Cost of Maintaining Green Infrastructure

Edited by

Jane Clary
Holly Piza, P.E.

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Multiple municipalities provided cost data or references useful for development of this report. See Table 2-1 for a complete list of these contacts. MWIC appreciates the time and effort of the municipal staff who were willing to compile and share data for use in this report. MWIC would also like to acknowledge the following individuals who shared information used in this report:

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CHAPTER 1
Introduction

Green infrastructure (GI), also known as green stormwater infrastructure (GSI), uses processes found in the natural environment to manage stormwater, with the end goal of reducing stormwater runoff volumes and corresponding pollutant loading from urban surfaces. These processes include storing, filtering, infiltrating, evaporating, and evapotranspiring stormwater while sequestering pollutants in the facility. Interactions among soil, vegetation, and water are key to managing stormwater with GI. GI practices can be implemented at a range of scales, such as regional (watershed scale), sub-regional (neighborhood scale), and widely distributed (smaller scale and single-lot scale). Distributed-scale GI practices have become more common, especially in high-density urban areas, where space is limited and the need for runoff volume reduction is great, such as in communities addressing combined sewer overflows (CSOs). Like traditional stormwater best management practices (BMPs) or control measures (SCMs), GI practices require maintenance to function effectively. Distributed GI practices have now been in place in some communities long enough to evaluate the comprehensive (whole-life) costs of implementation and maintenance.

In 2015, the Environmental and Water Resources Institute's (EWRI's) Municipal Water Infrastructure Council (MWIC) established two task committees to support municipalities implementing GI approaches. The committees are focused on these topics: (1) Comprehensive Costs of Implementing and Maintaining GI and (2) Sustaining Commitments to Municipal Stormwater System Infrastructure. This report has been completed to support the objectives of these two task committees. The primary focus of this report is compiling data to support whole-life cost estimates for a suite of small-scale distributed GI technologies, with particular emphasis on maintenance costs. The approach originally envisioned for this report involved contacting and surveying municipalities and organizations across the country regarding operation of their GI programs. Technologies of most interest included permeable pavements (parking lots, green streets, green alleys), infiltration/filtering technologies (rain gardens, street-side and bump-out planters, green gutters, tree trenches and pits, infiltration basins and trenches, media filters), and green building technologies (green roofs, green walls, planter boxes, disconnecting downspouts, rainwater harvesting). Information on more traditional technologies such as wetlands and detention ponds were also compiled when available. As part of this effort, information was pursued for the "hard costs" (initial construction, operation and maintenance [O&M], and ultimate rehabilitation) and "soft costs" (planning, engineering, and administration) of small-scale distributed GI technologies.

During the course of the survey effort, it became apparent that GI maintenance cost data were relatively limited. Thus, two additional tasks were integrated into this report: a summary of currently available GI cost tools (Chapter 6) and recommendations for improved reporting of GI maintenance cost data (Chapter 7).

CHAPTER 2
Survey Approach

The initial GI survey supporting this report focused on a list of national contacts identified by the MWIC GI task committees, with the list naturally expanding as the survey progressed. Prior to beginning the survey, a list of survey questions was developed to guide interviews with contacts, as summarized in the Appendix. When possible, this list of questions was sent to the contact point ahead of a scheduled phone conversation. Examples of information requested included GI program structure, types and frequency of maintenance activities, maintenance program costs, data tracking approach, and budgeting. Table 2-1 summarizes the contacts that were made and identifies whether GI cost data were provided or might be provided in the future as programs mature. Some communities did not respond or did not have data to share.

The highest-priority information requested was O&M data for GI. Survey discussions included questions about personnel that perform O&M (number of people, expertise, hours, pay rate); number, size, and age of facilities maintained; equipment use and cost; maintenance procedures (proactive, routine, and restorative); pretreatment practices (including street sweeping and other structural pretreatment); and any other costs outside of personnel and equipment. Other data of interest, although lower in priority, included other general stormwater program information such as annual budgets, stormwater master plans, software and other tools associated with stormwater needs assessment, training programs, and recommended design components to facilitate maintenance.

Although some municipalities were able to provide detailed maintenance cost information, most entities either had programs that were too new to be able to provide a useful data set or had programs that were so small that maintenance cost data for GI was rolled into a budget where it had not been tracked separately for each installation. In other cases, the local government may have had the information in some form, but did not have the resources to retrieve the requested information.

Table 2-1. Agencies and Points of Contact

City	*Agency name*	*Contact name*	*Data status*
Citrus Heights, CA	City of Citrus Heights	Stephanie Cawder	Contacted, no data
Daly City, CA	Daly City (Green Streets and Parking Lots Design Guidebook)	Patrick Sweetland	Contacted, no data
Los Angeles, CA	L.A. County Department of Public Works, Sun Valley Watershed	Richard Gomez	Contacted, no data provided
Los Angeles, CA	Environment LA, Green Streets	Wing Tam	Contacted, no data
San Diego, CA	San Diego Transportation and Stormwater Department	Chris Gascon, Jim Nabong	Future data source
San Francisco, CA	San Francisco Public Utilities Commission, Watershed Management and Stormwater Planning Program	Sarah Bloom, Michael Adamow, Kerry Rubin	Future data source
San Mateo, CA	City of San Mateo	Jocelyn Walker	Contacted, no data
San Mateo County, CA	San Mateo Countywide Water Pollution Prevention Program	Matthew Fabry	Contacted, no data
Aurora, CO	City of Aurora	Jill Piatt-Kemper, Joe McCreary	Contacted, GI data not available
Denver, CO	Denver Public Works	Saeed Farahmandi, Darren Mollendor	Maintenance cost data for GI not available
Fort Collins, CO	City of Fort Collins	Basil Hamden	Data provided

Arapahoe County, CO	Southeast Metro Stormwater Authority	Brad Cox	Data provided for extended detention basins
Denver (area), CO	Urban Drainage and Flood Control District	Holly Piza	Data provided
Washington, DC	DC Water	Bethany Bezak	Future data source
Atlanta, GA	Atlanta Department of Watershed Management	Cory Rayburn	Future data source
Iowa (statewide)	Iowa Economic Development Authority	Jeff Geertz and others	Data provided
Lenexa, KS	City of Lenexa	Ted Semadini	Future data source (data available)
Saint Paul, MN	Capitol Region Watershed District, Water Resource Improvement Projects	Mark Doneux	Data provided
Charlotte, NC	Charlotte-Mecklenburg Stormwater Services (CMSWS), Capital Improvement Projects	Steve Jadlocki	Data provided
Mecklenburg County, NC	Mecklenburg County	David Woodie	Contacted (see data for CMSWS)
New York, NY	NYC Department of Environmental Protection	Shane Ojar	Future data source / new program
Cleveland, OH	Northeast Ohio Regional Sewer District, Project Clean Lake	Matthew Scharver, Frank Greenland	Data provided

(Continued)

Table 2-1. Agencies and Points of Contact (Continued)

City	*Agency name*	*Contact name*	*Data status*
Portland, OR	Portland Bureau of Environmental Services, Office of Sustainable Development	Michelle Juon, Emily Hauth, Henry Stevens	Data provided
Lancaster, PA	City of Lancaster Stormwater Bureau	Ruth Hocker	Future data source
Philadelphia, PA	Philadelphia Water Department, Green City, Clean Waters Program	Gerald Bright	Future data source
Pittsburgh, PA	3 Rivers Wet Weather	Beth Dutton	Future data source
Austin, TX	Austin, Watershed Protection Department, Stormwater Treatment Program	Lee Sherman	Data provided
Seattle, WA	Seattle Public Utilities	Tracy Tackett, Drena Donofrio	Data provided
Tacoma, WA	Totem Ocean Trailer Express Terminal	Rand Lymangrover	Contacted, maintenance data available but not cost data
Milwaukee, WI	Milwaukee Metropolitan Sewage District, Greenseams Program	Lisa Sasso	Future data source

Note: Other cities were also contacted, but did not respond during the study timeframe. They included Chicago (Department of Water Management), Buffalo (Sewer Authority), and these California cities: Belmont, Brisbane, Burlingame, Pacifica, San Bruno, and San Carlos

CHAPTER 3

Survey Results for Communities Providing Maintenance Cost Data

3.1 OVERVIEW OF FINDINGS

Ideally, the outcome of the survey would have been a well-populated spreadsheet or database of consistently itemized cost data for individual BMP installations along with basic facility information (e.g., facility surface area, treated volume, tributary area). As the survey evolved, it became apparent that this type of information was not readily attainable. As a result, the survey and report focused on documenting available O&M data for bioretention, for which the most national data were available, and summarizing other qualitative findings about various GI programs.

Table 3-1 provides a summary of the information that was obtained for bioretention facilities after the originally reported costs were normalized both temporally and spatially. Two adjustments to the originally reported costs were applied to normalize the data sets for this summary. First, the average annual construction cost index from the *Engineering News-Record* was applied to older data to enable comparison of the cost data in 2015 dollars. Second, the RS Means City Cost Index - Site Work and Landscaping (2015) for Installation was used to normalize cost relative to national average cost based on the 30 City Average Index.[1]

Figure 3-1 provides a summary of findings for bioretention facilities, normalized to facility surface area in 2015 dollars, and Figure 3-2 provides the average annual maintenance cost per facility in 2015 dollars. (Note: not all data sources provided data suitable for both graphs.) The median annual maintenance cost for

[1]RS Means provides three city cost indexes: materials (Mat), installation (Inst), and total (Tot). Because routine GI maintenance cost for bioretention is most closely tied to labor cost, Inst was selected as the index to normalize maintenance cost. Tot is likely a better index for construction cost and major rehabilitation cost.

Table 3-1. Summary of GI Maintenance Cost Estimates for Bioretention from 2016 Survey

					Normalized cost estimate		
Data source	Orig. year	BMP ID	Location		Area (sq ft)	$ per BMP per year	$ per sq ft per year
Capitol Region WD	2009	Ar-McK	Saint Paul	MN	769	$431	$ 0.56
Capitol Region WD	2010	Ar-McK	Saint Paul	MN	769	$765	$ 1.00
Capitol Region WD	2009	Asbury N	Saint Paul	MN	945	$383	$ 0.41
Capitol Region WD	2010	Asbury N	Saint Paul	MN	945	$903	$ 0.96
Capitol Region WD	2009	Asbury S	Saint Paul	MN	1,719	$713	$ 0.41
Capitol Region WD	2010	Asbury S	Saint Paul	MN	1,719	$997	$ 0.58
Capitol Region WD	2009	Fr-McK	Saint Paul	MN	2,076	$939	$ 0.45
Capitol Region WD	2010	Fr-McK	Saint Paul	MN	2,076	$890	$ 0.43
Capitol Region WD	2009	Ham-Mid	Saint Paul	MN	10,756	$456	$ 0.04
Capitol Region WD	2010	Ham-Mid	Saint Paul	MN	10,756	$2,332	$ 0.22
Capitol Region WD	2009	Pascal C	Saint Paul	MN	534	$792	$ 1.48
Capitol Region WD	2010	Pascal C	Saint Paul	MN	534	$906	$ 1.70
Capitol Region WD	2009	Pascal N	Saint Paul	MN	357	$469	$ 1.31
Capitol Region WD	2010	Pascal N	Saint Paul	MN	357	$224	$ 0.63
Capitol Region WD	2009	Pascal S	Saint Paul	MN	706	$582	$ 0.82
Capitol Region WD	2010	Pascal S	Saint Paul	MN	706	$348	$ 0.49
Charlotte-Meck.	2006	Freedom	Charlotte	NC	6,300	$180	$ 0.03
Charlotte-Meck.	2007	Freedom	Charlotte	NC	6,300	$1,911	$ 0.30
Charlotte-Meck.	2009	Freedom	Charlotte	NC	6,300	$1,319	$ 0.21
Charlotte-Meck.	2010	Freedom	Charlotte	NC	6,300	$306	$ 0.05

Charlotte-Meck.	2012	Park Rd	Charlotte	NC	3,500	$2,182	$ 0.62
Charlotte-Meck.	2007	Bruns Ave	Charlotte	NC	2,500	$2,662	$ 1.06
Charlotte-Meck.	2008	Bruns Ave	Charlotte	NC	2,500	$3,330	$ 1.33
Charlotte-Meck.	2009	Bruns Ave	Charlotte	NC	2,500	$7,814	$ 3.13
Charlotte-Meck.	2010	Bruns Ave	Charlotte	NC	2,500	$1,412	$ 0.56
Charlotte-Meck.	2012	Bruns Ave	Charlotte	NC	2,500	$332	$ 0.13
Charlotte-Meck.	2015	Bruns Ave	Charlotte	NC	2,500	$1,276	$ 0.51
City of Fort Collins	2015	FC-BR	Fort Collins	CO	3,150	$1,139	$ 0.36
BMPDB/UDFCD	2011	UDFCD Iris	Lakewood	CO	1,135	$271	$ 0.24
BMPDB/ Del. DOT	2004	I-95 BR	Newark	DE	1,683	$3,875	$ 2.30
BMPDB/Johnson County, KS	2009	OP Rec	Overland Park	KS	1,673	$1,853	$ 1.11
BMP Database/UVA	2000	MHS	Charlottesville	VA	1,076	$721	$ 0.67
Seattle Public Utilities	2015	SPUC	Seattle	WA	–	–	$ 2.11
Portland BES	2015	BES	Portland	OR	–	$436	$ 1.54
City of Plymouth	2015	Sm-Plym	Plymouth	MN	–	$250	–
City of Plymouth	2015	Lg-Plym	Plymouth	MN	–	$333	–
City of Austin	2015	Austin	Austin	TX	–	$2,140	$ 0.13
Kansas City	2015	KC	Kansas City	KS	–	–	$ 1.58

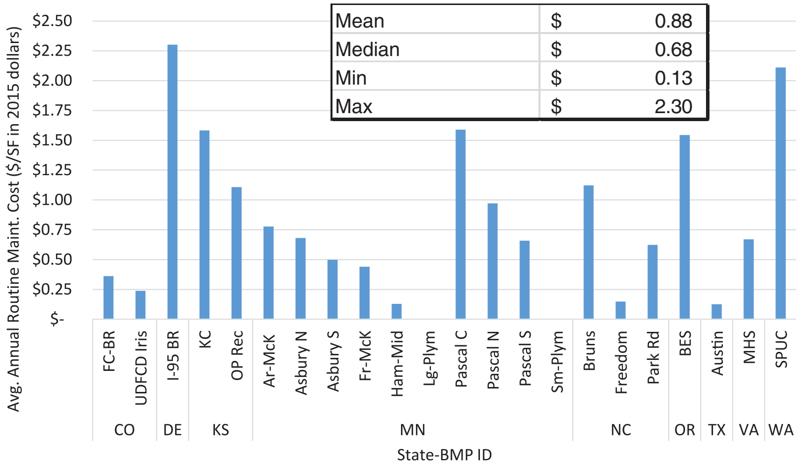

Figure 3-1. Range of Average Annual Bioretention Maintenance Costs (2015 dollars per square foot)

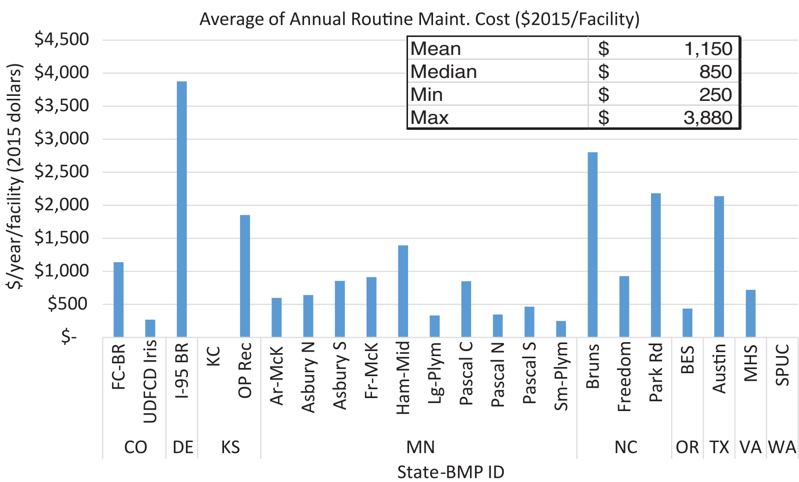

Figure 3-2. Range of Total Annual Bioretention Maintenance Costs (per facility, 2015 dollars)

bioretention was $0.68/sq ft, with a range of $0.13 to $2.30/sq ft; however, the authors believe the costs are significantly affected by differences in activities included in the cost estimate among local governments. Another constraint is that a minimum maintenance cost is incurred regardless of facility size; conversely, economies of scale are expected for larger facilities, so there are some limitations of a normalized cost per square foot approach. For this reason, the total average annual reported maintenance cost is also provided, with a median cost of $850/y (range: \$250–3,880/y). Also, from review of annual maintenance data provided by some data providers, year-to-year cost can vary substantially. For example, at one facility in Charlotte, NC, the annual maintenance cost varied from approximately \$330 to over \$3,300,[2] depending on whether mulch and plant replacement were completed.

