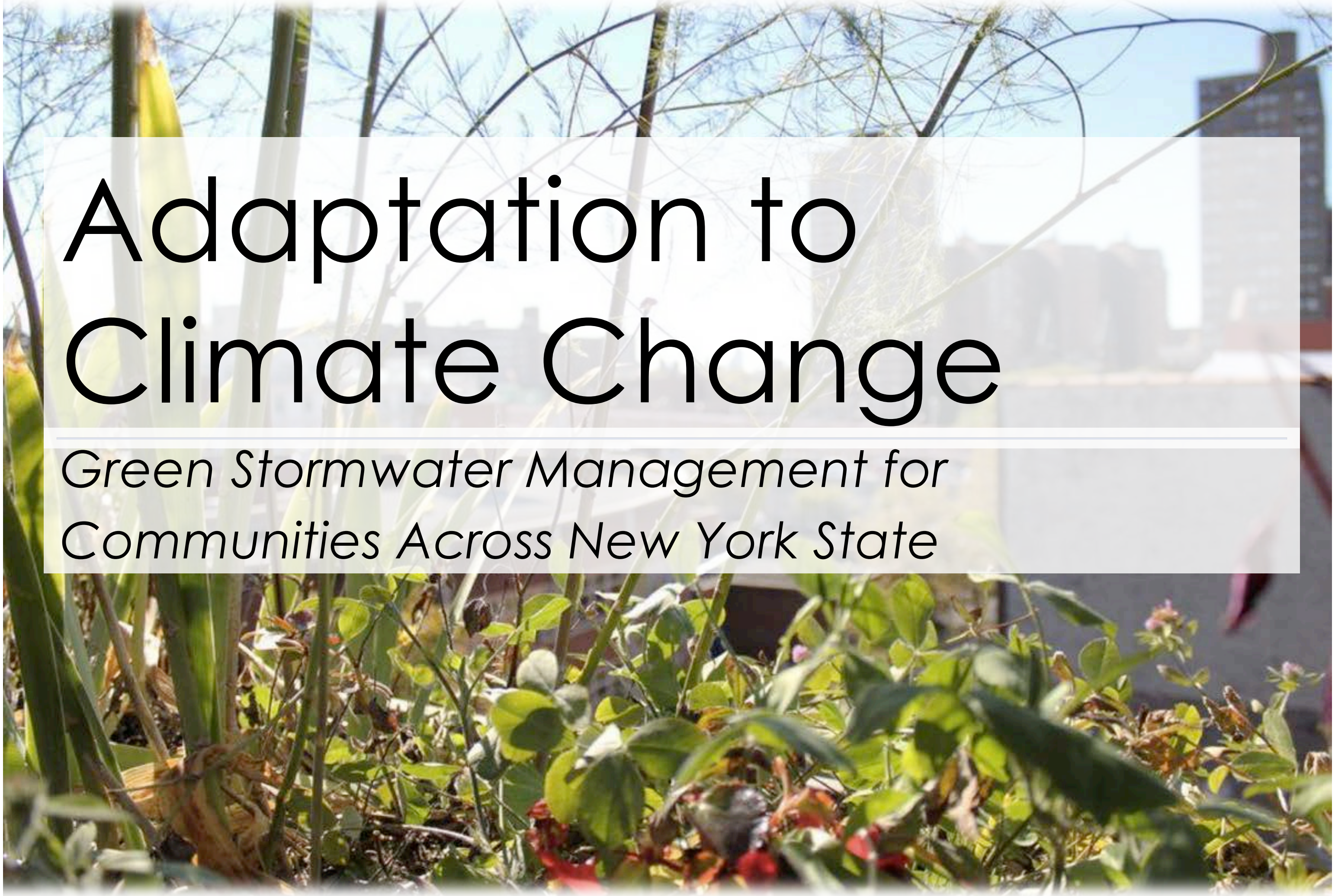

Adaptation to Climate Change

Green Stormwater Management for Communities Across New York State

Developed for:
The New York State Department of Transportation

In association with:
Columbia University School of Continuing Education and The Earth Institute

Christine Stearn – Project Manager
Simmy Martin – Deputy Manager
Inessa Klyachko
Chuck Samul
Maribel Santos
Molly Saso
Morgan Scott
Andrea Tenorio
Susanne DesRoches – Advisor

On the cover - Background Photo: Green Roof in New York. Photo courtesy of Minah Lee.

This report was developed by students completing the capstone workshop as a part of the M.S. Sustainability Management program at the Columbia University School for Continuing Education in association with the Earth Institute.

The capstone workshop is a client-based consulting project that students undertake to address critical sustainability management issues. The project is the culmination of their program studies and is a requirement to graduate. Through this experience, students receive hands-on sustainability management experience and increase their understanding of the real-world constraints under which sustainability managers operate.

.

Table of Contents

List of Acronyms[1]

AASHTO - American Association of State Highway and Transportation Officials
ASP – Amnesic Shellfish Poisoning
BMP – best management practice
CSO – combined sewer overflow
DDOE – District Department of the Environment
DEP – Department of Environmental Protection
DOT – Department of Transportation
EPA – Environmental Protection Agency
GHG – greenhouse gases
HAB – harmful algae blooms
MS4 – municipal separate storm sewer system
NPDES – National Pollutant Discharge Elimination System
NRCC – Northeast Regional Climate Change
NSP – Neurotoxic Shellfish poisoning
NYSDOT – New York State Department of Transportation
PCB – Polychlorinated Biphenyls
PSP – Paralytic Shellfish Poisoning
SRC – Stormwater Retention Credit
SSO – Separate Sewer Overflows
TMDL – Total Maximum Daily Load

Executive Summary

Background

New York State comprises a diverse landscape, geography, climate, and transportation infrastructure. New York's 47,000 square miles of land area is home to nearly 20 million residents and a state and local highway transportation network that handles over 130 billion vehicle miles annually.[2] [3] The diverse landscape, natural resources, and modes of transit make for an ambitious challenge for the New York State Department of Transportation (NYSDOT) to attain its mission, ensuring customers – those who live, work, and travel in New York State – have a safe, efficient, balanced, and environmentally sound transportation system.[4]

An evaluation of climate change projections for the New York region shows that the State can expect to see an increase in annual temperature, annual precipitation, and an increase in the frequency of extreme precipitation events.[5] For those who manage the State's transportation infrastructure, this will mean an increase in stormwater, which can significantly impact those transportation systems. In order to prepare for these forecasted increases in stormwater quantities, communities must act now to implement strategies, which can help mitigate the amount of stormwater reaching transportation and sewer infrastructure and ultimately receiving waters.

This report evaluates nine stormwater management strategies utilizing green infrastructure techniques. Green infrastructure is a way of utilizing or protecting already existing natural infrastructure (wetlands, parks, forest reserves, etc.) or the development of nature-mimicking infrastructure, to capture, cleanse, and reduce stormwater runoff.[6] While these strategies will not handle extreme event flooding, as seen during recent hurricanes Irene and Sandy, they are appropriate for managing a majority of the precipitation events the State experiences. These strategies are highlighted because they not only manage stormwater, but also have a number of secondary benefits for communities including, but not limited to, groundwater recharge, improved water quality, the support of natural biodiversity, improved air quality, and increased green space and recreational opportunities.

Each strategy is evaluated based on its life cycle, cost, implementation timeframe, required maintenance, and secondary benefits. This information is synthesized in a one-page evaluation matrix where decision makers can easily compare the strategies in relation to each other. A case study is also provided for each strategy to demonstrate successful implementation. Emerging research is also discussed and highlights new technologies and policies that are in development and may provide future solutions to New York communities.

Finally, recommendations are presented which stress the need for communities to consider enhancing their current stormwater management given climate change projections incentivizing them to install the green infrastructure strategies highlighted in the compendium. The compendium will serve as a starting point for communities throughout the State to begin planning for future stormwater management projects.

Strategies Summary and Evaluation Matrix

A brief description of each strategy is provided below, along with an associated benefit and challenge. A partial version of the final evaluation matrix is also provided below, with the full version available on page 64. The full discussion of recommendations is provided in the Recommendations & Conclusions section on page 74.

Strategies Summary

Pervious Pavement

Pervious pavement, commonly referred to as porous pavement, is one strategy used to alleviate the difficulties of excess water runoff from impervious surfaces by allowing water to pass through, rather than over, the surface. Pervious asphalt, sidewalks, and pavers were considered in the analysis of this strategy.

- **Benefit:** Total cost is relatively low.
- **Challenge:** Siting can be challenging, as they function optimally when placed on shallow slopes above soils with certain permeability rates.

Bioretention/Bioswales

Bioretention is a terrestrial-based water quality and quantity control practice that uses plants, soils and microbes for the removal or pollutants and retention of stormwater.

- **Benefit:** Maintenance frequency is very low.
- **Challenge:** Bioretention project sites must be 6 feet or more above the water table to provide sufficient water purification.

Rain Gardens

Rain gardens are generally larger in size than bioswales and are designed to manage rain events of 0.5 inches per hour but can be designed for higher rates of rainfall, if determined necessary, by increasing the size of the installation or by using more vegetation.

- **Benefit:** Maintenance cost is very low.
- **Challenge**: Capital cost can be quite high depending on the location and size of the rain garden.

Street Trees

Street trees is a strategy which uses trees to mitigate the impacts of stormwater through three ways that may be broadly defined as detention, retention and return.

- **Benefit:** When maintained properly, street trees can have a very long lifetime.
- **Challenge:** Street trees will be difficult to employ in areas with high bedrock.

Green Roofs

Green roofs are any type of vegetation system established on the roof of a building. Some precipitation that falls on green roofs is detained and can delay peak runoff, while a significant amount of precipitation is retained and absorbed by the vegetation itself.

- **Benefit:** Maintenance cost is low.
- **Challenge:** Buildings may require additional structural support to maintain the weight of the green roof and associated water.

Rain Barrels

Rain barrels usually collect stormwater runoff via roof gutter systems and generally have a capacity of 50 to 100 gallons. They are effective because they are able to temporarily detain stormwater and delay peak runoff.

- **Benefit:** Level of expertise required for installation is low.
- **Challenge:** Rain barrels are only effective if they are emptied when they reach full capacity.

Green Spaces

The use of green spaces such as parks, courtyards, greenways, and stepped vegetated cells are strategies that can effectively manage stormwater and mitigate flooding. Soil and native vegetation are able to store, filter, and infiltrate stormwater, often acting as natural pollution reduction mechanisms.

- **Benefit:** Capture rate is generally high.
- **Challenge:** Because vegetation is capable of absorbing and retaining the most amount of stormwater with mature roots and leaves, the benefits of green spaces are more long-term and are not maximized until the species have grown and matured.

Land Acquisition and Preservation

The acquisition and protection of watershed lands in order to reduce over-development can be critical to naturally managing stormwater. Preserved land provides natural locations for stored water. Through reduced development and therefore the prevention of increased presence of impervious surfaces, the amount and speed of stormwater runoff is reduced and the possibility for flooding reduced.

- **Benefit:** Capture rate is high.
- **Challenge:** The total cost of land can be high and financing for acquisition must be determined.

Bluebelt

A bluebelt program is an effort to preserve and enhance the use of naturally occurring wetlands to promote natural drainage and travel of stormwater away from developed locations and transportation systems. The bluebelts manage stormwater primarily utilizing existing natural infrastructure, taking advantage of wetlands to store stormwater. However, these natural resources are supplemented by "bluebelt facilities," constructed at locations where the sewer system ends and nature begins. These facilities, which include stormwater detention ponds and constructed wetlands, are intended to reduce the potential negative impact of stormwater drainage during precipitation events on the natural infrastructure.

- **Benefit:** Capture rate is very high.
- **Challenge:** The strategy requires the availability of wetland spaces for preservation.

Partial Evaluation Matrix

	Capture Rate	Capital Cost	Maint. Cost	Total Cost	Maint. Freq	Life-time	Exper-tise	Setting
Unit	g/m/sf	$/sf	$/sf/yr	$/sf	x/yr	yrs		U, S, R
Good ○	.005-.019	15-200	2-10	100-200	monthly		high	
Better (grey)	.02-.099	1-14.99	0.20-1.99	10-99.99	quarterly		medium	
Best ●	≥ .10	≤ 1	≤ 0.20	≤ 10	≤ 2x/year		low	
Pervious Pavement	varies[a]	Better	Best	Better/Best	Better	15-25+	Good	U, S, R
Swales	Good/Better	Good	Best	Better	Best	30	Good	U, S
Street Trees	Good/Better[b]	Good	Better	Good/Better	Better/Best	8-100+	Good/Better	U, S
Rain Gardens	Better	Good	Best	Better	Best	30	Good	U, S
Green Roofs	Good/Better	Good/Better	Better	Good/Better	Good/Better	30-50	Good	U
Rain Barrels	N/A[c]	Best[d]	Good[d]	Good[d]	Best	20	Best	U, S, R
Green Space	Better/Best	varies[e]	Best	varies[e]	Good/Better	100+[f]	Good/Better	U, S
Land Acq & Pres	Better/Best	Best	varies[g]	Best	varies[g]	100+[f]	Good	S, R
Bluebelts	Best	Best	Best	Best	varies[h]	20-50	Good	U, S

Note: Legends and notes for the matrix can be found starting on page 61.

This evaluation matrix provides a snapshot summary of all of the proposed green strategies against a set of varying metrics for easy cross-comparison. There are two ways to read the matrix, either by row or by column. If examined by row, a comprehensive summary and understanding of a given strategy through the selected attributes, such as capture rate, cost, and maintenance frequency, can be garnered. When isolating any given column, all strategies can be compared against one another to see which best performs in that category. A circle filled with two colors indicates that there is a range of values for that attribute (ranges for the "good," "better," and "best" categories can be found at the top of the evaluation tool).

A cursory glance at the evaluation tool shows that there are no clear "winners" across all categories of attributes. However, each strategy does perform well in at least a few categories. Depending upon the specific constraints of a town or area, a decision-maker can select management strategies that will best circumvent those impediments. A community working with a small amount of space, perhaps in a more urban setting, should consider the installation of pervious pavement, swales, street trees, or rain gardens. The ultimate choice of which strategies to utilize can be made by comparing the strategies against the attributes that are of most relevance to the community, whether it's capital cost or maintenance frequency, for example. Decision-makers can also encourage property owners to explore employing rain gardens, green roofs, and rain barrels on their own properties to assist the community in managing stormwater on the micro level. For communities in a suburban or rural setting, the green space, land acquisition and preservation, and bluebelt strategies should be further examined for installation. These strategies generally require more land, and in some case a certain type of land, such as wetlands for bluebelts; however, they are the best performing strategies analyzed in this report, and along with high capture rates and low costs, the strategies can have very long lifetimes when maintained properly.

This evaluation matrix highlights that there are green stormwater management options for any community bound by constraints. While this matrix provides a summary of all strategies explored in this report, decision-makers are encouraged to read the entire report, especially the Strategies to Mitigate Projected Increases in Stormwater Runoff section (starting on page 30), where more detailed information supporting the findings in the matrix can be found.

Introduction

Global climate change effects are being observed in New York State. Rain downpours, a forecasted climate change impact, are on the rise in the Northeast, posing an increased threat to the lives and economy of New York by impacting residential, commercial, government, and transportation buildings and infrastructure. New York State communities and municipalities need information and tools to manage this threat in order to protect the lives, infrastructure, and economies that rely on the built environment. To help equip communities and municipalities, Columbia University and the Earth Institute's Sustainability Management graduate students developed this compendium of best practices for reducing stormwater runoff through the utilization of green infrastructure strategies in urban and suburban settings as a capstone project for the New York State Department of Transportation (NYSDOT). The capstone project's overall objective is to develop a report to assist communities and transportation agencies in making informed climate change adaptation decisions to reduce the impacts on transportation infrastructure caused by extreme rainfall events. This project was sponsored by the NYSDOT Technical Advisory Committee:

> *Project Manager:*
> Elisabeth Kolb - Senior Environmental Specialist, Sustainability and Climate Change Section; Statewide Policy Bureau
> *Team Members:*
> Paul Krekeler - GreenLITES Manager, Sustainability and Climate Change Section; Statewide Policy Bureau
> Dave Graves - Head, Water/Ecology; Environmental Science Bureau
> George Long, PE - Hydraulics Group, Structure Division

This compendium report is designed to provide decision makers with an overview of stormwater strategy options available to reduce the negative impacts of and increase resilience against extreme and more frequent rainfall events, which affect infrastructure, public travel safety, commercial transport of goods and services, and water quality. This report is designed for distribution beyond the NYSDOT to representatives on town boards, town supervisors, mayors, engineers, transportation highway supervisors, metropolitan planning organizations, and general decision makers within the purview of NYSDOT located in New York State. This report provides these decision-makers information on climate change projections, stormwater impacts, and strategies utilizing green infrastructure for stormwater management.

---

[1] A Glossary of Terms is also included as Appendix A.

[2] US Census Bureau. *New York QuickFacts from the US Census Bureau*. 18 September 2012. Webpage http://quickfacts.census.gov/qfd/states/36000.html. 17 October 2012.

[3] NYSDOT. *Mission and Values*. 1999-20012. Webpage https://www.dot.ny.gov/about-nysdot/mission. 17 October 2012.

[4] ibid

[5] Rosenzweig, C., et al. *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation.* Annals of the New York Academy of Sciences 1244(1): 2-649.

[6] Wise, Steve. "Green Infrastructure Rising." *American Planning Association* (2008): 14-19.

Methodology

Methodology

The Columbia University Sustainability Management graduate student capstone team researched climate projections and climate change adaptation strategies for stormwater and then synthesized existing information into guidance for decision-makers, practitioners, and stakeholders. Recommendations were derived from insights identified while performing literature review, including manuals and reports, case study research, and interviews.

Broad Research Approach

In order to better understand the climate impacts expected in the New York State region, as well as the green stormwater management strategies appropriate for adaptation to those impacts, the team completed the following evaluation:

- Performed literature review and collected data regarding current stormwater practices from various national and international manuals, case studies, papers, and guides to understand how stormwater is currently managed as well as how climate projections affect stormwater.
- Synthesized existing stormwater practices and climate projections, including stormwater adaptation strategies that incorporate green infrastructure approaches.
- Developed evaluation metrics for best practice stormwater adaptation based on the literature review and created an evaluation tool so decision makers can easily compare these metrics.
- Selected green stormwater strategies and supporting case studies to help manage the increasing climate change-altered precipitation for New York State. These green strategies will not manage all stormwater, but can provide significant reduction of stormwater issues.

Analytic Framework

The team's process of identifying best practice stormwater adaptation strategies to address future rainfall projections was largely an inductive approach that included primarily qualitative data analysis and limited quantitative analysis. The goal of the qualitative data analysis was to identify emerging themes, patterns, insights, and best practices to adapt to intense rainfall scenarios.

The team's analysis included literature reviews and interviews. The interviews were conducted in various ways: in person interviews, telephone interviews, and when neither option was available, questionnaires via email. A list of those interviewed for the report is provided in Appendix C.

The goal of the quantitative data analysis was to summarize rainfall intensities from a sample of climate data, specifically data collected by ClimAID and the Northeast Regional Climate Center (NRCC), to locations and geographies in New York State. Determining if the predictive generalization of this data holds true is challenging, as climate projections are less accurate for higher degrees of geographic specificity. Nonetheless, this trending gives a basis for which future rainfall and stormwater runoff conditions can be assumed and designed for as proposed in this report.

Literature Review and Data Collection

The Literature Review was conducted using Columbia University's librarian subject specialist, *Google, Google Scholar*, *EBSCOhost*, and *Educat, and Derwent Innovations Index* databases. The review included five main areas: Northeast climate projections, general stormwater reports and guides, best practice stormwater research, stormwater case studies, and emerging stormwater practices.

The assessment of stormwater best practices focused on academic papers, government reports, and stormwater manuals and guides from government agencies. Emerging stormwater practices came from industry periodicals, government agency pilot project reviews and proposed rules, and a review of the national patent list allowing the team to identify technologies not yet available to the mainstream market but which may be appropriate in the future to manage stormwater.

While reviewing the various stormwater strategies to determine which were most appropriate for use in New York State's urban and suburban locations, the team utilized three primary assessment questions, including (1) what strategies would help alleviate the challenge of stormwater runoff given the current New York State climate and future projections for precipitation; (2) the feasibility of a particular strategy as a community or transportation investment; and (3) whether the strategy is considered green infrastructure, incorporating natural processes into the overall management strategy.

Once the stormwater strategies were selected, each was analyzed to assist the reader in understanding the best practice stormwater strategies and whether they were feasible for the reader's particular location. The following researched information is provided for each strategy:

- Description – explains the strategy's components and how it manages stormwater
- Life cycle – describes how long the strategy will be able to perform
- Cost – focuses on the initial capital cost required for implementation
- Implementation timeframe – outlines the expected time commitment
- Maintenance – includes both a look at what will be required and the cost to complete
- Impacts
    - Benefits – provides secondary benefits of implementation apart from the ability to manage stormwater
    - Challenges – explains the high-level challenges to implementation

For each stormwater strategy considered, team members researched case studies and existing practices in use nationally and internationally. Whenever possible, the case study featured was selected because the location was similar to the New York state climate, density, and topography.

An evaluation tool was developed to assist decision makers in evaluating the applicability and potential benefits of green stormwater management strategies in their communities using nine metrics: effectiveness (capture rate), cost (capital, maintenance, and total cost), maintenance requirements, lifetime, expertise required for installation, the setting the strategy works best in (urban, suburban, rural), and secondary benefits (improves water quality, recharges rainwater, increases recreational activities, etc.). These metrics have been organized in an easy-to-use evaluation tool, which can be used to quickly compare strategies and determine those that may be appropriate for further investigation for a site.

In total, the team compiled and reviewed the following sources of data and literature.

	Reviewed
Climate Projections	5
Best Practice Research	40
Reports	40
Pilot Projects / Case Studies	70

Table 1. Research metrics.

Interviews

Interviews with NYSDOT representatives shaped the priorities of this compendium report as well as provided critical information of current practices and impacts. Interviews with researchers and practitioners provided additional data and anecdotes not included in reports and case studies. A total of 31 interviews were conducted, and a full list of interviewees can be found in Appendix C.

Climate Change Impacts on Stormwater

Climate Change Impacts on Stormwater

In the State of New York, storm frequency and intensity are shifting, and it is expected that more severe storms will occur more often.[1] Changes in temperature, as well as rainfall intensity and frequency, are important to stormwater management as they influence (1) the amount of water that needs to be managed, (2) the saturation rate of soil and existing stormwater management infrastructure, which influence runoff quantities, and (3) the evaporation capacity, impacting stormwater removal from infrastructure. These changes will place increased demands on stormwater systems like sewer and flood control systems and will challenge municipalities to adopt new strategies to manage larger volumes and rates of stormwater. Furthermore, these stormwater systems are built to capture a certain amount of runoff and are based on historical hydrological data. In light of future projected increases of heavy precipitation and runoff, communities and transportation agencies should assess capacities and evaluate whether to invest in additional stormwater facilities. The strategies provided in this report provide for additional stormwater management capacity through the implementation of green infrastructure.

In order to understand these changes in New York, this report focuses on projections reflected in the ClimAID Report - Responding to Climate Change in New York State and precipitation projections from the Northeast Regional Climate Center (NRCC).

Projections of future climate conditions are characterized by large uncertainties like future land-use changes, future emissions of Greenhouse Gases (GHG), and other uncertainties like the sensitivity of the climate system to changes in GHG concentrations. At smaller regional and local geographical scales, such as projections specifically for New York State, uncertainties increase further due to naturally occurring changes in rainfall, which partially disguise the overall effects of climate change. Global climate models might not capture changes in local atmospheric processes operating on a small scale. Finally, extreme events, because of their rare occurrence, are characterized by even higher uncertainty than the annual averages.[2] The green strategies recommended in this report will help manage runoff during precipitation events but will not provide protection for extreme weather events like hurricanes and tropical storms, especially when accompanied with storm surge.

> *"Methodology that engineers use to quantify flows - intensity, duration, and frequency was developed in the 1950s. A lot of the assumptions are antiquated."* - Dave Graves, Head of Water/Ecology Unit, New York State Department of Transportation

New York State Climate Profile and Projections

ClimAID researchers divided New York State into seven regions (see Figure 1B in Appendix B for regions), evaluating historical climate trends and projecting future climate changes for each region and the state as a whole. This section is focused on synthesizing information related to rainfall, snowfall, temperature, and extreme events.

Existing and Historical Rainfall and Snow Trends

To understand the potential impacts of climate change in New York, it is important to first look at current rain and snow intensity trends, as historical values provide the foundation for many engineering design specifications and regulatory requirements.

Average Annual Rainfall

On average, New York State receives about 40 inches of precipitation per year. Western New York is considered relatively dry with an average of 30 inches of precipitation per year. The Adirondacks and Catskills, the Tug Hill Plateau, and portions of the New York City area average approximately 50 inches of precipitation per year.[3] Looking at historical trends, total annual precipitation has increased slightly in the Northeast region of the US by approximately 3.3 inches over the last 100 years.[4] Average precipitation received throughout NY State is depicted in Figure 1.

