GREEN ROOFS FOR DC

Residential Green Roof Implementation in Washington, DC

A Stormwater Management Tool for an Impervious Urban Environment

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Abstract

Green roofs have potential environmental and economic benefits of great consequence for our major cities if implemented at a broad scale. These benefits are beginning to be realized in commercial new construction and retrofitting, where green roofs are coming to be seen as a cost effective method of stormwater control and minimization of thermal heat gain in buildings. In Washington DC, green roofs are being explored as a tool to mitigate water quality problems across the city, and the benefits of retrofitting large buildings with green roofs are being examined and quantified. Here we explore the potential for green roof retrofitting in the residential sector, with a focus on the existing flat roofed architecture of residential neighborhoods in the District of Columbia, in particular the rowhouse. Our findings show that through green roof implementation on residential rowhouses in the District, it is possible to obtain an annual reduction of stormwater discharge volume within the Combined Sewer System area, where stormwater combines with sewage and released into the District's waterways after most rainfalls. Our evaluation shows a 12.18% reduction (279 million gallons) in contaminated discharge within the Combined Sewer System area. While this reduction will not change the number of contamination events, it will have a positive effect of water quality in the District of Columbia.

We approach residential green roof retrofitting as Landscape Architects and so this report includes the topics relevant to designers and their clients such as sustainability issues, construction materials, and economic obstacles. Our analysis also includes an assessment of the role residential green roof retrofits can play in stormwater management in the District, with a particular emphasis on how residential green roofs may be incentivized by the government. Green roofs can be made more cost-effective in the residential market with government incentives for homeowners to mitigate the first costs of retrofitting row houses.

Acronym Descriptions

CSS	Combined Sewer System
CSO	Combined Sewer Overflow
GBO Model	Green Build-out Model [3]
LTCP	Long Term Control Plan
LWA	Light Weight Aggregate
MS4	Municipal Separate Storm Sewer System

Approach

The goal of this paper is to explore the potential for green roof retrofitting in the residential sector in Washington, DC, particularly in regards to the role these green roofs could play in stormwater management. More specifically, we are interested in what impact they may have in the reduction of Combined Sewer Overflow (CSO) volume, which is a significant problem in the District. We chose to focus on residential retrofitting because flat roofed rowhouses are commonplace in the District, and have fewer design constraints than architecture with pitched roofs. Our intentions are to provide a clear and comprehensive introduction to green roof technology for the average homeowner in Washington, DC, in order to increase awareness of green roofs as a practical, green application in our urban areas. To begin the discussion, we provide some history on the practice of urban stormwater management, with a particular focus on the management issues facing Washington, DC. We examine the overall feasibility of building green roof retrofits in the residential sector, including analysis of potential contribution to stormwater control, economic considerations, and government policy issues. Next, we explain the function, design and construction of greenroofs relative to sustainability issues. These topics are important considerations as our analysis shows that residential green roofs can make a contribution to stormwater management as a significant component of the bigger framework of the District's long term stormwater management plan. Finally, we consider our role as landscape architects in the burgeoning field of green roof construction.

Introduction

Green roofs are becoming increasingly common because of their perceived environmental benefits and aesthetic appeal. Although it is the focus of this study, their role in stormwater management is just one of these environmental benefits. The full potential of green roofs as a viable method for stormwater management has yet to be realized, despite that greenroofs can be an important Low Impact Design (LID) technology. This is particularly true in highly urbanized areas in the U.S., such as Washington, DC, where there is little remaining open space for conventional stormwater management infrastructure such as detention or retention ponds. As in other urban areas, there is ample flat roofed architecture in the District, much of which could be retrofitted with green roofs. According to the EPA-funded 'Green Build-Out Model' project conducted by Casey Trees and LimnoTech, green roofs are able to make a contribution to stormwater management in the District of Columbia. This study showed that under a modeling scenario of intensive greening, "installing 55 million square feet of green roofs in the CSS [Combined Sewer System] area would reduce CSO [Combined Sewer Overflow] discharges by 435 million gallons or 19% each year" [3]. As a follow up to this study, we explore the potential impact of residential greenroof retrofitting on stormwater control in the District with a focus on the areas characterized by a Combined Sewer System.

We believe that the District's stated commitment to environmental issues and 'green' building should extend to support of green roof implementation in all sectors of the city. Washington, DC is second only to Chicago in green roof coverage. The city of Chicago's green roof initiative is responsible for "over 200 public and private green roof projects totaling approximately three million square feet" [4]. Nevertheless Washington, DC's mayor, Adrian Fenty has stated an ambitious goal of achieving 20% green roof coverage in 20 years [5]. During his dedication of 12,000 square feet of new green roof area on two DC government buildings, Mayor Fenty said, "These roofs are a symbol that the District of Columbia is committed to being the greenest and most environmentally sustainable major city in the country…By greening our government office buildings we are setting an example that hopefully will inspire others to follow" [6]. We are inspired by the mayor's words and believe that if the District really is to become a true 'green roof city', it must happen with green roofs big and small, commercial, governmental and residential.

PART 1: Urban Stormwater Management and the Utility of Green Roofs

Background and Context

In order to understand the complexity and enormity of the stormwater management problem that faces the District, and why comprehensive green roof implementation may make a significant contribution to stormwater management in the city, it is helpful to consider some context for the District's stormwater problems. Here is a brief history of stormwater management in the U.S. with a focus on the District. We also describe efforts being made by the District to deal with these stormwater issues, with special attention to the District's EPA-mandated Long Term Control Plan (LTCP).

The Stormwater Problem

Stormwater is rainwater runoff that runs along the surface of the ground by gravity. Depending on the permeability of the ground, stormwater can be infiltrate the soil, can be conveyed, retained or detained in a man made drainage system, or can flow to the nearest water body which might be a stream, lake, river, pond or ocean. In less developed, more pervious environments, stormwater is more likely to infiltrate the soil. As imperviousness increases (which happens when land is developed), stormwater runoff increases and is more likely to overwhelm the engineered drainage systems designed for less development. Ultimately, the excessive runoff, now contaminated as it washes the land surface in its path, flows into and contributes to pollution of natural water bodies Moreover, decreased infiltration into the soil means less opportunity for the breakdown of pollutants by soil and plants. This is a common scenario associated with urbanization that generates more impervious surface in the form of roofs, roads, sidewalks, parking lots, and less pervious surface, characterized by soil and vegetation. The consequences of these changes have a large impact on the surrounding environment, including a negative impact on the hydrologic cycle and increased pollution to water bodies [7].

The hydrologic cycle is impacted in several ways. The frequency and severity of flooding increase because runoff from big storms has less land to infiltrate. In a smooth and impervious environment, runoff velocity increases because there is little friction in the form of vegetation or soil to slow the runoff, resulting in limited infiltration and shorter overland travel times to nearby water bodies. This high velocity flow also affects streambed stability, as faster moving runoff erodes banks and beds. This erosion in turn releases increased sediment water bodies, thereby decreasing their flow capacity, and increasing the likelihood of flooding. Furthermore, the decrease in infiltration on land results in decreased groundwater recharge and the water table drops [7].

Beyond the hydrologic complications, there are issues of increased pollution to water bodies. Combined Sewer Overflow (CSO) events are one form of pollution that impacts the water quality of water bodies. A CSO is a mixture of raw sanitary sewage and stormwater that is conveyed by a combined sewer system (CSS), and released into nearby water bodies from CSO outfalls (i.e., outlet pipes along the CSS) when the system is overloaded. Additionally, storm water conveys the pollutants that accumulate on the paved surfaces to water bodies. As imperviousness increases with development, so too does the quantity of pollutants. These pollutants include petrochemicals associated with cars and trucks, construction, herbicides, pesticides and fertilizers, as well as refuse and litter. In an impervious environment, animal waste and organic matter, which would otherwise decompose in a pervious environment, are conveyed by surface runoff to water bodies as organic pollutants. Many of these pollutants stimulate algal growth, which in turn reduces oxygen availability, and increases nutrient and bacteria loads in water bodies. Ultimately, runoff pollution results in impaired water quality for human consumption and recreation as well as degraded wildlife habitat [7].

Legislative History Mandates Cleaner Water

Sewer and storm water effluent can act as both point and nonpoint pollution. Point source pollution originates from an identifiable location such as an industrial facility, or a wastewater treatment plant. Nonpoint pollution does not result from a discrete source, and is exemplified by polluted runoff. Beginning in the 1970s, as the distinctions between point and nonpoint pollution and their relative impacts on the environment became apparent, a wave of legislation was enacted to address these sources of pollution. The most significant legislation to deal with water pollution was the Clean Water Act of 1972, which was amended in 1987 and

2000. The earliest version of this legislation targeted point pollution sources, including combined sewer overflows (CSOs). These point pollution sources are subject to the Clean Water Act National Pollution Discharge Elimination System (NPDES) permit requirements. CSOs have been further addressed with the EPA's National CSO Control Strategy of 1989 [8]. In 1994, the EPA issued a National CSO Policy requiring municipalities to develop Long Term Control Plans (LTCPs) to creatively address reduce/eliminate the dumping of the raw sewage-stormwater mixture into natural water bodies, the source of our drinking water. The National CSO Policy became law when the Wet Weather Water Quality Act of 2000 was passed [2].

In 1987, the Clean Water Act was amended to address non-point pollution sources, which includes urban storm water runoff carried to surface waters. The amendment established that NPDES storm water discharge requirements be implemented by states in two phases. Phase I, implemented in 1990, was geared toward commercial development and storm sewer systems in large cities. Phase II, implemented in 1999, addresses stormwater management and water quality improvement in both large and small urbanized communities. To this end, Best Management Practices (BMPs) have been developed to mitigate negative stormwater impacts. BMPs are categorized as structural and non-structural. Structural BMPs include green roofs and constructed wetlands that are "designed to trap and detain runoff to settle or filter out the constituents before they enter receiving waters" [8]. Non-structural BMPs, such as bioswales and rain gardens, are meant to "control pollutants at the source to prevent or reduce contamination of stormwater runoff" [8].

Sewer System History

Sanitary sewer and storm water infrastructure was initially developed in the U.S. in response to public health concerns, and thereafter in response to increasing environmental awareness. However, development of this infrastructure was also influenced by prevailing attitudes that emphasized immediate short-term gains at the expense of long term planning. Originally, the goal of sanitary systems was to whisk effluent offsite. Where effluent originated, it was considered a nuisance, a health threat, or an aesthetic affront. This general approach has persisted from the earliest systems of the 18th Century to the now antiquated systems still in use today [9].

In their earliest incarnation, sewers were merely open ditches that conveyed effluent to the nearest water body. This included stormwater as well as any effluent from residences or other buildings, including privies. Over time, effluent removal happened in pipes, first made from wood or bricks, and eventually. Combined stormwater and sanitary sewer systems (CSS) became popular because they removed sewerage and accommodated drainage issues. Generally larger cities chose CSS to accommodate increased runoff, and smaller cities relied on single, separate sewer systems with no provision for stormwater. Initially, cities that chose a CSS found it an effective way to remove the amount of effluent produced. Much of the U.S. sewer infrastructure was in place by the early 20th Century, and little of it has been replaced since then [9]. Today, older cities in the U.S., particularly in the northeast and Great Lakes region, still use the older combined systems in addition to the separated systems that were later developed. As cities continued to grow and become more urbanized, debate over the relative merits of combined and separate systems began.

After World War II, cities contended with decaying sewer infrastructure and increasing 'urban crisis'- the spread of suburbs coupled with the decline of inner cities. Overall population growth due to the Baby Boom and the spread of development outwards from traditional city centers gave rise to metropolitan areas with more and more suburban residents. This trend also precipitated the building of more roads for more vehicles. During this era there was also a developing new environmental context, which has had long lasting implications for sewer systems. This new environmental context was more holistic in that it looked beyond disease-causing forms of pollution and their effects on human health to the role of industrial pollutants, urban runoff, and non-point pollution. This was coupled with a growing knowledge of ecological processes. One significant result of this was drastically increased governmental involvement in sewer 'affairs', both at the local and federal level. However, this did not precipitate any change in the type of sewer infrastructure being built. The goal remained to remove effluent as quickly as possible. Municipalities still tended to rely on the same infrastructure design, even as these systems showed their limitations [9].

