Inspection and Maintenance of Stormwater Control Measures

Stormwater Best Management Practices Maintenance Task Committee

ASCE

EWRI ASCE ENVIRONMENTAL & WATER RESOURCES INSTITUTE

Inspection and Maintenance of Stormwater Control Measures

Prepared by

Stormwater BMP Maintenance Task Committee

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Executive Summary

This guidance book is an introduction to the inspection and maintenance (I&M) of common stormwater control measures (SCMs). These measures include wet and dry swales, vegetated filter strips, bioretention and bioinfiltration, sand filters, wet ponds, stormwater wetlands, and extended detention basins (dry ponds). I&M protocols for other SCMs can be found in EWRI literature from respective task committees.

This book is structured to explain the function and operation of SCMs, as well as to provide suggestions on troubleshooting SCMs. Chapters 1 through 4 provide information for stormwater infrastructure asset managers (e.g., property owners, facilities managers, and municipal managers) on the implementation of I&M procedures to protect and sustain performance of stormwater infrastructure investments. Provided guidance is intended to be adapted by asset managers to regional and site-specific conditions. This guidance book is intended for use in I&M program planning, as well as in the field by maintenance personnel.

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CHAPTER 1
Literature Review

1.1 INTRODUCTION

ASCE recently reported on the environmental, economic, and social effects associated with aging infrastructure and reinforced the need for proper operation and maintenance practices to promote sustainability and resilience of US infrastructure systems. Essential to the performance of the nation's water resources, stormwater infrastructure includes best management practices (BMPs), also known as stormwater control measures (SCMs). ASCE/EWRI (Environmental and Water Resources Institute) has assembled a Stormwater BMP Maintenance Task Committee to assess and advance the current state of knowledge pertaining to the operation and maintenance of structural BMPs. Structural BMPs encompassed by the scope of the Task Committee include extended detention basins, wet ponds, stormwater wetlands, sand filters, bioretention practices, vegetated filter strips, bioinfiltration practices, and wet/dry swales. The BMP Maintenance Task Committee undertook a detailed literature review and developed a national survey to assess the effectiveness of current BMP operation and maintenance practices throughout the United States.

Pollution control technology has steadily advanced since the Federal Water Pollution Control Act (known as the Clean Water Act) was enacted in 1972. The field of stormwater management has arguably experienced more innovation over the last decades than any other environmental discipline. Unlike the treatment technologies implemented to address point source pollution, nonpoint source pollution controls have no universally agreed on maintenance protocols. When wastewater treatment plants are put into operation, a large volume of detailed information typically accompanies the facility, describing how the equipment is to be maintained and operated—often with live training and demonstrations. Such guidance is rare in the stormwater field. Operation and maintenance are often afterthoughts, if they are addressed at all.

Despite this lack of information, many states and municipalities have made regular inspection and maintenance of stormwater BMPs an ongoing legal requirement. For example, in St. Louis, Missouri, BMP owners are required not only to perform required inspection and maintenance but also to annually verify that such tasks have been completed (MSD 2006). In many locations, such as the city of Baltimore, recording of formal maintenance agreements outlining necessary maintenance and possible penalties for noncompliance are required

(Engineering Technologies Associates 2003). The various maintenance tasks required for BMPs may serve to not only meet legal requirements but also to ensure proper BMP function and to prevent flooding and negative effects to adjacent infrastructure. In addition, maintenance tasks ensure that BMPs stay aesthetically pleasing and gain community acceptance. Unfortunately, previous studies in Maryland and elsewhere have shown that maintenance of stormwater structures is often deferred or inadequate (Lindsey et al. 1992).

Maintenance tasks required for various BMPs may vary considerably, from simple mowing or litter pickup, to sediment removal, to full-fledged replacement of filter media or plantings. These tasks may be thought of as short-term (routine or more frequent), long-term (nonroutine or less frequent), and major restorative (rare) actions (Kang et al. 2008).

Some public agencies and municipalities offer guidance documents and protocols with respect to maintenance of structural stormwater BMPs (County of Los Angeles, Department of Public Works 2009, Hirschman et al. 2009, Minnesota Stormwater Steering Committee 2008, Southeast Michigan Council of Governments Information Center 2008, Upper Parramatta River Catchment Trust 2005, Wissink et al. 2003). Often, guidance in these documents is redundant from location to location but provides a useful reference or starting point when considering required maintenance. Conversely, inconsistencies or omissions in these documents highlight potential areas of concern, especially to those developing new protocols. Chapter 4 of this book, Management of Stormwater Controls, summarizes by general practice type several maintenance issues, schedules, and protocols from selected manuals and handbooks. Furthermore, it is worth noting that many BMP types have similar maintenance requirements (Hunt et al. 2005). For convenience, these practices are grouped as filter and infiltration practice maintenance, surface storage maintenance, and vegetative conveyance maintenance. General information related to stormwater BMP maintenance by practice type is presented in Section 1.2.

1.2 MAINTENANCE GUIDELINES AND PROTOCOLS

1.2.1 Filter and Infiltration Practice Maintenance

To improve function and increase longevity of stormwater control facilities, proper pretreatment is crucial, especially using infiltration practices such as infiltration basins, sand filters, permeable pavement, and bioretention. Pretreatment must be part of the design of the BMP. Without pretreatment, sediment or debris may impair the proper function of BMPs, resulting in clogging of filter media or infiltration beds or, in extreme cases, clogging of inflow, outflow, and overflow structures (Emerson et al. 2005). Accordingly, the design and installation of properly sized pretreatment devices, as well as attentive inspection and maintenance of pretreatment devices, or portions of the BMP dedicated to pretreatment, are necessary (Hunt et al. 2005a).

In addition to pretreatment, a key factor to ensure BMP functionality is stabilization of the upstream watershed before placing the BMP in operation (Emerson et al. 2005). This practice is particularly true of filtering or infiltration BMPs. Placing a filtering or infiltration BMP into operation while the upstream watershed is not stabilized is likely to result in clogging or fouling of the BMP, which may then require costly replacement or complete reconstruction. This requirement dictates that careful coordination between the sediment and erosion control plan, the site construction phasing, and BMP construction be considered in the earliest stages of the project design.

Filtration practices may fail because of clogging, which often results in standing water or filter bypass. Filters generally clog from the top down, so it may be possible to limit maintenance of clogged filters to the top few inches of the filter media. Filter media maintenance may range from rototilling the top 6 in. of filter media, to removing a layer of sediment layer and replacing the top 6 to 8 in. of filter media, to removing and replacing the entire media bed (Gulliver et al. 2010).

1.2.2 Surface Storage Maintenance

Surface storage BMPs include wet ponds, dry ponds, and stormwater wetlands. Some storage facilities may be quite large and may retain significant water volumes. As such, maintenance may require dredging or otherwise removing large quantities of sediment, often from pretreatment forebays (O'Louhglin et al. 1995). It should be noted that sedimentation BMPs may require large embankments, or even dams, with complex outflow devices or spillways. Accordingly, the design of such BMPs should take into account the required property rights for access and maintenance with heavy equipment.

Routine maintenance of various types of ponds generally includes facility inspection, inflow pipe inspection, cleaning of forebays or otherwise removing sediment, disposal of sediment, removal of debris and trash from outlet structures, and vegetation maintenance, including mowing. Structural repairs to outlets may be required on occasion, as may dredging of the pond (City of Durham 2008). If major dredging or reconstruction is required, the annual costs will be much greater.

1.2.3 Vegetative Conveyance Maintenance

Many BMPs such as vegetated buffer strips, wet swales, and dry swales make extensive use of plantings and landscaping. Plantings can be quite extensive and may represent a large investment. They can require the same sort of maintenance required for any landscaped area, such as replacement of dead plants, weeding, pruning, thinning, staking, and wound dressing. Care should also be taken to ensure that all plantings become established. This care may include watering, fertilizing, liming, and amending the filter media.

1.2.4 Universal Needs across BMP Types

Invasive species should be identified and immediately removed. These species can escape cultivation and reproduce in the wild, causing significant damage to native ecosystems. Additionally, invasive species can outcompete indigenous species and replace them in the wild (MSD 2009). Excessive plant growth may impede the function of outflow and overflow devices. Thus, particular care should be taken in these areas to ensure proper function of the BMP. In many localities, a reliance on native plantings increases plant survivorship and reduces the need for plant replacement. The deep root systems of native plants also help aerate the filter media and enhance infiltration.

Standing water, present in many BMPs, also presents a potential for the hatching and breeding of mosquitoes. This situation presents a public health risk that should be considered in the design and functioning of all BMPs. The presence of plantings and a functioning ecosystem, along with well-maintained BMPs, serves to provide many natural predators of mosquitoes and helps reduce their appearance.

1.3 CASE STUDIES

Understanding the maintenance burden associated with stormwater BMPs is critical not only in regard to stormwater management, but also to the proper budgeting and allocation of resources by municipalities, public agencies, and private stakeholders. This maintenance burden is influenced by factors such as BMP type, practice design, stakeholder community type, climate and other regional influences, and BMP maintenance approach (proactive versus reactive). The case studies described in the following sections of this chapter examine these facets, as well as different stakeholder approaches to gaining understanding of BMP maintenance burdens across three distinctive geographic areas of the United States.

1.3.1 California

As part of their BMP Retrofit Pilot Program, the California Department of Transportation (Caltrans) undertook a comprehensive study to understand life-cycle costs associated with the installation, operation, and maintenance of structural stormwater BMP retrofits. For this program, 36 total stormwater BMPs located within state-owned areas across Los Angeles and San Diego were studied (Caltrans 2004). The average annual precipitation volumes for Los Angeles and San Diego are 12.8 in. and 10.3 in., respectively (NOAA National Climatic Data Center 2011). This study marks one of the first significant evaluations of stormwater BMPs in a semiarid climate (Caltrans 2004).

During the three-year study period of the Caltrans BMP Retrofit Pilot Program, stormwater BMPs were inspected after every storm event. Operation maintenance and monitoring plans, along with site-specific inspection forms, were developed for this project to document all maintenance activities and costs. Using these data, maintenance burdens were summarized and evaluated for each stormwater BMP practice type. This evaluation includes the development of annual operation and maintenance unit costs for Caltrans operations. Unit costs

Table 1-1. Caltrans BMP Unit Costs

BMP Type	*Annual O&M Unit Cost (per m^3)*
Wet basin	$452
Extended detention basin	$83
Sand filter	$78
Biofiltration	$74
Infiltration trench	$71
Infiltration basin	$81

Source: Caltrans (2004).
Note: All units are 1999 US dollars.

were normalized by cubic meter of runoff volume that each BMP is designed to manage (Caltrans 2004). Caltrans' unit costs for structural BMP types encompassed by the scope of the ASCE/EWRI BMP Maintenance Task Committee are included in Table 1-1. The following paragraphs are concise summaries of notable study findings with regard to maintenance of these practice types.

A single wet basin was constructed, monitored, and maintained under the Caltrans BMP Retrofit Pilot Program. The majority of the maintenance burden for this practice was caused by vegetation management. This management included a significant burden associated with nonroutine vegetation management for mosquito control. Mosquitofish were introduced into the basin but were found to be only marginally effective. Caltrans also expressed concerns that wet basins may become habitats for endangered species, which could disrupt routine maintenance activities. Because only one wet basin was included in this program, the unit cost developed by this study may not be representative of other wet basins in Southern California.

Five extended detention basins were included in the study. Similar to the wet basin, the majority of the maintenance burden for these sites was caused by vegetation management and mosquito control. Unlined basins experienced no issues with vegetation establishment or erosion. Basin sedimentation measurements indicated that sediment removal may not be required for as many as 10 years, based on the criterion that removal should occur when sediment reduces the basin storage volume by 10%.

Six sand filters were constructed, monitored, and maintained under the pilot program. The only filter clogging observed was caused by cementing of the top layer of sand and not by sediment accumulation. In fact, no sediment removal was required during the three-year study period. Similar to the extended detention sites, sedimentation measurements indicated that sediment removal may not be required for as many as 10 years. The greatest maintenance burden associated with Caltrans sand filters was the operation and maintenance of pumps at sites where filters were not designed to operate solely by gravity flow. Lack of adequate maintenance access was also an issue for all sand filter sites.

Nine biofiltration sites were included in the study. Like the other vegetation practices, vegetation management was the largest maintenance burden for these sites. Irrigation was necessary to establish vegetation, and complete vegetation coverage was found to be difficult to maintain. Damage by burrowing gophers was also a problem at several sites.

Four infiltration practices were observed in the Caltrans study. These infiltration practices consisted of two infiltration trenches and two infiltration basins. Routine maintenance was found to be less for the infiltration trenches than for all other BMPs. This difference may be attributed to a lack of monitoring access for these practices. When clogging of these practices occurs, partial or complete reconstruction may be necessary; therefore, Caltrans unit costs may not be representative of long-term maintenance costs. The infiltration basins saw similar maintenance issues to those of the wet basin and the extended detention basins; the largest maintenance burden was attributed to vegetation management (Caltrans 2004).

1.3.2 Pennsylvania

The Philadelphia Water Department (PWD) Green Infrastructure Maintenance and Monitoring Program was initiated in 2009 to monitor, maintain, and track PWD green infrastructure practices. PWD green infrastructure practices, which include many of the structural stormwater BMPs encompassed by the scope of this BMP Maintenance Task Committee, are an integral part of the city of Philadelphia's Green City, Clean Waters Program for sustainable combined sewer overflow control (PWD 2011). Like the Caltrans study, PWD's maintenance and monitoring program is another example of a public organization taking the initiative to understand the maintenance burdens and lifecycle costs of stormwater BMPs. When comparing these two studies, regional influence may have an effect on maintenance burdens and costs because the city of Philadelphia has an average annual precipitation of 41.5 in. and can experience extreme winter temperatures not typically seen in southern California (NOAA National Climatic Data Center 2011).