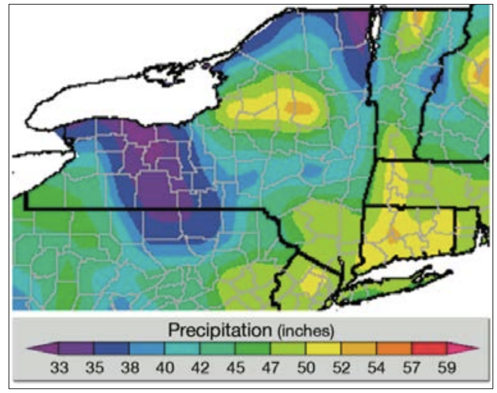

Figure 1. Normal average precipitation (Rosenzweig, Solecki and DeGaetano).

Average Seasonal Snowfall

On average, more than 40 inches of snow falls in New York State annually. Snowfall varies regionally, as seen in Figure 2, based on topography and the proximity to the Great Lakes and the Atlantic Ocean. In some of the western-most regions of the state, such as Hill Plateau and the Adirondacks, the highest seasonal snowfall exceeds 175 inches.[5] While snow itself may be a challenge, the associated melting and flooding can have damaging stormwater impacts as well.

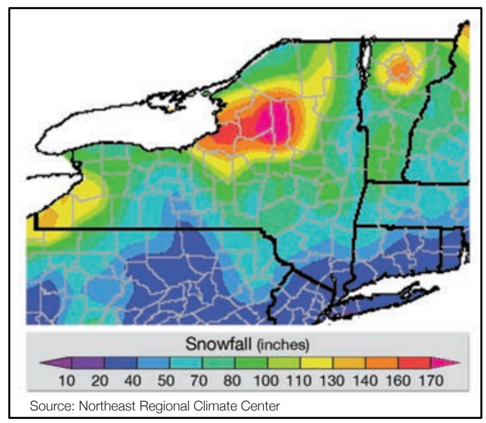

Figure 2. Normal average snowfall in New York State (Rosenzweig, Solecki and DeGaetano).

Heavy Precipitation Events

Heavy precipitation events can be associated with small-scale thunderstorms, large-scale coastal storms, nor'easters, and warm-season tropical cyclones.[6] With intense precipitation comes the concern of flooding. Looking at historical trends in the Northeast, there has been a 67 percent increase in the number of 2-inch rainfall events occurring over a 48-hour period since the 1950s.[7] A two-inch rain event means two or more inches of rain falling in a 48-hour period.

Figure 3. Flash Floods Strand Cars in Queens, August 2012 – the National Weather Service estimated that about two inches of rain fell in central Queens in 2 hours (Newman, 2012).

Projected Climate Change

Future climate projections are important to the performance of stormwater management systems as these systems are built around assumptions of regional hydrological cycles, such as precipitation and evaporation rates. To assess future stormwater needs, it is important to look at future climate change projections, specifically changes in temperature, precipitation intensity, and extreme events.

Potential Changes in Temperature, Precipitation, and Extreme Events

It is not possible to predict the temperature or precipitation for a particular month or year, due to uncertainties in the climate system, but projections can be made over decadal and multi-decadal time periods. In New York, climate models predict a higher mean temperature and an increase in intense precipitation events with likelihood greater than 95 percent and greater than 66 percent, respectively.[8]

Annual Temperature Change

Average annual temperature is projected to increase across New York State by 1.5 to 3 degrees Fahrenheit in the 2020s, 3.0 to 5.5 degrees Fahrenheit in the 2050s, and 4-9 degrees Fahrenheit in the 2080s.[9] These projections represent the middle 67 percent and have removed the outliers at the low-end and high-end.[10] Temperature impacts stormwater management because increased temperature allows for more moisture in the atmosphere and also increases evaporation rates.

Annual Precipitation Change

Typical precipitation variability is large, and thus precipitation projections are less certain than temperature projections. Climate change projections indicate regional precipitation across New York State may increase by approximately 0–5 percent by the 2020s, 0–10 percent by the 2050s, and 5–15 percent by the 2080s.[11] Again these increases in precipitation projections represent the middle 67 percent of values removing the low-end and high-end outliers. Figure 4 and Table 2 show these percentages by region with the greatest increases in precipitation forecasted by the end of the century in the northern regions of the state.[12]

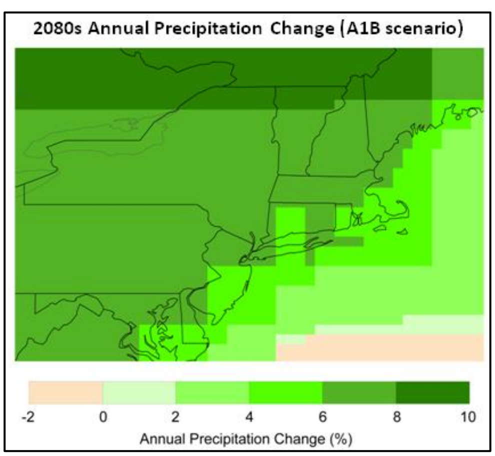

Figure 4. Projected changes in annual and precipitation for the 2080s in the Northeast, under the A1B ("middle") emissions scenario, relative to the 1970-1999 baseline (Rosenzweig, Solecki and DeGaetano).

Region	Baseline	2050	2080
1. Western New York Great Lakes Plain	37 in	0% to +10%	0% to +15%
2. Catskill Mountains and West Hudson River Valley	48 in	0% to +10%	+5% to +10%
3. Southern Tier	38 in	0% to +10%	+5% to +10%
4. New York City and Long Island	47 in	0% to +10%	+5% to +10%
5. East Hudson and Mohawk River Valleys	38 in	0% to +10%	+5% to +10%
6. Tug Hill Plateau	51 in	0% to +10%	+5% to +15%
7. Adirondack Mountains	38 in	0% to +5%	+5% to +15%

Table 2. Precipitation projections for the seven ClimAID regions (Rosenzweig, Solecki and DeGaetano).

Change in Extreme Precipitation Events

Despite their brief duration or infrequent occurrence, extreme precipitation events are a critical component of how climate will affect stormwater management. Because extreme events are by definition rare, they are characterized by higher uncertainty than the annual averages discussed earlier. Extreme precipitation events are likely to grow with significant increases projected in the intensity and frequency of extreme precipitation events.[13]

For precipitation intensity in the Northeast, increases of 8 to 9 percent are projected by mid-century, and 10 to 15 percent by the end of the century.[14] Aligning with these projections, there is already a positive trend in the number of events greater than one inch (within 24 hours) from 1961-2000 in New York State, as shown in Figure 5.

As for frequency, in the Northeast the reduction for recurrence intervals of the 2-, 50-, and 100-yr storm is approximately 30 percent.[15] This means that if a 100-year storm has a one percent chance of being exceeded in any year, a reduction of return interval by 30 percent would mean that the 100-year storm is now a 70-year storm and now has a 1.4 percent chance of being exceeded in any year.

When taken together, the amount of rain falling in a 100-year storm is projected to increase, while the number of years between such storms ("return period") is projected to decrease (shown in Figure 6). Thus, rainstorms will become both more severe and more frequent.

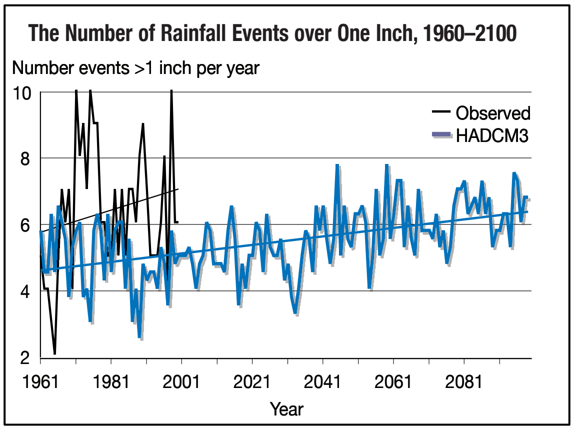

Figure 5. The observed number of rainfall events exceeding one inch from 1960 to 2000 is shown by the black line, and the projected number of such events is show by the blue line (Rosenzweig, Solecki and DeGaetano).

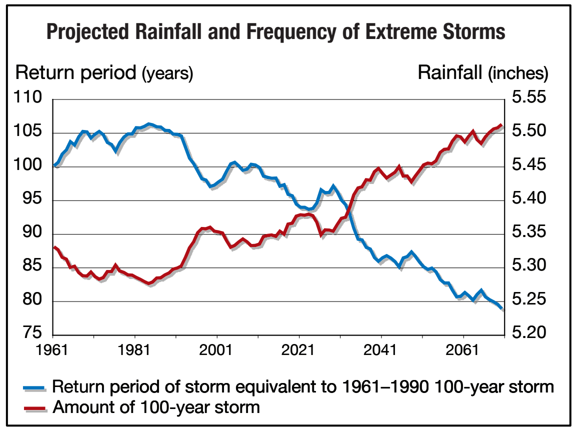

Figure 6. The amount of rain falling in a "100-year" storm is projected to increase (red line), while the number of years between such storms is projected to decrease (blue line). Thus, rainstorms will become both more severe and more frequent (Rosenzweig, Solecki and DeGaetano).

Conclusion

Climate change has already been linked to excess storm water and flooding impacts in New York, and the projections provided in the ClimAID report and through NRCC data support the notion that further changes are likely. The latest assessment of average temperatures in New York are projected to increase significantly over the coming decades, and rain is expected to fall more often as heavy downpours, leading to more flooding. The historical regional climate patterns of the past several decades, which is commonly used by transportation planners to guide operations and investments, may no longer be a reliable guide.[16] This further supports the need for communities to determine best management practices for stormwater management.

Additional Climate Change Resources

ClimAID Webinar Series - http://www.nyserda.ny.gov/Publications/Research-and-Development-Technical-Reports/Environmental-Reports/ClimAID-Webinar-Series.aspx?sc_database=web

ClimAID Report - http://www.nyserda.ny.gov/Publications/Research-and-Development/Environmental/EMEP-Publications/Response-to-Climate-Change-in-New-York.aspx

ClimAID Report Climate Risks Chapter - http://www.nyserda.ny.gov/Publications/Research-and-Development/Environmental/EMEP-Publications/~/media/Files/Publications/Research/Environmental/EMEP/climaid/11-18-response-to-climate-change-in-nys-chapter1.ashx

Northeast Regional Climate Center - http://www.nrcc.cornell.edu/

---

[1] Rosenzweig, C., et al. *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation.* Annals of the New York Academy of Sciences 1244(1):2-649.

[2] ibid

[3] ibid

[4] DeGaetano, Art, et al. *Climate Change Facts - New York's Changing Climate*. October 2011. Cornell University College of Agriculture and Life Sciences. PDF. 1 November 2012. <http://www.nrcc.cornell.edu/climate_change/climate_ny.pdf>.

[5] Rosenzweig et al., 2011

[6] ibid

[7] DeGaetano et al., 2012

[8] Rosenzweig et al., 2011

[9] ibid

[10] ibid

[11] ibid

[12] ibid

[13] ibid

[14] Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions.* Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists, 2007.

[15] DeGaetano, Arthur T. "Time-Dependent Changes in Extreme-Precipitation Return-Period Amounts in the Continental United States." *Journal of Applied Meteorology and Climatology* 48 (2009): 2086-2099. Document.

[16] Transportation Research Board. *Estimating Life Expectancies of Highway Assets*. NCHRP REPORT 713. Washington, D.C.: Transportation Research Board, 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_713v1.pdf.

Stormwater Impacts on Communities and Transportation

Stormwater Impacts on Communities and Transportation

Stormwater is the water associated with a rain or snow event that fails to percolate into the ground and instead runs on streets, parking areas, sports fields, gravel lots, and other land surfaces until it drains into receiving waters such as streams, lakes, and rivers. Stormwater has a wide range of adverse impacts affecting public health, ecosystems, transportation, and economic activities, but does not need to when managed properly. If continuing with status quo approaches, an increase in precipitation and heavy precipitation events are likely to cause more frequent adverse impacts affecting both communities and transportation in New York State.

Community Impacts

Under natural conditions, precipitation soaks into the ground, filters through the soil, and recharges the groundwater. However, impervious surfaces, such as paved roads, prevent rain and melting snow from soaking into the ground. As the stormwater runs over impervious surfaces like roofs, sidewalks, roads, and parking lots, it picks up loose soil, pet waste, plant fertilizers, chemicals from automobiles (gasoline, motor oil), hazardous household waste (insecticides, paint, solvents) and other debris (plastic bags, cigarette butts), as shown in Table 3. It then deposits these pollutants into receiving waters such as streams, lakes and rivers, causing water quality degradation, which, in turn, can cause other environmental, social, and industry impacts.

Urban Stormwater Pollutants	Common Sources
Sediments and particulates	Atmosphere, erosion, vehicle wear, industrial activities
Nutrients (nitrogen and phosphorous)	Atmosphere, fertilizers, detergents
Heavy metals (zinc, lead, iron, mercury, copper, cadmium, chromium, nickel, manganese, cyanide)	Fungicides, insecticides, galvanized building materials, tire wear, motor oil, engine parts, rust, machinery, erosion, industrial activities
Hydrocarbons (petroleum products)	Spills, leaks, antifreeze, hydraulic fluids, asphalt surface leachate
Organic Compounds (phthalate esters, phenolic compounds, and volatile organics)	Pesticides, plastics, cleaners
Microorganisms (bacteria and viruses)	Combined sewer overflows, illicit connections, pet waste
Salts (sodium, magnesium and chlorides)	Road de-icing salts

Table 3. Stormwater pollutants (Huntsinger).

Environmental Impacts

New York State has a variety of rich water bodies including rivers and streams, lakes and ponds, estuaries, and ocean coastline, all of which can be adversely affected by stormwater runoff. Stormwater can carry nutrients to a water body making it too nutrient rich and no longer able to support plant or aquatic life. In addition, excessive nitrogen and phosphorus loads can cause algal blooms. When algae die, they sink to the bottom and decompose in a process that removes oxygen from the water. Fish and other aquatic organisms cannot exist in water with low dissolved oxygen levels.[1] In addition, other algae species, like blue green algae, create toxins and blooms of organisms that are classified as Harmful Algae Blooms (HABs) and have both economic and cultural impacts. HABs are considered an environmental hazard because they can make people sick when contaminated shellfish are eaten, or when people breathe aerosolized HAB toxins near the beach. In addition, HAB events can result in the closure of shellfish beds, massive fish kills, death of marine mammals and seabirds, and alteration of marine habitats.[2]

Social Impacts

Public Health

Stormwater is also a public health issue when the water and food supplies contain toxins, or bacteria, viruses, protozoa, and parasites, from fecal contamination from wildlife, livestock, pets, and human waste because of failing septic systems and combined sewer overflows (CSOs). CSOs are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. The CSOs transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. However, during periods of heavy rainfall or snowmelt, wastewater volume can exceed the capacity of the sewer system or treatment plant where these plants are designed to overflow and discharge excess wastewater directly to nearby streams, rivers, or other water bodies.[3] A sign warning residents of a discharge point in New York is shown in Figure 7. As an example, in Walkerton, Ontario, a heavy precipitation event, combined with failing infrastructure, contaminated drinking water with E. coli and Campylobacter jejuni, resulting in an estimated 2,300 illnesses and seven deaths.[4]

Figure 7: New York discharge point (Uptownradio.org).

Recreation

Pollution from stormwater runoff is the most frequently identified reason for beach closings and advisory days, and the EPA estimates that more than 10 trillion gallons of untreated stormwater make their way into our surface waters each year.[5] These closings are mainly due to the presence of harmful bacteria. Beach closings impact the recreational activities of those going to the beach as well as reduce tourism revenues. In addition, pathogens from wet weather impacts and boat pollution can contribute to fishing restrictions in and around marinas and other recreational areas.[6]

Quantifying Stormwater Economic Impacts on a Community

The socio-economic and environmental costs as a result of stormwater runoff are difficult to quantify. The medical and lost productivity costs associated with water-borne illnesses can be significant, as the EPA estimates that CSOs and separate sewer overflows (SSOs) cause at least 5,576 illnesses every year from recreational exposure at recognized recreational beaches across the country.[7] HAB events adversely affect commercial and recreational fishing, tourism, and valued habitats, creating a significant impact on local economies and the livelihood of coastal residents. A 1976 New Jersey red tide caused losses estimated at more than $1 billion in 2000 dollars.[8] A report from 2000 estimates the average public health impact due to shellfish poisoning from HABs was approximately $1 million per year (caused by paralytic, neurotoxic, and amnesic shellfish poisoning, or PSP, NSP, and ASP, respectively).[9] Finally, a study looking at the economic impact of regional beach closings estimates that the Long Island economy lost 1.4 percent of its tourism-related economic activity, resulting in a loss of sales tax revenues of $4.8 million.[10]

Transportation Impacts

Over the next few decades, heavy precipitation events are likely to cause more frequent transportation problems, such as weather-related mass transit delays, traffic disruptions, flooded evacuation routes, and disruption of construction activities and business operations, such as supply chains and deliveries. Changes in rain, snowfall, and seasonal flooding can also impact safety and maintenance operations. Transportation impacts can include structural, operational, and safety impacts to roadways and bridges as well as overall impact on the system capacity.

Roadways

Roadways are a critical infrastructure for New York State's economy, but with long-term changes in climate, many state transportation officials have a growing concern to the vulnerability of the nation's transportation systems and the road network.[11]

Structural Impacts

Stormwater runoff on roadways can cause negative impacts through the loss of pavement friction and infrastructure cracks. In addition to causing the roads to be impassable, roadway flooding can cause dangerous situations that may harm human life. Flooding can wash away a road transport network and pose a serious challenge to road infrastructure, potentially leading to vehicular accidents.[12] In addition, increasing precipitation could lead to soil moisture levels becoming too high and the structural integrity of roads becoming compromised, leading to accelerated deterioration.[13] Finally, increased precipitation can also increase pavement rutting, a groove in the road.

Operational and Safety Impacts

Increased precipitation could result in increased weather-related accidents, delays, and traffic disruptions, loss of life and property, increased safety risks, and increased risks of hazardous cargo accidents.[14] This can happen through the degradation of roadway performance as traffic slows down, resulting in reduced roadway capacity, travel time delays, and increased accident risk with increased stormwater.[15] Excess stormwater can flood roads, resulting in road closures and affecting the operations of the functioning wider transportation network. Of weather-related roadway crashes, 75 percent occur on wet pavement and 47 percent during rainfall.[16]

Maintenance Impacts

Increased stormwater can result in more frequent road upgrades and maintenance such as the installation of larger culverts and regular culvert clean-outs to prevent washouts during major storms and floods. For in-progress road construction projects, as heavy rain events take place more frequently, severe erosion can occur and road construction activities will be disrupted.[17] Average annual precipitation increases can result in enhanced deterioration of road pavements, known as rutting, which requires more frequent repair of surfaces.[18]

Bridges

Stormwater can have significant effects on bridges, with those in low-lying areas particularly vulnerable to structural, operational, and safety impacts.

Figure 8. Bridge scour (Colson).

Structural Impacts

With increased and more intense precipitation, bridges are more prone to scouring (the removal of sediment such as sand and rocks from around bridge abutments and piers) from higher stream runoff, as shown in Figure 8.[19]

Operational and Safety Impacts

Bridges that become impassable, either because they have washed away or are determined to be structurally compromised, reduce the value of a roadway. In Vermont during hurricane Irene, rainfall totals of 3-5 inches were recorded throughout the state, with many areas receiving more than 7 inches, leaving many towns isolated because 35 bridges were destroyed and 960 culverts were damaged.[20] Not only is this a challenge for the transportation system as a whole, but also for dealing with events such as hurricanes, when bridges are often critical for disaster response and evacuation.

Maintenance Impacts

With changes in the intensity and frequency of storm events, there is a need for culverts, bridges, erosion controls, and stormwater systems to be designed and maintained to adequately handle the associated increased flow, sediment, and debris transport.[21]

Planning Impacts

As bridges and culverts have a long life (50-60 and 30-50 years, respectively), incorporating climate change considerations into any new project designs can reduce maintenance or repairs later in the life of the asset.[22] For example, Canada's Confederation Bridge, a 13 km bridge between Borden, Prince Edward Island, and Cape Tormentine, New Brunswick, is a completed project that took climate change into account during the planning and design phase by increasing the vertical clearance between the water and the bridge. The bridge was built one meter higher than was currently required to accommodate for sea-level rise and ensure the safe pass of boats beneath the bridge over its hundred-year lifespan.[23]

Quantified Losses Due to Road and Bridge Disruptions

Damage to roads and bridges as a result of stormwater runoff can have far reaching operational impacts on the transportation of people, goods, and services, as roads and bridges are often lifelines for communities. Roads and bridges are critical to the functioning of a modern economy, and the economic impacts of infrastructure closures are often many times larger than the costs associated with the physical damages themselves. Roadway and bridge disruptions, either due to slower vehicular speeds or complete closures, result in increased congestion on undamaged facilities that disrupts the transportation networks. This disruption of the transportation network is tightly intertwined with the functioning of the local economy.

Quantifying these impacts is difficult, as there are immediate impacts, such as not being able to travel to work or school, to farther reaching economic impacts, such as supply chain disruptions.[24]

Storm events, in combination with extreme precipitation and sea-level rise, have the ability to severely damage transportation systems in New York. At current sea levels, economic losses from a severe 100-year storm in the New York City metropolitan area alone would amount to about $58 billion.[25]

Other impact considerations include the fact that social and economic effects of excessive precipitation will not be distributed evenly. Low-income and elderly populations, especially in urban areas, are particularly vulnerable to disruption to transportation services, limiting their ability to get to work or evacuate during emergencies and extreme weather events.[26]

Climate Change Adaptation

Climate change adaptation refers to efforts by society to prepare for or adjust to future climate change. These adjustments can be protective (i.e. guarding against negative impacts of climate change), or opportunistic (i.e. taking advantage of any beneficial effects of climate change).[27]

For thousands of years humans have been transforming the natural landscape, from cutting down forests for farmland to building roads for safer and more efficient transport of people and goods. Part of the challenge of climate change is that humans have altered the natural environment to suit their needs within a particular climate. As climate conditions change, requirements for the built environment will shift. The National Research Council recommends incorporating climate change into long-term improvement plans, design, operations and maintenance, and land-use decisions.[28]

In addition, traditional practices of development have altered certain natural cycles, which could further the impact of climate change. For example, the development of land has increased stormwater runoff due to the prevention of water from infiltrating into the ground and being soaked up by plants.

As the intensity of precipitation and storms increases as forecasted by climate change modeling, the impacts of the resulting stormwater on transportation infrastructure will be exacerbated. However, an understanding of these climate changes and a willingness to act and adapt will give communities an opportunity to implement strategies to limit these negative impacts. Examples of adaptation could include increasing open space preserves along frequently flooded areas or areas where increased sea level could encroach, and moving populations away from vulnerable areas.

> *"It's very important - a necessity at this point to at least start to analyze the climate change risks for each municipality."* - Erin Morey, Deputy Director, New York City Department of Environmental Protection

Assessing local vulnerability is an important part of adaptation, and different assessment models have been developed. Washington State DOT undertook a vulnerability assessment by meeting with maintenance staff. This "on-the-ground" information regarding infrastructure elevation, state of repair, capacity of culverts, land development trends, and natural resource conditions –soil, land cover, land use change, and hydrology – are dominant factors in decisions regarding climate and extreme weather adaptation.[29] For example, an easy and important first step to evaluate a community's current stormwater capacity and adaptation needs is to meet with maintenance staff to ask where flooding problems currently occur. Asking maintenance staff, "When we have a precipitation event, what areas keep you up at night?" allows a community to map the highest leverage areas to begin implementing adaptation strategies. An additional component to the decision-making approach is to consider not only what areas flood, but also which of these flooding areas receive the average highest traffic and whether there are areas that would be isolated during flooding events with no alternative routes. This allows a community to start risk-based planning.

Climate change adaptation can consist of a wide variety of actions by individuals, communities, or organizations to prepare for climate change impacts. This report provides green infrastructure adaptation strategies for stormwater, which can be implemented in communities in New York State. Taking adaptation action now could limit damages and costs in the near-term and through the coming decades.

Additional Adaptation Resources

Climate Smart Communities - http://www.dec.ny.gov/energy/50845.html

US DOT Transportation and Climate Change Clearing House - http://climate.dot.gov/impacts-adaptations/planning.html

Center for Clean Air Policy – Adaptation and Resilience: http://www.ccap.org/index.php?component=issues&id=5

---

[1][1] EPA. *After the Storm - Weather | US EPA*. January 2003. 20 November 2012. <http://water.epa.gov/action/weatherchannel/stormwater.cfm>.

[2] National Oceanic and Atmospheric Administration. *Harmful Algal Blooms (HABS): NOAA Watch: NOAA's All-Hazard Monitor: National Oceanic and Atmospheric Administration: U.S. Department of Commerce*. n.d. http://www.noaawatch.gov/themes/habs.php. 20 November 2012.

[3] EPA, 2012

[4] Patz, Jonathan A., Stephen J. Vavrus, Christopher K. Uejio, Sandra L. McLellan. "Climate Change and Waterborne Disease Risk in the Great Lakes Region of the U.S." *American Journal of Preventive Medicine* (2008): 451-458.

[5] National Resources Defense Council. "NRDC: Rooftops to Rivers." 1 May 2006. *NRDC*. 13 October 2012. <http://www.nrdc.org/water/pollution/rooftops/contents.asp>.

[6] NYS Department of Environmental Conservation. *New York State Water Quality 2008*. Submitted Pursuant to Section 305(b) of the Federal Clean Water Act Amendments of 1977. Albany, NY: NYSDEC, 2008.