Today, the negative environmental impact of combined sewer systems has multiplied as impervious urban environments grow. There is increasing pressure from federal and state governments to address these issues. Communities with CSSs are required to develop Long

Term Control Plans (LTCP) to address CSOs. In light of the enormity of the problem, the plans developed by these communities tend to prescribe further massive infrastructure development, such as expensive underground storage tunnels, sized to hold millions of gallons of stormwater in an effort to minimize or eliminate CSO events. Likewise, communities increasingly explore the use of Low Impact Development-Retrofit BMPs, such as green roofs to augment their infrastructure plans.

History of DC Sewer System

Washington, DC is a good example of a community struggling to deal with its stormwater management problem. In order to understand why the District has had to develop a Long Term Control Plan (LTCP), it is instructive to consider the historical development of the city's sewer system. Like many older cities in the U.S., Washington, DC has both combined and separate sanitary sewers (see appendix B for clarifying illustrations).

According to the DC Water and Sewer Authority (DC WASA), "the District's sewerage system, one of the oldest in the United States, began around 1810, when sewers and culverts were constructed to safely drain storm and ground water from the streets. These drains were not all built at the same time, and were not linked together to form a "system" as we know it today" [10]. By the 1850s, piped drinking water was becoming standard in the District, resulting in the need for a more systematic approach to dealing with the resulting wastewater. This development, coupled with an increasing population and a series of disease epidemics forced the Federal Government to pursue solutions for wastewater management. As a result, the Board of Public Works built approximately 80 miles of [combined] sewer in the District during the 1870s. "Although the amount of construction was impressive, much of the work was poorly planned,

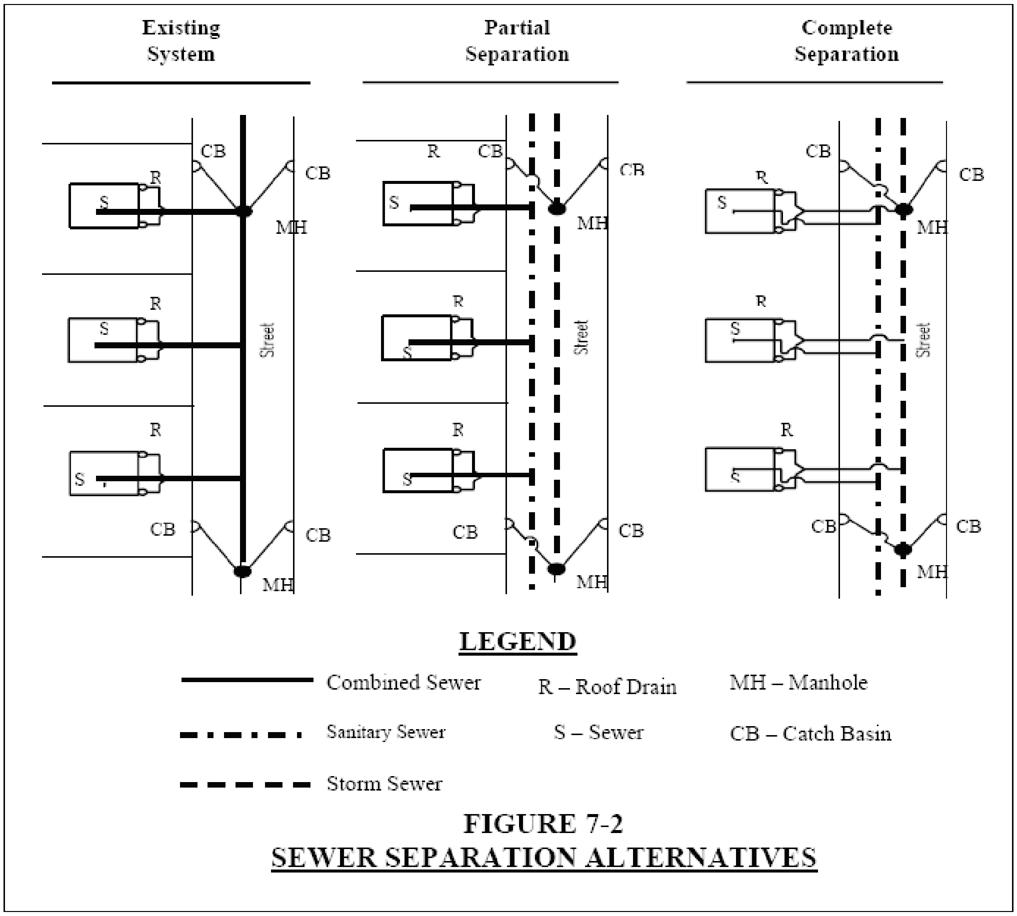


Figure 1: Diagram illustrating differences between combined (left), partially separate (middle) and separate (right) sewer systems [2]. The MS4 is a separate system.

structurally unsound and hydraulically inadequate," [10].

However, in the 1890s, as elsewhere in the U.S., there was debate over whether this type of system was preferred to separate storm water and sewer systems (Figure 1). Based on the recommendations of President Benjamin Harris's Board of Engineers it was determined that the recently built combined system would be retained, but that extensions for other parts of the city would have separate systems for stormwater and sewage. As a result, roughly two thirds of the District is serviced by the CSS. The remainder of the city is serviced by the Municipal Separate Storm Sewer System (MS4). The board also recommended that all sewage flows be discharged as far down the Potomac River as possible to avoid pollution of the city. This original discharge point is where the Blue Plains Waste Water Treatment Plant is located today, the largest advanced wastewater treatment facility in the world [11]. Additionally, they recommended that large interceptor sewers be built to convey the sewage and some portion of the stormwater to a pumping facility on the Anacostia River, and to the discharge point at Blue Plains [10].

The successful implementation of these recommendations accounts for the bulk of the sanitary system in place in the District today [10]. This means that the majority of the District's CSS infrastructure, considered deficient even as it was built, is now 130 years old. According to the LTCP report, no combined sewers have been built in Washington, DC since the early 1900s [2].

The Combined Sewer System consists of pipes that run through three sewersheds; the Potomac, the Anacostia and Rock Creek. There are 60 combined sewer outfalls throughout the system that function like pressure valves for the system and release sewage-contaminated storm water into the city's waterways in response to rainfall. Without these outfalls homeowners' sewers would back up and basements would flood. Even a relatively small storm can trigger a combined sewer overflow event at one of these outfalls. However, "the occurrence of a CSO event depends on many factors other than the total rainfall amount. These include temporal and spatial rainfall distribution, rainfall intensity, antecedent moisture conditions, and the operations of the control measures in the combined sewer system. Because of this complexity, it is not possible to develop a simple rule relating rainfall volume to the occurrence of an overflow" [2]. Various efforts were made throughout the decades to address the problems associated with the Combined Sewer System. These efforts were invariably aborted because of exorbitant costs or structural complexity. For example, in 1960 plans were laid to separate the CSS on a timeline that extended well beyond the year 2000. Although some sections were successfully separated, the program was ultimately scrapped because of the complexity of the required construction [2].

Washington, DC's Combined Sewer System and Long Term Control Plan

Within the CSS area of the District, during dry weather, sewage from all buildings is transported via the combined sewer to Blue Plains Waste Water Treatment Plant. When the capacity of the combined system is exceeded during storms, a CSO event occurs: a combination of sewage and stormwater is discharged into the cities' three water bodies: the Anacostia and Potomac Rivers, and Rock Creek (Figures 10, 11, Appendix B). There are 60 CSO outfall locations in the CSS system listed in the NPDES permit issued by the EPA. These CSOs have negative implications for water quality.

According to the Long Term Control Plan report, the goal is to “control CSOs such that water quality standards are met.” The designated use of all of the city’s waters is class A, meaning they should be suitable from primary contact recreation such as fishing and swimming. However, because of impaired water quality, all of the city’s waters are instead considered class B, meaning they are suitable only for ‘secondary contact recreation and aquatic enjoyment’. It is stated in the Control Plan report that the District’s waters are impaired not only because of CSOs, but because of other pollution sources such as stormwater runoff from the MS4 area and upstream events occurring beyond city limits. For this reason, the Control Plan is just a piece of what could eventually be a regional watershed-based approach for protecting water quality [2].

In 1996, Washington, DC was cited for non-compliance with the Clean Water Act, and in 2001, WASA was sued by the EPA for not having developed its Control Plan. In 2002, WASA published the final draft of its LTCP [12]. By 2005, this plan gained the official support of WASA, the District government, and the Federal government [13]. The Control Plan calls for a significant increase in stormwater storage capacity in each of the city’s three watersheds, as well as some separation of current combined sewer systems in the Anacostia and Rock Creek watersheds [2]. In total the Control Plan calls for 193.5 million gallons of storage capacity in the form of metro sized underground tunnels. When the CSS is overwhelmed during a rain event, the resulting mixture of stormwater and sewage will be diverted to the underground tunnels for storage until Blue Plains Treatment Plant can accept the mix for treatment. In addition to the stormwater storage capacity and sewer separation, the Control Plan also calls for the rehabilitation of pumping stations, improved functionality at the Blue Plains Treatment Plant, additional interceptor sewers, monitoring and CSO outfall consolidation. The total cost of the Control Plan is projected to be approximately $1.2 billion [2]. However, this price tag has increased in the past, and may increase again. The plan, which has a 40 year timeline, will be funded primarily by District property owners. This timeline was chosen because it would not be as prohibitively expensive as implementing the plan on a shorter timeline [2]. At this time, the planning stages for determining the route of the Anacostia tunnel are underway [14].

In their recommendations for system wide controls, WASA recommends Low Impact Development retrofit (LID-R) BMPs as a component of the Control Plan. Although they give green roofs as an example of LID-R technology, they do not recommend them as a stand-alone supplemental stormwater management tool. Instead, they argue that a comprehensive toolkit of LID-R BMPs including bioswales, rain gardens, permeable paving and rain barrels, as well as green roofs, has the potential to make a difference in CSO abatement [2].

MS4 Area

The roughly one third of the District's area not serviced by the CSS is serviced by the Municipal Separate Storm Sewer System (MS4). In the MS4 area, a separated sanitary sewer conducts waste to Blue Plains Treatment Plant, and a separated stormwater sewer conducts stormwater directly to the District's three water bodies. Like other large municipalities, the EPA requires the District to regulate this form of point source pollution to meet federal water quality standards mandated by the Clean Water Act. The District's first NPDES discharge permit was issued by the EPA for the MS4 area in 2000. The NPDES permit for the District calls for structural BMPs like green roofs and nonstructural BMPs like street cleaning. According to the Green Build Out Model (GBOM) in the MS4 area, "the District expects that additional stormwater control will be necessary as EPA develops Total Maximum Daily Load requirements to address water quality impairment. The District government is seeking to avoid a similar, if not greater, investment in underground storage tunnels" in the MS4 area [3]. Thus there is the potential that a comprehensive LID BMP program that includes green roofs could make a significant impact on water quality in the District's waters.

Potential Residential Rowhouse Contribution to Stormwater Control

Our approach to determining the potential contribution of green roofs on residential rowhouses to stormwater control in the District of Columbia involves the use of GIS data and the modeling of proposed green roof scenarios. Our modeling work is based on the Green Build Out Model study, which is an analysis of how green roofs and tree coverage can contribute to stormwater control in Washington, DC [3]. It should be noted that our calculations are based on rough estimations of residential rowhouse building footprint square footage. Consequently, the values derived from the application of our data to the GBO model's publically available Mini-model produce results that should be treated as preliminary. Future studies could further investigate the validity of our assumptions and conclusions.