The PWD Green Infrastructure Maintenance and Monitoring program began as a reactive maintenance program with the intent of resolving urgent issues. In 2010, this program expanded to include regular routine maintenance and monitoring of nine sites throughout Philadelphia. These sites consisted of bioretention sites, rain gardens, tree trenches, permeable pavements, and subsurface infiltration sites. PWD, working with the consulting firm AKRF, Inc. developed structured maintenance and monitoring protocols that include site-specific inspection forms with site feature mapping; routine monthly and post-storm event monitoring inspections and data collection by environmental and engineering professionals; and routine monthly and poststorm event maintenance visits by experienced and trained landscaping contractors.

Data collection and maintenance tracking are integral components of this program. Maintenance tracking consists of a database of measurements for sediment levels, water levels, and sinkholes within all BMP features; photo records of all BMP features before and after maintenance events; both imported and exported material quantities for site maintenance; labor effort at each site for each maintenance task; feedback or concerns from local residents; comprehensive monthly reporting; memorandums for special maintenance events and poststorm event inspections; and annual reporting with data analysis.

In 2010, the total maintenance cost for the nine monitored sites was recorded. Of this total, 64% was attributed to routine maintenance activities, and the other 36% was expended on special maintenance activities. Labor accounted for 77% of the total cost, and the remaining 23% was accredited to material costs. Routine removal of sediment and debris represented the largest portion of the total labor cost (23%). Labor costs exceeded material costs for all maintenance tasks except for replanting. The majority of the material cost for routine maintenance activities was dedicated to material removal from the sites (71%).

Some key performance issues identified in 2010 by PWD include sediment accumulation and erosion, settling and sinkhole formation, permeable pavement degradation, and target vegetation performance. Sediment accumulation rates were found to affect BMP performance at some sites. As expected, a strong correlation was observed between drainage area characteristics and sediment accumulation. Sediment loading for subsurface practices was not monitored because of a lack of maintenance access. As in the Caltrans study, this lack of access is a concern with regard to the long-term performance of these practices. Settling and sinkhole formation occurred at five of the nine PWD monitoring sites in 2010. This problem was identified as a serious maintenance and safety issue, possibly caused by insufficient compaction of subbase materials during construction. Porous pavement degradation may be attributed to installation issues and improper winter maintenance. Target vegetation performance was a common problem in all vegetated practices. Aside from vegetation performance, degradation caused by extreme weather, erosive flows, disturbance, and competition with invasive and aggressive nontarget species, some plants were simply not well adapted to site characteristics and BMP types. To address proper vegetation selection, PWD has expanded its maintenance tracking to include a vegetation database to more comprehensively assess species success for different BMP types and site constraints (PWD 2011).

1.3.3 Minnesota

Whereas the previous case studies described in this chapter examine individual BMP maintenance and monitoring programs, a study conducted by the University of Minnesota (UM) and the Minnesota Pollution Control Agency documents BMP maintenance efforts and cost across a wide range of local municipalities (Minnesota Stormwater Steering Committee 2008). A municipal public works survey was conducted for 28 Minnesota cities, 8 Wisconsin cities, and 2 Wisconsin counties (Erickson et al. 2010). Average annual rainfall ranges from 30.6 in. in Minneapolis to 34.8 in. in Milwaukee, which falls between the average annual rainfall totals that apply to the Caltrans and PWD studies (NOAA National Climatic Data Center 2011).

Similar to the Caltrans and PWD studies, the focus of the UM BMP Maintenance Survey was on parameters necessary to budget and schedule maintenance for various practice types. Data collected by the survey includes BMP types, inspection and maintenance frequencies, labor effort, maintenance complexity, factors reducing BMP performance, and maintenance costs. Of all the municipalities surveyed, more than half (61%) conduct routine maintenance at least once a year. Surface filters, wet ponds, dry ponds, filter strips, and swales were found to receive less frequent maintenance. Of filters and dry ponds surveyed, none were inspected or maintained more than once annually. Permeable pavements, underground sedimentation devices, and rain gardens were found to receive more frequent maintenance compared to other BMP types.

Most BMPs encompassed by the survey required a range of 1 to 4 hours for inspection and maintenance. Practices requiring vegetation management, such as constructed wetlands and rain gardens, typically required more staff hours than nonvegetated practices. Wetlands, sand and soil filters, and permeable pavements were identified as requiring moderate to complex maintenance activities. Maintenance associated with all other BMPs was classified as minimal to simple, meaning that a stormwater professional or consultant is needed on site less than half of the time. The most frequent factor found to reduce BMP performance was the accumulation of sediment, litter, and debris. The labor burden associated with sediment removal was identified as the most costly maintenance activity for all BMPs. For rain gardens, constructed wetlands, dry ponds, filter strips, and swales, invasive vegetation was found to be a substantial maintenance burden. Analysis of the survey results showed that maintenance costs are a significant portion of total BMP lifecycle costs. Analysis also revealed an economy of scale effect for maintenance costs of all practices except for rain gardens (Erickson et al. 2010). Further information regarding this study can be found in Erickson et al. (2010).

1.4 LITERATURE REVIEW FINDINGS

The detailed review of the maintenance guidance and protocols outlined in this chapter highlights several of the commonalities among these documents. Each document stresses the importance of ongoing maintenance to ensure proper functioning of BMPs, the costs for such maintenance, and the variety of activities required. Maintenance may vary from simple litter removal to dredging or reconstruction of various BMPs. All documents stress the importance of protecting BMPs from construction site runoff.

A wide variety of reporting and monitoring requirements are evident in the guidance documents. Varied approaches also exist to the preference of native versus ornamental plants and the approach to the control of invasive plant species. Many of these differences are expected, considering variations in local permitting and conditions. However, the differences also highlight the need for close attention to local plantings.

Case studies described in this chapter demonstrate varied stakeholder approaches to stormwater BMP maintenance and monitoring across three distinctive geographical regions. The Caltrans BMP Retrofit Pilot Program is an important first step in the assessment of the long-term sustainability of structural stormwater BMPs in southern California. Because the Caltrans study is one of the few comprehensive studies focused on stormwater BMPs in semiarid climates, further research and ongoing monitoring are necessary to confirm the study findings with regard to maintenance burdens and BMP unit costs. The fact that all study BMPs are retrofit projects located on California state-owned property may influence the practice loading rates and the associated performance and maintenance observations. Therefore, the results of this study may not be applicable to BMPs located across variable land uses and maintained by private stakeholders (Caltrans 2004).

The PWD Maintenance and Monitoring Program is an example of a municipality taking a proactive approach to understand BMP maintenance burdens and lifecycle costs; to improve practice performance through maintenance activities; and to properly budget and optimize physical and financial resources dedicated to maintenance. In recognition of the value of this undertaking, PWD expanded their program from nine sites in 2010 to 21 sites in 2011 and to more than 40 proposed sites for 2012. Ongoing monitoring and an expanded program scope strengthen the understanding of BMP performance and maintenance needs (PWD 2011).

The UM BMP Maintenance Survey documents maintenance efforts and cost across a wide range of municipalities in Minnesota and Wisconsin (Erickson et al. 2010). Throughout all case studies and geographic regions referenced, sediment accumulation was identified as a significant maintenance burden for all BMPs, and vegetation management was recognized as a substantial maintenance burden for all vegetated practices. Unit maintenance costs were observed to vary by BMPs and by general practice type. Because various reporting methodologies are used to develop maintenance unit costs, normalization is necessary to make direct comparisons. The development of a standardized method for the reporting of BMP maintenance burdens may be useful for evaluating current and future maintenance and monitoring studies.

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CHAPTER 2

National BMP Maintenance Survey

2.1 OVERVIEW

To advance the understanding of the current state of stormwater best management practice (BMP) operation and maintenance (O&M) in the United States, the ASCE/EWRI Stormwater BMP Maintenance Task Committee developed and conducted a nationwide survey of BMP owners, operators, and maintenance practitioners. The survey was composed of 28 questions related to maintenance planning and budgeting, inspection and monitoring, BMP performance issues, and routine maintenance and repair and/or replacement costs. The scope of the survey was focused on postconstruction BMPs and was limited primarily to structural BMPs. Specific BMP types that were the focus of the survey included extended detention basins (dry ponds), wet ponds, stormwater wetlands, sand filters, bioretention basins, wet swales, dry swales, infiltration trenches, and infiltration basins.

This chapter describes the survey respondents, provides a summary of survey results, and draws conclusions and recommendations. A complete collection of survey questions is included in the appendix of this book.

2.2 SURVEY RESPONDENTS

The survey received 21 total responses, and respondents were located across 11 states. Survey respondents consisted of professionals who represent the following general job descriptions: university facilities managers, department of transportation (DOT) environmental managers, DOT maintenance managers, military facilities managers, municipal department of public works (DPW) staff, park managers, stormwater management (SWM) maintenance contractors, and SWM regulators and inspectors. Those who responded have an average of 18 years of experience designing and/or maintaining BMPs, and more than half have obtained graduate level degrees (e.g., master of science). Professional certifications of respondents include professional engineer (P.E.), certified floodplain manager (CFM), certified professional in erosion and sediment control (CPESC), and certified hazardous materials manager (CHMM).

The respondents have significant experience with maintaining postconstruction BMPs in perpetuity, as 71% of respondents manage more than 10 facilities or properties with BMPs. Of these facilities and properties, 85% had been in operation for more than 10 years, and 50% had been in operation for more than 20 years at the time of the survey. Cumulatively, the group of survey respondents is responsible for the maintenance of more than 3,800 postconstruction stormwater BMPs, which manage more than 100,000 ac (40,469 ha) of impervious area. A summary of the information and experience shared through the survey by these respondents is provided in the next sections.

2.3 SURVEY RESULTS SUMMARY

2.3.1 Maintenance Planning and Budgeting

Survey respondents shared information related to planning and budgeting for BMP maintenance. The results of the survey returned worrisome data with regard to planning and budgeting; 56% of respondents indicated that they have no dedicated budget for stormwater BMP maintenance. Of those with a BMP maintenance budget, 71% indicated that they were over budget. More than two-thirds (78%) of respondents reported having maintenance plans in place for their BMPs, usually prepared by the design engineer. With regard to workforce and personal needs, 65% of respondents indicated that they believed special training was required for stormwater BMP maintenance. Significant annual time commitment for both professionals and maintenance crews was reported. Of the BMP types included in the survey, wet ponds were reported to require more annual maintenance effort than all other BMP types.

2.3.2 Inspection and Monitoring

Survey respondents provided feedback on inspection and monitoring of their BMPs; 84% of respondents state that they have inspection and/or monitoring programs for their BMPs. Reported BMP inspection frequencies varied significantly, from weekly visual inspections to quarterly and annual inspections. For example, one respondent reported that BMP inspections were limited to once every three years for roadway BMPs. Information provided on routine wet weather inspections was limited, with the exception of respondents who stated that these are conducted as a requirement to satisfy their industrial stormwater permits. Routine inspection and monitoring was typically reported as limited to a visual survey of BMPs; only 11% of respondents reported engaging in more quantitative performance monitoring.

2.3.3 Performance Issues

Survey respondents reported on their experience with BMP performance. Of all respondents, 72% keep some type of records of maintenance and/or performance.

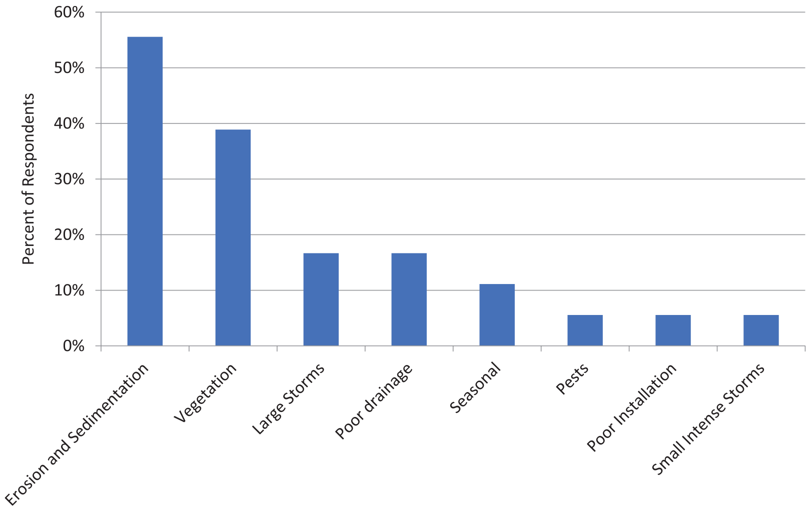

Figure 2-1. Summary of reported BMP performance issues.

BMP performance issues commonly reported during inspection and/or monitoring by respondents are summarized in Figure 2-1. The most common performance issues reported by respondents were related to erosion and sedimentation (56% of respondents) and to vegetation management (39%). Other reported performance issues were related to large storm impacts (17%), issues with poor drainage (17%), seasonal performance issues (11%), issues with pests (6%), issues related to BMP installation (6%), and issues during and after small intense storms (6%).

2.3.4 Routine Maintenance and Repair and Replacement Costs

Survey respondents were asked to report on their experience with typical annual routine maintenance costs for different BMP types. Data provided by respondents are summarized by BMP type in Figure 2-2. A range of costs was reported for wet ponds, detention basins, and sand filters; cost data provided for bioretention, infiltration trenches, and infiltration basins was limited to single data points. Costs of other BMP types were not reported by survey respondents. Reported maintenance costs ranged from up to $3,000 per year for wet ponds and detention basins to $250 per year for infiltration trenches and basins. Information was not provided by respondents on the size or scale of BMPs and on the scope of routine maintenance activities. There is a lack of data regarding the size information of BMPs, but economies of scale exist and if plotted by cost per acre treated, it would provide a different evaluation (Hunt et al. 2005b).