[7] EPA. Report to Congress Impacts and Control of CSOs and SSOs August 2004 Washington, D.C. 1-633.

[8] Anderson, Donald M., Yoshi Kaoru, Alan W. White. *Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States*. Technical Report. Woods Hole, MA: Woods Hole Oceanographic Institution, 2000.

[9] ibid

[10] Cantor, Martin R. *Economic Impact of Regional Beach Closings on the Long Island Economy*. Oakdale, NY: Dowling College, 2007.

[11] Pyke, Marni. *Can our roads weather the storm? - DailyHerald.com*. 20 August 2012. 3 November 2012. <http://www.dailyherald.com/article/20120820/news/708209923/>.

[12] Transportation Research Board. *Estimating Life Expectancies of Highway Assets*. NCHRP REPORT 713. Washington, D.C.: Transportation Research Board, 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_713v1.pdf

[13] Meyer, Michael D., Anne F. Choate and Emily Rowan. *Adapting Infrastructure to Extreme Weather Events: Best Practices and Key Challenges*. Traverse City, Michigan: AASHTO, 2012.

[14] ibid

[15] US Department of Transportation. *How Do Weather Events Impact Roads? - FHWA Road Weather Management*. 31 August 2012. 3 November 2012. <http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm>.

[16] ibid

[17] Meyer, Choate and Rowan, 2012

[18] Nemry, Françoise. "Impacts of climate change in Europe: A focus on road and rail transport infrastructures." 9 October 2012. *United Nations Economic Commission for Europe.* 4 November 2012. <http://www.unece.org/fileadmin/DAM/trans/doc/2012/wp5/01_Ms_Nemry_EC.pdf>.

[19] Meyer, Choate and Rowan, 2012

[20] ibid

[21] ibid

[22] Transportation Research Board, 2012

[23] Meyer, Choate and Rowan, 2012

[24] US Global Change Research Program. *Global Climate Change Impacts in the United States*. US Global Change Research Program. New York, NY: Cambridge University Press, 2009.

[25] Rosenzweig, C., et al. *Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation.* Annals of the New York Academy of Sciences 1244(1):2-649.

[26] ibid

[27] City of Minneapolis, Minnesota. n.d. 14 0ctober 2012. <www.minneapolismn.gov/publicworks/sotrmwater/green/stormwater_gree-initiatives_rain-garden>.

[28] Transportation Research Board, 2012

[29] Winkelman, Steve, Jan Mueller and Erica Jue. "Climate Adaptation & Transportation Identifying Information and Assistance Needs Summary of an Expert Workshop held November 2011 ." Workshop Summary. Center for Clean Air Policy and Environmental and Energy Study Institute, 2012.

Strategies to Mitigate Projected Increases in Stormwater Runoff

Strategies to Mitigate Projected Increases in Stormwater Runoff

With climate projections showing an increase in intense precipitation events with a likelihood of greater than 66 percent, there is a clear need to take early action to maintain existing and install new stormwater management strategies. With respect to stormwater infrastructure, there are two primary types to consider: green and grey. Grey infrastructure is the traditional approach to stormwater management and is the use of manmade sewers and tunnels to move stormwater away from transportation infrastructure and ultimately to a receiving water (naturally occurring waterways where wastewater is discharged) as well as the development and use of water treatment plants.[1] Green infrastructure is an innovative approach to stormwater management that manages stormwater through the protection and use of already existing natural infrastructure (wetlands, parks, forest reserves, etc.) or the development of nature-mimicking infrastructure, which in urban and suburban areas can prevent stormwater from entering the sewer system.[2]

The second consideration for stormwater source controls is whether to use a distributed or retention method. Retention source controls store stormwater, not allowing it to reach the roads or sewer systems. This retained water can either be evaporated off or utilized as water for processes such as flushing toilets or irrigation.[3] The distributed source control focuses on the movement of stormwater. Distributed source controls can be both green and grey approaches.[4]

This report will focus on those strategies that incorporate green infrastructure, as these not only effectively manage stormwater by either using or mimicking nature, but also have numerous secondary benefits to enhance communities throughout the state of New York. The following strategies, while effective at mitigating many rain events throughout New York, are not suited to manage extreme events such as hurricanes.

---

[1] Foster, Josh and Steve Winkleman Ashley Lowe. *The Value of Green Infrastructure for Urban Climate Adaptation*. Washington D.C.: The Center for Clean Air Policy, 2011.

[2] Wise, Steve. "Green Infrastructure Rising." *American Planning Association* (2008): 14-19.

[3] Freni, Gabriele, Giorgio Mannina and Gaspare Viviani. "Urban Storm-water Quality Management: Centralized versus source control." *Journal of Water Resources Planning and Management* (2010): 268-278.

[4] Coffman, Larry. "Low Impact Development: Smart Technology for Clean Water - Definitions, Issues, Roadblocks, and Next Steps." *Global Solutions for Urban Drainage* . Ed. Eric Strecker and Wayne Huber. Portland: American Society of Civil Engineers, 2002.

Green Streets

Green Streets are an opportunity for communities to alleviate stormwater difficulties resulting from impervious surfaces and incorporate a number of strategies. Green street strategies are some of the most applicable for the DOT and those in charge of town-owned transportation infrastructure to implement. Pervious pavement, commonly referred to as porous pavement, is one strategy used to alleviate the difficulties of excess water runoff by allowing water to pass through, rather than over, the surface. Additional green street techniques include: pervious sidewalks, bioswales, rain gardens, and street trees.

Pervious Roadways

Description

A pervious roadway encourages water infiltration through its surface into underlying soils by way of open spaces known as pores. Pores are intentional voids in the pavement material that allow water to travel and be removed from the surface. The primary issue with traditional asphalt is its non-absorbent qualities, which exacerbate the runoff of stormwater and flooding of low-lying areas; however, pervious pavement allows for water to move through the road into the ground below. It can be used in lieu of conventional pavement given certain conditions.

> *By capturing stormwater and allowing it to seep into the ground, porous concrete is instrumental in recharging groundwater, reducing stormwater runoff, and meeting U.S. Environmental Protection Agency (EPA) stormwater regulations.* – National Ready Mixed Concrete Association (National Ready Mixed Concrete Association)

The application of permeable pavement is limited to low traffic areas primarily because of surface wear and load bearing capacity.[1] Vehicles making sharp turns on pervious surfaces can tear up aggregate material, as the porosity of pervious surfaces lends to easier break up of aggregate surface material. Although the ability to bear heavier loads can be engineered, cost can increase substantially. By limiting the application of pervious pavement to parking lots, one avoids the challenges associated with significant movement and heavy loads like diesel vehicles.[2]

Case Study – Clarendon Place Pervious Pavement Project: North Buffalo, New York

The pervious pavement project in Clarendon Place North Buffalo was constructed to reduce combined sewer overflows (CSO) and was completed in August of 2012. The project consists of seven pilot green streets that are part of larger program valued at $3 million. While the benefits of this project have yet to be monetized, according to Jessie Fisher, Director of Greenway Planning with the Buffalo Niagara Riverkeeper, the Clarendon Place pervious pavement project enabled avoiding a sewer separation project that was budgeted at $1.5 million and would not have better stormwater quality (Fisher).

There are several different pervious pavement materials options – permeable asphalt, permeable concrete, concrete block pavers, concrete grid pavers, and plastic grid pavers. The installation of pervious roadways can avoid capital costs by eliminating the need for other stormwater management infrastructures like catch basins, stormwater ponds, and curbing.[3]

- **Permeable Asphalt:** Also referred to as porous asphalt, permeable asphalt allows for water infiltration, which mitigates or substantially reduces stormwater or snowmelt runoff. This is made possible by a variety of compositions that contain less-fine particulate matter, like sand, and create more air space allowing water to permeate through.

Permeable concrete is fundamentally the same as conventional concrete, but differs greatly in the installation process. The appropriate mix of sand, water, and other cement materials is critical to the successful installation of pervious concrete. To get the proper mix, one should work with an experienced supplier as well as leave voids and open spaces in the subsurface between 12 and 20 percent so as to ensure sufficient water infiltration capabilities.[4] Porous asphalt has a number of optional additional construction items such as perforated pipe to transport stormwater subsurface.

- **Pavers:** A paver is a pre-formed piece of aggregate material used in the construction of road surfaces. Permeable pavers are typically made of strong structural materials with regularly interspersed void areas filled with grass, sand, or rocks, to allow water to pass through. [5] Interlocking pavers are units constructed to fit neatly with others when laid in order to create a hard skeletal surface with porous centers allowing water to run through.
    - **Concrete block pavers:** Concrete block pavers increase pervious surface cover by approximately 20 - 50 percent, with the types of subsurface filler impacting the volume of filtration.[6] They increase pervious space by omitting surface cover with holes intentionally stamped out to increase infiltration. Concrete pavers have been used since the 1960s and are recommended for driveways, parking areas, shoulders along highways, ditch liners, embankment stabilization, roadway medians, boat launching ramps, emergency access roads, fire lanes, sidewalks, grassed rooftops, pool decks, and patios.[7]
    - **Concrete grid pavers:** Concrete gird pavers can be used in the same manners and locations as concrete block pavers. Concrete grid pavers allow water to permeate through the surface by way of porous material filling the center. In addition to being beneficial for areas with little need for sanding, concrete grid pavers should also be used in areas with careful snow plowing to minimize paver damage.[8]
    - **Plastic grid pavers:** Plastic grid pavers are typically made of recycled plastic with filled grass or rocks in the middle, as shown in Figure 9. Plastic grid pavers are best used in areas of low traffic, and if winter plowing is required, one must take extra care in order to reduce the chance of damage. Also, winter sanding must be minimal in order to maintain porosity.

- **Permeable Sidewalks:** Permeable sidewalks are created utilizing the same technologies as roadways, simply smaller in scale. Cities like Cerrito, California, and Olympia, Washington, have installed pervious sidewalks and pervious bike lanes. Pervious sidewalk projects are effectively the same as any other pervious pavement project except for the potential inability to use automated installation machinery that would save on time and labor costs.[9]

Life Cycle

The Charles River Watershed Association states that permeable pavements need to be repaved every 15 -25 years. [10] However, most studies available on pervious pavements estimate a lifespan of 25 years. [11] The United States Environmental Protection Agency states that the lifespan of pervious pavement is longer than that of impervious pavement due to a reduction of freeze-thaw periods.[12]

Cost

Installation costs for pervious pavements are estimated to be between $2 and $15 per square foot.[13] This price estimate incorporates the cost of underlying infiltration beds.[14] While material costs for pervious asphalt are approximately 20 - 25 percent more than traditional asphalt, the savings associated with reduced stormwater infrastructure is comparable to the cost of developing a standard asphalt project where stormwater infrastructure is required.[15] Furthermore, as porous pavements have been found to be more resistant to winter freezing than their conventional counterpart, this alleviates the cost associated with deicing roads.[16]

Implementation Timeframe

The time it takes to install a pervious surface will depend on the type of existing surface, the state of the subsurface, and the size of the project. It is common for a pervious pavement parking lot to be constructed in conjunction with new construction, thereby making the timeline for the pavement the same for the overall construction.[17] If the subsurface needs to be mixed in a way to increase porosity, this will add time, as will the need to install a subsurface drain pipe.

Maintenance

In order to prevent clogging, permeable surfaces need to be vacuum swept three to four times a year at approximately $200 to $500 per half-acre surface area per year.[18] In addition to vacuuming and pressure washing (when appropriate), the infiltration rates of a project should be checked at least once a year, and then additionally as needed, dependent on storm events.[19] The performance of the pavement is dependent on maintenance activities and the operator's understanding of the impacts of other road aspects such as loose soil.[20] When pervious pavements are not maintained properly, decreased porosity occurs until the surface is no longer permeable.

Figure 9. Plastic pavers (University of Connecticut, NEMO).

Impacts

Benefits: In addition to reducing stormwater runoff and flood risk, pervious pavements can reduce the heat island effect when not using pervious asphalt by eliminating dark, heat-absorbing surfaces.[21] Permeable pavement can also prevent hydroplaning by intercepting and temporarily retaining water.[22] Pervious pavement allows water to be naturally cleansed; during the infiltration process, as water percolates through underlying soils, pollutants are removed. Finally, pervious roadways are recognized as an effective method for meeting EPA requirements for Phase II of the Clean Water Act and for reducing the total maximum daily load (TMDL) of water runoff.[23] Total maximum daily load is the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards.[24]

Challenges*:* Location for porous pavements can be challenging as they function optimally when placed on shallow slopes above soils with permeability rates greater than .25 inches per hour.[25] However, it is generally recommended to build pervious roads on a slope of 5 percent or less because water flows along the choker course underground, parallel to the surface, and can cause washouts if the flow of water is too rigorous.[26] The choker lies directly below the pervious surface and serves to stabilize the upper permeable surface.[27] There are two vital location concerns to avoid when planning a permeable surface pavement project to protect groundwater quality. First, the project should not be located near areas of high particulate matter or areas prone to chemical spills. Second, it is recommended that pervious pavement be constructed above a low water table, or with sufficient space between surface and water table, so that water filtration is not inhibited by too much water or a subsurface flood.[28]

Additional Pervious Roadways Resources

[National Ready Mixed Concrete Association - http://www.perviouspavement.org/](http://www.perviouspavement.org/)

["Stormwater: Pervious Pavement" - http://www.lakesuperiourstreams.org](http://www.lakesuperiourstreams.org)

[The Concrete Network - http://www.concretenetwork.com](http://www.concretenetwork.com)

---

[1] Clark, Mark. *Associate Professor of Wetland Ecology, University of Florida* Molly Saso. 2 November 2012.

[2] ibid

[3] Robert M. Roseen, P.E., Ph.D. and Thomas P. Ballestero, Ph.D, P.E. n.d. UNH Stormwater Center University of Newhampshire. 30 September 2012. <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/napa_pa_5_08_small.pdf>.

[4] The Concrete Network. *Ten Strategies for Ensuring a Successful Pervious Concrete Installation* . n.d. 27 October 2012. <http://www.concretenetwork.com/pervious/installation-tips.html>.

[5] "Permable Pavers." n.d. 17 November 2012. <http://www.epa.gov/oaintrnt/stormwater/pavers.htm>.

[6] University of Connecticut, NEMO. "NEMO's Planing for Stromwater Management." 2012 30-September. <http://nemo.uconn.edu/tools/stormwater/pavements.htm>.

[7] ibid

[8] ibid

[9] Bean, Dr. Eban. *Professor, Department of Engineering at East Carlonia University* 2012

[10] Charles River Watershed Association. *Permeable Pavement*. 2008 September. 2012 3-November.

[11] The Low Impact Development Center, Inc. "Low Impact Development for Big Box Retailers." November 2005. <www.lowimpactdevelopment.org>.

[12] "National Pollutant Discharge Elimination System (NPDES)." n.d. 3 November 2012. <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=135>.

[13] Virginia Department of Conservation and Recreation, "*Virginia DCR Stormwater Design Specification No. 7. Permeable Pavement."* March 1, 2011.

[14] Charles River Watershed Association, 2008

[15] University of New Hampshire Stormwater Center. *Porous Asphalt Pavement for Stormwater Management*. n.d. 2012 September. <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/porous_ashpalt_fact_sheet.pdf>

[16] Roseen and Ballestero, 2012

[17] Bean, 2012

[18] Charles River Watershed Association

[19] Bean, 2012

[20] Clark

[21] Malec, Suzanne. "Storm Water Managemen in the City of Chicago." n.d. City of Chicago Department of Environment. 4 October 2012.

[22] Clark, 2012

[23] Roseen and Ballestero, 2012

[24] *Water: Total Maximum Daily Load*. n.d. 27 October 2012. <http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm>.

[25] Charles River Watershed Association

[26] Ballestero, Dr. Thomas. *Director of the UNH Stormwater Center, Associate Professor University of New Hampshire* Molly Saso. 6 November 2012.

[27] Ramsey-Washington Metro Watershed District. *Porous Asphalt Parking Lot*. n.d. 8 November 2012. <http://www.rwmwd.org/vertical/Sites/%7BAB493DE7-F6CB-4A58-AFE0-56D80D38CD24%7D/uploads/%7B495C857D-FED3-409E-B58A-E6A16D827DEA%7D.PDF>.

[28] Cremin, Phil. *Assistant Chief Civil Engineer, Port Authority of New York and New Jersey* Molly Saso. 20 November 2012.

Bioretention/Bioswales

Description

Bioretention is a terrestrial-based water quality and quantity control practice that uses plants, soils, and microbes for the removal of pollutants and retention of stormwater. [1] Bioretention, and in particular bioswales, can be valuable strategies for the DOT and those responsible for town-owned transportation infrastructure to implement as they are effective when installed next to roadways by diverting stormwater away from this infrastructure. With bioretention, stormwater runoff is allowed to flow through vegetated pathways to locations such as planters or open-space vegetation where water can be held and either evaporate or filter into groundwater supplies. This helps to mitigate the challenges associated with increased precipitation by reducing the amount of runoff that reaches the sewer system in a natural way.[2]

> *"Bioswales are as close to a natural system as we can get on a New York City street."* - Nette Compton, Head, Green Infrastructure Division, New York City Parks Department (Rosenblum)

Figure 10. This bioswale, located in Jamaica Bay, Queens, helps to control the flow of stormwater runoff and decrease localized flooding (Ulam).

Case Study - Dean Street Bioswales: Brooklyn, New York

The Dean Street Bioswales in the Boerum Hill section of Brooklyn were constructed in 2011 as part of the NYC Green Infrastructure Plan. These bioswales were anticipated to address the issue of flooding in the Gowanus Canal watershed. As a joint project, the Department of Environmental Protection, in conjunction with the Department of Parks and Recreation and the Department of Transportation, funded the bioswales (Yakowicz). The project consists of four bioswales that are 20 feet long by 5 feet wide and 5 feet deep. The pits are vegetated with trees and intended to retain stormwater long enough for it to seep into the ground. Each structure is designed with two curb cuts, so that water can come in on one end, get absorbed by the dirt, plants, and tree (in addition to traveling through gravel and a filtering net), and any remaining water can leave through the other curb cut to go into the sewer (Yakowicz). Each bioswale is designed to handle 1,870 gallons of stormwater per storm (New York City Department of Environmental Protection). Each pit cost around $1600 (Yakowicz).

Swales are open channels located next to roadways that are used to move stormwater. However, unlike traditional grey infrastructure, they are built out of soil and vegetation. They encourage infiltration, reducing the amount of stormwater which ultimately reaches the sewer system, contributing to the recharging of groundwater sources, and assisting in pollution control by allowing for natural filtration by way of vegetation modification, like trees, shrubs, or ponds.[3]

Life Cycle

The lifespan of a bioretention basin, including swales, is assumed to be 30 years. After this lifespan has been surpassed, the bioretention basin may face removal or replacement.[4]

Cost

Costs are dependent upon the size of the bioretention project. If there is a need to purchase land, plants, and vegetation to aid in the infiltration process, the costs will also be dependent upon the types and associated costs of each plant as well as the land value.

Implementation Timeframe

The installation of a bioswale is substantially influenced by location. In areas where site logistics present significant demolition work or have complicated engineering or permitting components, delivery could take one year or more. In areas with less complicated circumstances, it could take just a few weeks.[5] [6]

Maintenance

Routine period maintenance is necessary but only to the same extent that a natural landscape would require. Maintenance consists of inspecting structures regularly for erosion or repairs, sediment removal, mulch replenishment, and replacement of plants or trees that are either dead or distressed.[7]

Impacts

Benefits*:* Improved water quality and groundwater replenishment are both benefits of installing a swale along roadways. Water is naturally purified as it passes through soils into underground aquifers with soils acting as filters.[8]

Challenges*:* Bioretention project sites must be six feet or more above the water table.[9] This is because any spacing less than six feet between the water table and soil surface fails to provide sufficient water purification.

Additional Bioretention/Bioswales Resources

New Jersey Stormwater Best Management Practices Manual - http://www.njstormwater.org/bmp_manual2.htm

North Carolina State Cooperative Extension - http://www.bae.ncsu.edu/stormwater/PublicationFiles/NWQEPnotes2003.pdf

---

1 Department of Environmental Resources, The Prince George's County Maryland. "Bioretntion Manual." December 2009. <http://www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/Bioretention/pdf/Bioretention%20Manual_2009%20Version.pdf>.

2 ibid

3 McLaughlin, John. "NYC Bioswales Pilot Project Improves Stormwater Management." 2012.

4 The Low Impact Development Center, Inc. "Low Impact Development for Big Box Retailers." November 2005. <www.lowimpactdevelopment.org>.

5 Flynn, Kevin Martin. *Evaluation of Green Infrastructure Practices using Life Cycle Analysis*. Thesis. College of Engineering, Villanova University. Villanova: Kevin Martin Flynn, 2011.

6 Gomery, Jane. *Burlingame Commercial District Parking Lot and Street Project* Charles M Samul. Burlingame, 2102 11-October.

7 The Low Impact Development Center, Inc.

8 Department of Environmental Resources, Prince George's County Maryland

9 The Low Impact Development Center, Inc.

Rain Gardens

Description

Rain gardens are generally larger in size than bioswales and are a strategy useful for community associations, which can allocate land to assist with stormwater management. A rain garden is designed to manage rain events of 0.5 inches per hour, but can be designed for higher rates of rainfall if determined necessary. This is accomplished by increasing the size of the installation or by using more vegetation, for example large trees to intercept and trap rainfall and runoff. Appropriately sized, they have the capability of holding up to 12 inches of water in their surface basin awaiting infiltration and evaporation, for periods of up to 72 hours. Rain gardens have a greater emphasis on storage of stormwater runoff through natural infiltration but, in some cases, they may be used with underlying conventional storm sewer conveyance infrastructure.[1]

> *While [an] individual rain garden may seem like a small contribution, collectively, rain gardens can produce water quality benefits*. – University of Rhode Island (University of Rhode Island)

> ***Case Study – Serramonte Main Library: Daly City, California***
>
> Serramonte Main Library is located in Daly City, San Mateo County, California. This facility had chronic problems managing stormwater, which at times resulted in flooding of the main entrance area. In 2009 a project was completed installing four rain gardens and a bioswale. The total green infrastructure system consists of 4,600 square feet, which was formerly lawn area. The measures employed have been successful in dealing with heavy, seasonal rain events. The installation has successfully mitigated stormwater from a 30-year storm event (Gomery). Total project cost was $420,000. equating to $91 per square foot of bioswales and rain garden installed. Funding was obtained through a combination of primarily City money combined with a motor vehicle registration tax (San Francisco Estuary Partnership). In addition, influent/effluent testing has shown that the installation reduces major pollutants in the managed stormwater by as much as 99 percent.

Life Cycle

The useful life of rain gardens is thought to be 30 years. When they reach the end of their useful lives, they may be retired by removal. Retirement costs are a function of the size of the installation but are generally restricted to removal and disposal and possibly reuse as clean fill.[2]

Cost

The cost of installing this sort of green infrastructure is directly related to the particulars of the given location. In highly urban areas, where removal of existing pervious surface and relocation of utilities may be involved, costs may be as high as $90 per square foot.[3] In less urbanized areas, installation costs on green field sites are as low as $5 to $15 per square foot.[456] Those prices are all inclusive of design and construction costs. Overall, development costs are lower than traditional best management practices by as much as 29 percent.[7]

Implementation Timeframe

The installation of a rain garden is substantially influenced by location. In areas where site logistics present significant demolition work or have complicated engineering or permitting components, delivery could take one year or more. In areas with less complicated circumstances, it can take as little as a few weeks.[89]

Maintenance

Maintenance of rain gardens is minimal and consists of removing debris, invasive plants, and woody plant material. As installations are above ground, they are readily observable and therefore easier to access and maintain in comparison to grey infrastructure underground.[10] In some climates it is necessary to water the vegetation as needed for the first year or two of life to ensure it is well established.[11] Following that, maintenance is a few man-hours per year for weeding and removing debris.[12]

Figure 11. Rain gardens in action (San Francisco Estuary Partnership).

Impacts

Benefits: Rain gardens are effective at slowing the rate of runoff from pervious surfaces resulting from storm events. [13] Because they are capable of capturing runoff with soil infiltration, they may reduce the volume of water entering the traditional stormwater management system and increase groundwater recharge. Water being discharged from these installations has been shown to reduce levels of metals, hydrocarbons, PCB, suspended solids, and organic pollutants by 70-80 percent.[14] In addition to the tangible benefits, there are further benefits resulting from improved aesthetics, educational, and recreational opportunities.

Challenges: The capital costs associated with these installations are sometimes as high as $100 per square foot.[15] There is also a public health concern that standing water will allow mosquitoes to breed. This is usually not a problem, though, as most facilities are designed to hold surface water for 72 hours or less.

Additional Rain Garden Resources

Rain Garden Network –

http://www.raingardennetwork.com/

Scarsdale Conservation Advisory Council Resource Guide - Rain Gardens & Sustainable Landscaping - http://www.scarsdale.com/Portals/0/SCAC/Insert%20CAC2.pdf

UCONN Rain Gardens - A Design Guide For Homeowners - http://nemo.uconn.edu/publications/rain_garden_broch.pdf

---

1 Nevue Ngan Associates & Sherwood Design Engineers. "San Mateo County Sustainable Green Streets and Parking Lots Guidebook." Guidebook. 2009.

2 Flynn, Kevin Martin. *Evaluation of Green Infrastructure Practices using Life Cycle Analysis*. Thesis. College of Engineering, Villanova University. Villanova: Kevin Martin Flynn, 2011.

