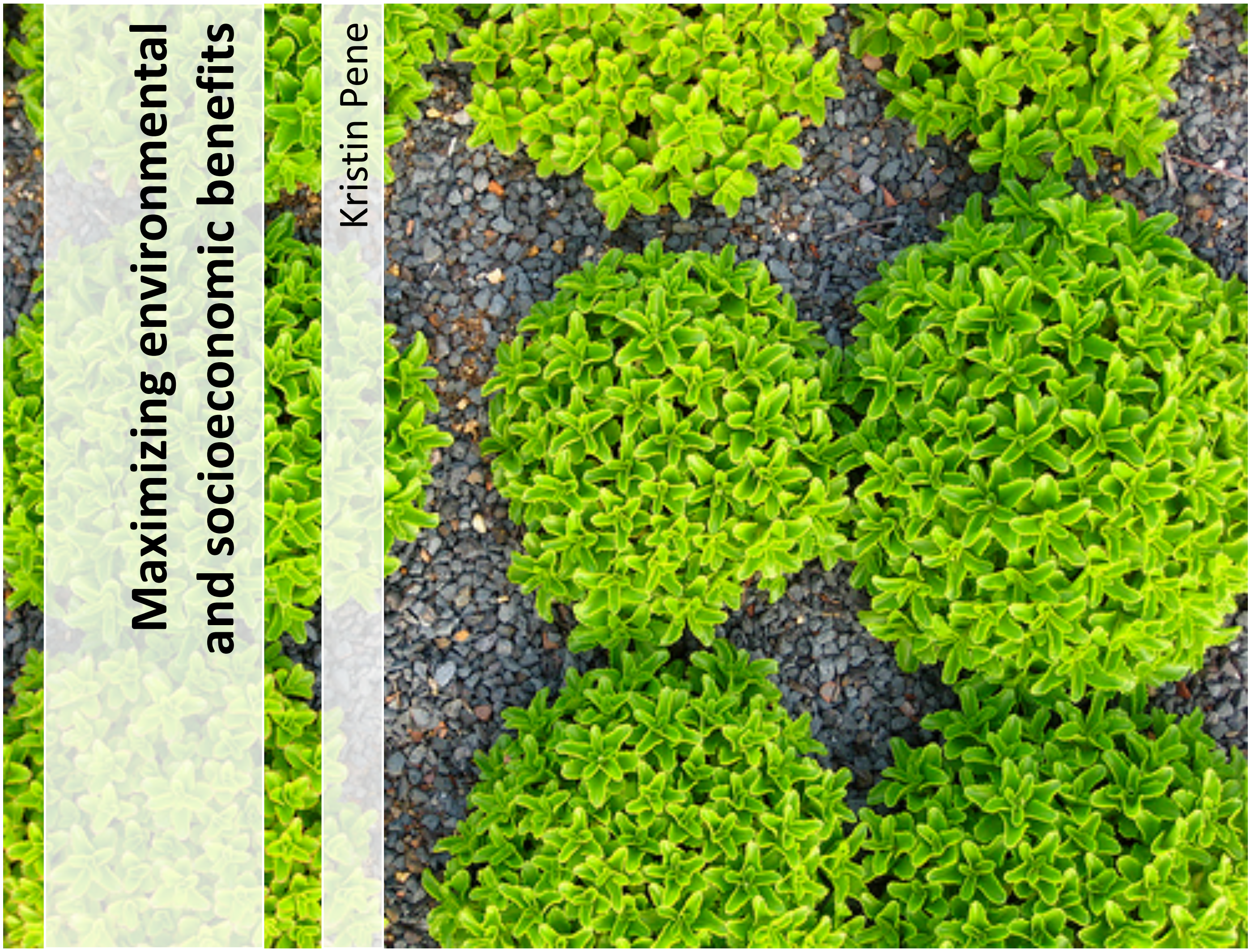
# Maximizing environmental and socioeconomic benefits

Kristin Pene



Yale School of Forestry & Environmental Studies • Fall 2010

# Maximizing environmental and socioeconomic benefits of green roofs in Washington, D.C.

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## Acknowledgement

This project was supervised by Dr. James Axley, Professor of Architecture and Senior Research Scientist at the Yale School of Forestry and Dr. John Wargo, Professor of Environmental Risk Analysis and Policy at the Yale School of Forestry and Environmental Studies.

This project was funded through the Hixon Center for Urban Ecology and in part by the Carpenter/Sperry Internship/Research Fund.

Thanks are also due to the staff at DC Greenworks and Larry Bonneau at the Center for Earth Observation.

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## 1. Abstract

This report, inspired by the work of a non-profit organization in Washington, D.C. that seeks to promote social revitalization through environmental restoration, offers recommendations for the development of green roof subsidy and promotional programs targeting Washington D.C.'s underserved communities. Results from sewer system modeling, academic studies on green roof performance, and thermal satellite imaging were used to identify areas of the District that would benefit most from the stormwater and cooling benefits green roofs provide. Lessons learned from first-hand involvement in past green roof subsidy and promotional programs comprise the basis for recommendations on how future programs can be structured to more effectively serve underprivileged communities. While the recommendations are specifically intended to give rise to programs that will more strategically maximize the environmental and socioeconomic benefits of green roofs in Washington, D.C., many of the findings could have implications for organizations working towards similar goals in other locations.

## 2. Introduction

Green roofs—lightweight, low-maintenance, vegetated roof systems—have become popular alternatives to traditional roofs in urban areas due to the many environmental benefits they afford. Green roofs decrease stormwater flow, counteract the Urban Heat Island Effect, and conserve energy used to heat and cool buildings.

In Washington, D.C., green roofs have been promoted primarily as stormwater management tools by the DC Water and Sewer Authority (DC WASA), the District Department of the Environment (DDOE), and local environmental non-profits. Largely thanks to their efforts, from 2004-2009 Washington, D.C. installed the second largest amount of green roofing in the nation—approximately 1,038,700 square feet. Washington, D.C. is topped only by Chicago (a city three-times its size), which has installed approximately 2,279,000 square feet.[i]

DC Greenworks, a non-profit with a mission to promote urban social revitalization through environmental restoration, has been instrumental in transforming the District into one of the nation's leading green roof cities. DC Greenworks "grows livable communities using livable materials," as it likes to advertise, through the provision of green roof consultation, design, installation, and subsidy funding.

Because DC Greenworks installs green roofs at a low cost and is willing to work on small-scale projects (usually too small to be of interest to commercial green roof installers), it makes green roofs available to building owners that would otherwise have difficulty accessing the technology.

This report, written at the close of DC Greenworks' most recent green roof subsidy and outreach program, will make use of lessons learned over the course of the program, industry and academic literature, and thermal satellite imaging to formulate recommendations on how an organization like DC Greenworks, with both social and environmental goals, can maximize the benefits of green roofs.

## 3. Green Roofs as Stormwater Management Tools

Green roofs can be classified into two primary categories: intensive and extensive. Intensive green roofs have growing medium depths of at least six inches and are therefore capable of supporting larger plants. They are, in essence, rooftop gardens and require maintenance. Due to the weight of the growing medium layer and substantial vegetation, intensive roofs require more structural support than extensive roofs. Extensive roofs typically have growing medium depths of two to six inches, are planted with *Sedum* (hardy leaf succulents), and require little to no maintenance. For the purposes of this paper, the term "green roof" refers to extensive green roofs.

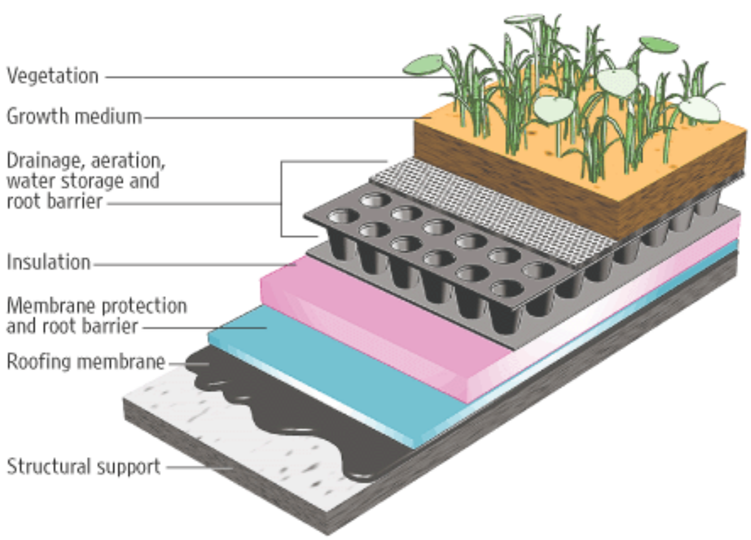


**Figure 1:** Basic layers of an extensive green roof system.[ii]

Extensive green roofs come in many varieties but are usually comprised of the basic elements depicted in **Figure 1** to the left: a structural support covered with a waterproofing membrane, root barrier and insulation, a drainage layer, primarily inorganic growing medium, and vegetation.