For the nine bioretention sites that reported capital cost, the annual maintenance cost averaged 6% of the capital cost of the facility. Maintenance cost as a percentage of capital cost is commonly estimated at 5–7% (USEPA 1999).

Results from the survey also generally affirmed several previously developed maintenance cost algorithms, such as the EPA's 2016 update of the National Stormwater Calculator and the Urban Drainage and Flood Control District's BMP-REALCOST tool, as shown in Figure 3-3. These cost tools are discussed further in Chapter 6. Figure 3-3 suggests that economies of scale may occur for larger facilities; therefore, maintenance cost tools may overestimate maintenance costs for these facilities. More data would be needed on larger facilities to confirm this observation.

Although the quantitative data from the survey were limited, much was learned regarding factors affecting maintenance costs as well as why it is difficult to summarize GI maintenance costs. Here are some of the key observations.

- Many municipalities do not currently use a centralized database (or spreadsheet) to collect and track maintenance cost information. Smaller municipalities rarely had a full-time staff person dedicated to managing GI, so there was often a lack of clarity about how cost was tracked.
- For communities that use asset management systems and work order systems, these tools may not be linked well to each other or they may be linked in a manner that is not conducive to running a database query to extract this information.
- GI facilities may be maintained at different frequencies for sites that are "community education" features. These features may be cleaned/weeded/maintained at least in part by teams of volunteers, which may result in lower maintenance costs for certain facilities. In cities where GI is used as a more significant component of stormwater infrastructure, this was less common.
- For facilities that are professionally maintained under a contract, it is easier to track maintenance costs; however, these contracts may not be itemized by activity or BMP—they may be tracked as a monthly or annual cost, which makes it difficult to relate costs back to specific BMP types. Tracking of costs for sites maintained by in-house staff may be difficult to summarize if multiple departments are responsible for the maintenance (e.g., a combination of public works and parks staff perform maintenance).
- When compiling data from multiple sources, labor hours needed to maintain a facility is a more easily transferable metric than labor cost to maintain a facility.

[2]Values reported are normalized nationally and reported in 2015 dollars.

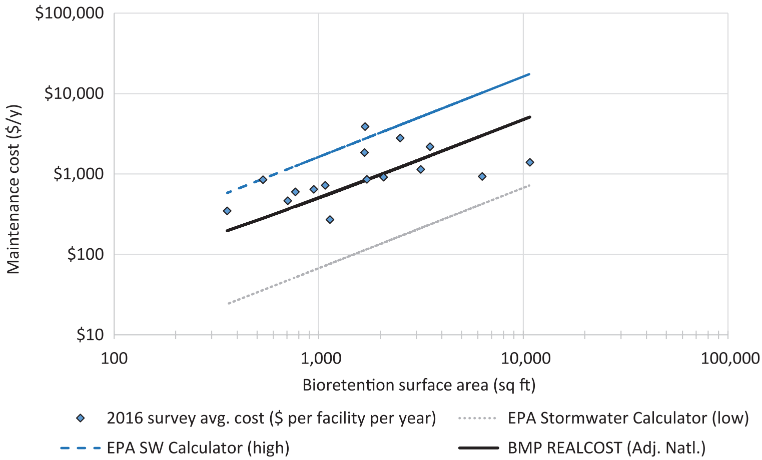

Figure 3-3. Comparison of Average Annual Maintenance Cost for Bioretention to Selected Maintenance Cost Estimating Tools

- Local regulations/specifications on GI (both installation and O&M, or lack thereof) influence the frequency and type of maintenance performed, inspections, and major restorative maintenance. Some municipalities have better-developed expectations for regular proactive maintenance than others.
- To compile and compare costs nationally for multiple BMPs, it is important to have common basic design metrics, such as water quality volume treated or facility surface area footprint (as two basic examples). Facility metadata and maintenance requirements/cost are often disconnected from maintenance costs or stored separately.

3.2 FINDINGS FOR INDIVIDUAL DATA PROVIDERS

Additional detail on survey results for 10 communities providing maintenance cost information in varying formats is provided below, followed (in Chapter 4) by a summary of information obtained from communities who may be able to provide cost data in the future.

3.2.1 Capitol Region Watershed District, MN

Capitol Region Watershed District (CRWD) in Saint Paul, MN, owns and maintains 18 stormwater BMPs in the Como Lake subwatershed and 12 in the Central Corridor Light Rail Transit project area. The BMPs in the Como Lake subwatershed were built as part of the multi-jurisdictional Arlington Pascal Stormwater Improvement Project, with the intention of reducing regional flooding and improving lake water quality. GI associated with this project includes eight rain gardens. (One stormwater detention pond is also part of this project.)

As part of a comprehensive maintenance program, all the rain gardens and the stormwater detention pond are routinely inspected and maintained by CRWD, with some assistance from volunteers and government entities. The maintenance activities at these rain gardens were extensively documented in *BMP Performance and Cost-Benefit Analysis of the Arlington Pascal Stormwater Improvement Project* (CRWD 2012). Section 3.1 of this report relies heavily on the CRWD data, as shown in Table 3-1 and Figures 3-1 and 3-2.

The Arlington Pascal Stormwater Improvement Project is the only project for which CRWD has quantified maintenance costs on individual GI BMPs. Total annual O&M costs were calculated for each BMP for 2009–10 based on the total cost of labor, equipment and materials, and contract services. Labor costs incorporated time and associated costs spent maintaining the BMPs by CRWD staff and by both staff and volunteers. Equipment and materials costs include tools and items used to maintain the BMPs. To maintain an accurate record of O&M activities, CRWD used electronic field forms to document all BMP site visits. Each site visit recorded the BMP being inspected or maintained, the inspection or maintenance activity occurring, time on and off site, and staff present on site.

3.2.2 Northeast Ohio Regional Sewer District

In 2011, a consent decree was filed between Northeast Ohio Regional Sewer District (NEORSD) and the U.S. Environmental Protection Agency (USEPA) addressing measures that will be taken by NEORSD to address CSOs over the next 25 years. One central component of the consent decree requires NEORSD to develop a plan to implement GI that uses "plant/soil systems, permeable pavement, or stormwater harvest and reuse, to store, infiltrate, or evapotranspire stormwater and reduce flows to the combined sewer system (CSS). Green infrastructure may include, but is not limited to, bioretention and extended detention wetland areas as well as green roofs and cisterns." The consent decree gives NEORSD eight years to meet a goal of capturing 44 million gallons of CSO water annually in addition to existing gray infrastructure. Figure 3-4 indicates that NEORSD anticipates that GI construction should be completed by the middle of 2019, at which point maintenance cost data could begin to be collected.

Although full implementation of NEORSD's GI program has yet to come to fruition, it was able to provide detailed O&M data from 2015 on two GI projects, the Green Ambassador Slavic Village Demonstration Project and the University Circle Demonstration Project, each maintained by an outside contractor. The Slavic Village Demonstration Project includes three surface rain gardens on land-bank/vacant properties in the Slavic Village neighborhood as stormwater control measures. The University Circle Demonstration Project includes underground storm chambers and pervious interlocking concrete pavers.

The watershed team leader, Matthew Scharver, provided a detailed cost spreadsheet for each project, including construction costs, total maintenance area, and types of maintenance performed. Each item has a budgeted contract amount along with costs incurred to date on a monthly basis. The GI portion of

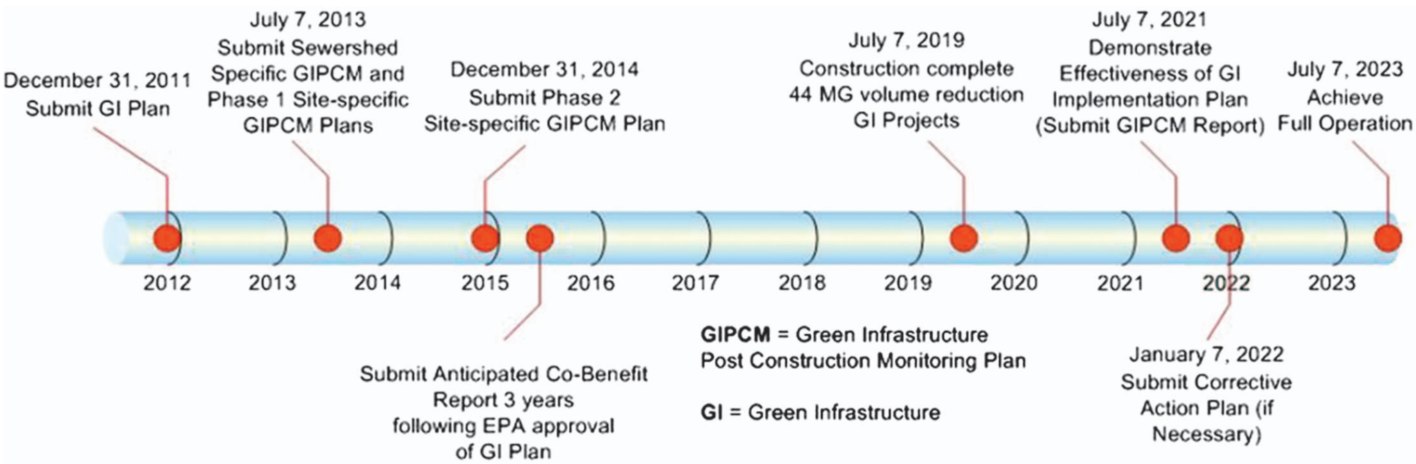

Figure 3-4. GI Cost Data Collection Schedule for NEORSD
Source: NEORSD 2012

both projects only began in August 2015; therefore, data were limited to a few months. Here is more information on the two projects.

The Green Ambassador Slavic Village Demonstration Project is in the Broadway-Slavic Village neighborhood of the city of Cleveland. It is designed to manage 200,000 gallons of stormwater in a typical year. The primary design includes three bioretention basins, which receive surface runoff from adjacent land and streets via curb cuts. Construction was completed in November 2014. The project repurposes vacant, land-banked parcels adjacent to the Morgana Run bike trail and adds a neighborhood amenity that the district will permanently maintain (NEOSD 2015). The project includes 46,800 sq ft of maintained demonstration project area for an 8-month contract cost of $35,350. Extrapolated to a one-year contract, this is approximately $1.13/sq ft maintained. (This estimate falls within the range of costs discussed in Chapter 3.) Budgeted activities include sediment and debris removal and disposal, trash removal and disposal, mowing and vegetation maintenance (weeding and pruning), mulch installation and replacement, weeding Japanese knotweed (a separate line item), and fall cleanup. The cost estimate also includes contingency items for tree, shrub, and plant replacement, pesticide and herbicide application, and replacement of topsoil, seed, and mulch. A non-specific allowance for other items is also included in the budget.

The University Circle Infrastructure Demonstration Project is in the University Circle neighborhood, close to downtown Cleveland. It is designed to manage 1 million gallons of stormwater in a typical year. GI at this site will reduce CSO volume by an estimated 400,000 gallons pre-gray and 100,000 gallons post-gray. The primary design includes underground storm chambers and pervious interlocking concrete pavers, taking advantage of existing sandy soils, in a hotel parking lot (Figure 3-5). Construction was completed in July 2013. District monitoring shows no runoff from the site up to the 100-year storm event (NEOSD 2015). This project

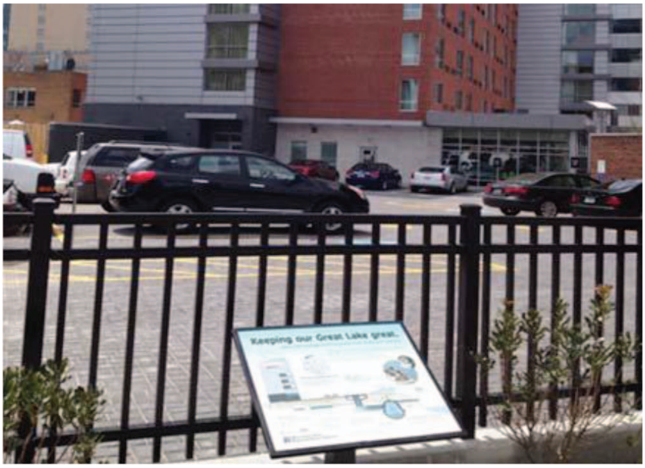

Figure 3-5. Permeable pavers at University Circle
Source: NEORSD (2015)

includes 21,394 sq ft of permeable pavers and related underground features, at a contract budget of $8,760 for an eight-month period. This is approximately $0.61/sq ft of paved area annually. Budgeted activities include permeable pavement spot cleaning, joint aggregate replenishment, and fall cleanup.

3.2.3 Iowa Economic Development Authority

The Iowa Green Streets Criteria of the Iowa Economic Development Authority (IEDA) require many IEDA funding recipients to use GI practices to infiltrate, evapotranspire, capture, and reuse the water quality volume (runoff from up to 1.25 inches of rain per 24 hours) to maintain or restore natural hydrologies (IEDA 2013). The GI practices are required to follow applicable design specifications in the Iowa Stormwater Management Manual (IDNR 2008). Typical rain garden sizes vary from site to site, in accordance with the water quality volume design. Most are smaller than 1,000 sq ft, with many in the 250–500 sq ft range (personal communication, Jeff Geertz, IEDA). Several Iowa cities and the neighboring city of Plymouth, MN, were able to provide maintenance cost data, as described below.

The city of Plymouth requests maintenance proposals each year for 28 rain gardens in the city. The rain gardens are inspected and maintained 8 to 10 times per year. With the exception of one rain garden that is much larger than the others, the 2014–15 annual cost was $330 per rain garden. The larger garden was $400. As the rain gardens have matured, the maintenance cost has decreased over time.

The city of Davenport also had maintenance information available for two overall categories, native prairie maintenance and vegetated stormwater BMP maintenance, with data summarized in Table 3-2.

3.2.4 City of Austin Watershed Protection Department

Austin, TX, is in the process of synthesizing installation and maintenance cost records for multiple GI projects throughout the city. For this report, the city shared cost data for both construction (including first year's maintenance) and maintenance costs (personal communication, Lee Sherman). Public Works maintains 18 rain gardens that include small rain gardens clustered in five areas, typically associated with traffic calming, roundabouts, and intersections. The maintenance cost assumptions are summarized in Table 3-3. Contract-related requirements for contractors maintaining rain gardens (in 2015 dollars) included

- Unit cost estimate: $0.08/sq ft, but with a minimum flat rate—most of the Austin rain gardens are so small that a per foot price would be less than the flat fee minimum
- Flat fee of $250 per visit for inspection, even if no work is done
- Flat fee of $500 per visit with trash removal only—additional charges apply for plant replacement
- A minimum of seven visits per year, required under maintenance contracts.

Table 3-2. Iowa Economic Development Authority GI

City	*BMP type/description*	*Maintenance activity*	*Maintenance frequency*	*Annual maintenance cost*
Dubuque, IA (John Deinst)	Green Alley, typically 300 ft × 12 ft pavers (approx. 200+ alleys being converted to paver systems)	Wash/flush pavers[1]	Yearly	\$0.28/sq ft
Plymouth, MN (Ben Scharenbroich)	28 rain gardens	Inspect/ maintain	8–10 per year	\$330 per rain garden, \$400 for largest rain garden
Davenport, IA (Brian Stineman)	Native prairie maintenance, vegetated stormwater BMP maintenance	Vegetation management	4 per season for prairie, 7 per season for stormwater BMPs	\$757/acre for prairie maintenance, \$5.41/sq ft for native planting maintenance in BMPs; 2014 total \$27,164

[1]The International Concrete Pavement Institute does not recommend pressure washing permeable interlocking concrete pavement

Table 3-3. City of Austin Annual Rain Garden Maintenance Costs (2015 dollars)

	Annual Cost Per Activity Type			
Site visit type	*Inspection/ visit only*	*Trash removal*	*Inspection of 18 sites*	*Trash removal for 18 sites*
Single site	$1,750	$3,500	$31,500	$63,000
Grouped maintenance (7 "pond flags")	n/a	n/a	$12,250	$24,500

Note: Cost of plant replacement not included

Each of the rain gardens has been assessed regarding maintenance needs. Some of the maintenance observations included

- Sediment buildup
- Weeds
- Bare patches
- Leaf litter, sticks, and trash
- Erosion
- Need for additional plants or replacement of grasses.