3 Gomery, Jane. *Burlingame Commercial District Parking Lot and Street Project* Charles M Samul. Burlingame, 2102 11-October.

4 Flynn, 2011

5 San Francisco Estuary Partnership. 2009. 5 October 2012. <www.sfestuary.org>.

6 City of Minneapolis, Minnesota. n.d. 14 0ctober 2012. <www.minneapolismn.gov/publicworks/sotrmwater/green/stormwater_gree-initiatives_rain-garden>.

7 Natural Resources Defense Councel. "After the Storm - How Green Infrastructure Can Effectively Manage Stormwater Runoff from Roofs and Highways." 2011.

[8] Flynn, 2011
[9] Gomery, 2012
[10] Bellona, Steven. *Vice President Facilities, Hamilton College* Charles Samul. 5 October 2012.
[11] MacDonagh,Peter. *Growing Large Urban Trees for Stormwater Management*. Presentation. Kestrel Design Group. Minneapolis: Kestrel Design Group, Inc., 2010.
[12] Flynn, 2011
[13] City of Minneapolis, 2012
[14] San Francisco Estuary Partnership, 2009
[15] ibid

Street Trees

Description

Street trees is a strategy that owners of sidewalk locations, parking lots, and rights of way throughout communities may use to mitigate the impacts of stormwater on nearby transportation infrastructure. Trees can interact with rainfall in three ways that may be broadly defined as detention, retention, and return. Trees are effective at preventing the first inch of a storm event from reaching the surface under their canopy.[1] Detained on leaf surfaces, the rain evaporates back into the atmosphere. The average tree prevents between 760 – 4,000 gallons of rainfall from reaching the ground annually, reducing the volume that enters the stormwater cycle.

> *Studies show that trees improve air and water quality, reduce flooding, reduce cooling and heating energy needs, increase property values and improve the quality of life for people and wildlife around them.* – New York State Department of Environmental Conservation (New York State Department of Environmental Conservation)

The capacity to absorb and remove water from the soil makes trees effective in a range of applications. Using its collective abilities, a single large tree can trap 200 cubic feet of water from a one-inch storm event.[2] Unlike other bioretention strategies, trees require little space and can be planted in any existing plantable space. Properly selected species of trees can be used in narrow occupancies, like tree pits and trenches. Trees are also highly effective in larger installations like rain gardens.[3]

In recent years the development of engineered soils has made it possible to have trees with large canopies and extensive root systems thrive in small planting areas. These engineered soils are compactable and therefore highly effective underneath pervious and even impervious pavements. The engineered soils promote enhanced root growth and water storage in relatively shallow soil profiles.[4]

Case Study - Townsend Street Parking Lot: Syracuse, New York

Syracuse in Onondaga County, New York, has a sixty-year average rainfall of 38.66 inches and an average annual snowfall of 118 inches in the city (NOAA). The subject parking lot is located on Harrison Street at the intersection of Townsend Street in the city center. The capture area consists of 55,000 square feet of impervious asphalt. To help limit stormwater runoff, tree pits were installed running the length of the parking lot. They are each eight feet wide, approximately 225 feet long, approximately 50 feet apart, and parallel to each other. The pits were constructed using Cornell University's patented engineered CU-Soil to increase drainage and storage capacity and to provide an optimal medium for tree growth. The installation was completed in 2010. The project cost was $342,000, which includes the repaving of the entire parking area surface. The total project cost equates to $5.60 per square foot of capture area and $.35 per gallon of stormwater managed. In total the volume of stormwater managed is 975,000 gallons per year. (Onondaga County, New York).

Life Cycle

While fifty years is not an unusual life span for a tree, recent studies indicate that in dense urban settings the range of life span of a typical street tree is 19 - 28 years.[5] Tree species and the specifics of the location have the greatest influence on tree lifespan. The Urban Horticulture Institute at Cornell University has a partial list of street trees suitable for use with CU-Soil engineered soil mix (see Appendix E). Recommendations are currently to use species that are indigenous to the area where they will be installed.[6] Among the trees recommended is the hybrid American Elm, which can live long beyond 100 years of age.[7]

Cost

The cost of street tree programs is a function of the approach used in installation. Simply planting a 10-foot, 2-inch diameter Maple tree in an already prepared site has a cost range from $127 to $365 per tree. That range is related to the geographic location and professional planting versus using a city or town's own forces.[8] The City of New York Parks & Recreation Department has published guidelines for planting trees in New York City streets and green spaces.[9] Following those guidelines, the cost to install a single, two-inch diameter tree in a six foot by five foot tree pit will range from $750 to $1200, depending on the density of the urban setting.[10] Larger trees are more expensive to plant than smaller trees, but have substantially greater capacity for rainfall interception and higher survival rates when compared to smaller trees.[11] [12] Costs for 15-inch diameter trees may exceed $8,000 per tree.[13] Installations that involve removal of pervious surface and the use of engineered soils and underlying drainage will have costs that approximate or exceed those associated with bioswales and rain gardens. Cost is increased by the use of engineered soil as well - if the local soil component is available on site, the cost can be as low as $8 per cubic yard.[14] However, if purchased from landscapers, engineered products like CU-Soil cost between $35 and $42 per cubic yard.[15]

Figures 12 and 13. Silva Cell installation and tree installation before and after (Onondaga County, New York).

Implementation Timeframe

Planting an individual tree takes as much time and equipment as it takes to excavate the appropriate area, place the tree, and backfill the area. Smaller trees may take under one hour while larger installations will require the time necessary to plan, design, and construct the specific project.

Maintenance

Maintenance in the first three years following planting will consist of irrigation, feeding, and possibly pruning and mulching the trees. Information from West Hartford, Connecticut, indicates that the maintenance cost is $50 to $300 for the three-year period following installation.[16] There is no associated maintenance for engineered soil.

Impacts

Benefits: Along with the ability to manage water, studies have also shown that before and after analysis of water entering tree infrastructure have substantially reduced levels of pollutants such as: suspended solids (85 percent reduction), total phosphorous (74 percent reduction), total nitrogen (68 percent reduction), and combined metals (82 percent reduction).[17]

Challenges: Street trees should not be utilized in areas where the water table is less than four feet below surface. In high water table areas, the tree roots will rot and the tree will die. They also have limited applications in areas with high bedrock. Street trees should not be used in conjunction with engineered soils in areas with high concentration of pollutants in stormwater. In those circumstances, infiltration may adversely affect groundwater quality.[18] The ability of street trees to manage stormwater is limited by the size of their infiltration area and nature of soil media. As a result individual pits or potted trees are mainly effective due to canopy interception.

Additional Street Trees Resources

[NYS Dept of Environmental Conservation Urban and Community Forestry - Guidance and How To Links - http://www.dec.ny.gov/lands/4957.html](http://www.dec.ny.gov/lands/4957.html)

[NYS Environmental Facilities Corporation - Street Trees / Urban Forestry Grant - http://www.nysefc.org/GreenGrants/ApplicationProcess/StreetTreesUrbanForestryPrograms.aspx](http://www.nysefc.org/GreenGrants/ApplicationProcess/StreetTreesUrbanForestryPrograms.aspx)

[Trees New York (TreesNY) - http://www.treesny.org/](http://www.treesny.org/)

---

[1] Bassuk, Nina, PhD. *Professor of Horticulture and Director of Urban Horticulture Institute, Cornell University* Charles Samul. 22 October 2012.

[2] MacDonagh,Peter. *Growing Large Urban Trees for Stormwater Management*. Presentation. Kestrel Design Group. Minneapolis: Kestrel Design Group, Inc., 2010.

[3] Bassuk, Nina. *Professor of Horticulture*. Interview. Charles Samul. 22 October 2012.

[4] Bassuk, Nina, et al. *Using Porous Asphalt and CU-Structural Soil*. Technical Report. Urban Horticulture Institute. Ithaca: Cornell University, 2007.

[5] Roman, Lara A and Frederick N Scatera. "Street tree survival rates: Meta-analysis of previous studies and application to a field survey in Philadelphia, PA, USA." University of California, Berkeley and University of Pennsylvania, 2011.

[6]Bassuk, Nina, et al, 2007

[7] Cornell Univesity Cooperative Extension. "The LIfe of a Sugar Maple Tree." *Bulliten*. 235. Ithaca: Cornell University, 1996.

[8] National Arbor Day Association. n.d. 15 October 2012. <www.arborday.org>.

[9] City of New York Parks & Recreation Department. "Tree Planting Standards." New York: Parks & Recreation Department, April 2008.

[10] Posner, Gerald. *Arborist- Davidson Estate, Connecticut* Charles Samul. 6 November 2012.

[11] Marritz, Leda. *American City*. 10 October 2012. 16 November 2012. <www.americancity.org>.

[12] Roman, 2011

[13] MacDonagh, 2010

[14] Day, Susan D. "Assistant Professor and Director of the Urban Horticlture Center, Virgina Polytechnic Institute." *Using Engineered Soils in Tree Installations to Manage Stormwater.* Charles Samul. 19 October 2102.

[15] Urban Forestry Institute. *CU-Structural Soil*. 2006. 2 November 2012. <www.urban-forestry.com>.

[16] Burden, Dan. *22 Benefits of Urban Street Trees*. Glatting Jackson. Port Townsend: Walkable Communities, Inc, 2006.

[17] Charles River Watershed Association. *Permeable Pavement*. 2008 September. 2012 3-November.

[18] Dickinson, Susan Downing and Sarah B. *Managing Stormwater for Urban Sustainability Using Trees and Structural Soils*. Virginia Polytechnic Institution and State University. Blacksburg: US Department of Agricultural Forest Service Urban and Community Forestry Program, 2008.

Green Roofs

Description

While green roofs may not be a primary option for the DOT, their implementation throughout communities can have a positive impact on stormwater management and keeping stormwater away from transportation infrastructure. Green roofs are any type of vegetation system established on the roof of a building and can be a great tool for communities to implement throughout cities and towns to reduce the amount of stormwater that reaches roadways and sewer systems. Green roofs include a number of components including the vegetation, substrate, and a drainage layer.[1] Green roofs are often defined as intensive or extensive. Intensive roofs are thicker with deep soil layers, allowing them to support larger vegetation like trees.[2 3]

> *Green roofs provide many of the same benefits that trees and other ground level vegetation provide. Green roofs have an advantage, though, in that they can be used in dense, built-up areas that may not have space for planting at the ground level.* – United States Environmental Protection Agency (United States Environmental Protection Agency)

Traditional rooftops consist of up to 40 percent of the impermeable surface in a city, from which nearly all precipitation ends up as stormwater runoff.[4] However, green roofs have the ability to capture rainfall that falls on these surfaces. Some precipitation that falls on green roofs is detained. This detention process can delay peak runoff by up to 2 hours, and peak runoff amounts by up to 70 percent, depending on the intensity of the storm.[5 6] More important, however, is that a significant amount of precipitation that falls on green roofs is retained. This means that it is evaporated back into the atmosphere and never reaches sidewalks and roads.[7]

Case Study - Consolidated Edison Company of New York Inc (Con Edison): Long Island City, Queens, NY

Con Edison constructed a green roof learning center (Con Edison TLC) in Long Island City, Queens, New York, in 2008, which spans 10,600 square feet (O'Karma). It consists of three roof surface treatments—traditional black, highly-reflective white, and green—and has been instrumented to collect energy-related data, rainfall, and other key metrics (Gaffin, Rosenzweig and Eichenbaum-Pikser). Although the primary driver was to realize energy savings (O'Karma), two studies of the roof from Columbia University show that the impact on stormwater management might be much more significant than that on energy savings.

Construction of the green roof was completed within about two months in the spring of 2008 and consists of pre-planted modular trays (2'x4'x4') (ConEdison). They were ordered a month before construction and cost about $18 per square foot (ConEdison). The trays consist of 15 varieties of Sedum genus plants, a drought resistant succulent that are fully developed within 12 months, and do not require any watering after that time (ConEdison). The only regular maintenance is fertilizing the roof once a year and weeding no more than four times a year (O'Karma). The plants can go four months without watering, and as of October 2012 the roof had only been watered once during a heat wave in 2010 (O'Karma).

Studies of extensive green roofs show average retention rates of 51 percent in Storrs, Connecticut and 30 percent in Long Island City, New York.[8 9]

The specific amount retained depends on the depth and type of substrate; the type of vegetation; the age of the roof; local climate; and season.[10 11]

Life Cycle

While a traditional roof can last between 20-40 years a green roof is expected to last between 30-50 years.[12 13 14 15 16] This is because green roofs protect roof materials, such as the waterproofing membrane, from temperature swings and other natural elements.[17 18]

Figure 14. Con Edison green roof modular system after one year, with two sensors that measure radiant energy absorbed by the roof, ambient air temperature, relative humidity and wind speed and direction (Gaffin, Rosenzweig and Khanbilvardi).

Cost

The cost of installing a green roof installation can range from $5 - $25 per square foot for an extensive roof, and $25 - $40 per square foot for an intensive roof.[19] When comparing costs to that of a traditional roof, it is important to consider the longer lifetime of a green roof, and any savings associated with benefits like a decrease in stormwater runoff (which can avoid stormwater management fees in some areas) or energy reductions.[20]

Implementation Timeframe

The construction of a green roof may only take a few weeks to a few months, but it may take up to a year for vegetation to mature and completely cover the roof. Purchasing pre-grown vegetation prior to installation can expedite this process.[21] There is also a design phase, as it is important to choose plants based on region and maintenance constraints.[22] Finally, some plants might be better planted in a particular season, which can influence scheduling.

Case Study – Queens, NY, Continued

Two studies of this green roof were completed by Columbia University. The more recent one focused on the ability of the roof to retain stormwater, and concluded that the structure retained about 30% of the annual rainfall and snowfall water volume that fell upon its surface. This equates to around 10.2 gallons per square foot per year at a cost of $0.15 per gallon annually, based on a 40-year lifespan of the roof. This study goes further to estimate that if New York City's approximate one billion square feet of roof surface area were converted to a 4-inch sedum-based green roof layer, about 10-15 billion gallons of annual rainfall could be retained (Gaffin, Rosenzweig and Khanbilvardi).

Maintenance

Extensive roofs are commonly designed to require very little or no maintenance (except for initial fertilization to achieve full vegetation cover), while intensive roofs typically require weeding, fertilizing, and watering.[23] The maintenance cost is estimated to be between $0.20 and $1.50 for the first two years for extensive roofs, and $0.75 and $1.50 per square foot over the lifetime of intensive roofs, and depends on the size of the installation and the type of vegetation used.[24] These costs could also change over time. While intensive maintenance costs tend to stay constant, the cost declines for extensive roofs once the vegetation has reached maturity.[25]

Impacts

Benefits: Green roofs provide numerous benefits in addition to managing stormwater runoff. For example, vegetation adds a layer of insulation that keeps buildings cooler in the summer and warmer in the winter.[26] This can reduce the need for mechanical heating and cooling, and improve human health and comfort.[27] For example, the Chicago City Hall green roof reduces the building's annual energy costs by $5,000.[28] In addition, the evaporation of water off of the green roof can cool the exterior environment, which can mitigate the urban heat island effect.[29] Vegetation also creates urban habitat for birds and insects; filters pollution from both water and air; serves as a noise barrier; and increases land value.[30] A Toronto modeling study showed that green roofs can reduce air pollution by 10 - 45 percent in addition to the reductions obtained by existing vegetation.[31]

Challenges: While there are many benefits to a green roof, there are also some associated challenges. Some roof owners have experienced interior damage due to incorrect installation of waterproofing and drainage materials.[32] Buildings may also require additional structural support to maintain the weight of the green roof and associated water.[33] An extensive roof typically weighs 15 - 30 pounds per square foot, while an intensive roof can weigh much more.[34] Also, if adaptive species are chosen for top performance (those not native to the area) and the seeds are blown from the roof, native species can be threatened.[35] Finally, some studies have found concerns regarding water pollution. Extensive green roofs are often fertilized in order to attain full vegetation cover. This could pollute stormwater that flows through the vegetation.[36] One example of this was an increased level of phosphorus, a chemical component of many fertilizers, in stormwater released from a green roof in Pittsburgh.[37]

Additional Green Roof Resources

Green Roof resources from the United States Environmental Protection Agency - http://www.epa.gov/hiri/mitigation/greenroofs.htm

Study analyzing Stormwater Retention of Con Edison's "Learning Center" Green Roof by Columbia University - http://www.coned.com/greenroofcolumbia/

---

[1] Berndtsson, J. "Green roof performance towards management of runoff waterquantity and quality: a review." *Ecological Engineering* (2010): 351-360.

[2] ibid

[3] Getter, K and D. Rowe. "The role of extensive green roofs in sustainable development." *Hort Science* (2006): 1276–1285.

[4] Ostendorf, M, et al. "Storm Water Runoff from Green Retaining Wall Systems." *Cities Alive!: Ninth Annual Green Roof and Wall Conference*. Philadelphia: Cities Alive, 2011. 1-15.

[5] Berndtsson, 2010

[6] Bliss, Daniel J., Ronald D. Neufeld and Robert J. Ries. "Storm Water Runoff Mitigation Using a Green Roof." *Environmental Engineering Science* 26.2 (2009): 407-417.

[7] Gaffin, S.R., et al. "A Temperature and Seasonal Energy Analysis of Green, White, and Black Roofs." Columbia University, n.d.

[8] Gregoire, Bruce and John Clausen. "Effect of a modular extensive green roof on stormwater runoff and water quality." *Ecological Engineering* (2011): 963-969.

[9] Gaffin, S.R. et al.

[10] Berndtsson, 2010

[11] Roehr, Daniel and Yuewei Kong. "Runoff Reduction Effects of Green Roofs in Vancouver, BC, Kelowna, BC, and Shanghai, P.R. China." *Canadian Water Resources Journal* 35.1 (2010): 53-68.

[12] Susca, T., S.R. Gaffin and G.R. Dell'Osso. "Positive effects of vegitation: Urban heat island ang green roofs." *Environmental Pollution* (2011): 2119-2126.

[13] Gaffin, S.R. et al.

[14] Carter, T. and A. Keeler. "Life-cycle cost-benefit analysis of extensive vegetated roof systems." *Journal of Environmental Managment* (2008): 350-363.

[15] Gaffin, S.R. et al.

[16] United States Environmental Protection Agency. "Reducing Urban Heat Island: Compendium of Strategies. Green Roofs Chapter."

[17] Susca, T. et al., 2011

[18] Carter and Keeler, 2008

[19] United States Environmental Protection Agency

[20] Carter and Keeler, 2008

[21] Getter and Rowe, 2006

[22] Schroll, Erin, et al. "The role of vegetation in regulating stormwater runoff from green roofs in a winter rainfall climate." *Ecological Engineering* 37 (2011): 595-600.

[23] Berndttson, 2010

[24] United States Environmental Protection Agency

[25] Peck, S. and M. Kuhn. *Design Guidelines for Green Roofs*. Toronto: National Research Council Canada, 2001.

[26] United States Environmental Protection Agency

[27] Climate Protection Partnership Division in the U.S. Environmental Protection Agency's Office of Atmospheric Programs. "Reducing Urban Heat Islands: Compendium of Strategies." n.d.

[28] Department of Environment. *Green Chicago - Green Roofs*. 2012. 2012 29-September.

[29] United States Environmental Protection Agency

[30] Gaffin, S.R. et al.

[31] Curie, B.A. and B. Bass. "Estimates of Air Pollution Mitigation with Green Plants and Green Roofs Using the UFORE Model." *Sixth Biennial Canadian Society for Ecological Economics (CANSEE) Conference*. Toronto, 2005.

[32] National Institute of Building Sciences. *Extensive Vegitative Roofs*. 2012. 2012 5-November.

[33] Stovin, Virginia. "The potential of green roof to manage Urban Stormwater." *Water and Environment Journal* 24 (2010): 192-199.

[34] United States Environmental Protection Agency

[35] greenroofs.com, LLC. *Issues*. 2011. 2012 29-September.

[36] Berndttson, 2010

[37] Bliss, D. et al.

Rain Barrels

Description

Rain barrels and cisterns are the simplest, lowest-cost measure which community organizations and individual businesses and citizens can implement to reduce stormwater runoff from building roofs.[1] In some areas, they are available for free as part of sponsored stormwater management programs.[2] A rain barrel consists of vessels that resemble traditional barrels, but are typically made from injection-molded or roto-molded plastic. They may be purchased at low cost or made from scavenged materials. Rain barrels usually collect runoff via roof gutter systems and generally have a capacity of 50 to 100 gallons. Rain barrels are effective because they are able to temporarily detain stormwater but are only effective if they are emptied when they reach full capacity.[3] The water detained may be used to water gardens or lawns. In larger building applications the vessels are larger, significantly different in construction, and are sometimes known as cisterns.

Figure 15. Three 60-gallon barrels linked in series (Buffalo Niagara Riverkeeper).

Life Cycle

Rain barrels are generally made of plastic and are very durable. Cisterns may be made of fiberglass, plastic, metal or concrete. The durability of the material and the conditions to which it is exposed will determine the life span of the device. A typical plastic rain barrel can be expected to last 20 years or more if properly maintained.[4]

Case Study - War Memorial Arena Rainwater Re-use Cistern: Syracuse, New York

The War Memorial is home to the Syracuse Crunch of the American Hockey League and also hosts many large concerts and sporting events each year. The roof surface is 44,000 square feet and the annual runoff generated is 400,000 gallons per year. Using a series of cisterns with a combined capacity of 15,000 gallons, 220,000 gallons of that rainwater is collected and used in making and maintaining the ice surface and other building operating needs. The remaining 180,000 gallons is released when it is not raining. The project was completed in 2011 at total cost of $1,229,251 (Onondaga County, New York).

Cost

Rain barrels cost between $59 and $100, depending on size and features.[5] In some areas, sponsored programs provide them at no cost. Cisterns are designed to manage larger volumes of water from larger buildings, which can be treated for building use for irrigation and other grey water applications. Cisterns are capital projects and may carry much higher per gallon capacity costs than rain barrels. The 15,000-gallon cistern in place at the War Memorial On Center in Syracuse manages 44,000 square feet roof area and was installed at a cost of $1,229,251.[6]

Implementation Timeframe

The design phase consists of a simple roof area runoff calculation. Installation takes minutes and may be undertaken by an untrained worker. Larger cisterns may require substantial engineering and construction and will take greater lengths of time according to the circumstances.

Maintenance

Rain barrels must be emptied if overfilled in order to avoid overflowing. They must be disconnected and stored during winter months.[7]

Impacts

Benefits: Rain barrels usually do not require permits from municipalities.[8] Four 60-gallon rain barrels are capable of detaining runoff from a one-half inch storm event falling on a 1,000 square foot roof.[9] They can also provide a good source of water for gardens and lawns. Cisterns may be used to collect water for building operations.[10] With no moving parts, maintenance is simple, which encourages use. Single barrels may be easily linked in tandem to increase storage capacity.

> *These [1000] rain barrels will capture thousands of gallons of water that would have otherwise flowed into the streets, leading to flooding and increasing the likelihood and intensity of combined sewer overflows. This is exactly the kind of smart, local investment envisioned in the NYC Green Infrastructure Plan that Mayor Bloomberg launched last September.* – Commissioner Halloway, New York City Department of Environmental Protection (Sklerov and Padilla)

Challenges: Small barrels must be disconnected and stored during winter months to avoid freezing that could damage the barrels and potentially the gutter system as well.[11] Cistern installations usually can remain in service in all seasons but can have limited capacity. If not properly equipped with overflow, collection of rainwater in the barrel will quickly be overwhelmed in heavy rain events. They should be emptied as they fill to avoid overflow and the encouragement of mosquito breeding.[12] Finally, larger-sized cisterns may carry higher capital costs, especially when used for large-scale water capture and reuse.

Additional Rain Barrel Resources

Stroud Water Research Center - Rain Barrel Guidance - http://www.stroudcenter.org/education/projects/rain_barrels.shtm

Harvest H_cO.com- http://www.harvesth2o.com/resources.shtml

---

[1] City of Minneapolis, Minnesota. n.d. 14 0ctober 2012. <www.minneapolismn.gov/publicworks/sotrmwater/green/stormwater_gree-initiatives_rain-garden>.

[2] Onondaga County, New York. *Save the Rain*. 2012. 15 October 2012. <savetherain.us/str_project/rain-barrel-program>.

[3] City of Philadelphia Common Council. 2012. 15 October 2012. <www.nextgreatcity.com/actions/trees>.

[4] Gannon, Mike. *President, The Pond Hunter/Ful Service Aquatics* 27 October 2012.

[5] Hayneedle. *Prices for Rain Barrels*. n.d. 15 October 2012. <www.hayneedle.com>

[6] Onondaga County, New York

[7] City of Minneapolis, Minnesota

[8] ibid

[9] ibid

[10] Onondaga County, New York, 2012

[11] City of Minneapolis, Minnesota, 2012

[12] City of Arlington, Virginia. Ed. Dickinson. 28 September 2012. 14 October 2012 . <http://www.arlingtonva.us/departments/environmentalservices/sustainability/eporaingarden.aspx>.

