The Importance of Operation and Maintenance for the Long-Term Success of Green Infrastructure

A Review of Green Infrastructure O&M Practices in ARRA Clean Water State Revolving Fund Projects

Clean Water
State Revolving Fund

Executive Summary

Green infrastructure reduces stormwater pollution by infiltrating, evapotranspiring, capturing, and using rainwater, and can be used to replace or augment traditional or gray stormwater infrastructure. The use of green infrastructure as a stormwater management strategy can help communities and other stakeholders effectively address some of our nation's most pressing water quality concerns.

On February 17, 2009, the American Recovery and Reinvestment Act (ARRA) was signed into law. ARRA appropriated $4 billion dollars to the Environmental Protection Agency's (EPA) Clean Water State Revolving Fund (CWSRF). ARRA included several new requirements for the CWSRF, one of which was to establish a Green Project Reserve (GPR). The GPR specified that 20 percent of ARRA CWSRF funds be directed to four categories of projects: green infrastructure, water efficiency improvements, energy efficiency improvements, and environmentally innovative activities. The ARRA GPR provided the opportunity for eligible CWSRF recipients to implement a variety of green infrastructure approaches, whether for the first time or as a way to add to their existing green infrastructure portfolio. Through the CWSRF Green Project Reserve, 259 green infrastructure projects worth over $209 million were funded.[1] These projects include a variety of green infrastructure practices such as rain gardens, pervious pavement, constructed wetlands, rain barrels, bioswales, and green roofs. Similar to traditional or gray infrastructure, the long-term success of green infrastructure is dependent on adequate maintenance. While maintenance needs for gray infrastructure are well-established, there is less research and information available on green infrastructure operation and maintenance (O&M). This report is intended to provide information for communities and funders to help ensure that ARRA-funded green infrastructure projects are operated and maintained to optimize long-term performance and effectively assist communities in reducing stormwater runoff and improving water quality. Other communities may also find this report useful.

The report examines the O&M practices of 22 green infrastructure projects funded by the ARRA CWSRF, and highlights both the opportunities and challenges associated with green infrastructure O&M. Activities examined include planning and tracking of maintenance, training and education, use of partnerships, and funding. Although there was significant variability in these activities across projects, there were some trends that emerged. Fifty-five percent of the projects were found to have accountability mechanisms, such as an O&M plan or manual in place, and 27 percent have established

[1] Data downloaded from the EPA Clean Water Benefits Reporting System on January 24, 2011 capturing ARRA GPR data through the quarter ending 12/31/2010.

tracking systems, such as manual log forms and electronic database systems to document and track maintenance activities. Tracking systems can help communities identify gaps in current maintenance practices and help establish more preventative and effective maintenance controls. Fifty-nine percent of the projects have also developed training or education programs related to O&M. Many of the green infrastructure projects profiled in this report depend on involvement from community members and volunteers, and in addition to providing practical instruction, training can provide valuable information on the environmental benefits and important water quality impact that green infrastructure can have when properly maintained. In approximately 36 percent of the projects profiled, public-private partnerships were developed to provide funding or labor for O&M activities. Fifty-nine percent of the projects have a dedicated source of funding established. Funding sources range from the use of municipal or district general funds to stormwater utility fees. The four projects with stormwater utilities in place have varying rate structures, ranging from a flat monthly service charge to fees charged based on the amount of impervious surface in residential and commercial areas. The report also found that having some type of authority in place to assure compliance, such as maintenance agreements or legal agreements with private landowners, residents, or contractors, can provide a strong incentive for responsible parties to ensure that proper maintenance activities are performed at regular intervals.

While maintenance plans and strategies vary by project and project type, the findings in this report demonstrate that proper maintenance is essential to maximizing the environmental, social, and economic benefits of green infrastructure, as well as ensuring that projects perform as they were designed to. Whether green infrastructure activities are implemented to meet regulatory requirements or as a voluntary effort to improve water quality, establishing written plans and procedures to assure long-term maintenance is important in ensuring the success of the project.

Introduction

Growth in urban and suburban communities across the country has reduced available rainwater infiltration and natural groundwater recharge areas where land is covered by buildings, parking lots, roads, sidewalks, and other impervious surfaces. In areas with high levels of impervious surfaces, rain events result in increased concentrations of pollutants in stormwater runoff as well as a higher volume of runoff. It is estimated that the runoff volume generated by impervious surfaces can be as much as 20 times greater than the volume in undisturbed watersheds, and can lead to flooding and erosion of streambeds and streambanks.[2] Traditional or gray stormwater infrastructure is designed to collect and convey stormwater into municipal storm sewer systems, where it is often discharged untreated into area waterways. Although untreated stormwater is cleaner than wastewater, it still carries pollutants from impervious surfaces. In communities with combined wastewater and stormwater systems, the water is sent through the sewer system to a treatment plant, which cleans the water and then discharges it into local waterways. When large storm events send more water into the combined sewer system than can be conveyed and treated, it causes a combined sewer overflow (CSO) that releases untreated wastewater directly into area waterways. CSO discharges are often detrimental to the receiving waterbody and can result in water quality violations. Green infrastructure approaches to stormwater management can be successful tools for reducing the pollutant loads and volume of stormwater runoff, as well as the frequency of CSOs.

The U.S. Environmental Protection Agency defines green infrastructure as approaches and technologies that maintain and restore natural hydrology by infiltrating, evapotranspiring, capturing and using stormwater.[3] Green infrastructure includes a wide array of practices at multiple scales. At its largest scale, the preservation and restoration of natural landscape features such as forests and wetlands are integral components of green stormwater infrastructure. By protecting these ecologically sensitive areas, communities can improve water quality and provide wildlife habitat and opportunities for outdoor recreation. On a smaller scale, green infrastructure consists of site- and neighborhood-specific practices such as rain gardens, porous pavement, green roofs, trees and tree boxes, and rainwater harvesting for non-potable uses such as toilet flushing and landscape irrigation. Green infrastructure has numerous environmental, social, and economic benefits that include stormwater runoff volume and pollutant reduction, reduced sewer overflow events, flood prevention, enhanced groundwater recharge, increased carbon sequestration, increased land values, urban beautification, reduced urban heat island effects, and reduced energy demands. This report focuses on the smaller scale green infrastructure efforts to help manage runoff and improve water quality in urbanized areas, as these efforts are increasingly being implemented by communities.

All stormwater management systems, whether gray or green, require maintenance. Appropriate operation and maintenance activities ensure that green infrastructure will continue to function properly and yield expected water quality and environmental benefits, protect public safety, meet legal standards, and protect communities' financial investment. If properly constructed and maintained,

[2] Lampe et al (2005). *Performance and Whole-Life Costs of Best Management Practices and Sustainable Urban Drainage Systems*. Water EnvironmentResearch Foundation.

[3] U.S. EPA. *Managing Wet Weather with Green Infrastructure*. Retrieved October 21, 2011. Available at: http://water.epa.gov/infrastructure/greeninfrastructure/index.cfm

studies have shown that green infrastructure is capable of near complete attenuation of stormwater flow volume, with mean flow volume reductions measuring 99 percent for reported storm events.[4] In addition, these types of projects can also cost less to construct than gray stormwater technologies. Green infrastructure proponents also claim that green infrastructure practices can potentially reduce traditional municipal infrastructure and utility maintenance costs.[5] Unlike gray wastewater infrastructure, there is not a nation-wide standard for the operation and maintenance of green infrastructure, although there is a rapidly growing body of literature on proper O&M for various green infrastructure activities. One challenge facing communities is funding green infrastructure O&M. Many water quality funding programs, such as the Clean Water State Revolving Fund (see text box on page 5) can fund the construction and limited monitoring of green infrastructure, but cannot fund ongoing O&M activities. Operation and maintenance of green stormwater infrastructure is an evolving area that has been steadily gaining importance as the environmental, social, and economic benefits of these types of projects are recognized by a growing number of communities.

This report provides an overview of O&M practices and highlights both the opportunities and challenges associated with green infrastructure O&M. It documents lessons learned from the green infrastructure projects funded by the CWSRF under the American Recovery and Reinvestment Act. The purpose of this report is to provide information to communities and operators of funding programs, such as the CWSRF, to help ensure that ARRA-funded green infrastructure projects, once implemented, are operated and maintained in such a way that they remain successful over the long-term and effectively assist communities in meeting their water quality goals.

[4] Horner, R. et al (2002). *Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Projects*. University of Washington Department of Civil and Environmental Engineering. Water Resources Series No. 170 available at: https://www.seattle.gov/util/groups/public/@spu/@usm/documents/webcontent/spu02_020016.pdf

[5] Low Impact Development Center (2002). *Municipal Guide to Low Impact Development*. Retrieved November 1, 2011. Available at: http://lowimpactdevelopment.org/lid%20articles/Municipal_LID.pdf

Financing Green Infrastructure Through the Clean Water State Revolving Fund

The Clean Water State Revolving Fund program was established in 1987 through amendments to the Clean Water Act. Each year since the inception of the program, the federal government has appropriated funds to EPA, which are then distributed to states based on a formula set in the enabling legislation. Today, all fifty states and Puerto Rico have active CWSRF programs that provide low-cost financing to a variety of water quality projects, including traditional municipal wastewater treatment projects as well as nonpoint source, watershed protection or restoration, and estuary management projects. Green infrastructure practices are eligible for CWSRF funding, but historically the majority of program funding has been directed to the construction, repair, replacement, and rehabilitation of traditional municipal wastewater and stormwater infrastructure. In 2007, EPA released a draft white paper, *The Clean Water State Revolving Fund Program: Tapping its Untapped Potential*, highlighting the potential uses of CWSRF funding for green stormwater infrastructure projects to address point and nonpoint source pollution.

The American Recovery and Reinvestment Act was signed into law on February 17, 2009 and appropriated $4 billion to the CWSRF. Along with the money came several new requirements, including the requirement to establish a Green Project Reserve. Under the GPR, to the extent that there were sufficient applications, each state CWSRF program was to allocate at least 20 percent of its ARRA funds to four categories of projects: green infrastructure, water efficiency improvements, energy efficiency improvements, or environmentally innovative activities. Of the $4 billion that was appropriated to the CWSRF, $1.1 billion went to GPR-eligible projects, of which $209 million went towards 259 green infrastructure projects. Projects include rain gardens, green roofs, vegetated swales, rainwater harvesting, constructed wetlands, porous pavement in parking lots, bike lanes and other impervious surfaces, and riparian and shoreline restoration efforts. The ARRA GPR provided a catalyst for state CWSRF programs to fund an unprecedented number of green infrastructure projects to manage stormwater and improve water quality. Similar to ARRA, the EPA appropriation bills for Fiscal Years 2010 and 2011 specify that at least 20 percent of a state's CWSRF capitalization grant be directed to projects that qualify for the GPR. For FY 2012, the GPR requirement was reduced to at least 10 percent of each state's CWSRF capitalization grant.

Data downloaded from the EPA Clean Water Benefits Reporting System (CBR) on January 24, 2011 capturing ARRA GPR data through the quarter ending 12/31/2010.

Research and interviews were conducted with representatives from 22 green infrastructure projects funded by the ARRA CWSRF to determine what type of plans are in place to inspect and maintain these projects, and how these activities are funded and implemented.[6] Where available, maintenance cost estimates for these projects are included. Though the profiled projects exhibit significant variation in scope, size, and combinations of green infrastructure approaches used, the majority include efforts to establish some form of long-term operation and maintenance structures to protect each respective infrastructure investment.

[6] Thirty ARRA CWSRF green infrastructure projects from across the country were contacted to participate in this report. Of the 30, 23 are represented. The other seven project sponsors either did not respond or did not have sufficient information on their projects' O&M activities to be included.

Green Infrastructure O&M: Challenges and Opportunities

The role of green infrastructure as an effective stormwater management solution is increasingly the focus of environmental stakeholders and of federal, state, and local governments. In 2008, EPA partnered with environmental and trade organizations such as American Rivers, the Natural Resources Defense Council, the National Association of Clean Water Agencies, the Low Impact Development Center, and the Association of Clean Water Administrators to develop a national green infrastructure strategy, *Managing Wet Weather with Green Infrastructure: Action Strategy 2008*.[7] The strategy recognized many of the water quality impacts associated with hydrologic modification, increased urbanization of our nation's watersheds and the problems resulting from stormwater runoff. In April 2011, EPA launched the *Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure*.[8] The *Agenda* updates the 2008 strategy and outlines activities that the Agency will undertake to help communities implement green infrastructure approaches. The *Agenda* also calls for the development of green infrastructure O&M best practice guidelines and cost comparison tools. In the wake of ARRA, the EPA CWSRF Branch has held a number of regional workshops that focus on the Green Project Reserve, opportunities for implementing green infrastructure, and the importance of O&M in ensuring long-term viability for green infrastructure projects.

One of the challenges communities face when making stormwater management decisions is determining when a green solution is the right solution. The most effective solutions to improving water quality are often not achieved through traditional stormwater management or through green infrastructure alone, but through a blend of both approaches. Because of this, it is important to consider both gray and green infrastructure alternatives. The planning and design phase of stormwater infrastructure projects is the most opportune time to consider integrating green infrastructure approaches into proposed projects. Factors to consider include cost-effectiveness, what the short-and long-term environmental benefits are expected to be, and the anticipated O&M costs. Comparing these costs for both gray and green alternatives over the anticipated life of a project can yield useful estimates that can aid in the decision-making process. However, because green infrastructure approaches have not been used as extensively as gray infrastructure to manage stormwater, the O&M costs are not as well documented and quantified. In many of the green infrastructure O&M studies that have been conducted to date, estimates of O&M costs are not based on actual costs, but on engineering estimates. As green infrastructure projects continue to be implemented by an increasing number of communities, more data on performance, installation costs, and maintenance costs will become available to better quantify the costs and benefits of these types of projects.

[7] U.S. EPA (2008). *Managing Wet Weather with Green Infrastructure: Action Strategy 2008*. Retrieved November 10, 2011. Available at: http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_action_strategy.pdf

[8] U.S. EPA (2011). *Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure.* Retrieved November 13, 2011. Available at: http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_agenda_protectwaters.pdf

Weighing the Cost-Effectiveness of Gray vs. Green Infrastructure

Recent studies have examined the effectiveness of green infrastructure in managing stormwater, as well as its cost effectiveness when compared to gray infrastructure. One study found that in general, green infrastructure is just as effective at removing pollutants from stormwater, reducing peak flows, and mitigating flooding and sedimentation as gray infrastructure, but on average costs 5-30 percent less to construct and is approximately 25 percent less costly to maintain over the life cycle of a project.[9] Depending on the project type and scope, green infrastructure can have more intensive maintenance demands due to the need for greater frequency and subsequent additional labor hours necessary for optimal performance. However, it is generally a less costly alternative than gray infrastructure due to savings in installation, cost of maintenance activities, and greater adaptability of the infrastructure.