A spreadsheet is used to track inspections, with the following information recorded (along with internal site IDs):

- Date visited
- Presence of weeds/invasives
- Plants blocking street or sidewalk
- Vegetative bare areas over 10 sq ft
- Vegetation blocking inflow/outflow structure
- Dead vegetation
- Excessive vegetation height
- Functionality (at least two inspections per year)
- Mulch or topsoil washed away or redistributed
- Sediment or debris deposited at the inlet
- Sediment over 3 inches deep in bottom of basin
- Infiltrates in less than 48 hours?
- Is litter or debris present?
- Photos taken and time-stamped

- Additional notes or comments
- Work completed.

3.2.5 Portland Bureau of Environmental Services

The city of Portland, OR, is well known for its extensive GI program, implemented in part to assist the city with CSO challenges. Many small-scale distributed GI facilities are installed throughout the city as part of its Sustainable Stormwater Management Program. Figure 3-6 provides a map of lined and unlined green streets facilities in CSO and non-CSO areas. Types of GI include rain gardens and bump-out planters in the Green Streets Program, green roofs as part of the Portland Ecoroofs program, and other innovative GI through the Innovative Wet Weather Program.

At the time that this survey was completed, the city was in the process of significant enhancements to its asset management system (Hansen), which will be a useful source of maintenance cost data in the future. In lieu of BMP-specific maintenance cost records, the city shared a general cost estimate of approximately \$1.55/sq ft as the annual unit maintenance cost for green streets facilities in their long-term maintenance program. (This estimate applies after the two-year startup or "warranty" period.) This cost estimate is "fully loaded," including city staff,

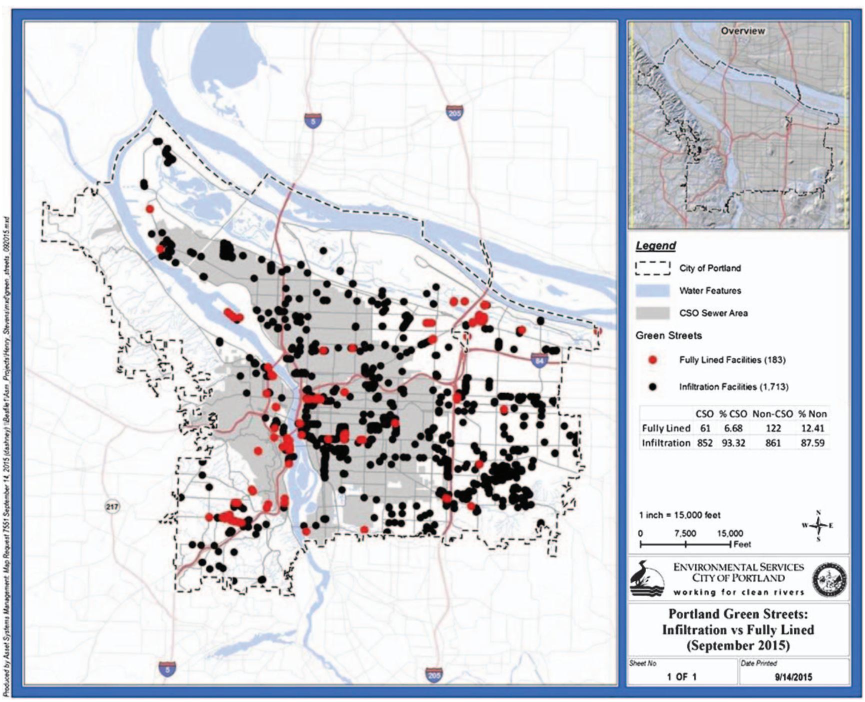

Figure 3-6. City of Portland's Green Streets Program Facilities
Source: Courtesy of Henry Stevens, City of Portland

contract staff, and some summer watering during the third summer after construction. During extreme summer weather it's sometimes necessary to extend watering through the third summer of the life of a facility. To put Portland's cost estimates in context, their green streets facilities are relatively compact (with a small footprint relative to their catchment), and most do not have pretreatment for sediment prior to flows entering the facility (personal communication, Henry Stevens and Michelle Juon).

Maintenance activities and frequencies for Portland's Green Streets program generally include

- Routine maintenance (three or four times per year):
  - Inlet cleaning and sediment removal
  - Leaf and trash removal
  - Weeding
- Periodic maintenance (as needed):
  - Tree and shrub pruning
  - Irrigation
- Repair:
  - Replanting (plant coverage or health below service level)
  - Structural damage.

The city noted that many factors affect GI maintenance cost, with examples including

- Year-to-year hydrologic variation (wet vs. dry years)
- Exposure (full sun or shade)
- De-icing practices
- Design features such as sediment forebay, lined or unlined, underdrain, etc.
- Proximity to heavy traffic.

The city recently transitioned to an integrated asset management system that enables facility data to be linked with work order data without requiring duplicate data entry. Given the breadth of Portland's GI program, it remains an important source of GI maintenance cost data.

3.2.6 Seattle Public Utilities

SPU has a well-known Green Stormwater Infrastructure Program, with many GSI installations and well-developed design, installation, and maintenance guidance. Addressing CSOs is a key driver for the SPU program. SPU shared information on their overall program budget, which is summarized in Table 3-4. This budget is an overall program-level estimate. Most of the practices maintained are roadside bio-retention facilities, but additional practices are also included in this program budget.

Table 3-4. Seattle Public Utilities GSI Budget for 2014 with Projections through 2020

GSI O&M asset management budget	*2014*[b]	*2015*[b]	*2016*[d]	*2017*[d]	*2018*[d]	*2019*[d]	*2020*[d]
Square footage totals at top of swale	202,900	226,500	295,712	339,912	407,312	474,712	497,712
Voluntary roadside rain garden in right-of-way[c]	0	500	1,000	2,500	4,000	5,000	6,000
Total square footage maintained	202,900	226,500	295,712	339,912	407,312	474,712	497,712
Cost estimate components							
Vegetation management estimated	\$438,870	\$506,950	\$529,017	\$613,498	\$700,018	\$760,208	\$881,861
DWW LOB[a] crews/contractor estimated	\$62,739	\$70,055	\$51,059	\$89,575	\$97,872	\$106,800	\$130,123
Additional allowance for unexpected damage, est. at \$0.26/sq ft	\$54,158	\$61,698	\$81,097	\$94,376	\$101,240	\$119,804	\$131,197
Total cost (in 2014 dollars without inflation adjustment)	\$555,767	\$638,703	\$661,173	\$797,449	\$899,130	\$986,812	\$1,143,181
Estimated cost per sq ft	\$2.47	\$2.55	\$1.96	\$2.07	\$1.96	\$1.83	\$2.03

[a]Seattle Public Utilities Drainage and Wastewater Line of Business (DWW LOB) plans, builds, operates and maintains over 2,100 miles of conveyance facilities that capture/convey urban runoff and/or wastewater to treatment facilities or local waterbodies

[b]2014 dollars

[c]Voluntary, not maintained by SPU

[d]For the 2016–20 estimates, increase planning costs from 2014 dollars as follows:

Vegetation management estimated (0–3 y) from \$2.21/sq ft to \$2.30/sq ft

Vegetation management estimated (4+ y) from \$1.68/sq ft to \$1.75/sq ft

For individual practices, Drena Donofrio (SPU) provided the following additional explanation of maintenance costs for curbside bioretention practices:

- For new bioretention installations (first three years), SPU budgeted $2.21/sq ft (in 2014 dollars) to allow for vegetation management, including irrigation costs. (As of 2016, $2.30/sq ft was being used.) The watering requirement and method are important components of the cost during establishment of the installation. Depending on the site, the actual cost could be four times this estimate, particularly when considering watering method, access to water, permitting requirements, and cost of water.
- After three years, the cost estimate falls to approximately $1.68/sq ft in 2014 dollars for vegetation-related maintenance, if watering is not required. (As of 2016, $1.75/sq ft is being used.) SPU is working on a refined estimate for other maintenance-related components related to underground facility components and pipes. Currently, an allowance of $0.31/sq ft is used for budgeting purposes for other maintenance requirements, such as jetting the underdrain and removing sediment.
- Use of average estimates for maintenance costs has some limitations because the actual cost of maintenance at any particular site can vary substantially. Some of the factors that affect the cost include
  - Surrounding land use—industrial/commercial areas where a lot of trash pickup is required can require more time, whereas installations in residential areas, where homeowners help keep the facility clean and attractive, can be lower.
  - Microclimate—facilities in shaded areas require less weeding, and facilities with a lot of sun exposure may require ongoing or periodic watering.
  - Year-to-year weather variations such as drought also affect maintenance costs, particularly in terms of water requirements.
  - Random, unforeseen issues such as dumping of recreational vehicle (RV) waste tanks into bioretention cells or homeless-related issues can cause unexpected costs.
  - Cost per square foot as a cost estimating tool has some limitations for smaller facilities (less than 500 sq ft). These facilities will still have a minimum maintenance cost of about $5,000 per year.

In July 2015, SPU and King County Wastewater completed the *Green Stormwater Infrastructure Manual Volume V: Operations & Maintenance*, which provides guidance and some standard procedures for operations and maintenance, including annual inspections of GSI facilities under the responsibility of SPU or King County Wastewater Treatment Division (WTD) along streets in city of Seattle rights-of-way, particularly focused on the public works aspect of bioretention facilities. The manual integrates guidance from several sources in the Pacific Northwest, such as the Washington State Department of

Ecology's *Western Washington Low Impact Development (LID) Operations and Maintenance* (2013) and the Portland Bureau of Environmental Services' *City of Portland Green Street Stewards Guide* (2012).

SPU categorizes its maintenance guidance according to

- Establishment-period maintenance;
- Routine maintenance, which includes the standard maintenance tasks that take place once the establishment period is completed; or
- Major corrective action and long-term maintenance, which covers emergency conditions and extreme events, major repairs, and infrequent, long-term maintenance activities.

Volume V of the GSI manual provides guidance for integrating maintenance activities into asset management and work order databases. The manual recognizes the importance of routine, streamlined tracking of facilities using the agency's asset management program, with maintenance information tied to facility tracking numbers. Guidance for reporting activities in the asset management system is clearly defined. Maintenance activities are classified according to categories defined in the manual, as described in Table 3-5. Inspection and maintenance activities are classified according to the categories in Table 3-6. The manual also provides a detailed checklist according to these categories to facilitate inspection and tracking of maintenance activities. Consistent terminology and spatial location data are needed for various asset management programs (e.g., MAXIMO) to be used most effectively. Use of the asset management program to track maintenance activities and costs should also lead to more robust cost data in the future.

Another noteworthy aspect of this manual is that it provides guidelines for professional (public works) versus volunteer maintenance for roadside bioretention facilities.

Professional crews

- Check for proper function
- Remove sediment
- Clear curb openings and top of overflow drain
- Remove trash and debris
- Remove weeds
- Water plants if necessary
- Prune, replace or remove trees or plants if necessary.

Citizens/volunteers

- Remove trash and debris
- Clear curb openings and top of overflow drain
- Push aside accumulated sediment

- Water during dry periods
- Remove weeds.

3.2.7 Charlotte-Mecklenburg Stormwater Services

CMSS manages many GI installations and provided cost data for several of their facilities (Table 3-7). These facilities included three bioretention sites, three wetlands, and two stormwater detention ponds.

Table 3-5. Seattle Public Utilities Maintenance Activity Classifications

Classification	*Description*
Reactive maintenance (RM)	Includes work required (perceived or actual) because something else happened to trigger the need for the work; otherwise it would not have been done.
Predictive maintenance (PDM)	Inspection and Maintenance PM program: Time- or meter-based inspections detecting the possibility of failure/condition assessment activities. Inspection may include cleaning or other minor maintenance. (proactive)
Preventive maintenance (PM)	Maintenance PM program: Time- or meter-based maintenance. (proactive)
Condition based maintenance (CBM)	Maintenance performed as a direct result of inspections determining that an asset's condition has declined and/or that performance no longer meets defined minimum SPU standards. Includes opportunistic work performed to ensure assets are maintained to minimum SPU standards. (proactive)
Project (PROJ)	Intentional, pre-planned improvements, enhancements, new installations. Includes routine rehab.
Overhead (OH)	Use of O&M resources for activities outside of their normal functions such as training, equipment maintenance/cleaning, meetings, personal protective equipment issues, etc.
Demand work (DM)	Performed in response to external or internal request to perform non-repair/maintenance work, QA/QC review, studies, new customer installations not associated with a project, etc.

Table 3-6. Seattle Public Utilities GSI Facility Maintenance Components

Component	*Description*
Facility footprint	Soils, check dams, weirs, vertical walls, extents
Inlet/outlets/pipes: surface	Grates, trash racks, drain curb cuts, pre-settling cells, direct connection catch basins, inlet pipes, outlet pipes
Inlet/outlets/pipes: subsurface	Maintenance holes, catch basins, inlets, underdrains, liners, storm drains, service drains
Vegetation	Cell bottom, cell slope, step-out zone, crossings, intersection zones, trees, and other related tasks
Mulch	Compost, arborist wood chip, coarse bark, and other materials
Watering	Hand or truck watering, quick couplers and automated irrigation
Deep infiltration (over 6 ft)	Underground injection control, upstream maintenance holes, pit drains, drilled drains, and other facilities
Permeable pavement facility	Pavements in streets and alleys that perform GSI management functions including underdrains and check dams
Hardscape	Special surface treatment on streets, sidewalks, curb edge cells, paved crossings, step-out zones, facility-related traffic control signage
Specialty elements	Facility may include elements such as interpretive signage, street furnishings such as benches, trash cans, mutt mitts stations, or public art

3.2.8 City of Fort Collins, CO

Fort Collins maintains several GI facilities and provided maintenance activities and cost records, which are summarized in Table 3-8. These facilities include a permeable interlocking concrete paver (PICP) site, a bioretention site, and a tree planter site. Notes supporting the cost data are also provided.

