
75%	84	71	67	62	56	48	40	**38**		
80%	86	73	70	65	60	52	44	40		
85%	89	77	74	70	65	58	49	42	**38**	
90%	92	81	78	74	70	65	58	48	42	**38**
95%	95	85	82	78	75	70	65	57	50	39
100%	98	89	86	83	80	76	72	66	59	40

Hydrologic Soil Group B										
%I	**RCN***	**P_E = 1"**	**1.2"**	**1.4"**	**1.6"**	**1.8"**	**2.0"**	**2.2"**	**2.4"**	**2.6"**
0%	61									
5%	63									
10%	65									
15%	67	**55**								
20%	68	60	**55**	**55**						
25%	70	64	61	58						
30%	72	65	62	59	**55**					
35%	74	66	63	60	56					
40%	75	66	63	60	56					
45%	78	68	66	62	58					
50%	80	70	67	64	60					
55%	81	71	68	65	61	**55**				
60%	83	73	70	67	63	58				
65%	85	75	72	69	65	60	**55**			
70%	87	77	74	71	67	62	57			
75%	89	79	76	73	69	65	59			
80%	91	81	78	75	71	66	61			
85%	92	82	79	76	72	67	62	**55**		
90%	94	84	81	78	74	70	65	59	**55**	
95%	96	87	84	81	77	73	69	63	57	
100%	98	89	86	83	80	76	72	66	59	**55**

Hydrologic Soil Group C										
%I	RCN*	P_E = 1"	1.2"	1.4"	1.6"	1.8"	2.0"	2.2"	2.4"	2.6"
0%	74									
5%	75									
10%	76									
15%	78									
20%	79	**70**								
25%	80	72	**70**	**70**						
30%	81	73	72	71						
35%	82	74	73	72	**70**					
40%	84	77	75	73	71					
45%	85	78	76	74	71					
50%	86	78	76	74	71					
55%	86	78	76	74	71	**70**				
60%	88	80	78	76	73	71				
65%	90	82	80	77	75	72				
70%	91	82	80	78	75	72				
75%	92	83	81	79	75	72				
80%	93	84	82	79	76	72				
85%	94	85	82	79	76	72				
90%	95	86	83	80	77	73	**70**			
95%	97	88	85	82	79	75	71			
100%	98	89	86	83	80	76	72	**70**		

Hydrologic Soil Group D										
%I	RCN*	P_E = 1"	1.2"	1.4"	1.6"	1.8"	2.0"	2.2"	2.4"	2.6"
0%	80									
5%	81									
10%	82									
15%	83									
20%	84	**77**								
25%	85	78								
30%	85	78	**77**	**77**						
35%	86	79	78	78						
40%	87	82	81	79	**77**					
45%	88	82	81	79	78					
50%	89	83	82	80	78					
55%	90	84	82	80	78					
60%	91	85	83	81	78					
65%	92	85	83	81	78					
70%	93	86	84	81	78					
75%	94	86	84	81	78					
80%	94	86	84	82	79					
85%	95	86	84	82	79					
90%	96	87	84	82	79	**77**				
95%	97	88	85	82	80	78				
100%	98	89	86	83	80	78	**77**			

Appendix 5: Individual School Inventory and Calculations Steps

The following are the steps undertaken to calculate the annual green roof runoff retention volume.

The annual green roof runoff retention volume is based on annual rainfall of Prince George's county and the green roof water retention rate.

V_A= Annual green roof runoff retention volume (in gallon)
= $(P_A)(A_G)(R)$
Where
P_A= Prince George's Annual Rainfall
= 43" (USGS,)
A_G= Available roof area that can be transformed to green roofs (in acre)
= A_S x R_g; A_S= total school roof area;
R_g= green roof coverage rate
= 50%, 63%, 75%
R= Green Roof Retention Rate
= 65% (As used in Greening DC report)

Determining the Size of Individual ESD Practices

The criteria for sizing ESD practices are based on capturing and retaining enough rainfall so that the runoff leaving a site is reduced to a level equivalent to a wooded site in good condition as determined using United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) methods (e.g., TR-55). The basic principle is that a reduced runoff curve number (RCN) may be applied to post-development conditions when ESD practices are used. The goal is to provide enough treatment using ESD practices to address Cpv requirements by replicating an RCN for woods in good condition for the 1-year rainfall event (MDE 2009).