The University of New Hampshire Stormwater Center conducted a 4-year pilot study that examined the performance and required maintenance of various types of pervious pavement. The installation costs of the pervious pavement were found to be 20 - 25 percent higher than the costs for standard, impervious applications. However, the study results indicated that this type of green infrastructure demonstrated improved surface infiltration during the winter months and required 75 percent less road salt application as a result of minimized standing water and ice. This represents a significant water quality benefit for communities in cold-weather climates who struggle with rising chloride levels in local rivers and streams. In addition, pervious pavement installations have demonstrated life spans that exceed 30 years, as compared to traditional pavement which typically lasts 12 -15 years in cold climates.[10]

If installed correctly, pervious pavement is an effective design alternative that can provide many water quality and economic benefits. Pervious pavement has the capability to provide effective storage for an area approximately three times its surface area, and can retain as much as 10 inches of direct rainfall.

Project Cost-Effectiveness Ranking Criteria in the CWSRF

The CWSRF program has emphasized the importance of funding the most cost-effective alternative project solutions. Some state SRF programs have already built mechanisms for gauging project cost-effectiveness into their priority ranking systems in which construction and O&M costs, as well as cost/benefit indicators, are assessed.

Maryland's CWSRF program has incorporated scoring criteria that allocates points based on project cost efficiencies using a ratio of capital costs to acres of drainage area or linear feet of stream restoration that will be completed by a project.

Pennsylvania's program has a nonpoint source rating system that includes a cost-effectiveness rating that also factors in anticipated O&M costs.

[9] Jaffe, M. et al (2010). *The Illinois Green Infrastructure Study: A Report to the Illinois Environmental Protection Agency on the Criteria in Section 15 of Public Act 96-0026, The Illinois Green Infrastructure for Clean Water Act of 2009.* Retrieved October 2, 2011. Available at: http://www.epa.state.il.us/green-infrastructure/docs/draft-final-report.pdf

[10] Gunderson, J. (2008). Pervious Pavements: New findings about their functionality and performance in cold climates. *Stormwater*. Retrieved October 10, 2011.Available at: http://stormh2o.com/september-2008/pervious-asphalt-concrete-3.aspx.

Municipalities are increasingly seeing reduced stormwater treatment costs as a result of using pervious pavement to treat and reduce the overall volume of stormwater flows.[11] The use of pervious pavement also reduces the need for more costly infrastructure traditionally used to manage flow volumes such as drainage piping and catch basins. Land development that involves a reduced amount of disturbance can also generate cost savings. The elimination of these types of gray infrastructure installations can provide a significant cost savings to communities.

Though there are case studies and modeling scenarios that illustrate the economic benefits of choosing green infrastructure alternatives, it is important to note that green infrastructure approaches may not always be less expensive to construct or maintain than gray stormwater infrastructure. This is highly dependent on a multitude of variables that may include size and surface area, costs of plant materials and survival rates, proximity to pollution sources, site and slope preparation required, necessary soil amendments, and the complexity of underdrain systems. Another consideration is the extent of maintenance necessary for different types of green infrastructure. Some green infrastructure types require less maintenance than their gray counterparts, while many will require more. Green and gray infrastructure approaches can be used in concert to address stormwater pollution and runoff, manage sewer overflows, and provide necessary adaptations to increases in intense storm events. For more information on green infrastructure planning and modeling tools, see Appendix D.

[11] University of New Hampshire (2011). Forging the Link: Linking the Economic Benefits of Low Impact Development and Community Decisions. Retrieved November 8, 2011. Available at: http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/docs/FTL_Resource%20Manual_LR.pdf

Designing with Maintenance in Mind

Ensuring that green infrastructure projects are planned and designed with maintenance in mind can help maximize environmental benefits and reduce the cost of the project over its lifespan. For green infrastructure projects to capture and infiltrate stormwater onsite to the maximum extent, there are a number of important O&M factors to consider prior to project implementation. These include:

- Type of maintenance to be performed
- Frequency of maintenance and available personnel to perform maintenance
- Cost of component replacement, e.g. plants, shrubs, porous pavement
- Sufficient funds in place to cover O&M activities, including cost of replacement components.

Developing an O&M plan or manual can also help ensure green infrastructure projects maintain long-term viability and continue to protect water quality and effectively manage stormwater. O&M plans may include basic elements such as: identification of the party(ies) responsible for maintenance, maintenance schedules, inspection requirements, frequency of inspections, easements or covenants for maintenance, and identification of a funding source(s).[12] A description of basic maintenance activities such as weeding, mulching, trimming of shrubs and trees, replanting, sediment and debris removal, and inlet/outlet cleaning may also be included.

Decatur Street in Edmonston, MD utilizing both green and gray infrastructure. Photo courtesy of the Town of Edmonston, MD

Without a plan to ensure necessary maintenance is conducted with sufficient frequency, the project may fail to achieve desired objectives. Failure to properly maintain green infrastructure can lead to excessive sedimentation, clogged inlets and outlets, loss of vegetative plantings, soil compaction, and failure to properly infiltrate stormwater. This can lead to additional overflows and have a harmful effect on water quality, thus negating the original intent of the project. Because projects such as rain gardens, pervious pavements, and green roofs constitute a relatively new approach to stormwater management, in many cases communities have had to advocate for these types of projects with stakeholders and rate payers in order to garner support for them. Projects in disrepair can erode confidence in the viability of green infrastructure. The proper design, construction, and maintenance of green infrastructure projects, as well as targeted public education and outreach, can effectively mitigate these issues.

[12] Tetra Tech (2010). *Operation and Maintenance of Green Infrastructure.* Retrieved October 2, 2011. Available at: http://www.raingardeninitiative.org/documents/pdfs/3pm_Maintenance_Christian.pdf.

Green Infrastructure Project Types

Green infrastructure encompasses a broad spectrum of project types. Assistance recipients who implemented ARRA GPR-funded projects through the CWSRF program demonstrated creativity in their use of green infrastructure, employing multiple project types and incorporating green components into gray infrastructure projects. The variety of project types that were implemented is reflected in Table 1. Each represents a different method for infiltrating, evapotranspiring, capturing, and using stormwater. Common green infrastructure practices funded by the ARRA CWSRF include:

- **Pervious pavement**: A paved surface that allows for the infiltration of water into a subsurface storage layer (generally consisting of rock, gravel, or sand). This can be accomplished either through gaps between paver blocks with permeable infill or vegetation, or through pavement that is manufactured to be permeable. Permeable paving materials include porous aggregate, porous turf, open-jointed block, porous concrete, and porous asphalt.
- **Rain barrels or cisterns**: Vessels used to collect rainwater at a particular site. They are often connected to a downspout to capture runoff from a roof, and the collected water is typically reused onsite. This conserves potable water in addition to reducing stormwater runoff.
- **Infiltration basins**: A shallow depression constructed over permeable soil that temporarily retains stormwater prior to it infiltrating. Infiltration basins reduce runoff and contribute to groundwater recharge.
- **Green roofs**: An area of a building roof or deck structure that is intentionally vegetated to provide a range of environmental benefits that include reduced runoff. Green roofs fall into two broad categories: extensive green roofs are those that are vegetated only with shallowgrowing plants and grasses, while intensive green roofs make use of a broader range of plants, including shrubs and flowering plants. Green roofs often also reduce energy costs by providing better building insulation and reducing the urban heat island effect.

Table 1: ARRA GPR Green Infrastructure Projects by Type*

Project Type	No. of Projects
Pervious pavement	*28*
Rain barrels/cisterns	*17*
Infiltration basins	*18*
Green roofs	*9*
Biorention/Bioswales	*53*
Wetlands	*27*
Riparian/shoreline restoration	*70*

**Some projects include more than one than one type of green infrastructure and as a result may be double counted.*

- **Bioretention**: Bioretention areas, or rain gardens, are depressed, landscaped areas with permeable soil that are designed to retain and filter runoff before it is removed through infiltration or evapotranspiration. They are often applied at small sites, such as in residential areas, in parking lots, along highways, in urban settings, and adjacent to industrial or commercial facilities.

Green roof at the EPA Region 8 office in Denver, CO

- **Bioswales**: Constructed conveyance channels designed to direct stormwater runoff while reducing velocity of water flow and increasing overall infiltration rates. Vegetated swales allow for biofiltration processes that partially treat stormwater during conveyance.
- **Wetlands**: Transitional areas between land and water that can have surface or near-surface water year-round, although some are fully saturated only periodically. They include bogs, swamps, floodplains, marshes, tidal wetlands, and man-made wetlands.
- **Riparian/shoreline restoration**: Natural areas at the interface between land and water of rivers, streams, or other water bodies. These are often used in agricultural areas to reduce the impact of nutrient pollution from animal waste or fertilizers.

More detailed information on the various types of green infrastructure and relevant design and maintenance considerations can be found in Appendix A, and a summary table of green infrastructure O&M practices can be found in Appendix B.

Findings and Results of the ARRA GPR Green Infrastructure O&M Study

Green infrastructure O&M practices and activities were examined for 22 green infrastructure projects funded through the ARRA CWSRF Green Project Reserve. On-site visits were conducted at five of the 22 projects to obtain more detailed information on O&M practices. Complete case studies for each of the five on-site project visits can be found in Appendix C. Table 2 provides an overview of the green infrastructure projects that were included in the study, as well as their O&M structures. Information is based on interviews, site visits, and research that were undertaken for the purposes of this study.

55%	**Have an O&M plan, manual, or similar guidelines in place**
59%	**Have a dedicated revenue source to pay for O&M activities**
27%	**Have a formalized O&M tracking system**
59%	**Provide training and/or educational materials on how to maintain green infrastructure**
36%	**Municipality or government agency is responsible for O&M**
23%	**Private organizations, entities, or homeowners are responsible for O&M**
36%	**Responsibilities split between private and public sectors**

Some of the projects profiled are in communities that have previously implemented green infrastructure projects. For other communities, ARRA GPR funding provided the opportunity to use green infrastructure as a stormwater management strategy for the first time. Municipalities such as Toledo, OH, Lenexa, KS, and Spokane, WA have been implementing various green infrastructure practices such as vegetated swales and rain gardens for many years. Spokane has used grass swales for over 25 years with a great deal of success.[13] Similarly, special districts like the Long Creek Watershed Management District in Maine and non-governmental organizations like the Chesapeake Bay Trust have also implemented green infrastructure projects prior to the introduction of the ARRA GPR. However, non-traditional CWSRF recipients such as the Chemung County Library District in New York, which used ARRA funds to install a green roof at a local library, had never funded any type of green infrastructure before.

The ARRA GPR provided the opportunity for eligible CWSRF recipients to implement a variety of green approaches to stormwater management challenges, whether for the first time or as a way to expand their existing green infrastructure portfolio through the use of such practices as rain gardens, tree plantings, pervious pavement, rainwater harvesting programs, and green roofs.

[13] Peacock, William R., P.E., City of Spokane (2011). Personal communication with the author

Table 2: ARRA GPR Green Infrastructure O&M Study: Overview of Maintenance Structures

State	Project Sponsor	GI Subcategories	O&M Plan in Place	Municipal Responsibility	Private Responsibility	Training Provided	O&M Tracking	Previous GI BMPs in Place	Dedicated Revenue Source
CA	American Rivers, Yuba Watershed	Bioretention/Bioswales, Pervious Pavement, Vegetative Plantings	✓	✓		✓			
CA	Friends of the Santa Clara River	Wetlands, Riparian Restoration	✓		✓	✓			
CA	Truckee River Watershed Council	Riparian Restoration		✓	✓	✓			✓
CA	Hermosa Beach	Vegetative Plantings, Unspecified	✓	✓					
CA	Oakland	Rainwater Harvesting	✓	✓	✓	✓			
CA	Literacy for EJ, Heron's Head	Bioretention/Bioswales, Wetlands	✓		✓	✓	✓		
KS	Lenexa	Wetlands, Riparian Restoration, Pervious Pavement, Vegetative Plantings	✓	✓		✓	✓	✓	✓
MD	Chesapeake Bay Trust – Anne Arundel Co.	Wetlands, Riparian Restoration	✓		✓	✓			✓
MD	Takoma Park	Green Roof		✓					✓
MD	Edmonston	Bioretention/Bioswales, Pervious Pavement, Vegetative Plantings	✓	✓	✓				✓
ME	Long Creek Watershed Management District	Bioretention/Bioswales, Riparian Restoration, Vegetative Plantings	✓		✓	✓	✓	✓	✓
NY	Amherst	Bioretention/Bioswales, Pervious Pavement			✓				
NY	Rome	Pervious Pavement, Vegetative Plantings		✓	✓				✓
NY	Tioga CSWCD	Wetlands		✓					
NY	Chemung County Library District	Green Roof		✓		✓			✓
NY	Lindenhurst Memorial Library	Bioretention/Bioswales, Pervious Pavement		✓					✓
OH	Toledo	Bioretention/Bioswales, Rainwater Harvesting, Pervious Pavement, Vegetative Plantings	✓	✓	✓	✓	✓	✓	✓
PA	Chester CCD	Bioretention/Bioswales, Riparian Restoration		✓	✓				✓
PA	PA Environmental Council	Rainwater Harvesting, Pervious Pavement, Vegetative Plantings		✓	✓	✓			
UT	Salt Lake County	Riparian Restoration, Vegetative Plantings		✓					
WA	Spokane	Bioretention/Bioswales, Pervious Pavement	✓	✓	✓	✓	✓	✓	✓
WA	Olympia	Bioretention/Bioswales, Wetlands, Pervious Pavement, Unspecified	✓	✓		✓	✓	✓	✓

◆ Bioretention/Bioswales ◆ Riparian Restoration ◆ Rainwater Harvesting (rain barrels and cisterns) ◆ Vegetative Plantings (Including Trees)

◆ Wetlands ◆ Green Roof ◆ Pervious Pavement ◆ Unspecified green stormwater Improvement projects/BMPs

O&M responsibilities were classified as municipal, private, or a combination of both. Of the 22 projects that were included, eight projects shared responsibilities between municipal Public Works departments and private entities, and eight undertook O&M through municipal efforts alone. Only five projects have O&M responsibilities assigned solely to private entities or organizations. A little over half of the projects had developed an O&M plan, manual or similar guidance, as well as provided various