During a rainfall event, water is absorbed by the green roof's growing medium until it becomes saturated. After this point, the retention cups fill with water and any excess is drained from the roof to a rain gutter. For light rainfall events, green roofs might eliminate roof stormwater runoff entirely. For more intense rainfall events, green roofs can help delay peak flow.[iii]

The degree to which green roofs retain stormwater is dependent upon the characteristics of the specific system. Studies have shown that the amount of growing medium and retention cup size are the most important factors influencing stormwater retention.[iv] As one might intuit, the relationship between growing medium depth and the potential to absorb stormwater is positive. One recent study found little difference between the stormwater retention capacity of unplanted (growing medium only) and planted green roofs.[v] Vegetation, though, plays an important role in preventing erosion of the growing medium and recharges the stormwater storage potential of the growing medium through transpiration. Of course, vegetation is also vital to a green roof's ability to cool and improve air quality. While studies have shown that other guilds of plants (such as grasses and forbs) can be more absorptive than *Sedum*, grasses and forbs generally do not perform as well as *Sedum* in shallow soil and in extreme rooftop conditions.[vi]

Each of these studies then demonstrates that green roofs can be designed to maximize stormwater retention. However, stormwater retention is rarely the sole design goal. A property owner, for example, might need to design for the lightest-weight system possible due to structural load limitations and therefore opt for a very shallow layer of growing medium. Another might favor plants that are aesthetically pleasing or that require minimum maintenance, especially if accessing the rooftop is difficult.

## 4. Stormwater Management in Washington, D.C.

Washington D.C.'s major waterways—the Anacostia River, Potomac River, and Rock Creek—all suffer from sewage overflow and stormwater runoff pollution. Sewage and untreated stormwater runoff negatively impact the quality of the District's receiving waters for both aquatic life and District residents.

As seen in **Figure 2** on the following page, approximately one third of the District (12,470 centrally-located acres) is served by a Combined Sewer System (CSS) that routes sewage and stormwater together to a treatment facility. During consecutive or severe wet weather events, however, when large quantities of stormwater overload the system, sewage and stormwater are discharged directly into water bodies without being treated. These events are known as Combined Sewer Overflows (CSOs). There are a total of 53 CSO outfalls in the District's CSS—15 that discharge to the Anacostia River, 10 that discharge to the Potomac River, and 28 that discharge to Rock Creek.[vii] Approximately 2,490 million gallons of sewage overflow pollute the District's waters annually.[viii]

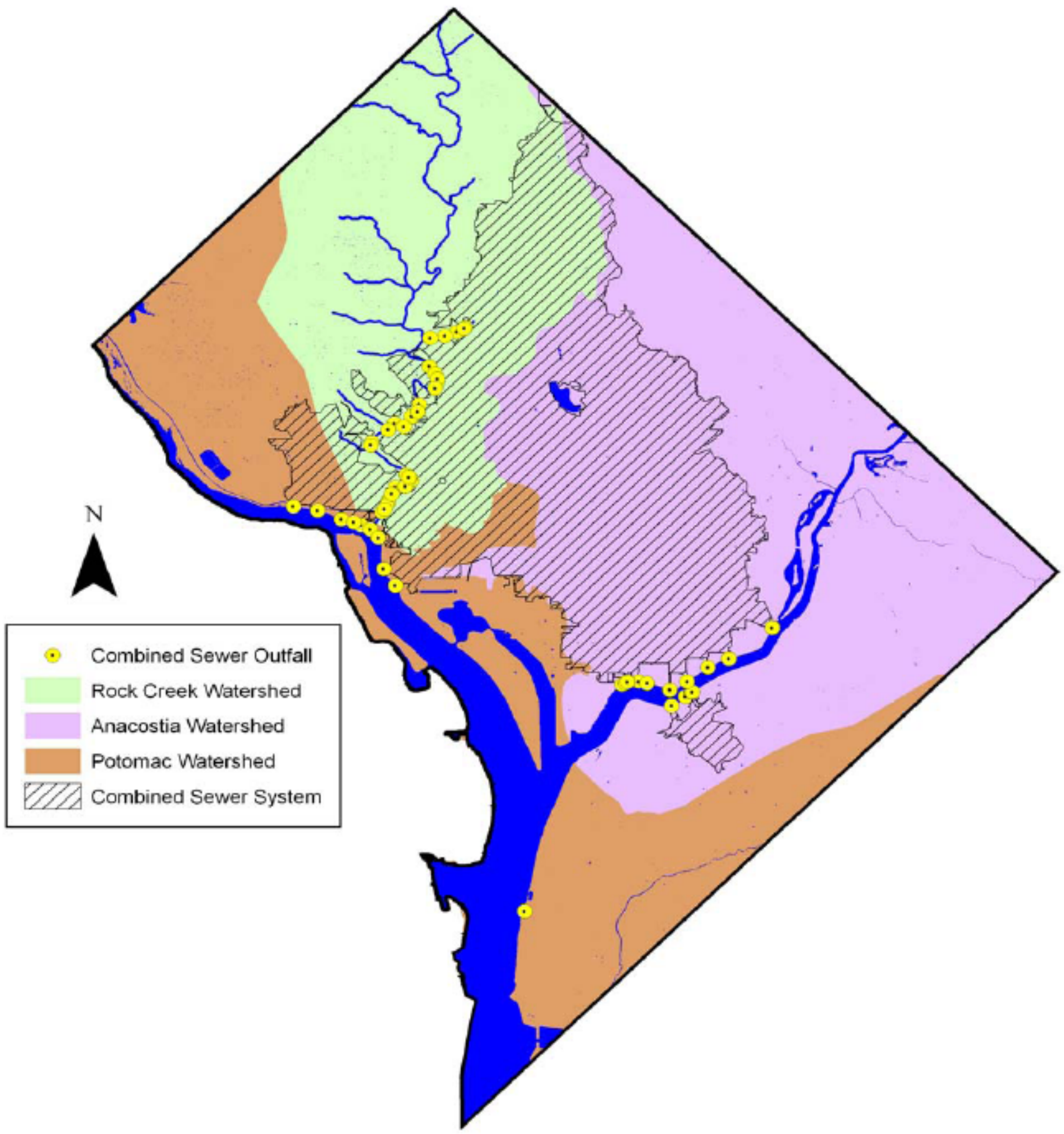


**Figure 2:** Map showing CSOs, CSS area, and Anacostia River, Potomac River, and Rock Creek sewersheds.[ix]

The other two thirds (21,250 acres) of the District is served by a Municipal Separate Storm Sewer System (MS4), in which stormwater and sanitary flows are routed independently. Only sewage is carried to a treatment facility before it is discharged. Stormwater is discharged directly to receiving waters.[x]

Unlike stormwater that falls in rural areas and is absorbed by natural groundcover, stormwater that falls on impervious urban surfaces cannot be as readily absorbed—it "runs off" and delivers sediment, excess nutrients, bacteria and other pathogens, debris, and household hazardous waste to receiving waters. In Washington, D.C., approximately 8,755 million gallons of MS4 stormwater runoff enters the Anacostia and Potomac Rivers, and Rock Creek each year.[xi]

| | CBOD5 | | TSS | | Fecal Coliforms | | E. coli | |
|---|---|---|---|---|---|---|---|---|
| | lb x 1000 | (lb x 1000)/ MG | lb x 1000 | (lb x 1000)/ MG | # x $10^{14}$ | (# x $10^{14}$)/ MG | # x $10^{14}$ | (# x $10^{14}$)/ MG |
| **CSS** | 699 | 0.28 | 2470 | 0.99 | 509 | 0.20 | 368 | 0.15 |
| **MS4** | 1383 | 0.16 | 6841 | 0.78 | 93 | 0.01 | 54 | 0.01 |

**Table 1.** Annual levels of baseline carbonaceous biological oxygen demand, total suspended solids, fecal coliforms, and E. coli (total and adjusted by total annual discharge volume).[xii]

**Table 1** above provides a volumetric comparison of the major pollutants carried in CSO discharge and MS4 stormwater discharge. As expected due to the sewage contents of CSO discharge, levels per unit volume of CBOD, TSS, and fecal bacteria are higher for the CSS than the MS4. Data sets on nitrogen, phosphorus, and oil and grease loads are incomplete for Rock Creek and the Potomac, so figures for these pollutants cannot be provided for the entire District. Data from the Anacostia River Basin Total Maximum Daily Load (TMDL) Decision Rationales, however, indicate similar levels of nitrogen, phosphorus, and oil and grease loads in CSO discharge relative to MS4 stormwater.[xiii] Several studies have also shown sewer outfalls to be major vectors for transporting endocrine disrupting polychlorinated biphenyls (PCBs) into the Anacostia River.[xiv]

#### 4.1. Regulatory Compliance & the Long Term Control Plan

Washington, D.C.'s CSS and MS4 are both subject to National Pollution Discharge Elimination System (NPDES) permit program controls, which are established by the Clean Water Act and enforced by the US Environmental Protection Agency (EPA).