Green Spaces

Description

The use of green spaces such as parks, courtyards, greenways, and stepped vegetated cells are strategies that government agencies and community organizations can use to effectively manage stormwater and mitigate flooding,

> *When designed to include stream networks, wetlands, and other low-lying areas, a city's green space system can provide numerous stormwater management benefits, including storing, carrying, and filtering storm runoff.* – American Planning Association: (American Planning Association - Green Infrastructure)

especially for urban locations. When cities and towns are able to use green spaces as part of an interconnected system, they can realize much greater benefits than from singular, disconnected green spaces.[1] Soil and native vegetation are able to store, filter, and infiltrate stormwater, often acting as natural pollution reduction mechanisms. The benefits of linked green spaces can also be financial, as green infrastructure can reduce the need for built infrastructure to manage stormwater. This green infrastructure can be used in conjunction with more conventional stormwater management practices to capture stormwater.

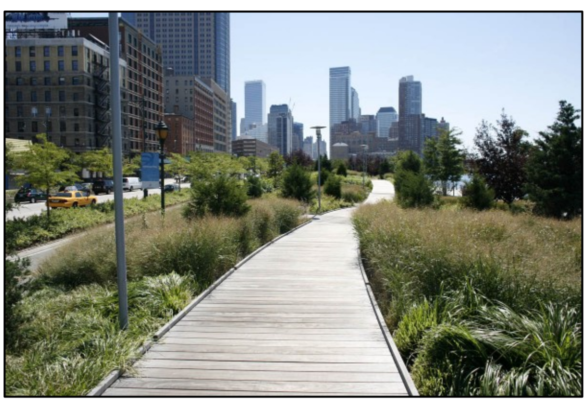

Figure 16. Hudson River Park in New York City (Hudson River Park).

Case Study - The Viewlands Cascade: Seattle, Washington

In the late 1990s, the city of Seattle turned to green infrastructure to mitigate urban stormwater runoff. Seattle Public Utilities installed several pilot projects to mimic natural hydraulic functions. Designed to reduce stormwater runoff to Pipers Creek, a tributary of Puget Sound, the Viewlands Cascade project uses a series of 16 stepped vegetated cells formed by log weirs, or horizontal barriers to the flow of stormwater, each 8 to 12 feet wide (Gaynor, Inc.). The cells collect and filter runoff from nearby land, while the decreased amount of cleaned stormwater that eventually discharges supports the ecosystem of the river (National Resources Defense Council).

Completed in 2000 with an estimated construction cost of $225,000, the project has exceeded performance expectations (Gaynor, Inc.). Hydraulic monitoring indicates that the system decreases stormwater runoff volume by 75- 80 percent and peak flow rates by 60 percent (University of Washington). Over a three-year monitoring period, half of the total volume of stormwater that entered the cascade system was retained in the steps and not discharged to Pipers Creek (National Resources Defense Council). Replacing an old drainage ditch, it is estimated that the cascade system retains three times as much stormwater volume and holds stormwater in the system for over 2.5 times longer when compared to the ditch (National Resources Defense Council).

Life Cycle

With proper maintenance, green spaces can essentially have a life cycle as long as the user would like. As with any typical park or garden, maintenance of the plant life and media is required to perpetuate the longevity of the stormwater management strategy. Because this strategy does not incorporate any grey infrastructure, there is an infinite service life when maintained properly.

Cost

Depending on the type of vegetation used, plant media required, and initial state of the soil, smaller green space installation costs can range between $10 and $40 per square foot.[2] In urban locations, green spaces and parks can cost up to $150 per square foot.[3] However, installation costs in suburban settings of larger green spaces, including meadows and spaces with natural landscaping, are typically between $.05 and $.10 per square foot.[4] Maintenance costs can vary but are generally very low, between $.001 and $.028 per square foot per year.[5] [6] The reduction or elimination of lawn mowing and the application of chemicals can lead to significant cost savings.

Figure 17. Stepped vegetated cells with stone walls (Elements of Land Design, LLC).

Implementation Timeframe

Smaller green spaces can be implemented quite quickly. Parks, meadows, and other larger green space systems may take many months to plan and design and additional months to construct. Compared to large grey infrastructure implementation timeframes, green space stormwater management systems are much quicker and easier to install.

Maintenance

Owners and operators of green spaces can to a certain extent choose their desired level of maintenance, as certain plants will require more or less attention. Carefully selected natural vegetation often perform best in their natural environment and will require less maintenance than foreign vegetation. Maintenance requirements are greater in the years immediately following installation and become less burdensome after the vegetation is fully mature.[7] The maintenance of green spaces includes periodically visually inspecting that the vegetation is alive and not diseased. The application of chemicals, including fertilizers and pesticides, will be occasionally necessary in select locations. Weeding, reintroducing plants to replace dead or diseased vegetation, and reseeding will be required until the vegetation is established and mature.[8] Annual controlled burning and annual or seasonal mowing can help revitalize the vegetation.[9] Spaces using natural landscaping require less maintenance than conventionally landscaped areas because they use less irrigation, need less mowing, and require less fertilizer and pesticides.[10]

Impacts

Benefits: There are numerous benefits to employing green spaces as a stormwater management tool. Groundwater can be recharged as stormwater infiltrates trickles down into the groundwater below.[11] Vegetation used in green spaces can effectively trap pollutants present in runoff, such as nitrogen and phosphorus, and provide cleaner water.[12] [13] As green spaces require smaller areas of land to provide an impact, there are also fewer siting and land constraints than larger management strategies.[14] Maintenance costs of green spaces that utilize natural landscaping are significantly lower (half to one-fifth) than traditional landscaped areas.[15]

There are a number of other environmental benefits associated with green spaces. Green spaces and plants are effective at sequestering carbon and filtering other air pollutants, thus increasing the quality of air surrounding the system and decreasing disruption to the global atmospheric composition.[16] Green spaces can also lower the surface temperature through shading and evapotranspiration.[17] Additionally, parks alter and enhance local wind patterns because the cooler air over parks replaces warmer air nearby. This cooler air also aids in reducing precipitation anomalies.[18] Wildlife habitat and ecological functions can be improved.[19] Finally, green spaces can be important to overall urban planning by improving aesthetics, quality of life, and property value.[20] [21]

Challenges: Because vegetation is capable of absorbing and retaining the most amount of stormwater with mature roots and leaves, the benefits of green spaces are more long-term and are not maximized until the species have grown and matured.[22]

Additional Green Space Resources

American Planning Association - http://www.planning.org/cityparks/briefingpapers/greeninfrastructure.htm

City of Chicago - Natural Landscaping - http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design

---

[1] American Planning Association - Green Infrastructure. "How Cities Use Parks for... Green Infrastructure." 1 June 2012. *American Planning Association.* 18 October 2012. <http://www.planning.org/cityparks/briefingpapers/greeninfrastructure.htm>.

[2] City of Chicago - Bioinfiltration. *Bioinfiltration: Rain Gardens*. 1 January 2012. 8 October 2012. <http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design/bioinfiltration_raingardens.html>.

[3] New York City Economic Development Corporation. *Harlem River Park*. 28 February 2012. 19 October 2012. <http://www.nycedc.com/project/harlem-river-park>.

[4] City of Chicago - Natural Landscaping. "Natural Landscaping." 1 July 2012. *City of Chicago.* 27 October 2012. <http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design/natural_landscaping.html>.

[5] United States Environmental Protection Agency - Section 319 Success Stories. (2010 13-January). *Polluted Runoff (Nonpoint Source Control).* Retrieved 2012 11-November from http://www.epa.gov/owow/NPS/Section319I/NJ.html

[6] Fentress, F. (2009). Sustainable Landscape Management Practices. *Watershed-Friendly Landscape Workshop.*

[7] Pennsylvania Department of Environmental Protection. "Pennsylvania Stormwater Best Management Practices Manual - Chapter 6.7.2." 30 December 2006. *Pennsylvania Department of Environmental Protection.* 27 October 2012. <http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305>.

[8] ibid

[9] City of Chicago - Natural Landscaping , 2012

[10] ibid

[11] "Why Green Infrastructure?" 25 October 2012. *U.S. Environmental Protection Agency.* 27 October 2012. <http://water.epa.gov/infrastructure/greeninfrastructure/gi_why.cfm#WaterQuality>.

[12] National Resources Defense Council. "NRDC: Rooftops to Rivers." 1 May 2006. *NRDC.* 13 October 2012. <http://www.nrdc.org/water/pollution/rooftops/contents.asp>.

[13] City of Chicago - Natural Landscaping, 2012

[14] ibid

[15] ibid

[16] American Planning Association - Climate Change Management. "How Cities Use Parks for... Climate Change Management." 1 July 2012. *American Planning Association.* 19 October 2012.

<http://www.planning.org/cityparks/briefingpapers/climatechange.htm>.

[17] ibid

[18] ibid

[19] American Planning Association – Green Infrastructure, 2012

[20] ibid

[21] National Resources Defense Council, 2012

[22] Pennsylvania Department of Environmental Protection, 2012

Land Acquisition and Preservation

Description

While many stormwater management strategies handle water "downstream," it is important to recognize that there are ways to manage stormwater upstream as well. For communities located in more suburban and rural locations, the acquisition and protection of watershed lands in order to reduce over-development can be critical to naturally managing stormwater. Preserved land provides natural locations for stored water. Through reduced development and therefore the prevention of increased presence of impervious surfaces, the amount and speed of stormwater runoff is reduced and the possibility for flooding reduced.[1] This water is water that will never reach transportation infrastructure.

> *From April 2006 to September 2009, developments reviewed and approved by the County protected 31 percent of open space, 67 percent of the tree canopy, 27 percent of upland habitat, 59 percent of strategic ecosystems, and 100 percent of wetlands… On a regional scale, Alachua's land acquisition program has protected an impressive network of open space in the 10 years since its conception. Alachua County Forever has protected over 18,000 acres of land worth over $81 million.* – U.S. Environmental Protection Agency (EPA Office of Wetlands, Oceans and Watersheds)

Life Cycle

Once the land is purchased or re-zoned, this strategy can last as long as the land remains in possession of the protecting entity. If there are Best Management Practices installed on the land, then they will last as long as the particular infrastructure chosen will; however, this does not impact the life cycle of the land itself. The placement of a voluntary easement can ensure the permanence of land conservation for a particular area.[2]

Case Study – Alachua County Forever: Alachua County, FL

Alachua County, Florida, is located near Gainesville and has experienced a significant growth in population quickly developing natural lands and stressing the local water systems. As a result, the county has undergone a significant green infrastructure effort, which includes a mix of regulatory changes, educational programming, and significant land acquisition. The county, through the support of voters, initiated the Alachua County Forever fund worth $29 million and collected through property taxes. This fund is able to acquire land in three ways – through donation, purchase, and dedications of interest. The results have been impressive with over 18,000 acres worth a combined $81 million acquired and protected since 2000. The people of Alachua County remain involved as well. In 2008, eight years after the first vote to establish the Alachua County Forever fund, voters approved the Wild Spaces Public Places referendum, which raised the sales tax for two years by $.015, money which was used for recreational improvements and to continue funding land preservation efforts. This protected land is serving a number of purposes for the people of Alachua, including assisting in the management of stormwater (EPA Office of Wetlands, Oceans and Watersheds).

Cost

The cost of land will be variable depending on a number of factors including primarily location. Average cost for watershed protection has been noted at $1,071 - $6,071 per acre ($.03-$.14/sq. ft.) depending on location and amount of restoration effort needed at that location.[3] An evaluation of 14 current 2012 listings for land in upstate New York (non-irrigated and without a house) provides an estimated average cost of $8650 per acre.[4] It has also been noted that for those looking to protect a wetland area, it is generally accepted that more land will be needed to be effective and will therefore drive up costs.[5]

Implementation Timeframe

Land acquisition and protection is a long-term management strategy; depending on the targeted land availability, it could take many years before an effective portfolio can be built.

Maintenance

While there may be restoration activities associated with this strategy in order to utilize the land to its maximum capacity, there is no maintenance associated with this type of stormwater

Figure 18. Once a brownfield, Depot Pond is a restored location that is part of the Alachua, FL, land preservation project (EPA Office of Wetlands, Oceans and Watersheds).

management strategy.[6] The owner of the protected lands may decide to install certain Best Management Practices (BMPs) in order to increase the amount of water retained on the property; if this were to happen, they would have the types of life expectancies and maintenance needs associated with that type of BMP.[7]

Impacts

Benefits: Along with decreasing flooding and increasing water storage as a means of stormwater management, the acquisition and protection of land provides additional benefits. One such benefit is improved air quality due to the increased amount of vegetation. The protection of natural habitats also translates to wildlife protection (animal and plant species), aquifer recharge, and water resource development.[8] [9] [10] There has also been noted a positive influence on property values for those located next to and near protected lands.[11]

Challenges: The primary challenges associated with this strategy are the cost of land and determining financing for acquisition; to acquire land for conservation purposes, towns often need to use a combination of government funding as well as donations and grants.[12]

Additional Land Acquisition and Protection Resources

Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure - www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf

Protecting Water Resources and Managing Stormwater: A Bird's Eye View for New Hampshire Communities - http://extension.unh.edu/CommDev/documents/Stormwtr_Guide.pdf

Milwaukee Metropolitan Watershed Plan: http://www.epa.gov/owow/NPS/natlstormwater03/26MOLeary.pdf

---

[1] Peterson, Julia, Amanda Stone and James Houle. *Protecting Water Resources and Managing Stormwater: A Bird's Eye View for New Hampshire Communities*. n.d. Electronic Report.

[2] ibid

[3] O'Leary, Mark, et al. "A Conservation Plan for Three Watersheds within the Milwaukee Metropolitan Sewerage District." *National Conference on Urban Storm Water: Enhancing Programs at the Local Level*. Chicago: U.S. Environmental Protection Agency, 2003. 272-290.

[4] *New York Farmland for Sale*. 2012 13-October. 2012 13-October. <http://www.farmlandsearch.com/view.aspx?sc=new-york&p=0-4-0>.

[5] Weiss, Peter, John Gulliver and Andrew Erickson. "Cost and Pollutant Removal of Storm-Water Treatment Practices." *Journal of Water Resources Planning and Management* (2007): 218-229.

[6] O'Leary, M. et al., 2003

[7] Northern Virginia Regional Commission. *Maintaining Stormwater Systems: A Guidebook for Private Owners and Operators in Northern Virginia*. Fairfax: Virginia Coastal Zone Management Program at the Department of Environmental Quality, 2007.

[8] Angelo, Mary Jane. "Integrating Water Management and Land Use Planning: Uncovering the Missing Link in the Protection of Florida's Water Resources?" *UF Law Scholarship Repository* 2001: 224-248.

[9] Ernst, Caryn. *Protecting the Source: Land Conservation and the Future of America's Drinking Water*. Ed. Kim Hopper and David Summers. Prod. The Trust for Public Land and American Water Works Association. San Francisco, 2004. Electronic Report.

[10] Dexter, Jessica. *Land Use Tools to Protect Groundwater: Preserving Recharge*. Chicago, July 2011. Online Report.

[11] Geroghehan, Jaqueline, Lori Lynch and Shawn Bucholtz. "Capitalization of Open Spaces into Housing Values and the Residential Property Tax Revenue Impacts of Agricultural Easement Programs." *Agricultural and Resource Economic Review* (2003): 33-45.

[12] Peterson, n.d.

Bluebelt Project

Description

A bluebelt program is an effort to preserve and enhance the use of naturally occurring wetlands to promote natural drainage and travel of stormwater away from developed

> *Perhaps the best testament to the success of the Bluebelt has been its stellar performance during major storms and hurricanes. Hurricane Ivan, which dropped 2.3 inches (5.8cm) of rainfall over a 24-hour period, passed quietly through the region on September 17-18, 2004. Tropical Storm Tammy and Subtropical Depression 22, which combined to produce 6.4 inches (16cm) of rainfall over a 24-hour period, went by unnoticed on October 8-9, 2005. Areas that were once flooded even by minor precipitation events handled these major storms without issue.* – Gumb, Rossi and Mehrotra (Gumb, Rossi and Mehrotra)

locations and transportation systems. This strategy is only appropriate for those locations where wetlands are already in existence and part of the water transportation system. The bluebelts manage stormwater primarily utilizing existing natural infrastructure, taking advantage of wetlands to receive stormwater. These natural resources are supplemented by "bluebelt facilities," constructed at locations where the sewer system ends and nature begins. These facilities, which include stormwater detention ponds and constructed wetlands, are intended to reduce the potential negative impact of stormwater drainage during precipitation events on the natural infrastructure. It is important to note that the bluebelt is not entirely a replacement for but a supplement to grey infrastructure; while it will avoid the need for significant new grey infrastructure, some small additions may be necessary to allow for the most beneficial management of stormwater for a particular location.[1] The bluebelt can be built to manage a determined storm size – the Staten Island

Case Study - Staten Island Bluebelt: Staten Island, NY

The Staten Island blue belt system covers 16 different watersheds and over 10,000 acres of Staten Island, New York. The program was initially started because it was determined that traditional grey infrastructure (sewer system) would not be suitable on the island due to the amount of wetlands available that would be overwhelmed through population growth and development. Instead, the focus became how to use these wetlands and naturally occurring drainage pathways to manage stormwater. A model was developed utilizing data for a five-year storm identifying locations where traditional grey sewer systems were lacking and could be installed as well as naturally occurring drainage patterns which could be supplemented through the installation of bluebelt facilities, also referred to as BMPs (Gumb, Rossi and Mehrotra). To date, 63 BMP sites have been installed including extended retention basins, outlet filling basins, and sand filters (Gumb, Chief Engineer- Bureau of Water and Sewer Operations, Staten Island Blue Belt Unity). Each of these BMPs is developed to be site specific with a focus on maintenance of the location, vegetation, and incorporating stone in homage to the location's agrarian history. The results have been encouraging – since the implementation of the program, Hurricane Ivan (2.3 inches) and Tropical Storm Tammy combined with Tropical Depression 22 (6.4 inches) passed through without significant flooding impacts (Gumb, Rossi and Mehrotra). Performance on the south shore was also good during bluebelt has been designed to manage the water associated with a 5-year storm. A new bluebelt facility in the Bronx, New York, has been designed to manage 8 gallons per square foot and a calculated .13 gallons per minute per square foot.[2]

Life Cycle

The lifecycle of the bluebelt is dependent on the type of infrastructure utilized. The natural infrastructure (protected wetlands) will last for as long as they remain protected. It is important to note that in some instances, this could be threatened by the rise in sea levels.[3] The bluebelt facilities themselves have varying life expectancies including wet and dry ponds (wet holds water all the time while dry is intended only for stormwater) and sand filters (sand beds installed to absorb and transfer water) all of which last from 20 - 50 years.[4]

Cost

The cost for a bluebelt facility is dependent on land costs as well as the cost of the bluebelt facilities needed to be installed. The Staten Island Bluebelt facility has cost over $100 million to install with an additional $700,000 a year budgeted for maintenance.[5] However, the avoided grey infrastructure cost is also important, and it has been estimated that as of 2007, $80 million in capital projects has been avoided through the implementation of their bluebelt.[6]

Case Study - Staten Island, NY, Continued

Hurricane Irene event of 2010, and work continues to maintain the existing and continue developing additional BMPs to improve future performance (Gumb, Chief Engineer- Bureau of Water and Sewer Operations, Staten Island Blue Belt Unity).

Implementation Timeframe

The timeframe for this type of project is dependent on the existing state of the wetland areas, the current zoning, and how much construction needs to be done in stormwater discharge locations. The Staten Island Bluebelt was started in the mid-1990s, with construction still taking place and the addition of a new BMP planned for 2013. However, the construction of each BMP can take just a few months.[7]

Maintenance

The construction of the bluebelt facilities is intended to address the maintenance needs of the overall system. The aim is to do no maintenance in the natural areas themselves. With this said, the primary maintenance associated with the bluebelt facilities is to vactor them in order to remove sediment build up protecting both the natural channels and extending the life expectancy of the bluebelt facilities themselves. Maintenance is also done before any expected major storm, with

Figures 19 and 20. South Richmond intersection – prior to bluebelt establishment (left) and after (right) (Gumb, Rossi and Mehrotra; Gumb, Rossi and Mehrotra).

resources being sent to bluebelt facilities to ensure no debris build-up has taken place.[8]

Impacts

Benefits: Along with enhancing the ability to move water from transportation infrastructure through the natural watershed, bluebelts are beneficial in that they are able to enhance water quality. Studies have shown that the time spent in the wetlands allows for nitrogen loads and pollutant levels to decrease in comparison to the runoff itself.[9] Biodiversity is also positively impacted, protecting and encouraging development of native plant and animal species.[10] [11][12] Land value has also shown to increase with the protection of wetlands.[13] [14] [15] Finally, the protection of wetlands will offer both aesthetic, educational, and recreational benefits for surrounding communities.

Challenges: Primary challenges appear to be the ability to manage the maintenance of facilities with staffing.[16] Another challenge is the availability of wetland spaces for preservation and implementation timeframe and costs. This type of project is one that would require a community to commit to its development with significant resource dedication.

Additional Bluebelt Resources

New York City Department of Environmental Protection: Staten Island Blue Belt - http://www.nyc.gov/html/dep/html/dep_projects/bluebelt.shtml

Staten Island History and Bluebelt Land Acquisition - http://urbanomnibus.net/main/wp-content/uploads/2010/12/Staten-Island-History-and-Bluebelt-Land-Acquisitions.pdf

Staten Island Bluebelt Program: A Natural Solution to Environmental Problems - http://www.stormh2o.com/SW/Articles/Staten_Island_Bluebelt_Program_A_Natural_Solution_3321.aspx

---

[1] *The Staten Island Blue Belt: A Natural Solution to Storm Water Management*. 2007 20-March. http://www.nyc.gov/html/dep/html/dep_projects/bluebelt.shtml. 2012 15-October.

[2] Gilbride, Chris and Mercedes Padilla. *DEP's First Bluebelt Wetland in the Bronx Controls Stormwater at The New York Botanical Garden and Reduces Combined Sewer Overflows*. New York, 2012 7-September.

[3] Gumb, Dana. *Chief Engineer- Bureau of Water and Sewer Operations, Staten Island Blue Belt Unity* Morgan Scott. 2012 9-October .

[4] Northern Virginia Regional Commission. *Maintaining Stormwater Systems: A Guidebook for Private Owners and Operators in Northern Virginia*. Fairfax: Virginia Coastal Zone Management Program at the Department of Environmental Quality, 2007.

[5] ibid

[6] Gumb, Dana, et al. "The Staten Island Bluebelt: A Case Study in Urban Stormwater Management." *Novatech* (2007): 19-26.

[7] ibid

[8] Gumb, 2012

[9] ibid

[10] Vokral, Jack, et al. "Staten Island Bluebelt Program: Stormwater Management Using Nature." *Proceedings of the Water Environment Federation*. Water Environment Federation, 2001. 563-578.

[11] Vokral, John, et al. "Wetlands at Work." *Civil Engineering* (2003): 56-63.

[12] Hsu, David. "Sustainable New York City." 2006.

[13] Geroghehan, Jaqueline, Lori Lynch and Shawn Bucholtz. "Capitalization of Open Spaces into Housing Values and the Residential Property Tax Revenue Impacts of Agricultural Easement Programs." *Agricultural and Resource Economic Review* (2003): 33-45.

[14] Thibodeau, F.R. "An Economic Analysis of Wetland Protection." *Journal of Environmental Management* (1981): 19-33.

[15] Brown, Hillary, et al. *High Performance Infrastructure Guidelines*. New York: New York City Department of Design and Construction and the Design Trust for Public Space, 2005.

[16] Gumb, D, 2012

Evaluation Matrix

In an effort to provide an easy-to-use tool for decision makers to evaluate green infrastructure stormwater management strategies, this evaluation tool synthesizes the most critical and quantifiable information.

The following tool evaluates stormwater management practices in terms of their effectiveness in capturing stormwater, cost, maintenance, and installation difficulty. It also identifies which setting each strategy is best suited for, and which secondary benefits exist for each strategy, such as improved water and air quality, and increased areas for recreation. Each strategy is evaluated in terms of other strategies within the tool.