Basil Hamden of the city of Fort Collins was interviewed regarding maintenance costs and experiences at the city's GI sites. He noted that it is hard to generalize costs because the level of maintenance depends on tributary area conditions (high urban use, or low use), economies of scale for maintenance

Table 3-7. Charlotte-Mecklenburg Bioretention Maintenance Summary

Freedom Dr. LID Bioretention (9 cells) (Placed in Service FY 2007)		
Date	*Description*	*Cost*
9/20/06	Invasive plant and weed removal.	$263
11/8/06	Invasive plant and weed removal.	$450
4/30/07	Invasive plant and weed removal.	$285
5/9/07	Replenished mulch (w/ double-hammered hardwood mulch) in all cells. Est $5000	$5,000
8/1/07	Due to drought conditions and extreme heat, TAD watered all cells on 4 dates in August 2007. Est $1200	$1,200
7/19/07	Weed removal and tree pruning.	$480
9/27/07	Weed removal (lots of nutgrass) and tree pruning.	$599
11/7/07	Weed removal and tree pruning.	$190
5/12/09 & 5/14/09	Removed trash and sediment and replenished mulch with double-hammered hardwood mulch.	$5,488
8/27/09	Weed removal (nutgrass) from lowest cells.	$270
10/18/10	Invasive plant management and trash removal. Invoice 47463.	$1,373
	Total	$15,598
	Maint. Event Avg. Cost	$1,418
	Avg. Annual Cost	$3,899
	Watershed Treated (Acres)	3.20
	Avg. Annual Cost/Acre Treated	$1,219

Park Road Park LID Bioretention (Placed in Service FY 2011)		
Date	*Description*	*Cost*
2/28/12	Invasive plant and weed removal, mulch replacement	$1,150
	Total	$1,150
	Maint. Event Avg. Cost	$1,150
	Avg. Annual Cost	$1,150
	Watershed Treated (Acres)	2.20
	Avg. Annual Cost/Acre Treated	$523

Bruns Avenue LID Bioretention (Placed in Service FY 2006)		
Date	*Description*	*Cost*
10/11/07-10/16/07	Mulch replacement and complete plant removal. Time and cost included with wetland work as documented below. Est $1200 (25%)	$1,200
7/7/08-7/10/08	Weed removal. Time and cost included with Bruns Wetland. Est $260	$260
8/14/08-8/18/08	Weed removal. Time and cost included with Bruns Wetland. Est $275	$275
12/4/08	Berm tilling, 11 CY planting mix, and 136 SY seeding (w/ grass) and straw.	$1,031
5/11/09	Mulch replacement, complete plant removal, mowing and seeding of berm.	$2,894
7/7/09-7/14/09	Blanket spraying of entire bioretention area. Cost included with Bruns Wetland. Est $612	$612

(Continued)

Table 3-7. Charlotte-Mecklenburg Bioretention Maintenance Summary (Continued)

Bruns Avenue LID Bioretention (Placed in Service FY 2006)		
Date	*Description*	*Cost*
9/5/09-9/8/09	Blanket spraying of entire bioretention area (only patches of vegetation present). Cost included with Bruns Wetland. Est $285	$285
6/16/10 & 6/18/10	Hand pulled weeds from bioretention area and mowed berm between bioretention area and wetland. Time and cost included with Bruns Wetland. Est $350	$350
9/13/10 & 9/14/10	Applied herbicide to all vegetation within bioretention area and mowed berm around bioretention area. Cost included with Bruns Wetland. Est $353	$353
10/12/12	Seed bioretention with fescue to establish ground cover. Est $175 (25% of bill)	$175
6/4/15 & 6/5/15	IPM, mowing and clearing. Est $724.75 (25% of bill)	$725
	Total	$8,159
	Maint. Event Avg. Cost	$742
	Avg. Annual Cost	$1,360
	Watershed Treated (Acres)	1.00
	Avg. Annual Cost/Acre Treated	$1,360

Table 3-8. GI Maintenance Cost for City of Fort Collins, CO, Cost Year 2015

BMP name	*BMP surface area (sq ft)*	*Routine annual maintenance cost*	*Rehabilitation cost*
Permeable Pavers	10,000	$2,700	$15,000
Bioretention	~3,150	$900	
Tree Planter		$260	

outings (e.g., is the maintenance mobilization/disposal allocated among multiple practices or one practice?), and maintenance history (if not historically well maintained, then maintenance costs are higher). Specific conditions and assumptions related to the cost estimates in Table 3-8 include

Permeable pavement site

- $0.25/sq ft to vacuum and rechip (for 10,000 sq ft site); however, there are economies of scale with a lower cost ($/sq ft) on larger sites, and a higher cost on smaller sites.
- Inspect twice a year, in spring and fall.
- Maintain once a year (depending on site).
- On one site, maintenance was deferred, resulting in a rehabilitation-level major maintenance cost of $15,000–10,000 or $1.50/sq ft. This involved taking the pavers out, washing them, removing/replacing top layer of base course, and putting the pavers back in place.
- Cost of maintenance may be lower in cities like Denver; mobilizing the contractor to Fort Collins costs extra.

Bioretention

- Assumes facility has a well-designed forebay for ease of maintenance.
- Forebay shoveling once a month (April–October) and plant maintenance by Parks Dept. (~1 hour at site).
- Once a year, replace plants and some gravel pack/surface; 6 hrs labor (@$20/hr) × $50–100 per plant × 2–3 plants (typically shrubs); replace gravel (~$100/y).
- Areas affected by salt/de-icing typically require some plant replacement every year.
- Watershed conditions, sizing, and design affect the maintenance requirements.

Tree grate/tree filter

- Once a year, remove grate and replace mulch, 2 staff × 1 hr (@$20/hr) to replace mulch, plus travel time to get the mulch and dispose of mulch (totaling around 4 hrs).

- Pre-mixed mulch for a tree planter costs ~$50 per planter, excluding delivery. For multiple units close together, delivery cost (~$100) can be split.

3.2.9 City of Lenexa, KS

Lenexa's stormwater maintenance crews care for GI owned by the city, including rain gardens, bioretention cells, swales, green roofs, and other structures. Over 80 facilities are maintained by the city. Lenexa's public and privately owned BMPs are regularly inspected by the city during construction and periodically after completion to verify performance. The city works with owners and maintenance contractors to ensure that once BMPs are installed, they are kept in working order to provide the intended water protection and flood control benefits. Lenexa stormwater managers establish expectations for each facility in terms of both design (intended function) and public expectations for appearance. The city creates a document for each BMP that is updated each year to define and record actions and expectations for the BMP. This includes a list of tasks needed to maintain each BMP, recognizing that different BMPs have different maintenance needs.

Lenexa is an example of a city that is effectively linking its asset management system (Lucity) and maintenance records in a manner that enables development of normalized BMP cost estimates. BMPs are tracked through Lucity, and maintenance activities are recorded through a work order system that can be viewed as a "dashboard" by stormwater maintenance crew members. Lenexa has found that developing schedules of maintenance activities generally enables routine maintenance, as opposed to emergency maintenance (Ted Semadini, APWA 2013 webinar handout).

3.2.10 Urban Drainage and Flood Control District, Denver, CO

UDFCD was established by the Colorado legislature in 1969 to assist local governments in the Denver metropolitan area with multi-jurisdictional drainage and flood control problems. The district covers 1,608 square miles and includes Denver, parts of the six surrounding counties, and 32 incorporated cities and towns.

GI facilities are relatively new in the Denver metro area, relative to other BMP types. UDFCD provided data for one facility in Lakewood, CO, the 21st and Iris bioretention site (Table 3-9). This site is maintained and monitored for performance by UDFCD. UDFCD submits performance data for this facility to the International Stormwater BMP Database (http://www.bmpdatabase.org) annually.

UDFCD also provided maintenance data for four permeable pavement sites (Table 3-10). Specific maintenance records for the Denver Wastewater Building and Lakewood Shops installations are summarized in Table 3-11 and Table 3-12, respectively. UDFCD has also monitored these sites for performance. For the Lakewood Shops Slotted Concrete site, it is noteworthy that this BMP is a retrofit that replaced the pervious concrete installation. The old wearing course was

Table 3-9. 21st and Iris Bioretention Site Costs, Denver, CO

Facility construction cost and selected design data	*Construction cost*
Facility construction cost	$112,984
Monitoring features cost	$12,551
Facility cost (without monitoring features)	$100,433

Design/watershed characteristics	*Design data*	*Unit construction cost*	
Total surface area (sq ft)	406	$247.37	per sq ft
Total volume (cu ft)	1960	$51.24	per cu ft (of WQCV)*
Tributary watershed area (acres)	3.4	$29,366	per acre tributary
Tributary impervious area (acres)	2.8	$35,869	per impervious acre
Additional features	Includes underdrain. Located in residential area. Vegetated with native grasses.		

Maintenance activities	*Frequency*	*Notes*
Clean out sediment forebay	Once per year	2 workers, 45 minutes to drive to site, remove sediment, and dispose
Mow native grasses	Once per year	
Estimated annual maintenance cost	$270/yr	

*WQCV = Water Quality Capture Volume

Table 3-10. UDFCD-Sponsored Permeable Pavement Sites in International BMP Database

Test site name	*BMP name*	*Pavement type*	*Surface area (sq ft)*	*Date installed*	*Total facility costs*
Denver Wastewater Building	PICP*	Interlocking concrete block pavers	1,970	5/12/2008	$34,375
Denver Wastewater Building	Porous Asphalt	Porous asphalt	1,970	6/12/2008	$36,966
Lakewood Shops	Lakewood PC	Porous concrete	2,000	4/12/2005	$20,750
Lakewood Shops	Slotted Concrete	Slotted concrete (retrofit)	2,000	11/2/2012	$15,544

*PICP = Permeable Interlocking Concrete Pavers

Note: At time of submittal to BMP Database, routine maintenance costs were estimated at $200/y, with a $7,000 estimate of corrective maintenance costs

Table 3-11. UDFCD Permeable Pavement Maintenance Activities and Costs at Denver Wastewater

Date	*Denver WW BMP site*	*Expense*	*Maintenance notes*
7/1/2009	Porous asphalt and PICP*	n/a	Denver Street Maintenance vacuumed the permeable pavement with a broom vacuum. Approximately 6 passes were completed covering the entire area. Water was used with the sweeper truck.
10/16/2009	Porous asphalt	n/a	Street sweeper with pressure washer.
6/21/2010	Porous asphalt and PICP*	n/a	Only porous asphalt was pressure washed. Broom sweeper was then used on both pavements. It removed about 1/4″ of gravel from the PICP side. Porous asphalt was pressure washed again, moving perpendicular to the original direction.
11/19/2010	Porous asphalt	n/a	Fire hose used to open up the porous asphalt BMP. Process took about 1 hour.
5/18/2011	Porous asphalt and PICP*	n/a	Regenerative air vacuum using water.
7/21/2011	Porous asphalt	n/a	Vacuum truck and pressure washer.
6/29/2012	Porous Asphalt	n/a	A Johnson 650 vacuum truck (vacuum sweeper) was used to clean the surface, followed by a pressure washer and then again by the vacuum truck. The vacuum truck was operated for about 45 minutes.
3/22/2013	Porous asphalt and PICP*	\$80 (contractor)	Regenerative air vacuum. Initially, site had excess loose debris. Vacuuming removed most of the gravel. Deeper, more compacted soil/sediment was barely touched. Multiple passes were made. Cost also includes work at Lakewood.

(Continued)

Table 3-11. UDFCD Permeable Pavement Maintenance Activities and Costs at Denver Wastewater (Continued)

Date	*Denver WW BMP site*	*Expense*	*Maintenance notes*
5/3/2014	PICP*	$950 (contractor)	Contractor used a "hydro jet" to loosen caked-on sediment, followed by a wand nozzle. Two different wand nozzles were used. The inlet was blocked and a vacuum hose suctioned sediment-laden water for the duration of the maintenance. (Note: UDFCD recommends vacuuming and not pressure washing PICP.)
5/5/2014	PICP*	$1,340	Contractor had 2 tons of 3/8" washed aggregate delivered and used brooms and shovels to move it into the pavers.
7/15/2014	Porous asphalt (partial)	(no-cost demo)	Demonstration to unclog porous asphalt used a vacuum/pressure washing unit and water filtering system. Pressure washing used angled nozzles at 3,500 psi. The perimeter of the unit was vacuumed as it was pressure washed. Water was heated to 185°. Future infiltration tests determined this method could be used to improve infiltration in clogged porous asphalt.

*PICP = Permeable Interlocking Concrete Pavers

Table 3-12. UDFCD Permeable Pavement Maintenance Activities and Costs at Lakewood Shops

Date	*Lakewood Shops BMP Site*	*Expense*	*Maintenance Notes*
5/24/2012	Pervious Concrete	(no-cost demo)	Contractor brought an Elgin Megawind (vacuum sweeper) to the site to determine whether the pavement could be restored. Cleaning area was limited to a small test section. The area was vacuumed twice. When this sweeper was proven ineffective, the contractor pressure washed the area, followed by two more passes of the vacuum truck. This revised procedure made a noticeable difference in observed infiltration.
9/28/2012	Slotted Concrete	n/a	The slotted concrete was cleaned with a wet/dry vacuum. First the slots were cleared with a screwdriver, then each slot was wetted and vacuumed.
3/22/2013	Pervious Concrete	$80	Vacuuming was performed using a Stewart-Amos Galaxy R-6 regenerative air sweeper. A minimum of three passes were made over the pavement. While the sweeper was in service, it sprayed a light coating of water to limit dust generation.
8/25/2014	Slotted Concrete	(no-cost demo)	Vacuumed pavement with a walk-behind ProVac SP Little Wonder. Also tried hot power wash/vacuum, without success. Pressure washing used angled nozzles at 3,500 psi. The perimeter of the unit was vacuumed as it was pressure washed. Water was heated to 185°.

replaced with conventional concrete, and a pattern of full-depth cuts was made in the surface with a circular blade. Maintenance and available performance data for these sites were also submitted to the International Stormwater BMP Database.

3.2.11 Proprietary Manufactured Devices

A variety of manufactured devices are now available that can be categorized as GI practices, particularly proprietary tree planters, bioretention units (e.g., Filterra), proprietary infiltration systems, and permeable pavement systems. An inventory of these practices was not completed for this report. However, an interview with Jim Lenhart,[3] chief technology officer–stormwater with Contech, yielded the following insights on maintenance costs, based on his contacts with maintenance providers.

- Economies of scale for maintenance activities can significantly affect cost. For example, if a contractor is maintaining multiple facilities on the same day, the cost per facility will likely be lower than if multiple single trips are required.
- Maintenance contractors may be reluctant to disclose maintenance cost estimates in surveys such as this one, as costs can be highly site-specific and prices are competitive.
- Maintenance cost data can be difficult to compare due to differences in the individual cost components. For example, some communities may only record the labor time needed to conduct maintenance at the facility and materials, whereas others may include administrative scheduling, travel, and amortization of equipment, among other expenses.
- Materials disposal costs can vary, depending on whether the removed material can be disposed of at a municipal landfill or testing and potential disposal at a hazardous waste landfill is required.
- Conditions in a watershed can affect the level of maintenance needed, as can design and installation conditions. For example, a properly sized and installed facility with pretreatment may have a lower maintenance cost than an undersized facility without a sediment forebay. Similarly, BMPs in high-use or disturbed areas may require more frequent maintenance than facilities in lower-impact areas.

[3]Many of these observations were consistent with an older paper by Lenhart and Harbaugh (2000).

CHAPTER 4

Potential Future Maintenance Cost Data Sources

Many municipalities are still in the early stages of gathering maintenance cost data, and some indicated that they will have cost data available within the next year or two. Other municipalities have data in some form already, but the time required to retrieve the data prevented them from sharing information in response to this survey. Also, some entities do not share data for specific facilities due to information security policies. Some programs were willing to share overall program costs, but the information was not in a format conducive to parsing out costs for maintenance for individual BMP types or locations. The remainder of this chapter describes survey results for municipalities that did not provide specific maintenance cost data in response to this survey, but who may be sources in the future, given the substantial investments they are making in GI programs.

4.1 PHILADELPHIA WATER DEPARTMENT

PWD is in the fifth year of its 25-year Green City, Clean Waters program, which is driven by CSO requirements under consent agreements with both the EPA and the Pennsylvania Department of Environmental Protection. PWD will have implemented approximately 750 "greened acres" by the end of FY16. PWD has worked with schools, developers, and water customers to incorporate and maintain GI in their properties through stormwater easements, grant agreements, maintenance agreements, and similar arrangements. Projects are located on public and private land and are funded through a variety of public and private sources (City of Philadelphia 2016).

At this point in the GSI Maintenance Program's development, PWD is actively maintaining over 500 individual systems, with another 250 expected in the 2016 fiscal year. Routine surface and subsurface maintenance is implemented mainly through contracted labor. PWD also works with other city agencies and partners to support maintenance of their GSI facilities and create additional pathways to use workforce development to assist in maintenance efforts. PWD has completed its Fiscal Year 2015 Year in Review, which detailed labor and material costs at each system/project site, aggregated to BMP category (basin, rain garden, green roof, infiltration trench, etc.). The summary also categorized the expenditures into surface costs ("landscaping," pretreatment device maintenance, and material removal/disposal) and subsurface maintenance costs (inlet cleaning, pipe inspection, and jet-rodding). These cost data may become available to the public in the future, but were not yet available at the time this report was completed (personal communication, Gerald Bright). Cost data included in the public summary are expected to include system-level cost data associated with labor and materials (by BMP type, by season, by subcontractor, etc.), as well as program-level data and analyses that include contract and procurement costs.

PWD has implemented CityWorks to track service requests as well as work orders for system maintenance and repair generated in the field units. It has replaced the individual systems that were previously used by each unit to track infrastructure repairs, replacements, and related projects. This has streamlined work, consolidated data in one location, and reduced duplication of efforts between units. Recent improvements to CityWorks included linking with the street opening permit system, inclusion of maintenance of green stormwater infrastructure, and testing of the application on tablets (City of Philadelphia 2016).

4.2 NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION

New York City's GI program is a multiagency effort led by the Department of Environmental Protection (DEP). DEP and agency partners design, construct, and maintain a variety of GI practices, including green roofs, rain gardens, and right-of-way bioswales on city-owned property such as streets, sidewalks, schools, and public housing. DEP is currently building GI in compliance with New York State Department of Environmental Conservation (DEC) requirements to reduce CSO discharges into New York City's waterbodies. DEP is also exploring the use of GI to reduce polluted runoff reaching waterbodies through the municipal separate storm sewer system (MS4) (City of New York n.d.).