ESDv = Runoff volume (in cubic feet) used in the design of specific ESD practices
= $(P_E)(R_V)(A) / 12$

Where

P_E = Rainfall Target from Appendix 1 used to determine ESD goals and size practices

R_v = the dimensionless volumetric runoff coefficient
= 0.05 + 0.009(I) where I is percent impervious cover within disturbed area

A = the disturbed area in square feet
= A_S - A_C where A_S is the entire school property area; A_C is the tree canopy area

Calculation Example: Carrollton Elementary School

Location:

Site Area (A_S): 9.45 Acres

Roof Area: 1.28 acres

Soil: 100% C

Tree Canopy Area (A_C): 0.49 Acres

Impervious Area: 2.72 Acres

Step 1: Determine Imperviousness in Disturbed Area (%I)

%I = Impervious Area / (Site Area – Tree Canopy Area)
= 2.72 acres / (9.45 acres – 0.42 acres)
= 30 %;

Step 2: Determine P_E from Table

P_E =Rainfall used to size ESD practices

During project planning and preliminary design, site soils and proposed

imperviousness are used to determine the target P_E for sizing ESD practices to mimic wooded conditions.

Using %I = 30% and C Soils:

		Hydrologic Soil Group C				
%I	RCN*	P_E = 1"	1.2"	1.4"	1.6"	1.8"
0%	74					
5%	75					
10%	76					
15%	78					
20%	79	70				
25%	80	72	70	70		
30%	81	73	72	71		
35%	82	74	73	72	70	

P_E = 1.6 inches of rainfall as the target for ESD implementation.

If %I is between two values, both values should be checked and the more

conservative

result used to determine target P_E.

Step 3: Compute ESDv

ESDv = Runoff volume (in cubic feet) used in the design of specific ESD practices

$= (P_E)(R_V)(A) / 12$

Where

P_E = 1.6 inches

$R_v = 0.05 + 0.009(I)$; I= 30

$= 0.05 + (0.009 \times 30) = 0.32$

A = (9.45 acres – 0.42 acres) x 43560

= 390006.19 square feet

ESDv = 1.6 inches x 0.32 x 390006.19 square feet / 12

= 16640.26 cubic feet

Computing the Proposed Green Roof Storage Volume

Green roof storage volume for particular site directly demonstrates how much rainwater can be retained by green roof if the site is proposed for new construction or restoration projects.

GR_V= proposed green roof runoff storage volume (in cubic feet)
= $(P_E)(A_G)(R)$
P_E = calculated from step 2 in section 3.3.1.1
A_G = calculated from section 3.2.2
R= Green Roof Retention Rate
= 65% (As used in Greening DC report)

In the example,
GR_{V1}= 1.6 inches x 0.64 acres x 65%
= 2416.13 cubic feet

GR_{V2}= 1.6 inches x 0.80 acres x 65%
= 3020.16 cubic feet

GR_{V3}= 1.6 inches x 0.96 acres x 65%
= 3624.19 cubic feet

Computing the Proposed Green Roof Storage Rate R

Proposed green roof storage rate R can directly reflect three coverage type of green roof's stormwater management contribution to a proposed restoration of each property.