In 1994, EPA issued a policy that required municipalities with a CSS to develop a Long Term Control Plan (LTCP) in order to reduce CSO events and achieve compliance with NPDES permit requirements. DC WASA published a draft plan in 2002, and in 2005, the plan was officially approved and adopted.[xv]

Those hoping for a District plan akin to Philadelphia's recently released LTCP, *Green City Clean Waters Philadelphia*, were left disappointed. Philadelphia's plan puts forth an ambitious goal of converting 4,000 acres of impervious area (34 percent of total existing impervious area) in the CSS to green space in the next 20 years, rather than construct storage tunnels deep under the Delaware River, and thereby places great emphasis on "green" rather than "grey" infrastructure. In contrast, DC WASA's LTCP calls for the construction of several major storage tunnels and pipelines (where overflow will be stored until it can be treated), pumping station rehabilitation, and the separation and consolidation of several CSOs (the complete separation of the whole CSS was deemed economically infeasible and too disruptive).

While developing its plan, DC WASA did weigh the effectiveness and costs of various traditional engineering solutions against "green" or low-impact development (LID) techniques using computer modeling of the District's sewer system and historical weather data. As DC WASA explains, "the goal of low impact development (LID) is to mimic predevelopment site hydrology by using site design techniques that store, infiltrate, evaporate and detain runoff. LID has the potential to reduce both the volume of storm water generated by a site and its peak overflow rate, thereby improving the quality of the storm water."[xvi] Green roofs, along with rain gardens (a plating bed designed to maximize runoff collection), increased tree cover, permeable pavement, and rain barrels (cisterns that capture rain for later reuse in the garden), are amongst the most common LID techniques. DC WASA's modeling efforts, however, showed traditional engineering solutions would more effectively limit the volume and frequency of CSOs than these LID techniques.

In two of DC WASA's alternative scenarios it considered the potential that green roofs could have on decreasing the load on the CSS. The first scenario assumed that 15 percent of the District's impervious surface area (1,963 acres or 85,508,280 square feet) was treated with LID technologies (200 acres of green roofs and the rest other LID technologies).[xvii]

The second scenario considered what impact “aggressive” green roofing alone would have on the CSS load. Under this scenario, DC WASA assumed it feasible to green 589 acres (25,656,840 sq ft), or 25 percent of institutional, federal, and commercial buildings in the District.[xviii]

As the data in **Table 2** indicate, neither the general LID nor aggressive green roofing scenario greatly reduced CSO volume or occurrence and could not be looked to as the sole solution to CSO control. Additionally, DC WASA expressed that it was hesitant to rely on LID technologies because it had limited control over private property and therefore could not guarantee that the technologies would be implemented or maintained to the degree necessary to meet water quality standards.

| | Anacostia | Potomac | Rock Creek | Total |
|---|---|---|---|---|
| **CSO Volume (MG/year)** | | | | |
| **Baseline** | 1,485 | 953 | 52 | 2,490 |
| **LID** | 1,090 | 543 | 41 | 1,674 |
| **Aggressive Green Roofing** | 1,218 | 607 | 47 | 1,871 |
| **Accepted Plan** | 54 | 79 | 5 | 138 |
| **Number of Overflows (per year)** | | | | |
| **Baseline** | 75 | 74 | 30 | 186 |
| **LID** | 73 | 72 | 30 | 175 |
| **Aggressive Green Roofing** | 75 | 71 | 30 | 176 |
| **Accepted Plan** | 2 | 4 | 5 | 11 |

**Table 2.** CSO volume and occurrence for baseline, accepted, and two alternative LTCP scenarios.[xix]

The limited potential of even widespread green roofing in Washington, D.C. to solve the District’s stormwater management problems is supported by several other studies. In 2007, non-profit CaseyTrees and LimnoTech made use of DC WASA’s hydrologic and hydraulic model (known as the Mike Urban model) to measure the impact of moderate and intensive greening scenarios on CSO frequencies and

| Scenario | CSO Volume (MG/year) |
|---|---|
| Baseline | 2,291<br>(0% reduction) |
| Moderate<br>11 million sq. ft. in CSS | 2,196<br>(4.2% reduction) |
| Intensive<br>55 million sq. ft. in CSS | 1,856<br>(19% reduction) |

**Table 3.** CSO volume according to CaseyTrees scenarios.[xxi]

volumes. The moderate scenario, in which 11 million square feet of impervious surface were converted to green roof, showed only a four percent reduction in CSO overflow volume. Under the intensive scenario, in which 55 million square feet of impervious surface was converted to green roof, CSO volume was reduced by only 19 percent, as shown in **Table 3**. Accordingly, the report concludes that, "tunnels are still needed in the CSS," and that green roofs, "provide limited reduction in CSO frequencies. Their cumulative storage capacity alone will not replace the need for storage tunnels in the CSS […] However, they do provide significant reduction in stormwater runoff volumes that could have implications for the detailed design of the LTCP."[xx]

Because green roof installation is often most practical and cost-effective on larger buildings, it was assumed for both the study's moderate and intensive coverage scenarios that green roof installation would occur on larger governmental and commercial buildings in the city center. As a follow-up to this study, graduate students of landscape architecture at the University of Michigan's School of Natural Resources and Environment modeled the impact that concentrating green roofs on small-scale residential properties would have on the District's CSO frequencies and volumes. Under the most intense coverage scenario in their study—green roofing 80 percent of the residential row house footprint area in the CSS (34,290,454 square feet)—only a 12 percent reduction in CSO volume was achieved.[xxii]

The results of these two studies suggest then that even if the majority of large governmental buildings and residential row houses in the CSS were green roofed, the subsequent reduction in CSO volume would not likely exceed 30 percent. In light of these findings, DC WASA's conclusion that that LID technologies like green roofs have potential to only *partially* contribute to the improvement of the quality of the District's waterways seems appropriate. To show its partial support, it committed to spending $3,000,000 to incorporate LID at its facilities, $300,000 to subsidize green roof installation, and $1,700,000 to plant trees and install rain gardens throughout the CSS.

Perhaps more importantly, DC WASA agreed to reevaluate or perhaps even eliminate the Rock Creek storage tunnel depending on the extent and performance of LID that will be implemented in the area in the coming years.[xxiii] Construction on the Rock Creek storage tunnel will not begin until after the Anacostia River storage tunnel is complete (now expected in 2018).[xxiv] As the baseline numbers show in **Table 2**, the Anacostia is most impacted by CSOs, and so was given priority.

DC WASA, with the help of Greeley and Hansen and LimnoTech, is in the process of modeling a variety of LID techniques (green roofs, rain barrels, rain gardens, and tree canopy expansion, etc.) at different intensities within the Rock Creek sewershed. Unlike DC WASA and LimnoTech's previous LID modeling effort in which it was assumed that green roofs would be installed where most feasible (i.e., on the larger buildings in the city), this hydrologic analysis will be used to determine where within the Rock Creek sewershed LID technologies can make the greatest impact. The modeling effort will allow DC WASA to determine what degree of rainfall capture and what percentage of reduction of impervious surface is necessary to realize a reduction in the size (or elimination) of the Rock Creek storage tunnel.[xxv]

### 4.2. Municipal Separate Storm Sewer System (MS4)

When the storage tunnels are complete throughout the CSS, the water quality of stormwater runoff in the MS4 will be comparatively worse than that discharged from the CSS because stormwater in a separate system is discharged without treatment. This suggests that once the Plan is complete, green roofs in the MS4 might contribute more to improving the water quality of the District's rivers than green roofs in the CSS would.[xxvi]

The District Department of the Environment (DDOE) is responsible for developing a stormwater management program to ensure that stormwater from the MS4 meets NPDES permitting requirements. The recently-released proposed permit update, if accepted, will require the District government to install 350,000 square feet of green roof on District-owned properties.[xxvii] This permitting requirement is justified in light of the findings of the Casey Trees study, which show green roofs to have "particular promise in the MS4 area where subsequent reductions in pollutant loadings could provide the District an option to make progress toward meeting TMDL requirements for its impaired waters."[xxviii]