Based on a phone interview with NYCDEP staff, GI maintenance cost data are not currently available to share with this survey because the program is new and costs have not been tracked in a manner appropriate for sharing with others (personal communication, Shane Ojar). More information on the New York City GI program is provided below.

NYC has a pilot implementation and monitoring program that began in 2010, and more than 30 GI practices have been constructed and monitored as part of this pilot program (Figure 4-1). These controls include right-of-way GI facilities such as enhanced tree pits, rooftop practices like blue roofs and green roofs, subsurface detention systems with open bottoms for infiltration, porous pavements, and bioretention. In general, the purpose of the monitoring effort is (1) to evaluate the effectiveness of various GI practices at managing the 1-inch rainfall

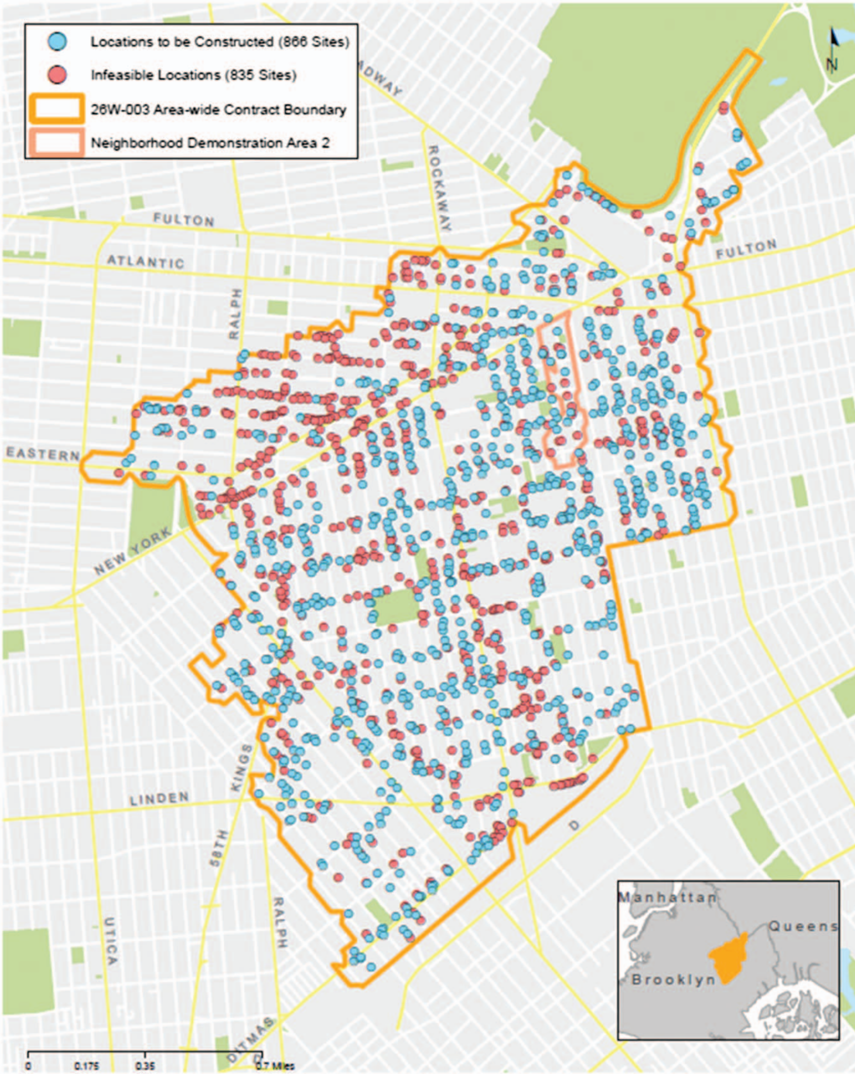

Figure 4-1. New York City's Existing and Planned GI Installations
Source: NYDEP (2015)

event, and (2) to provide data that will allow DEP to extrapolate the runoff reduction benefits to a large scale.

DEP has also continued to develop its programs for Project Tracking and Asset Management system and GI Maintenance. Both programs provide critical services for managing the growing set of decentralized GI assets that the DEP will build in the coming years. In 2014, DEP continued the development of a GIS-based Project Tracking and Asset Management System capable of compiling, tracking, managing, mapping, reporting data, and providing asset management for thousands of GI assets throughout their life cycle. DEP launched the GIS component of an interim tracking database in 2014, which has formalized the tracking process during area-wide contract site selection and design. GI assets in the city include right-of-way bioswales, stormwater green streets, right-of-way rain gardens, and installations on public and private property such as rain gardens and other bioretention systems, permeable paving, subsurface systems or turf fields with infiltration capability, rainwater harvesting, and green and blue roofs.

During 2014, DEP and the Department of Parks and Recreation continued to provide maintenance for right-of-way GI locations in Brooklyn, Queens, and the Bronx. In 2015, DEP's Bureau of Water and Sewer Operations took over the lead on GI maintenance. As the program grows over the next several years, DEP will hire new maintenance positions and will evaluate the maintenance capacity of the crews going forward. The maintenance of GI practices on publicly owned property, such as the Department of Education's schoolyards, is typically carried out by the owner agency. But DEP has agreed to maintain the GI retrofits on New York City Housing Authority property.

4.3 SAN FRANCISCO PUBLIC UTILITIES

San Francisco Public Utilities has completed one GI project and has begun to build eight other large-scale GI projects. The completed project has been maintained by the contractor for the last three years. The first GI project was part of a larger streets project, and cost data for the GI component of the project were not readily extractable from the overall project cost. The other eight projects will all be completed by 2020, and the San Francisco Public Utilities Commission (PUC) plans to track O&M cost after the projects are constructed.

Concurrent with the MWIC GI Cost Survey, the PUC conducted its own survey of GI maintenance costs (personal communication, Kerry Rubin, AECOM). The Sewer System Improvement Program (SSIP) of the PUC is working to develop a GI maintenance manual to help public- and private-sector maintenance crews, working on private land or in the public realm, conduct proper maintenance of GI for stormwater management. The maintenance manual will be a field guide for hands-on maintenance activities and will include GI maintenance procedures for the most common GI technologies. As part of the effort to develop the maintenance manual/field guide and ensure that it reflects the latest developments related to GI operations and maintenance procedures, the project team conducted (1) research on existing GI maintenance manuals, guidelines, field guides, and other related materials from U.S. jurisdictions with GI maintenance programs, and (2) follow-up interviews with selected jurisdictions to clarify and gain additional understanding of maintenance issues. People were interviewed in Columbus, OH, El Cerrito, CA, Kansas City, MO, Onondaga County, NY, and

San Jose, CA. Based on the draft report, key lessons learned from SFPUC's interviews, as stated in their draft report (SFPUC 2016), include

- Maintenance inspection is performed in-house.
- Few municipalities fully track GI maintenance costs and compile data in a way that can be easily shared.
- System maintenance as a combination of in-house staff and contractors is the most common and efficient approach: assign tasks that are best suited for in-house crews and contract out those that would be costly or inefficient.
- Placement of staff from workforce development programs is challenging. Ensure that proper demand is available.
- Consider maintenance in design, and develop effective feedback loops.
- Use levels of maintenance to prioritize maintenance efforts.
- Using asset management software to track time and materials is valuable for understanding long-term maintenance costs, specific system maintenance costs, and materials.
- Quarterly site visits are an appropriate baseline for bioretention facilities, with the need for additional maintenance activities determined for individual sites on an ad hoc basis.

4.4 SOUTHEAST METRO STORMWATER AUTHORITY, CO

The Southeast Metro Stormwater Authority (SEMSWA) is a stormwater utility in the southern suburbs of Denver, CO. SEMSWA provided several years of inspection and maintenance records for extended detention basins installed and maintained in the southern suburbs of Denver. Although cost records were not associated with these maintenance activities, detailed labor estimates and activities were recorded according to the maintenance activities described in Table 4-1. This information can be used to develop cost estimates on an annual basis since a record was provided for each site visit.

4.5 CITY OF LANCASTER, PA

Lancaster is implementing a significant GI program. Ruth Hocker, stormwater manager for the city, was interviewed to obtain information about the city's efforts and information needs related to GI maintenance. The city is particularly interested in guidance related to optimizing their asset management system (Lucity) to better track GI maintenance activities and costs.

The city of Lancaster covers approximately 7.4 square miles, including 248 acres of publicly owned parkland and playgrounds, 125 miles of streets, and

Table 4-1. Summary of Activities Recorded on SEMSWA Maintenance Forms

Site	
BMP type	
Date	
Labor time/units	e.g., minutes, hours
Maintenance activities (yes/no)	
Routine	Inspection
	Mowing
	Trash/debris removal
	Outlet works cleaning
	Weed control
	Vacuum/sweep
Restoration	Sediment removal
	Erosion repair
	Vegetation removal/thinning
	Revegetation
	Jet-Vac/clear drains
Rehabilitation	Sediment removal (dredging)
	Erosion repair
	Structural repair
Equipment/tools used	e.g., shovel, Bobcat
Other costs	e.g., plant materials, mulch, disposal fees, etc.
Comments	

27 miles of alleys. The city is heavily paved with impervious surfaces, and approximately 45% of the city is served by combined sewers. During wet-weather events, combined sewage flows exceed the capacity of the Advanced Wastewater Treatment Plant, and combined sewage is discharged directly to the Conestoga River. The Conestoga is a tributary of the Susquehanna River, which discharges to the Chesapeake Bay.

The Chesapeake Bay is a high priority for pollutant load reductions required by the revised total maximum daily load (TMDL) issued by EPA, as well as President Obama's 2009 executive order 13508 requiring a new strategy for protecting and restoring the Chesapeake Bay. The city is also required to reduce the frequency and volume of CSOs and stormwater discharges. The city has developed an integrated approach to reduce the impacts of these pollutant sources through the use of GI and is saving money by integrating stormwater reduction projects into its core public works practices.

The city's GI program reduces costs by integrating GI into public works processes and partnerships with private property owners to allow public works programs to better leverage public investments to meet clean water goals for CSO, MS4, and nutrient TMDLs at the same time as other city infrastructure, including parks, roads, and buildings, is restored. The city's GI plan and implementation program are demonstrating that integrating runoff management into typical public works projects can achieve runoff reduction benefits that are more cost-effective than traditional conveyance and storage approaches while also providing community improvements and therefore extending the existing city budgets to accomplish more.

4.6 MILWAUKEE METROPOLITAN SEWERAGE DISTRICT

MMSD provides support and grants to subsidize projects in 28 surrounding municipalities; however, MMSD does not complete GI projects in-house. A funding agreement was developed in 2015 that required municipalities to report detailed annual O&M costs for facilities funded by MMSD. But at the time of this survey, these cost data were not available.

4.7 DISTRICT OF COLUMBIA WATER AND SEWER AUTHORITY

DCWSA conducted its own research on estimated GI costs in other municipalities across the country and plans to launch its own large-scale GI program beginning in 2017. In May 2015, DCWSA published their *Long Term Control Plan Modification for Green Infrastructure* to highlight how GI would be integrated into their Clean Rivers Project to more effectively manage CSOs. They are setting up the infrastructure to track future maintenance cost data. DCWSA is also a leader in the national effort to develop a Green Infrastructure National Certification Program (http://www.chesapeakewea.org/docs/5_-_GI_Certification.pdf).

4.8 SAN DIEGO TRANSPORTATION AND STORMWATER DEPARTMENT

In the most recent version of their Stormwater Standards Manual, the San Diego Transportation and Stormwater Department added new stormwater treatment and flow control requirements. These standards will increase the number of projects required to implement GI, such as bioretention and infiltration, and will also increase the level of treatment required. The department anticipates that this expansion of GI will focus additional attention on GI BMP maintenance costs, although data were not available at the time of this report.

4.9 ATLANTA DEPARTMENT OF WATERSHED MANAGEMENT

The Atlanta Department of Watershed Management recently began implementing GI and does not yet have a system to track maintenance costs. The department anticipates that it will have useful data within the next one to two years.

4.10 3 RIVERS WET WEATHER, PENNSYLVANIA

3 Rivers Wet Weather founded the Green Infrastructure Network, which is a collaboration of over 80 organizations, universities, businesses, and government partners with an interest in developing GI in Allegheny County, PA. While one of the goals of the network is to help members share cost data, members are generally still in the very early stages of data collection.

The 3 Rivers Wet Weather website provides a municipal data support (MDS) tool to assist municipalities in wet-weather planning, implementation, operation and maintenance (http://mds.3riverswetweather.org/). The tool enables sharing of regional information, such as mapping and flow monitoring data, and wet-weather guidance documents, among municipalities.

4.11 WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

In 2012, WSDOT began estimating costs to complete new BMP maintenance requirements in the agency's latest National Pollutant Discharge Elimination System (NPDES) permit. WSDOT's maintenance policy manager, Rico Baroga, indicated that WSDOT is in the process of linking their maintenance record-keeping and accounting system to track work on individual sites, but this information was not yet available at the time this report was completed.

CHAPTER 5

U.S. Environmental Protection Agency Resources

EPA has compiled a variety of resources relevant to GI O&M costs, as described in a 2013 review and through references posted on their GI website. These two sources of information are generally described below. (EPA's National Stormwater Calculator is discussed in Section 6.1.)

5.1 EPA'S 2013 REVIEW OF GREEN INFRASTRUCTURE O&M PRACTICES

In 2013, EPA published *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* (http://www.epa.gov/sites/production/files/2015-04/documents/green_infrastructure-om_report.pdf). This report contains some information on GI O&M costs, as summarized below.

The American Recovery and Reinvestment Act (ARRA) appropriated $4 billion dollars to EPA's Clean Water State Revolving Fund (CWSRF). Through the CWSRF Green Project Reserve, 259 GI projects worth over $209 million were funded. These projects include a variety of GI practices, such as rain gardens, pervious pavement, constructed wetlands, rain barrels, bioswales, and green roofs. EPA's 2013 report was intended to provide information for communities and funders to help ensure that ARRA-funded GI projects are operated and maintained to optimize long-term performance and effectively assist communities in reducing stormwater runoff and improving water quality. The report examines the O&M practices of 22 GI projects funded by the ARRA CWSRF; however, the level of detail in the report is relatively general, so it was not feasible to use the information to support normalized cost estimates for this MWIC report. For example, average annual O&M costs were provide for five communities, but information was not provided to enable normalization of costs on a per-area or per-volume-treated basis. Nonetheless, follow-up research on the 22 communities in this report could provide more information. Activities examined in EPA's report include planning and tracking of maintenance, training and education, use of partnerships, and funding. Although there was significant variability in these activities across projects, some trends emerged. Selected highlights of the report follow.

EPA (2013a) summarized information for the 22 communities as follows.

O&M plans and tracking

- 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 GI.

Responsibilities for maintenance

- In 36%, the municipality or government agency is responsible for O&M.
- In 23%, private organizations, entities, or homeowners are responsible for O&M.
- In 36%, responsibilities are split between the private and public sectors.

EPA (2013a) reported that the majority of the projects did not have a formalized documentation or O&M activity tracking system in place. Also, those that are undertaking such efforts are predominantly doing so through the use of manual log forms. Only two projects (in the city of Spokane and the city of Lenexa) employed electronic tracking systems at the time of EPA's report; however, several communities were in the process of developing systems to manage their O&M responsibilities.

The reported O&M activities were performed at various intervals—daily, monthly, quarterly, or annually. Approximately 50% of the projects involved private entities responsible for O&M (solely or with a municipality) and report that 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 (USEPA 2013a).

One of the findings of the EPA report that is consistent with MWIC's research effort is that effective oversight of O&M is improved by the development of a system to document and track maintenance activities. Only 6 of the 22 communities included in the EPA study reported using some form of documentation or O&M tracking system. This is often part of a computerized maintenance management system or asset management system that enables the electronic logging of O&M tasks. For example, EPA reports that the city of Spokane, WA, constructed a network of 37 rain gardens between curbs and sidewalks to intercept stormwater runoff on either side of a major thoroughfare. Spokane's Sewer Maintenance Division uses a system that links to a GIS platform and enables the city to use field laptops. This linkage allows 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 preventive maintenance controls for green and gray infrastructure projects throughout the city.