Survey respondents were also asked to report on their experience with major repair and replacement costs for different BMP types. Data provided by respondents is summarized by BMP type in Figure 2-3. A range of costs was reported for wet ponds, detention basins, sand filters, and bioretention; cost data provided for

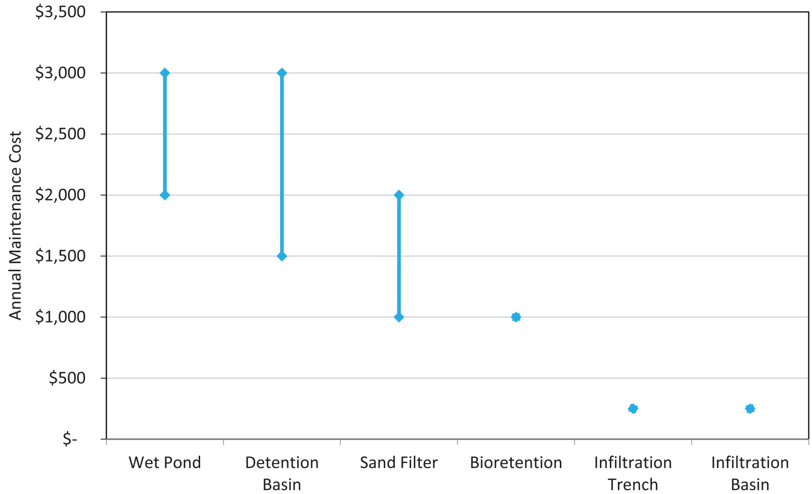

Figure 2-2. Reported annual routine maintenance cost by BMP type.

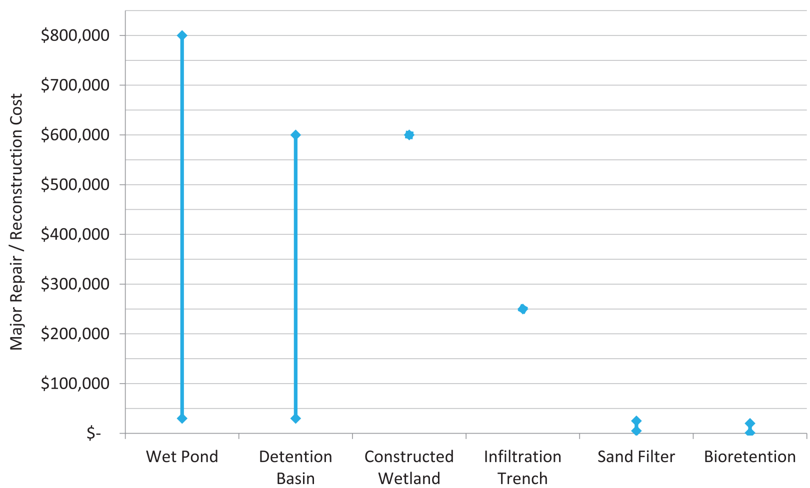

Figure 2-3. Reported major repair and replacement costs by BMP type.

constructed wetlands and infiltration trenches was limited to single data points. Costs of other BMP types were not reported by survey respondents.

The reported major repair and/or replacement costs varied significantly for both different BMPs and for the same BMP type. Reported wet pond repair and/or replacement cost had both the largest range, from $30,000 to $800,000, and the maximum reported cost for all BMP types. On the lower end of provided cost data, bioretention and sand filter repair and/or replacement costs were reported to range from $1,000 to $20,000 and from $5,000 to $25,000, respectively. Information was not provided by respondents on the size or scale of BMPs and on the scope of repair or replacement activities.

2.4 CONCLUSIONS AND RECOMMENDATIONS

The results of the survey provide high-level insights to the current state of O&M for stormwater management BMPs, while at the same time uncovering the need for a more comprehensive understanding of the resources required to maintain BMPs in perpetuity. Lack of routine maintenance cost data by BMP type reported indicates a knowledge gap and limited understanding of the resources needed to maintain different types of BMPs. This result is worrisome and is supported by the reported absence of maintenance budgeting specific to BMPs (56% of respondents without dedicated BMP maintenance budgets) and reports of inadequate funding by the majority of asset managers with BMP maintenance budgets (71% over budget).

Application of maintenance cost data collected by the survey is limited for the following reasons: (1) The size and scale and environmental conditions of the BMPs reported on is unknown, (2) the scope of routine maintenance activities is not defined for each data point, and (3) the number of data points collected by this survey does not allow for any BMP type comparisons to be made. It is recommended to conduct a detailed study or survey to develop a more robust data set of maintenance costs by BMP type. These data, if made publicly available, would provide asset managers with a significant resource for planning and budgeting and also could provide a resource for designers considering lifecycle costs when making decisions selecting postconstruction BMPs (Sandoval-Solis et al. 2011).

An encouraging finding of the survey is that the majority of the asset managers who responded to the survey are inspecting and/or monitoring their BMPs on a routine basis (84%) and keeping records of BMP maintenance and/or performance (72%). Although it cannot be concluded that this sample of asset managers is representative of the entire population, it is clear that there would be significant value in further investigating the BMP inspection, monitoring, and record-keeping programs of these asset managers. The goal of this effort would be to coalesce industry best practices both as a resource to asset managers to improve the efficiency and effectiveness of inspection and data collection efforts and as guidance for managers of programs that lack resources to develop inspection and data collection tools.

Based on the survey results, the most common BMP performance issues were related to erosion and sedimentation, and vegetation management. Further investigation is recommended about these common performance issues reported by respondents. Specifically recommended are follow-up interviews and/or surveys on causes and lessons learned related to erosion and sedimentation, and vegetation management issues. Furthermore, follow-up on the causes of reported BMP major repairs and replacements is recommended. These follow-up investigations can provide insights to asset managers and designers alike.

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CHAPTER 3

Tiered Inspection and Maintenance

3.1 SCOPE

This chapter introduces the concept of tiered inspection and maintenance (I&M). A tiered protocol for I&M can help managers understand the frequency of different I&M procedures, as well as staff needs, skills and training, and equipment.

3.2 TIERED INSPECTION AND MAINTENANCE

The recommended frequency of inspection and maintenance can vary for stormwater control measures (SCMs) in different settings based on SCM design goals, watershed and drainage area characteristics, regulatory requirements, and stakeholder interests. It is therefore important to incorporate an I&M program that considers these variable elements. Assessing I&M tasks using a tiered approach can help asset managers to optimize resources and promote sustained performance of SCMs. This document promotes a three-tiered I&M approach that includes routine (Tier 1), preventative (Tier 2), and rehabilitative (Tier 3) practices.

3.2.1 Tier 1: Routine Visual Inspection and General Maintenance

Inspecting for and correcting aesthetic issues should be performed by property maintenance personnel on a routine basis, especially for high-visibility SCMs in prominent locations. Maintaining visual appeal is important for community acceptance and awareness, and it ensures that preventative (Tier 2) and rehabilitative (Tier 3) maintenance issues are not overlooked. Many aesthetic issues can also indicate functional and safety problems. Scheduled Tier 1 inspections should be incorporated into standard property maintenance contracts (alongside lawn mowing and routine litter removal).

Example Tier 1 I&M activities include frequent visual inspections for functional issues such as trash, sediment, and debris (within the SCM, SCM outlets, and throughout the drainage area). These issues are easily resolved with minimal effort and simple gardening tools. Planting, pruning, mowing, mulching, and weeding (for vegetated systems) qualify as general maintenance and should be performed regularly. Mosquito control and reporting of unpleasant odors, plant die-off, or atypical water levels are signs of functional issues that may require Tier 2 or Tier 3 maintenance activities. Tier 1 I&M may be performed on a biweekly basis in areas that do not receive frequent rainfall (except when practices receive significant dry weather flows from irrigation overspray or other sources). Tier 1 measures serve as "first lines of defense" by which decision makers can monitor the SCMs under their management.

3.2.2 Tier 2: Scheduled Inspection and Preventative Maintenance

Extending the functional life of SCMs by identifying and preventing maintenance problems reduces the risk of expensive and potentially hazardous failures caused by neglect. Preventative maintenance, also known as cyclical maintenance, should be scheduled with trained SCM inspection staff based upon the type of SCM and the predicted rate of degradation (e.g., rate of sediment accumulation). However, routine Tier 1 I&M may indicate the need for required preventative maintenance (Tier 2) before the regularly scheduled interval.

Tier 2 inspection techniques could include infiltration tests; measurement of forebay or basin sediment depths; field visits after rain events to determine drawdown rates; investigation of filter media or pretreatment devices for excessive sediment accumulation; and inspection of the drainage area for sources of problematic pollutants (Brown, et al. 2010). Maintenance that should be scheduled as part of Tier 2 includes inlet cleaning; pipe jetting; repair and stabilization of erosion; outlet structure cleaning; removal of surface sediment deposits; minor structural repairs, such as repointing, lining, or parging; mitigation of sinkholes and settling; and invasive species control. Asset managers are strongly encouraged to consult a professional if they do not have the equipment or expertise to perform preventative maintenance tasks.

3.2.3 Tier 3: Rehabilitative Maintenance

In the event that Tier 1 or 2 I&M tasks fail to resolve the observed problems, or have been neglected, Tier 3 rehabilitative maintenance is the last resort. If critical functions are impaired, rehabilitative maintenance may be required to promptly restore SCM performance. Depending on the severity of the issue, rehabilitative maintenance (also known as reconstruction, emergency maintenance, or "red flag" situations) may require special contractors and equipment in addition to normal maintenance staff resources and should be arranged on an as-needed basis immediately after the identification of impaired functions. Also, the designer should always be consulted before major rehabilitative maintenance to ensure that the proper methods are used and that the integrity and design intent of the practice is kept. Tier 3 maintenance can be minimized or avoided by diligent Tier 1 and Tier 2 I&M protocols.

Tier 3 rehabilitative maintenance includes (but is not limited to) excavation and replacement of clogged filter media, permanent pool or forebay dredging, embankment replacement, outfall structure replacement, repair of major erosion, eradicating monoculture colonization for mosquito prevention, and major replanting if the system drowns.

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CHAPTER 4

Management of Stormwater Control Measures

4.1 SCOPE

This chapter defines types of stormwater control measures (SCMs). Practices are grouped into functional categories based on similar maintenance needs, and inspection and maintenance (I&M) are suggested for each functional category. For each specific practice, details are provided on the critical functions and design features that must be maintained to prevent failure. Many practices, especially hybrid systems, may be classified into multiple categories, so it is important for decision makers to understand the functions of specific systems under their management. A summary of functional SCM categories is included in Table 4-1, and specific SCM functions and design features are shown in Table 4-2.

4.2 VEGETATED CONVEYANCE PRACTICES

4.2.1 Description

Vegetated conveyance practices implemented as SCMs generally consist of vegetated drainage ways that both convey and treat stormwater. They can be used in combination with other SCMs. They are typically dry between storm events, though some are designed to remain wet at all times.

4.2.2 Identification

4.2.2.1 Dry Swale

Synonyms: Grass swale, drainage channel, grass channel, grassed waterway, and bioswale (if underdrained)

Dry swales are typically grass-lined channels that are integrated into sites as conveyance methods and are often constructed adjacent to roadways. They can appear similar to a drainage ditch, but they tend to be wide (side slopes ≥ 3:1) and/or have milder longitudinal slopes (e.g., <4%). There may be check dams

Table 4-1. Functional SCM Categories.

Category	*Practices*
Vegetated conveyance	Dry swale, wet swale, filter strip
Filter and infiltration	Bioretention and/or bioinfiltration (rain garden) and sand filter
Surface storage—Ponds	Wet pond, stormwater wetland or constructed wetland, extended detention (dry pond)

Table 4-2. SCM Functions and Design Features.

Feature	*Description*	*Function*
Vegetation	Dry or wet-tolerant species	Reduces erosion, slows velocities, and promotes treatment and sedimentation
Cross-sectional area	Mild, elongated slopes with shallow channel depths	Slows velocities to promote treatment and sedimentation
Subsurface (optional)	Matrix of filter media or stone storage from a depth of 2 to 5 ft. May include an underdrain	Stores, treats, and infiltrates or conveys stormwater
Storage volume	Volume where runoff is stored	Reduces flooding and provides sedimentation
Outlet structure	Often concrete structure that regulates overflow, and often slow-releases discharge	Slowly discharges water to reduce flooding and detains water for treatment

when steeper (longitudinal) slopes are encountered. Dry swales may incorporate underdrains and outlet structures if soils are not deemed suitable for infiltration and if wet swales are not desired for the location. In addition, dry swales also can incorporate soil amendments to enhance stormwater treatment of nutrients in watersheds where these pollutants are a high priority (e.g., Chesapeake Bay Watershed). Examples of dry swales are shown in Figure 4-1, and Figure 4-4 shows a dry swale cross section.

Figure 4-1. Examples of dry swales.

4.2.2.2 Wet Swale

Synonyms: Wetland channel, wetland swale, and wet channel

Wet swales are landscaped with vegetation that can withstand both periods of dry and wet weather and are designed to capture and sometimes infiltrate runoff. Wet swales are similar to dry swales, but they are not designed to convey runoff, only to capture, treat, and infiltrate it. These SCMs are typically located adjacent to roadways. Examples of wet swales are shown in Figure 4-2, and a cross section is shown in Figure 4-5.