Legends

Legend: Evaluation Matrix Units		
Criteria	Unit	Additional Information
Capture Rate	g/m/sf	Unit gallons/ minute/ square foot Description: The gallons of stormwater that can be captured by each strategy per minute per square foot. It is important to note that each strategy has a maximum capacity at which point it would not be able to capture any additional rainwater until the water that is currently being retained by the strategy is released as runoff, utilized by vegetation or evaporated. Rating Good: 0.005-0.019: one-half to two inches per hour Better: 0.02-0.099: two to ten inches per hour Best: ≥ 0.10: more than 10 inches per hour Context The NYS Stormwater Management Design Manual shows a 100-year storm event across the state of NY as ranging between 4.4-8.0 inches over a 24-hour period; and a 10-year storm event ranging from 3.2-6 inches over a 24-hour period. Hurricane Irene (a Category 1 hurricane that became a tropical storm as it travelled through New York State in September of 2011) delivered between 0.5-7.5 inches of rainfall in various counties throughout New York State.[1] Rainfall from Hurricane Sandy (October of 2012) delivered up to 10 inches of rainfall over New York City.[2]
Capital Cost	$/sf	Unit dollars/ square foot Description The initial cost to install the strategy
Maintenance Cost	$/sf/yr	Unit dollars/ square foot/ year

		Description The cost per year to maintain the strategy
Total Cost	$/sf	Unit dollars/ square foot Description The total cost to install and maintain the strategy over its lifetime. This is calculated by adding the capital cost to the total maintenance cost (maintenance cost per year times the lifetime of the project in years).
Maintenance Frequency	x/yr	Unit times/ year Description The number of times per year that the strategy needs to be maintained
Lifetime	yrs	Unit years Description The expected lifetime of the project in years before it needs to be replaced
Expertise	high medium low	Description The level of expertise required to install the project high: expert (engineer, architect, other certified labor) medium: skilled labor that does not require certification low: unskilled labor
Setting	U S R	Description The most suitable setting for the installation of a strategy U: Urban S: Suburban R: Rural

Legend: Secondary Benefits	
	Improves water quality
	Recharges ground water
	Mitigates urban heat island effect *(An urban heat island is a metropolitan area that is warmer than surrounding rural areas because of heat retention by materials used in urban development.)*
	Harvests rain water *(Although it is possible to harvest rainwater for most strategies if additional processes are employed, this benefit is only identified for those strategies that do not require additional processes to harvest rainwater.)*
	Improves air quality
	Increases biodiversity *(This refers to animal/ wildlife biodiversity.)*
	Increases surrounding land value
	Improves aesthetics
	Increases recreational opportunities
	Saves energy

Evaluation Matrix

	Capture Rate	Capital Cost	Maint. Cost	Total Cost	Maint. Freq	Life-time	Exper-tise	Setting	Secondary Benefits
Unit	g/m/sf	$/sf	$/sf/yr	$/sf	x/yr	yrs		U, S, R	[water drop] [lightning] [thermometer] [bucket] [tree] [bird] [house] [flower] [light bulb] [runner]
Good ○	.005-.019	15-200	2-10	100-200	monthly		high		
Better ◍	.02-.099	1-14.99	0.20-1.99	10-99.99	quarterly		medium		
Best ●	≥ .10	≤ 1	≤ 0.20	≤ 10	≤ 2x/year		low		
Pervious Pavement	varies[a]	◍	●	◍/●	◍	15-25+	○	U, S, R	[water drop] [lightning] [thermometer] [house]
Swales	○/◍	○	●	◍	●	30	○	U, S	[water drop] [lightning] [thermometer] [house] [flower]
Street Trees	○/◍ [b]	○	◍	○/◍	◍/●	8-100+	○/◍	U, S	[water drop] [lightning] [thermometer] [tree] [house] [flower]
Rain Gardens	◍	○	●	◍	●	30	○	U, S	[water drop] [lightning] [thermometer] [house] [flower]
Green Roofs	○/◍	○/◍	◍	○/◍	○/◍	30-50	○	U	[water drop] [thermometer] [tree] [bird] [house] [flower] [light bulb]
Rain Barrels	N/A[c]	● [d]	○ [d]	○ [d]	●	20	●	U, S, R	[bucket] [flower]
Green Space	◍/●	varies[e]	●	varies[e]	○/◍	100+[f]	○/◍	U, S	[water drop] [lightning] [thermometer] [tree] [bird] [house] [flower] [runner]
Land Acq & Pres	◍/●	●	varies[g]	●	varies[g]	100+[f]	○	S, R	[water drop] [lightning] [tree] [bird] [house] [flower] [runner]
Bluebelts	●	●	●	●	varies[h]	20-50	○	U, S	[water drop] [thermometer] [bird] [house] [flower] [runner]

<u>Notes:</u>

a – Permeable Pavements can be designed to capture nearly any volume of rainfall. Unlimited capacity is 24 inches over a 24-hour period, or 0.249 gal/ min/ sq ft.[3] If pavement is limited by 24-36 inches of engineered soil beneath the surface, this would impose a capture rate equivalent to 6.24-9.36 inches over a 24-hour period, or 0.0027-0.0041 gal/ min/ sq ft.[4]

b - Since street trees often have a similar substrate to swales, the capture rates calculated for swales were used for street trees.[5] In addition, trees generally capture the first inch of rainfall in the shadow of their canopy.[6] For a tree with a 16-foot diameter in an 8x20 foot tree pit (160 square feet), this means that the tree canopy could intercept the first 0.78 gal/ sq ft of rainwater.

c - Rain barrels capture water based upon their size, which defines their capacity. Once they have been filled to capacity they cease to be valuable for additional capture.

d – The square footage for rain barrels was calculated as the amount of land that the rain barrel sits on. In most cases, rain barrels capture rainwater from an area that is larger than its own.

e – The capital cost of green spaces could be as low as $0.02/ sq ft for natural landscaping or meadows, or as high as $200/ sq ft for some urban parks.

f - Given the indefinite lifetime of green spaces and acquired/ preserved land, the lifetime of these strategies is listed as 100+ years.

g – Maintenance frequency and cost will vary significantly for each location depending on purpose and BMP installation. Those sites set aside as preserved land and left as natural preserves will require minimal maintenance. However, sites with recreational activities or installed BMPs will require more maintenance.

h – Bluebelt facilities require regular maintenance as well as maintenance before every storm to ensure that they are free of debris.

This evaluation matrix provides a snapshot summary of all of the proposed green strategies against a set of varying metrics for easy cross-comparison. There are two ways to read the matrix, either by row or by column. If examined by row, a comprehensive summary and understanding of a given strategy through the selected attributes, such as capture rate, cost, and maintenance frequency, can be garnered. When isolating any given column, all strategies can be compared against one another to see which best performs in that category. A circle filled with two colors indicates that there is a range of values for that attribute (ranges for the "good," "better," and "best" categories can be found at the top of the evaluation tool).

---

[1] National Oceanic and Atmospheric Administration. *Harmful Algal Blooms (HABS): NOAA Watch: NOAA's All-Hazard Monitor: National Oceanic and Atmospheric Administration: U.S. Department of Commerce*. n.d. http://www.noaawatch.gov/themes/habs.php. 20 November 2012.

[2] Gutro, Rob. "Hurricane Sandy (Atlantic Oenan): NASA Adds Up Hurricane Sandy's Rainfall from Space." 2012 1-November. 2012 20-November <http://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Sandy.html>.

[3] Bassuk, Nina, et al. *Using Porous Asphalt and CU-Structural Soil*. Technical Report. Urban Horticulture Institute. Ithaca: Cornell University, 2007.

[4] ibid

[5] Gomery, Jane. *Burlingame Commercial District Parking Lot and Street Project* Charles M Samul. Burlingame, 2012 11-October.

[6] Nisbet, T. (2005, April). *www.forestry.gov.uk.* Retrieved November 22, 2012, from http://www.forestry.gov.uk/pdf/FCIN065.pdf/$FILE/FCIN065.pdf.

Emerging Research

Emerging Research

Emerging Regulatory/Policy Approaches

In addition to the green infrastructure strategies proposed in this report, there are new, emerging regulatory and policy approaches to combating stormwater runoff. Although these regulations may not be applicable to all municipal settings, the following proposed or piloted programs and rules are particularly noteworthy and may indicate future trends of high-level stormwater management.

Proposed Rulemaking to Strengthen the Stormwater Program

National – Environmental Protection Agency

Building upon the Stormwater Phase II Final Rule of 1999, the U.S. Environmental Protection Agency (EPA) is currently in the early stages of drafting the newest rule of its Stormwater Program. EPA is expecting to propose the rule by June 10, 2013, and to complete a final action by December 10, 2014.[1]

Phase II of the Stormwater Program strengthened the original Phase I of 1990. Similarly, the proposed rule is aiming to further strengthen the Stormwater Program and reduce stormwater discharges by establishing a program targeting newly developed and redeveloped sites. Other regulatory improvements are also being considered. EPA's website provides the following six rulemaking actions that are currently being considered:

1. Develop performance standards from newly developed and redeveloped sites to better address stormwater management as projects are built;
2. Explore options for expanding the protections of the municipal separate storm sewer systems (MS4) program;
3. Evaluate options for establishing and implementing a municipal program to reduce discharges from existing development;
4. Evaluate establishing a single set of minimum measures requirements for regulated MS4s. However, industrial requirements may only apply to regulated MS4s serving populations of 100,000 or more;
5. Explore options for establishing specific requirements for transportation facilities; and
6. Evaluate additional provisions specific to the Chesapeake Bay watershed.[2]

Current federal stormwater regulations under the Phase II Rule only apply to MS4s in urbanized areas, construction sites, and certain categories of industrial sites. The proposed rule would expand the purview of the stormwater program to any and all "newly developed" and "redeveloped" sites. Aiming to have these sites mimic natural infiltration processes, sustainable practices would be encouraged. EPA has indicated that a post-development site's runoff reduction requirement may attempt to mimic the site's pre-development hydrology state.[3]

Regarding the specific requirements for transportation facilities in the fifth action, EPA is examining the possibility of establishing specific MS4 requirements for transportation facilities. Currently transportation MS4s are managed under the National Pollutant Discharge Elimination System (NPDES), which EPA has authorized most states to administer. The details of the proposed requirements for transportation facilities have yet to be disclosed.[4]

Following a 2010 settlement with the Chesapeake Bay Foundation, EPA agreed to propose this post-construction stormwater rule, although the release date has been delayed at least four times since the original date of September 30, 2011. A major reason as to why EPA has continually delayed the release of the proposed rule is that assessing and quantifying the costs and benefits of the rule is a complex task.[5] EPA must consider the intermittent nature of stormwater, variations in national rainfall patterns, and the numerous types of technology that could be utilized to meet compliance.[6] Critics of the proposed rule contend that the cost of implementation will be very high and may cost state and local governments billions of dollars.[7]

Proposed Stormwater Retention Credit (SRC) Mechanism

District of Columbia – District Department of the Environment

In August of 2012, the District of Columbia's District Department of the Environment (DDOE) released a Notice of Proposed Rulemaking regarding stormwater management, soil erosion, and sediment control. The rule aims to provide flexibility for meeting the requirements of the District's Municipal Separate Storm Sewer System (MS4) Permit, which is issued by the United States Environmental Protection Agency.

Set to take effect by July 22, 2013, the MS4 Permit requires the District to implement a 1.2 inch stormwater retention standard for "major land-disturbing activities" and a 0.8 inch stormwater retention standard for "major substantial improvement activities."[8] Major land-disturbing activities qualify as activities affecting 5,000 square feet of soil. A renovation that has a cost that equals or exceeds 50 percent of the market value of the structure before the project is started is considered a substantial improvement. For the 0.8 inch retention standard to be applicable, the major substantial improvement must affect a sum total of the buildings' footprint and area of soil disturbance equal to 5,000 square feet. Additionally, if an individual project does not meet the 5,000 square feet limit for either type of activity, but is part of a larger common plan of development that does meet the threshold, then the activity will be regulated under the amendments.

The DDOE proposed rule introduces several mechanisms by which compliance for the new amendments can be met. The rule is intended to promote the most cost-efficient compliance method. Although these regulated projects must retain a minimum of 50 percent of their stormwater retention volume on site, the rule provides the flexibility of using off-site retention to meet the remainder of the requirement. Additionally, regulated sites may over-control stormwater volume of up to a 1.7 inch storm in one area of a site in order to offset any other areas of the site where retention is below the required 50 percent. Any drainage area that does not meet the minimum on site retention requirement must provide water quality treatment for the remaining retention volume. A site must prove that retaining the required 50 percent retention is technically infeasible or environmentally inappropriate in order to retain less than the on-site minimum.

There are three options to achieve any remaining stormwater retention off-site. The site can use Stormwater Retention Credits (SRCs), the site can pay DDOE's in-lieu fee, or the site can use a combination of SRCs and the in-lieu fee. The SRC and in-lieu fee both correspond to one gallon of retention for one year. Off-site SRCs can be obtained either on the private market or from an owner's other site that has earned an SRC. Owners may bank SRCs indefinitely, although once an SRC is used to satisfy off-site retention volume, that SRC has a one-year lifespan. An owner has the flexibility to pay multiple years' worth of in-lieu fees at one time or purchase multiple years' worth of SRCs, given that they are available on the market. The cost of the in-lieu fee will reflect

DDOE's relatively limited opportunities for installing retention technologies, either on District-owned properties, through cost-share/subsidy programs, or on private property.

The DDOE will certify SRCs for eligible Best Management Practices (BMP) and land cover changes in the District. Unregulated sites may also voluntarily install stormwater retrofits to earn SRCs and sell them in the market. In addition to a required current maintenance agreement or contract for the BMP or land cover change, it must also be designed in accordance with a DDOE-approved Stormwater Management Plan, pass a post-construction final inspection and on-going inspections, and achieve retention in excess of the requirement, but less than the 1.7 inch ceiling. Following the approval of an SRC credit, each SRC will be assigned a unique serial number, and the DDOE will certify up to three years' worth of SRCs for that capacity.

Following a thorough assessment, the District expects that the mechanism of combining both on-site and off-site retention will maximize benefits for the District waterbodies (by reducing stormwater pollution runoff and improving their health over time), increase the flexibility for regulated sites, and increase the number of green jobs. DDOE also believes that the rule will improve equity in how the burden of stormwater management is allocated in the District.[9] The use of a private market for SRCs will promote leveraging resources and installing low-cost retrofits, thus appealing to unregulated sites that can easily obtain an SRC for profit.[10]

Charging Stand-Alone Parking Lots for Wastewater Services

New York City – Department of Environmental Protection

In January of 2011, the New York City Department of Environmental Protection (DEP) launched a pilot program for stand-alone parking lots, whereby owners must pay a charge for the stormwater runoff produced from their lots. Owners can alternatively demonstrate that they are using green infrastructure or other methods to address the stormwater. The pilot project was instituted with the stormwater runoff goals of the NYC Green Infrastructure Plan in mind. Parking lot owners were not previously charged for stormwater runoff, despite contributing a significant amount into the combined sewer system, because they did not receive a water bill.[11] As of FY2011, wastewater charges for those who did receive a water bill were levied at 159% of water consumption charges.[12]

For FY2011 the 267 stand-alone parking lots in New York City were charged $0.05/square foot of lot. The charge was based on DEP's stormwater expense budget, which remains steady. The revenue generated from these charges is used for stormwater-related expenditures. The program provided consideration for exemption from charge if Best Management Practices (BMPs) were implemented. As of December 2011, the pilot compliance rate (based on totally revenue collected vs. total billed amount) was 72 percent, excluding exemptions. Seven accounts were granted exemptions based on existing on-site retention or topographical challenges, while no BMPs were implement to wave the cost through a credit program. This pilot project not only tests the ability of the billing system to assess and collect charges, but it also set the precedent for these stormwater charges.[13]

Because DEP's expense budget remains steady from year to year, they are considering using an alternative equation, such as based on capital expenses, to generate future charges. Other considerations to promote the installation of green infrastructure on parking lots include hosting workshops on teaching BMP alternatives and increasing outreach for design. DEP is already examining the expansion of the program to include public parking lots as it upgrades the overall billing system. The investigation of discrepancies between the billed vs.

paid amounts is an on-going process, while DEP is also exploring including debt service on stormwater-related capital expenditures and identifying future additional market segments.[14]

Emerging Technological Practices

This report has provided a number of green infrastructure stormwater management best practices strategies for consideration in multiple settings. While the proposed and analyzed strategies are currently in use around the country and the world, there are emerging technological trends that are worthy of attention and discussion. The following areas of research indicate growing trends in stormwater management technology.

One of the major categories of emerging technology for stormwater management is in roofing design and roofing systems. For a variety of reasons, whether related to weight, wind, safety, or budgetary concerns, not all roofs are suitable for vegetative, green roofing systems or detention facilities.[15] Engineers and scientists are developing alternative roofing options to facilitate temporary retention of stormwater, which ultimately can aid in decreasing the peak flow into conveyance systems. As roofing and other construction materials are known to release harmful pollutants into stormwater runoff, a deeper study of the utilized materials of these new technologies is necessary to determine the potential, if any, of pollutant discharge. The maintenance requirements and life cycle of these new technologies are not yet fully known.

Another trend pertaining to roofing systems is that of using roofs for farming or aquaculture. These green systems often rely on precipitation and/or stormwater for their ponding and hydroponic needs. Technologies to appropriately filter roof stormwater for these farming uses are in development. The cost-effectiveness and life cycle of these filtration systems has yet to be fully provided.

A final trend in stormwater management technology is in the diversion of stormwater from roads in urban and suburban settings. Previously discussed in this report are strategies such as Green Streets and Street Trees, which are effective in retaining and filtering stormwater as it travels over their surfaces. New diversion technologies look to divert stormwater from roadways and into the soil and roots of trees and plants lining the roadways. Similar to other emerging technologies, the cost-effectiveness, maintenance requirements, and life cycle analysis of these technologies has yet to be fully examined.

Provided below are examples of the discussed emerging technological trends for addressing stormwater. Considering the newness of the technologies and the little information offered, proper analyses cannot be provided at this point. Rather, the information is intended to enlighten readers about the newest technologies and serve as a starting point for future research in the developing areas of stormwater management.

Roofing Shingle Designed to Temporarily Retain and Store Precipitation

Doberstein and Harris – Innovation Eng. LLC[16]

Approved in June of 2010, Doberstein and Harris patented a roofing shingle (see Figure 1 below) that can temporarily store precipitation and gradually release it through the storage media. The shingle has a storage layer (108) on top of a base layer (102) and above a drainage layer (104). Composed of non-growing storage media, the storage layer is capable of absorbing and temporarily detaining 0.3175 cm of precipitation. The non-growing storage media is intended to inhibit unwanted biological growth on the roof.

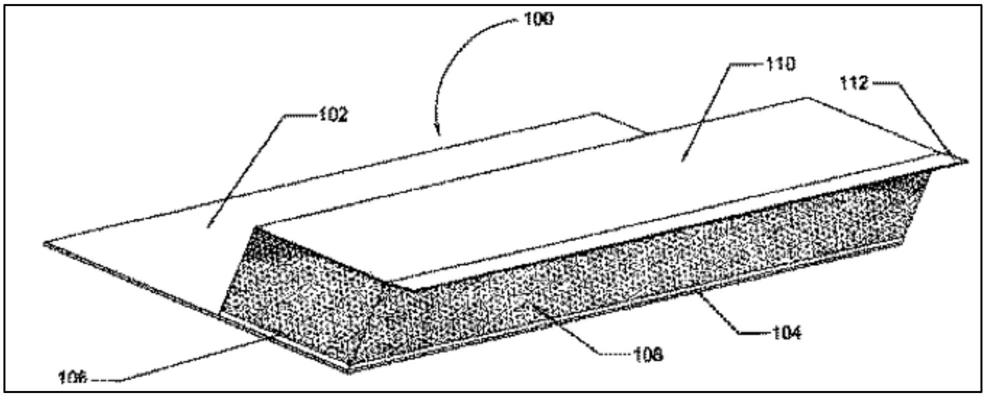

Figure 21. Doberstein and Harris Roofing Shingle.

Easily manufactured, stockpiled, distributed, and installed, the shingles can be customized for varied thicknesses, porosity, and hydraulic conductivity. Customization allows for the shingles to meet site-specific precipitation, stormwater regulations, and roof slope properties. Applicable for existing or new structures, the shingle was designed to be lightweight yet withstand harsh outdoor conditions, such as hail, freezing and thawing, snow, high winds, and foot traffic. Doberstein and Harris contend that compared to other roofing materials, this new shingle provides a higher fire rating and offers equal or superior product longevity.

Green Roof System for Treating Stormwater in Wet Ponds for Fish Farm

Chang and Wanielista – University of Central Florida Research Foundation Inc.[17]

Approved in April of 2012, Chang and Wanielista patented a green roof system for treating stormwater in wet ponds and dry ponds for aquaculture (see Figure 2 below). The system comprises a retention pond (310), in-situ treatment unit (360), and a sump pump (340). Utilizing natural and recycled materials such as sawdust, a tire crumb, sand, and limestone as the sorption media, the in-situ treatment unit is composed of the sorption media as a filter, entrance pipes (350), and a recirculation pipe (330). The entrance pipes move the stormwater captured by the sump pump into the filter for the removal of nutrients and pollutants.

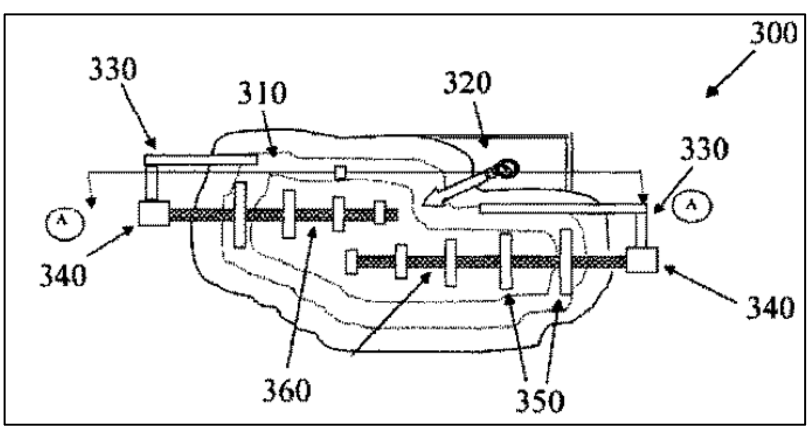

Figure 22. Chang and Wanielista Green Roof System.

The green roof system is reusable and flexible and treats stormwater effectively, economically, and environmentally soundly. The system filters the stormwater and removes particulates and contaminates, producing highly cleaned water. Chang and Wanielista assert that their system can be used for treating stormwater in wet ponds and dry ponds for aquaculture operation, including shrimp and fish farms.

Water Diversion System for Irrigation Use of Urban Road Plants and Trees

Wiese – Wiese Innovations PTY LTD[18]

Comprised of two patents, the latter of which was approved in May of 2012, Wiese has developed a water diversion system for use in urban environments for the irrigation of road-side plants and trees (see Figure 3 below). The system has a filter (20) that removes solid particulates and prevents them from entering the stormwater distribution unit. Capturing stormwater next to the edge of a road (1), a stormwater receptacle is connected to 16 outlets (16) of the distribution unit to enable the contained, filtered stormwater to flow out of the receptacle. The outlets are placed in a soil profile below the level of the pavement (2) for access by a plant or tree (4). This passive irrigation reduces the volume of stormwater runoff that would be conveyed to traditional, grey stormwater infrastructure.

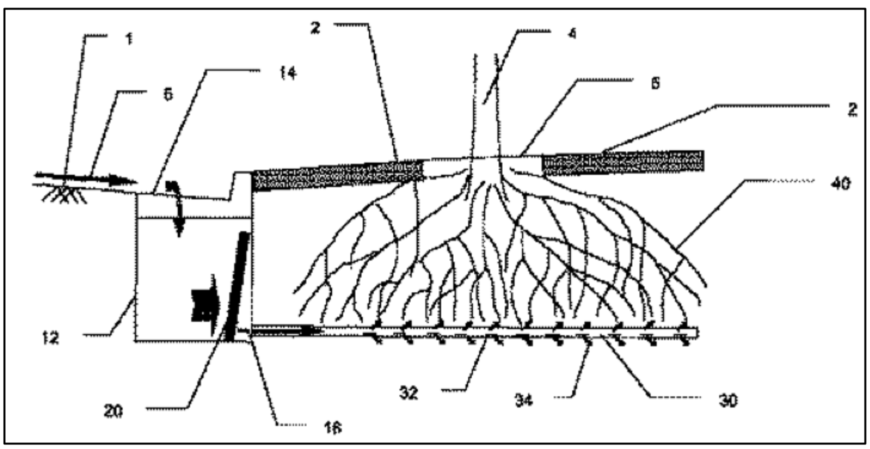

Figure 23. Wiese Water Diversion System.

Conclusion

There are many emerging regulatory and technological approaches to stormwater management that may have broader implications beyond their initial piloting or patenting. NYSDOT and New York State municipalities are encouraged to further explore the applicability of these innovative approaches in their specific settings and perhaps even pilot them if deemed appropriate.

Only a selection of emerging approaches was provided in this report; however, there are many other cities and researchers actively tackling the issue of stormwater management. Information regarding innovative approaches can often be found on municipality websites or in stormwater trade magazines and websites. Regular review of these sources is suggested so as to stay aware of any new practices that could have wider geographical implications.

[1] U.S. Environmental Protection Agency. *Proposed National Rulemaking to Strengthen the Stormwater Program*. 10 July 2012. 1 November 2012. <http://cfpub.epa.gov/npdes/stormwater/rulemaking.cfm>.

[2] ibid

[3] Cady, Benjamin and Stephen Elkind. *Shaping EPA's New Stormwater Regulations*. 25 September 2012. 2 November 2012. <http://www.stormh2o.com/SW/Articles/Shaping_EPAs_New_Stormwater_Regulations_18848.aspx>.

[4] U.S. Environmental Protection Agency, 2012

[5] Associated General Contractors of America. *EPA Not in Hurry to Propose National 'Post-Construction' Stormwater Rules; Another Deadline Missed*. 25 July 2012. 2 November 2012. <http://news.agc.org/2012/07/25/epa-not-in-hurry-to-propose-national-post-construction-stormwater-rules-another-deadline-missed/>.

[6] Dwyer, Kaitlyn. *EPA Continues to Stall Stormwater Rule*. 1 May 2012. 5 November 2012. <http://www.asashop.org/ASA/Press_Releases/2012_Press_Releases/2012_pr24.aspx>.

[7] Associated General Contractors of America, 2012

[8] District Department of the Environment - Proposed Rule. "Proposed Rulemaking on Stormwater Management and Soil Erosion and Sediment Control." 10 August 2012. *DDOE.* 22 October 2012. <http://ddoe.dc.gov/proposedstormwaterrule>.

[9] ibid

[10] Wye, Brian Van. "WE&T Magazine Features." 31 August 2012. *Water Environment Federation.* 27 October 2012. <http://www.wef.org/publications/page_wet.aspx?id=8589935179&page=feature>.