Table 3: O&M Responsibilities and Frequency of Maintenance Required

State	Project Sponsor	Municipal Responsibilities	Frequency Maintenance Performed (Municipal)	Documentation Tracking System	Private Responsibilities	Frequency Maintenance Performed (Private)
CA	American Rivers, Yuba Watershed	Weeding Trash Removal	As needed	N/A	N/A	N/A
		Clean drainage structures	As needed			
		Watering	2-3 times/week			
	Friends of the Santa Clara River	N/A	N/A	N/A	Weeding Replanting Invasive Species	As needed
	Truckee River Watershed Council	Inspections	As needed	No data	N/A	No data
	Hermosa Beach	Pump maintenance Clean baffle box Clean divergence	Annually	Manual reporting	N/A	N/A
	Oakland	Inspections	Annually	No data	Rain barrel cleaning	Annually
	Literacy for Environmental Justice, Heron's Head	N/A	N/A	Manual Reporting	Inspections	Monthly-Quarterly (differs by component)
					Weeding	Monthly
					Plant Pruning	Annually
					Tank cleaning	As needed
KS	Lenexa	Trash removal Mowing	Monthly	Electronic	N/A	N/A
		Clean streamway irrigation system Clean pervious pavement	As needed			
MD	Chesapeake Bay Trust – Anne Arundel County	N/A	N/A	N/A	Inspection Trash Removal Erosion Control Invasive Species	Semi-Annually
	Takoma Park	Weeding	Quarterly	N/A	N/A	N/A
		Trash Removal	Bi-weekly			
		Watering	As needed			
	Edmonston	Trash removal Weeding Inspections	Daily	N/A	Replanting Fertilizing	As needed
		Clean catch basins	As needed			

Table 3 continued: O&M Responsibilities and Frequency of Maintenance Required

State	Project Sponsor	Municipal Responsibilities	Frequency Maintenance Performed (Municipal)	Documen-tation Tracking System	Private Responsibilities	Frequency Maintenance Performed (Private)
ME	Long Creek Watershed Management District	N/A	N/A	Electronic	Inspections Clean catch basins	Annually
					Mulching Weeding Trash removal Reseeding	As needed
NY	Amherst	N/A	N/A	N/A	Mowing	No data
	Tioga CSWCD	Inspections	Annually	In development	N/A	N/A
	Chemung County Library District	Inspections Watering Weeding	Bi-Monthly	N/A	N/A	N/A
	Lindenhurst Memorial Library	Inspections Weeding	No data	N/A	N/A	N/A
OH	Toledo	Underdrain system	No data	No data	Rain barrel cleaning Catch basin cleaning	As needed
PA	Chester CCD	Inspections Monitoring	As needed	N/A	Inspections Monitoring	As needed
	PA Environmental Council	Watering Trash removal Weeding	No data	N/A	Weeding Rain barrel cleaning	No data
UT	Salt Lake County	Watering Weeding	No data	No data	N/A	N/A
WA	Spokane	Inspections Catch basin cleaning Underdrain system	Annually	Manual reporting	Mowing Weeding Trash removal Replanting	City performs bi-annual inspections; residents perform maintenance
		Trash removal Snow removal	As needed			
	Olympia	Trash removal Weeding	Daily	Manual reporting	Replanting	As needed
		Irrigation system Replanting	As needed			

informational and educational materials to staff, stakeholders, and residents on how to properly care for different types of green infrastructure. The majority of the projects did not report having a formalized documentation or O&M activity tracking system in place. Those that are undertaking such efforts are predominantly doing so through the use of manual log forms. Though only two projects (the City of Spokane and the City of Lenexa) currently employ electronic tracking systems, several communities are in the process of developing systems to manage their O&M responsibilities.

The reported O&M activities are performed at intervals ranging from daily, monthly, quarterly, and annually. Approximately, 50 percent of the projects with private entities responsible for O&M (sole or shared with a municipality) report maintenance is performed on an as-needed basis. Sixty-one percent of the projects in which responsibility for O&M is assumed solely by municipalities had more defined frequency intervals. Table 3 illustrates the accountability structures and frequency of various O&M activities for these green infrastructure projects.

Observed Green Infrastructure O&M Practices

This study highlights a number of common elements shared among green infrastructure projects. Observed O&M practices from the 22 ARRA-funded green infrastructure projects, as well as from a comprehensive literature review,[14] include the following:

- Accountability mechanisms such as an O&M plan or manual
  - Having a written O&M plan, manual, or similar guidance in place helps ensure that project sponsors are aware of and can be held accountable for O&M responsibilities, and helps ensure the long-term viability of a project.

- Documentation and tracking systems
  - Tracking systems can help improve oversight by assisting project sponsors in keeping track of O&M activities and costs, and by identifying opportunities for more effective strategies for preventative maintenance. They can also help ensure that green infrastructure projects are performing as designed.

- Training and education
  - Effective O&M training is provided in an easy-to-understand format, occurs at regular intervals, and is targeted to the activities employees or volunteers are expected to perform. Education and training can also provide information on the water quality and environmental benefits that green infrastructure can yield when properly maintained.

- Partnerships
  - Partnerships can help ensure that the necessary resources, such as adequate personnel, equipment, and funding are in place to maintain the environmental benefits as well as the aesthetic amenities provided by green infrastructure projects.

- Vehicles for compliance assurance
  - When multiple parties such as contractors and private landowners are involved in publicly funded green infrastructure projects, having some type of authority in place to assure compliance can help communities ensure that maintenance activities are being performed as expected. Maintenance agreements and local ordinances may include maintenance schedules, inspection requirements, and permission to access private property, and repercussions for failure to perform.

- Dedicated funding source(s)
  - A dedicated source of funding provides a means to cover maintenance costs, including labor, equipment, and the repair and replacement of green infrastructure components as necessary. Funding sources used in the projects profiled here include municipal or district general funds and stormwater utility fees.

[14] For information on the literature consulted, see "References" in Appendix A.

Accountability and O&M Plans

Accountability is essential to the success of a project. Many of the projects profiled in this report, particularly in the smaller communities, had strong support from prominent city officials, such as the Mayor or City Council members, and they helped facilitate implementation of the project. The projects are well maintained as a result of their continuing support, even when no formal O&M plan is in place. When these individuals leave office however, the support may not be as strong and new officials may choose to direct funding to other efforts. To hold public officials accountable and help ensure green infrastructure project maintenance is not at the mercy of changing municipal priorities, communities or sponsoring organizations can develop an O&M plan that clearly states who is responsible for maintenance, what the funding source is, and the environmental benefits to the community when the project is properly maintained.

The EcoCenter at Heron's Head Park in San Francisco, CA developed an O&M Plan that includes a description of O&M activities and monitoring procedures, as well as work sheets and record-keeping forms for components of the facility. The O&M Plan will be reviewed and updated once a year or after significant system changes. The EcoCenter at Heron's Head Park is run by the organization Literacy for Environmental Justice in San Francisco, CA and serves as a learning center for community youth on issues such as energy efficiency, water conservation, and green infrastructure. The EcoCenter used ARRA funds for constructed wetlands that are used to treat its own wastewater, a green roof, rain

Table 4: EcoCenter at Heron's Head Park Maintenance Schedule

Task	Frequency	Year 2011				Year 2012				Year 2013				Year 2014				Year 2015			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Settling Tank Inspection	Quarterly	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Advantex Unit Inspection (Control Panel)	Quarterly	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
UV Disinfection System Inspection and Cleaning	Annually				X				X				X				X				X
Drip Irrigation Disposal Field Inspection	Quarterly	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pump Inspections	Quarterly	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Constructed Wetland – Weed Control	Monthly	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Constructed Wetland – Native Plant Inspections	Monthly	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Constructed Wetland – Native Plant Pruning	Annual		X				X				X				X				X		
Constructed Wetland – Cutback Native Species	Annual		X				X				X				X				X		
Constructed Wetland – Inspect for anoxic conditions	Weekly	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
UV Disinfection System Lamp Replacement	Every 2 Years								X								X				
Setting Tank Pumping	Every 3-5 Years, or as needed													X							
Advantex Unit Cleaning	Every 3-5 Years, or as needed													X							
Testing Remote Emergency Alarm System	Annual		X				X				X				X				X		

water catchments, and native landscaping. The purpose of the O&M Plan is to "ensure that equipment is properly functioning, to maximize system reliability, and to ensure that equipment meets its expected service life and does not require unnecessary and excessive repairs."[15] The Plan includes a detailed maintenance schedule that very clearly outlines specific maintenance tasks and the frequency at which they should be performed (Table 4). Having a written maintenance schedule in place that details the type and frequency of maintenance activities helps ensure long-term project viability.

Documentation and Tracking Systems

Another important element that aids in the effective oversight of O&M is the development of a system to document and track maintenance activities. This is often part of a computerized maintenance management system or asset management system that allows for the electronic logging of O&M tasks. The City of Spokane, WA constructed a network of 37 rain gardens between the curbs and sidewalks to intercept stormwater runoff on either side of a major thoroughfare. The City's Sewer Maintenance Division currently uses a system that will link to a GIS platform and enable the City to utilize all of the laptops that have been deployed in the field. This will allow work orders to be opened and date-stamped directly from the laptop, eliminating duplication and increasing the accuracy of maintenance tracking. The City will be using this system to log information that will help the City establish better preventative maintenance controls for green and gray infrastructure projects throughout the City.[16] Other forms of documentation and tracking that may also be effective include electronic database systems, use of time logs or timesheets with specific references to the maintenance activities performed. Six of the 22 communities that were included in the study reported using some form of documentation or O&M tracking system. For example, the Long Creek Watershed Management District in Maine currently uses log sheets and is in the process of developing an electronic database to track O&M tasks, and Lenexa, KS tracks O&M activities via an electronic asset management database system. Regardless of the format, a formalized documentation and tracking system can assist operators of green infrastructure projects with keeping track of O&M activities, costs, and staff time, as well as in identifying opportunities for more effective strategies for preventative maintenance. This can also help ensure that green infrastructure practices are performing as designed.

Photo courtesy of Literacy for Environmental Justice, EcoCenter at Heron's Head Park, San Francisco, CA

Training and Education

Education and training is an essential part of O&M. Training courses or workshops for municipal employees and contractors responsible for green infrastructure O&M are a necessary component of a well-developed maintenance program. Training targeted to the activities employees are expected to perform provides practical instruction on the proper care and maintenance of green infrastructure

[15] Eckman Environmental Corp. (2011).*Operations and Maintenance Guidelines for On-Site Wastewater Treatment System at Heron's Head Park, Pier 98, San Francisco, California*. Literacy for Environmental Justice.
[16] Schug, Mike, City of Spokane (2011). Personal communication with the author.

projects. Training can also provide information on the environmental benefits and important water quality impact that green infrastructure can have when properly maintained.

Many green infrastructure projects are often implemented by private landowners, nonprofit organizations or other nontraditional CWSRF recipients, and may rely on private residents or volunteers to conduct project maintenance. In these cases, many of the individuals involved may not have experience performing the maintenance activities required for the project to function optimally. To prevent this from causing problems, successful projects not only have an O&M plan in place, but have also conducted public education efforts, outreach campaigns, and training programs. Friends of the Santa Clara River, a nonprofit organization sponsoring a constructed wetland and riparian restoration project in California, conducts training workshops at the project site to educate volunteers on the necessary maintenance required, which includes identification and removal of invasive plant species. The cities of Toledo, OH, Oakland, CA, and Spokane, WA have implemented green infrastructure projects on private property or provided rain barrels or cisterns to private landowners/residents. These municipalities have provided detailed brochures, manuals, and one-on-one training sessions with residents and private landowners on how to properly care for their green infrastructure. Taking steps to educate individuals about required maintenance can prevent accidental damage to the system, such as removal of native species or application of strong pesticides, herbicides, or other chemicals that are undesirable in the watershed.

The Maywood Avenue project in Toledo uses rain gardens, bioswales, porous pavement, and rain barrels as a strategy to mitigate CSO events and improve water quality in the Maumee Watershed. The City of Toledo and Lucas County in Ohio created a website (www.raingardeninitiative.org) dedicated to green infrastructure stormwater management solutions. It contains educational materials, including *A Homeowner's How-To Guide: Rain Gardens for Northwest Ohio*,[17] which provides detailed guidance on:

- Benefits of rain gardens and how they work
- Location considerations
- Determining the slope
- Proper sizing and identification of the drainage area
- Soil testing and selection
- Choosing the right native plants
- Required maintenance
- Common mistakes and how to correct them

According to Patekka Bannister, Stormwater Specialist with the City of Toledo's Public Utilities Department, involving the community and empowering the residents by connecting them to their water resources, teaching them to be better stewards, promoting environmental education and awareness, and providing a homeowner maintenance manual and individual trainings are the key to the success of this project.[18]

[17] Toledo-Lucas County Rain Garden Initiative (2011).*A Homeowner's How-To Guide: Rain Gardens for Northwest Ohio.* Retrieved September 29, 2011.Available at http://www.raingardeninitiative.org/documents/pdfs/NW_Ohio_Manual.pdf.
[18] Bannister, Patekka Pope, City of Toledo (2011). Personal communication with the author.

Partnerships and Contracting

Partnerships are an important component of many green infrastructure O&M strategies. The City of Olympia, WA's Yauger Park stormwater improvement project was implemented by the City's Department of Public Works (DPW) and includes the construction of a porous pavement parking lot, a rain garden, and constructed wetlands in a high-use urban park. Although maintenance activities are paid for with revenues from DPW's stormwater utility fee, the Olympia Parks Department is responsible for maintenance activities of the rain gardens and other landscaped areas of Yauger Park. Unlike gray infrastructure, green infrastructure is highly visible to the public and is often considered an aesthetic amenity. As a result, the quality and quantity of maintenance that green infrastructure projects receive is often influenced by public expectations of how green space should look. DPW will perform bi-monthly inspections to ensure proper maintenance activities are being performed by the City's Parks Department's expectations of how green space should look. DPW performs bi-monthly inspections to ensure proper maintenance activities are being performed by the City's Parks Department and that the rain gardens and other vegetated areas of the park are maintained at a weed-free level.[19] The partnership between DPW and the Parks Department helps ensure that the necessary resources, including adequate staffing levels, equipment, and funding are in place to maintain the environmental benefits and the aesthetic amenities provided by this highly visible urban stormwater improvement project.

Some projects have elected to enlist contractors to perform some of the required maintenance activities such as inspections, application of fertilizers/fungicide, pumping, tank cleaning, or removal of trash and debris. The City of Hermosa Beach, CA entered into an agreement with the Los Angeles County Flood Control District as well as a third-party contractor to establish roles and responsibilities for this full-scale pilot project to determine the effectiveness of subsurface infiltration in an urban beach environment in controlling stormwater run-off and pollution. The City maintains the infiltration trench downstream from the pump station, the private contractor is responsible for the cleaning of the baffle box, and Los Angeles County maintains the divergent structure, tide gate, and pump.