R= GR_V/ ESDv

In the example,

R_1= 2416.13 cubic feet / 16640.26 cubic feet
= 15%
R_2= 3020.16 cubic feet / 16640.26 cubic feet

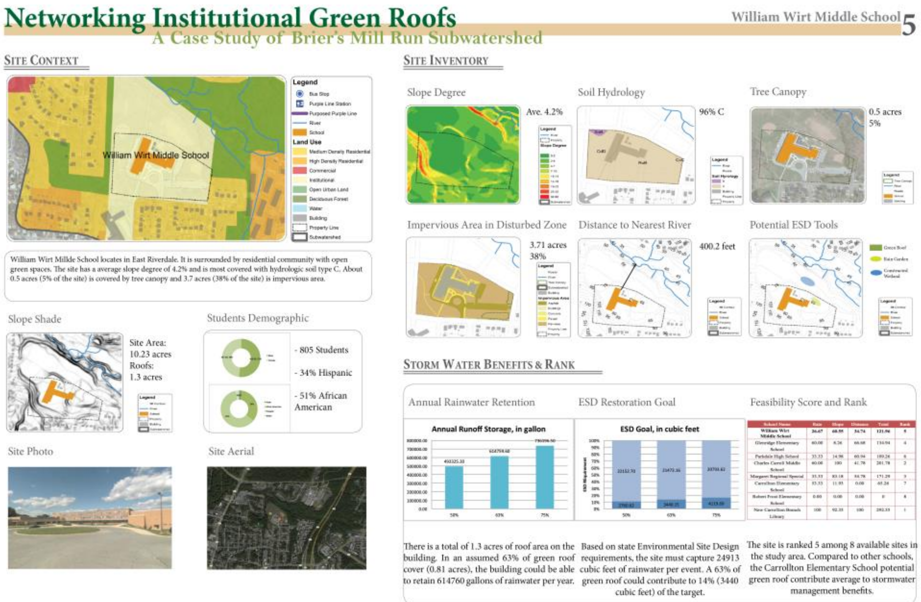
= 18%

R_3= 3624.19 cubic feet / 16640.26 cubic feet

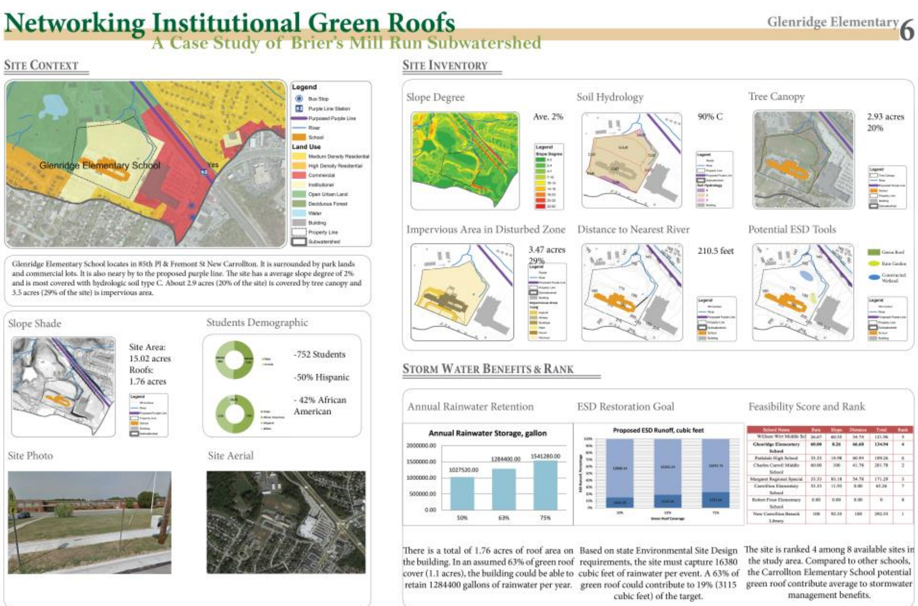