Table 5-1. EPA's List of Green Infrastructure Cost-Benefit Resources

Resource title	*Description (adapted from EPA)*	*Capital cost*	*Maintenance cost*
Cost analysis			
Low Impact Design vs. Conventional Development (Shaver 2009)	Compares the construction costs of conventional and LID approaches for nine subdivisions in the U.S. and Auckland, New Zealand.	Yes	No
Pembroke Woods: Lessons Learned in the Design and Construction of an LID Subdivision (Clar 2003)	Case study of a 43-acre residential subdivision in Frederick County, MD, documents the cost savings achieved by adopting a GI approach.	No	No
Changing Cost Perceptions: An Analysis of Conservation Development (Conservation Research Institute 2005)	Compares the stormwater management costs of conservation development with those of conventional development. It defines conservation development as an approach that "addresses stormwater on-site by distributing water across the landscape."	No	No
Low Impact Development at the Local Level: Developers' Experiences and City and County Support (ECONorthwest 2009)	Focuses on two aspects of LID adoption at the local level: the experiences that developers have had with LID, and actions that local jurisdictions can take to increase LID use.	No	No
Forging the Link, Chapter 3: Economics and LID (University of New Hampshire Stormwater Center 2011)	Documents case studies demonstrating how adopting a GI approach can lead to more cost-effective site designs and stormwater management systems.	Yes	Yes

(Continued)

Table 5-1. EPA's List of Green Infrastructure Cost-Benefit Resources (Continued)

Resource title	*Description (adapted from EPA)*	*Capital cost*	*Maintenance cost*
Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices (USEPA 2007)	Summarizes 17 case studies of developments that include LID practices and compares project costs to typical costs for conventional development.	Yes	No
The Economics of Low Impact Stormwater Management in Practice: Glencourt Place (Vesely et al. 2005)	Compares the life cycle costs of a GI approach with those of a conventional approach to a retrofit of a residential subdivision.	No	No
Cost-benefit analysis			
The Economic Benefits of Green Infrastructure: A Case Study of Lancaster, PA (USEPA 2014b)	Case study estimates the value of several of the cost benefits of Lancaster's GI plan. It highlights the importance of including the multiple benefits of GI in cost-benefit assessments and adding GI into planned improvement projects.	Yes	No
Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs (USEPA 2013b)	Summarizes 13 economic benefit analyses conducted by public entities to assess the effectiveness of their GI programs. The case studies represent a range of methodologies, geographic contexts, and program types.	No	No

The Economics of Low Impact Development: A Literature Review (ECONorthwest 2007)	Summarizes the benefits of LID, methodologies for assessing the economic impact of LID, and results of more than 50 studies.	No	No
NYC Green Infrastructure Plan: A Sustainable Strategy for Clean Waterways (NYCDEP 2010)	Provides modeling results indicating that a CSO reduction strategy that combines green and gray infrastructure can yield greater reductions in CSO volumes at a lower cost than an all-gray strategy while providing more community benefits.	No	No
A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds (Stratus Consulting 2009)	Compares the benefits of a GI approach to CSO control to the benefits of a traditional tunnel approach. It monetizes a range of environmental, social, and public health benefits.	No	No
Fresh Coast Green Solutions: Weaving Milwaukee's Green & Grey Infrastructure for a Sustainable Future (Milwaukee Metropolitan Sewerage District 2011)	Describes Milwaukee's goal of achieving zero sewer overflows with combined green and gray systems. Compares capital costs for different GI measures and provides detailed summary of environmental, social, and economic benefits associated with the measures.	No	No
Municipal Forest Benefits and Costs in Five US Cities (McPherson et al. 2005)	Article describes the structure, function, and value of street and park tree populations.	No	Yes
Cost Benefit Evaluation of Ecoroofs 2008 (Portland Bureau of Environmental Services 2008)	Attempts to quantify the private and public costs and benefits of green roofs in Portland, Oregon.	Yes	Yes

(Continued)

Table 5-1. EPA's List of Green Infrastructure Cost-Benefit Resources (Continued)

Resource title	*Description (adapted from EPA)*	*Capital cost*	*Maintenance cost*
Tools			
Low Impact Development, An Economic Fact Sheet (North Carolina State University Extension n.d.)	This fact sheet is intended to help citizens, developers, and policymakers have an informed discussion about the costs, benefits, and trade-offs of LID.	No	No
The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental, and Social Benefits (Center for Neighborhood Technology 2010)	Describes the steps to quantifying and valuing many of the environmental, social, and public health benefits of GI. Includes simple, illustrative examples to assist decision-makers, planners, and communities in performing their own calculations.	No	No
Green Values National Stormwater Management Calculator (Center for Neighborhood Technology 2009)	This screening-level tool allows site designers to quickly compare the performance, costs, and benefits of GI practices to conventional stormwater practices.	Yes	Yes
Office for Coastal Management, National Oceanic and Atmospheric Administration (http://coast.noaa.gov)	Programs and data tools for analyzing costs and benefits of GI for coastal areas.	No	No

Source: http://www.epa.gov/green-infrastructure/green-infrastructure-cost-benefit-resources

5.2 SUMMARY OF GREEN INFRASTRUCTURE COST RESOURCES (EPA WEBSITE)

EPA has compiled a list of GI cost resources (http://www.epa.gov/green-infrastructure/green-infrastructure-cost-benefit-resources). Table 5-1 summarizes the resources listed as of February 2016. These resources were reviewed as potential sources of capital and maintenance costs for use in this report. As shown in the table, most of these studies do not include cost data at a level of detail that supports the objectives of this research report. For example, the report may provide some information on capital costs, but most did not provide maintenance costs on an individual BMP basis or treated unit-volume or unit-area basis.

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CHAPTER 6

Cost Estimating Tools and Resources Developed by Others

In addition to compiling empirical data from various local governments and researchers, a limited-scope inventory of several recent cost tools that incorporate GI was made. These tools include capital costs, but that component is not summarized in this MWIC report.

6.1 NATIONAL STORMWATER CALCULATOR

The National Stormwater Calculator is a simple-to-use tool developed by EPA for computing small-site hydrology for any location in the United States. It estimates the amount of stormwater runoff generated from a site under various development and stormwater-control scenarios over a long-term period of historical rainfall. The analysis takes into account local soil conditions, slope, land cover, and meteorology. In the tool, different types of GI can be employed to help capture and retain rainfall on-site. The calculator uses the EPA Stormwater Management Model (SWMM) as its computational engine. EPA states that the calculator is most appropriate for screening-level analysis of small-footprint sites (up to several dozen acres) with uniform soil conditions (USEPA 2014a).

In January 2017, EPA published the Version 1.2 of the National Stormwater Calculator, which can be accessed at https://www.epa.gov/water-research/national-stormwater-calculator. The updated tool integrates construction and maintenance cost data. Table 6-1 provides a summary of maintenance costs used to support development of the tool's maintenance cost algorithms, which are summarized in Table 6-2. The cost algorithms are based on regression equations that include a fixed cost component plus a variable cost component associated with BMP size. BMP size (x) is expressed as square feet of surface area, except for rainwater harvesting, where size is expressed as gallons.

Table 6-1. Maintenance Cost Estimates for GI Practices Supporting Maintenance Cost Algorithms in the EPA Stormwater Calculator

	GI Type (see note)							
GI type code	*ID*	*RH*	*RG*	*GR*	*SP*	*IB*	*PP*	*VS*
Literature Low ($/sq ft, or $/gal for RH)	$0.04	$0.075	$0.06	$0.03	$0.04	$0.04	$0.05	$0.05
Literature Low Year	2006	2005	2009	2008	2009	2005	2009	2006
Literature High ($/sq ft, or $/gal for RH)	$0.06	$0.18	$1.45	$0.20	$0.80	$1.32	$0.23	$0.06
Literature High Year	2006	2005	2009	2001	2005	2005	2005	1991
2014 Low	$0.05	$0.10	$0.07	$0.03	$0.05	$0.05	$0.06	$0.06
2014 High	$0.08	$0.24	$1.63	$0.28	$1.07	$1.77	$0.31	$0.12
References		LID Center 2005; SBPAT Tool 2005	CNT 2009; Barr 2011	BES 2008; Peck and Kuhn 2001	BES 2005; WE&RF 2009	Weiss 2005	CNT 2009; LID Center 2005; MPCA 2011	PA DEP 2006; SEWRPC 1991

Abbreviations: ID = reducing directly connected impervious area; RH = rainwater harvesting; RG = rain garden; GR = green roof; SP = street planter; IB = infiltration basin; PP = permeable pavement; VS = vegetated swale

Source: USEPA (2017), prepared by Geosyntec Consultants

Table 6-2. Maintenance Cost Algorithms for GI Practices in the EPA Stormwater Calculator

GI Control	*Simple Maintenance Cost Curve Cost in 2014 Dollars*	*Complex Maintenance Cost Curve Cost in 2014 Dollars*
Impervious Area Disconnection	0.0500 x (sq ft of impervious area disconnection)	0.0750 x (sq ft of impervious area disconnection)
Rainwater Harvesting	0.1000 x (gal of storage)	0.2410 x (gal of storage)
Rain Garden	0.0675 x (sq ft of rain garden)	1.6320 x (sq ft of rain garden)
Green Roof	0.0281 x (sq ft of green roof)	0.2821 x (sq ft of green roof)
Street Planter	0.0450 x (sq ft of street planter footprint)	1.0697 x (sq ft of street planter footprint)
Infiltration Basin	0.0487 x (sq ft of basin footprint)	1.7689 x (sq ft of basin footprint)
Permeable Pavement	0.0563 x (sq ft of permeable pavement)	0.3075 x (sq ft of permeable pavement)
Vegetated Swale*	0.0626 x (sq ft of vegetated swale)	0.1215 x (sq ft of vegetated swale)

*Not included in National Stormwater Calculator
Source: USEPA (2017), prepared by Geosyntec Consultants

For the rain garden costs referenced in the Stormwater Calculator, the two key references cited include

- Barr Engineering (2011), which reported an annual average cost per cubic foot for maintenance of bioretention basins of $1.25/cf (in 2010 dollars) based on data for eight bioretention facilities; and
- Center for Neighborhood Technology's Green Values National Stormwater Management Calculator (2009).

6.2 UNIVERSITY OF MINNESOTA AND MINNESOTA DEPARTMENT OF TRANSPORTATION

University of Minnesota researchers have completed several papers that address BMP costs. In Weiss et al. (2007), cost estimation algorithms were developed that recognized O&M costs as a significant expense that should be considered when selecting a BMP. At the time of their paper, they did not find data that documented the actual costs of O&M. For the most part, O&M data were presented as expected costs. They included a table referencing work by USEPA (1999), which provided a summary of typical annual stormwater BMP O&M costs, along with a range of cost data from other researchers (SEWRPC 1991; Landphair et al. 2000; Caltrans 2004; Moran and Hunt 2004) (Table 6-3).

University of Minnesota researchers also compiled data on construction costs and annual operating and maintenance costs for 20 years to estimate the total present cost (TPC) of each practice (in 2005 dollars). The total present cost for each practice is estimated as a function of size (water quality volume, or in the case

Table 6-3. Typical Annual O&M Costs as a Percentage of Construction Cost

BMP	*Typical O&M as % of construction cost*	*Range of collected cost data as % of O&M cost*
Retention basins / constructed wetland	3–6	1.9–10.2 ("wet basin")
Detention basins	1	1.8–2.7
Constructed wetlands	2	4–14.1
Infiltration trench	5–20	5.1–126
Infiltration basin	1–3, 5–10	2.8–4.9
Sand filters	11–13	0.9–9.5
Swales	5–7	4.0–178
Bioretention	5–7	0.7–10.9
Filter strips	$320/acre	–

Source: USEPA (1999), as summarized by Weiss et al. (2007)

of swales, the top width). Weiss et al. (2007) observed that annual O&M cost as a percentage of the construction cost decreased with increasing construction cost (with the exception of infiltration trenches, which were evaluated using a different approach). Their report provides equations for calculating the total present cost based on 20 years of annual O&M costs that were converted to a present value based on historical values of inflation and municipal bond yield rates. The original data exhibited a large amount of scatter, which resulted in large confidence intervals for the estimates of both the total present costs and mass of contaminants removed. Although O&M is not broken out separately, Table 6-4 summarizes the resulting constants in 2005 dollars over a 20-year period for these equations, assuming typical O&M as a percentage of construction costs. The equation used is:

$$TPC = \beta_0 (WQV)^{\beta_1}$$

where:

TPC = total present cost in 2005 U.S. Rainfall Zone 1 Dollars

WQV = water quality volume (m^3)

β_0 and β_1 are constants, as defined in Table 6-3.

Although not oriented to cost data, *Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance Book* by Erickson et al. (2013), of the University of Minnesota St. Anthony Falls Laboratory, provides information on recommended maintenance frequencies and activities that could be used to refine cost estimates based on unit activities per year.

6.3 UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER

In 2013, UNHSC researchers Houle et al. published their "Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management." This study examined seven different types of BMPs for the first two to four years of operations and studied maintenance demands in the context of personnel hours, costs, and system pollutant removal. The BMPs studied included conventional systems such as a wet pond, a dry pond, and a swale, as well as GI/LID systems including bioretention, sand filter, subsurface gravel wetland, and a porous asphalt pavement. The systems were located at a field facility designed to distribute stormwater in parallel, to normalize watershed characteristics including pollutant loading, sizing, and rainfall. System maintenance demand was tracked for each system and included materials, labor, activities, maintenance type, and complexity. Houle et al. concluded that compared to conventional systems, LID systems generally had lower marginal maintenance burdens (as measured by cost and personnel hours) and higher water quality treatment capabilities as a function of pollutant removal performance.

Their cost estimates incorporated several concepts related to maintenance complexity (e.g., minimal, simple, moderately complicated) and expense based on

Table 6-4. Constants for Total Present Cost (TPC) Calculations Developed by Weiss et al. (2007)

	Average TPC (2005 dollars)		*Upper confidence limit for TPC*		*Lower confidence limit for TPC*		
BMP	β_0	β_1	β_0	β_1	β_0	β_1	*WQV* (m^3)*
Dry basins	1,281	0.634	2,024	0.671	1,055	0.585	85–101,000
Wet basins	4,398	0.512	6,119	0.536	3,592	0.484	410–215,000
Sand filters	6,153	0.594	13,618	0.596	3,495	0.592	3–5,500
Bioretention filters	1,542	0.776	3,838	0.723	897	0.802	26–990
Construction wetland	1,515	0.565	2,579	0.585	1,076	0.537	200–215,000
Infiltration trenches	2,237	0.817	4,039	0.817	1,418	0.817	13–870

*Water Quality Volume

the relative cost of staff expertise required to maintain the facility. Maintenance activities were also categorized in a manner similar to that previously recommended by others (Debo and Reese 2002), including

- Proactive: adaptive and applied increasingly as familiarity with the system develops;
- Periodic and predictive: driven by inspections and standards embodied in an O&M plan; can be calendar-driven, known, or schedulable activities; and
- Reactive: complaint- or emergency-driven.

Key findings from Houle et al. that are pertinent to this MWIC report include the following.

- Maintenance costs vary not only by practice type, but also based on overall design, system sizing, location, land use, and other watershed characteristics.
- In most cases, maintenance approaches are not static but change as maintenance staff become familiar with the systems and are better able to plan for maintenance activities. Maintenance tasks often start out as reactive (expensive) but evolve into periodic and proactive approaches. Maintenance activities, approaches, and expenditures generally became less intensive and diminished over time as maintenance familiarity increased. For example, maintenance of vegetated systems required more attention during the first months and years of vegetation establishment.
- If maintenance activities are simple, then periodic and routine maintenance costs are kept at a minimum. Practices with higher percentages of periodic and predictive or proactive maintenance activities have lower maintenance burdens than practices with more incidences of reactive maintenance.
- Maintenance burdens for vegetated filtration systems were generally lighter with respect to cost and personnel hours, compared to conventional practices such as ponds, with vegetated swales and sand filters as the exceptions.
- Cost estimates are provided in Table 6-5. The authors concluded that although LID system maintenance will be different and may require additional training, it should not require unusual burdens for management.

Houle et al. recommended additional research on scalability, costs with respect to temporal variations, and costs associated with different land uses and location (urban vs. rural), which are all expected to affect maintenance costs.