The Green Build Out Model Study

In order to quantify the contribution that greening can make in the District, the Green Build Out Model (GBOM) was created to evaluate the effect of urban vegetation on stormwater hydrology in the District of Columbia. This model can be used to calculate stormwater reductions within the CSS and MS4 areas under different greening scenarios. The GBOM study [3] focuses on the effect of ground-level trees and green roofs under two levels of greening: 'intensive' and 'moderate'. The model makes the assumption that all greenroofs are the extensive type and hold small plants in structural soils that are 3-4 inches deep. This design can store up to 1" of stormwater. Under the 'intensive' scenario, ground-level trees and extensive green roofs occur wherever physically possible. The 'moderate' greening scenario assumes 20% of the vegetative coverage achieved under the 'intensive' scenario. The 'moderate' scenario is considered to be a more realistic application. The GBOM study analyzed green roof coverage on all buildings regardless of type. Building footprint area was calculated and assigned to a size category (Table 1). Using these data on the relative proportions of building types and footprint sizes, this study showed that:

Table 1: Assumptions for Intensive and Moderate Greening Scenarios from GBOM [3]

Roof Size	Total Roof Area, square feet (sf)	Green Roof-Ready Area (= 75% of roof area)	Number of Buildings	Type of Building	Implementation Considerations	Intensive Greening %	Intensive Greening Green Roof-Ready Area, sf	Moderate Greening % (20% of Intensive Scenario)	Moderate Greening Green Roof Area, sf
<1,000 ft	57,423,950	43,067,963	98,748	Most small rowhomes, garages, sheds	These homes may choose to implement less expensive/ easier LID such as rain barrels. Homes may also be historical and/or less structurally capable of supporting a green roof. Many owners to target.	10%	4,306,796	2%	861,359
1,000ft - 2,000ft	62,224,642	46,666,982	46,126	Larger rowhomes	Generally flat roofs, but potential structural issues. Many owners to target.	30%	14,000,544	6%	2,800,109
2,000ft - 5,000ft	33,295,571	24,971,678	11,447	Single family homes, large rowhomes	Many of these buildings are single family homes, which may have sloped roofs, structural issues.	50%	12,485,839	10%	2,497,168
>5,000ft	106,469,278	79,851,959	5,509	Large commercial, institutional or government buildings	Generally no structural issues. There may be some historical issues and sloped roofs.	90%	71,866,763	18%	14,373,353
Total	**259,413,441**	**194,560,081**	**161,830**	-	-	**53% of Green roof ready area (or 40% total building area)**	**102,659,943**	**20% of Green roof ready area (or 10.5% of total building area)**	**20,531,989**

- 41% of all building footprint area in the District is greater than 5,000 sf. consisting of commercial, multi-family residential, municipal, or federal land uses
- 59% of all building footprint area in the District is less than 5,000 sf. consisting of residential and small commercial land uses
- 53% of the building footprint area in the CSS area consists of building footprint areas less than 5,000 sf.
- 64% of the building footprint area in the MS4 area consists of building footprint areas less than 5,000 sf.

These results suggest a significant opportunity for the residential sector to contribute to stormwater control via green roofs, as residential and small commercial buildings represent a large proportion of building footprint area within the CSS (53%) and the MS4 area (64%).

Residential Rowhouse Calculation

Our report focuses on rowhouses, a common architectural type in the District's residential sectors. Rowhouses are generally flat-roofed and, therefore, more amenable to green roof retrofitting compared to pitched roofs. Since the GBO model study does not distinguish the flattop residential rowhouses from other residential and small commercial architectural styles, we developed our own estimation of total building footprint area occurring as residential rowhouses. Using GIS data of building footprint polygons and residential properties, we singled out those building footprints that were indicated to be rowhouses by a residential property data set, and calculated residential rowhouse building footprint area (see Figure 2 for map of residential rowhouses relative to the sewer system). We found that residential rowhouse building footprint area constituted approximately 19% of the total building footprint area in the District, and nearly a third (31%) of the total building footprint area within the CSS. For detailed methods on these calculations and GIS data manipulation, see appendix A. We used this value for building footprint area of residential rowhouses in the District calculate the area that could be used as green roof surface.

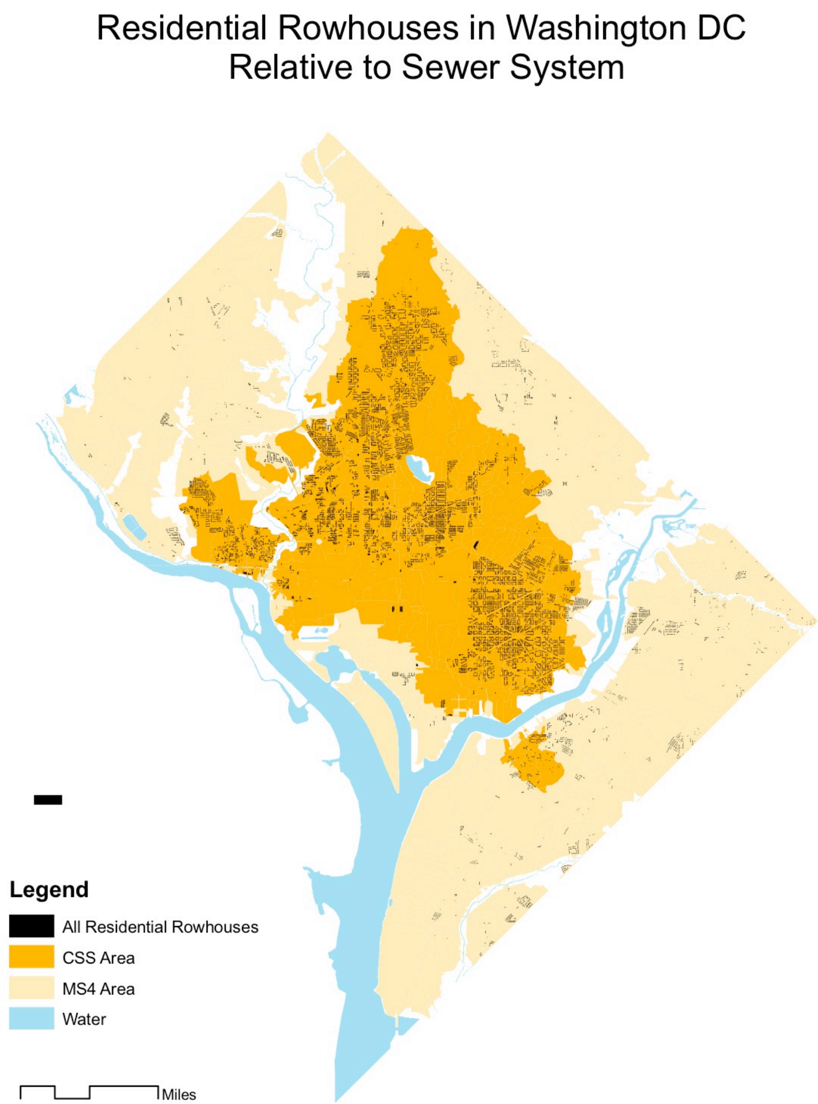


Figure 2: Map of Residential Rowhouses within the CSS versus outside of the CSS

Not all of a building's footprint area is available for the installation of a green roof. The GBO model study makes the assumption that the roof area is equivalent to the building footprint, and that the green roof-ready area was equal to 75% of the building footprint for all building types. This assumption was based on a review of extensive green roofs in the District (demo projects) and extensive green roof installations in other cities which showed that the maximum rooftop coverage for extensive green roofs was 75% of the building footprint [3], because 25% of the roof is needed for HVAC, access, and maintenance. We made the same initial assumption- that a building's footprint was equal to roof area. We then developed two greening scenarios, each of which assumed a different percentage of extensive green roof-ready area for residential townhouses. In scenario 1 we assume that a non-accessible green roof occupies 80% of the building footprint area. In scenario 2, an accessible green roof occupies only 60% of the building footprint area (Figure 3). Basically, these scenarios differ from the GBOM study by the amount of space available for human (versus vegetation) occupation. Both include area for maintenance and HVAC systems Landscape architect and co-author of the GBOM study, Barbara Deutsch, deemed that the percentages we used for green roof-ready area reasonable for residential rowhouses [15]. We chose to consider non-accessible green roofs because they offer more stormwater control, compared to accessible roofs, simply because there is more absorbent surface. Accessible green roofs have the advantage of popular support and the opportunity improving urban aesthetics. Note that the designation 'green roof-ready' in no way speaks to the structural capability these buildings for supporting green roofs.

In order to make calculations for the entire District area as well as the CSS area, it was necessary to create sub-scenarios for scenarios 1 and 2. We wanted to run both scenarios for different degrees of neighborhood 'coverage'. 'Coverage' refers to the number of rowhouses available for green roof installation in a given area. Both 'green roof-ready area' and

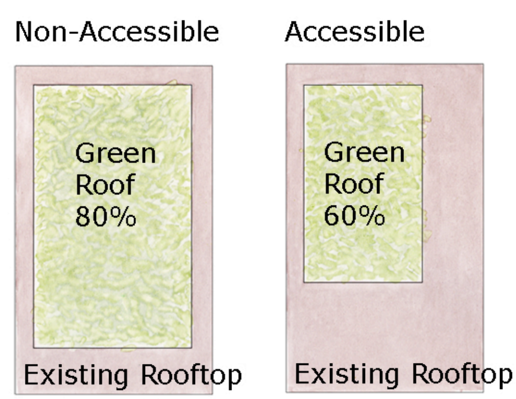


Figure 3: Diagrams of percent green roof-ready areas for our scenarios 1 (left) and 2 (right)

Table 2: Description of our Scenarios 1 and 2, indicating breakdown of sub-scenarios as percentages of Residential Rowhouse Building Footprint (RRBF)

	Scenario	Green Roof Ready Area in % of RRBF	Accessibility A= Accessible NA= Non Accessible	Coverage of Residential Rowhouses in % of RRBF
District Wide	1a	80%	NA	100%
	1b	80%	NA	50%
	2a	60%	A	100%
	2b	60%	A	50%
CSS	1c	80%	NA	100%
	1d	80%	NA	50%
	2c	60%	A	100%
	2d	60%	A	50%

'coverage' are calculated as a percentage of residential rowhouse building footprint area (see Tables 2 and 3, and figure 4 for clarification). While 100% coverage is intended to show the biggest contribution that residential green roofs can make, we also included values at 50% coverage as a more reasonable alternative to full coverage. In both scenarios, green roofs are extensive, generalized at 3-4" substrate depth, following the GBO Model study.

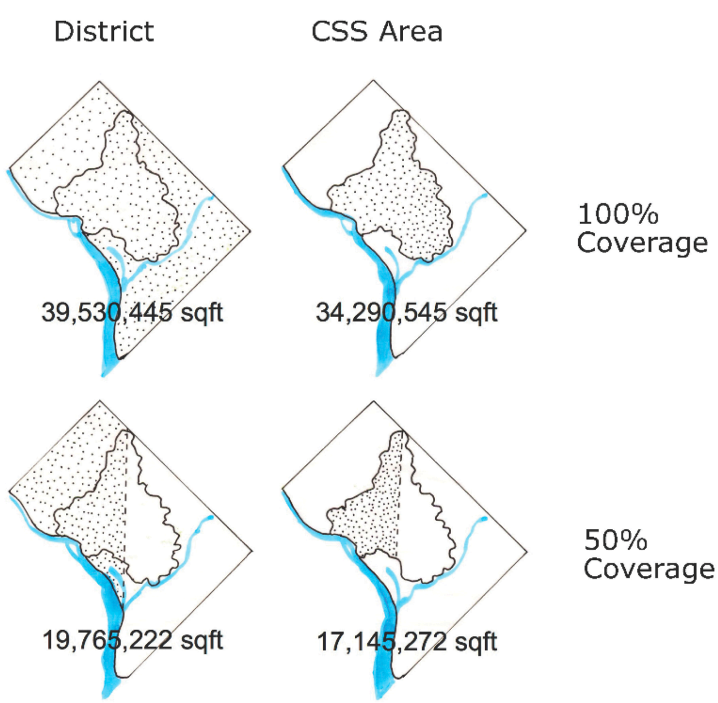


Figure 4: Coverage % for two scenarios for green roofs of rowhouses (calculated square footages for green roof area on rowhouses shown)

Since residential rowhouses make up approximately 31% of the building footprint area within the CSS, at our highest coverage scenario, about 25% of the total building footprint area was green roofed (Table 3). This represents a sizable urban area. We wanted to know whether greening this much space reduce stormwater runoff sufficiently to reduce discharge volumes during CSO events.