As **Table 4** shows, if green roofs were installed according to the intensive scenario (55 million square feet), a five percent reduction in flow reduction would likely be achieved. It should be considered though that the model concentrated its application of green roofs in the CSS, where buildings are larger and therefore assumed more likely to be topped with a green roof. If concentration of the 55 million square feet of green roof were shifted to the MS4 the model would likely predict greater reductions in the volume of runoff in the MS4 flow.

| | MS4 Baseline Flow (MG/year) | Moderate Green Roof Scenario Flow (MG/year) | Moderate Scenario % Flow Reduction | Intensive Green Roof Scenario Flow (MG/year) | Intensive Greening Scenario Flow Reduction |
|---|---|---|---|---|---|
| **Anacostia** | 3,719 | 3,684 | .94% | 3,535 | 4.68% |
| **Potomac** | 3,177 | 3,141 | 1.12% | 3,000 | 5.56% |
| **Rock Creek** | 1,860 | 1,841 | 1.01% | 1,768 | 4.93% |
| **Total** | 8,755 | 8,667 | 1.01% | 8,313 | 5.05% |

**Table 4.** MS4 flow derived from Casey Trees' Green Build-Out Model Display Tool[xxix]

Given the results of sewer system modeling and the agenda set forth in the LTCP, from a stormwater management standpoint, programs aimed at promoting green roofs and other LID techniques should be focused in the Rock Creek sewershed and the MS4. Because plans for the Anacostia storage tunnel are already finalized, green roofs installed in the Anacostia CSS will not affect CSO volume or occurrence and will simply lower operational costs for DC WASA.[xxx] Installing green roofs in the Rock Creek watershed, however, will increase the likelihood that DC WASA and DDOE will turn to green rather than grey stormwater management infrastructure in the future.

Promoting green roofs within the MS4 would be valuable in that it would reduce the quantity of untreated stormwater runoff routed directly to receiving waters. But if large-scale green roof implementation is pursued in the MS4, caution should be taken to minimize the potential of green roofs to be a *source* of pollution. Green roofs effectively help to reduce the quantity of stormwater runoff, but studies have shown that in general, concentrations of nutrients (nitrogen and phosphorus) and heavy metals from green roof runoff are similar to that in impervious surface runoff (although the pH of green roof runoff is usually less acidic).[xxxi] Green roofs can, however, serve as both sinks and sources for these pollutants depending on choices of growing medium and fertilization.

To minimize nutrient runoff from green roofs (and to prevent the deterioration of an already thin growing medium layer), growing medium should be comprised of a low content of organic material. According to Edmund and Lucie Snodgrass, owners of the first green roof nursery in US, "initial medium should have sufficient fertility for the first growing season and supplemental fertilization should occur a year after planning, using a slow-release fertilizer (SRF) only."[xxxii] Once plants are established and begin to recycle the nutrients in fallen organic matter, fertilization might not be necessary.

The Snodgrasses' recommendation to use controlled-release fertilizers is supported by research literature. Although more expensive than conventional fertilizers, controlled-release fertilizers make available nutrients in the growing medium at rates at which they can be metabolized by plants. Findings from a study conducted at the Swedish University of Agricultural Sciences indicate that the use of conventional fertilizers on green roofs, as opposed to SRFs, results in high nutrient concentrations in the runoff.[xxxiii]

## 5. The Urban Heat Island Effect & Air Quality

Because green roofs can play only a limited role in stormwater management in Washington, D.C., consideration should also be given to the cooling effects, and consequent air quality benefits, that green roofs can provide when deciding in what areas to strategically focus future programs.

Urban areas, like Washington, D.C., often suffer from higher temperatures relative to surrounding less-developed areas because surfaces like concrete, asphalt, and traditional roofing materials absorb more energy from the sun than vegetation. Vegetation, through evapotranspiration, cools ambient air temperature and produces lower surface temperatures, which have consequent positive impacts on outdoor thermal comfort and air pollution chemistry. Increased temperatures in urban areas caused in part by a lack of vegetation cover, lead to higher levels of cooling energy consumption and reduced air quality.

Studies have shown that green roofs can help counteract the Urban Heat Island Effect. Green roofs reflect more incoming radiation than traditional roofs, cool through evapotranspiration, and add thermal mass that attenuates surface temperatures.[xxxiv] In one experiment, which measured surface heat budgets of several surfaces: concrete, grey paint, bare soil, vegetation, and white paint, daytime temperatures were observed on each surface in descending order, confirming the efficacy of green roofs as Urban Heat Island mitigation tools.[xxxv]

Because air pollutants such as $NO_x$ and volatile organic compounds (VOCs) form more readily at higher temperatures to form ground-level $O_3$, the temperature reductions achieved by green roof vegetation improve air quality. Vegetation also has the ability to improve air quality directly, by uptaking air pollutants (particulate matter, $O_3$, $SO_2$, $NO_x$, and CO) via leaf stomata. Exposure to these pollutants is associated with numerous respiratory health effects. People who suffer from lung disease, children, the elderly, and those who engage in intense physical activity outdoors are considered especially sensitive.[xxxvi] This implies then that green roofs can indirectly positively impact human health through their ability to improve air quality.

In a 2005 study, Casey Trees used the US Forest Service's Urban Forest Effects computer model to quantify the air pollution reductions that green roofs could achieve in the District. Local hourly pollution concentrations, meteorological data, and plant-specific air pollution removal rates served as inputs to the model. Because no *Sedum*-specific air pollution removal rates had been developed, a 50:50 mix of grasses and evergreen shrubs was used as a proxy. Perhaps the most notable finding, displayed in **Figure 3**, is that the two pollutants that green roofs have the highest potential to reduce (particulate matter and $O_3$) are also those for which Washington, D.C. has failed to meet federal standards established under the Clean Air Act.[xxxvii] The total amount of pollutants removed under different coverage scenarios are listed in **Table 5**.

| Green Roof Coverage (sq. ft.) | Total Annual Pollutant Removal (Metric Tons) |
|---|---|
| 14,994,000 | 11.6 |
| 29,988,000 | 23.2 |
| 44,982,000 | 34.8 |
| 59,976,000 | 46.4 |
| 74,970,000 | 58.0 |

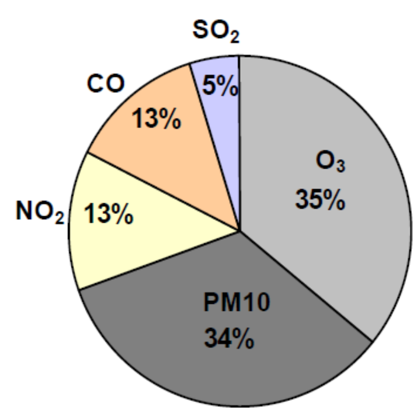


**Table 5 & Figure 3.** Tons of pollutants removed by green roofs under various coverage scenarios and relative share of pollutants removed.[xxxviii]

The suite of image below (**Figure 4.A-C**) reveal what areas of the District might benefit most from the cooling potential of green roofs. **Figure 4.A**, adapted from an image captured in August 2010 from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery instrument flying on the Terra satellite, shows relatively high temperatures in the center of the District and along the southeastern banks of the Anacostia. **Figure 4.B**, indicates vegetation cover using the Normalized Difference Vegetation Index (NDVI) as a measure. A quick visual comparison reveals the close correspondence between surface temperatures and vegetation. High temperatures correspond with areas of sparse vegetation. And the coolest area of the District is clearly Rock Creek Park, located within the Rock Creek MS4.

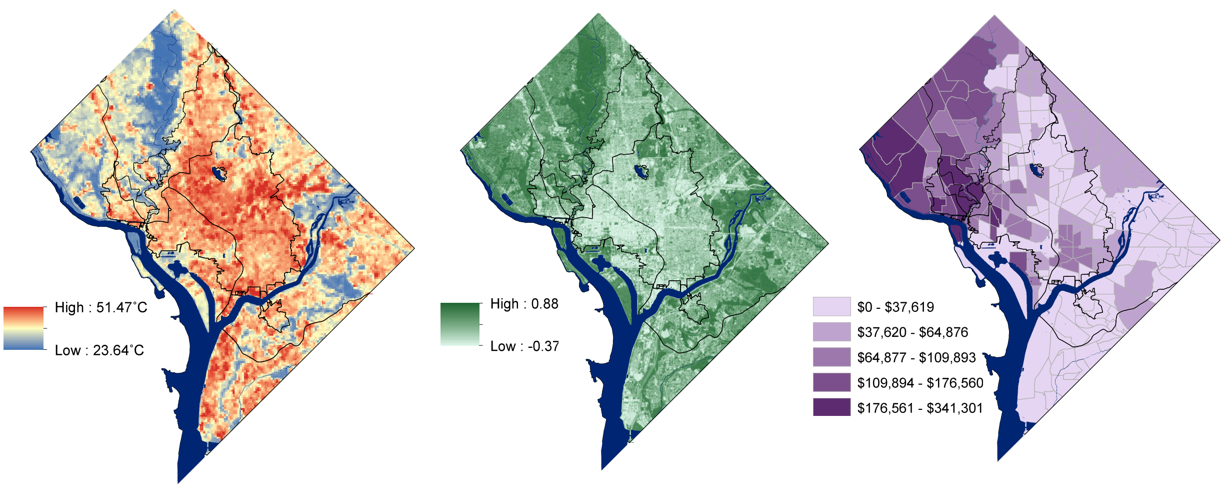


**Figure 4.A-C.** District surface temperatures, vegetation cover, and adjusted gross net income distributions with sewershed overlays.