= 22%

Appendix 6: Individual School Inventory and Calculations

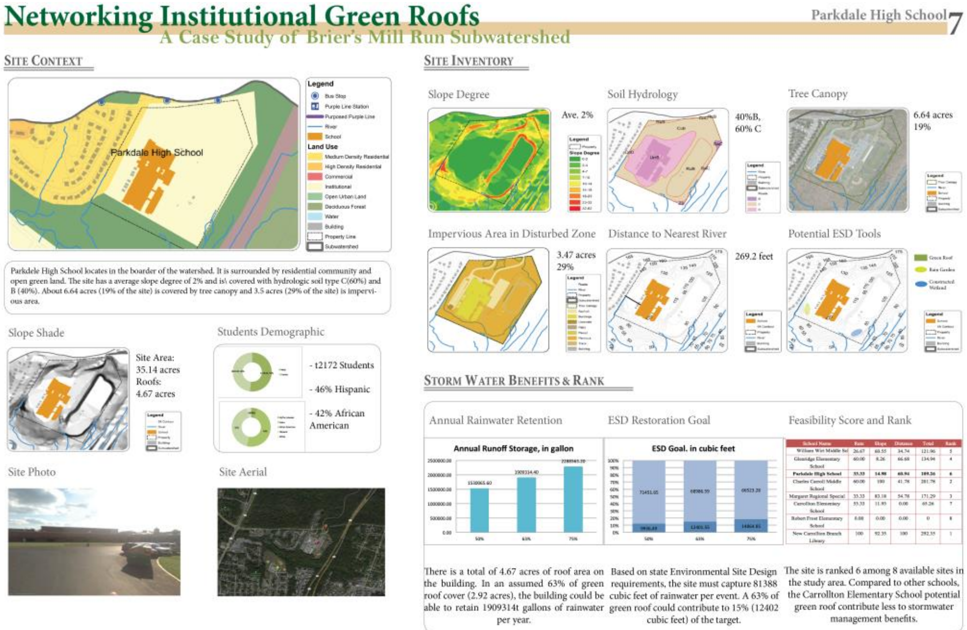
William Wirt Middle School



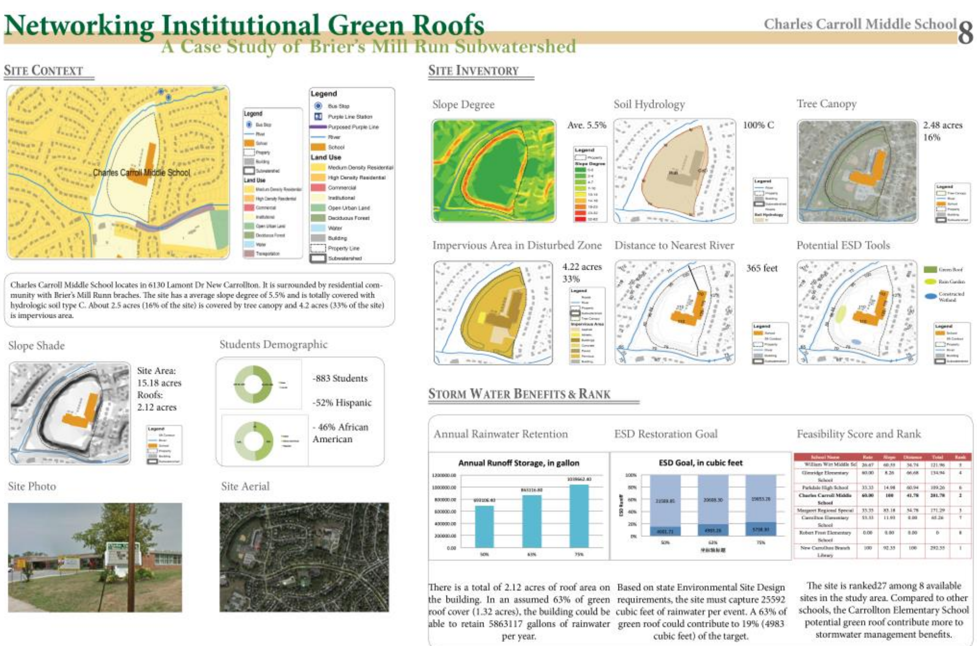
Glenridge Elementary School



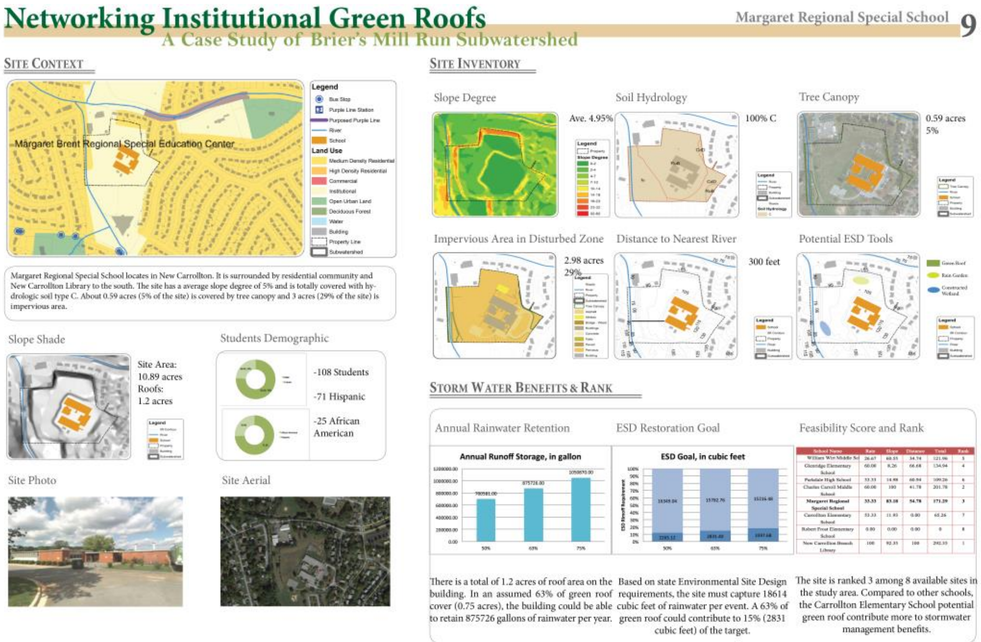