Compliance Assurance

When multiple parties are involved, including contractors, private landowners and/or homeowners, as well as the various municipal departments that may be responsible for performing O&M activities, many municipalities have found it useful to have some form of authority in place to assure compliance. In the event that a responsible party fails to fulfill its maintenance duties and the project is in danger of falling into damage or disrepair, having some kind of legal authority can help bring such issues to a formalized resolution. A number of the communities profiled in this report have secured such authority through binding, legal agreements with private landowners, residents, and contractors. The Long Creek Watershed Management District in Cumberland County, Maine, entered into individual contracts with each of the private landowners involved in this stormwater improvement and riparian restoration project. These contracts require the landowners to perform minimum good housekeeping standards that include landscape and winter maintenance such as removal of debris, sediment and floatables, sweeping, and vacuuming. Other communities profiled for this report that entered into

[19] Haub, Andy, City of Olympia (2011). Personal communication with the author.

maintenance agreements with private landowners and residents include the Chesapeake Bay Trust and Anne Arundel County, MD, the City of Toledo, OH, and the City of Spokane, WA. Maintenance agreements may include elements such as a clear description of the maintenance to be performed, maintenance schedules, inspection requirements, establishment of permission to access the green infrastructure project or enter onto the property where it is located, and repercussions for failure to perform. Furthermore,

Photo courtesy of Lindenhurst Memorial Library, Lindenhurst, NY

maintenance agreements be recorded with the city and County Recorder to ensure that the requirements remain bound to the property in perpetuity.[20] This practice can help to ensure maintenance activities continue with the transfers of property ownership and also provides clear documentation of responsibilities that are conveyed with the title.

In the absence of maintenance agreements, communities can also rely upon local ordinances to provide compliance assurance. The City of Toledo, in addition to its individual contracts with residents for the maintenance of the Maywood Avenue project, can also turn to the Toledo Municipal Code, which passed an emergency ordinance (Ord. 253-09) in April 2009 that amends the municipal code to include requirements for the design, construction, and maintenance of pervious parking/surfaces, bioretention areas, and rain gardens. Section 1108.0206 of the Municipal Code specifically requires that "bioretention area(s) shall be maintained by the property owner for its intended function for the duration of its life."[21] Without some form of legal authority to assure compliance, municipal stormwater managers are left with little or no recourse available to require at least minimal maintenance activities that will assure the viability of green infrastructure projects. As a result, investments in these types of capital improvement projects may be jeopardized if measures are not taken to ensure accountability, identify acceptable design, construction, and maintenance requirements, and clearly articulate the repercussions for failure to perform such requirements. These measures are necessary for green infrastructure to continue to gain acceptance as an effective stormwater management solution on par with gray infrastructure.

Funding

The establishment of a dedicated source of funding that will allow for a budget capable of covering the costs associated with maintenance, staff, equipment, and the repair and replacement of green infrastructure components as necessary, helps to ensure the continued success of an O&M system for green infrastructure projects. Table 5 illustrates the average costs of maintaining green infrastructure as reported by five of the 22 projects profiled in this report. Overall, 59 percent of the respondents

[20] Stormwater Center (2011).Maintenance Agreements and Arrangements. Retrieved November 4, 2011. Available at: http://www.stormwatercenter.net/Manual_Builder/Maintenance_Manual/4Maintenance_Agreements/Maintenance%20Agreements%20Introduction.htm

[21] Toledo Municipal Code. Retrieved November 15, 2011. Available at: http://www.toledo.oh.gov/LinkClick.aspx?fileticket=_rb1qNBBQ2I%3D&tabid=310

reported having a dedicated source of funding that would be used to help fund the O&M activities necessary to properly care for and protect these green infrastructure projects.

Table 5: Average Annual Cost of Green Infrastructure O&M for Selected ARRA Clean Water SRF Projects*

State	Project Sponsor	Type of GI BMP	Average cost of O&M	O&M Funding Sources
ME	Long Creed Watershed Management District	◆◆	$78,308, annually (includes all monitoring and equipment costs)	Participating landowners fee assessment by LCWMD
MD	Edmonston	◆◆◆◆	$15,000 - $20,000 annual operating budget	Facility maintenance operating budget
KS	Lenexa	◆◆◆	$19,140 annually	Stormwater utility fees
CA	American Rivers – Yuba Watershed	◆◆	$780 - $2,440 annually for O&M and necessary plant replacements	Included in existing county maintenance budget
WA	Olympia	◆◆◆◆	$100,000 budgeted for first year, with plans to reduce in future years	Stormwater utility fees

* Estimated project costs vary due to project scope, size, and location

◆ Bioretention/Bioswales ◆ Riparian Restoration ◆ Rainwater Harvesting (rain barrels and cisterns) ◆ Vegetative Plantings (Including Trees)

◆ Wetlands ◆ Green Roof ◆ Pervious Pavement ◆ Unspecified green stormwater Improvement projects/BMPs

While there are a number of potential grant and loan options for implementing green infrastructure solutions, those funds generally will not pay for the operations and maintenance of this infrastructure. Consequently, some communities have established user fees for stormwater infrastructure, similar to those for traditional wastewater infrastructure to aid in funding O&M activities. Others have used municipal or district general funds for this purpose.

The findings from this study of 22 ARRA-funded green infrastructure projects indicate that municipalities with more experience with green infrastructure (Spokane, Olympia, Lenexa, and Toledo) have a stormwater utility that collects fees dedicated to the maintenance of these systems. Typically, the rates assessed to customers are based on the amount of impervious surface area on a residential or commercial basis. For instance, the City of Lenexa bases its stormwater fees on $7.50/Equivalent Dwelling Unit (EDU). The City of Spokane charges commercial properties per impervious acre while residential properties are assessed a flat rate. The City of Olympia also has a stormwater utility that is administered through the Department of Public Works. Olympia residents and businesses are charged a flat monthly stormwater service charge. The primary difference between a stormwater utility and a conventional municipal stormwater management program is that a utility has the authority to charge fees, which enables it to act independently of municipal general taxation processes. Stormwater utilities can also implement watershed-based planning and regional stormwater


Photo courtesy of the Town of Edmonston, MD

management solutions.[22] These utilities play an important role in spreading awareness about stormwater pollution. According to Raylene Gennett, the Storm Water District Supervisor for the City of Spokane, the creation of a stormwater utility with discrete and separate rates has helped increase public awareness of stormwater issues.

For those projects in communities that do not have a stormwater utility, several different methods of generating revenues were observed that include the use of a municipal or special district general fund or a facility maintenance operating budget, the establishment of landowner fee assessments, and partnerships. In Maryland, the City of Takoma Park and the Town of Edmonston's green infrastructure projects are paid for out of the respective communities' facility maintenance operating budget and general operating fund. The Long Creek Watershed Management District in Cumberland County, Maine undertook an innovative approach to addressing the need for a revenue source to maintain this large riparian restoration project that spans across several municipalities within the Long Creek Watershed. Landowners were given the option of participating in a group permit at a cost of $3,000/acre of impervious surface annually for ten years, or securing individual permits at a cost estimated to be approximately double that of the group permit. Almost all of the landowners entered into an agreement to participate in the group permit, accounting for over 91 percent of the impervious surface area in the watershed. The assessments are expected to generate approximately $1.6 million in the first year to pay for O&M, equipment, administration, and water quality monitoring efforts.[23]

The City of Rome, NY relies on its continuing partnerships with the National Grid Power Company and the Division of Urban Forestry to cover the cost of small tree plantings and maintenance for their urban canopy restoration project. This project includes tree plantings to reduce stormwater runoff and the replacement of impervious surfaces with pervious rubber pavement. National Grid has helped pay up to one-half of the costs for tree plantings under overhead conductors and will continue to support green infrastructure projects, canopy restoration in the downtown area, and other urban neighborhoods. While O&M is not eligible for funding under the CWSRF, the program is able to fund project-monitoring activities for the purposes of assessing the effectiveness of green stormwater management practices for up to three years for green infrastructure projects that are not required by a

[22] Fuss & O'Neill (2010).*Technical Memorandum: Evaluating the Role of Stormwater Utility Districts in the Implementation of Low Impact Development*. Retrieved September 28, 2011. Available at: http://www.ct.gov/dep/lib/dep/water/nps/swgp/tm2_role_swu.pdf.
[23] Buranen, Margaret (2010).The Restoration of Long Creek. *Stormwater.* Retrieved October 12, 2011.Available at: http://www. stormh2o.com/november-december-2010/restoration-long-creek.aspx.

NPDES permit. However, communities will still need to ensure they have funds for operations and maintenance, and funds for project monitoring, if needed, beyond the three-year period.

Conclusion

The use of green infrastructure as an urban stormwater management strategy can help communities and other stakeholders effectively address some of our nation's most pressing water quality concerns. There are numerous environmental, social, and economic benefits that may be realized when proper consideration is given to size, scope, and maintenance needs of green infrastructure projects. The 22 ARRA CWSRF Green Project Reserve projects that were profiled for this study illustrate the variety of green infrastructure practices and projects that can be used to effectively manage stormwater, as well as the necessary O&M structures to ensure that these projects continue to function as intended over the long-term. Though the findings in this report demonstrate that one size does not fit all when it comes to green infrastructure and its proper maintenance, there were common and overarching themes applicable to the projects that were identified. These include: the establishment of accountability and maintenance schedules through an O&M plan, the tracking and documentation of maintenance activities, training and education on green infrastructure maintenance, the presence of mechanisms to ensure compliance, and the importance of securing a dedicated source of funding to pay for O&M.

Projects that use green infrastructure to address stormwater runoff and sewer overflows will continue to gain traction within the CWSRF program through the Green Project Reserve. These types of projects are also gaining increasing visibility through EPA initiatives such as the Agency's Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure, and through the work of communities and environmental organizations across the country. As green infrastructure becomes more integrated into the traditional stormwater management framework, there will be more opportunities for improved research and better quantification of the benefits of these types of projects. Opportunities will also increase for communities and other stakeholders to share in lessons learned and to develop and implement maintenance programs specifically targeted toward green infrastructure.

Appendix A - Green Infrastructure Design and Maintenance Practices

The maintenance needs of various types of green infrastructure vary considerably by type and design. As green infrastructure approaches to stormwater management become more common within the CWSRF program, understanding these maintenance requirements is critical for the success of projects. Green infrastructure is new to many communities, and many CWSRF assistance recipients are unfamiliar with the O&M costs and activities for these types of projects. Although the CWSRF program cannot provide funding for O&M activities, ensuring that assistance recipients have adequate capacity to maintain projects after construction is complete is vital to achieving water quality objectives. For green infrastructure, this means not only that the community has financial resources, but also the knowledge base to maintain projects appropriately.

This appendix is intended to provide more detailed information about green infrastructure and familiarize CWSRF funders and assistance recipients with common practices for green infrastructure operation and maintenance. Information was gathered from academic sources, state and local guidelines, and industry publications. It is intended to present a broad overview of requirements and highlight the most important considerations for each project type. Because O&M should be evaluated by a community during the project planning phase, important design elements that can influence long-term maintenance needs and costs are included as well.

O&M information is presented by project type, and a summary is presented in Appendix B. The information in these sections is primarily summarized from sources identified in the reference section at the end of this Appendix, except where otherwise noted. These references can also be used as sources of more comprehensive technical information on specific project types.

Overview of Green Infrastructure Types

The water treatment benefits provided by green infrastructure are due largely to the effects of filtration and retention. Various project types make use of natural ecosystem processes to remove pollutants from stormwater by filtering runoff through a moist, vegetated environment. Retaining stormwater helps to reduce the overall flow volume, while also providing time and an environment for removal of the water by infiltration, evapotranspiration, or capture and use. These methods provide an inexpensive way to improve water quality, and projects of this type often bring the aesthetic benefits of additional green space to communities as well.

Water quality improvements can result from several different processes. First, passing water over a vegetated area slows flow rates and moderates the impact of peak flows during high volume events by providing temporary retention for runoff. When water speed is slowed, sediment and other suspended solids settle to the bottom the same way they would in a traditional settling pond. Similarly, capture of rainwater for later use reduces peak flow and may prevent some pollutants from entering water bodies. Direct benefits are also achieved from vegetation itself. Many plants have the capacity to remove pollutants such as excess nutrients, organic compounds, metals, and other contaminants. Allowing runoff to infiltrate into soil also creates an opportunity for pollutants to filter out as the water flows through the soil.

All types of green infrastructure rely on the processes described above to improve water quality to some extent. The following section reviews general design and maintenance practices for those green infrastructure systems that are most commonly funded by the CWSRF. Detail on specific concerns for each project type is presented after the general discussion.

Design and Maintenance

The design of green infrastructure systems can be very significant to long-term maintenance needs and costs. In addition to selecting the correct type of project for the circumstances, of primary importance during the planning phase is designing a project appropriate for local climate and rainfall patterns. It is common for a system designed to absorb stormwater to be designed to accommodate the flow volume typical of a large, periodic storm event in that location, such as a 2-year, 5-year, or 10-year storm event. Alternatively, they may be designed with a mechanism to control overflow, such as with an underdrain or diversion to a storm drain system. The permeability of soil for both conveyance and detention or retention areas in a project should allow sufficient infiltration to prevent undesirable pooling. In some cases, this may mean that an engineered soil design will be necessary.

Design should also consider the potential for erosion, which can be a problem if substrate is insufficiently secured, if there are steep slopes, or if the system experiences particularly high flow rates. Where water flows into a system, slopes should be sufficient to allow for continuous flow without being damaged by erosion. Erosion will reduce the effectiveness and the life span of the system and can allow channels to form through the system. Weed mats, hardwood mulch, or similar materials can be used to secure substrate and reduce erosion. In extreme cases, periodic re-grading of slopes and replanting of damaged vegetation may be necessary.

The Benefits of Native Vegetation in Green Infrastructure

Native species are best adapted to an area's existing climate and precipitation patterns. Therefore they are likely to require minimal, if any, irrigation or fertilization once established, will be better equipped to compete with weeds in the area, and will contribute to ecological restoration of the area.

In systems that include vegetation, plants should be selected to thrive in the local climate, with native species being most desirable. Vegetation should be hardy enough to withstand extremes of precipitation and temperature, as well as the expected concentration and type of pollutants. This will help to increase the rates of plant survival and minimize maintenance costs for communities.

Ensuring the health of vegetative plantings is also important to the success of many systems. The first one to three years or growing seasons is the most critical time for vegetation and is known as the establishment period. In some cases contractors involved in construction will consider the establishment phase a part of construction or cover costs of maintenance during the first year under a warranty or guarantee. For communities unfamiliar with green infrastructure maintenance, such a provision can greatly assist the success of a project during the critical establishment phase. Examples of best practices during the establishment period include:

More frequent inspections: Inspections should occur every few weeks and follow major rain events, to ensure that growth is going as planned and desirable species are not being crowded out by weeds.

• Plant maintenance: Weed removal, extra watering, and minimal fertilization may be necessary as the young plants take root. Herbicides are not recommended for weed removal, due to the difficulty of preventing the herbicide from entering groundwater.

• Erosion control: Additional erosion control may be necessary in this period, as roots may not be deep enough yet to limit erosion, and the soil will have recently been disturbed.

• Minimize shock to plants: Where an inflow control mechanism exists, minimize wastewater or stormwater entering the system to reduce shock to the newly planted vegetation. Polluted water can begin to be introduced as plants establish. A good sign that plants are thriving in their new environment is when they begin to put out new growth.