The black lines overlaid on the images trace the sewershed boundaries of the Anacostia CSS and MS4, the Potomac CSS and MS4, and the Rock Creek CSS and MS4. A full-page visual of the sewershed breakdowns is provided in **Appendix A**. Interestingly, the sewershed that would benefit the most from the cooling effects of green roofs appears to be the Anacostia CSS. The dramatic difference in temperature and vegetation cover within the Potomac MS4 is also significant. Surface temperatures are much higher in the southeastern portion of the Potomac MS4 than they are in the more wooded residential neighborhoods of the northwestern portion of the sewershed. This finding, along with the adjusted gross income distributions from the 2000 Census in **Figure 4.C**, makes a strong case that programs offered in the Potomac MS4 sewershed aimed at both social and environmental restoration should be focused in the southeastern portion of the sewershed.

Finally, it should be added that from a fundraising perspective, framing green roof promotional programs not only as stormwater management initiatives, but also as city cooling initiatives, would open the door for organizations to apply for funds that support Urban Heat Island mitigation activities. For example, EPA's Local Climate and Energy Program makes funding available through its Climate Showcase Communities grant program for Urban Heat Island management projects.

Now that several geographic priorities areas for future programs have been identified, the section to follow will lay out how green roof incentive and outreach program could be structured to effectively serve communities in need of socioeconomic revitalization. Whereas industry, academic, and GIS data were used to formulate recommendations on geographic priority areas, experiential lessons from DC Greenworks' recent Green Roofs for Environmental and Economic Northeast Revitalization (GREENER) program provide the primary bases for recommendations in the section to follow.

## 6. GREENER Program

As its title suggests, the GREENER program promoted and subsidized green roofing along the economically depressed commercial corridor of H Street Northeast. The program was designed to make available the private economic benefits (such as reduced utility costs) to business owners on the commercial strip and, of course, to reduce the volume of CSO in the Anacostia River.

To fund the program, Greenworks augmented DDOE's District-wide green roof subsidy with a Neighborhood Investment Fund (NIF) Target Area Grant for a total combined subsidy of twelve dollars for each square foot of green roof installed. With the combined subsidies and DC Greenworks' project management, labor, and installation (performed by volunteers from the community at no cost to the building owner), DC Greenworks was able to offer businesses green roofs at the price of a traditional roof. Greenworks hoped to install 11 roofs along the one-and-a-half mile stretch of approximately 220 businesses.

The results of a survey of H Street NE business owners, administered by students at the University of Maryland's Robert H. Smith School of Business prior to the GREENER program's launch, indicated that the businesses most likely to opt for the subsidy program were those located in buildings that were being refurbished (many of the buildings along H Street NE were in extreme states of disrepair), newer businesses as opposed to those that had been located on H Street NE prior to revitalization efforts, and restaurants and bars (because they tended to be most likely to have access to large amounts of capital).

As the marketing plan predicted, several new bars, a coffee shop, and a yoga studio on H Street NE expressed interest in installing a green roof. They were extremely slow to act, however, and when after several months, Greenworks still had not received a serious applicant, it decided to lower its target number of roofs and increase its portion of the subsidy in order to help business owners cover some of the cost of specialized waterproofing—a necessary step before the green roof is installed that can cost up to an additional $7-12 per square foot.

While DC Greenworks was running its GREENER program along H Street NE I worked to promote green roofs along Mt. Pleasant Street in northwest DC—a commercial corridor also undergoing revitalization. If business owners there showed enough interest in greening their commercial strip, DC Greenworks might have considered applying for another NIF grant to augment the subsidy offered through DDOE, and this time work to reduce CSOs in the Rock Creek watershed.

Although its commercial corridor is smaller (one half mile with approximately 70 businesses) than H Street NE's, Mt. Pleasant seemed a promising neighborhood in which to replicate the GREENER program for several reasons. In its recently-released commercial revitalization strategy, Mt. Pleasant announced its hope to transform its mainstreet into a "green street" by "enhancing the physical condition of the corridor through sustainable development practices."[xxxix] Mt. Pleasant is also home to DC's first solar cooperative, which indicates neighborhood support for environmentally friendly initiatives.

Because many of the business owners along Mt. Pleasant Street speak Spanish as their first language, all outreach material and information on the subsidy program was available in both Spanish and English. Prior to this project, DC Greenworks had not yet developed Spanish outreach materials and had yet to conduct targeted outreach in Spanish-speaking communities in Washington DC. In this respect, the outreach efforts were successful. However, as on H Street NE, at the end of the outreach effort few business owners expressed serious interest in installing a green roof.

### 6.1. Program Implementation Challenges

#### *6.1.1. Narrow Pool of Properties*

On both H Street NE and Mt. Pleasant Street, the number of properties on which green roofs would make financial sense was narrowed-down rapidly by several factors. Installing a green roof makes financial sense when a property owner is in need of a new roof anyway—green roofs cannot simply be installed over existing roofs. So, assuming the lifespan of a traditional roof is approximately 20 years, only an average of 10 buildings on a commercial strip of 200 buildings would require roof replacements in any given year. Short-term, tightly geographically bound programs like GREENER, therefore, are unlikely to effectuate a large quantity of green roof installations.

Furthermore, commercial property owners are usually only attracted to the financial benefits of green roofs when they are also the business owners. While a property owner who rents his/her building would benefit from increased roof longevity (it is generally believed that green roofs have twice the lifespan of traditional roofs because they protect the actual roof membrane from UV ray and intense temperature fluctuations) the energy savings benefits of a green roof would be lost so long as the lessees are responsible for utilities. This further narrowed the pool of interested property owners on H Street NE and Mt. Pleasant Street.

#### *6.1.2. Structural Limitations*

Several of the property owners on H Street NE and Mt. Pleasant Street who did express interest in installing a green roof were deterred because their buildings could not meet the structural load requirements necessary for a green roof retrofit. Most District row house roofs were designed for live loads less than what a green roof requires. The average extensive green roof (three to four inches of growing medium) weighs approximately 20 pounds per square foot when saturated with rainwater. This load is less of an impediment when installing a green roof on a new building because it can be incorporated into early designs, but for programs like GREENER that entail retrofitting long-lived row-house-style buildings, it is a major obstacle. To determine whether an existing building is green-roof-ready, a structural engineer must certify that the building can support the necessary load. This is an added step and expense that prevented some property owners from moving forward with green roof installation. Although row house roofs generally are flat and therefore ideal for green roofing, the buildings often require structural reinforcement before a green roof can be installed, which can be cost-prohibitive for the property owner.

It should be noted here though that the drive in Washington, D.C. to retrofit buildings with green roofs is in part dictated by DDOE, as only retrofit projects are eligible to receive the green roof subsidies that it offers. DDOE does not incentivize the installation of green roofs on new construction because stormwater management plans are already required as prerequisites for new construction (technically classified as "land disturbing activity").[xl] There are no stormwater management requirements that can be imposed on existing buildings so DDOE instituted its green roof subsidy programs to motivate property owners to retain stormwater on-site.

DDOE also runs the RiverSmart Homes program, which offers homeowners financial incentive to implement stormwater management landscape enhancements. Homeowners can earn up to $1,200 in rebates for installing rain barrels, planting shade trees, replacing impervious pavement with pervious pavement, and creating rain gardens.[xli] These ground-level stormwater management strategies are a good alternative when structural limitations preclude green roof installation.

#### *6.1.3.High Up-front Capital Investment*

Though the subsidies funded by DDOE and NIF and distributed through the GREENER program made green roofs available at a cost similar to a traditional roof, property owners were still required to pay the majority of the installation costs up front. Property owners were to receive the first 10 percent of the subsidy after they submitted an application complete with a structural analysis report from a District-registered structural engineer, photos of the structure before installation, green roof plans (including a list of materials), a budget, an installation schedule, and a maintenance schedule. In order to receive the remaining 90 percent of the subsidy, the property owner must have installed the roof within 6 months and have had it inspected by a DC Greenworks employee, who was to ensure that the roof met the minimum requirements for eligibility in the program. The high initial capital costs of green roofs likely served as another barrier to program implementation in economically-depressed commercial corridors like Mt. Pleasant and H Street NE.