Mini-Model Findings

With estimates of green roof ready area, it is possible to use a form of the Green Build Out Model to estimate stormwater reduction values for district rowhouses. The GBO Model is a complex hydrologic and hydraulic model, which incorporates many factors to determine stormwater reduction volumes in different sewersheds within the District. We have chosen to use the simpler, more user-friendly version of the GBOM, dubbed the Mini-Model, which is readily available on the Internet [16]. Plugging in the green roof ready square footage values from Scenario 1, we generated values for annual reduction in stormwater volume owing to the storage capacity of the rowhouse greenroofs (Table 4).

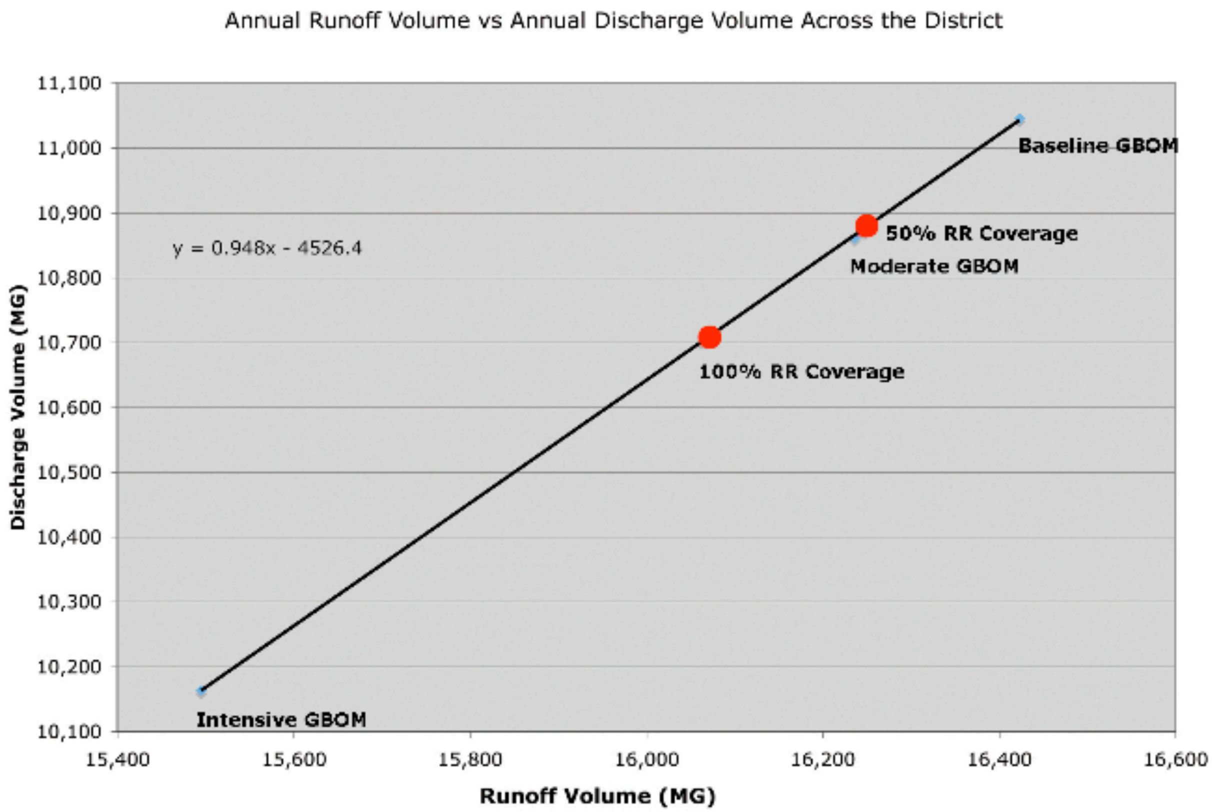
Table 3: Calculations illustrating green roof ready areas of the sub-scenarios

DISTRICT WIDE CALCULATIONS	Area in Square Feet	% Total Land Area of the District	
Total Land Area within District	2,052,786,649.25	100.00%	
Land Area within CSS	1,124,366,517.24	54.77%	
Total Building Footprint	261,923,098.62	12.76%	
			% Total Building Footprint
Residential Rowhouse Building Footprint (RRBF)	49,413,056.48	2.41%	18.87%
1a: Green Roof Area (80% of RRBF at 100% coverage)	39,530,445.18	1.93%	15.09%
1b: Green Roof Area (80% of RRBF at 50% coverage)	19,765,222.59	0.96%	7.55%
2a: Green Roof Area (60% of RRBF at 100% coverage)	29,647,833.89	1.44%	11.32%
2b: Green Roof Area (60% of RRBF at 50% coverage)	14,823,916.94	0.72%	5.66%
CSS CALCULATIONS	Area in Square Feet	% Land Area Within the CSS	% Building Footprint Within the CSS
Total Building Footprint within CSS	138,583,794.91	12.33%	
Residential Rowhouse Building Footprint (RRBF)	42,863,181.29	3.81%	30.93%
1c: Green Roof Area (80% of RRBF at 100% coverage)	34,290,545.03	3.05%	24.74%
1d: Green Roof Area (80% of RRBF at 50% coverage)	17,145,272.52	1.52%	12.37%
2c: Green Roof Area (60% of RRBF at 100% coverage)	25,717,908.77	2.29%	18.56%
2c: Green Roof Area (60% of RRBF at 50% coverage)	12,858,954.39	1.14%	9.28%

Table 4: Data generated from the Mini-Model illustrating estimated stormwater reduction volume and discharge reduction values of the sub-scenarios. Our values in green cells, GBOM values in white cells

	Annual Reduction in Stormwater Volume (MG)	Percent Reduction in Runoff Volume	Average Year Wet Weather Point Untreated Discharges (MG)	Runoff Volumes for the CSS and MS4 Areas (MG)	Discharge Reduction Volume (MG)	Percent Discharge Reduction
District Wide						
Moderate GBOM			10,862	16,236		
Intensive GBOM			10,164	15,495		
Baseline GBOM			11,046	16,423		
1a: 100%	358	2.20%	10,703	16,065	343	3.10%
1b: 50%	179	1.10%	10,873	16,244	173	1.57%
CSS						
Moderate GBOM			2,196	7,569		
Intensive GBOM			1,856	7,182		
Baseline GBOM			2,291	7,668		
1c: 100%	310	4.00%	2,012	7,358	279	12.18%
1d: 50%	155	2.00%	2,150	7,513	141	6.16%

Taking our analysis a step further, we asked if this stormwater reduction translates into reduction of CSO volumes within the CSS area. While there was an annual reduction in stormwater volume using scenario 1, we wanted to know if this stormwater reduction was correlated with a reduction in contaminated discharge into the city's rivers, particularly within the CSS. To begin, we found the relationship between stormwater runoff volume across the district, and actual discharge (of combined stormwater and sewage) volume into the city's waters. These values were taken from the GBO Model study, shown in white cells in Table 4. In the MS4 area, stormwater runoff volume is roughly equivalent to the discharge volume. For the CSS area, a regression analysis of average wet weather point untreated discharge volumes from average year runoff volumes reveals the linear relationship between runoff and discharge volumes from the GBO model [17]. In the scenarios, this means that as the amount of greening increases, runoff volume and discharge volume decreases at a constant rate. We applied these two equations provided by the GBO model to our rowhouse area data to estimate discharge volumes under Scenario 1 for both the entire District and the CSS area. See Figure 5 for the graphs of runoff vs. discharge volumes. Table 4 shows the discharge reduction values that we calculated with these equations.



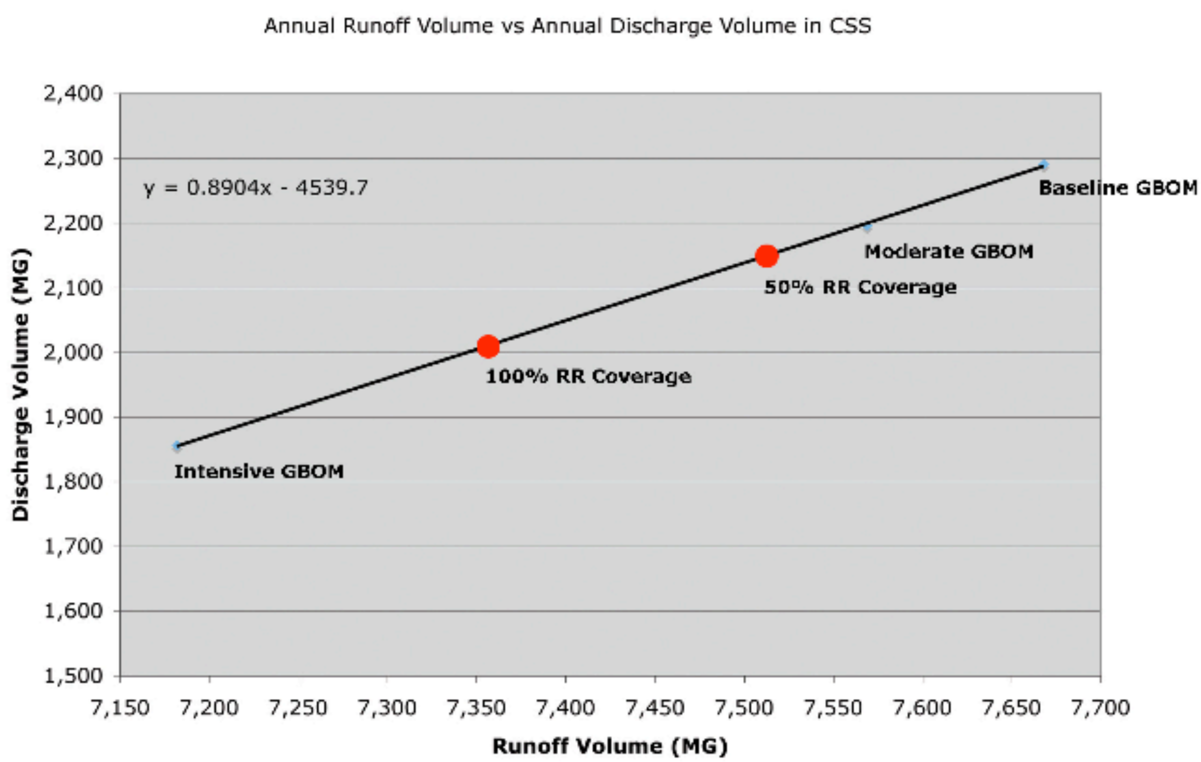


Figure 5: Annual runoff versus discharge volume graphs showing GBO Model data points in tiny blue squares for the baseline, moderate and intensive scenarios, and our data points in big red circles, showing the four sub-scenarios of Scenario 1 – top graph within entire District and bottom graph within CSS area alone

Our work shows that with 100% coverage (green roof coverage on 100% of the residential rowhouses) of non-accessible (green roof-ready area is 80% of the total building footprint) extensive green roofs in the District, 343 million gallons of untreated water (3.1% discharge reduction) could be prevented from discharging into the city's waters annually. In the CSS area, assuming 100% coverage of non-accessible extensive green roofs, 279 million gallons could be prevented from discharging into the cities waters annually, a 12.2 % reduction.