Parkdale High School



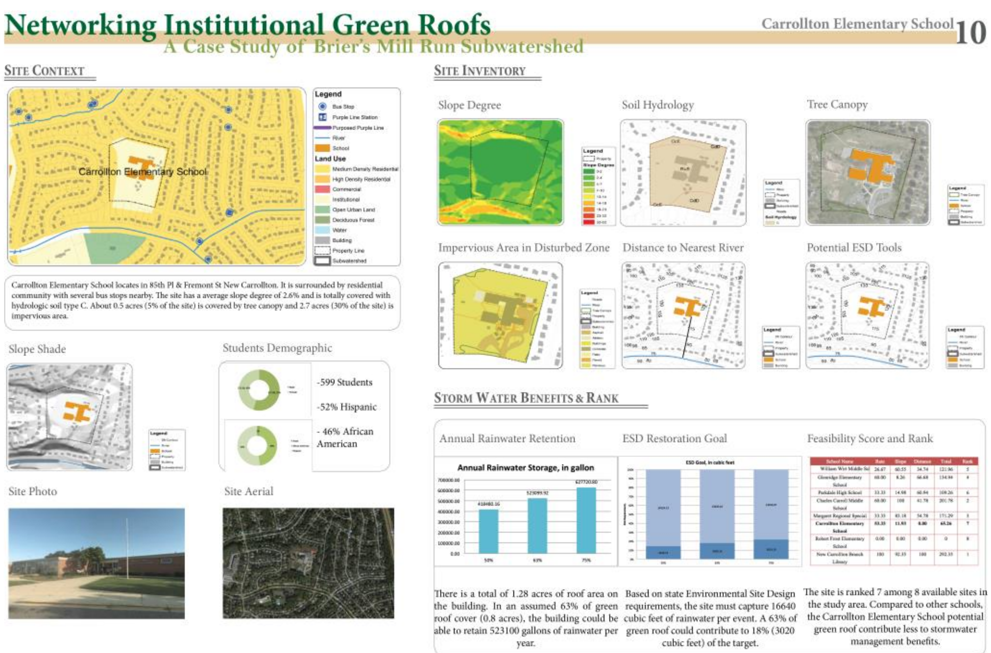
Charles Carroll Middle School



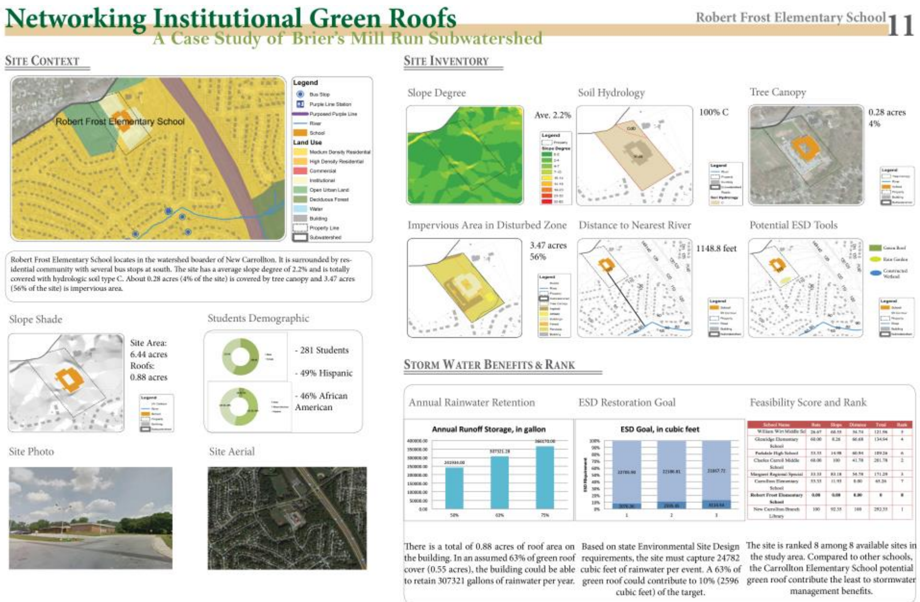
Margaret Regional Special School



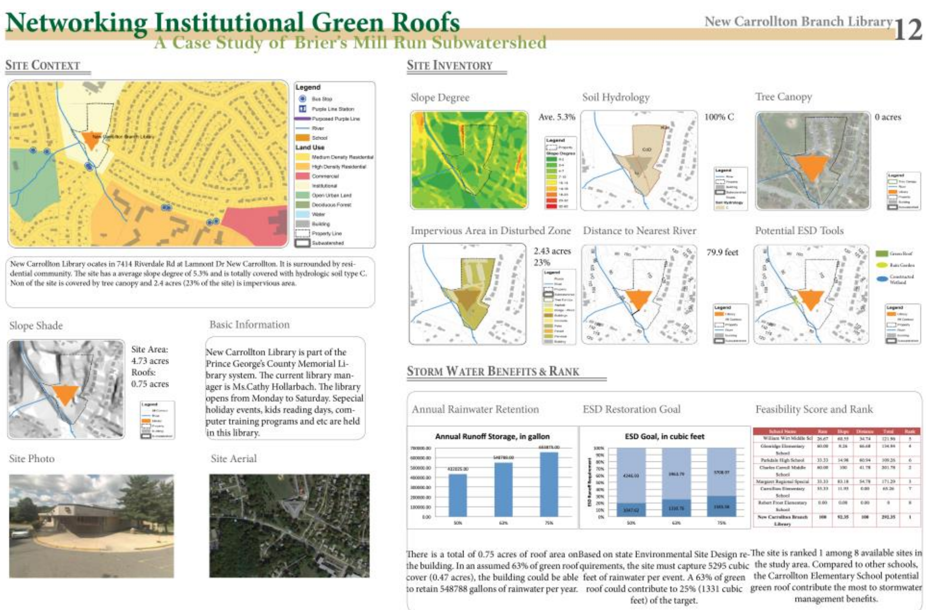
Carrollton Elementary School



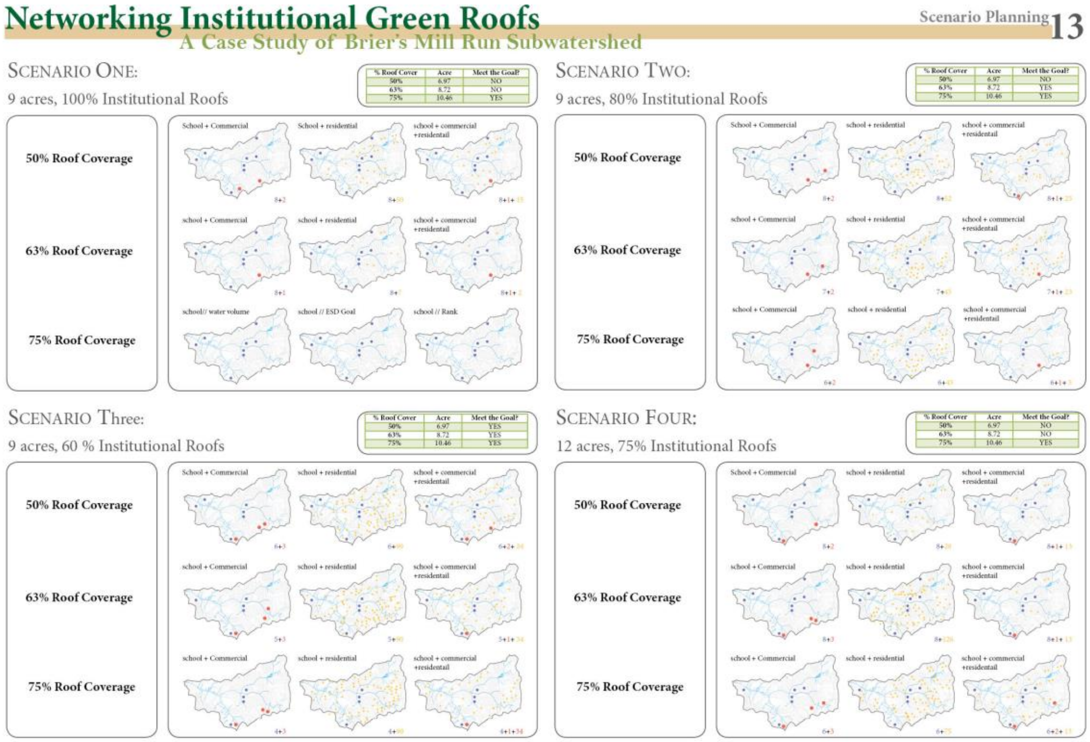
Robert Frost Elementary School



New Carrollton Branch Library



Appendix 7: Scenario Results



Scenario One:

% Roof Cover	Acre	Meet the Goal?
50%	6.97	NO
63%	8.72	NO
75%	10.46	YES

Scenario Two:

% Roof Cover	Acre	Meet the Goal?
50%	6.97	NO
63%	8.72	YES
75%	10.46	YES

Scenario Three:

% Roof Cover	Acre	Meet the Goal?
50%	6.97	YES
63%	8.72	YES
75%	10.46	YES

Scenario Four:

% Roof Cover	Acre	Meet the Goal?
50%	6.97	NO
63%	8.72	NO
75%	10.46	YES

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