### *6.1.4.Energy Savings Difficult to Predict*

While property owners could count on high capital installation costs, the money they would have saved on utilities if they had installed a green roof was not as easy to quantify. Rightfully, before business owners on H Street NE and Mt. Pleasant Street invested in a green roof, they wanted to know how much they would save on utility bills. However, these numbers can be difficult to estimate because the energy savings a green roof can provide varies depending on the characteristics of the entire building envelope, not just the roof, and also on the energy use behaviors of occupants.

EnergyPlus, a building energy simulator developed for the US Department of Energy, is one of the best available tools for estimating the degrees of convective and radiative cooling that green roofs can provide. The simulator can account for various design parameters of the building envelope, specific characteristics of the green roof itself (leaf area index, vegetation type and height, growing medium depth, etc.) and local weather patterns.[xlii] However, EnergyPlus can only be used by sophisticated analysts and thus its use for single residence predictions is costly. Furthermore, using EnergPlus, it is difficult to account for direct natural ventilation and night cooling.

The Green Building Research Laboratory at Portland State University used the EnergyPlus simulator to develop a simplified Green Roof Energy Calculator that allows property owners to estimate the energy savings a green roof will provide based on the area and depth of the green roof and city-specific utility rates. Unlike the EnergyPlus simulator, however, this tool does not take into account specific features of the building envelope or occupant-specific energy use behavior when generating its estimate.

A recent study aimed at estimating the average economic benefits of widespread green roof implementation in Washington, D.C., made use of the EnergyPlus simulator, local weather data, and average utility rates from 2008, to estimate the difference in annual electricity and natural gas consumption of buildings with green roofs versus conventional roofs at four different building scales.[xliii]

Results that showed an eight percent average reduction in gas consumption and a two percent average reduction of electricity use were similar to estimates generated in similar studies of other cities (i.e., Chicago and Houston).[xliv] But such modest savings in electricity, which are primarily achieved through a reduced need for air conditioning, could also be achieved through a revival of traditional natural ventilation strategies (e.g., managing window openings and controlling solar gain through window

| | Electricity Savings (MWh) | Electricity Savings (Dollars) | Natural Gas Savings (MWh) | Natural Gas Savings (Dollars) | Total Savings (Dollars) |
|---|---|---|---|---|---|
| Residential (55 m²) | 0.2 | $26.50 | 0.3 | $16.40 | $42.90 |
| Residential (125 m²) | 0.4 | $52.90 | 0.6 | $32.80 | $85.70 |
| Residential (270m²) | 0.7 | $92.60 | 1.2 | $65.70 | $158.30 |
| Commercial (1795 m²) | 4.7 | $601.10 | 1.6 | $73.80 | $674.90 |

**Table 6:** Estimated annual utility savings at different building scales in Washington, D.C.[xlv]

shading).[xlvi] As displayed in **Table 6** above, the total yearly monetary savings that property owners on H Street NE and Mt. Pleasant Street would realize if they installed green roofs is less than $100 per year (assuming that the size of their commercial property is similar to a moderately-sized residential building).

#### *6.1.5.Green Labeling*

While green roofs count for credits towards the US Green Building Council's Leadership in Energy and Environmental Design (LEED) certification, the certifications are more commonly pursued for large and new commercial properties than for small-scale retrofits. Property owners along H Street NE and Mt. Pleasant Street were not motivated by green labeling schemes like LEED or even LiveGreen, a local green label that endorses businesses, rather than buildings.

To achieve LEED certification and LiveGreen endorsement property owners have to do more than install a green roof. LiveGreen endorsed partners, for example, must offer eco-friendly products, services, and operations. Property owners were not convinced that certification or endorsement would positively impact their customer base or revenue enough to justify the expense of achieving certification or endorsement. Property owners did see the potential marketing value of green roofs in cases where their roofs could be directly accessed and viewed by their patrons (e.g., at a roof top bar).

Though most business owners were unwilling to commit to greening their individual businesses, many were interested in a vision of a business district with a critical mass of green roofs and/or green-certified businesses. Especially in the case of Mount Pleasant, which vies for customers with revitalized

Columbia Heights (just two blocks away), a district-wide greening effort might help distinguish the commercial corridor from its competitor. Accordingly, neighborhood organizations like the Mt. Pleasant Advisory Commission, Mt. Pleasant Business Association and the Mt. Pleasant Mainstreet Association backed the GREENER program but the individual property owners of which the member organizations were comprised were hesitant to invest individually.

#### *6.1.6.Tax Incentives*

Unlike municipalities like Philadelphia and New York City, Washington, D.C. has yet to institute tax abatements or credits for property owners who install green roofs. The New York City Green Roof Tax Abatement, for example, allows for a one-year $4.50 per square foot of green roof installed property tax abatement.[xlvii] And the Philadelphia Green Roof Tax Credit allows property owners a credit of 25 percent of all costs incurred to construct the green roof against the City's Business Privilege Tax.[xlviii]

At the federal level, green roof tax incentives have been proposed but have yet to be introduced. In 2009, Washington Senator Maria Cantwell introduced Senate Bill 320 Clean Energy Stimulus and Investment Assurance Act that proposed a 30 percent property tax credit for qualified green roofs. The Bill was read twice and is now sitting in the Senate Committee on Finance.[xlix]

#### *6.1.7.Stormwater Fee-bates*

For years, DC WASA's sewage fees ignored the degree to which properties contribute to stormwater runoff. Residential and commercial property owners were billed for sanitary sewer service only according to their metered water usage. In May of 2009, DC WASA revised its billing system to incorporate an Impervious Surface Area Charge (IAC). Under the new system, DC WASA still bills on water usage—although at a decreased rate (from $3.47 to $3.31)—to compensate for the new IAC. The revenue from the charges is being used to fund projects outlined in the LTCP.

The basic unit of the IAC is an Equivalent Residential Unit (ERU)—the amount of impervious surface area based on a statistical median for a single family residential property (1000 square feet). All residential customers are charged for one ERU of impervious cover. Non-residential customers are charged according to the total number of ERUs on their lot. The ERU fee was initially set at $1.24/ERU a month—a negligible charge now, but as the table on the following page indicates, one that is projected to increase up to $16 dollars by 2017 (see **Figure 5**).[l]

DDOE restructured its stormwater fee based on the ERU at the same time that DC WASA changed its sewage fee. The monthly stormwater fee, which funds street sweeping and green roof, rain garden, and tree planting subsidy programs, is now set at $2.57 per month. With the DDOE stormwater fees and the DC WASA charges combined, DC residents currently pay a total of approximately $60 per year in stormwater-related fees.

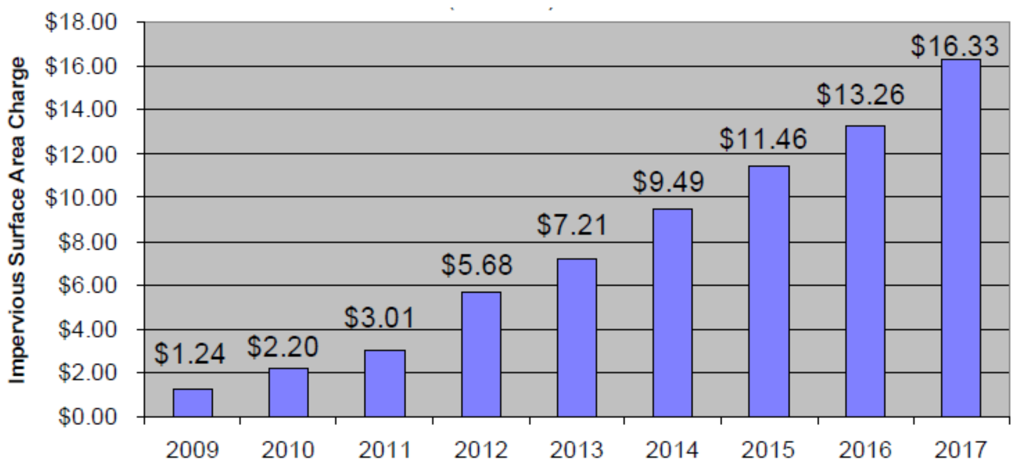


**Figure 5:** Projected monthly residential IAC charges per ERU.[li]

As of now, DC WASA and DDOE have yet to announce their stormwater fee discount program, which is intended to reduce stormwater fees for property owners who implement stormwater management techniques such as green roofs. According to DC Council rule, the program was to be established by May 2010. Even if the program is established soon, the fact that the combined DC WASA and DDOE storm water fees are so low indicates that this incentive is not likely to prompt business owners of small commercial properties, whose lots are not much larger than one ERU, to install a green roof. The program is more likely to do so with time, as fees steadily increase.