• Compensate for short growing seasons: In cold climates, the planting of larger, more mature plants may help to accelerate establishment.

Subsequent to the establishment period, required maintenance is generally not as intensive. Regular inspections can be reduced to three to five times a year. Additional inspections can be conducted as-needed following major rain events or during snowmelt, due to high flow rates and the possibility of damage to plants. Inspection should include both monitoring and routine activities to ensure the success of the system, including removal of trash and debris.

Photo courtesy of Literacy for Environmental Justice, EcoCenter at Heron's Head Park, San Francisco, CA

During inspections, removal of weeds and invasive species, as well as replacement of desirable plants that have been damaged or died, can help to maintain system health. In general, about 85 percent of land area should have healthy vegetation.[24] In some systems, such as grassed swales or riparian areas, regular mowing will improve the aesthetic appearance and help spur growth of plants. However, this is not appropriate for all project types, especially those with a landscaped design, such as rain gardens or green roofs. Similarly, periodic harvesting is also sometimes used to spur plant growth, but should be carefully considered before employed. While there are documented benefits to plant harvesting in some systems, it can damage habitat and decrease the rate of maturation of the ecosystem. Choices about plant harvesting should be made on a case-by-case basis, depending on the needs of the system and the intended goals of the project.[25]

---

[24] Pennsylvania Department of Environmental Protection (2006).*Pennsylvania Stormwater Best Management Practices Manual.* Retrieved December 5, 2011.Available at: http://www.stormwaterpa.org/assets/media/BMP_manual/07_Chapter_6.pdf
[25] US EPA (2008). *A Handbook of Constructed Wetlands*. Retrieved December 15, 2011.Available at http://water.epa.gov/type/wetlands/restore/upload/1998_04_02_wetlands_pdf_hand.pdf

Pest control is one final aspect of general maintenance that applies to most systems. Insects and animals can cause considerable damage if they are not controlled, and in suburban or urban locations they can contribute to the project becoming a blight or nuisance. In some cases, such as with riparian restoration, systems are designed to provide necessary and beneficial habitat, and in these cases animal and insect life should be welcomed. There is only cause for concern when the system fosters pests. In moist, and slow-moving or stagnant, designs, mosquito proliferation is a common concern. Mosquitoes typically require about 10 days of stagnant water to breed. However, they may go through their lifecycle in as little as 4.5 days.[26] A good way to prevent mosquito proliferation is to ensure that water is not allowed to remain undisturbed or pooled for more than a few days.[27] Providing nearby habitat for natural predators of mosquitoes, such as bats, purple martins, or swallows can also help to control their populations. Muskrats and geese are also common problematic species. These animals eat roots of plants, and will burrow or dig to reach them. Deer will also consume a wide variety of plants. Installation of fencing and utilizing a ground cover, such as chicken wire, can reduce damage from pest animals by limiting the amount of digging that is possible and protecting root systems.[28] All of these measures will protect the project and ensure that it remains a positive improvement for communities that are investing in green infrastructure.

These general aspects of design and maintenance are important for the successful use of green infrastructure to address water quality and stormwater concerns. More project-specific information for each of the more common green infrastructure project types funded by the CWSRF is below.

Bioretention Areas

A bioretention area, or rain garden, is an area of land that has been designed to filter or infiltrate stormwater before it is discharged to a stormdrain or another body of water. Bioretention areas can be used in residential areas, parking lots, along highways, in urban settings, and adjacent to industrial or commercial facilities. When well maintained, they bring both water quality and aesthetic benefits, but their ability to improve water quality depends on a design that is suitable for the location.

Bioretention areas are depressed from the surrounding land area and are underlain by a permeable soil. Stormwater that flows in is retained for up to 72 hours before it is infiltrated or removed through evapotranspiration. Critical design elements include size, shape, soil composition, and plant selection. These ensure the success of the bioretention area and minimize maintenance concerns. Plant selection in a bioretention area depends on both the location and the expected pollutant load. Areas along roadways or in traffic medians generally include lower-growing plants that can be easily maintained and do not impact visibility. When constructed near industrial or commercial facilities, high pollutant loads are likely and mean that hardier plants should be chosen, and that an underdrain and an impervious

[26] http://www.vdh.virginia.gov/lhd/CentralShenandoah/EH/WNV/mosquito_breeding_habitats.htm
[27] *Rain Barrel Guide*. Retrieved October 11, 2011. Available at: http://www.rainbarrelguide.com/safety-maintenance/
[28] Ibid.

liner (at least 30 mm thick) are necessary to prevent groundwater contamination.[29] The size and shape of a bioretention area should be specifically designed for the amount of rainfall at a given location, with an inflow mechanism designed to handle appropriate water volumes without eroding. Often, a vegetated swale is used in combination with a bioretention area in places with high volume storm events. Because bioretention areas are not intended to have permanently standing water, soil design is critical to ensure the success of the cell at removing pollutants and infiltrating water. Including a pretreatment area, such as a grassed swale, prior to the bioretention area may prevent sedimentation that can cause clogging or disrupt the soil design. Within the bioretention area, there should be a base consisting of an engineered mixture of mulch, organic material, and sand layered to achieve the desired infiltration rate. Hardwood mulch is recommended for the top layer as this can prevent weed growth. For remaining layers, resources are available to assist planning the appropriate mixture. A base layer of aggregate or gravel to provide filtration is recommended beneath soil layers. In areas with natural clay or impervious subsoil, an underdrain may be necessary to ensure sufficient drainage and prevent pooling during high volume precipitation events.

Is Road Salt Damaging to Wetlands?

De-icing salt in runoff can be damaging to wetland plants. If runoff to the wetland is likely to have high salt content in the winter, salt-tolerant plants should be chosen. A grassy buffer installed adjacent to the wetland to absorb some of the chlorides will also help to maintain plant health.

Constructed Wetlands

Wetlands are transitional areas between land and water that can have surface or near-surface water year-round, although some are fully saturated only periodically. Constructed wetlands are a common method for treating runoff by recreating natural hydrological processes that improve water quality. They often include a mechanism for controlling the rate of inflow, as well as a drain or other outflow structure to enhance control in case there is a need for repairs or an unusual flow event. Unlike some types of green infrastructure, constructed wetlands are typically designed to fit into the existing environment and often are intended to restore habitat as well as improve water quality. In order to minimize maintenance needs, wetlands should be fit into the existing topography of the site. By designing them this way, water flows and wetland plants will work more smoothly with nature, making it possible to capitalize on beneficial ecosystem services. There have been

Bioretention Areas vs. Rain Gardens – What's the Difference?

Although the terms are often used interchangeably, the term "rain garden" usually refers to a well-landscaped, manicured bioretention area with a variety of plants selected for both aesthetics and their effectiveness at managing stormwater. This type of bioretention area is common in residential and high visibility urban settings. Generally, they do require a higher degree of maintenance to maintain appearance.

[29] Prince George's County, MD Department of Environmental Resources, Environmental Services Division (2009). *Bioretention Manual*. Retrieved October 21, 2011. Available at http://www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/Bioretention/pdf/Bioretention%20Manual_2009%20Version.pdf.

anecdotal cases in which wetlands that were not designed to fit into the natural shape of the site cost up to 20 times as much as those that took such parameters into consideration during project design.[30]

Maintaining adequate water levels is critically important to the health of the wetland, particularly during the establishment period. Certain time periods require that particular attention be paid to water level. For example:

- During establishment: Water levels should initially be kept low to allow sufficient oxygen to reach the roots of young plants – they can be increased when the establishment period has ended.
- During periods of high runoff: Water levels should be controlled to prevent overwatering of plants and shortened residence times that reduce water quality benefits.
- During periods of low runoff or high evapotranspiration: Water should be contributed to the system as necessary to ensure it does not dry out.
- During cold weather: As long as water is flowing, even wetlands with a layer of ice should continue to provide water quality benefits, but colder temperatures are likely to reduce biological activity. If possible, residence times should be increased to ensure treatment levels remain adequate. Excess water can be stored for use in dry periods.

To achieve maximum water quality benefits, flow should be even throughout the wetland. Pooling water or channels will reduce the overall area of the wetland being used for infiltration and may create areas where water stagnates, creating habitat in which insects can breed. Disrupted flow can result from the roots of woody species, accumulation of debris, or trash in the wetland. Raking to redistribute substrate, limiting growth of larger, woody plants, and removing debris from the wetland can help to prevent these problems. Accumulation of sediment can also damage plants, lead to channelization, and reduce infiltration rates. If sediment accumulation becomes problematic, it should be removed, either by flushing or by draining and dredging the area. Similarly, where inflow and outflow structures are present, they should be checked regularly for clogging, and flushed or cleaned when necessary.

What is Channelization?

Channelization occurs when channels form in the substrate from water flow. As channels become more defined, water will flow more quickly through them, creating erosion and reducing infiltration. Channel formation reduces the surface area that water travels through and increases flow rates, reducing the overall treatment that water receives.

Bioswales

Bioswales, or swales, are a type of constructed conveyance channel that directs stormwater runoff while reducing flow speeds and increasing overall infiltration rates. A swale is a linear, sloped structure, with a grade that is typically between 1-3 percent longitudinally, and should not exceed 5-6

[30] Curatolo, Jim, Upper Susquehanna River Coalition (2011). Personal communication with the author

percent.[31] Swales should drain an area less than 10 acres to prevent erosion and sediment buildup that can necessitate significant, frequent maintenance and may cause the swale to fail.[32]

Swales can be used in addition to or in lieu of a traditional stormwater conveyance system and come in two main types: open channel and bioswales/vegetated swales. The former is not heavily vegetated and transports stormwater runoff at a reduced velocity, providing minimal filtration along the sides and base of the channel. Bioswales or vegetated swales have the additional benefit of biofiltration processes to partially treat stormwater during conveyance. Swales are frequently constructed adjacent to impervious surfaces such as parking lots or along highways or road medians and can discharge to an existing stormwater management system, a bioretention area, or an infiltration basin. Because of this, routine maintenance considerations for the swale may be linked to the maintenance needs for the rest of the system. The useful lifespan of swales has been estimated at anywhere from 20 – 50 years.[33]

Erosion is a primary concern for swales. In addition to carefully designing the width and slope of a swale, deep rooted plants are critical to minimize erosion and ensure the longevity of the swale. Erosion controls and repair may be required while soil is loose and vegetation is forming; reseeding or replanting may be necessary in some situations if vegetation does not take hold.

Swales require inspection to ensure their effectiveness and to determine if maintenance is needed to repair damage to vegetation or the structure of the channel. For an established swale, inspections should at minimum be conducted annually and after any single event with more than one inch of rainfall. During inspections, debris and dead vegetation should be removed; otherwise, they will block the flow of water and result in overflow and further damage. Both the swale inlet and outlet should be cleared of any material that may block the flow of water. Ponding time must be checked to make sure it does not exceed 24 – 48 hours; otherwise, remedial maintenance such as re-grading, tilling, or replanting may be necessary.[34] If significant sediment build-up occurs, it may be necessary to flush inflow and outflow drains, as well as infiltration trenches, where they are present. In areas with a cold climate, the swale should be inspected immediately after spring snowmelt and any remedial maintenance should be done at that time.

Riparian or Shoreline Buffers

Riparian or shoreline buffers are a natural area at the interface between land and water, such as a river or lake. They are typically strip-shaped and, as a result of their shape and location, are very well-suited to capture and slow sheet flow. They are most effective when they can be designed to be continuous. In contrast to wetlands, riparian buffers are not intended to be fully saturated the majority of the time.

---

[31] Pennsylvania Department of Environmental Protection (2006).Pennsylvania Stormwater Best Management Practices Manual. Retrieved December 5, 2011.Available at: http://www.portal.state.pa.us/portal/server.pt/community/best_management_practices_manual/10631

[32] University of Florida (2008).Florida Field Guide to Low Impact Development: Bioswales/Vegetated Swales. Retrieved September 10, 2011.Available at http://buildgreen.ufl.edu/Fact_sheet_Bioswales_Vegetated_Swales.pdf

[33] Pennsylvania Department of Environmental Protection (2008). *Pennsylvania Stormwater Management Plan*. Retrieved October 12,2011. Available at http://www.elibrary.dep.state.pa.us/dsweb/Get/Version-48475/05_Chapter_6.pdf

[34] Ibid.

These systems are commonly used as an agricultural BMP, to reduce the impact of runoff containing high nutrients from animal waste or fertilizers.

Appropriate width of a riparian buffer typically ranges from 35-100 feet.[35] This should be determined based on the slope and nature of the river. Steeper slopes require greater width as well as deeper root systems and/or ground cover to limit erosion. Mowing and flow control in riparian buffers is more complex than in other systems. Due to the additional goal of restoring natural habitat and reducing erosion, trees, shrubs, and some accumulation of natural debris are desirable in restored riparian areas. Therefore, mowing should be controlled so as not to inhibit growth of these plants. Because buffers are designed to have water infiltrate quickly, pooling of water should be minimal. If roots of woody plants and accumulation of plant debris cause channel formation or uneven flow patterns, raking of substrate and replacing damaged or dead plants may help to reduce problems.

Infiltration Basins

A stormwater pond is an area that is intended to capture water from a severe storm event and store it for slow release. An infiltration basin is a shallow depression constructed over permeable, uncompacted soil which captures runoff and retains it temporarily. They are typically a minimum of 15 feet across and have a base which is covered by dense vegetation.[36] Unlike detention ponds, which were not eligible for the ARRA GPR, an infiltration basin is specifically designed so that water can pass through a permeable layer of soil and recharge groundwater. Because the aim is to ensure runoff infiltrates to groundwater, no mechanism or structure is constructed to discharge stormwater during regular conditions. Outflow mechanisms constructed for an infiltration basin should only operate during unusually high volume events to manage overflow. Infiltration basins should retain water for between 6 and 72 hours.[37]

When considering whether or not to use an infiltration basin, location-specific concerns are critical.

Infiltration basins are effective stormwater management solutions in areas where vegetation might be minimal and soil compaction may have

When are Infiltration Basins a Risk?

A major concern with this type of green infrastructure is that poor filtration can result in groundwater contamination. For this reason infiltration basins have fewer applications than other types of green infrastructure. Although they can be effective when used in conjunction with other types of green infrastructure, such as swales, infiltration basins are not a good option for locations with a high pollutant load. They also should not be used near locations where groundwater is withdrawn for public or private consumption. If considering an infiltration basin, it is important to check local regulations and guidelines to ensure it is an appropriate solution for your site.