Figure 4-2. Examples of wet swales.

4.2.2.3 Vegetated Filter Strip

Synonyms: Buffer strip, forest buffer strips, grass buffer, grass filter, and engineered filter strip

Vegetated filter strips are typically grass areas designed to treat sheet flow from adjacent impervious surfaces. These strips generally act as a buffer between impervious surfaces and wet or dry swales. Their function is mainly to mitigate

Figure 4-3. Examples of filter strips.

velocities from sheet flow and to encourage infiltration before runoff enters another management practice (e.g., wet swale, dry swale, or inlet). Unlike dry (and in some cases wet) swales, these filter strips are not generally designed to convey flow to a desired point. Examples of filter strips are shown in Figure 4-3, and a cross section is shown in Figure 4-6.

4.2.3 Functions and Design Features

Vegetated conveyance SCMs are designed to promote slower velocities and treat stormwater through filtering and sedimentation, and they can temporarily store

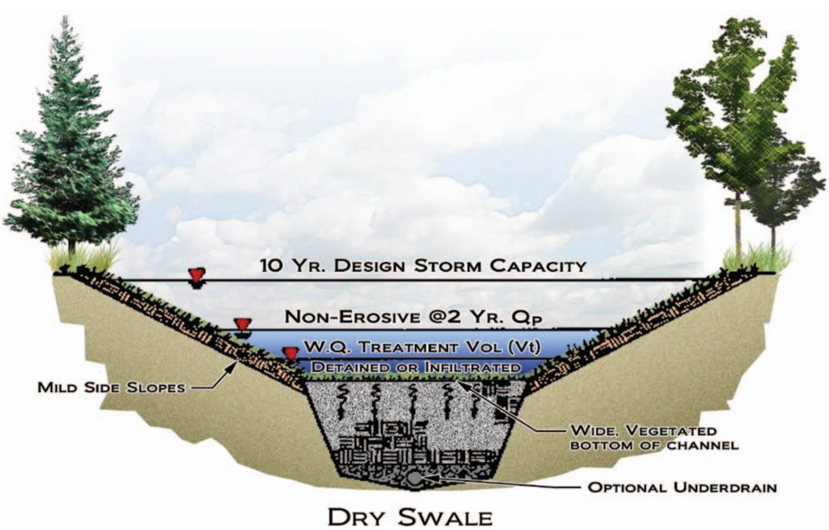

Figure 4-4. Cross-sectional concept of a typical dry swale.

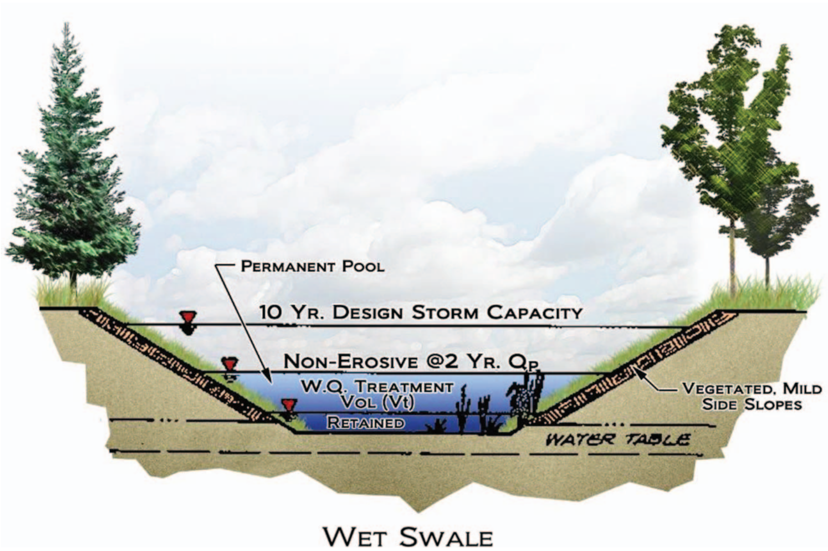

Figure 4-5. Cross-sectional concept of a typical wet swale.

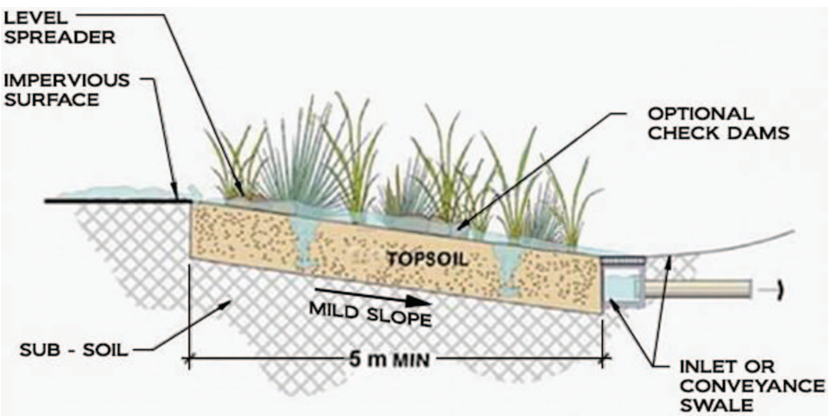

Figure 4-6. Cross-sectional concept of a vegetated filter strip.

stormwater, reducing peak flows. Figures 4-4 through 4-6 demonstrate design considerations for each of the aforementioned vegetated conveyance SCMs: dry swales, wet swales, and vegetated filter strips. Tables 4-3 and 4-4 describe typical design functions and typical inspection and maintenance tasks, respectively.

Table 4-3. Description and Functions of Typical Design Features: Vegetated Conveyance Practices.

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Vegetation	Vegetation should be selected based on the hydrologic regimes. Dry and wet tolerant plant species should be selected for wet swales, whereas grasses are typical to vegetated filter strips	Provides habitat and aesthetic values Extracts nutrients Stimulates beneficial soil microbes Roots mitigate soil compaction Shades the soil media	Plants wilting and/or dead Invasive plants present Bare soil	Identify cause of stress (overly wet or dry), address performance problems, and replace with plants more tolerant of extremes; remove invasive species, replace with native species
Soil media	Dry swale, if used: well-draining soils to filter stormwater. Soil may be amended with organic matter. Preferred soil media depth for vegetation is min 2 ft. Compaction should be minimized to keep filtration rates at 1–6 in./h	Remove sediment, nutrients, metals, organics, and other pollutants from stormwater Regulate flow rate	Standing surface water for excessive durations (greater than 24 h) Rills or gullies	Investigate media for clogging or compaction; remove restrictive layers or alleviate compaction by tilling if needed. Ensure sheet flow to facility. Add level spreader, soil stabilization matting, seeds, and mulch

Underdrain system	Needed if standing water occurs, by installing perforated plastic pipe at the bottom of the soil media. Underdrains can be connected into an existing drainage structure or may discharge to a location downstream. Cleanout ports allow for maintenance of underdrains	Drains excess water from the soil media when underlying soils are poorly drained or where infiltration is discouraged Prevents the formation of wetland conditions	Standing surface water for excessive durations (greater than 24 h)	Investigate underdrain for plant or animal obstructions, damage, or clogging; clean drain if necessary. CCTV investigation may be needed. Perform Tier 3 maintenance to repair or replace section of underdrain or stone as needed
Underlying soils	Native soils below conveyance feature. If soil is contaminated or poses hazards (e.g., swelling clays or sinkholes), consult engineer before altering this feature	Provide further treatment of pollutants Allow infiltration of stormwater into groundwater (when practicable) High water tables within allow for wetland swales	Standing surface water for excessive durations (greater than 24 h) and/or soil media smells "swampy" with gray, depleted colors forming, except in the case of wet swales	If underlying soils are too impermeable to infiltrate water in desired time, install underdrains (if not already present) or increase number of drains

(Continued)

Table 4-3. Description and Functions of Typical Design Features: Vegetated Conveyance Practices. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Surface detention area	Temporary surface ponding of stormwater with depths typically ranging from 6 to 18 in. Peak flows are reduced	Promotes infiltration into the soil media Partly determines volume of stormwater capture Allows sediment and trash to settle out Deeper depth allows more treatment	Practice overflows more frequently than intended, excessive mulch and debris deposits on outlet structure. Excessive sediment accumulation within the conveyance systems, pretreatment devices, or the SCM channel overflows or dries out	The surface detention volume may be too small; contact designer for ways to retrofit the system to increase average ponding depth. Stabilize eroded areas within the contributing drainage area. Check designed surface detention area vs. as-built surface detention area
Stable outfall	Location where the system is conveyed to an existing storm sewer, channel, or vegetated area	Delivers treated and bypassed stormwater to the receiving network in a nonerosive manner	Excessive erosion or sediment and debris deposits that cause water backup	Contact designer; may need to improve energy dissipation measures Excessive bypass of untreated water must be remedied

Table 4-4. Typical Vegetated Conveyance Practice I&M Tasks.

Tier	*Frequency*	*Inspection and Maintenance Tasks*
1: Routine inspection and maintenance	Weekly	Inspect for standing water (dry swale) Inspect permanent pool (wet swale) Inspect side slopes Record and report maintenance tasks In some cases, mow
	Monthly	Mow grass Inspect check dams Record and report maintenance tasks
2: Scheduled preventative maintenance	3 to 6 Months	Remove invasive species Remove any trees in side slopes Record and report maintenance tasks Test soil
	1 to 3 Years	Inspect underdrain, if present Scarify and replace permeable soil Record and report maintenance tasks Add lime to soil, if necessary
3: Rehabilitative maintenance	As needed	Replace features that prevent performance Inspect and/or replace underdrains, check dams, and outfalls Regrade swale or backfill voids Record and report maintenance tasks

4.3 FILTRATION AND INFILTRATION PRACTICES

4.3.1 Description

Stormwater control measures (SCMs) that have stormwater flowing through filter media require similar inspection and maintenance (I&M) tasks. Stormwater typically enters filter and infiltration practices by gravity. Pretreatment practices are often incorporated into the designs to remove trash, debris, and larger sediment. Pretreatment can be provided by features such as swales, vegetated filter strips, forebays, inlet filter bags, trash racks mounted over conveyance pipes, or grit chambers. Stormwater then passes vertically through media such as sand, native soil, or an engineered soil mix, where pollutants are removed. The stormwater is temporarily stored in this subsurface medium before seeping into the underlying soils or draining through an underdrain to be released into an outlet. Filtering practices can be vegetated (e.g., bioretention or bioinfiltration) or can have media subsurface (e.g., sand filters) that influence specific maintenance tasks (Emerson et al. 2008).

Although this section focuses on bioretention and/or bioinfiltration and sand filters, there are other SCMs that incorporate filtration, such as infiltration trenches, permeable pavements, vegetated conveyance practices (Section 4.2), and some cisterns, but their I&M needs are detailed in other guidance documents. Typical locations for filtration and infiltration SCMs are parking lot islands, roadway medians, traffic circles, perimeters of development sites, downspouts of residential lots, schools, parks, and public spaces. This section presents (1) identification of filtration and infiltration practices with a description and picture for all types; (2) design features, maintenance indicators, and recommended remediation tasks; and (3) a table outlining the tiered inspection and maintenance tasks for filtration and infiltration practices.

4.3.2 Identification

4.3.2.1 Bioretention and/or Bioinfiltration

Synonyms: Rain garden, biofilter, biocell, and bioswale

Bioretention and/or bioinfiltration (hereinafter referred to as rain garden) facilities are shallow, vegetated basins designed to collect, detain, and treat stormwater runoff from small drainage areas. These practices are composed of a depressed area that can be located in a wide range of settings depending upon site constraints and design goals. These practices are located downslope of stormwater flow paths and can accommodate rainfall volume from larger drainage areas. Surface water is designed to pond for no more than 24 h after a storm in most cases so that permanent pools do *not* occur under normal conditions. When bioretention facilities are installed on a slope to allow for stormwater conveyance, they are known as bioswales. These systems should be inspected and maintained using principles of both rain gardens and swales (Sections 4.2.2.1 and 4.2.2.2). Examples of bioretention and/or bioinfiltration practices are shown in Figure 4-7.

4.3.2.2 Sand Filter

Synonyms: Underground sand filter, Austin sand filter, and Delaware sand filter

Sand filters are used for water-quality improvement. They consist of multiple chambers and filter media used to treat stormwater runoff. The runoff is typically piped into the system, treated through the sand filter media, and then discharged to a stable outlet or storm drain system by an underdrain. The facility can be used in ultraurban areas or areas with limited space. Regular maintenance is necessary to avoid any clogging in the media. Figures 4-8 and 4-9 show examples of an underground sand filter and a surface sand filter, respectively.

Figure 4-7. Example of rain garden facilities: A: Recently constructed facility at an elementary school; B: bioretention treating rooftop and parking lot runoff; C: bioretention facility in parking lot island; D: small rain garden in residential setting.
Source: NCSU (2012).