Figure 5 shows the relationship of our scenarios for residential rowhouse greenroofs with those of the Green Build Out Model scenarios (see Table 1) in each of the two areas under study– the CSS area and the entire District. Our results show that the 100% coverage scenario in the District falls between the moderate and intensive scenarios of the GBOM. Within the CSS both our 100% and the 50% coverage scenarios fall between the moderate and intensive scenarios of the GBOM. From these results we infer that green roofs on residential rowhouses can make an important contribution to stormwater quality and control, as part of a larger greening plan within the Long Term Control Plan. We understand that green roofing residential rowhouses in isolation of any other stormwater Low Impact Design techniques will not reduce the frequency of CSO events. However, green roofs on residential rowhouses can reduce large volumes of untreated stormwater and sewage from entering the District's river ecosystems. For this reason, retrofitting residential rowhouses with green roofs should not be discounted from a larger greening plan. The specifics of implementing green roofs as a tool for a healthier urban environment in this sector merit exploration.

Retrofitting Rowhouses in Residential DC

No matter how convincing the argument for implementing green roofs across residential rowhouses in the District of Columbia is, the difficulties of actually building these green roofs cannot be ignored. There are clear cost constraints for the homeowner. There are also opportunities to support costs by establishing government incentives. There is interest amongst government entities to create green roof incentives to further the long-term goals of LID-R through widespread green roof implementation.

Economic Considerations

As appealing as it may be for a homeowner to install a green roof on their residence, it will not come without economic obstacles. For new construction, the cost of a green roof is comparable to the cost of a traditional roof. However, for retrofitting an existing residence, the cost of a green roof can be significantly higher than refitting with a traditional roof. Pitched roofs, for example, add a whole extra suite of complications due to the extreme slope of the roof. Therefore, we chose to focus on flat roofed architecture for extensive green roofs. Even though we are suggesting that flat roofs would be better candidates for retrofitting, they do not come without constraints as well. It is possible that even for an extensive roof, additional structural reinforcement may be needed in order to support the extra weight of the structural layers of a green roof. In the District of Columbia, rowhouses differ in whether structural reinforcement is needed, according to Katrin Scholz-Barth, a green roof expert based in Washington, DC [18]. Scholz-Barth acknowledges the economic difficulty of implementing green roofs on residential rowhouses in the district. She does however, comment on the benefit of needing to run her air conditioning unit in her own green roofed rowhouse only on the very hottest days of the summer, due to the reduction in heat load by the greenroof above. Additionally, she has observed a lack of rainwater exiting through her downspouts during rainy conditions [18]. Mrs. Scholz-Barth runs her own consulting company which focuses on extensive green roofs, particularly by trying to find more meaningful ways to compare the costs of a conventional roof versus a green roof. Her philosophy is “to truly make green roof affordable by selecting materials that perform multiple functions to reduce the amount of layers, labor, and thus overall costs,” [19]. Finding ways to streamline green roof design is important, as is finding legitimate ways to quantify all possible economic benefits of green roofs, including finding ways to equate environmental benefits to economic benefits [20]. With the benefits of green roofs being converted into an economic framework to gain financial support for green roofs through government entities, the challenge is moves to the arena of government policies and initiatives.

Stormwater Fees and Green Roof Incentives

It appears that green roofs have significant yet limited applications as a tool for stormwater mitigation in the District. Due to the fact that stormwater in the District is being managed in two different systems and by two different agencies, it is instructive to consider the two situations separately. The two agencies, the District Department of the Environment (DDOE) and DC Water and Sewer Authority (WASA), are both pursuing stormwater fees for property owners. Both agencies appear to be developing discount and incentive programs for LID BMPs associated with those fees, but are in different stages of that process.

DDOE and the MS4

The District's newly formed DDOE is the agency responsible for the Municipal Separate Storm Sewer System (MS4). In 2007, the DDOE convened a multi agency stormwater management task force to establish a stormwater utility fee based on impervious area for property owners within the MS4. This fee will replace a flat stormwater fee that is currently part of the water utility bill for property owners in the MS4. The task force is simultaneously developing an associated discount and incentive program to promote LID BMPs to property owners in an effort to reach water quality goals for the District's waters. Both the fee and discount and incentive program are still under development [21].

The discount and incentive program would allow property owners to implement LID BMPs on their property and receive a discount of up to 50% of the new impervious based stormwater fee. The level of discount will depend on the BMP they choose to employ. Description of the program also suggests that there may be some subsidization available for selected BMPs. In the case of green roofs, this would take the form of 'small grants' for green roofs. DDOE hopes to have the fee in place by October 2008 [21].

Based on how the DDOE's discount and incentive program appears to be structured, a homeowner who is interested in putting a green roof on their rowhouse will be unlikely to pursue anything more elaborate than the most inexpensive and basic extensive green roof. If they only recoup at maximum 50% of the stormwater utility fee and only receive a relatively 'small' grant for green roof construction, there isn't much incentive to pay for a more expensive, semi-intensive or intensive green roof. In fact, depending on how steep the fee actually is and how big the grant is, some homeowners may have no incentive whatsoever to choose a green roof as their preferred LID measure. However, those homeowners who live in rowhouses with little extra room for more space intensive LID practices, like increased tree cover or rain gardens may indeed choose a green roof. Nevertheless, until figures for these fees and grants are established and suggest otherwise, it does not seem that WASA or DDOE view broad scale green roof implementation (in the residential sector) as an integral component of their stormwater management plans.

According to Dr. Hamid Karimi of the DDOE, the intention of the proposed discount and incentive program is to familiarize homeowners and other members of the private sector with the concepts of Low Impact Development. However, he argues that by incentivizing simpler LID BMPs such as rain barrels, tree planting, rain gardens, and porous pavement, residents will be encouraged to look at and consider more sophisticated measures like green roofs [personal communication]. Dr. Karimi believes that a quantum leap in education is needed to take the idea of green roofs out of the 'exotic' realm and make them a commonplace idea for the general public. During a phone interview (Dec. 2007), he pointed out that 20 years ago the idea of green roofs for large commercial buildings was exotic and, whereas it is now increasingly common in that sector, it is still generally an unfamiliar idea for the average homeowner. Thus, he said, the District is starting with green roof implementation on larger commercial roofs. Karimi believes that by subsidizing simpler LID applications on a larger scale, this will also leverage the idea of green roofs for the general public.

When asked if green roof implementation at the residential level is an important goal, Dr. Karimi agreed that it is. He said that the District does not have the luxury of ignoring the impact of smaller, residential roofs when it comes to stormwater management goals. He pointed out that the District has a significant rainfall of approximately 40 inches per year, and because the city is a compact, impervious urban center without much room for space intensive LID or conventional stormwater measures, the city must work within these constraints. He also pointed out that the residential sector makes up a significant proportion of the impervious area of the city. So, it is valuable to support green roof implementation despite the challenge of construction constraints, long-term maintenance and education [22].

WASA and the CSS

DC Water and Sewer Authority (WASA), is the District agency responsible for the Combined Sewer System (CSS). The agency is establishing an 'Impervious Rate Structure' to help recoup costs of the Long Term Control Plan, which will be a fee that all District property owners have to pay, regardless of whether their property is within the CSS or MS4 area of the District. WASA hopes to have this fee in place by October 2008 [23]. According to the multi agency Stormwater Management Task Force website, it appears that WASA is considering some sort of credit program for property owners promoting LID BMPs, however no specific details are available [21].

Although WASA's LTCP report describes LID-R as an important supplement to the proposed tunnels, when WASA assessed the implications of a greenroof program, it was determined that green roofs alone would be insufficient to impact CSO events. However, the LTCP report does suggest that a comprehensive LID program including green roofs could impact CSO events [2].

Generally, it appears that there is more support for green roofs as a significant component of stormwater management in the Municipal Separate Storm Sewer System (MS4) area, than there is in the Combined Sewer System, which is managed by WASA. This is in part because of the nuanced differences in the nature of the stormwater problem in the two sewer areas. In the MS4, the main target is a reduction in stormwater pollution, as pinpointed by the NPDES permit issued for the MS4. In the CSS, the main issue is a reduction in CSO events, as targeted by the LTCP. Both agencies involved call for LID practices as part of a larger toolkit necessary to combat the problems associated with stormwater management. However, because green roofs have been shown to have little impact on the frequency of CSO events, which is the main focus of the LTCP they are included but not highlighted as a part of the LID toolkit for CSO events [2].

PART 2: Green Roof Technology and its Application in the Residential Sector

Green Roof Function and Design

The term “green roof” has been applied to many different types of vegetated rooftops, from those with shallow soil and low plant diversity (extensive green roofs) to the more extravagant roof gardens with soil deep enough to sustain woody plants (intensive green roofs). Most of the information that is available on green roof function is focused on extensive green roofs, as a bare minimum to achieve environmental benefits. These have substrate depths typically between 3-4 inches, while intensive green roofs may have substrate depths of 6 inches or more [3]. In fact, there is a continuum from extensive to intensive categories as soil depth increases. If green roof soil depth falls around the 6-inch break point, or if a green roof holds a spatial mixture of the extensive and intensive structure, the green roof is called “semi-intensive.” On a functional level, the most cost effective green roof is an extensive one, thus there is a drive to quantify the environmental benefits of the basic extensive green roof, the focus of our stormwater quantifications in this study. Even for the simple extensive green roof, there are a wide variety of construction materials and plants to choose from. Each design decision will have different implications for the green roof function.

Environmental Benefits

The environmental benefits that green roofs offer come primarily from the living plant factor. Since greenroofs are a living surface of plant material, they undergo evapotranspiration, the process by which water is released to the atmosphere as a result of evaporation from the soil and transpiration by plants [24] (see Figure 5). The benefits of evapotranspiration include improvement of air quality through the absorption of carbon dioxide (a common greenhouse gas) and release of oxygen. Evapotranspiration during wet periods on greenroofs also acts to create a passive cooling system. This allows a green roof to keep its building at a lower temperature than the traditional roof. Absorption and reflection of solar energy by roof plants also contributes to the cooling effect. This cooling of the surrounding air reduces the amount of thermal energy contributing to the urban heat island effect in large cities [25]. 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. [26]. Negative impacts of heat island effect include higher energy bills for summer cooling, greater impacts of air pollution, plus heat related illness and mortality [27]. The structural layers of green roofs act to reduce the urban heat island effect by providing insulation for the roof of the building. 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 [28].

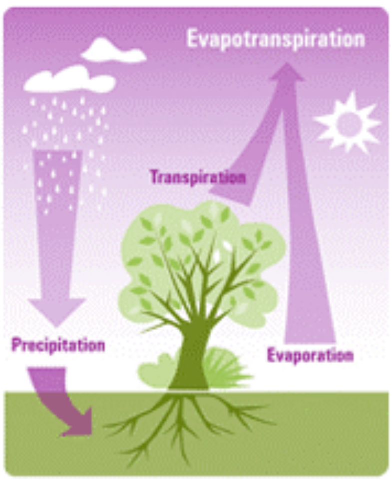


Figure 6: Diagram of evapotranspiration
http://www.conserveh2o.org/outdoors_irrigation_watersmart.html

Green roofs can also serve as stormwater control because soil and plants hold onto some of the rainwater that would enter the already overtaxed conventional stormwater systems. Extensive green roofs can typically retain water from light rainfall events (2.1 mm or less) if they do not occur in rapid succession. Green roofs cannot retain water once the soil is saturated and so they are ineffective for management of stormwater from heavy rainfall events. Rather than conventional soil, green roofs typically use a lightweight aggregate (LWA). This specialty green roof substrate has positive and negative effects on the water quality of runoff. LWA acts as a storage layer for atmospheric pollutants, which are washed out in heavy rain events. However, green roof runoff tends to have higher concentrations of sulphates and Ca-Mg-salt because of their presence in the substrate. Negative effects from the LWA green roofs on water quality are offset by the benefits of green roofs in urban environments, such as reduction in heat island effect, reduction of thermal loading in buildings, and the stormwater control that they can provide [29]. In other words, while there may be some water contamination as a result of using LWAs, the greater reductions in stormwater pollution and other environmental benefits that are offered through green roofs with LWAs are well worth this tradeoff. Nevertheless, more research into the effects of green roof substrate on water quality will help us optimize the benefits of green roofs in the future.