### 6.2. Recommendations Based on GREENER Experience

#### 6.2.1. *Revolving GREENER Loans*

If a program like GREENER is to be replicated in other commercial areas undergoing revitalization in the District a small-scale Revolving Loan Fund (RLF) should be established for businesses who wish to participate. Even though DC Greenworks offered green roofs at a similar cost to that of traditional roof through its combined subsidy programs, property owners were daunted by the high initial capital cost of installing a green roof (90% of the subsidy funding was distributed after the roof had been installed and inspected). The loan fund could be setup similar to some of the clean energy RLFs already available in many states. As loans issued from the fund are repaid, new loans could be issued so that the fund could be used to cover the installation costs for multiple roofs over time.

#### *6.2.2. Other Mainstreets*

H Street NE is one of seven commercial corridors in need of revitalization that the District government is supporting through its DC Mainstreets Program. The Program aims at supporting retail investment through the retention, expansion, and recruitment of businesses. Each of the corridors supported through the Mainstreets Program also benefits from the District Department of Transportation's (DDOT) Great Streets Program. Through this program DDOT will widen sidewalks and install street lighting, benches, bike racks, and public artwork in each of the commercial corridors.

None of the seven commercial corridors supported by these programs is located within the Rock Creek CSS. Two of them, however, are located within the MS4: Congress Heights and Deanwood Heights. Congress Heights, located in the Potomac MS4, is a predominately African-American neighborhood that, like H Street NE, began its decline in late 60s and suffered outmigration of urban residents to the suburbs. Deanwood Heights, also a historically African-American neighborhood, is located in the Anacostia MS4.[lii] Notably, both the Congress Heights and Deanwood Heights corridors are eligible to receive Neighborhood Investment Fund (NIF) grants (the mechanism used by DC Greenworks to help fund its GREENER program on H Street NE).

#### *6.2.3. From Revitalized Commercial Corridors to Affordable Housing*

Given the challenges that come with promoting green roofs along revitalized commercial corridors and the limited success of the GREENER program on H Street NE and Mt. Pleasant Street, it might be advisable to target affordable housing projects instead. DC Greenworks could apply for funding to augment DDOE's District-wide subsidy, as it did for the GREENER program, through organizations that support eco-friendly affordable housing initiatives. The Home Depot Foundation, for example, runs a biannual grant cycle for its Affordable Housing Built Responsibly grant program. Funding is also available at the national level through the Department of Housing and Urban Development's Green Retrofit for Multifamily Housing Program. Concentrating on the affordable housing community would allow an organization like DC Greenworks to continue to serve its targeted demographic but shed the tight geographic confines that come with working along a single commercial corridor.

This recommendation to target affordable housing projects stems from interest that affordable housing communities, particularly in Mt. Pleasant, showed during the GREENER program. Although businesses were the primary outreach targets, members of tenant associations of affordable housing communities expressed interest in installing green roofs on two apartment buildings, the Deauville and the St. Dennis, that were in the process of being restored by the National Housing Trust (NHT), a DC-based organization whose mission is to preserve and revitalize affordable housing apartments.

The NHT, committed to sustainable development that reduces energy use so that low-income inhabitants can save on utility bills, had already finalized construction plans that called for a cool roof rather than a green roof on the St. Dennis. As the NHT's Sustainability Manager Matt Latham explained, a green roof was considered in a design charettes but was deemed too costly. At that time, NHT had not been aware of the $7 per square foot green roof subsidy offered by DDOE (and administered by the Anacostia Watershed Society) for properties over 4,000 square feet, like the St. Dennis. In light of this available funding, Mr. Latham plans to propose a green roof for the Deauville once design charettes begin.

As the case of St. Dennis suggests, the community of affordable housing developers in Washington, D.C. might be unaware of the subsidies available that would make installing green roofs on affordable housing projects financially feasible. DC Greenworks is uniquely positioned to bridge the goals of organizations that are more socially-focused (like the NHT) with organizations that are more environmentally focused (like the District Department of the Environment and the Anacostia Watershed Society). It should reach out to local affordable housing developers to broadcast the availability of DDOE's green roof subsidies, as well as the low installation and labor costs that DC Greenworks provides.

The Housing Association of Non-Profit Developers (HAND) would be a particularly effective vehicle through which DC Greenworks could channel its outreach. Jill Norcross, the Association's executive director, welcomed the idea of having DC Greenworks share information at HAND's green building trainings and discussions and in its weekly newsletter that is e-mailed to over 500 affordable housing providers.

Working to promote the installation of green roofs on affordable housing projects would not come without its own set of challenges. Mr. Latham echoed one of the findings from DC Greenworks' 2010 Survey of Green Roof Incentive Policies: "[…] the specified timeline associated with grant programs may be extremely problematic for developers and owners interested in the funds. Larger development projects may take years to move from the planning process into actual build-out. Even after the project is fully permitted, delays in construction can mean delays in the green roof installation, possibly making a project ineligible to receive the grant funding, which jeopardizes the inclusion of the green roof." To address this challenge, Mr. Latham suggested that grant programs that target affordable housing be structured in such a way that funding can be set aside or guaranteed once a project's application is accepted. Without assurance that funding will be available through the subsidy—regardless of the construction timetable—housing developers will be unable to plan and budget for the incorporation of a green roof on their projects.

#### *6.2.4. Combine Forces with Solar Cooperatives*

To garner more support for its green roof programs DC Greenworks should build its relationship with the existing network of solar coops in the District. Property owners who are interested in installing solar panels in order to live more sustainably and save on utility costs are also likely to be interested in learning more about green roofs. The possibility of a green-solar roof, and the financial and environmental gains associated with both technologies, should be introduced to every person who contacts the solar coops and DC Greenworks. Particular energy should be invested in improving the relationship between DC Greenworks and the Mt. Pleasant and Petworth coops because they serve members in the Rock Creek CSS sewershed.

Combining the subsidies and tax credits from solar programs and green roof programs might make both options more attractive for certain property owners. In the District, there are more financial incentives available for District residents to install PV panels than to install a green roof. Most members of solar coops install 3.0 kW systems at a cost of approximately $18,000.[liii] The DDOE Renewable Energy Incentive Program offers $9,000 subsidy on the first 3.0 kW installed, property owners receive a one-time federal tax credit that covers 30 percent of the system's cost, $1,000 per year in renewable energy credits, and annual energy savings.

Plus, installing green roofs near solar panels might result in a positive environmental synergy. The relationship is being tested in a three-year study at Portland State University entitled, "Integrating Green Roofs and Photovoltaic Arrays for Energy Management and Optimization of Multiple Functionalities." Specifically, the study will test (1) whether increased rates of evapotranspiration will enhance PV efficiency; (2) whether the shade solar panels can provide green roof plants will increase their ability to sequester carbon; and (3) whether green roofs are capable of lowering ambient temperatures and off-set the warming effects and high surface temperatures of solar panels.[liv]

In addition to making the financial and possible environmental benefits of green roofs and solar panels better known, Anya Schoolman, president of the Mount Pleasant Solar Cooperative, suggested that DC Greenworks staff meet with the solar PV installers that the coops typically recommend to discuss design challenges and best practices. It is important that the green roof and solar panel installers communicate so roofs can be designed appropriately. On a section of green roof that will be heavily shaded by solar panels, for example, shade tolerant plants like *Sedum ternatum*, *Sedum kamtschaticum*, or *Sedum spurium* 'Coccineum,' would be wise design choices.[lv]

Ms. Schoolman also suggested lobbying DDOE to institute a solar thermal subsidy—as of now, DDOE's REIP applies only to PV installations. She added that combining solar thermal and green roofs might be more practical because solar thermal equipment takes up much less space than PV panels, and consequently makes more roof area available for plant cover. Plus, solar thermal panels are approximately three times more efficient than PV panels, and therefore produce less waste heat that could contribute to the Urban Heat Island Effect.