4.3.3 Functions and Design Features

4.3.3.1 Bioretention and/or Bioinfiltration (Rain Garden)

Stormwater may flow into bioretention by sheet flow (diffuse overland flow, such as from a parking lot) or concentrated flow (through discharge from a curb cut, pipe, or swale). Pretreatment of sheet flow typically occurs in a gravel verge and vegetated strip along the bank of the cell (as illustrated in Figure 4-6), or with a small detention basin that can trap sediments. For concentrated inflows, a forebay or other pretreatment device (energy dissipater, filter bag, trash guard, or a proprietary product) calms the flow and either captures or allows larger sediment to settle out of solution, thereby extending the life of the filter media within the practice. It is important that inflow areas and the perimeter remain stabilized because these areas are susceptible to erosion that leads to sediment buildup and clogging of the filter media. Mulch is used in many bioretention facilities and should be considered a maintenance item. Mulch may become infested with

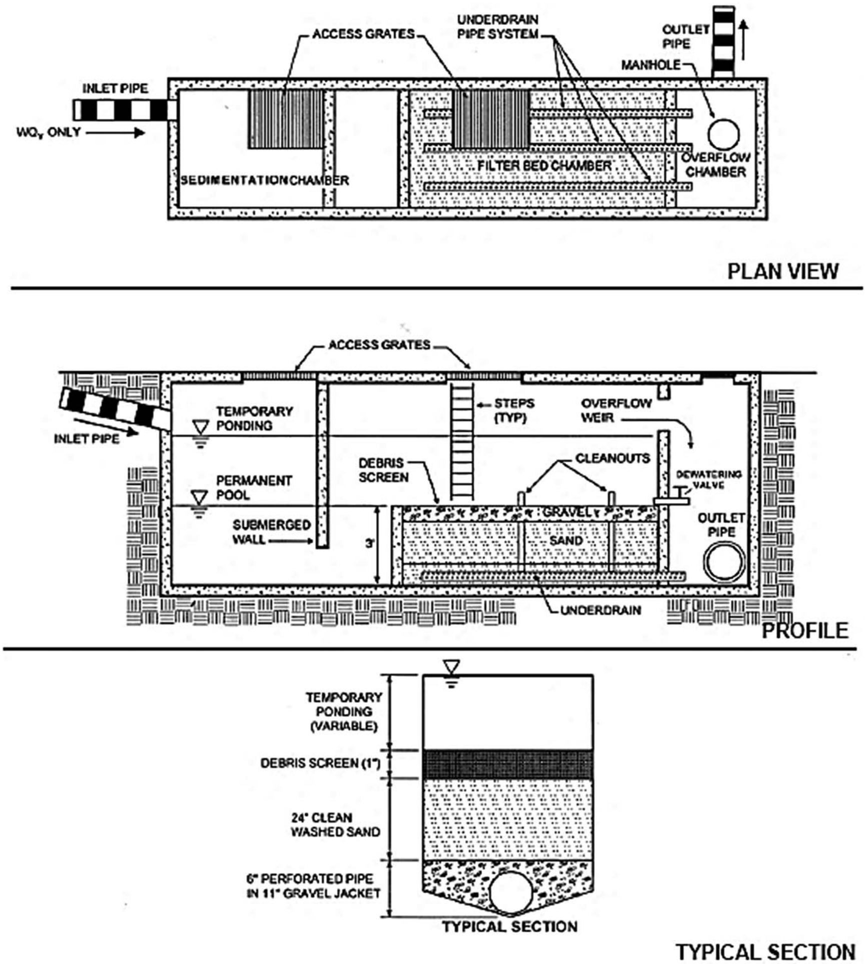

Figure 4-8. Example of underground sand filter section.
Source: Maryland Stormwater Design Manual (2000).

vectors or laden with sediment, or it may float and displace. Thus, it is recommended that mulch be removed and replaced approximately once every two to three years (Hunt and Lord 2005).

After flowing through pretreatment devices (if present), stormwater enters the filter media and temporarily ponds before percolating through the subsurface media, as shown in Figure 4-10a. An outlet structure can be used to control the ponding volume above the basin if specific ponding depths are desired; it safely bypasses large storms. As stormwater percolates through the media, pollutants are treated by physical, chemical, and biological processes via the media and plants. Stormwater can infiltrate, drain to an outlet point through the underdrain, or be

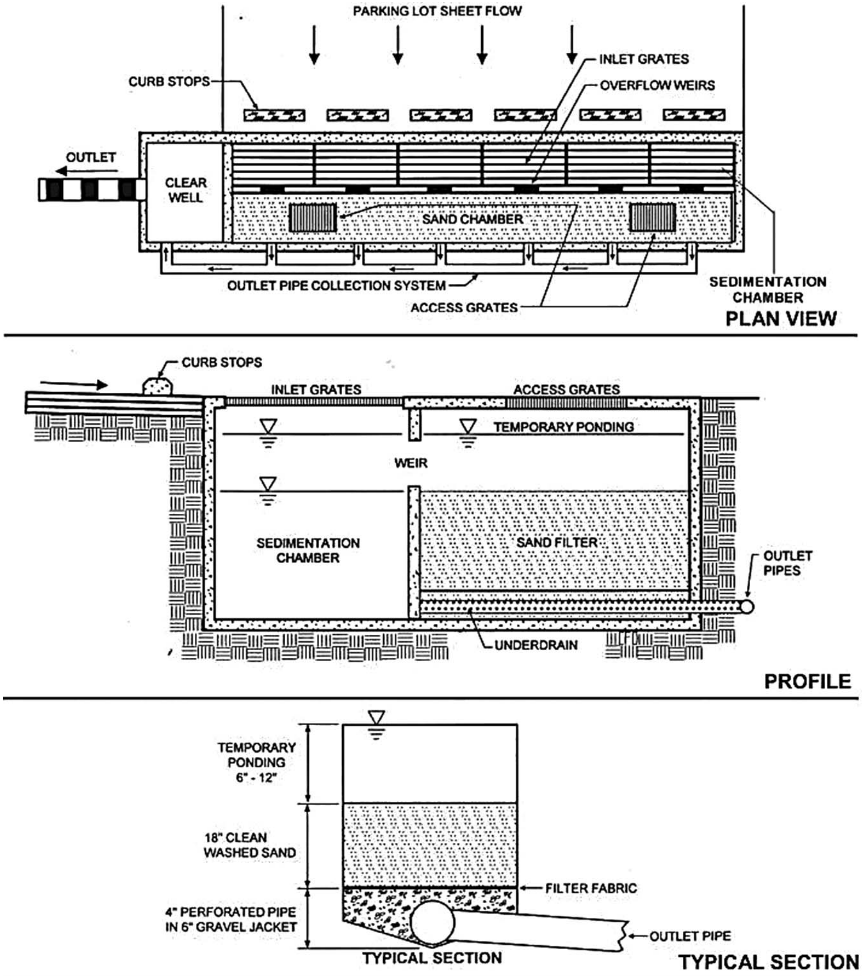

Figure 4-9. Example of surface sand filter section.
Source: Maryland Stormwater Design Manual (2000).

taken up by plants and then released into the atmosphere. These processes are intended to mimic the water cycle of a natural landscape. Where nitrogen removal is desired, designers can provide an upturned underdrain pipe to create a sump and internal water storage layer within the media. Treated stormwater and untreated overflow leave the site through the outlet control structure, which may outfall to a storm or combined sewer infrastructure or to a nearby ditch, stream, or vegetated area, as shown in Figure 4-10b. Figure 4-10a, 4-10b, and Table 4-3 show and describe the typical components of a rain garden SCM. Table 4-4 describes the typical vegetated conveyance practice I&M tasks, and Table 4-5 describes typical maintenance tasks.

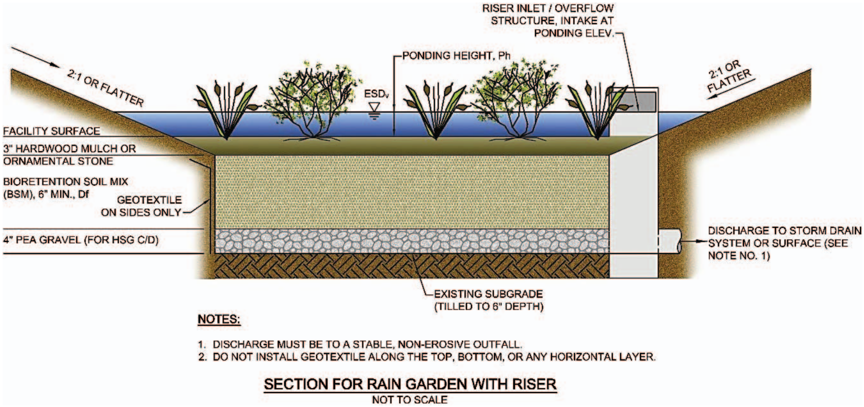

Figure 4-10a. Concept of typical rain garden with riser (see also Table 4-3).

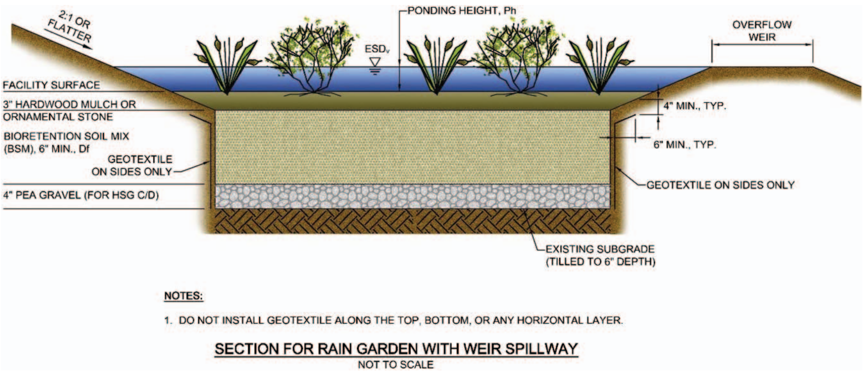

Figure 4-10b. Concept of typical rain garden with weir spillway (see also Table 4-3).

4.3.3.2 Sand Filter

A sand filter can be constructed using partially buried concrete chambers or installed with the surface exposed at grade, but both are designed to treat stormwater through sand filtration. In subsurface sand filters, there are generally three chambers. The first chamber removes debris; the second contains layers of gravel, sand, and filter fabric; and the third chamber discharges filtered water through an underdrain to a stable outlet or storm or combined sewer system. For surface sand filters, stormwater is ponded within basins similar to rain gardens, where water infiltrates the sand media and is ultimately released into the underlying soils or through an underdrain to a stable outlet or storm or combined sewer system. Figure 4-11 and Table 4-6 describe the typical components of sand filters. Table 4-7 describes typical maintenance tasks.

Table 4-5. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Bioretention and Bioinfiltration SCMs.

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Drainage area	Surfaces upslope from the bioretention facility that contribute stormwater runoff, including pavement, landscaped areas, and rooftops	Proper installation of erosion and sediment control measures for earth-disturbing construction in the drainage area is important to the long-term performance of filtering practices	Excessive sediment accumulation within the conveyance systems, pretreatment devices, or the SCM	Stabilize eroded areas within the contributing drainage area
Stabilized inlet and/or pretreatment	Location where stormwater runoff enters the bioretention cell. For sheet inflow, gravel verge or turf fringe are typically used. For concentrated inflow, a rock-lined basin or sediment box is used	Flow dissipation Erosion control Initial settling of sediment	Erosion forming where flow enters	Use permanent soil stabilization techniques (stone, matting)
			Excessive sediment, trash, debris buildup. Water cannot pass freely through inlet	Remove accumulated materials

(Continued)

Table 4-5. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Bioretention and Bioinfiltration SCMs. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Hardwood mulch	2 to 4 in. of hardwood mulch over filter area. Pine bark and other forms of mulch tend to float and should not be used. Note: Mulch is not necessary in systems completely vegetated with turf grass	Retains soil moisture for plant health Controls weeds Reduces soil erosion and compaction Absorbs oil, grease, and metals Filters trash and other coarse sediment Promotes beneficial soil microbes	Mulch layer excessively thick or overly decomposed (greater than 4 in.) Sediment buildup in mulch formed a "caked" layer Mulch layer too thin (less than 1 in.)	Remove excessive buildup of decomposed mulch Stabilize source areas of sediment and remove or replace mulch Restore mulch depth
Vegetation	Woody or herbaceous vegetation within the cell. May include trees, shrubs, or grasses. Turf grass, when used, should cover the entire surface of the bioretention cell	Take up (transpire) soil water Provide habitat and aesthetic values Extract nutrients from soils Stimulate beneficial soil microbes Roots mitigate soil compaction Shades the soil media	Plants wilting and/or dead Plants overgrown	Identify cause of stress (e.g., overly wet or dry), address performance problems, and replace with plants more tolerant of conditions Prune and/or mow to allow access to facility for inspection, and increase safety

Soil media	A well-draining soil mix to filter stormwater. Soil specification varies, but sandy loam soils amended with organic matter are typical (may use native soils if appropriate). Depth of media ≥2 ft, and compaction should be minimized to keep filtration rates at 1–6 in./h	Removes sediment, nutrients, metals, organics, and other pollutants from stormwater Supports plant growth Stores stormwater and regulates rate of outflow	Standing surface water for excessive durations (greater than 24 h)	Investigate media for clogging or compaction; remove restrictive layers or alleviate compaction by tilling if needed; may need to replace media
			Soil media smells “swampy” and gray, with depleted colors forming	Poor subsurface drainage; inspect underdrains (if present), drawdown rate (using observation wells), and contact designer for solution; may need to replace media

(Continued)

Table 4-5. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Bioretention and Bioinfiltration SCMs. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Underdrain system	Perforated plastic pipe at the bottom of the soil media that ties into drainage structure or discharges to surface. Cleanout ports allow for maintenance of underdrains. May include an inverted elbow to create a sump for internal water storage	Drains excess water from the soil media when underlying soils are poorly drained or where infiltration is discouraged (i.e., contaminated soils) Prevents the formation of wetland conditions	Standing surface water for excessive durations (greater than 24 h)	Investigate underdrain for plant or animal obstructions, damage, or clogging; clean or jet drain if necessary
Observation wells and cleanouts	Plastic standpipes in bioretention cells connected to the underdrain system. Note: Caps should be watertight to prevent ponded surface water from bypassing the soil filter media	Used to observe water levels within soil media that aids in determining filtration performance Allows access to underdrains for inspection and cleaning	Missing or broken surface cap	Repair and replace with watertight cap