Even when it doesn't rain, green roofs are environmentally beneficial. During dry summer conditions when the cooling effect of evapotranspiration is negligible, the green roof provides higher solar reflection and absorption of solar energy of the greenery when compared to traditional roofing surfaces. [25]. An added benefit to keeping one's roof cooler in sunny periods with green roofs could be more efficiently functioning photovoltaic panels (also known as solar panels). There are indications that by reducing operating temperatures of solar panels by using green roofs, the efficiency and energy yield of the panels can be increased [30].

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 [31, 32].

Construction Considerations

In their book, Planting Green Roofs and Living Walls, Nigel Dunnet and Noel Kingsbury sum up the emphasis on highly engineered green roofs replete with numerous layers that have come to dominate the green roof market place: "Contemporary systems can be very complex, with many product options and many different layers. This complexity has arisen partly from the very existence of green-roof suppliers and manufacturers, with each company developing its own patented systems. But also, as the concept of green roofs gained wider application in Germany where the modern green roof movement began, there was a need to ensure uniformity and dependability of the product, resulting in the application of technology and research to maximize the reliability of the products." As green roofs become more commonplace, there is the need for streamlining the process of design and construction. In this way it is much like the standardization of the automobile in the early twentieth century. To make green roofs available to a mass market, they have to be dependable, reliable, cheap, and easy to build.

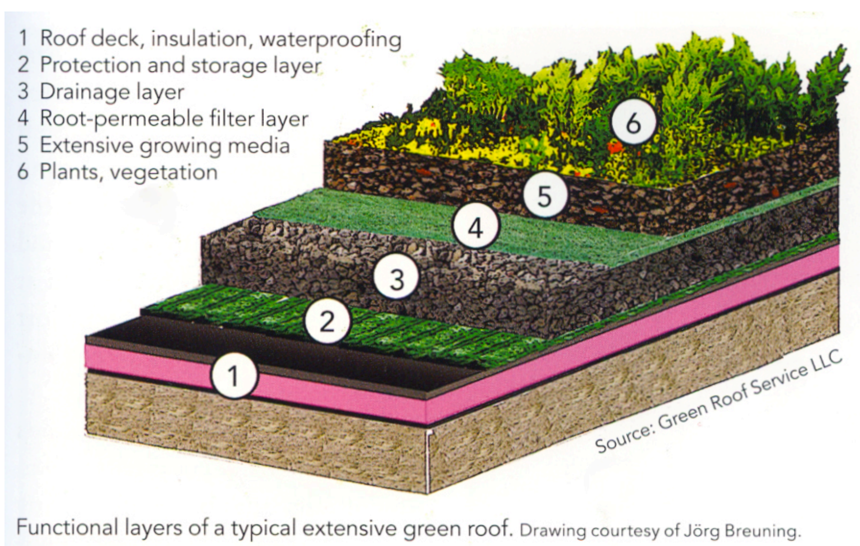


Figure 7: Structural components of a green roof [1]

Here in the US, a typical green roof is made up of the several functional layers, which include a waterproofing membrane, a root barrier, a drainage layer, a filter cloth layer, growing medium, and then of course, the vegetation layer [33] (see Figure 6). All these components come together to provide an ecologically functional green roof where plants survive and rainwater does not leak into the building. There are available versions of these structural systems of green roofs in America, from the basic separate components installed one layer at a time, to modular systems that can be installed in discrete units. Designers and professionals working in the green roof industry have many different companies to choose from, each with a considerable amount of information that is available for their green roof products. Each green roof is different, meriting careful selection of the green roof system based on the programmatic criteria from the design phase.

Green Roof Materials and their Sustainability

Green roofs certainly provide a variety of ecological services that lend to their sustainability, but in their current highly engineered incarnation, one might argue that green roofs in fact are not sustainable at all. This is because green roofs rely on various forms of plastic and other manufactured materials to provide reliable functionality, such as highly manufactured substrate in lieu of native soil. As the number of highly engineered and manufactured green roofs increase, the issue of relative sustainability is introduced. In today's market, it has become a process of choosing the lesser of evils inherent in our available materials for green roof construction. For example, the waterproofing layer of green roofs tends to be either PVC or bituminous based, each with environmental negatives, while environmentally friendly alternatives are all but nonexistent. This issue of relative sustainability will become more commonplace as products purporting to be sustainable continue to be introduced in the marketplace.

A way to measure relative sustainability is by running an analysis known as life cycle assessment (LCA). According to the EPA, a life cycle assessment's purpose is "evaluating the potential environmental impacts associated with identified inputs and releases," [26] of different materials. This assessment takes into consideration the use of raw materials, materials transport, resource use, disposal and so forth of different materials, weighing in on the level of impact on the environment. In an ideal world, our construction materials would be completely recyclable, sustainable, and with no net impact on the environment through their creation. In reality, the aim it to minimize the impact on the environment caused by our construction materials.

Plastics happen to pervade many components of green roof construction. While plastics may be avoided in some components of a green roof, they are more difficult to evade as part of the water proofing membrane, critical for keeping the building interior dry. Plastics are made from synthetic materials, requiring manufacturing processes that require large inputs of fossil fuels, and while some can be recycled at the very end of their life cycle, others end up in landfills where they will not degrade for many years. Some of these plastics are made up of polyvinyl chloride (PVC), the production and disposal of which gives rise to emissions of dioxin, vinyl monomer, and other dangerous, chlorinated organic pollutants. PVC is ubiquitous in the building industry, as it is a convenient and inexpensive product [34]. It is often the basis for the plastic waterproof membrane in green roofs. However, PVC alternatives seem to becoming more available in the green roof industry, along with the increasing awareness of the complications resulting from the use of PVC.

Research involving alternatives to plastic membranes in green roofs appears to be somewhat limited at this point in time. Currently, the major alternative to plastic membranes, particularly PVC membranes, is a bituminous-based waterproofing membrane. It should be noted that while bituminous membranes are devoid of PVC, they are a petroleum-based product, therefore unsustainable as a non-renewable resource and a contributor to the global warming effect due to manufacturing. Bituminous membranes appear to be a suitable option for now, as they last 20-60 years while the PVC membranes last only 10-20 years. The bituminous membrane also has a higher level of water tightness, and has more tensile strength than PVC barriers. However, it requires the addition of a root barrier, whereas the PVC does not [35]. Research into a life cycle assessment comparison between PVC and bituminous waterproofing would be useful to the designer in this decision making process, in an effort to select the material with the lowest embodied energy.

Green roofs that are comparatively low in embodied energy do exist, and they are those that are not entirely reliant on non-natural products for their functionality. The Moos water treatment plant in Zurich has green roofs that were constructed in 1914, without the benefit of modern plastics. These roofs are constructed of 8 cm thick slab concrete finished with a layer of

2 cm thick mastic asphalt, which serves as the waterproofing layer. The drainage layer is a five centimeters thick mix of sand and gravel, and the growing medium is made up of 15 to 20 centimeters of local topsoil. Through their more than ninety year lifespan, these green roofs have required no maintenance except at the edges. The gravel and sand layers have combined over time, but the waterproof layer has never been compromised. In this particular green roof, a heavy reliance on plastics is unnecessary, as it has achieved longevity and integrity, as well as providing native plant and wildlife habitat [36]. While there may be some inherent difficulties in trying to replicate this structure today, it would be relevant to explore how to adapt the Moos structure for today's green roof implementation.

There are plenty of barriers to adoption of environmental design at all levels in green roofs, like with any new technology. The main issues, cited in a study by Calkins [37], are those of cost, lack of testing and data on performance of strategies, time available for research, and resistance by project stakeholders, other consultants and code officials. Likewise, the results of Calkins' study highlight the need for further research, education and dissemination of information about ecological design, which certainly holds true in the case of green roofs in general. As the author points out, often it is the designer who must push a new form of ecological design. Therefore, it is the designer who needs see and understand functional, dependable green roofs created without PVC or other kinds of plastics from the research sector in order to advocate these holistic, environmentally-friendly green roofs. New options for greener green roof materials will likely become available as this technology progresses, and with increased awareness of the sustainability issues and research of green roofs, this green technology will continue to evolve. At present, the use of today's construction materials is acceptable, as long as professionals and the public alike are cognizant of the Life Cycle Assessments of these materials, and tries to minimize negative and maximize positive environmental effects in green roofs.

Plant Selection

The mental image of greenroofs often includes an expanse of hardy succulents; the low growing, shallow rooting, tough little plants that typically adorn extensive green roofs. And while intensive and semi-intensive green roofs can manage deeper rooting and larger plants, extensive green roofs are restricted in plant choice because of the shallow soils and a harsher microclimate. Hardy succulents, such as sedums [1] handle these limitations well. There are tried and true sedums and other commercially available plant species that survive the shallow substrate, high temperatures and windy conditions of our urban rooftops. An excellent resource for information on plant selection is Green Roof Plants by Edmund and Lucie Snodgrass [1], which is a pleasant surprise for designers who believe that extensive green roofs must be bland and monocultural. This informative book illustrates the diverse array of successful green roof plants available in the trade, from succulents to grasses to bulbs. There are many functional green roofs that use beautiful and compelling assortments of these types of plants.

For many landscape architects and other plant designers aiming to create wildlife habitat, it may be desirable to use native plants on extensive green roofs, rather than the non-native sedums that are so popular. From a functional point of view, it is important to understand how native plants on green roofs compare to the standard green roof succulents. This has been a popular topic among horticulturalists. There have been several studies on the function of native plants on green roofs in different regions of the US (for example, the Green Roof Research Program at Michigan State University). A common limitation in finding suitable native species is the requirement that plants be able to survive the more extreme conditions of rooftop living. For example, prairie grasses, which typically have large rooting depths in order to reach groundwater in dry conditions, would be unsuited for the shallow soiled green roof. A study in Europe exploring the potential of green roofs to support biodiversity suggested that by allowing varying depths of natural soils on green roofs, a greater diversity of native plants and wildlife can be cultivated on rooftops [31]. While this introduces a compelling design element for the use of native plants on green roofs, it also brings up the important factor of manufactured substrate versus soil and native plants. The typical option for extensive green roofs in this country is the use of LWA in lieu of native soils for structural reasons. These lightweight aggregates have been developed to weigh far less than true soil in order to minimize additional weight on green roofs. This further complicates a design goal of ecological restoration on rooftops if one is to use the American industry standard lightweight aggregate on green roofs. Lightweight aggregates are imbued with minimal amounts of organic matter. Furthermore, their structure can allow nutrients to be washed out by rainfall. Consequently, it is critical to include a management plan with the green roof to ensure that the nutritional requirements of its plants are being met. To ensure longevity of green roofs, a fertilization regime may be needed to in the green roof maintenance routines. The simple act of leaving decaying plant material behind could supplement the nutrient loss by rain events.