#### *6.2.5. Raise Awareness of Cool Roofs as Alternatives*

Several property owners on Mount Pleasant Street who were interested in saving on utility costs but ultimately deterred from installing a green roof due to structural limitations and high capital costs, chose to install a cool roof instead. The cost of a cool roof, a roof constructed from light-colored materials that reflect the sun's rays, is comparable to that of a traditional roof. Similar to green roofs, cool roofs extend the longevity of the roof (due to their ability to prevent thermal fatigue and therefore cracking) and reduce summer cooling costs. Selective roof surface coatings (specifically, white elastomeric coatings) have also been shown to have equal if not greater solar reflectance and infrared emittance.[lvi]

A recent study in which Columbia University scientists monitored the temperatures of traditional, green, and cool roofing segments of the Con Edison facility in Manhattan shows that green roofs reduced summer rooftop temperatures by up to 84 percent relative to traditional roofs whereas the cool roof reduced temperatures by up to 67 percent.[lvii] In the previously mentioned Kobe University study that compared surface heat budgets of different roofing materials found the daytime temperatures of white roofs to be even lower than those on green roofs.[lviii]

Thus, cool roofs combat the urban heat island effect, making them an environmentally-friendly alternative to traditional roofs, and should be introduced as an alternative to property owners who are prevented from installing a green roof due to financial or structural constraints. Although cool roofs do not provide public stormwater benefits *per se*, they could be installed alongside rain barrels (funded in the District through the RiverSmart Homes program) or greywater systems that harvest rainwater for reuse in toilets or irrigation. Educational material on the benefits of cool roofs should be prepared and presented to property owners in the event that they are unable to install a green roof.

## 7. Conclusion

To maximize the environmental benefits of green roofs in Washington, D.C. thought should be given to both the stormwater management and the cooling and air quality benefits that green roofs provide. Because the storage tunnel is already being constructed in the Anacostia, green roofs installed in the Anacostia CSS will have little positive impact from a stormwater management perspective. However, the relative temperatures and vegetated cover of the sewersheds of Washington, D.C. reveal that the Anacostia CSS would probably benefit most in terms of air quality from the installation of green roofs.

Green roofs have the potential to make the greatest impact in the Rock Creek CSS and the MS4. Because DC WASA has agreed to reconsider its tunnel design for the Rock Creek CSS at a later date, in the near-term the Rock Creek CSS should be treated as an "LID showcase" to promote the advancement of green over grey stormwater infrastructure. In the long-term, there is reason to focus programs in the MS4. Once controls are in place throughout the CSS, the quality of the runoff in the MS4 will be comparatively worse (as stormwater in the system will be discharged without treatment). Installing green roofs in the MS4 would decrease the quantity of this untreated discharge. A look at the relative temperatures, vegetated cover, and adjusted net income distributions within the MS4 help to identify areas of focus within the MS4 (e.g., the southeastern portion of the Potomac sewershed).

Experience has shown that green roof subsidy programs that target revitalized commercial corridors are unlikely to result in a large quantity of green roof raisings because they tend to be geographically restrictive and because the financial incentives that green roofs provide are usually not substantial enough to justify the investment necessary for installation. If, however, future green roof subsidy programs are to be offered in the Congress and Deanwood Heights corridors, a revolving loan fund that would assist business owners in covering the high initial costs of green roof installation should first be created.

But designing a subsidy program for affordable housing developers might be a more fruitful way of providing underserved communities with access to green roofs. Public sector and private sector funding sources available at the national level could be combined with the subsidy that DDOE provides to finance such a program. And, affordable housing organizations, like the Housing Association of Non-Profit Developers in Washington, D.C., would be excellent and willing partners for future projects.

The installation of green roofs is an obvious goal of any green roof subsidy program, but for the many reasons outlined in this paper, green roof retrofits might not be a viable option for every property. While the recommendations provided in this report should help DC Greenworks and similar organizations to maximize the socioeconomic and environmental benefits of green roofs in urban contexts, DC Greenworks will no doubt continue to face formidable challenges in striving to install small-scale green roof retrofits in underserved communities. Thus, it is crucial that technologies that result in similar energy savings (e.g., cool roofs) and stormwater management benefits (e.g., rain barrels) be introduced as alternatives to property owners interested in but precluded from installing a green roof. In other words, in the quest to promote green roofs, the reasons for which the technology is valued should not be overlooked or forgotten.

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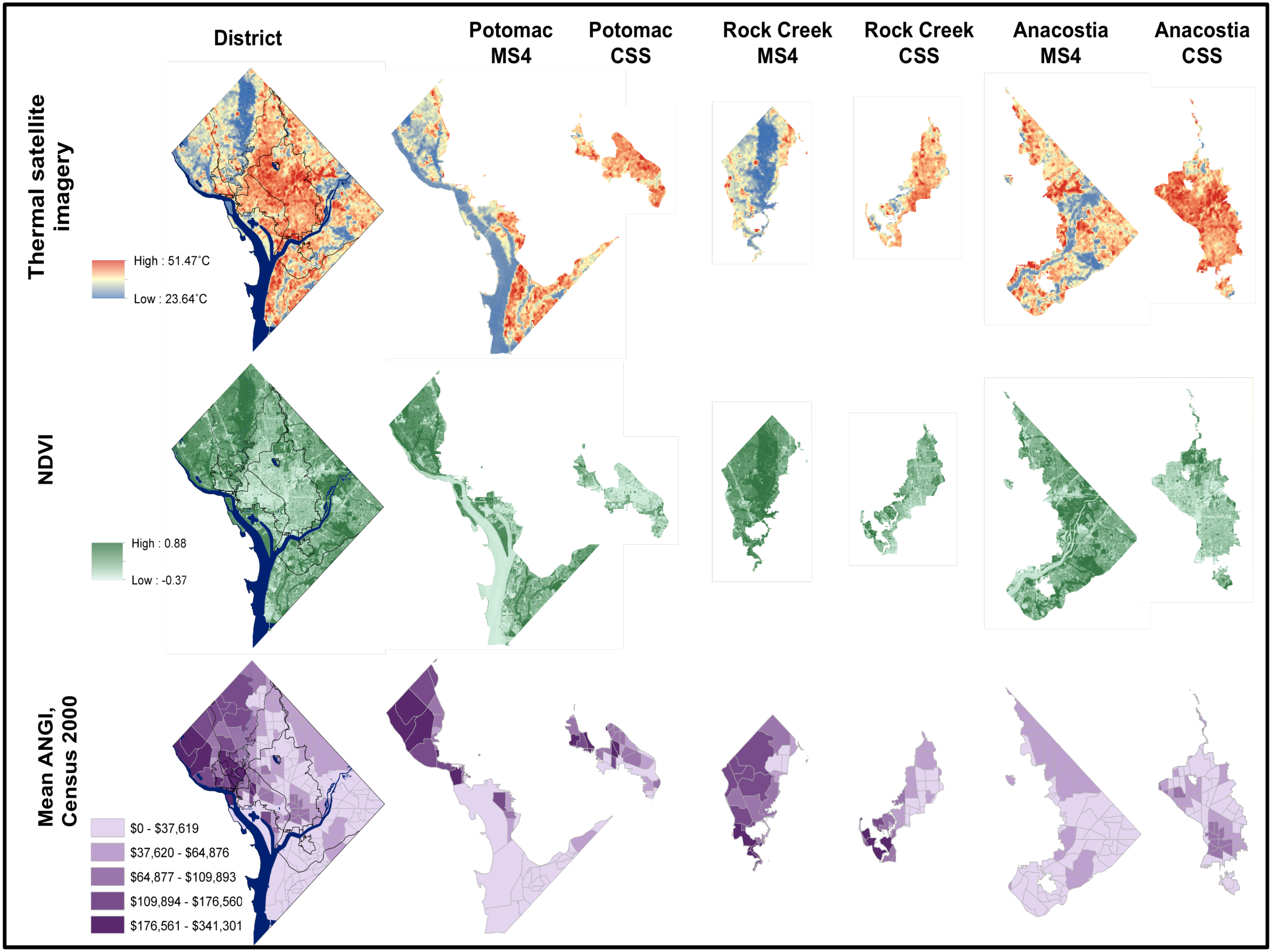
## Appendix A. Acronyms

| | |
|---|---|
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| CSO | Combined Sewer Overflow |
| CSS | Combined Sewer System |
| DC WASA | District of Columbia Water and Sewer Authority |
| DDOE | District Department of the Environment |
| DDOT | District Department of Transportation |
| EPA | Environmental Protection Agency |
| ERU | Equivalent Residential Unit |
| GREENER | Green Roofs for Environmental and Economic Northeast Revitalization |
| HAND | Housing Association of Non-Profit Developers |
| IAC | Impervious Surface Area Charge |
| LEED | Leadership in Energy and Environmental Design |
| LID | Low-Impact Development |
| MS4 | Municipal Separate Storm Sewer System |
| NHT | National Housing Trust |
| NIF | Neighborhood Investment Fund |
| NPDES | National Pollution Discharge Elimination System |
| RLF | Revolving Loan Fund |
| SRF | Slow-release Fertilizer |
| TMDL | Total Maximum Daily Load |
| VOCs | Volatile Organic Compounds |

## Appendix B. Thermal Imaging & GIS Data

**Appendix B:** Sewershed breakdowns of District surface temperatures and vegetation cover from August 2010 ASTER satellite image along with adjusted net gross income distribution from Census 2000.



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