Drainage gravel	Layer of gravel surrounding the buried underdrain pipes. Pea gravel is often used	Prevents soil media from clogging holes in underdrain	Standing water in facility or observation well	CCTV and jet underdrain; if ineffective, replace gravel
Underlying soils	Native soils in which the bioretention cell is constructed. Note: Native soils may be contaminated from past uses or may pose hazards associated with swelling clays or sinkholes; the designer should be contacted before altering the soil–water interactions of the bioretention cell	Provide further treatment of pollutants Allow infiltration of stormwater into ground (when practicable)	Standing surface water for excessive durations (greater than 24 h) and/or soil media smells “swampy” and gray, depleted colors form	Underlying soils are too impermeable to infiltrate water in desired time; install underdrains (if not already present) or increase number of drains
Surface detention area (bowl)	Temporary surface ponding of stormwater with depths ranging from 6 to 18 in.	Promotes filtration into the soil media Partly determines volume of stormwater capture Allows sediment and trash to settle Deeper depth allows more treatment Detains water for peak flow mitigation	Practice overflows more frequently than intended, excessive mulch or debris deposits on outlet structure. Collection of trash	The surface detention volume may be too small; contact designer for ways to retrofit the system to increase average ponding depth. Remove mulch or sediment if too thick. Media may be clogged and need to be replaced. Remove any trash

(Continued)

Table 4-5. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Bioretention and Bioinfiltration SCMs. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Overflow or outlet structure	Outlet structure or stabilized overflow area that allows bypass of large storms and provides an outlet for optional underdrain pipes. Unlike traditional drainage structures, the outlet should be elevated 6 to 18 in. above the mulch surface to allow ponding in the surface detention area	Controls surface ponding depth (to prevent nuisance flooding) Regulates volume of stormwater captured Provides outlet for treated stormwater	Mulch found outside basin, standing water in facility, upstream features experience backups, adjacent flooding	Remove and clean trash rack weirs and orifices, inspect outfall piping (CCTV if needed), flush piping high-pressure water, run pipeline pig through piping, replace or reline piping as needed
			Practice overflows more frequently than intended, excessive mulch or debris deposits on outlet structure	Outlet structure may be installed too low; contact designer for ways to retrofit the system to increase average ponding depth
			No surface ponding during rainfall	Inspect structure to ensure that surface water is not flowing in through damaged areas; seal or grout any leaks to allow surface ponding

Stable outfall	Location where the system outlets to an existing storm sewer, channel, or vegetated area	Delivers treated and bypassed stormwater to the receiving network in a nonerosive manner	Excessive erosion	Contact designer; may need to improve energy dissipation measures
			Excessive sediment or debris deposits causing water backup	Contact designer; excessive bypass of untreated water must be remedied

Figure 4-11. A: Filter chamber of underground sand filter contained in Towson University parking garage; B: Filter media chamber and bypass pipe; C, D, E: surface sand filter from University of New Hampshire; F: exposed surface sand filter, Montgomery County, Maryland Department of Environmental Protection.

4.4 SURFACE STORAGE PRACTICES

4.4.1 Description

Surface storage practices are facilities that temporarily or permanently store and treat runoff before releasing it downstream. The main functions of surface storage SCMs are to control the peak runoff rate and remove pollutants through sedimentation, vegetation, and soil–water contact interactions. Typical locations for surface storage SCMs are low points or depressions along the perimeter of development sites, adjacent to roadways, regions where the water table is exposed or close to the surface or with restrictive underlying soil. This section presents (1) identification practices with a description and picture for all types; (2) design features, maintenance indicators, and recommended remediation tasks; and (3) a table outlining the tiered inspection and maintenance tasks for each surface storage practice.

Table 4-6. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Sand Filter SCMs.

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Drainage area	Surfaces upslope from the bioretention facility that contribute stormwater runoff, including pavement, landscaped areas, and rooftops	Proper installation of erosion and sediment control measures for earth-disturbing construction in the drainage area is important to the long-term performance of filtering practices	Excessive sediment accumulation within the conveyance systems, pretreatment devices, or the SCM	Stabilize eroded areas within the contributing drainage area
Pretreatment forebays	Stills the water entering the BMP before it moves into the sand-filled filter chamber	Removes any debris as it enters the vault through temporary ponding	Sediment and debris accumulation	When sediment accumulates to 6 in. deep, remove sediment and sediment-laden water and dispose of it at an approved location
Filter chambers	Pass water through stone, sand, and gravel	Temporarily hold a large portion of the water quality volume. Reduce pollutants entering the sand filter	Water not draining out of chambers Noticeable odors Erosion Sediment accumulation Sediment discoloration	Remove any excess water Check for surface clogging of filters Remove and replace old stone and excess sediments May require toxicity testing

(Continued)

Table 4-6. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Sand Filter SCMs. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Water holding chambers	Discharges treated stormwater from the sand filter	Releases water that has passed through the entire sand filter	Leakage, water not holding at normal pool elevation	Repair using grout or parging to achieve normal operation
Structural components	Concrete vault encasing filter, manholes, trash rack, pipes, and pipe joints	Contain and filter water through the BMP	Evidence of structural deterioration, spalling, or cracking	Repair to good condition Possible lining of facility needed
Outlets	Location where the system outlets to an existing storm sewer, channel, or vegetated area	Delivers treated and bypassed stormwater to the receiving network in a nonerosive manner	Evidence of erosion, rills, or gullying	Stabilize all eroded areas and grade to provide stable conveyance
			Riprap outlet not functioning properly	Repair or replace riprap and filter cloth

Table 4-7. Typical Filter and Infiltration Practice I&M Tasks.

Tier	*Frequency*	*Inspection and Maintenance Tasks*
1 Routine Visual Inspection and Maintenance	Weekly	Remove litter and debris. Inspect for and repair surface damage (e.g., erosion in drainage area, vandalism, vehicle-induced damage) and report to manager. Remove buildup of debris from inlet and/or inflow device and outlet and/or overflow device. Observe watershed and/or drainage area condition.
	Monthly	Inspect outlet device for clogging. Identify and report abnormal surface water conditions (e.g., discoloration, mosquito larvae, odors, and invasive species). Remove buildup of sediment within pretreatment areas (if applicable) and filter media. Record and report issues that may require Tier 2 maintenance. Mow.
2 Scheduled Preventative Maintenance	3 to 6 Months	Investigate inflow area and outfall for erosion damage and repair. Open observation wells, record water level. Walk embankment and ensure stability. Record and report maintenance tasks.
	1 to 3 Years	Inspect drain lines for damage or sediment buildup. Assess filtration rate into underlying soils (observe drawdown rate in observation wells or cleanout pipes). Investigate surface drawdown rate (by field testing or observation after large rain event). Clean inlets. As necessary, inspect pipe and underdrain jetting. Inspect all structural features. Record and report maintenance tasks.

(Continued)

Table 4-7. Typical Filter and Infiltration Practice I&M Tasks. (Continued)

Tier	*Frequency*	*Inspection and Maintenance Tasks*
3 Rehabilitative Maintenance	As needed	If filter media appears clogged, remove top 2 to 6 in. to restore filtration. Rehabilitate deteriorated vegetation by replanting. Remove surface clogging layers or till soil to alleviate compaction if performance is deteriorating. If subsoil interface has clogged (for infiltrating systems), consult with designer to determine infiltration performance. If appropriate, excavate filter media to remove restrictive layer or replace with new media. If piping is clogged, flush piping via access points. If surrounding vegetation is damaged, replace it. Record and report maintenance tasks.

For surface storage practices, unchecked vegetation growth can lead to colonization of the SCM by vegetation prone to harboring mosquitoes. Hunt et al. (2006) and Greenway et al. (2003) demonstrated that the presence of the *Typha* species and certain tree species such as *Salix nigra* both contributed to an increase of mosquito population. If SCMs become breeding grounds for mosquitoes, the risk of disease increases, causing concerns for public health. To avoid these issues, designers can plant species such as *Pontederia cordata* and *Sagittaria latifolia*, which are known to be conducive to rapid growth and attracting mosquito predators (Hunt and Lord 2006).

4.4.2 Identification

4.4.2.1 Wet Ponds

Synonyms: Retention pond, wet extended detention pond, and stormwater pond

Wet ponds hold runoff in a pool area to treat stormwater, primarily by sedimentation. Wet ponds can be used for water-quality improvement, downstream flood control, or to reduce the peak runoff rate to a predevelopment rate. Stormwater is directed to the permanent pool after storm events, and pollutant removal occurs through settling and biological activity in the pond. Downstream erosion potential can be minimized through the slow release of water stored in the pond.

Wet ponds are not feasible in arid climates because of the nature of the permanent pond, which needs a water supply. A large contributing drainage area of at least 10 ac (4.0 ha) is necessary to maintain a permanent pool. Wet ponds can be combined with other stormwater practices to improve pollutant removal rates.

4.4.2.2 Stormwater Wetlands

Synonyms: Constructed wetlands, engineered wetlands, and constructed stormwater wetlands.

Constructed stormwater wetlands (CSWs) are wetlands designed to treat stormwater. Stormwater wetlands can be used for water-quality improvement, downstream flood control, channel erosion control, or to reduce the peak runoff rate to a predevelopment rate. A large drainage area of at least 10 ac (4.0 ha) is necessary to maintain the permanent pool and wetland plants. Wetlands are generally shallow, with intermittent regions of deep pools (Figure 4-12). CSWs are permanently wet surface storage areas where wetland plants are present in a shallow pond used to remove pollutants by settling and filtering through vegetation and sediments. Because this type of SCM uses wetlands as its means to treat runoff, SCMs have significant potential for stormwater quantity and quality management. There are two types of CSWs: surface and subsurface flow. Surface-flow wetlands (as shown in Figure 4-12) encourage natural ecosystems because the water is exposed to the atmosphere, but they require large amounts of land, whereas subsurface flow wetlands (Figure 4-13) are generally used when space is limited. Wetland plant species, soil media, microorganisms, and natural ecology allow for removal of pollutants, reduction of runoff velocities, and hydrograph peak mitigation.

4.4.2.3 Extended Detention

Synonyms: Dry pond, enhanced water-quality basin, extended detention pond, and detention pond

Extended detention (Figure 4-14) differs from wet ponds and CSWs in that it does not maintain a permanent pool of water because this basin dewaters between events. Extended detention basins can be used for water-quality improvement, downstream flood control, or to reduce peak runoff rate to a

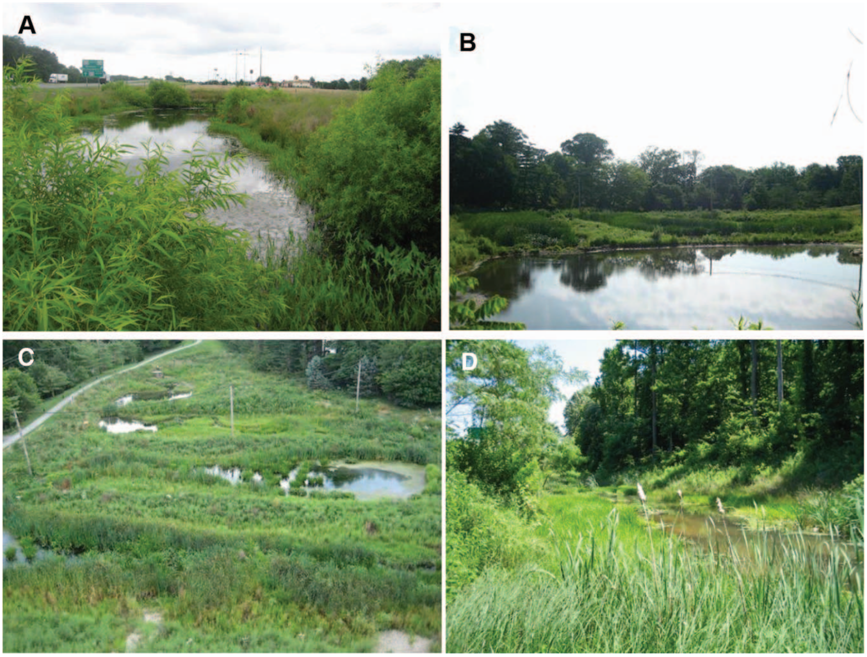

Figure 4-12. Example of wet ponds (A, B) and stormwater wetlands (C, D).

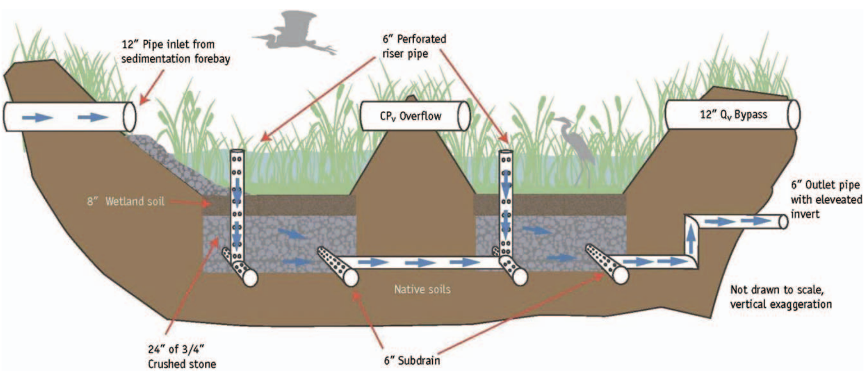

Figure 4-13. Gravel subsurface flow stormwater wetland schematic.
Source: Roseen et al. (2012).

predevelopment rate. Runoff is directed to the basin after a storm event and released through a controlled outlet structure. Pollutants settle during the detention period.