[11] NYC Department of Environmental Protection. *DEP Launches Parking Lot Stormwater Pilot Program*. 2011 January 2011. 28 October 2012. <http://www.nyc.gov/html/dep/html/press_releases/11-04pr.shtml>.

[12] NYC Green Infrastructure Steering Committee. *Agenda and Minutes - NYC Green Infrastructure Steering Committee*. Agende and Minutes. New York: NYC Environmental Protection, 2011.

[13] ibid

[14] ibid

[15] Liscum, Curtis. *Sustainable Roofing: Material Management*. 1 February 2012. 5 November 2012. <http://www.facilitiesnet.com/roofing/article/Sustainable-Roofing-Material-Management--13020#>.

[16] Doberstein and Harris. Roofing shingle for use in building, has drainage layer included units to direct water downslope beneath drainage layer, and separation layer between drainage layer and storage layer to support storage layer. USA: Patent US7743573-B1. 29 June 2010.

[17] Chang and Wanielista. Green roof system for treating stormwater in wet ponds for fish farm, comprises retention pond, in-situ treatment unit, and sump pump, where in-situ treatment unit comprises sorption media of filter, entrance pipes and recirculation pipe. USA: Patent US8153005-B1. 10 April 2012.

[18] Wiese. Water diversion system for use in urban environment for irrigation of road-side plant and tree, has filter which removes solid particulates from stormwater entering distribution unit. Australia: Patent WO2011041850-A1; AU2010305331-A1. 3 May 2012.

Recommendations & Conclusions

Recommendations & Conclusions

The analysis and synthesis performed in this guide provides mayors, town officials, decision-makers, and NYSDOT with information to effectively choose and implement green stormwater management strategies to combat the impacts of climate change. As the knowledge and precision regarding future climate projections is enhanced with technological improvements, the importance of locally addressing projected impacts is becoming more apparent. Because the effects of climate change vary widely across New York State, NYSDOT and municipalities will need, to the best of their ability, to assess their local vulnerabilities and projected impacts. With an understanding of how climate change will affect stormwater in a given locality over the coming decades, the next step is to select appropriate management strategies to mitigate the associated negative consequences.

The evaluation tool found on page 61 provides a snapshot summary of all of the proposed green strategies against a set of varying metrics for easy cross-comparison. A cursory glance at the tool shows that there are no clear "winners" across all categories of attributes. However, each strategy does perform well in at least a few categories. Depending upon the specific constraints of a town or area, a decision-maker can select management strategies that will best circumvent those impediments.

When looking to implement strategies with the highest capture rates, those that generally require larger amounts of land perform the best, such as green spaces, land acquisition and preservation, and bluebelts. However, all of the remaining strategies can perform moderately well, depending on certain considerations, such as vegetation choice and level of maintenance. To determine the most suitable option for a given location, the detailed information provided for each strategy in this report should be reviewed thoroughly. Supplemental information can be found in the links in the Additional Resources box at the end of each strategy.

If costs are the biggest consideration when selecting a management strategy, there are three qualifying metrics against which the strategies have been measured: capital cost, maintenance cost, and total cost. While the green space, land acquisition and preservation, and bluebelt strategies perform well across all three cost metrics, these strategies can require larger amounts of land for optimal efficacy. However, rain barrels, pervious pavement, and green roofs can be ideal options for urban and suburban settings when the initial capital cost is of primary concern. Maintenance costs are low for pervious pavement, swales, and rain gardens, while the total cost for pervious pavement is the lowest among strategies utilizing less space.

For instances where the frequency of maintenance is a hindering factor to application, decision-makers may want to choose to implement swales, street trees, rain gardens, and rain barrels. Certain types of green spaces, such as meadows, will also require infrequent maintenance, while there are no associated maintenance operations for the land acquisition and preservation strategy. The lifetime of most of the strategies is dependent upon multiple factors, such as maintenance, climate, and vegetation choice. Most strategies have a lifetime of at least 30 years, with many capable of exceeding 100 years. The level of expertise required to install each strategy is generally high, indicating that the knowledge of and input from an expert will be necessary. However, for some of the strategies, maintenance can be performed by unskilled labor, such as for green space.

Technically, urban, suburban, and rural settings do not hinder the implementation of any of the strategies. Some may be less appropriate or more difficult to implement, though, mainly due to siting constraints. Land acquisition and preservation inherently requires high acreage, while certain forms of green space strategies also necessitate a sizable amount of land.

All of the proposed strategies realize additional benefits beyond the primary objective of retaining or detaining precipitation and stormwater runoff. These secondary benefits bring to light the advantages of utilizing green infrastructure over traditional grey infrastructure. The proposed strategies can already potentially decrease long-term costs associated with managing stormwater, and these additional benefits may also lead to decreased costs in other sectors, such as those associated with electricity and water consumption. Many of the strategies will provide health benefits, increase property values, preserve wildlife, mitigate the urban heat island effect, and recharge groundwater levels. Thus, while trying to address and alleviate the most rudimentary issue of stormwater management, most of these strategies will also aid in diminishing other climate change-related issues.

Climate change is occurring and will continue to require the implementation of additional adaptation measures. New York State employees, businesses, and residents are already experiencing the effects of greater intensity storms with higher frequency. Adaptation does not come down to the matter of *if*, but rather to the matter of *when* it will be necessary. The sooner municipalities begin to implement adaptation strategies, the sooner they will reap the benefits. As many stormwater impacts spread well beyond their point of origin, the greatest benefits will be realized when the entire state tackles the issue holistically with an integrated approach.

Appendix A – Glossary of Terms

Berm – constructed barrier of compacted earth

Bioinfiltration— Bioretention systems are soil- and plant- based facilities employed to filter and treat runoff from developed areas. Bioretention systems are designed for water infiltration and evapotranspiration, along with pollutant removal by soil filtering, sorption mechanisms, microbial transformations, and other processes.

Choker Course— This layer in pervious pavement that is composed of single size, 1⁄2-inch crushed granules and functions to stabilize the open-graded asphalt surface for paving. Provide a solid base yet still drains well.

Combined Sewer System—Combined sewer systems are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body.

Combined Sewer Overflow—During periods of heavy rainfall or snowmelt, wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. These overflows contain not only stormwater but also untreated human and industrial waste, toxic materials, and debris.

Culvert – a tunnel carrying a stream or open drain under a road or railway. A culvert can be a pipe or concrete box structure, which drains to open channels, swales, or ditches under a roadway or embankment typically with no catch basins or manholes along its length.

Detention – release of surface and stormwater runoff from the site at a slower rate than it is collected by the drainage facility system, the difference being held in temporary storage.

Discharge – runoff, excluding offsite flows, leaving the proposed development through overland flow, built conveyance systems, or infiltration facilities.

Evapotranspiration – is the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere.

Flow control facility – a drainage facility designed to mitigate the impacts of increased surface and stormwater runoff generated by development. Flow control facilities are designed either to hold water for a considerable length of time and then release it by evaporation, plant transpiration, and/or infiltration into the ground, or to hold runoff a short period of time and then release it to the conveyance system.

Green infrastructure—Green infrastructure is an approach to wet weather management that use natural systems—or engineered systems that mimic natural processes—to enhance overall environmental quality and provide utility services. As a general principal, green infrastructure techniques use soils and vegetation to infiltrate, evapotranspire, and/or recycle stormwater runoff.

Grey infrastructure—In the context of stormwater management, grey infrastructure can be thought of as the hard, engineered systems to capture and convey runoff, such as gutters, storm sewers, tunnels, culverts, detention basins, and related systems.

Groundwater – underground water usually found in aquifers. Groundwater usually originates from infiltration. Well tap the groundwater for water supply uses.

Impervious Cover (Or, Impervious area, imperviousness)—Any surface that cannot be effectively (easily) penetrated by water, thereby resulting in runoff. Examples include pavement (asphalt, concrete), buildings, rooftops, driveways/roadways, parking lots and sidewalks.

MS4 – stands for municipal separate storm sewer system. It is a drainage system owned by a municipality intended to carry only surface runoff i.e. stormwater. A separate sewer is not intended to, nor should it, carry stormwater combined with sanitary sewage or with any other pollutant.

Nonpoint source (NPS) pollution – occurs when rainfall, snowmelt, or irrigation runs over land or through the ground, picks up pollutants, and deposits them into rivers, lakes, and coastal waters or introduces them into ground water.

Point source pollution - Point source pollution is pollution that comes from a single source, such as a factory or wastewater treatment plant.

Receiving Waters - A river, ocean, stream, or other watercourse into which wastewater or treated effluent is discharged.

Return Period – is an estimate of how long it will be between rainfall events of a given magnitude

Rutting - A sunken track or groove made by the passage of vehicles.

Sanitary Sewer System—A sanitary sewer specifically transports sewage and industrial wastewater from houses and commercial buildings and industrial areas to wastewater treatment plants. Sanitary sewers are operated separately and independently of storm sewers.

Sanitary Sewer Overflows—Sanitary sewer overflows are occasional unintentional discharges of raw sewage from municipal sanitary sewers. These types of discharges have a variety of causes, including but not limited to blockages, line breaks, sewer defects that allow stormwater and groundwater to overload the system, lapses in sewer system operation and maintenance, power failures, inadequate sewer design and vandalism.

Scour – bridge scour is the removal of sediment such as sand and rock from around bridge abutments or piers.

Separate Sewer System—In a separate sewer system, the storm sewer infrastructure is completely separate from the sanitary sewer system that carries wastewater (as opposed to a combined sewer system).

Stormwater (or, Runoff)—Stormwater runoff is precipitation that becomes polluted once as it flows over driveways, streets, parking lots, construction sites, agricultural fields, lawns, and industrial areas. Pollutants associated with stormwater include oils, grease, sediment, fertilizers, pesticides, herbicides, bacteria, debris and litter. Stormwater washes these pollutants through the storm sewer system and into local streams and drainage basins. In addition, because impervious surfaces prevent precipitation from soaking into the ground, more precipitation becomes runoff, and the additional volumes and velocities of stormwater can scour stream and river channels, creating erosion and sediment problems.

Surface water – water naturally open to the atmosphere; water from estuaries, lakes, ponds, reservoirs, rivers, seas, etc.

Total maximum daily load—is the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards.

Vactoring —uses a high powered suction hose to withdraw debris from a catch basin.

Appendix B – Climate Projection Detail

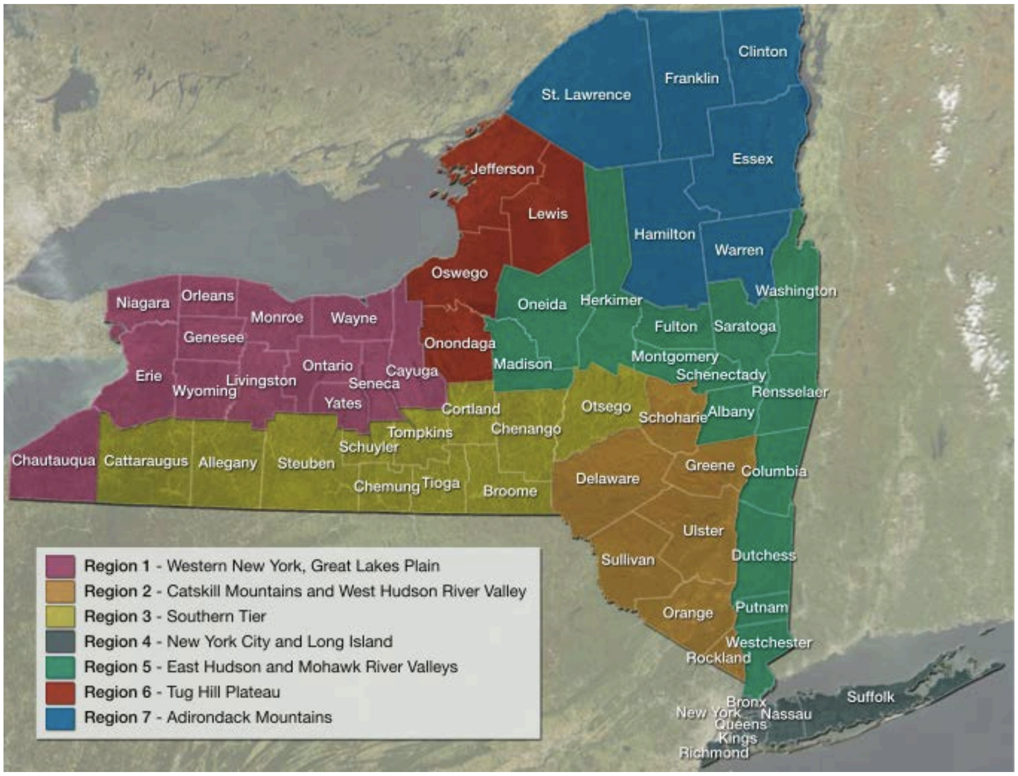

Figure 1B. Climate regions of New York State used in the Climate Assessment (Rosenzweig, Solecki and DeGaetano).

		Baseline[1] 1971–2000	2020s	2050s	2080s
Region 1					
Stations used for Region 1 are Buffalo, Rochester, Geneva and Fredonia.	Air temperature[2]	48ºF	+1.5 to 3.0ºF	+3.0 to 5.5ºF	+4.5 to 8.5ºF
	Precipitation	37 in	0 to +5%	0 to +10%	0 to 15%
Region 2					
Stations used for Region 2 are Mohonk Lake, Port Jervis, and Walton.	Air temperature[2]	48ºF	+1.5 to 3.0ºF	+3.0 to 5.0ºF	+4.0 to 8.0ºF
	Precipitation	48 in	0 to +5%	0 to +10%	+5 to 10%
Region 3					
Stations used for Region 3 are Elmira, Cooperstown, and Binghamton.	Air temperature[2]	46ºF	2.0 to 3.0ºF	+3.5 to 5.5ºF	+4.5 to 8.5ºF
	Precipitation	38 in	0 to +5%	0 to +10%	+5 to 10%
Region 4					
Stations used for Region 4 are New York City (Central Park and LaGuardia Airport), Riverhead, and Bridgehampton.	Air temperature[2]	53ºF	+1.5 to 3.0ºF	+3.0 to 5.0ºF	+4.0 to 7.5ºF
	Precipitation	47 in	0 to +5%	0 to +10%	+5 to 10%
Region 5					
Stations used for Region 5 are Utica, Yorktown Heights, Saratoga Springs, and the Hudson Correctional Facility.	Air temperature[2]	50ºF	+1.5 to 3.0ºF	+3.0 to 5.5ºF	+4.0 to 8.0ºF
	Precipitation	51 in	0 to +5%	0 to +5%	+5 to 10%
Region 6					
Stations used for Region 6 are Boonville and Watertown.	Air temperature[2]	44ºF	+1.5 to 3.0ºF	+ 3.5 to 5.5ºF	+4.5 to 9.0ºF
	Precipitation	51 in	0 to +5%	0 to +10%	+5 to 15%
Region 7					
Stations used for Region 7 are Wanakena, Indian Lake, and Peru.	Air temperature[2]	42ºF	+1.5 to 3.0ºF	+3.0 to 5.5ºF	+4.0 to 9.0ºF
	Precipitation	39 in	0 to +5%	0 to +5%	+5 to 15%

Table 1B. Baseline climate and mean annual changes for the 7 ClimAID regions (Rosenzweig, Solecki and DeGaetano).

Appendix C – Interviewee List

Person Interviewed	Title	Organization / Company
Brian Van Wye	Stormwater Management Division	DC Department of Environment
Chris O'Karma	Sr. Engineer	Consolidated Edison
Dana Gumb	Chief Engineer	Bureau of Water and Sewer Operations, Staten Island Bluebelt Unit
Dave Graves	Head, Water/Ecology	New York State Dept. of Transportation, Environmental Science Bureau
David Orr, PE	Director of Local Roads Program	Cornell University
Debra Nelson	Assistant to Director	NYSDOT Office of Operations
Dr. Eban Bean	Department of Engineering Professor	East Carolina University
Dr. Floyd Lapp	Executive Director	South Western Regional Planning Agency
Dr. Thomas Ballestero	Director of the UNH Stormwater Center, Associate Professor University of New Hampshire	University of New Hampshire Stormwater Center
Elisabeth Kolb	Senior Environmental Specialist, Sustainability and Climate Change Section	New York State Dept. of Transportation, Statewide Policy Bureau
Erin Morey	Deputy Director	New York City Department of Environmental Protection
Erin Williams	Green Infrastructure Coordinator	Philadelphia Water Department
Frank Stearn	Former Supervisor	St. Thomas Township
George Irwin	President and CEO	Green Living Technologies, LLC
George Long, PE	Hydraulics Group	New York State Dept. of Transportation, Structure Division
Jane Gomery	Program Manager	City of Burlingame, California Department of Public Works Engineering
Jennifer Crowther	Economic Development Coordinator	Philadelphia Industrial Development Corporation
Jennifer Krebs	Principal Environmentalist	San Francisco Estuary Partnership

Jessie Fisher	Director of Greenway Planning	Buffalo Niagara Riverkeeper
Lorey Schultz	Green Infrastructure Specialist	City of Buffalo, New York Mayor's Office
Marie Venner	Principal	Venner Consulting, Inc.
Mark Clark	Associate Professor of Wetland Ecology	University of Florida
Matt Millea	Deputy County Executive	Onondaga County
Nicole Davis	Regional Planner	South Western Regional Planning Agency
Nina Bassuk, PhD	Professor and Director of Urban Horticulture Institute	Cornell University
Paul Krekeler	GreenLiTES Manager, Sustainability and Climate Change Section	New York State Dept. of Transportation, Statewide Policy Bureau
Rob Hyman	Consultant to Federal Highway Administration	Federal Highway Administration
Robin Martin	Former Chairman	D.C. Water and Sewer Authority
Rose Baglia	Extension Specialist	Cornell Cooperative Extension
Steven Bellona	VP Facilities	Hamilton College
Susan Day, PhD	Assistant Professor and Director of the Urban Horticulture Institute	Virginia Polytechnic Institute

Appendix D – Protecting Existing Infrastructure

While the focus of this report is to provide information about green infrastructure strategies for managing stormwater, it is also important to promote the proper maintenance and upkeep of existing infrastructure, whether it is grey or green, which will allow for better overall handling of water in a high precipitation event. In the 2012 AASHTO Climate Change Briefing, a list of the top ten activities to prepare for extreme weather events was provided by Mike Meyer, a leading expert on climate change and transportation. A few of the items on that list are provided is as follows:

- Remove debris from culverts to allow for proper water flow;
- Protect infrastructure located in waterways such as piers and bridge columns from damaging flows to prevent reinforcing sediment from eroding away;
- Identify evacuation routes and ensure proper maintenance of systems along these roadways;
- Identify staging areas for materials necessary to perform work on any infrastructure that fails during an emergency;
- Ensure back-up power generators are available to keep streetlights active in the event of a power outage;
- Utilize drought-resistant vegetation near roadways to ensure as much natural retention as possible.[1]

[1] Meyer, Mike. “'Top Ten' Activities for O&M to Prepare for Extreme Weather.” *AASHTO Climate Change Briefing* 2012 11-September: 5.

Appendix E – Partial List of Suitable for Use as Street Trees[1]

Botanic Name	Common Name
Acer campestre	Hedge Maple
Acer miyabei	Miyabei Maple
Acer nigrum	Black Maple
Acer pseudoplatanus	Sycamore Maple
Acer truncatum	Painted Maple
Carpinus betulus	European Hornbeam
Celtis occidentalis	Hackberry
Cercis canadensis	Redbud
Cornus foemina (Cornus racemosa)	Gray Dogwood
Corylus colurna	Turkish Hazelnut
Crataegus crus-galli	Cockspur Hawthorn
Crataegus phaenopyrum	Washington Hawthorn
Crataegus viridis	Green Hawthorn
Eucommia ulmoides	Hardy Rubber Tree
Fraxinus americana	White Ash
Fraxinus excelsior	European Ash
Fraxinus pennsylvanica	Green Ash
Ginkgo biloba	Ginkgo
Gleditsia triacanthos	Honey Locust
Gymnocladus dioicus	Kentucky Coffee Tree
Koelreuteria paniculata	Goldenrain tree
Maclura pomifera	Osage Orange
Malus spp.	Crabapple

Platanus x acerifolia	London Plane
Pyrus calleryana	Callery Pear
Pyrus ussuriensis	Ussurian Pear
Quercus macrocarpa	Mossy Cup Oak
Quercus muehlenbergii	Chinkapin Oak
Quercus robur	English Oak
Styphnolobium japonicum (Sophora japonica)	Japanese Pagoda Tree
Syringa reticulata	Japanese Tree Lilac
Tilia cordata Littleleaf	Linden
Tilia tomentosa	Silver Linden
Tilia x euchlora	Crimean Linden
Ulmus americana	American Elm
Ulmus carpinifolia	Smooth-Leaf Elm
Ulmus parvifolia	Lace Bark Elm
Ulmus spp.	Elm Hybrids
Zelkova serrata	Japanese Zelkova

(Names in parentheses reflect recently changed botanical names)

---

[1] Bassuk, Nina, PhD. *Professor of Horticulture and Director of Urban Horticulture Institute, Cornell University* Charles Samul. 22 October 2012.

Works Cited

American Planning Association - Climate Change Management. "How Cities Use Parks for... Climate Change Management." 1 July 2012. *American Planning Association.* 19 October 2012. <http://www.planning.org/cityparks/briefingpapers/climatechange.htm>.

American Planning Association - Green Infrastructure. "How Cities Use Parks for... Green Infrastructure." 1 June 2012. *American Planning Association.* 18 October 2012. <http://www.planning.org/cityparks/briefingpapers/greeninfrastructure.htm>.

Anderson, Donald M., Yoshi Kaoru, Alan W. White. *Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States*. Technical Report. Woods Hole, MA: Woods Hole Oceanographic Institution, 2000.

Angelo, Mary Jane. "Integrating Water Management and Land Use Planning: Uncovering the Missing Link in the Protection of Florida's Water Resources?" *UF Law Scholarship Repository* 2001: 224-248.

Associated General Contractors of America. *EPA Not in Hurry to Propose National 'Post-Construction' Stormwater Rules; Another Deadline Missed*. 25 July 2012. 2 November 2012. <http://news.agc.org/2012/07/25/epa-not-in-hurry-to-propose-national-post-construction-stormwater-rules-another-deadline-missed/>.

Ballestero, Dr. Thomas. *Director of the UNH Stormwater Center, Associate Professor University of New Hampshire* Molly Saso. 6 November 2012.

Bassuk, Nina. *Professor of Horticulture* Charles Samul. 22 October 2012.

Bassuk, Nina, et al. *Using Porous Asphalt and CU-Structural Soil*. Technical Report. Urban Horticulture Institute. Ithaca: Cornell University, 2007.

Bassuk, Nina, PhD. *Professor of Horticulture and Director of Urban Horticulture Institute, Cornell University* Charles Samul. 22 October 2012.

Bean, Dr. Eban. *Professor, Department of Engineering at East Carlonia University* n.d.

Bellona, Steven. *Vice President Facilities, Hamilton College* Charles Samul. 5 October 2012.

Berndtsson, J. "Green roof performance towards management of runoff waterquantity and quality: a review." *Ecological Engineering* (2010): 351-360.

Bliss, Daniel J., Ronald D. Neufeld and Robert J. Ries. "Storm Water Runoff Mitigation Using a Green Roof." *Environmental Engineering Science* 26.2 (2009): 407-417.

Brown, Hillary, et al. *High Performance Infrastructure Guidelines*. New York: New York City Department of Design and Construction and the Design Trust for Public Space, 2005.

Buffalo Niagara Riverkeeper. *bnriverkeeper.org*. 2012. 15 October 2012. <bnriverkeeper.org/programs/rain-barrels/>.

Burden, Dan. *22 Benefits of Urban Street Trees*. Glatting Jackson. Port Townsend: Walkable Communities, Inc, 2006.

Cady, Benjamin and Stephen Elkind. *Shaping EPA's New Stormwater Regulations*. 25 September 2012. 2 November 2012. <http://www.stormh2o.com/SW/Articles/Shaping_EPAs_New_Stormwater_Regulations_18848.aspx>.

Cantor, Martin R. *Economic Impact of Regional Beach Closings on the Long Island Economy*. Oakdale, NY: Dowling College, 2007.

Carter, T. and A. Keeler. "Life-cycle cost-benefit analysis of extensive vegetated roof systems." *Journal of Environmental Managment* (2008): 350-363.

Chang and Wanielista. Green roof system for treating stormwater in wet ponds for fish farm, comprises retention pond, in-situ treatment unit, and sump pump, where in-situ treatment unit comprises sorption media of filter, entrance pipes and recirculation pipe. USA: Patent US8153005-B1. 10 April 2012.

Charles River Watershed Association. *Permeable Pavement*. 2008 September. 2012 3-November.

City of Arlington, Virginia. Ed. Dickinson. 28 September 2012. 14 October 2012 . <http://www.arlingtonva.us/departments/environmentalservices/sustainability/eporaingarden.aspx>.

City of Chicago - Bioinfiltration. *Bioinfiltration: Rain Gardens*. 1 January 2012. 8 October 2012. <http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design/bioinfiltration_raingardens.html>.

City of Chicago - Natural Landscaping. *Natural Landscaping*. 1 July 2012. *City of Chicago.* 27 October 2012. <http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design/natural_landscaping.html>.