[35] Ibid. 33, p. 33

[36] Lowndes, Mary Anne (2004). *Infiltration Basins: Post-Construction Stormwater Management Workshops*. Wisconsin Department of Natural Resources. Retrieved December 9, 2011. Available at: http://dnr.wi.gov/runoff/stormwater/post-constr/Infiltrationbasin.pdf

[37] Southeast Michigan Council of Governments (2008).*Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers.* Retrieved November 12, 2011. Available at: http://www.semcog.org/uploadedfiles/Programs_and_Projects/Water/Stormwater/LID/lid_manual_intro.pdf

increased runoff and reduced infiltration rates. However, an infiltration basin should not be constructed too close to buildings or facilities, as they can increase the risk of basement flooding. It is recommended that the base of an infiltration basin be at least two feet above the seasonal high water table for groundwater.[38] The location should ideally have soil that is naturally permeable. Infiltration rates will be difficult to maintain in any area where soil has high clay content. Areas with karst topography should avoid construction of infiltration basins because of the increased risk for sinkhole formation.[39]

Maintenance for an infiltration basin involves:

- Regular inspections to ensure water is draining within 72 hours: If this is not the case, it may be necessary to clean and flush inflow and outflow mechanisms and remove any sediment build-up. This is usually done during a time when the basin is completely dry when materials can be most easily removed.
- Mowing, weeding, and debris removal: This should occur on average once per month for most locations.
- Semi-annual or annual inspections: To check for petrocarbon or contaminant build-up, vegetation health, and any erosive or structural damage. After a few years, it may be necessary to remove sediment build-up, replant vegetation, and add compost or top soil.

Many states have published documents that provide guidelines to local regulations and conditions for those considering an infiltration basin. For example, Wisconsin, New Jersey, Michigan, and several other states have published manuals or presentations regarding the use of infiltration basins. Because there are more site-specific concerns with this type of green infrastructure, it is critical that local guidelines and considerations be taken into account during the planning and design of infiltration basins.

Rain Barrels/Cisterns

A rain barrel or cistern is any vessel that is used to collect rainwater at a particular site. They are often connected to a downspout at a private residence to capture rainwater that runs off the roof, but they can also be used on larger buildings, such as schools and libraries. Rain barrels are typically small, aboveground units, while cisterns are a larger alternative that is sometimes placed underground. Rain barrels are most commonly plastic, but cisterns can be constructed of a variety of materials, such as concrete, plaster, metal, or impervious stones. The volume of water generated in the collection area during a typical storm event should be considered in determining what size unit is most appropriate. As an example, 600 square feet of roof will

[38] New Jersey Department of Environmental Protection (2004).New Jersey Stormwater Best Practices Manual. Retrieved November 28, 2011. Available at: http://www.nj.gov/dep/stormwater/bmp_manual/NJ_SWBMP_9.5.pdf
[39] Schrenkel, Jim. *Karst Topography*. Retrieved November 29, 2011. Available at: http://www.dcnr.state.al.us/watchablewildlife/Watchablearticles/karst.cfm

generate more than 90 gallons of water during a 0.25-inch storm event.[40]

Because rain barrels do not require much technical expertise or maintenance, they are a good option for homeowners and relatively small sites, where rainwater can be reused on the property. Collected rain water can either be released slowly to recharge groundwater, or it can be stored for water gardens or other nonpotable uses. As it is returned to groundwater, the collected rain water is also filtered through the soil, improving water quality. Reuse of the water makes it possible for homeowners to save hundreds of gallons of potable water in addition to reducing stormwater runoff.

Rain barrel maintenance is inexpensive and can usually be handled solely by the property owner. Choosing the correct type and location of rain collection systems can make the process much easier.

• Collected rainwater should be accessible and able to be moved to the desired location without moving the container, either through a gravity-fed line, with a watering can, or using a pump system.
• Water should be released slowly onto well-vegetated, stable, and non-eroding soil.
• Rain barrels should be placed on level ground to prevent tipping.
• Rain barrels should be appropriately sized for the expected amount of runoff. Water should not be allowed to sit in the rain barrel for long periods of time. If overflow is expected, an overflow hose or similar mechanism should direct it away from house foundations.

The most important regular maintenance activity for rain barrels is emptying them. This will ensure that there is room in the barrel for future rain events and prevent undesired overflow. Regularly emptying the barrel will also prevent water from becoming stagnant and reduce or eliminate other issues, such as insect or algae problems. Mosquitoes can reproduce in stagnant water in as little as a few days, so it is important that water is not left undisturbed for long periods of time. If mosquitoes become a problem, it is possible to purchase nontoxic water additives to help control it. Mosquito dunks, which can be added to the water to kill mosquito larvae, are inexpensive and nontoxic to humans and animals. Annual cleaning with a nontoxic cleaner, such as vinegar, or putting a few tablespoons of bleach in the water will help to prevent water quality problems and algal growth. Storing the barrel in a dark and shady location will also help to control algal growth, as light and warmth contribute to an optimal environment for algae.[41]

Can Rain Water be Collected in Cold Weather?

If below-freezing temperatures are common in the winter, the water collection system should be disconnected. Empty rain barrels should be stored upside down to prevent water or debris from accumulating inside.

Rain water collection is not appropriate for all sites. The surfacing material on a roof may introduce pollutants to the water that will be damaging for plants. Specific concerns include treated cedar shake roofs, roofs that have asbestos in the material, and gutters that have lead in the paint or solder.[42] In these cases, rain water harvesting is not recommended.

[40] Sands, K. and T. Chapman (2003). *Rain Barrels – Truth or Consequences*. Retrieved December 15, 2011. Available at http://www.epa.gov/owow/NPS/natlstormwater03/32Sands.pdf
[41] Rain Barrel Guide. Retrieved October 11, 2011. Available at http://www.rainbarrelguide.com
[42] Sands, K. and T. Chapman (2003). *Rain Barrels – Truth or Consequences.* Retrieved December 15, 2011.Available at http://www.epa.gov/owow/NPS/natlstormwater03/32Sands.pdf

Permeable Pavement

Permeable or pervious pavement describes paving options that allow for the infiltration of water. Permeable pavement reduces runoff by allowing infiltration, but because runoff is not always treated, areas paved with permeable pavement may include a drainage system as well to help prevent groundwater contamination. Permeable pavement types can be broadly characterized as follows:

Photo courtesy of Lindenhurst Memorial Library, Lindenhurst, NY

- Concrete grid: Concrete pavers that include a gap that can be filled with soil, gravel, or vegetation to allow for infiltration.
- Porous gravel: An alternative to conventional gravel.
- Pervious concrete or asphalt: A type of asphalt made with an aggregate designed to leave significant voids, which allows for the penetration of water.
- Permeable pavers: Permeable or semi-permeable paving stones placed on a permeable aggregate, sometimes with gaps to allow for further infiltration.

If well-maintained, permeable pavement can be effective for more than 30 years and can be less costly over its lifetime than traditional paving methods.[43][44]

To ensure adequate infiltration, it is important to prevent clogging of and damage to the pavement. Measures that can be taken to prevent this include:

- Gardens surrounding the paved area should be planned to prevent sediment running off onto the pavement.
- Permeable pavement should not be installed in areas with trees and large shrubs. Large roots can damage the surface and debris from trees can lead to clogs.
- Weed growth should be prevented and contained with controlled use of herbicides when necessary to prevent cracking of pavements during removal.
- During construction, measures should be taken to limit loose sediment reaching the pavement and to prevent vehicle or foot traffic from compacting sediment into pavement pores.
- Sand should not be used for snow control. When necessary, mechanical snow removal is the most effective for permeable pavements.

Drainage

Ensuring the area on which the permeable pavement is to be located has appropriate drainage is critical to the long-term success of the project. This will likely need to be determined by an engineer. Soil alteration or installation of an underdrain system may be necessary, depending on the nature of the existing soil, the groundwater depth, and the anticipated pollutant level in the absorbed runoff. This is particularly true for permeable pavements that do not filter as well as infiltrate. Cold climates will also have to take into consideration the potential for frost action on saturated soil.

---

[43] Gunderson, J. (2008). Pervious Pavements: New findings about their functionality and performance in cold climates. Stormwater. September 2008. Available at http://www.stormh2o.com/SW/Articles/1071.aspx.

[44] Ibid. 33, p. 33

Periodically, usually about one to two times a year, sediment will need to be removed. Frequency can be determined by monitoring infiltration rates. For permeable pavements, vacuuming with a vacuum sweeper is recommended. For systems that contain infill, such as permeable pavers or concrete grids, the first ½"-1" can be removed and replaced. Clean aggregate can simply be added using a push broom. For cracked or otherwise damaged pavement, the method of repair will vary depending on the type of pavement being used. Porous pavement and concrete can be patched most easily and cost effectively with normal concrete or asphalt; however, if it is a large area that needs patching, this can impact the effectiveness of the system and an engineer should be consulted. Individual pavers are advantageous because the paver can simply be replaced. Porous gravel and similar, less structured pavement systems should be inspected regularly for wear on the material. Uneven compaction could enable the formation of channels and pools, which will prevent infiltration and could create habitat for insect breeding. Regular inspections, particularly shortly after installation and following major rain events, should check for this. Redistribution or addition of fill material where problems are found will help to limit long-term problems and increase water treatment benefits.

Green Roofs


Green roof at the EPA Region 8 office in Denver, CO

A green roof is an area of a building roof or deck structure that is intentionally vegetated to provide a range of environmental benefits. In addition to reducing stormwater runoff levels, green roofs also provide habitat, improve air quality, and reduce urban heat island effect.[45] By providing greater insulation than traditional roof structures, green roofs have been shown to improve the energy efficiency of buildings and reduce cost and energy necessary for heating and cooling. Some studies suggest that the service life of a green roof may be longer than traditional roofing, as water is removed through evapotranspiration and places less stress on the waterproof lining of the roof itself.[46]

Green roofs typically fall into two broad categories, extensive and intensive green roofs. Extensive green roofs have a shallow substrate and low-growing vegetation. They consist of simple vegetation without deep root structures, such as grasses, and require minimal maintenance. Intensive green roofs have a deeper substrate where a range of vegetation can be grown, including shrubs and flowering plants. Sometimes called roof gardens, these intensive green roofs require more regular maintenance and upkeep than their extensive counterparts. Intermediate types which combine features from the two are referred to as semi-intensive.

---

[45] U.S. EPA. *Heat Island Effect*. Retrieved December 2, 2011. Available at: http://www.epa.gov/heatisland/about/index.htm
[46] Low Impact Development Center. *Green Roofs*. Retrieved November 15, 2011. Available at: http://www.lidstormwater.net/greenroofs_cost.htm

Many state and local guidelines as well as numerous international standards exist to provide information and assistance for green roof construction. Internationally, the German standard is referenced by many national and local guides.[47][48] Canada and the United Kingdom have also issued codes for green roofs. Within the U.S., several states as well as EPA have issued guidance on design and maintenance of green roofs.[49] However, even with the existence of many broad standards to provide background information, the design of a green roof must carefully consider the specific site. Overall, a more intensive green roof will provide more benefits and may achieve objectives beyond stormwater management, such as providing wildlife habitat in an urban or suburban setting. However, intensive green roofs are more costly and require significantly more maintenance. Green roofs constructed in arid climates or locations with severe winter weather will also have additional considerations.

The first 12 – 15 months after construction is considered the establishment phase for a green roof. During this time, fertilization, irrigation, and regular weeding should be performed to ensure plant survival. Some contractors will provide a warranty after construction, during which time they will return to the roof to care for vegetation and replace any dead or diseased plants. Beyond the establishment phase, extensive green roofs require significantly less irrigation and in some cases may only require irrigation during drought conditions. These roofs are not maintenance-free, however; they require inspection to check for leaks, blocked drains, dead vegetation, or debris. This should be done semi-annually at a minimum. Intensive green roofs will require more frequent inspections. Because they may include a variety of plants, shrubs, and trees, irrigation may be needed regularly. Many guidelines suggest installing a recycled water or rain water collection system on-site to minimize cost and ensure overall water efficiency of the building.

While other types of green infrastructure have largely been researched and piloted by academic groups, state and local government, and nonprofit coalitions, green roofs are more industry-driven. Low-impact green roof design is an emerging market, with businesses arising to assist with planning, consulting, and construction of green roofs. Many of these companies participate in certification programs such as the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) program, an example of the way in which industry-wide coalitions have begun establishing standards for the industry as green building design becomes more widespread.[50]

[47] Green Roof Technology. Retrieved November 3, 2011. Available at: http://www.greenrooftechnology.com/industry-standards
[48] Tolderlund, L. et al (2010). *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West*. Retrieved October 20, 2011. Available at http://www.epa.gov/region8/greenroof/pdf/GreenRoofsSemiAridAridWest.pdf
[49] Green Roof Organization (2011). *GRO: The Green Roof Code for the United Kingdom*. Retrieved October 14, 2011. Available at http://www.nfrc.co.uk/docs/initiatives/grogreenroofcodeuk2011online.pdf.
[50] U.S. Green Building Council. *USGBC: LEED*. Retrieved December 11, 2011. Available at: http://www.usgbc.org/DisplayPage.aspx?CategoryID=19.

Reference List

Bartsch, L.D. and J.S. Raible. *Bioswales: A Guide to Low-Impact Development Design and Maintenance.* Retrieved October 17, 2011.Available at http://arkansaswater.org/319/pdf/05-1100%20Urban%20Low%20Impact%20Bioswale%20Binder%20Intro.pdf

California Stormwater Quality Association (2003).*New Development and Redevelopment Handbook.* Retrieved December 15, 2011.Available at http://www.cabmphandbooks.com/Documents/Development/Section_6.pdf

City of Eugene, OR (2008). *Stormwater Management Manual.* Retrieved December 15, 2011.Available at http://www.eugeneor.gov/portal/server.pt?open=512&objID=689&PageID=1795&cached=true&mode=2&userID=2

Connecticut Department of Environmental Protection (2004). *2004 Connecticut Stormwater Quality Manual.* Retrieved December 15, 2011. Available at: http://www.ct.gov/dep/cwp/view.asp?a=2721&q=325704&depNav_GID=1654#chapter

Green Roof Organization (2011). *GRO: The Green Roof Code for the United Kingdom.* Retrieved October 14, 2011.Available at http://www.nfrc.co.uk/upload/GRO%20CODE%202011.pdf

Hathaway, H.M. et al (2008). *A Field Study of Green Roof Hydrologic and Water Quality Performance.* Transactions of the American Society of Agricultural and Biological Engineers, Vol. 51, Issue 1: 37-44.