6.4 WE&RF-AWWA-UKWIR 2005 BMPs/SUDS WHOLE-LIFE COSTS

In 2005, Lampe et al. completed *Post-Project Monitoring of BMPs/SUDS to Determine Performance and Whole-Life Costs: Phase 2* for the Water Environment and Reuse Foundation (WE&RF), the American Water Works Association (AWWA), and the United Kingdom Water Industry Research (UKWIR). The

Table 6-5. Normalized UNHSC Installation and Maintenance Cost Data

Parameter	*Vegetated swale*	*Wet pond*	*Dry pond*	*Sand filter*	*Gravel wetland*	*Bioretention (3 sites)*	*Porous asphalt*
Surface area (m^2)	260	299	299	15	179	25 (2 sites) 218 (1 site)	523
WQ volume (m^3)	97.7	97.7	97.7	97.7	97.7	97.7	13.3
Inflated 2012 capital cost	$36,200	$40,700	$40,700	$37,700	$67,800	$63,200	$65,700
Maintenance-capital cost comparison (years)[a]	16	5	7	5	12	13	25
Personnel (h/year)	24	69	59	70	54	51	15
Personnel ($/year)	$2,030	$7,560	$5,880	$6,940	$5,280	$4,670	$939
Materials ($/year)	$247	$272	$272	$272	$272	$272	$-
Subcontractor cost ($/year)	$-	$-	$-	$-	$-	$-	$1,730
Annual O&M cost ($/year)	$2,280	$7,830	$6,150	$7,210	$5,550	$4,940	$2,670
Annual maintenance/ capital cost (%)	6	19	15	19	8	8	4

[a]Number of years at which amortized maintenance costs equal capital construction costs

objectives of the project were to document the performance and whole-life costs of BMPs and sustainable urban drainage systems (SUDS). Sustainable urban drainage systems (SUDS) is a term used in the United Kingdom that is comparable to best management practices, stormwater control measures, etc. Practices considered in the study included retention ponds, extended detention basins, vegetated swales, bioretention, porous pavements, and various infiltration practices. A whole-life cost model was developed in a spreadsheet framework to allow calculation of the expected cost of a facility based on drainage area, maintenance expectations, and other factors.

With regard to maintenance costs, an extensive survey of the experience of U.S. agencies with BMPs was conducted to document differences in cost and maintenance requirements as a function of climate and other socioeconomic and cultural factors. This survey documented a wide range in cost, much of it attributable to expectations regarding aesthetics of the local community. This information was supplemented with site visits to seven cities across the United States to record differences in design elements and determine the reasons for these differences. A similar effort was undertaken in the United Kingdom, with more of an emphasis on repeated visits to the same facilities to record the maintenance activities that occurred, the time to complete these activities, and to the extent possible the impact of these activities on facility performance.

With regard to GI practices, the whole-life cost model spreadsheets developed for this effort were superseded by an update by WE&RF in 2009, as discussed in Section 6.5. Nonetheless, many of the findings of the report are noteworthy:

- Differences in geography (climate, topography, soils, etc.), culture (aesthetics, materials, program goals, etc.), and economics (availability and willingness to use financial resources) prompted a wide variety of choices in selecting and maintaining BMPs.
- The whole-life cost model was used to develop estimates of expected construction cost vs. facility size which were compared to reported costs for actual facilities. There was a wide spread in actual costs compared to the increase in cost with size predicted by the model. This highlights the site-specific nature of costs for any particular facility and should caution the model user against relying exclusively on average costs experienced by others.
- The level of maintenance specified had a pronounced effect on the whole-life cost for most facilities. For instance, the level of maintenance for retention ponds had a much greater influence than construction cost. The model predicted that small sites with a high level of maintenance would have a greater whole-life cost compared with facilities that were 10 times as large, but maintained at low or medium levels. For a given size of facility, a high level of maintenance increased the whole-life cost by two to three times compared with the same facility with a lower level of maintenance.
- Maintenance budgets were found to be established largely by market-driven factors rather than based on technical or functional inputs. Essentially, no

public agency or council interviewed had the resources to fully maintain the BMPs/SUDS in their jurisdictions to the extent expected or hoped for in their maintenance guidelines.

- Two clear lessons from this qualitative monitoring effort are the degree to which maintenance is dominated by vegetation management and the variability in the level of maintenance that citizens of different areas expect. In many jurisdictions vegetation management dominates the maintenance activities, rather than tasks one might expect such as sediment, debris and trash removal, or structural repair. Thus, most activities have little effect on BMP performance, but result from the level of service expected by residents living near these facilities. The frequency of maintenance depends on the economic status of the neighborhood and the visibility of the system.
- This study also has clearly shown that the design and operation of BMPs/SUDS must consider the damage which inevitably arises when construction-stage runoff is permitted to enter systems. The survey team encountered repeated instances where high sediment loads associated with construction activities had caused almost irreparable damage to downstream BMPs/SUDS, especially those relying on an infiltration component.
- BMP size and complexity affect maintenance activities. Large systems (retention ponds, extended detention basins) are easier to track, inspect, and ensure that they are working (since there are fewer of them), but require specialized contractors or agency crews to maintain. Small landscaped systems (swales and bioretention) are more difficult to track but are more straightforward to maintain using landscaping contractors (excepting some types of rehabilitative work).
- Many problems and costs can be avoided by using an adequate inspection program. Inspection during the design and construction phase helps ensure proper design, construction techniques, and sediment and erosion controls. Inspections following the construction phase serve to inspect, track, and help ensure that BMPs/SUDS continue to exist and function properly. Regular monitoring not only ensures that maintenance activities are being carried out as specified but also identifies any areas of potential system failure.
- Agency representatives consistently agreed that lack of routine maintenance leads to disproportionately greater long-term expenses. For example, structural damage caused by growth of large trees in outfalls and embankments could be easily prevented with periodic mowing. Repairing such structural damage costs much more than mowing would have cost. Where a frequent landscaping maintenance program is in place, there may be very little additional cost to maintain the BMPs/SUDS.
- The accuracy of the whole-life cost model is reduced by the lack of detailed information about the number of hours spent on the various maintenance activities. It is recommended that more detailed information be recorded on the hours spent on various types of activities, focusing on vegetation

management, sediment and debris removal, and facility inspection. U.K. water utilities and agencies in the United States conducting routine maintenance should be advised to set up a system for gathering BMP/SUDS maintenance costs. This will provide better input to the whole-life cost model and enable benchmarking of maintenance costs. More information on long-term changes in permeability of porous pavement and the effectiveness of various maintenance techniques would also be useful.

As a result of analysis by Lampe et al., the average annual BMP maintenance costs were summarized for the United States and the United Kingdom, with the U.S. costs summarized in Table 6-6. Activities included in O&M costs are labor and equipment, materials, replacement and/or additional planting, and disposal (i.e., contaminated sediments). Maintenance costs were categorized as *routine*, *infrequent*, and *corrective*. Routine maintenance consisted of basic tasks done on a frequent and predictable schedule. These included vegetation management, litter and minor debris removal, and inspections. Sediment removal was considered an infrequent task: performed periodically, but on a much less frequent and predictable basis than routine tasks. Corrective maintenance included more heavy-duty, unpredictable, and intermittent tasks to keep systems in working order, such as repair of structural and erosion damage, and, potentially, complete facility reconstruction.

In addition to the summary costs identified in Table 6-6, Lampe et al. further classified the O&M activities according to these categories:

- Monitoring (inspection);
- Regular, planned maintenance, e.g., rodding culverts, clearing debris from manholes, grass-cutting, vegetation management, litter removal, jetting of permeable surfaces, and silt extraction from engineered silt traps;

Table 6-6. WE&RF-UKWIR Average Annual BMP Maintenance Cost Estimate in 2004 & 2015 U.S. Dollars

	Average annual BMP cost, 2004 U.S. dollars		
BMP/SUD type	*Preventative (Routine)*	*Corrective maintenance*	*Total*
Retention pond	$590	$4,750	$5,340
Extended detention basin	$590	$1,780	$2,370
Swale, bioretention	$530	$480	$1,010
Infiltration trench	$230	$1,010	$1,240
	Average annual BMP cost, 2004 U.S. dollars		
Retention pond	$832	$6,700	$7,532
Extended detention basin	$832	$2,511	$3,343
Swale, bioretention	$748	$677	$1,425
Infiltration trench	$324	$1,425	$1,749

- Unplanned maintenance/rehabilitation, e.g., responding to problems like blocked culverts/trash-racks, pollution incident, vegetation death, erosion damage, etc.;
- Intermittent maintenance, e.g., for major mid-life refurbishment, such as sediment removal, geotextile replacement, vegetation replacement, or soak-away replacement.

6.5 WE&RF'S 2009 WHOLE-LIFE COST TOOL

In 2009, WE&RF published the *BMP and LID Whole Life Cost Models Version 2.0*. This work was completed by University of Utah, Black and Veatch, Center for Research in Water Resources, University of Texas, H. R. Wallingford, and Glenrose Engineering. The tool includes a written user's guide and a series of Excel spreadsheet tools that calculate whole-life costs for cisterns, curb-contained bioretention, green roofs, in-curb planter vaults, rain gardens, permeable paving, swales, extended detention basins, and retention ponds. Each spreadsheet includes the following types of information:

Design and maintenance options

- Watershed characteristics
  - Drainage area
  - BMP area
- Design and maintenance options
  - Installation (self/volunteered) or professional
  - Single house or entire neighborhood
  - Level of maintenance: high, medium or low
- Whole life cycle cost option: discount rate.

Capital cost options (using rain gardens as an example)

- Method A: simple cost based on drainage area, includes the following default values:
  - \$3,782 per 1,000 sq ft residential rain garden (in 2008 dollars)
  - Cost includes landscape design, base cost, first year maintenance/establishment costs, and an option for a discount for neighborhood installations
- Method B: user-entered engineers' estimate.

Maintenance costs (using rain gardens as an example)

- Allows user to select high, medium or low maintenance costs, along with an option for "self" labor. Based on the type of maintenance selected, two cost categories are completed:

- Routine maintenance (frequent, scheduled events)
  - Rain gardens: vegetation management ($72 annually in 2008 dollars)
- Corrective and infrequent maintenance events (unplanned or > 3 years between events)
  - Rain Gardens: replace mulch (every 3 years), till soil (every 5 years) ($560 in 2008 dollars; annualized cost = $156/year)

6.6 NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 792

NCHRP's Report 792, *Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices* (2014), was sponsored by the Transportation Research Board. For treatment BMPs, this guidance provides an evaluation tool to assist in selection and in determining whole-life costs of treatment, including

- BMP performance metric
- Comparative service life and long-term BMP effectiveness for enhancing water quality for typical highway runoff constituents
- Life-cycle costs based on capital investment, maintenance, and operational expense data
- Constituent removal performance.

GI practices addressed in NCHRP's tool and report include swales and bioretention facilities, with routine maintenance practices in highway settings summarized in Table 6-7. NCHRP reports that required maintenance frequency depends on the surrounding land use, with more maintenance requests generated in urban areas. Thus, the expected maintenance cost for a given type of facility can vary significantly depending on the expectations of the nearby community. In NCHRP's whole-life cost tool, two general maintenance categories are considered: routine and intermittent. *Routine* maintenance consists of basic tasks performed on a frequent and predictable schedule. These include inspections, vegetation management, and litter and minor debris removal. NCHRP uses three maintenance level characterizations for the routine maintenance component:

- Low/minimum—a basic level of maintenance required to maintain the function of the stormwater control
- Medium—the normal level of maintenance to address function and appearance; allows for additional activities, including preventative actions, at some facilities
- High—frequent maintenance activities performed as a result of high sediment loads, wet climate, and other factors such as safety and aesthetics.

Table 6-7. Routine GI Maintenance in Highway Settings

Routine swale maintenance	*Routine bioretention maintenance*
• Remove sediment accumulation in swale bottom • Remove trash and debris • Check for standing water and repair • Remove clogging if necessary • Restore vegetative cover where required • Repair check dams • Mow to maintain ideal grass height • Remove invasive and woody vegetation • Repair minor erosion/scour • Till swale bottom	• Remove sediment accumulation in basin • Remove trash and debris • Fertilize and maintain basin vegetation • Repair minor erosion/scour • Check for standing water and repair • Check inlets/outlets for obstructions • Add mulch if necessary • Remove invasive and woody vegetation

Source: NCHRP (2014)

The *intermittent* maintenance category typically consists of corrective and infrequent maintenance activities. These are typically more resource-intensive and unpredictable tasks to keep systems in working order, such as repair of structural damage, sediment removal, and regrading eroded areas. In some cases, complete facility reconstruction may be required. The intermittent category can include a wide range of tasks that might be required to address maintenance issues at a BMP (invasive species removal, animal burrow removal, forebay cleanout, etc.). The NCHRP tool calculates costs individually for routine BMP maintenance items, while corrective and infrequent items are calculated as a generalized cost, since these maintenance activities are typically unplanned.

In the cost tool, maintenance cost estimation is based on

- Maintenance event frequency (defined as years between events)
- Hours per event
- Average labor crew size
- Average (pro-rated) labor rate per hour
- Machinery cost per hour
- Materials and incidentals cost per event.

The tool provides guidance on the estimated number of hours needed per maintenance event. As part of the whole-life cost calculation, the net present value of the maintenance costs over the design life of BMP is calculated as a line item.

6.7 URBAN DRAINAGE AND FLOOD CONTROL DISTRICT'S BMP-REALCOST TOOL

The Urban Drainage and Flood Control District in Denver, CO, developed a whole-life cost model, BMP-REALCOST, to assist engineers, planners, developers, consultants, and decision-makers in determining the life-cycle costs and effectiveness of structural stormwater runoff BMPs as they are applied in an urban/suburban setting. This Excel-based model operates by first having the user input information describing the physical characteristics of a watershed that affect runoff quality and quantity (e.g., contributing area, land use, imperviousness). Second, the user enters information that describes what type(s) of BMP(s) will be applied to the watershed/development and the area (number of impervious acres) from which each BMP will receive runoff. Next, the user decides whether to use default cost and BMP effectiveness values, or input their own. The model then takes the user-entered (or default) information and estimates the size of each BMP, determines the number of BMPs needed to treat the watershed, produces estimates of average annual runoff quality and quantity for the entire watershed/development, and calculates life cycle costs for the BMP(s) selected. Maintenance cost equations are summarized in Table 6-8.

Maintenance cost equations include a lump-sum factor, a size-dependent factor, and a rehabilitation/replacement factor. The lump-sum factor accounts for activities that are assumed to be independent of the size of the BMP (e.g., annual inspection, traffic control), while the size-dependent factor accounts for activities

Table 6-8. BM-REALCOST Tool Maintenance Cost Assumptions

		Rehabilitation/replacement	
BMP category	Annual maintenance cost equation (2009 dollars)	Frequency (years)	Percentage of initial construction cost
Extended detention basin	1,075 + 2,375 × AF	35	80%
Retention pond	554 + 1,281 × AF	35	80%
Constructed wetland basin	19 + 3,636 × AF	35	80%
Bioretention	19 + 0.32 × CF	10	30%
Permeable interlocking concrete pavers	19 + 1,635 × Acre	35	80%
Sand filter basin	19 + 535 × AF	25	80%

Note: AF = storage volume in acre-feet; CF = storage volume in cubic feet; Acre = surface area in acres for which the costs are assumed to be dependent on the size of the BMP (expressed as either a storage volume or design flow-through rate). For each maintenance activity, average annual costs are computed from user inputs of maintenance frequency, labor costs, equipment costs, and miscellaneous costs. Rehabilitation/replacement costs are assumed to be a fixed percentage of the initial construction costs and are applied at the end of the BMP's expected useful life.

The types of maintenance activities included for each BMP and the frequencies of those activities were based on informal interviews with persons experienced in BMP maintenance and "best engineering judgment" by the authors. The frequencies of maintenance activities were estimated for a "proactive" BMP maintenance program. Attempts were made to obtain maintenance costs from local stormwater utilities, but several problems were encountered during this process. Many utilities were not actively tracking BMP maintenance costs, and those that were either did not break down costs into various activities or suggested that the costs might not be representative of proactive maintenance costs since many BMP maintenance programs were still operating under reactive circumstances (only performing maintenance after a serious problem was identified). Thus, the unit costs for individual maintenance activities were generally obtained from RS Means Cost Estimating Handbooks (http://www.rsmeans.com).