Figure 4-14. Extended detention basin with control structures. (A, B) Dry pond with control structure. (C) Extended detention pond undergoing rehabilitative maintenance. (D) Weir wall outlet structure.
Source: A, B: chesapeakestormwater.net.

4.4.3 Functions and Design Features

4.4.3.1 Wet Pond

Synonyms: Retention ponds

Wet ponds hold a permanent pool of water to which stormwater is directed. The permanent pool promotes settling of particles. Figures 4-15 and 4-16 and Table 4-8 describe typical design features. The forebay in particular is an integral part of the wet pond, especially from a maintenance perspective, because it increases the longevity of the pond. The aquatic bench promotes growth of wetland and aquatic plants and reduces shoreline erosion. Typical inspection and maintenance tasks are described in Table 4-11.

4.4.3.2 Stormwater Wetland

Inlet pipes typically empty into the forebay of the wetland. This region of deeper water allows for larger and heavier sediment-borne pollutants to settle out of

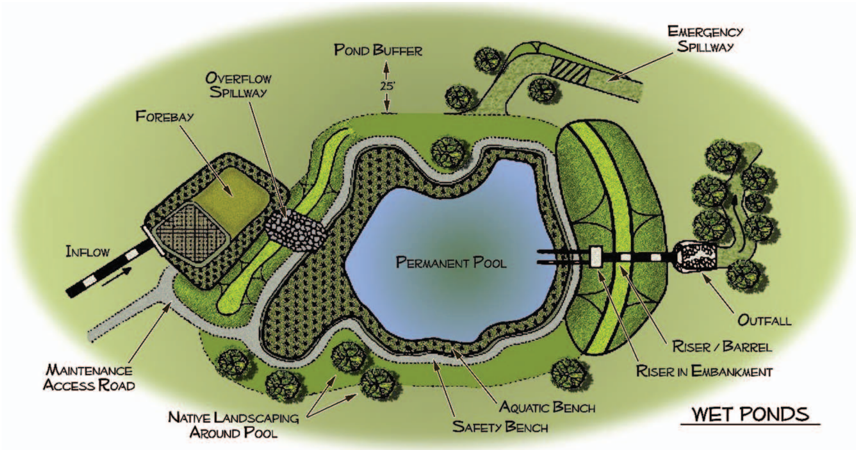

Figure 4-15. Wet pond features and components: Plan view.

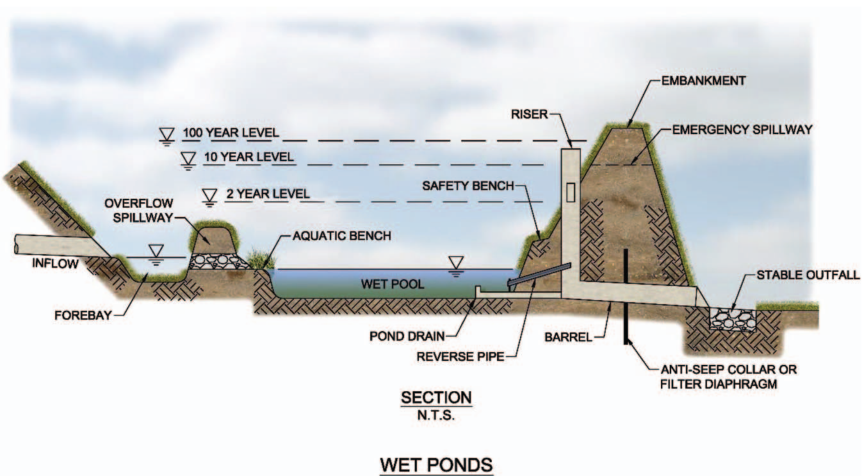

Figure 4-16. Wet pond features and components: Section view.

solution. Once exiting the forebay, the water is directed through an overflow spillway or gabion wall to a wetland treatment area, dominated by (often braided) rivulets among swaths of emergent vegetation. Many microbial and chemical removal processes occur here. Discharge from the CSW is regulated by an outlet structure, just as in a wet pond. Figures 4-17 and 4-18 and Table 4-9 describe typical design features. Typical inspection and maintenance tasks are described in Table 4-11.

Table 4-8. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Wet Ponds.

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Drainage area	Surfaces upslope that contribute to stormwater runoff; key areas are low-quality or disturbed soils and impervious areas, such as pavement and rooftops	Proper construction in the drainage area for long-term performance of facility	Erosion Sediment accumulation	Stabilize eroded areas Clear areas of sediment, trash, or debris
Vegetation	Areas that are required to be grassed should be completely grassed Wetland plants should be present on the benches	Provides habitat, aesthetic values Sequesters nutrients Stimulates beneficial soil microbes Roots mitigate soil compaction	Erosion Invasive species Grass and plants wilting or dead	Remove any invasive species Replace vegetation as needed Mow

(Continued)

Table 4-8. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Wet Ponds. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Underlying soils	Native soils below surface storage	Provide further treatment of pollutants Allow limited infiltration of stormwater into groundwater (when practicable)	Lack of standing water within permanent pools Signs of burrowing animals	Inspect subsurface soils and liner Rototill existing soils to promote infiltration Add liner clay or geosynthetic material
Forebay and/or upstream pretreatment	Online minipond for pretreatment	Reduces runoff velocity Prevents clogging of outfall Eases routine maintenance	Sediment and gross solid accumulation	Remove sediment buildup
Aquatic and/or safety benches	Shallow area inside the perimeter of the permanent pool	Promotes growth of aquatic and wetland plants Reduces erosion Safety for those who fall in	Erosion Invasive species Plants wilting or dead	Remove any invasive species Replace vegetation as needed Remove trash

Permanent pool	Pool where runoff is stored	Stores and treats runoff from design storm	Sediment accumulation Lack of permanent pool in nondrought conditions	Remove sediment buildup Check outfall and/or embankment Unclog inflow piping
Embankment	Sloped sides of basin	Ties into non-SCM land use Contains and temporarily stores runoff	Erosion Invasive species Burrowing animals Trees and/or root penetration	Mow and replace vegetation as needed Fill burrows, remove burrowing animals
Emergency spillway	Channel used to convey flood discharge so water does not overtop embankment	Conveys large design storm events	Erosion Invasive species	Mow and replace vegetation as needed Remove any woody plant growth Repair erosion such as filling ruts, gullies, and provided erosion control lining.
Outlet structure	Structure used to release runoff contained in the basin	Controls the slow release of runoff	Clogging Cracks and/or leaks Inspect trash rack	Clean structure, if clogging or obstructions are present Perform structural evaluation

(Continued)

Table 4-8. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Wet Ponds. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Stable outfall	Location where the system outlets to an existing storm sewer, channel, or vegetated area	Delivers discharged stormwater to the receiving network in a nonerosive manner	Excessive erosion Excessive sediment and/or debris deposits causing water backup	Remove sediment deposits Check orifice control within outlet structure and riprap or reinforced turf apron. Repair erosion such as filling ruts, gullies, and provided erosion control lining.
Access road	Paved or cleared area used for maintenance and inspection vehicles	Connects paved roadways with BMPs, provides access for vehicles and personnel	Low spots Ponding water Erosion Excessive or woody vegetation Cracking or failure of paving material	Depending on paving condition, overlay or full depth replacement may be needed Mowing and/or bush hogging Filling of low spots

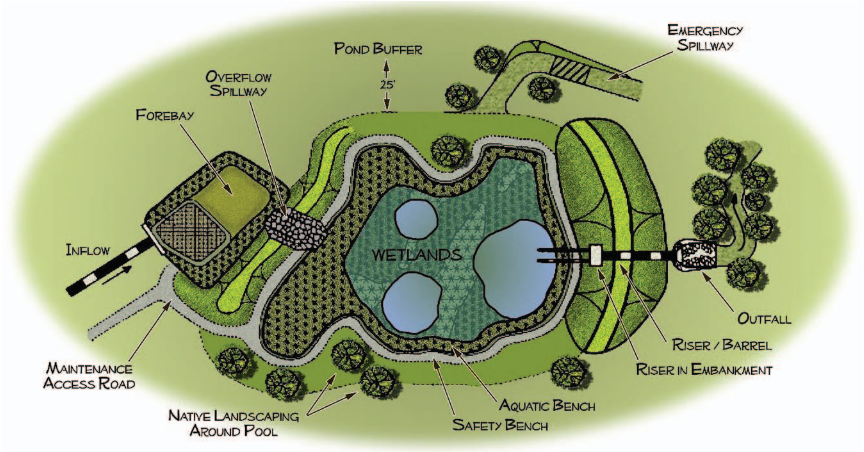

Figure 4-17. Stormwater wetland features and components: Plan view.

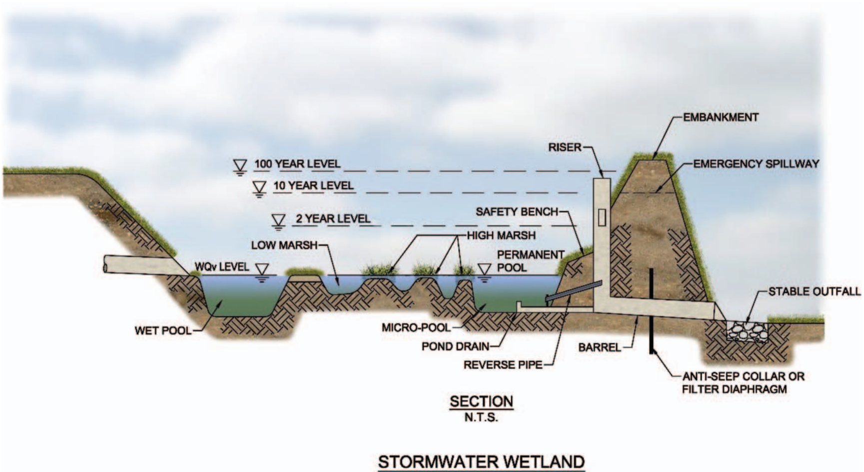

Figure 4-18. Stormwater wetland features and components: Section view.

Table 4-9. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Stormwater Wetlands.

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Drainage area	Surfaces upslope that contribute to stormwater runoff; key areas are impervious areas, such as pavement and rooftops	Proper construction in the drainage area for long-term performance of facility	Erosion Sediment accumulation	Stabilize eroded areas Clear areas of sediment, trash, or debris
Vegetation	Wetland plants should be present on the benches	Takes up soil water Provides habitat, aesthetic values Extracts nutrients Stimulates beneficial soil microbes Roots mitigate soil compaction	Erosion Invasive species Grass and plants wilting or dead	Remove any invasive species Replace vegetation as needed Mow and/or prune
Underlying soils	Native soils below surface storage	Provide further treatment of pollutants Allow for plant growth	Lack of standing water within permanent pools Look for burrowing animal dens	Inspect subsurface soils and liner Add liner clay or geosynthetic liner

Forebay	Online minipond for pretreatment	Treats runoff Reduces runoff velocity Prevent clogging of outfall Eases routine maintenance	Sediment accumulation	Remove sediment buildup
Micropool	Pool used to store stormwater runoff and to provide habitat for mosquito predators	Store and treat runoff from design storm	Sediment accumulation	Remove sediment buildup
High and low marshes	Wetland plants located in both high and low marsh zones throughout the wetland area	Encourage filtering and settling of runoff particles Nutrient removal	Plants wilting or dead Marshes inundated with open water Lack of permanent pool in nondrought conditions	Replace vegetation as needed Check outfall structure elevations Check if outfall is clogged
Embankment	Sloped sides of basin	Ties SCM into surrounding landscape Contains and temporarily stores runoff	Erosion Invasive species Burrowing animals Trees and/or root penetration	Mow and replace vegetation as needed Fill burrows, remove burrowing animals
Emergency spillway	Channel used to convey flood discharge so water does not overtop embankment	Conveys large design storm event	Erosion Invasive species	Mow and replace vegetation as needed Remove any woody plant growth

(Continued)

Table 4-9. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Stormwater Wetlands. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Outlet structure	Structure used to release runoff contained in the basin	Controls the slow release of runoff	Clogging Cracks and/or leaks Inspect trash rack	Clean structure, if clogging or obstructions are present Perform structural evaluation
Stable outfall	Location where the system outlets to an existing storm sewer, channel, or vegetated area	Delivers discharged stormwater to the receiving network in a nonerosive manner	Excessive erosion Excessive sediment and/ or debris deposits causing water backup	Remove sediment deposits Check orifice control within outlet structure and riprap of reinforced turf apron
Access road	Paved or cleared area used for maintenance and inspection vehicles	Connects paved roadways with BMPs, provides access for vehicles and personnel	Low spots Ponding water Erosion Excessive or woody vegetation Cracking or failure of paving material	Depending on paving condition, overlay or full depth replacement may be needed Mowing and/or bush hogging Filling of low spots

4.4.3.3 Extended Detention

Extended detention basins are surface storage structures used to temporarily hold runoff and release it with a controlled flow rate after a storm event. Larger particles settle in the forebay, and pollutants are removed by sedimentation. The basin is typically turf-lined and is designed to remain dry between storm events. The outflow structure can be fitted with a valve so that discharge can be regulated. It should also include a trash rack to prevent clogging at the entrance to the outflow pipes. Extended detention basins are less expensive to install and require less maintenance than wet ponds and stormwater wetlands. Figures 4-19 and 4-20 and Table 4-10 describe typical design features. Typical inspection and maintenance tasks are included in Table 4-11.