Jurries, D., Oregon Department of Environmental Quality Northwest Region (2003). *Biofilters for Storm Water Discharge Pollutant Removal.* Retrieved September 9, 2011. Available at www.deq.state.or.us/wq/stormwater/docs/nwr/biofilters.pdf

Lowndes, Mary Anne (2004). *Infiltration Basins: Post-Construction Stormwater Management Workshops.* Wisconsin Department of Natural Resources. Retrieved December 9, 2011. Available at: http://dnr.wi.gov/runoff/stormwater/post-constr/Infiltrationbasin.pdf

Massachusetts Low Impact Development Toolkit. *Fact Sheet #1: Bioretention Areas.* Retrieved September 9, 2011.Available at http://www.lowimpactdevelopment.org/raingarden_design/downloads/BioretentionMassachusetts.pdf

Natural Resource Conservation Service (2005). *Bioswales Fact Sheet.* Retrieved September 9, 2011.Available at ftp://ftp-fc.sc.egov.usda.gov/MT/www/technical/water/Bioswale.pdf

New Jersey Department of Environmental Protection (2004). *New Jersey Stormwater Best Practices Manual.* Retrieved November 28, 2011. Available at: http://www.nj.gov/dep/stormwater/bmp_manual/NJ_SWBMP_9.5.pdf

Peck, S. and M. Kuhn (2009). *Design Guidelines for Green Roofs.* Retrieved October 14, 2011.Available at http://www.cmhc.ca/en/inpr/bude/himu/coedar/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=70146

Pennsylvania Department of Environmental Protection (2008). *Pennsylvania Stormwater Management Plan.* Retrieved October 12, 2011. Available at http://www.elibrary.dep.state.pa.us/dsweb/Get/Version-48475/05_Chapter_6.pdf

PA Department of Environmental Protection (2006). *Pennsylvania Stormwater Best Management Practices Manual.* Retrieved December 5, 2011.Available at http://www.stormwaterpa.org/43

Prince George's County, MD Department of Environmental Resources, Environmental Services Division (2009). *Bioretention Manual.* Retrieved October 21, 2011. Available at: http://www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/Bioretention/pdf/Bioretention%20Manual_2009%20Version.pdf

Saiz, S. et al (2006). *Comparative Life Cycle Assessment of Standard and Green Roofs.* Journal of Environmental Science and Technology, 40, 4312-4316.

Sands, K. and T. Chapman (2003). *Rain Barrels – Truth or Consequences.* Retrieved December 15, 2011.Available at http://www.epa.gov/owow/NPS/natlstormwater03/32Sands.pdf

Southeast Michigan Council of Governments (2008). *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers.* Retrieved November 12, 2011. Available at: http://www.semcog.org/uploadedfiles/Programs_and_Projects/Water/Stormwater/LID/lid_manual_intro.pdf

Tennessee Valley Authority. *Riparian Restoration Fact Sheets.* Retrieved October 12, 2011.Available at http://www.tva.gov/river/landandshore/stabilization/

Tjaden, B. and G.M. Weber (1998). *Riparian Forest Buffer Design, Establishment, and Maintenance.* Retrieved October 14, 2011.Available at http://www.riparianbuffers.umd.edu/fact/FS725.html

Tolderlund, L. et al (2010). *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West.* Retrieved October 20, 2011.Available at http://www.epa.gov/region8/greenroof/pdf/GreenRoofsSemiAridAridWest.pdf

University of Florida (2008). *Florida Field Guide to Low Impact Development: Bioswales/Vegetated Swales.* Retrieved September 10, 2011.Available at http://buildgreen.ufl.edu/Fact_sheet_Bioswales_Vegetated_Swales.pdf

Urban Drainage and Flood Control District (2010).*Urban Storm Drainage Criteria Manual Volume 3.* Retrieved September 9, 2011.Available at http://www.udfcd.org/downloads/down_critmanual_volIII.htm

US EPA (2008). *A Handbook of Constructed Wetlands.* Retrieved December 15, 2011.Available at http://water.epa.gov/type/wetlands/restore/upload/1998_04_02_wetlands_pdf_hand.pdf

Vermont Agency of Natural Resources (2002). *The Vermont Stormwater Management Manual.* Retrieved December 15, 2011.Available at http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf

Appendix B

Summary of Green Infrastructure O&M Requirements

	Weeding, Mowing, & Watering	Trash & Debris Removal	Sediment Removal, Draining, & Flushing	Re-grading & Erosion Control	Seasonal Considerations	Plan & Component Replacement	Monitoring & Inspection
Bioretention Cells/Rain Gardens	Necessary on a regular basis; more frequent for manicured cells, in urban areas, or near roads/walkways	Necessary on a regular basis, particularly in urban settings	As-needed; if water is standing for long periods of time	As needed for prevention of channel formation or to repair erosion damage	Snow removal if necessary; monitor to prevent channel formation during snowmelt	Plant replacement as necessary; regular mulching to minimize weed growth	Regular monitoring and inspection to ensure adequate infiltration rate
Wetlands	Seasonal mowing of emergent areas; maintain adequate water levels for habitat; regular removal of weeds/ woody growth	Regular trash and debris removal; debris should be prevented from creating areas of pooled water	Sediment removal at a predetermine d depth of sediment accumulated (6-12”); flushing of inflow/ outflow mechanisms when clogged	As needed for prevention of channel formation	System will be less effective in winter, inflow should be slowed; irrigate during dry periods	As needed; Plant replacement as necessary to maintain 85% vegetation cover of emergent land	Several inspections/y r and following major rain events and snowfalls; Every 2-3 weeks during establishment
Swales	Necessary on an occasional basis for vegetated swales	Removed as quickly as possible to prevent channel blockage	Not necessary unless swale is damaged	Regularly during establishment; as needed subsequently to prevent channel blockage	As needed after high volume winter storms or snowmelt	Plant replacement as necessary if the channel is damaged by erosion	Inspect regularly to ensure water is not pooling and channel is not eroded or damaged
Riparian & Shoreline Restoration	Seasonal mowing; water as necessary during first 3-5 years and dry periods; mulch at tree bases; weeds kept under ~12	Trash should be removed; natural debris can be allowed to accumulate	Prevention of channel formation, as necessary	Prevention of channel formation, as necessary; replanting if erosion destabilizes stream banks	Area should not be disturbed during the spring	Plant replacement as necessary to maintain vegetation cover of about 85% of emergent land	Several inspections/y r and following major rain events; every 2-3 weeks during establishment

	Weeding, Mowing, & Watering	Trash & Debris Removal	Sediment Removal, Draining, & Flushing	Re-grading & Erosion Control	Seasonal Considerations	Plan & Component Replacement	Monitoring & Inspection
Infiltration Basins	Mowing and weeding should be conducted on average once per month	As needed	Necessary any time water is not infiltrating within 72 hours	As needed basis if damage is Incurred during a high volume event	Monitor during snowmelt to ensure infiltration rate is maintained	May be necessary after basin has been in use for several years	Monitor to ensure water infiltrates within 72 hours. Inspect 1-2x yr for contaminant build-up
Rain Barrels/ Cisterns	N/A	Mesh screen can filter out debris	Water should be removed 7-10 days after a rain event	Water should drain onto stable, non-eroding soil	If freezing is common, rain barrels should be disconnected, and stored upside down; mosquito dunk may be needed during summer	As necessary	Periodically ensure water is not running into house foundations or erodible areas
Pervious Pavement	Controlled herbicide as necessary so as not to disturb pavement	Necessary on a regular basis	Vacuuming at a min. of 1-2x/yr and, where present, flushing of drainage system	Sediment should be prevented from eroding directly onto pavement	Mechanical snow removal (plowing); sand not recommended	Damaged pavers replaced with spares; small areas can also be repaired with traditional pavement. Infill, can be replaced with a broom	1-2x a year; no standing water should be on surface after a rain event
Green Roofs	Irrigation and fertilization regularly during establishment; weeding on a regular basis subsequently	Necessary on a regular basis. Critical if debris or dead vegetation creates a fire hazard	Drains should be inspected regularly	N/A	As needed during high snowfall volumes	As needed; frequency will depend on vegetation type and roof design	Regular inspections; ensure compliance with local guidelines and/or building codes

Appendix C

Project Case Studies

Site visits were conducted at five of the 22 green infrastructure projects funded through the ARRA CWSRF Green Project Reserve that were examined for this report. The following case studies from each site visit provide detailed information on the project and its O&M activities. The site visits took place at ARRA GPR projects in:

- Spokane, Washington
- Edmonston, Maryland
- Lenexa, Kansas
- Takoma Park, Maryland
- Nevada City, California

Spokane Urban Runoff Greenways Ecosystem (SURGE) Project
Spokane, WA

Background

The City of Spokane is located on the Spokane River in eastern Washington and has a population of almost 210,000 people. Polluted stormwater is now considered the largest source of pollution in the Spokane River, a tributary of the Columbia River. The City implemented a demonstration program to construct street-side rain gardens to capture, treat, and infiltrate stormwater runoff as close to where it falls as possible. The Spokane Urban Runoff Greenway Ecosystem (SURGE) program retrofits existing urban landscapes around the City using green infrastructure. The SURGE program was conceived prior to ARRA as a way to achieve municipal stormwater management goals while reducing runoff to the Spokane River. To fund SURGE efforts, a stormwater utility was created in 1998 with discrete and separate rates. However, in 2009 ARRA funding was used to sponsor one project as part of the overall SURGE effort. Because of the ARRA funding that was provided, City leaders were able to justify the construction of the West Broadway SURGE project, which received $572,839 in ARRA CWSRF funding, and get the project completed several years earlier than originally planned.

Project Description

The City constructed a network of 37 rain gardens, along with five drainage structures and over 1,200 square yards of pervious sidewalk to intercept stormwater runoff on either side of Broadway Avenue between Elm and Oak Streets. To ensure the success of these rain gardens, native vegetation was chosen for its ability to thrive during the long, dry summers and cold, snowy winters of the inland Northwest. Careful selection of the proper soils to augment the treatment and infiltration process was another specific planning element in the creation of the greenway ecosystem. Each rain garden is comprised of a layering of structural soil, creating a cascading and dynamic system. When capacity is reached, stormwater flows past the gardens and is collected in the combined sanitary sewer system. One of the more innovative aspects of the West Broadway SURGE was the use of the “tree zone” concept, which encourages planners to take into consideration multiple site conditions such as building set-back distances and amounts of available sunlight when selecting the types of trees to be planted. Planners selected five different tree varieties suitable for the existing site conditions.

O&M Structure and Activities

The City of Spokane formalized their O&M process through a City Council ordinance. The stormwater utility's 2007 NPDES permit included the requirement for an ordinance to be in place. An ordinance was passed in April 2010 specifically addressing erosion and sediment stormwater controls.

The West Broadway SURGE, which is located in a commercially zoned part of town and is 100 percent in the public right-of-way, is maintained by the City's stormwater maintenance division. The City's maintenance is divided into four quadrants, with each quadrant assigned a maintenance crew. The Broadway Avenue rain gardens have been added to the annual inspection and cleaning routine for the maintenance crew assigned to the corresponding quadrant. One of their primary functions is to inspect and clean catch basins. There is one catch basin crew that monitors the rain gardens, as well as 30 grates with sumps which were incorporated as part of the rain storm garden infrastructure design.

The O&M annual inspection and cleaning routine undertaken by the City includes the following:

Picture courtesy of City of Spokane, WA

- Grates and catch basins are cleaned and sump areas in the channel between the curb and storm gardens are pumped out
- Trash and debris are removed at entrance and exit pads and curb-outs
- Inspections are conducted of both vegetative plantings and physical structures (concrete curbing, grates, drains) and findings are submitted to the Storm Water District Supervisor
- Sumps are vacuumed when inspections reveal build-up of sediment and debris

O&M activities required during the winter months largely depend on the amount of snowfall. Snow and ice can create conditions that do not allow for infiltration to occur. In response, sewer maintenance crews break, dislodge, and remove ice and excess snowpack as needed. The City does not use sand or salt to maintain roads during the winter months as part of continuing efforts to curtail pollutant loads to the water-quality impaired Spokane River, but instead utilizes a liquid de-icer mix of magnesium chloride to deal with icy road surfaces. During precipitation events and snowmelt that result in pooling and inundation of the rain gardens, the City deploys vactor trucks to pump out excess water on an as-needed basis.

Maintenance crews document their O&M activities for the SURGE projects on their timesheets using specific references to the sewer and stormwater system map pages. They also identify areas in need of follow-up activities and provide brief status reports on the status of the infrastructure. Timesheets are reviewed by the Storm Water District Supervisor.

City representatives indicated that they have not developed a complete plan for green infrastructure asset management because the City has not accumulated enough operational experience to establish parameters for its repair, rehabilitation, or replacement. The City is transitioning to a computerized maintenance management system for tracking operation and maintenance of all of its wastewater and stormwater projects. The new SURGE program numbers have been assigned and input into the system with the hope that this information can be used to establish preventative maintenance controls in the future. Currently, adjacent property owners have primary responsibility for maintenance of vegetation (e.g., plants, flowers and trees) and weed removal. The City acknowledged that maintenance crews may need to perform these functions if property owners fail to do so.

The Greening of Decatur Street
Edmonston, MD

Background

Edmonston is a small town with approximately 1,400 residents. It straddles the Northeast Branch of the Anacostia River and is located 2.5 miles from Washington, D.C. The Anacostia River is one of the nation's most polluted rivers, and stormwater is a large source of pollution. In an effort to address these issues and spur green development, Edmonston partnered with the Chesapeake Bay Trust (CBT) to retrofit one of its busiest streets using green infrastructure. Construction began in November 2009 and was officially completed in November 2010. The project was funded with a $1.1 million CWSRF ARRA loan. EPA Administrator Lisa Jackson was present at the construction launch for this project in fall 2009 and called Decatur Street "one of the greenest streets in the country."[51]

Project Description

The project involved narrowing the two-lane Decatur Street to accommodate eight rain gardens, each with a variety of native grasses, plants, and shrubs. Rainfall is diverted from storm drains into the rain gardens via an opening in the curb. Non-native trees were replaced with native tree species such as oaks, maples, and sycamores. Permeable crosswalks and bike lanes were installed to allow more rainfall to infiltrate the ground. Two types of permeable pavement were used on Decatur Street: interlocking concrete pavers in the crosswalks and porous asphalt in the bike lanes. Town officials considered replacing the sidewalks on Decatur Street with pervious pavement but found it would be cost prohibitive to do so. Instead, the sidewalks were repaved and are now sloped in places to allow water to drain into the rain gardens. The pervious pavement and the rain gardens are expected to absorb approximately 80 percent of the runoff from most rainfall events. Nearby, communities are in the process of implementing green infrastructure projects modeled after Edmonston's with the goal of reducing stormwater runoff and protecting the Anacostia River and ultimately the Chesapeake Bay.