6.8 NORTH CAROLINA STATE UNIVERSITY BIOLOGICAL AND AGRICULTURAL ENGINEERING

North Carolina State University (NCSU) Extension offers training in Stormwater BMP Inspection & Maintenance Certification Workshops (http://www.bae.ncsu.edu/bae/topic/bmp-im/). NCSU's Bill Hunt and Bill Lord were interviewed regarding additional maintenance data that could be used to update previous research, but the primary publication containing cost findings is still research conducted and summarized by Wossink and Hunt's *An Evaluation of Cost and Benefits of Structural Stormwater Best Management Practices in North Carolina* (2003).

A summary of Wossink and Hunt's findings is provided in Table 6-9. Construction and maintenance costs were collected for more than 40 stormwater BMPs, principally in North Carolina. From these data, the cost equations in Table 6-9 were developed, relating costs to watershed size. Their statistical analysis indicated that the relationship between the size of the watershed and the construction cost was not strong. They found that other factors affecting construction cost, such as watershed composition, required excavation depths, and many other relevant engineering considerations, were not included in the construction cost curves. They also found that bioretention construction costs were significantly different for clayey and sandy soils, so they provide different construction cost formulas for those two site types. For maintenance costs over the 20-year period, a discount rate of 10% for the private developer was used. This rate

Table 6-9. Summary of Construction Cost Curves, Maintenance Cost Curves, and Required Surface Area for Stormwater BMPs in North Carolina (in 2003 dollars)

Cost component	*Wet ponds*	*Stormwater wetlands*	*Sand filters*	*Bioretention in clay soils*	*Bioretention in sandy soils*
Construction cost	$C = 13{,}909X^{0.672}$	$C = 3{,}852X^{0.484}$	$C = 47{,}888X^{0.882}$	$C = 10{,}162X^{1.088}$	$C = 2{,}861X^{0.438}$
20-year maintenance cost	$C = 9{,}202X^{0.269}$	$C = 4{,}502X^{0.153}$	$C = 10{,}556X^{0.534}$	$C = 3{,}437X^{0.152}$	$C = 3{,}437X^{0.152}$
Required surface area of BMP in acres					
Residential development					
Piedmont (CN 80-90)	SA = 0.015X	SA = 0.02X		SA = 0.025X	SA = 0.025X
Coastal Plain (CN 65–75)	SA = 0.0075X	SA = 0.01X		SA = 0.015X	SA = 0.015X
Highly impervious area (CN 80)	SA = 0.02X	SA = 0.03		SA = 0.03X	SA = 0.03X
100% impervious areas (CN 100)	SA = 0.05X	SA = 0.065X	SA = 0.017X	SA = 0.07X	SA = 0.07X

Note: C = cost in 2003 dollars; CN = curve number; X = size of watershed in acres; SA = surface area of BMP in acres
Source: Wossink and Hunt (2003)

includes the risks associated with the specific industry. All BMPs, except for bioretention not in sandy soil, display economies of scale within the practice—the construction cost and the maintenance cost per acre treated decrease as the size of the watershed increases.

6.9 NARAYANAN AND PITT AND WINSLAMM

In *Costs of Urban Stormwater Control Practices*, Narayanan and Pitt (2006) present a method to determine the costs of several types of stormwater control practices using published literature sources and RS Means. The cost data were transformed into equations and used to develop the cost module for the Source Loading and Management Model for Windows (WinSLAMM). Much of the underlying cost data for grass filter strips, swales, permeable pavement, and infiltration trenches was derived from work completed by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in 1991. Cost data summarized in this report were categorized as

- Outfall stormwater controls (wet detention ponds, dry detention ponds, wetlands, infiltration ponds, chemical treatment);
- Critical source area controls (hydrodynamic separators, oil-water separators, storm drain inlet inserts, stormwater filters, multi-chambered treatment train);
- Conservation design controls (grass filter strips, grass swales, permeable pavement, infiltration trenches, rain gardens, biofilters, bioretention devices, green roofs, cisterns for water storage);
- Public works practices (street cleaning, catchbasin cleaning);
- Combined sewage overflow controls that can be applied to stormwater (surface storage, deep tunnels, swirl concentrators, screens, sedimentation basins, disinfection);
- Gross solids controls; and
- Costs associated with educational programs.

The "conservation design" category of practices in this report corresponds to GI practices. Maintenance costs for grass strips and swales include lawn mowing, general lawn care, grass reseeding with mulch and fertilizer, and inspection. Mowing frequency is assumed to be eight times per year; revegetation requirements are assumed to be 1% of lawn area per year, with inspections four times per year. Requirements for permeable pavement assume vacuuming and jet-hosing four times per year.

CHAPTER 7

Recommendations for Standardized Maintenance Cost Reporting

The primary recommendation resulting from this survey and review of GI maintenance cost data is to improve tracking of data on maintenance activities. A national repository of GI cost data would benefit many municipalities around the country. This information could be readily stored and made publicly accessible in the International Stormwater BMP Database (http://www.bmpdatabase.org) with relatively minor adjustments to the BMP Database structure. During 2017, EWRI and WE&RF began an effort to implement this enhancement to the BMP Database, building on the initial recommendations summarized in this chapter.

Utilizing a relational database structure, three tables of information are recommended to track maintenance variables including tables focused on 1) BMP characteristics, 2) maintenance events conducted for the BMP, and 3) maintenance activities conducted as part of the maintenance event. This O&M database can be related to other databases such as an agency's local asset management system or the performance monitoring data in the International Stormwater BMP Database, provided that facility IDs properly link these databases.

Tables 7-1 through 7-3 provide an initial list of recommended reporting parameters to enable normalization of cost data nationally so that more robust GI maintenance cost estimates can be developed to support whole-life cost analysis and O&M planning by local governments. Based on experience with the BMP Database, it is important to find a balance between asking for the minimum amount of information needed to properly use the data and asking for too much information so that the effort becomes administratively cumbersome and time-consuming, thereby deterring participants from sharing data. Research should also be conducted to formulate practical guidance on better linkages between various asset management, work order, and GIS resources that local governments already maintain, but that may not yet be well integrated in a manner that enables straightforward querying of cost data.

Table 7-1. Initial Recommended Reporting Data for GI Maintenance Costs: BMP Facility Information

Parameter	*Description/Picklist*
Facility Information (facility information is provided in one record and then related to multiple maintenance records in Table 7-2)	
Asset ID	Use number in asset management system, if applicable
Facility Type	Individual, cluster, other
Decimal Latitude	GPS centroid/geolocated address–enables mapping of facilities and integration with GIS/asset management systems
Decimal Longitude	
BMP Name	General facility name
BMP Type	Picklist: bioretention, grass swale, grass buffer, tree planter, permeable pavement, composite (treatment train), etc.
City	Enables geographic comparison of records locally and nationally
State	Enables geographic comparison of records nationally
Date Installed	Enables tracking of maintenance cost over time
Tributary Land Area (acres)	Size of drainage area to facility
Imperviousness (%)	Percent impervious area
Land Use(s)	Picklist
Snow/Ice Management	Picklist
Qualitative Site Loading Intensity	High, moderate, low [i.e., *is the site heavily use/dirty, or is it lightly used/clean*]
Tributary Land Area Description/Conditions	Include other pertinent characteristics affecting maintenance.
Treatment Volume (cf)	Provides treatment volume, e.g., Water Quality Capture Volume (WQCV).

Surface Area (sq ft)	Provides information on the footprint of the facility that is maintained
Facility Sizing	Picklist: standard, oversized, undersized (e.g., not to design standards)
Media Type	Picklist: In situ soils, engineered media, not applicable
Vegetation Type	Picklist: highly manicured, moderately manicured, low maintenance, native grasses, turf, wetland vegetation, not applicable
Pretreatment Features	Describe pretreatment features that facilitate ease of maintenance, e.g., sediment forebay
Inlet Features	Describe inlet(s), including features affecting maintenance requirements
Facility Ownership	Picklist: public, private, private-easement, private-HOA, other
Public Visibility	Picklist: high, medium, low
Monitoring Data?	Yes/no/unknown (flag to trigger tie-in to BMP Database)
Comments	Additional description of facility that influences maintenance costs, if needed.

Table 7-2. Initial Recommended Reporting Data for GI Maintenance Costs: Maintenance Event Records for Facility

Maintenance Event Records (Multiple event records over time, linked to the facility information in Table 7-1)	
Asset ID	*Use number in asset management system, if applicable*
Maintenance ID	Maintenance Record number (auto-populated)
Event Record Type	Annual summary, individual event, other
Work Order ID	Work order ID used in asset management system (if applicable)
Work Order Description	Individual facility visit, multiple facility visits, individual facility-multiple visits, multiple facility-multiple visits, unknown
Mobilization Type	Picklist: multiple facilities, single facility
Facility Stage at Time of Maintenance	Picklist: establishment, mature, post-mature (overgrown)
Facility Performance Status	Normal, failing, unknown
General Climate Condition	Picklist: normal, wet, dry
Maintenance Type	Picklist: Inspection only, routine, restoration/reactive, rehabilitation, other
Maintenance Entity	Picklist: contractor, municipal, volunteer, combination
Maintenance Date	Enables normalization of cost data over time and documents frequency
Maintenance Narrative	Describe activities conducted or use additional detailed checklist in Table 3
Disposal Type	Solid waste, hazardous waste, storage for bulk disposal, unknown
Irrigation	Irrigation required, no irrigation
Total Cost ($)	Total overall cost
Cost Type	Picklist: flat fee, time & materials
Labor Cost ($)	Total labor cost
Labor Time (min)	Time required to complete maintenance/site visit
Labor Rate ($/hr)	Hourly labor rate
Materials Description	Plants, mulch, media, hardscape, chipping materials, etc.
Materials Cost ($)	Cost of materials

Equipment Description	Equipment used, e.g., vacuum sweeper, shovel, backhoe
Equipment Ownership	Own, rent, contractor
Equipment Cost Basis	Describe basis for allocating cost of owned equipment
Equipment Cost ($)	Rental cost or owner cost
Disposal Cost ($)	Cost of sediment/materials disposal, if applicable
Admin./Overhead Cost ($)	Administrative cost of scheduling/tracking maintenance not reflected in labor cost
Other Cost	Additional costs for traffic management or other costs not included above
Comments	Additional comments that identify unusual aspects of maintenance event

Table 7-3. Initial Recommended Reporting Data for GI Maintenance Costs: Maintenance Activity Records

Maintenance Activity Detail (Activities conducted during maintenance event defined in Table 7-2)	
Asset ID	*Use number in asset management system, if applicable*
Maintenance Record ID	Maintenance Event ID (from Activity Table)
Sediment removal	(Provide yes/no check boxes for each activity performed)
Weeding/thinning/vegetation removal	
Plant replacement/seeding/sodding	
Supplemental Irrigation	
Mowing	
Fertilization	
Pruning	
Trash/debris/leaf removal	
Erosion repair	
Mulch replacement	
Inlet cleaning	
Outlet cleaning	
Vacuum/sweep surface	
Jet-Vac/subsurface vacuum	
Rechip permeable pavement	
Replace media	
Structural repair	
Clear pipes	
Mosquito control	
Algae control	
Rodent management/ address animal damage	
Other activity/comment	Describe other activities/provide comments

The information summarized in these tables could easily be adapted to a tablet application for use in the field to record maintenance activities as they occur rather than using additional staff time to transcribe field notes into an electronic format.

In addition to the descriptive elements in Tables 7-1 through 7-3, photos at the time of maintenance, facility diagrams, permits, and so on, could be linked to the facility information.

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CHAPTER 8
Conclusion

Like all stormwater control measures, GI practices require proper maintenance to perform over the long term. Experience is being gained nationally regarding maintenance needs and costs; however, a robust maintenance cost data set remains limited, based on the results of the survey conducted for this report and a review of existing cost resources. Here are the key findings of this research.

1. Many communities across the country have relatively young GI programs; therefore, robust GI cost data sets remain relatively limited at this time. Communities with young programs may be particularly receptive to recommendations for GI maintenance reporting protocols.
2. Greater consistency is needed in GI maintenance practice reporting to develop better long-term cost estimates for these practices. Although this report summarizes some existing available data and approaches that have been used to estimate maintenance costs, standardized reporting and data sharing through a centralized publicly available database such as the International Stormwater BMP Database would be useful to many local governments, contractors, and property owners. Initial suggestions for standardized reporting parameters have been provided in this report.
3. Maintenance costs vary based on many factors, such as the physical characteristics of the BMP, the intensity of surrounding land use, level of desired maintenance, design of the BMP, climate and weather, and the extent to which economies of scale are realized in larger municipal maintenance programs, as a few examples.
4. It is hypothesized that some communities may be underutilizing existing asset management and work order systems that could be useful in developing improved cost estimates for GI/BMP maintenance. A comprehensive review of features and maintenance management tools offered through these systems was not completed for this survey. As a next step in supporting communities in optimizing use of these systems, the MWIC task committees should complete a basic review of key features of these tools, including opportunities for customization. Examples of asset management systems used by the entities interviewed for this survey include CityWorks, Lucity, Maximo, and Hansen.

5. Bioretention facilities had the best-developed maintenance cost data set of all GI practices. Based on the survey conducted to support this report, the median annual maintenance cost for bioretention was \$0.68/sq ft, with a range of \$0.13–2.30/sq ft in 2015 dollars. This estimate is believed to be significantly affected by differences in activities included in the cost estimate among local governments. Other constraints include the fact that a minimum maintenance cost is incurred regardless of facility size; conversely, economies of scale are expected for larger facilities, so there are some limitations of a normalized cost per square foot approach. The total average annual reported maintenance cost for individual bioretention facilities included a median cost of \$850/year (range: \$250–3,880/year) in 2015 dollars. From the review of annual maintenance data provided by some data providers, costs can also vary substantially year to year.
6. It is recommended that this report be updated in two to three years, as more experience is gained with GI maintenance in more communities nationally.

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APPENDIX

BMP Cost Questions Focused on Green Infrastructure/ Small-Scale Distributed Controls

1. What kind of green infrastructure technologies to manage stormwater (stormwater BMPs) have you installed and used in recent years?
   a. Examples: permeable pavements (parking lots, green streets, green alleys), infiltration/filtering technologies (rain gardens, streetside and bumpout planters, green gutters, tree trenches and pits, infiltration basins and trenches, media filters), and green building technologies (green roofs, green walls, planter boxes, disconnecting downspouts, rainwater harvesting)
2. How many small-scale, distributed green infrastructure practices does your organization maintain? Is maintenance limited to practices in the public right-of-way or do you also maintain practices on private property (if so, under what conditions)?
3. Do you have written maintenance plans/requirements documented for these facilities?
4. Do you have maintenance cost data available that you would be willing to share? If so:
   a. How do you track maintenance requirements for GI practices?
   b. How do you plan/budget for maintenance—do you have a summary spreadsheet/ticketing/software system used to develop maintenance budgets?
   c. Do you have costs broken out by BMP type? By individual project?
   d. Do you track metadata/characteristics of the BMP being maintained as part of maintenance records (e.g., BMP design basis, size, tributary drainage area, land use, etc.)

   e. Do you incur "preventative" maintenance or pre-treatment costs that are not captured in the maintenance cost for facility? Example: street sweeping, proprietary device, upstream trash control, etc.
   f. Are maintenance costs for preventative, routine and restorative activities planned for/tracked separately?
   g. Are maintenance costs explicitly divided among categories such as equipment purchase/rental, labor hours, frequency of maintenance, activity type, etc., or are the costs tracked in a more general manner?
   h. How do personnel requirement vary for green infrastructure vs. traditional BMPs? Is the same labor pool used? Any special skills or additional training required?
5. Have you encountered any unique challenges maintaining GI/distributed controls relative to traditional BMPs?
6. How do you "ensure" maintenance for MS4 permit requirements?
7. Do you have other GI-related cost data that you could share? If so, are these broken down into subcategories such as engineering/planning/administration, construction, land costs, etc.?

Notes from SCSI Scope to Record in Master Spreadsheet:

1. Priority data:
   a. Personnel (including expertise and hours);
   b. Number, size (impervious acreage tributary), and age of facilities maintained;
   c. Equipment needs and use;
   d. Maintenance (proactive, routine, and restorative) procedures;
   e. Pre-treatment (including street sweeping and other structural pretreatment); and
   f. Costs outside of personnel and equipment.
2. Nonessential data:
   g. Annual budgets, stormwater master plans, and CIPs;
   h. Program structure and organization specific to stormwater;
   i. Software and other tools associated with stormwater needs assessment, maintenance activities, and compliance;
   j. Training programs; and
   k. Recommended design components to facilitate maintenance.

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