Greenroofs often present extreme conditions. In many cases, rooftop environments are vastly different in soil and plant composition from most native landscapes. In other words, even if a subset of plants from a native ecotype were to survive on a roof, they may not resemble the character or function of the actual ecosystem from which they are derived. This presents a challenge if the greenroof intended as wildlife habitat. However, there are benefits to be had from growing native plants on green roofs. If they are to survive to the reproductive stage on green roofs, native plants contribute native seed stock to the surrounding environment. Natives may also be more successful than a non-native, hardy succulent in offering suitable habitat to smaller wildlife species. It may be possible to create a green roof habitat template which would more closely emulate functional ecosystems through careful study of wildlife and ecosystem interactions of the natural analogs of extensive green roofs (rock barren ecosystems for example))[32].

Sustainability, Landscape Architecture and Green Roof Design

In the face of the world's various environmental crises, many are beginning to support the principles of sustainability to ensure that the planet remains a functional biosphere. Particularly in the American building industry there has been a considerable movement as of late to support low-impact green building to minimize the negative environmental effects of urban development. Even landscape architecture seems to be re-evaluating itself, with the field beginning to emphasize better understanding of ecological values and how to incorporate functional ecosystems with human land uses. What is quickly being discovered is that in order for our natural areas to be protected and ecosystem health to be valued, the public needs not only to understand what these ecosystem values are and why they are important, but also come to an aesthetic appreciation of local natural ecosystems. Landscape architects, well versed in the art and science of landscape design, should be the ones stepping up to the plate to integrate the goals of ecological health and human culture. When feasible, this means relying on Low Impact Design (LID) measures, such as rain gardens and constructed wetlands. But land is at a premium in our major urban centers, and although the ground plane is largely accounted for, there is a whole landscape waiting to be utilized on our rooftops. Green roofs offer one viable solution for the various ailments of our cities; they clean the air, they absorb and retain stormwater, they cool buildings and the surrounding air, and finally, they are aesthetically interesting and can even provide wildlife habitat. They may not be reminiscent of any local native landscapes (at least in our colder climates) and they may look like highly engineered curiosities existing many stories above the ground plane, but they are also highly ecologically and culturally functional.

We are beginning to realize the value of green roofs in the US where the green roof market is beginning to take off, as evidenced by the ever-expanding Green Roofs for Healthy Cities Conference [38]. There is however, a certain level of consumer fear, fear that the green roof will not work as advertised, that it will leak, or that it will not look as predicted. This concern is to be expected with such a new technology, especially given the lack of examples in local communities, and the lack of long term studies on green roof performance in the US. This is why it is critical to build well-designed and engineered green roofs that can speak for themselves. Landscape architects in particular are well suited to join the design professionals in green roof development because of our basic understanding of the science behind landscape design, which includes site analysis and stormwater management.

Figure 8: ASLA green roof visited by the authors, August 2007

To help gain universal acceptance of these new technology, green roofs must simultaneously function well and pique public interest through good design and visibility. An excellent example can be found at the American Society for Landscape Architects (ASLA) in Maryland, designed by the prestigious landscape architecture firm Michael Van Valkenburgh Associates. This green roof, designed by a landscape architecture firm for a landscape architecture organization, illustrates how well matched landscape architecture and green roofs are. Through the careful design of the accessible spaces, showcasing of plant selections at various depths, and monitoring the roof for reduction in heat loading and retention of stormwater, the ASLA green roof exemplifies the integration of functions that is possible in green roofs. Since green roof design encompasses many of the facets of landscape architecture, landscape architects can bring important design skills into this field, enhancing the popularity and success of green roofs in the U.S This may be particularly important in the residential or small business sector, where relatively few green roof examples exist, and there is more opportunity for high design features. According to Charlie Miller, founder and owner of the green roof company Roofscapes, this is a sector of the market that is underdeveloped, and could be adopted by those in landscape architecture [39].

Discussion

A Watershed Based Approach for Washington, DC

Implemented on a wide scale, green roofs can be a significant contributor to the reduction of pollution in the District of Columbia. Important as they may be for water quality in the MS4, they won't stand alone as a silver bullet for stopping the contamination of district waterways. Instead, they need to be a part of a larger LID toolkit, meaning one component of a suite of technologies to fight the water quality battle. This LID toolkit needs to be implemented by all municipalities that have jurisdiction over all of DC's watersheds, and ultimately the Chesapeake Bay watershed. This is the only way comprehensive planning of a solution to the water quality problem can take place.

In the Long Term Control Plan report, DC WASA calls for a watershed based approach to dealing with pollution in the District's waterways. The report points out that although CSOs are a significant part of the pollution, they are only one contributor to a larger problem. This stems from the fact that the three watersheds in the District extend beyond the boundaries of the city, and are thus also under the jurisdiction of other municipalities. Pollution created upstream from the District, coming from three watersheds that encompass parts of Maryland, Virginia, West Virginia and Pennsylvania, is also responsible for the water quality problems the District faces. Moreover, these three watersheds, the Potomac River, the Anacostia River, and Rock Creek are themselves part of the larger Chesapeake Bay watershed (Figure 12, Appendix B). The Chesapeake Bay is severely impaired and has very low water quality, in part because of the pollution in its tributaries.

With the enactment of the Clean Water Act, municipalities have increasingly broadened their understanding of the implications of water pollution and its myriad of sources. Likewise, municipalities have broadened their efforts to combat these problems by creating coalitions between jurisdictions, coming closer to creating unified planning operations for watershed areas. Much of this revolves around Low Impact Development efforts. Greenroofs are one of the LID solutions that can be strategically implemented as an important feature of stormwater management.

The Legitimacy of Residential Rowhouse Green Roofs

The aim of this report was to consider whether green roof retrofitting of residential rowhouses might have an impact on stormwater control in the District of Columbia, in light of the inherent complications of the combined sewer system. The findings of the Green Build Out Model suggest that under their green coverage scenarios which includes green roofs, trees, and large tree boxes, it is possible to achieve significant reductions in stormwater runoff volume [3]. It is clear that our scenarios of residential rowhouse green roof coverage alone will not have any effect on the frequency of Combined Sewer Overflow events [17], as the GBO model study had, with maximum greening, only had a limited impact on CSO frequencies. However, it is possible to attain large reductions in the volume of stormwater runoff through green roof coverage on residential rowhouses in the District, particularly within the CSS. This volume reduction will contribute to improving the water quality of area waterways by reducing the amount of nutrients, heavy metals and other pollutants as well as some amount of sewage from discharging into the city's waters. For this reason, residential rowhouse green roofs are a worthy Best Management Practice, although the scope of this report did not include a cost-benefit analysis that might indicate if green roofs would be worth the cost in this highly residential sector.

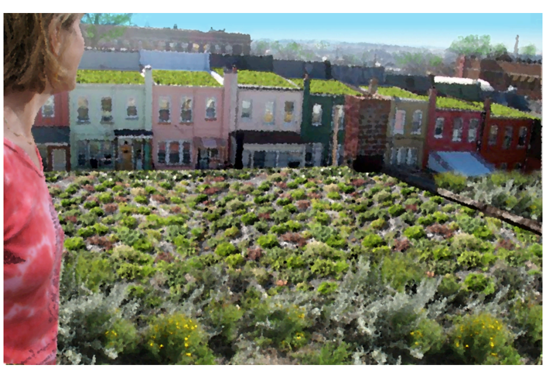
It is important to note that that green roofs do in fact have many more benefits than simply stormwater control when making a comprehensive analysis of the costs of these green roofs versus their benefits. "In addition to stormwater management benefits, implementation of increased tree cover, green roof coverage, and larger tree boxes would also provide improvements in air quality, public health, social capital, and economic development, and reductions in carbon, UV radiation, and the urban heat island effect for the same investment,"

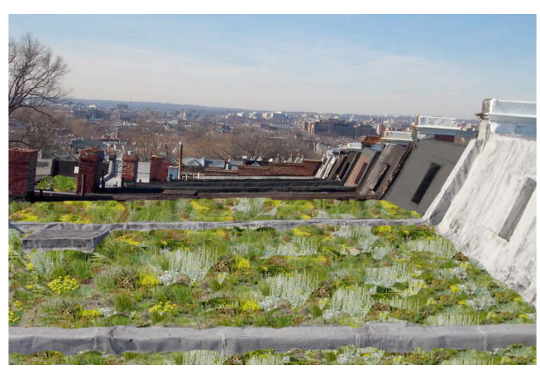
[3]. Although the GBO model study involved the added component of trees and tree boxes, this statement still holds true for green roofs alone as an integrative approach to a variety of environmental complications. Green roofs are clearly capable of stormwater management, reducing energy loads, and mitigating air pollution. By finding better ways to integrate these functions for an economic analysis, we will become better advocates for green roofs [20].

Understanding the suite of environmental benefits that green roofs provide can help us get closer to their wide spread implementation, in turn bringing us closer to a sustainable future. In planning for a truly sustainable future, all facets of green roof design and construction must be accounted for. Non-renewable resources are currently at the heart of many of the components of green roofs, from the petroleum-based layers, to the fossil fuels used in the intensive manufacturing processes of their substrates and in their transport. As in other construction fields, green roof construction must find ways to lessen their ecological footprint. Research into alternative, eco-friendly materials of green roof construction must continue in order to create real integrity for green roofs as a sustainable practice.

Other ways to contribute to ecological health when implementing green roofs are to consider how the use of native plant communities can maintain or recreate native landscapes and wildlife habitat. There is great potential for the utilization of green roofs for the purposes of ecological restoration, and it will become increasingly important to utilize any and all surfaces for this purpose as native landscapes continue to disappear.

Finding creative ways to integrate green roofs, native landscapes, and the human element is critical to the survival of green roofs as a new technology. Our quest for a sustainable future with green roofs in the picture involves innovative designers who look to the rooftops to create places that we inherit as a part of our culture.





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Appendix A: GIS Analysis

The GIS data used was obtained from the Office of the Chief of Technology Officer website (http://dcgis.dc.gov/dcgis/site/default.asp). Data used was the BldgPly shapefile, showing polygons of building footprints in the District, and the CAMA – Residential Property point dataset, of which source data came from the Office of Tax and Revenue. CAMA – residential property was clipped to show only categories 6 and 7, “row in” and “row out”, assuming point data of only rowhouses. This point data was then overlaid with the building footprint polygons, and building footprints which intersected with point data were exported into a new layer, showing building foot prints of residential rowhouses. Unfortunately, points and building footprint polygons did not always intersect. It appeared that points were intended for specific properties, but that physically the point did not touch the actual building footprint polygon. Building footprint polygons were then manually selected and data exported using a “best guess” procedure for where the points were intended to intersect with actual properties. This data manipulation was only to provide a rough estimate of building footprint area for residential rowhouses, and was not intended to provide concrete values for any purposes beyond the scope of this project.

In determining District and CSS land area, it was noted that there was some overlap between polygons of the CSS and the polygons of the MS4 areas. To avoid counting the those areas in the overlap twice, the area within the CSS that was overlapping was eliminated, based on visual interpretation of the CSS area determined by the GBO model study.