City of Minneapolis, Minnesota. n.d. 14 0ctober 2012. <www.minneapolismn.gov/publicworks/sotrmwater/green/stormwater_gree-initiatives_rain-garden>.

City of New York Parks & Recreation Department. "Tree Planting Standards." New York: Parks & Recreation Department, April 2008.

City of Philadelphia Common Council. 2012. 15 October 2012. <www.nextgreatcity.com/actions/trees>.

Clark, C., P. Adriaens and F. Talbot. "Green roof valuation: a probabilistic economic analysis of environmental benefits." *Environmental Science and Technology* (2008): 2155-2161.

Clark, Mark. *Associate Professor of Wetland Ecology, University of Florida* Molly Saso. 2 November 2012.

Clark, Mark. *Associate Professor of Wetland Ecology, University of Florida* Molly Saso. 6 November 2012.

Climate Protection Partnership Division in the U.S. Environmental Protection Agency's Office of Atmospheric Programs. "Reducing Urban Heat Islands: Compendium of Strategies." n.d.

Coffman, Larry. "Low Impact Development: Smart Technology for Clean Water - Definitions, Issues, Roadblocks, and Next Steps." *Global Solutions for Urban Drainage* . Ed. Eric Strecker and Wayne Huber. Portland: American Society of Civil Engineers, 2002.

Colson, Bill. "Abutment bridge scour." *United States Geological Survey*. 13 April 1979. Image.

ConEdison. "The Learning Center Green Roof Demonstration Project." 2008 June. Powerpoint Presentation.

Cornell Univesity Cooperative Extension. "The LIfe of a Sugar Maple Tree." *Bulliten*. 235. Ithaca: Cornell University, 1996.

Cremin, Phil. *Assistant Chief Civil Engineer, Port Authority of New York and New Jersey* Molly Saso. 20 November 2012.

Cummings, J., et al. *UCF Recommissioning, Green Roofing Technology, and Building Science Training; Final Report*. Orlando: University of Central Florida, 2007.

Curie, B.A. and B. Bass. "Estimates of Air Pollution Mitigation with Green Plants and Green Roofs Using the UFORE Model." *Sixth Biennial Canadian Society for Ecological Economics (CANSEE) Conference*. Toronto, 2005.

Day, Susan D. "Assistant Professor and Director of the Urban Horticlture Center, Virgina Polytechnic Institute." *Using Engineered Soils in Tree Installations to Manage Stormwater.* Charles Samul. 19 October 2102.

DeGaetano, Art, et al. *Climate Change Facts - New York's Changing Climate*. October 2011. Cornell University College of Agriculture and Life Sciences. PDF. 1 November 2012. <http://www.nrcc.cornell.edu/climate_change/climate_ny.pdf>.

DeGaetano, Arthur T. "Time-Dependent Changes in Extreme-Precipitation Return-Period Amounts in the Continental United States." *Journal of Applied Meteorology and Climatology* 48 (2009): 2086-2099. Document.

Department of Environment. *Green Chicago - Green Roofs*. 2012. 2012 29-September.

Department of Environmental Resources, The Prince George's County Maryland. "Bioretntion Manual." December 2009. <http://www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/Bioretention/pdf/Bioretention%20Manual_2009%20Version.pdf>.

Dickinson, Susan Downing and Sarah B. *Managing Stormwater for Urban Sustainability Using Trees and Structural Soils*. Virginia Polytechnic Institution and State University. Blacksburg: US Department of Agricultural Forest Service Urban and Community Forestry Program, 2008.

District Department of the Environment - Proposed Rule. "Proposed Rulemaking on Stormwater Management and Soil Erosion and Sediment Control." 10 August 2012. *DDOE.* 22 October 2012. <http://ddoe.dc.gov/proposedstormwaterrule>.

District Department of the Environment. *Proposed Rulemaking on Stormwater Management and Soil Erosion and Sediment Control*. 10 August 2012. 19 October 2012. <http://ddoe.dc.gov/proposedstormwaterrule>.

Doberstein and Harris. Roofing shingle for use in building, has drainage layer included units to direct water downslope beneath drainage layer, and separation layer between drainage layer and storage layer to support storage layer. USA: Patent US7743573-B1. 29 June 2010.

Dwyer, Kaitlyn. *EPA Continues to Stall Stormwater Rule*. 1 May 2012. 5 November 2012. <http://www.asashop.org/ASA/Press_Releases/2012_Press_Releases/2012_pr24.aspx>.

Elements of Land Design, LLC. *Elements of Land Design, LLC*. 1 July 2010. 3 November 2012. <http://www.elementsoflanddesign.com/contact.htm>.

Engineers, Nevue Ngen Associates and Sherwood Design. "San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook." 2009.

EPA. *After the Storm - Weather | US EPA*. January 2003. 20 November 2012. <http://water.epa.gov/action/weatherchannel/stormwater.cfm>.

"EPA Combined Sewer Overflows - Office of Wastewater Management." 2012 February 2012. *National Pollutant Discharge Elimination System (NPDES)*. 5 November 2012. <http://cfpub.epa.gov/npdes/home.cfm?program_id=5>.

EPA Office of Wetlands, Oceans and Watersheds. *Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure*. Washington D.C.: United States Environmental Protection Agency, 2010.

EPA. Report to Congress Impacts and Control of CSOs and SSOs August 2004 Washington, D.C. 1-633.

Ernst, Caryn. *Protecting the Source: Land Conservation and the Future of America's Drinking Water*. Ed. Kim Hopper and David Summers. Prod. The Trust for Public Land and American Water Works Association. San Francisco, 2004. Electronic Report.

Fentress, F. (2009). Sustainable Landscape Management Practices. *Watershed-Friendly Landscape Workshop.*

Fisher, Jessie. *Director of Greenway Planning* Chuck Samul. 2012.

Flynn, Kevin Martin. *Evaluation of Green Infrastructure Practices using Life Cycle Analysis*. Thesis. College of Engineering, Villanova University. Villanova: Kevin Martin Flynn, 2011.

Foster, Josh and Steve Winkleman Ashley Lowe. *The Value of Green Infrastructure for Urban Climate Adaptation*. Washington D.C.: The Center for Clean Air Policy, 2011.

Freni, Gabriele, Giorgio Mannina and Gaspare Viviani. "Urban Storm-water Quality Management: Centralized versus source control." *Journal of Water Resources Planning and Management* (2010): 268-278.

Frumhoff, P.C., et al. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions.* Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists, 2007.

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions.* Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists, 2007.

Gaffin, S.R., et al. "A Temperature and Seasonal Energy Analysis of Green, White, and Black Roofs." Columbia University, n.d.

Gannon, Mike. *President, The Pond Hunter/Ful Service Aquatics* 27 October 2012.

Gaynor, Inc. "Services and Work." 1 January 2008. *Gaynor, Inc.* 13 October 2012. <http://www.gaynorinc.com/services.html>.

Geoghegan, Jaqueline, Lori Lynch and Shawn Bucholtz. "Capitalization of Open Spaces into Housing Values and the Residential Property Tax Revenue Impacts of Agricultural Easement Programs." *Agricultural and Resource Economics Review* (2003): 33-45.

Getter, K and D. Rowe. "The role of extensive green roofs in sustainable development." *Hort Science* (2006): 1276–1285.

Gilbride, Chris and Mercedes Padilla. *DEP's First Bluebelt Wetland in the Bronx Controls Stormwater at The New York Botanical Garden and Reduces Combined Sewer Overflows*. New York, 2012 7-September.

Gomery, Jane. *Burlingame Commercial District Parking Lot and Street Project* Charles M Samul. Burlingame, 2012 11-October.

Green Roofs. 2012 21-June. 2012 9-September.

greenroofs.com, LLC. *Issues*. 2011. 2012 29-September.

Gregoire, Bruce and John Clausen. "Effect of a modular extensive green roof on stormwater runoff and water quality." *Ecological Engineering* (2011): 963-969.

Gumb, Dana. *Chief Engineer- Bureau of Water and Sewer Operations, Staten Island Blue Belt Unity* Morgan Scott. 2012 9-October .

Gumb, Dana, et al. "The Staten Island Bluebelt: A Case Study in Urban Stormwater Management." *Novatech* (2007): 19-26.

Gunderson, J. "Pervious Pavements: New Findings About Their Functionality and Performance in Cold Climates." 2008.

Gutro, Rob. "Hurricane Sandy (Atlantic Oenan): NASA Adds Up Hurricane Sandy's Rainfall from Space." 2012 1-November. 2012 20-November <http://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Sandy.html>.

Hayneedle. *Prices for Rain Barrels*. n.d. 15 October 2012. <www.hayneedle.com>.

Hsu, David. "Sustainable New York City." 2006.

Hudson River Park. *Hudson River Park*. 5 September 2010. 3 November 2012. <http://hudson-river-park.com/3-2/hudson-river-park-downtown/>.

Huntsinger, Teresa. *Stormwater Solutions - Turning Oregon's Rain Back Into a Resource*. Portland, OR: Oregon Environmental Council, 2007.

Liscum, Curtis. *Sustainable Roofing: Material Management*. 1 February 2012. 5 November 2012. <http://www.facilitiesnet.com/roofing/article/Sustainable-Roofing-Material-Management--13020#>.

"LOW IMPACT DEVELOPMENT for BIG BOX RETAILERS." Preparted under EPA assistance agreement #AW-83203101, 2005.

MacDonagh, Peter. *Growing Large Urban Trees for Stormwater Management*. Presentation. Kestrel Design Group. Minneapolis: Kestrel Design Group, Inc., 2010.

Malec, Suzanne. "Storm Water Managemen in the City of Chicago." n.d. City of Chicago Department of Environment. 4 October 2012.

Marritz, Leda. *American City*. 10 October 2012. 16 November 2012. <www.americancity.org>.

McLaughlin, John. "NYC Bioswales Pilot Project Improves Stormwater Management." 2012.

Meyer, Michael D., Anne F. Choate and Emily Rowan. *Adapting Infrastructure to Extreme Weather Events: Best Practices and Key Challenges*. Traverse City, Michigan: AASHTO, 2012.

Meyer, Mike. "'Top Ten' Activities for O&M to Prepare for Extreme Weather." *AASHTO Climate Change Briefing* 2012 11-September: 5.

Michigan.gov. "Current Deicing Practices and Alternative Deicing Materials." n.d. 21 November 2012. <http://www.michigan.gov/documents/ch2-deice_51438_7.pdf>.

National Arbor Day Association. n.d. 15 October 2012. <www.arborday.org>.

National Asphalt Pavement Association. *Porous Asphalt*. n.d. 3 November 2012. <http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=359&Itemid=863>.

National Institute of Building Sciences. *Extensive Vegitative Roofs*. 2012. 2012 5-November.

National Oceanic and Atmospheric Administration. *Harmful Algal Blooms (HABS): NOAA Watch: NOAA's All-Hazard Monitor: National Oceanic and Atmospheric Administration: U.S. Department of Commerce*. n.d. http://www.noaawatch.gov/themes/habs.php. 20 November 2012.

"National Pollutant Discharge Elimination System (NPDES)." n.d. 3 November 2012. <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=135>.

National Ready Mixed Concrete Association. *Pervious Pavement*. 1 November 2011. 9 November 2012. <http://www.perviouspavement.org/>.

National Resources Defense Council. "NRDC: Rooftops to Rivers." 1 May 2006. *NRDC.* 13 October 2012. <http://www.nrdc.org/water/pollution/rooftops/contents.asp>.

Natural Resources Defense Council. *Testing the Waters*. Washington DC: 2012, 2012.

Nemry, Françoise. "Impacts of climate change in Europe: A focus on road and rail transport infrastructures." 9 October 2012. *United Nations Economic Commission for Europe.* 4 November 2012. <http://www.unece.org/fileadmin/DAM/trans/doc/2012/wp5/01_Ms_Nemry_EC.pdf>.

Nevue Ngan Associates & Sherwood Design Engineers. "San Mateo County Sustainable Green Streets and Parking Lots Guidebook." Guidebook. 2009.

Newman, A. (2012, August 1). *Flash Floods Strand Cars in Queens - NYTimes.com*. Retrieved November 2, 2012, from NYTimes.com: http://cityroom.blogs.nytimes.com/2012/08/01/flash-floods-strand-cars-in-queens/.

New York City Department of Environmental Protection. 10 Novemner 2011. <http://www.nyc.gov/html/dep/html/press_releases/11-99pr.shtml>.

New York City Economic Development Corporation. *Harlem River Park*. 28 February 2012. 19 October 2012. <http://www.nycedc.com/project/harlem-river-park>.

New York Farmland for Sale. 2012 13-October. 2012 13-October. <http://www.farmlandsearch.com/view.aspx?sc=new-york&p=0-4-0>.

New York State Climate Action Council. *New York State Climate Action Plan Interim Report*. Albany, 2010.

New York State Climate Office. *The Climate of New York*. n.d. 2012 5-November.

New York State Department of Environmental Conservation. *Urban and Community Forestry*. 1 November 2012. 9 November 2012. <http://www.dec.ny.gov/lands/4957.html>.

Nina Bassuk, Jason Grabowsky, Ted Haffner, Peter Trowbridge. *Using Porous Asphalt and CU-Structural Soil*. Technical Report. Urban Horticuture Institute. Ithaca: Cornell University, 2007.

Nisbet, T. (2005, April). *www.forestry.gov.uk.* Retrieved November 22, 2012, from http://www.forestry.gov.uk/pdf/FCIN065.pdf/$FILE/FCIN065.pdf.

NOAA. *National Weather Service Forecast Office*. n.d. 19 October 2012. <www.erh.noaa.gov/bgm/climate/syr/syr_annual-totals.html>.

Northern Virginia Regional Commission. *Maintaining Stormwater Systems: A Guidebook for Private Owners and Operators in Northern Virginia*. Fairfax: Virginia Coastal Zone Management Program at the Department of Environmental Quality, 2007.

NRDC. "After the Storm - How Green Infrastructure Can Effectively Manage Stormwater Runoff from Roofs and Highways." 2011.

NYC Department of Environmental Protection. *DEP Launches Parking Lot Stormwater Pilot Program*. 2011 January 2011. 28 October 2012. <http://www.nyc.gov/html/dep/html/press_releases/11-04pr.shtml>.

NYC Green Infrastructure Steering Committee. *Agenda and Minutes - NYC Green Infrastructure Steering Committee*. Agende and Minutes. New York: NYC Environmental Protection, 2011.

NYS Department of Environmental Conservation. *New York State Water Quality 2008*. Submitted Pursuant to Section 305(b) of the Federal Clean Water Act Amendments of 1977. Albany, NY: NYSDEC, 2008.

NYSDOT. *Mission and Values*. 1999-20012. Webpage https://www.dot.ny.gov/about-nysdot/mission. 17 October 2012.

O'Karma, Chris. *Senior Engineer, Consolidated Edison Company of New York Inc.* Morgan Scott. 2012 10-October.

O'Leary, Mark, et al. “A Conservation Plan for Three Watersheds within the Milwaukee Metropolitan Sewerage District.” *National Conference on Urban Storm Water: Enhancing Programs at the Local Level*. Chicago: U.S. Environmental Protection Agency, 2003. 272-290.

Onondaga County, New York. *Save the Rain*. 2012. 15 October 2012. <savetherain.us/str_project/rain-barrel-program>.

Ostendorf, M, et al. “Storm Water Runoff from Green Retaining Wall Systems.” *Cities Alive!: Ninth Annual Green Roof and Wall Conference*. Philadelphia: Cities Alive, 2011. 1-15.

Past & Present. 1999-2012. Webpage https://www.dot.ny.gov/about-nysdot/history/past-present. 17 October 2012.

Patz, Jonathan A., Stephen J. Vavrus, Christopher K. Uejio, Sandra L. McLellan. "Climate Change and Waterborne Disease Risk in the Great Lakes Region of the U.S." *American Journal of Preventive Medicine* (2008): 451-458.

Peck, S. and M. Kuhn. *Design Guidelines for Green Roofs*. Toronto: National Research Council Canada, 2001.

Pennsylvania Department of Environmental Protection. "Pennsylvania Stormwater Best Management Practices Manual - Chapter 6.7.2." 30 December 2006. *Pennsylvania Department of Environmental Protection.* 27 October 2012. <http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305>.

Permeable Pavement, Low Impact Best Management Practice (BMP) Information Sheet." September 2008. Charles River Watershed Association. <www.charlesriver.org>.

"Permable Pavers." n.d. 17 November 2012. <http://www.epa.gov/oaintrnt/stormwater/pavers.htm>.

Peterson, Julia, Amanda Stone and James Houle. *Protecting Water Resources and Managing Stormwater: A Bird's Eye View for New Hampshire Communities*. n.d. Electronic Report.

Philadelphia Water Department. "(Amended) Green City Clean Waters." Philadelphia Water Department, 2011.

"Porous Asphalt Pavements for Stormwater Management." 30 September 2012. UNH Stormwater Center University of New Hampshire. <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/napa_pa_5_08_small.pdf>.

Porsche, U. and M. Köhler. "Life Cycle Costs of Green Roofs: a Comparison of Germany, USA, and Brazil." *Proceedings of the World Climate and Energy Event*. Rio de Janeiro, 2003.

Posner, Gerald. *Arborist- Davidson Estate, Connecticut* Charles Samul. 6 November 2012.

Potential Impacts of Climate Change on U.S. Transportation. Washington, D.C.: Committee on Climate Change and U.S. Transportation, 2008.

Pyke, Marni. *Can our roads weather the storm? - DailyHerald.com*. 20 August 2012. 3 November 2012. <http://www.dailyherald.com/article/20120820/news/708209923/>.

Ramsey-Washington Metro Watershed District. *Porous Asphalt Parking Lot*. n.d. 8 November 2012. <http://www.rwmwd.org/vertical/Sites/%7BAB493DE7-F6CB-4A58-AFE0-56D80D38CD24%7D/uploads/%7B495C857D-FED3-409E-B58A-E6A16D827DEA%7D.PDF>.

"Reducing Urban Heat Island: Compendium of Strategies. Green Roofs Chapter." n.d.

Robert M. Roseen, P.E., Ph.D. and Thomas P. Ballestero, Ph.D, P.E. n.d. UNH Stormwater Center University of Newhampshire. 30 September 2012. <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/napa_pa_5_08_small.pdf>.

Roehr, Daniel and Yuewei Kong. "Runoff Reduction Effects of Green Roofs in Vancouver, BC, Kelowna, BC, and Shanghai, P.R. China." *Canadian Water Resources Journal* 35.1 (2010): 53-68.

Roman, Lara A and Frederick N Scatera. "Street tree survival rates: Meta-analysis of previous studies and application to a field survey in Philadelphia, PA, USA." University of California, Berkeley and University of Pennsylvania, 2011.

Rosenblum, Dan. “The bioswales of New York: A city plan to make more tree-stands and less sewage runoff.” 2012 13-March. *Capital - This is How New York Works.* 2012 7-November .

Rosenzweig, C., et al. Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Annals of the New York Academy of Sciences 1244(1): 2-649.

San Francisco Estuary Partnership. 2009. 5 October 2012. <www.sfestuary.org>.

SAVATREE. 2012. 27 October 2012. <www.savatree.com/tree-fact.html>.

Schroll, Erin, et al. “The role of vegetation in regulating stormwater runoff from green roofs in a winter rainfall climate.” *Ecological Engineering* 37 (2011): 595-600.

Sklerov, Farrell and Mercedes Padilla. *DEP Offers Free Rain Barrels to New Yorkers*. 2011 16-April. 2012 7-November.

Storm Water Technology Fact Sheet Porous Pavement. September 1999. <http://www.cleanwatermn.org/Documents/MS4%20toolkit%20files/Good%20Housekeeping/Porous%20Pavement/porouspa.pdf>.

Stormwater Retention for a modular green roof using energy balance data. Research. New York: Columbia University, Center for Climate Research, 2011.

Stormwater Trees and the Urban Environment. Boston: CRWA, 2009.

Stovin, Virginia. “The potential of green roof to manage Urban Stormwater.” *Water and Environment Journal* 24 (2010): 192-199.

Susca, T., S.R. Gaffin and G.R. Dell'Osso. “Positive effects of vegitation: Urban heat island ang green roofs.” *Environmental Pollution* (2011): 2119-2126.

Terracing. *Terracing A Slope*. 1 July 2012. 3 November 2012. <http://terracing.terracedhousing.com/terracing-a-slope/>.

The Concrete Network. *Ten Strategies for Ensuring a Successful Pervious Concrete Installation* . n.d. 27 October 2012. <http://www.concretenetwork.com/pervious/installation-tips.html>.

The Low Impact Development Center, Inc. "Low Impact Development for Big Box Retailers." November 2005. <www.lowimpactdevelopment.org>.

The Staten Island Blue Belt: A Natural Solution to Storm Water Management. 2007 20-March. http://www.nyc.gov/html/dep/html/dep_projects/bluebelt.shtml. 2012 15-October.

Thibodeau, F.R. “An Economic Analysis of Wetland Protection.” *Journal of Environmental Management* (1981): 19-33.

Transportation Research Board. *Estimating Life Expectancies of Highway Assets*. NCHRP REPORT 713. Washington, D.C.: Transportation Research Board, 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_713v1.pdf.

Ulam, Alex. *Sweeter Swill - The Architects Newspaper*. 2011. 2012 7-November.

United States Environmental Protection Agency. *Adaptation Overview | Climate Change | US EPA*. n.d. 27 October 2012. <http://www.epa.gov/climatechange/impacts-adaptation/adapt-overview.html>.

United States Environmental Protection Agency. *Proposed National Rulemaking to Strengthen the Stormwater Program*. 10 July 2012. 1 November 2012. <http://cfpub.epa.gov/npdes/stormwater/rulemaking.cfm>.

United States Environmental Protection Agency - Section 319 Success Stories. (2010 13-January). *Polluted Runoff (Nonpoint Source Control)*. Retrieved 2012 11-November from http://www.epa.gov/owow/NPS/Section319I/NJ.html

University of Connecticut, NEMO. "NEMO's Planing for Stromwater Management." 2012 30-September. <http://nemo.uconn.edu/tools/stormwater/pavements.htm>.

University of New Hampshire Stormwater Center. *Porous Asphalt Pavement for Stormwater Management*. n.d. 2012 September. <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/porous_ashpalt_fact_sheet.pdf>.

University of Rhode Island. *Healthy Landscapes: Rain Gardens*. 1 July 2012. 9 November 2012. <http://www.uri.edu/ce/healthylandscapes/raingarden.htm>.

University of Washington, Dept. of Environmental and Civil Engineering. *Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Projects*. Technical. Seattle: University of Washington, 2002.

Uptownradio.org. "CSO Warning Sign." n.d. *Uptownradio.org.* 5 November 2012. <http://uptownradio.org/wp-content/uploads/2011/04/CSO-Warning-sign.jpg>.

Urban Forestry Institute. *CU-Structural Soil*. 2006. 2 November 2012. <www.urban-forestry.com>.

US Census Bureau. *New York QuickFacts from the US Census Bureau*. 18 September 2012. Webpage http://quickfacts.census.gov/qfd/states/36000.html. 17 October 2012.

US Department of Transportation. *How Do Weather Events Impact Roads? - FHWA Road Weather Management*. 31 August 2012. 3 November 2012. <http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm>.

US Global Change Research Program. *Global Climate Change Impacts in the United States*. US Global Change Research Program. New York, NY: Cambridge University Press, 2009.

Virginia Department of Conservation and Recreation, "*Virginia DCR Stormwater Design Specification No. 7. Permeable Pavement.*" March 1, 2011.

Visel, Tim. “Stormwater Runoff Can Degrade Fishiers Habitats.” *The Sea Grant Marine Advisory Service* (1990): 3-10.

Vokral, Jack, et al. “Staten Island Bluebelt Program: Stormwater Management Using Nature.” *Proceedings of the Water Environment Federation*. Water Environment Federation, 2001. 563-578.

Vokral, John, et al. “Wetlands at Work.” *Civil Engineering* (2003): 56-63.

Water: Total Maximum Daily Load. n.d. 27 October 2012. <http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm>

Weiss, Peter, John Gulliver and Andrew Erickson. “Cost and Pollutant Removal of Storm-Water Treatment Practices.” *Journal of Water Resources Planning and Management* (2007): 218-229.

"Why Green Infrastructure?" 25 October 2012. *U.S. Environmental Protection Agency.* 27 October 2012. <http://water.epa.gov/infrastructure/greeninfrastructure/gi_why.cfm#WaterQuality>.

Wiese. Water diversion system for use in urban environment for irrigation of road-side plant and tree, has filter which removes solid particulates from stormwater entering distribution unit. Australia: Patent WO2011041850-A1; AU2010305331-A1. 3 May 2012.

Winkelman, Steve, Jan Mueller and Erica Jue. "Climate Adaptation & Transportation Identifying Information and Assistance Needs Summary of an Expert Workshop held November 2011 ." Workshop Summary. Center for Clean Air Policy and Environmental and Energy Study Institute, 2012.

Wise, Steve. “Green Infrastructure Rising.” *American Planning Association* (2008): 14-19.

Wye, Brian Van. "WE&T Magazine Features." 31 August 2012. *Water Environment Federation.* 27 October 2012. <http://www.wef.org/publications/page_wet.aspx?id=8589935179&page=feature>.

Yakowicz, Will. *Street of the Future*. 2011 11-November. <http://carrollgardens.patch.com/articles/street-of-the-future>.