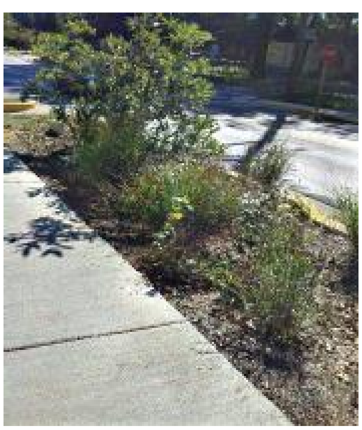

Photo courtesy of the Town of Edmonston, MD

O&M Structure and Activities

This project was designed with maintenance in mind. The design included a variety of hardy native plants, trees, and grasses. Using native vegetation served to reduce the amount of watering necessary for it to thrive. A local nursery did the initial plantings and in the spring of 2011 the Town retained the nursery to inspect the rain gardens,

[51] Wheeler, Timothy (2009). "Remaking Main Street," *The Baltimore Sun*. Retrieved June 22, 2010. Available at: http://www.baltimoresun.com/features/green/bal-md.gr.street25nov25,0,2052577.story

apply fertilizer, and conduct a supplementary planting. In the future Edmonston Public Works maintenance staff will take care of replanting in order to reduce costs. The Town will try to obtain grant funding to purchase new trees, shrubs, and other vegetation when needed. Edmonston has not developed a formal maintenance plan for Decatur Street. However, Public Works Department employees perform daily inspections. Maintenance activities for the rain gardens include daily weeding and debris removal, watering plants during dry periods, and repair of eroded areas on an as-needed basis. Pesticides and herbicides are not used in rain garden maintenance. Each rain garden includes an observation port which permits maintenance personnel to inspect and clean the underdrains, which are inspected weekly and cleaned as needed. When necessary, areas of bare soil surrounding vegetation and trees are mulched and trees are trimmed.

Maintenance activities for the pervious surfaces are limited to daily litter and debris removal. Town officials indicated that the pervious pavement and rain gardens had performed as designed during the first 11months of operation.

Edmonston has two Public Works employees responsible for maintenance of the Decatur Street rain gardens, trees, and pervious pavement as well as maintenance of 14 other rain gardens in the Town. They are also responsible for mowing public fields, trash pick-up from town property, and various other tasks. Their salary is paid out of the Town's general fund; Edmonston does not have a stormwater utility. The Town is planning to hire a part-time employee whose sole responsibility will be maintenance of Decatur Street as well as the other rain gardens on public property.

Central Green Streamway
Lenexa, KS

Background

Lenexa is a mid-sized community of approximately 48,000 residents located 12 miles south of Kansas City, MO. The Central Green Streamway Project is part of Lenexa's new City Center North development, a mixed-use development that will create a new central meeting place for residents with retail, commercial and entertainment venues. The Lenexa City Center is expected to offer about 4.5 million square feet of mixed-use development at build-out. Stormwater runoff from the impervious areas of the development will be channeled to the Central Green Streamway, which will drain 60 acres of land into a discrete drainage area. The project received $1.1 million in ARRA funding. Construction on the project was completed in spring 2011.

Photo courtesy of the City of Lenexa, KS

Project Description

The Central Green Streamway consists of four primary elements: an open space adjacent to 87th Street Parkway under which a large box culvert conveys stormwater into a series of two man-made step pool systems designed to dissipate energy and help oxygenate the water, and finally into a constructed wetland to provide stormwater treatment, and a water re-circulation system to capture and re-use stormwater onsite for irrigation purposes. These improvements are consistent with Lenexa's Rain to Recreation program, whose mission is to reduce flooding, protect environmental and water quality, and provide recreational and educational opportunities.

O&M Structure and Activities

The City's Municipal Services Stormwater Division has primary responsibility for O&M of the stormwater conveyance portion of the project, defined as the main channel that lies between the adjacent paved paths. They have a 10-person crew that monitors both gray and green stormwater infrastructure, with a 4-person crew dedicated to green infrastructure maintenance. Routine maintenance activities include vegetation management and trash pickup. Seasonal maintenance activities include open water management such as cattail removal. Cattails can reduce the hydraulic capacity of the channel and negatively impact the aesthetic of the open water. Standard Operating Procedures (SOPs) have been developed for all green infrastructure maintenance activities, along with fact sheets available on the City's website.

Additional O&M responsibilities are performed by the City's Parks Division and its Streets Division. Parks is responsible for mowing, the irrigation/water reuse system, and trash pickup for all areas not maintained by the Stormwater Division. There are two pump systems for irrigation that will require regular maintenance by Parks. The Streets Division maintains hard surface pathways, performing snow removal and the repair and replacement of surfaces. Because the project was recently constructed, the City has not yet integrated the site into their long-term asset management program. However, they do have expectations for the lifecycle of various components based on experience with similar facilities. Long-term asset management is projected to include the replacement of the irrigation pumps, repair of the stormwater channel due to flood damage, pathway replacement, and pond sediment removal.

The City has a stormwater utility and has developed an operations budget. Ongoing O&M is paid for through stormwater fees based on the amount of impervious area at $7.50/Equivalent Dwelling Unit (EDU). A Capital Development Charge is also assessed on new development projects with property draining to a public facility. The charge can be waived if the developer includes its own 100-year detention or retention facility.

Task	Timeframe
Wet basin sediment removal	Forebay, approximately 5 yrs; Entire basin, approximately 20 years
Wet basin general maintenance	Monthly trash removal, annual plant maintenance, cleaning out wetland outlet structure
Native upland plant weeding and replacement	Monthly during establishment, seasonal thereafter
Native wetland plant weeding and replacement	Monthly during establishment, seasonal thereafter
Irrigation pump/piping	As needed based on manufacturers' recommendations

Maintenance schedule developed by the City of Lenexa and its O&M Plan

Green Roof at Takoma Park Community Center
Takoma Park, MD

Background

The City of Takoma Park has approximately 17,200 residents and shares a border with Washington, D.C. The Community Center was completed in 2006 and houses several City offices. The 4,000 square foot green roof was constructed in 2009 on the roof of the Community Center parking deck, accessible to City employees and the public from the first floor of the building. This was the first green roof to be installed at a municipal facility and the City undertook the project to help reduce stormwater runoff and alleviate leakage from the roof to the parking deck below. The roof has an estimated 20-year service life.

Photo courtesy of Takoma Park, MD

The total project cost was $76,700 and the project received $69,500 in ARRA CWSRF grant funds.
Although the cost for the green roof was almost double the cost of a conventional roof, during site visits City officials indicated they are glad they made the investment because the green roof is much more attractive and user-friendly than a conventional roof. A walking path and sitting areas were incorporated into the design, so the space is attractive and accessible to staff and building visitors.

Project Description

The Takoma Park Community Center's green roof is classified as an extensive green roof. Extensive green roofs have a shallow soil medium, shallowly rooted plants, and comparatively low weight loadings. These types of green roofs typically have minimal maintenance requirements as compared to green roofs with a wider variety of vegetation. The green roof is comprised of a sequence of layers: vegetation rooted in a soil composite, filter fabric, a drain board, a polyisocyanurate insulation layer, a water impermeable membrane, and a concrete roof deck. Vegetation has been established on the roof and has achieved a 50 percent ground cover. It is on track to achieve its target ground cover of 80 percent. Vegetation was established using 3-inch plugs of various Sedum varieties. Sedum was chosen because it is capable of thriving in poor soils and low moisture conditions. The planting medium was composed of a compacted soil composite layer that is a mix of expanded slate and compost material. There are two storm drains on the roof, one is located under the pavers and the other is installed near the center of the roof to collect and drain precipitation that exceeds the infiltrative capacity of the green roof. The project was included in the City's Watershed Implementation Plan (WIP), which describes how it aims to meet the Chesapeake Bay Total Maximum Daily Load (TMDL) allocations. The project is provided as an example of an urban stormwater best management practice that uses environmental site design (ESD), a comprehensive design strategy for maintaining predevelopment runoff characteristics and protecting natural resources by integrating site design, natural hydrology, and smaller controls to capture and treat runoff.

O&M Structure and Activities

The City discussed required maintenance activities with the project designer while the project was still in development. Indications were that maintenance would be minimal. Maintenance activities in the first year following construction included weeding and fungicide application by licensed contractors. Watering was not required during the six-week plant establishment period as there were heavy spring rains at the time of project completion. The City had a 2-year maintenance contract, but since maintenance activities were minimal it did not renew the contract for the second year. Activities were taken over by City maintenance staff, who already maintain numerous stormwater infiltration basins throughout the City. City crews inspect the roof bi-weekly and current maintenance activities include trash and debris removal, quarterly weeding, and removal of dead or dying plants as-needed. Replanting will take place in spring 2012, and in the future on an as-needed basis. The sub-soil layer does not receive any type of preventative maintenance. The roof membrane is covered by a 20-year warranty from the vendor.

Photo courtesy of Takoma Park, MD

The green roof installation did not include an integrated irrigation system. If rainfall is inadequate, supplemental watering would be performed by City maintenance crews through a sprinkler system. During construction of the green roof, the paved walkway leading up to the roof was waterproofed to ensure that water from adjacent surfaces will not permeate the roof membrane and drain mat. The funding for green roof maintenance comes out of Takoma Park's facility maintenance operating budget.

Stormwater Management in the Yuba Watershed
Nevada City, CA

Background

American Rivers' ARRA-funded CWSRF project involved the construction of green infrastructure projects at the Rood Center site in Nevada City, CA. Nevada City is located in a rural area of eastern California and shares a border with Nevada. The Rood Center is a county facility that encompasses several government buildings, including the Nevada County Government Center building, the Madelyn Helling Library, and the Rood Government Center building. This project includes one rain garden and a bioswale, with curb cuts to direct stormwater flow to these features, and a walking path constructed of permeable concrete. In the construction phase, a second rain garden was also added behind the library.

Stormwater runoff at the Rood Center empties into the Oregon Ravine, which flows through Nevada City to Deer Creek, a tributary of the Yuba River. The Yuba River was named by American Rivers as one of the top ten most endangered rivers in the United States in 2011 because it is one of the few remaining habitats in California for the threatened Chinook salmon.[52] Additionally, the South fork of the Yuba River has been designated as a Wild and Scenic River. Working with American Rivers, Nevada County decided to undertake this water quality improvement project as a part of a greater

[52] American Rivers. *Hydropower Dams Endangering Local Fish Species.* Retrieved November 30, 2011. Available at: http://www.americanrivers.org/our-work/protecting-rivers/endangered-rivers/endangered-yuba.html

effort to green the area and to protect and improve water quality. Using $375,000 in ARRA funds, they were able to implement stormwater control techniques to reduce pollution reaching the Yuba River. Construction took place during the summer of 2010 and was complete by the fall of 2010.

O&M Structure and Activities

An O&M manual for the project was prepared by a contractor, Integrated Environmental Restoration Services, in August 2010. This manual outlines maintenance needs for the various project components in terms of irrigation, infiltration rates, seed replacement, and drainage structures. As a joint project between American Rivers and Nevada County, the maintenance plans were designed collaboratively. However, long-term maintenance responsibilities will be undertaken by Nevada County.

Nevada County and American Rivers have indicated that these green infrastructure systems have been designed to require minimal maintenance. To that end, native plants were selected that would thrive even in California's dry summers. Maintenance needs and responsibilities have been incorporated into the existing maintenance budget and folded into the responsibilities of ground maintenance crews.

Maintenance for the rain gardens and bioswales is expected to be minimal during the first year or two, while many plants are still establishing and some are still young enough that it is difficult to differentiate desirable species from weeds. Up to this point, maintenance has generally included irrigation, trash removal, and weeding when necessary. In general, about one hour has been dedicated to these O&M activities per month. The maintenance needs are expected to increase as plants get larger and weeding must take place more frequently. Additionally, it is expected that after about five years some plants will begin to die off and will require replacement.

The permeable concrete walkway aspect of the project was also designed to entail minimal maintenance. Because the path is slightly raised, sediment accumulation and clogging are not expected to be a problem. At this time, no regular maintenance schedule exists for this component of the project. However, one section of the pavement has heaved, and a plan to replace this section has been established.

In addition to regular O&M of the system, monitoring of infiltration rates and water quality improvements were undertaken for one year by the South Yuba River Citizens League. Between October 2010 and March 2011, monitoring took place during the first measurable storm event and seven subsequent events. These studies tested water quality influent and effluent for pollutant concentrations, total dissolved solids, and total suspended solids. Overall sediment was found to be reduced in runoff, as were concentrations of several pollutants. The bioswale and rain garden were found to be particularly effective at reducing lead concentrations, which initially were well above regulatory action levels.

Photo courtesy of American Rivers

Appendix D

Green Infrastructure Planning Tools

There are several planning tools that are available online that can assist water quality managers and their teams in finding the right opportunities for implementing green infrastructure into the existing built environment as well as in new developments. The Water Environment Research Foundation (WERF) is a non-profit organization that funds and manages water quality research through a diverse set of partnerships with municipal utilities, corporations, academia, industry, and the federal government. In cooperation with the EPA, WERF has developed a set of modeling tools to help water quality managers make decisions regarding the integration of green infrastructure practices called the LID Whole Life Cost Models. These models are a comprehensive set of spreadsheet tools that allow the user to examine the capital costs and ongoing maintenance costs of various types of green infrastructure to help them determine the estimated costs over the useful life of a project. There are spreadsheet models for each of the following green infrastructure types:

- Swales
- Permeable Pavement
- Green Roofs
- Cisterns
- Residential rain gardens
- Curb-contained bioretention cells
- In-curb planter vaults

Each of the spreadsheet models require user data inputs for parametric cost estimations, watershed characteristics, facility storage volume capacity, and design and maintenance options to generate automatic outputs and calculations for estimated capital and whole-life costs, including maintenance costs. The tool also generates graphs representing the present value cost over time along with cumulative discounted costs and discounted costs over time.

The O&M costs that were incorporated into the model were developed through a series of interviews with stormwater management agencies and extensive literature review. However, because of the high variability in available data, engineering estimates were used. Furthermore, it was not generally possible to correlate the influence of project size on O&M costs due to the presence of more significant factors potentially influencing the level of maintenance required for a particular site, such as its proximity to the nearest pollution source. This was the case for the swale and permeable pavement models, which do not account for relationships between size and O&M costs. However, the models for green roofs, curb-contained bioretention, and rain gardens scale O&M costs relative to the surface area of the installation. The WERF LID Whole Life Cost Models allow the user to anticipate O&M costs associated with routine maintenance activities, corrective and unplanned-for activities at their respective frequency intervals, and a breakdown of activities according to whether they are considered high, medium, or low in maintenance demand.

The entire suite of planning tools and the user's guide to the WERF LID Whole Life Cost Models are available at:
http://www.werf.org/c/KnowledgeAreas/Stormwater/ProductsToolsnonWERF/BMP_and_LID_Whole_Li.aspx

The EPA Green Infrastructure website features a page that includes a wide selection of available predictive modeling tools and calculators that may be used to help users simulate watershed hydrology and rainfall-runoff, make informed decisions on pollutant load reductions, and predict the anticipated benefits and cost savings associated with the inclusion of green infrastructure BMPs into their projects. Some of these tools can also allow the user to compare the inspection and maintenance costs of different stormwater BMP systems. This web page (http://water.epa.gov/infrastructure/greeninfrastructure/gi_modelingtools.cfm) contains links to the following planning tools:

- Casey Trees "Green Build-Out" Model
- System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model
- The Center for Neighborhood Technology Green Values® Calculator
- Virginia Runoff Reduction Method

Clean Water
State Revolving Fund

Office of Water March 2013 PA-832-R-12-007