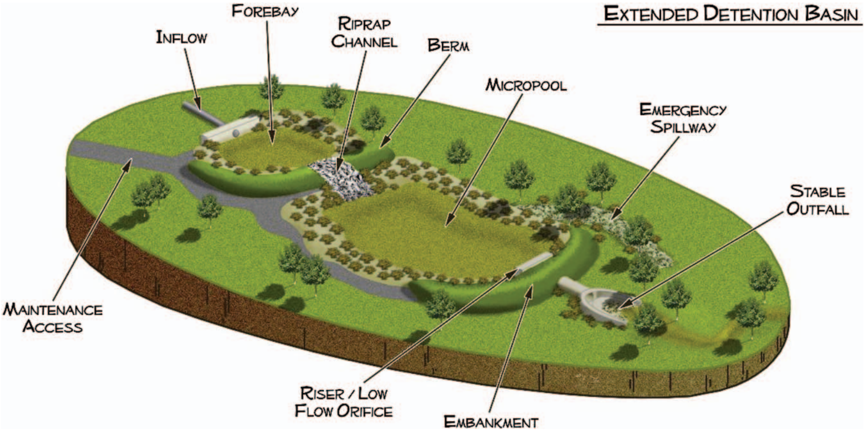

Figure 4-19. Extended detention basin features and components: Plan view.

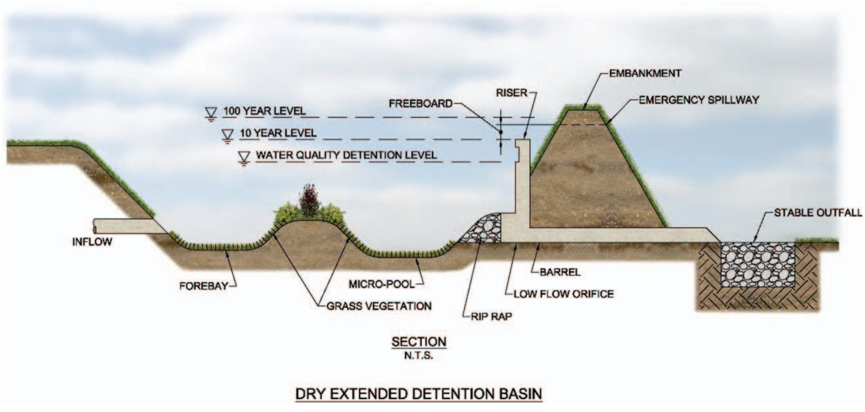

Figure 4-20. Extended detention basin features and components: Section view.

Table 4-10. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Extended Detention.

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Drainage area	Surfaces upslope that contribute stormwater runoff; key areas are impervious areas, such as pavement and rooftops	Proper construction in the drainage area for long-term performance of facility	Erosion Sediment accumulation	Stabilize eroded areas Clear areas of sediment, trash, or debris
Vegetation	Areas that are required to be grassed should be completely grassed	Provides habitat, aesthetic values Extracts nutrients Stimulates beneficial soil microbes Roots mitigate soil compaction	Erosion Invasive species Grass and plants wilting or dead Aesthetically displeasing to clients	Remove any invasive species Replace vegetation as needed Mow
Underlying soils	Native soils below surface storage	Provides further treatment of pollutants Allow infiltration of stormwater into groundwater (when practicable)	Standing water for excessive durations	Inspect subsurface soils Add underdrain Rototill existing soils to promote infiltration

Forebay	Online depression for pretreatment	Treats runoff Reduces runoff velocity Prevents clogging of outfall Eases routine maintenance	Sediment and gross solid accumulation	Remove sediment and gross solid buildup
Surface detention area	Temporary surface ponding of stormwater	Stores and treats runoff from design storm	Standing water after storm event Mosquito population	Remove sediment buildup Check outfall
Embankment	Sloped sides of basin	Contains and temporarily stores runoff Ties SCM into surrounding landscape	Erosion Invasive species Burrowing animals Trees and/or root penetration	Mow and replace vegetation as needed Fill burrows and remove burrowing animals Remove trees and woody plants
Outlet structure	Structure used to release runoff contained in the basin	Controls the slow release of runoff	Clogging Cracks and/or leaks Inspect trash rack	Clean structure if clogging or obstructions are present Perform structural evaluation

(Continued)

Table 4-10. Design Features, Maintenance Indicators, and Recommended Remediation Tasks: Extended Detention. (Continued)

Feature	*Description*	*Function*	*Maintenance indicators*	*Recommended remediation*
Emergency spillway	Channel used to convey flood discharge, so water does not spill over embankment	Conveys large design storm event	Erosion Invasive species	Mow and replace vegetation as needed Remove any woody plant growth
Stable outfall	Location where the system outlets to an existing storm sewer, channel, or vegetated area	Delivers treated and bypassed stormwater to the receiving network in a nonerosive manner	Excessive erosion Excessive sediment and/or debris deposits causing water backup	Remove sediment deposits Check orifice control within outlet structure and riprap of reinforced turf apron
Access road	Paved or cleared area used for maintenance and inspection vehicles and personnel	Connects paved roadways with BMPs, provides access for vehicles and personnel	Low spots Ponding water Erosion Excessive or woody vegetation Cracking or failure of paving material	Depending on paving condition, overlay or full depth replacement may be needed Mowing and/or bush hogging Fill low spots

Table 4-11. Typical Surface Storage Practice I&M Tasks.

Tier	*Frequency*	*Inspection and Maintenance Tasks*
1 Routine Inspection and Maintenance	Weekly	Remove any debris or litter Record and report maintenance tasks Inspect for standing water (extended detention basin)
	Monthly	Mow grasses Inspect inflow piping and outlet structure for clogging Record and report maintenance tasks
2 Scheduled Preventative Maintenance	3 to 6 Months	Inspect sediment forebay and record sediment depth Remove invasive species Remove woody vegetation from embankment and access road Record and report maintenance tasks
	1 to 3 Years	Check for erosion Survey vegetation for invasive species; remove if necessary Reestablish aquatic bench vegetation if necessary Assess structural integrity of embankment and outfall Inspect trash rack antivortex collar Record and report maintenance tasks
3 Rehabilitative Maintenance	As needed	Remove significant sediment buildup when basin is completely dry Dredge forebay Sliplining and/or parging of outfall structure Embankment reconstruction Record and report maintenance tasks

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Appendix: BMP Maintenance Survey Questions

1. What is your current position?

2. Describe your current roles and responsibilities:

3. Describe your professional background (please note length of career, degrees, qualifications, and accreditations):

4. How many facilities/sites/buildings/campuses/properties do you manage?

5. How large are the facilities/sites/buildings/campuses/properties?

   ☐ <1 acre
   ☐ 1 acre to <10 acres
   ☐ 10 acres to <50 acres
   ☐ 50 acres to <100 acres
   ☐ >100 acres

6. How long have these facilities/sites/buildings/campuses/properties been in operation?

   ☐ <1 year
   ☐ 1 year to <5 years
   ☐ 5 years to <10 years
   ☐ 10 years to <20 years
   ☐ >20 years
   ☐ NA

7. How many stormwater best management practices (BMPs) do you maintain? (If multiple sites, please note the approximate number per site.)

8. Approximately how much impervious cover is treated by your BMPs?

9. Please note the number of each type of BMP you are responsible for:

	One	*Two*	*Three*	*Four*	*Five*	*Six*	*Seven*	*Eight*	*Nine*	*Ten+*	*NA*
Extended Detention Basin (Dry Pond)	○	○	○	○	○	○	○	○	○	○	○
Wet Pond	○	○	○	○	○	○	○	○	○	○	○
Stormwater Wetland	○	○	○	○	○	○	○	○	○	○	○
Sand Filter	○	○	○	○	○	○	○	○	○	○	○
Bioretention	○	○	○	○	○	○	○	○	○	○	○
Wet Swales	○	○	○	○	○	○	○	○	○	○	○
Dry Swales	○	○	○	○	○	○	○	○	○	○	○
Infiltration Trenches	○	○	○	○	○	○	○	○	○	○	○
Infiltration Basins	○	○	○	○	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○	○	○	○	○

10. What is the age of BMPs you are responsible for? If multiple BMPs, please provide a range.

Extended Detention Basin (Dry Pond)	
Wet Pond	
Stormwater Wetland	
Sand Filter	
Bioretention	
Wet Swales	
Dry Swales	
Infiltration Trenches	
Infiltration Basins	
Other	

11. Have you ever had to perform major reconstruction or rehabilitation for any of the following types of BMPs? If so, please note the cost.

Extended Detention Basin (Dry Pond)	
Wet Pond	

Stormwater Wetland	
Sand Filter	
Bioretention	
Wet Swales	
Dry Swales	
Infiltration Trenches	
Infiltration Basins	
Other	

12. On an annual basis, how much money was spent maintaining each type of BMP?

Extended Detention Basin (Dry Pond)	
Wet Pond	
Stormwater Wetland	
Sand Filter	
Bioretention	
Wet Swales	
Dry Swales	
Infiltration Trenches	
Infiltration Basins	
Other	

13. On an annual basis, how much of your time was spent maintaining each type of BMP? (Numbers indicate respondent hours spent per year.)

	0–8	*9–39*	*40–80*	*81–120*	*120+*	*NA*
Extended Detention Basin (Dry Pond)	○	○	○	○	○	○
Wet Pond	○	○	○	○	○	○
Stormwater Wetland	○	○	○	○	○	○
Sand Filter	○	○	○	○	○	○
Bioretention	○	○	○	○	○	○
Wet Swales	○	○	○	○	○	○
Dry Swales	○	○	○	○	○	○
Infiltration Trenches	○	○	○	○	○	○
Infiltration Basins	○	○	○	○	○	○
Other	○	○	○	○	○	○

14. On an annual basis, how much of your maintenance staff's time was spent maintaining each type of BMP? (Numbers indicate labor crew work-hours spent per year.)

	0–10	*10–40*	*41–80*	*81–120*	*121–160*	*160+*	*NA*
Extended Detention Basin (Dry Pond)	○	○	○	○	○	○	○
Wet Pond	○	○	○	○	○	○	○
Stormwater Wetland	○	○	○	○	○	○	○
Sand Filter	○	○	○	○	○	○	○
Bioretention	○	○	○	○	○	○	○
Wet Swales	○	○	○	○	○	○	○
Dry Swales	○	○	○	○	○	○	○
Infiltration Trenches	○	○	○	○	○	○	○
Infiltration Basins	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

15. Do you have a written maintenance plan for the BMPs?
    - ○ Yes
    - ○ No

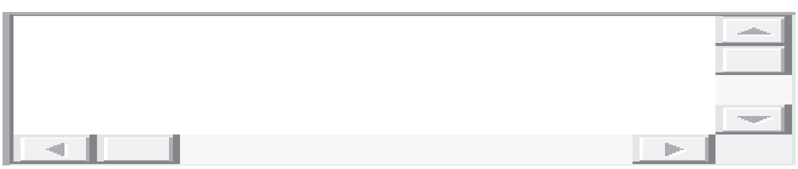
16. If you have a maintenance plan, who prepared it (design engineer, yourself, local municipality, etc.)?

17. Do you have a dedicated maintenance budget for stormwater BMPs?
    - ○ Yes
    - ○ No

18. Have you been within the funds budgeted for BMP maintenance since they were placed into operation?
    - ○ Over budget
    - ○ Under budget
    - ○ No dedicated budget for BMP maintenance

19. Is special equipment and/or training required for BMPs?
    - ○ Yes
    - ○ No

    Additional Comment



20. Is there inspection testing and monitoring of the BMPs?
   - ○ Yes
   - ○ No
   - ○ If yes, please describe the inspection testing and monitoring program:

21. Are you aware of any performance issues with the BMPs?
   - ☐ Seasonal
   - ☐ Maintenance-related
   - ☐ Large storms
   - ☐ Small storms
   - ☐ Vegetation
   - ☐ Pests
   - ☐ Burrowing animals
   - ☐ Erosion/sedimentation
   - ☐ Injury/loss of life
   - ☐ Poor design (e.g., storm drain backups, flooding, overtopping)
   - ☐ Other; please specify

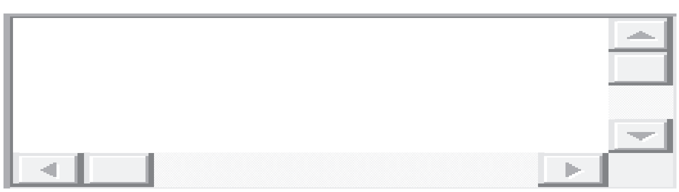
22. Are you able to access the BMPs you need to maintain?
   - ○ Yes
   - ○ No

23. Describe typical maintenance procedures (i.e., mowing, removing sediment, removing trash, replacing soil and/or plantings, vacuuming porous pavement):

24. Do you have any records of maintenance and performance?
   - ○ Yes
   - ○ No

25. Would you be willing to share those for use in this study? (Submissions will be treated with confidentiality and will be compiled as anonymous data.)
   - ○ Yes
   - ○ No

   If yes, please include your email address:



26. Are you content with the performance and maintenance of BMPs?

Not Satisfied	Somewhat Satisfied	Satisfied	Very Satisfied
○	○	○	○

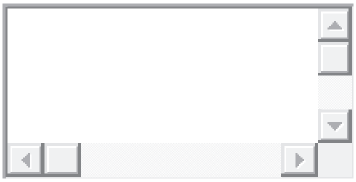
27. Would there be any advice you would give to the design engineer if given the opportunity?

28. Would you be willing to clarify some of your answers by telephone and/or provide additional detail?

○ Yes

○ No

If yes, please provide a contact number where you can be reached:



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