Appendix B: Figures

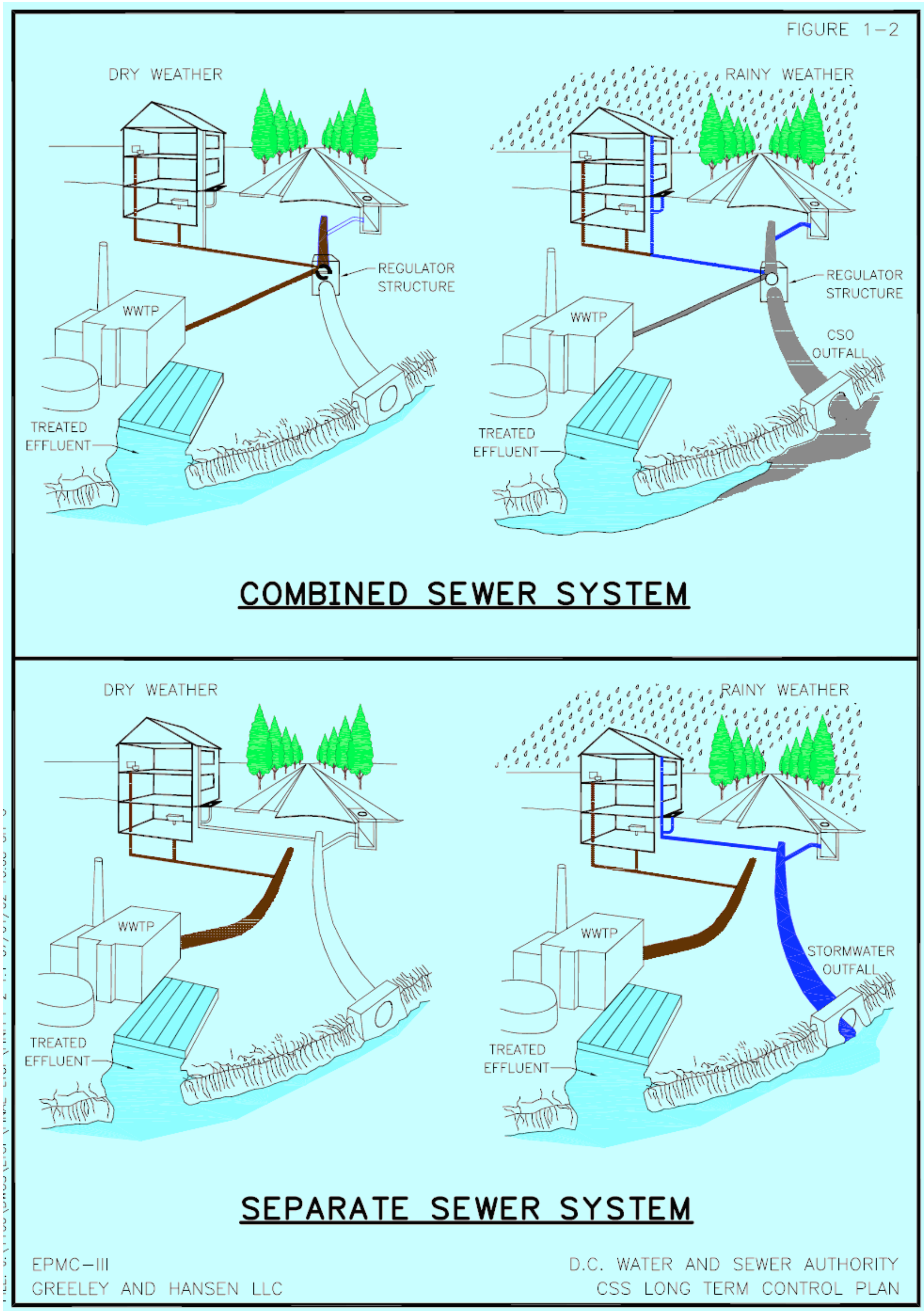

Figure 9: Illustrations of Combined Sewer System and MS4 function [2]

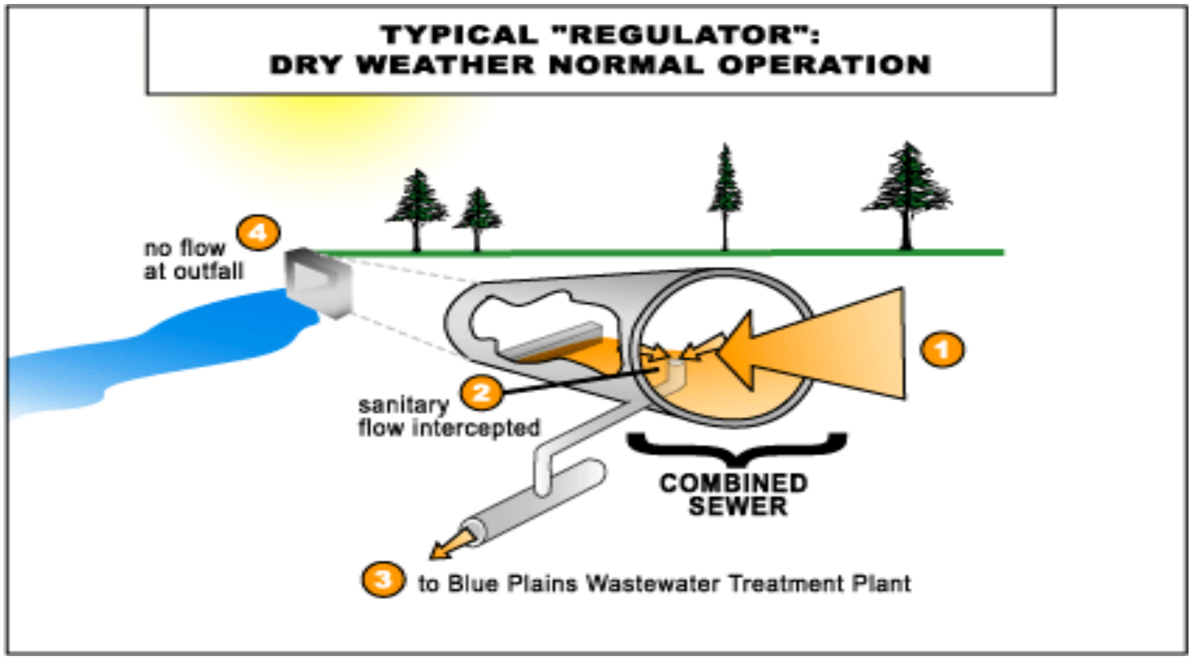

Figure 10: Combined Sewer function in dry weather [11]

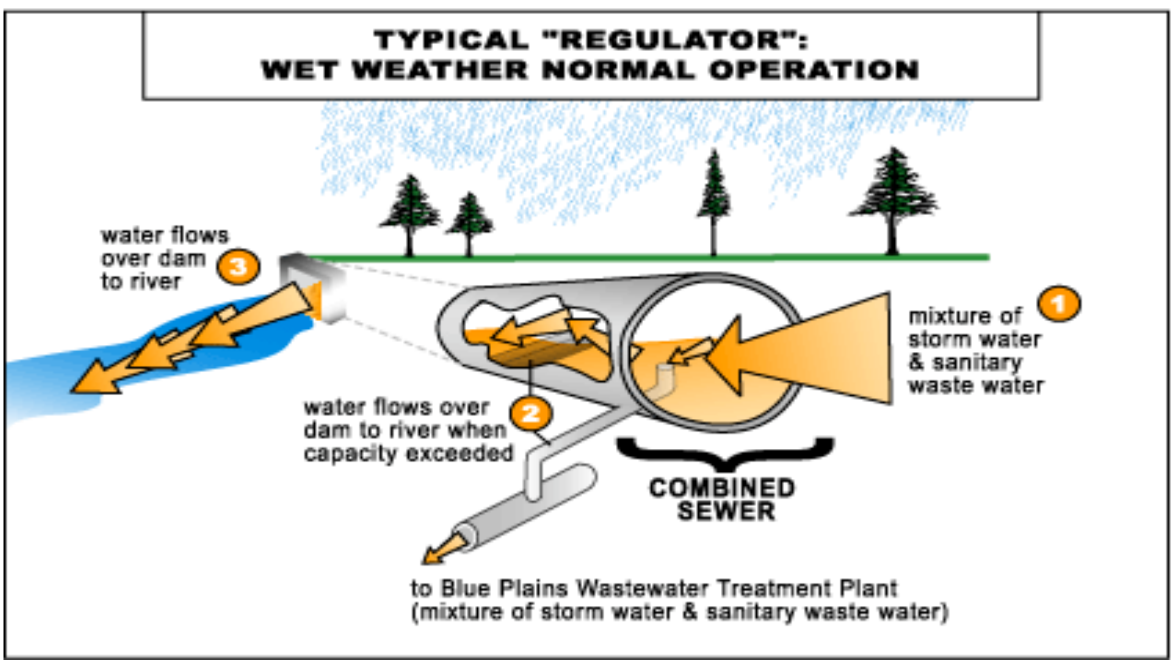

Figure 11: Combined Sewer function in wet weather, showing a CSO event [11]

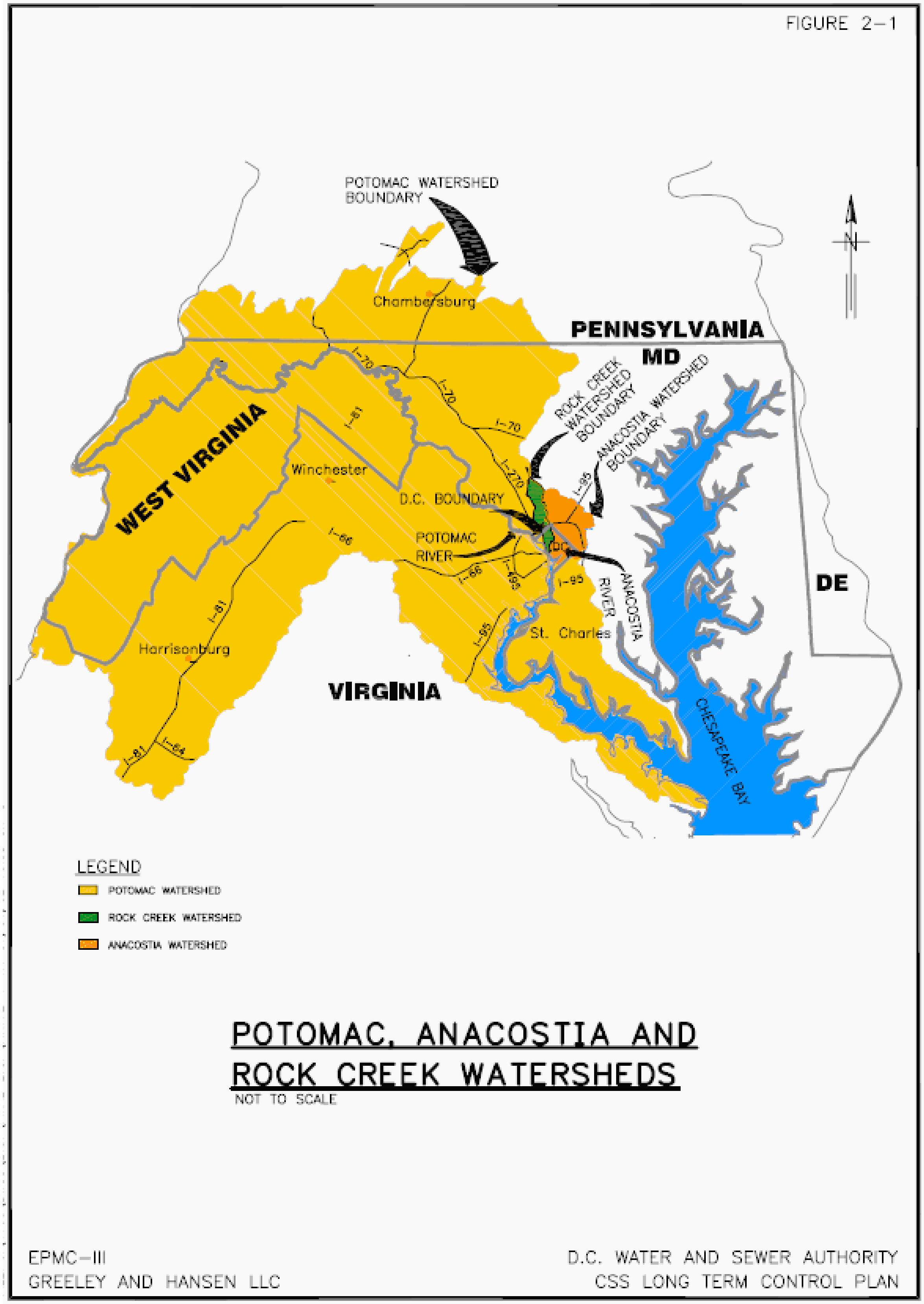

Figure 12: Chesapeake Bay Watershed Map [2]