Operation and Maintenance Assessment for Structural Stormwater BMPs

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ABSTRACT

The American Society of Civil and Engineers (ASCE) recent reporting on the environmental, economic, and social impacts associated with aging infrastructure has reinforced the need for proper operation and maintenance practices in order to promote sustainability and resilience of United States infrastructure systems. Essential to the performance of the nation's water resources infrastructure are stormwater best management practices (BMPs). ASCE/EWRI 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 this Task Committee include extended detention basins, wet ponds, stormwater wetlands, sand filters, bio-retention practices, vegetated filter strips, and wet/dry swales. The BMP Maintenance Task Committee has undertaken a detailed literature review and developed a national survey to assess the effectiveness of current BMP operation and maintenance practices throughout the United States. This paper summarizes the results of the Task Committee literature review and describes the ongoing survey effort. The maintenance survey results are to be evaluated with regard to BMP type, regional influence, and class of asset manager. The survey results and literature review will assist in making recommendations to enhance design methodologies to allow for efficient, regular, and effective maintenance and to provide contractors and owners with cost effective techniques to manage their stormwater infrastructure. This paper summarizes the progress to date of the Stormwater BMP Maintenance Task Committee's effort to develop detailed operation and maintenance protocols for structural BMPs.

INTRODUCTION

Pollution control technology has steadily advanced since the Clean Water Act was enacted in 1972. The field of stormwater management has arguably experienced more innovation over the past decades than any other environmental discipline. Unlike the treatment technologies implemented to address point source pollution, non-point source pollution controls have no universally agreed upon maintenance practices to ensure proper operation. When wastewater treatment plants are put into operation there is a large volume of detailed information that typically accompanies the facility which describes how the equipment is to be maintained and operated – often with live training and demonstrations. This type of guidance is unheard of in the stormwater field. Operation and maintenance is often an afterthought, if it is addressed at all.

Despite this lack of information, many states and municipalities have taken the lead by making regular inspection and maintenance of stormwater BMPs an ongoing legal requirement. For example, in St. Louis Missouri, owners of BMPs are required not only to perform required inspection and maintenance but to provide annual reporting verifying such tasks have been completed (MSD, 2006). In many locations, such as the City of Baltimore, the recording of formal maintenance agreements outlining necessary maintenance and possible penalties for noncompliance are required (Engineering Technologies Associates, Inc., 2003). The various maintenance tasks required for BMPs may serve to not only meet legal requirements, but also to to ensure proper BMP function and to prevent flooding and negative impacts to adjacent infrastructure. Additionally, these tasks ensure that BMPs continue to be aesthetically pleasing and gain community acceptance. Unfortunately, previous studies in Maryland and elsewhere have shown that maintenance of stormwater structures if often deferred or inadequate (Lindsey, 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 (non-routine or less frequent), and major (rare) actions (Kang, 2008).

Some public agencies and municipalities offer guidance documents and protocols with respect to maintenance of structural stormwater BMPs. Much of the guidance in these documents is redundant from location to location but provide a useful reference or starting point when considering required maintenance activities. Conversely inconsistencies or omissions in these documents highlight potential areas of concern, especially to those developing new protocols. The Maintenance Guidance and Protocols section of this paper summarizes, by general practice type, some of these maintenance issues, schedules, and protocols from selected manuals and handbooks. Further, it is worth noting that many BMP types have similar maintenance requirements (Hunt, 2005b). For convenience, these practices are grouped as filter/infiltration practices, sedimentation practices, and vegetative practices. General Information related to stormwater BMP maintenance by practice type is presented in the following section of this paper.

MAINTENANCE GUIDELINES AND PROTOCOLS

Filter and Infiltration Practice Maintenance

To improve function and increase longevity of BMPs, especially, infiltration practices, proper pretreatment is crucial. This pretreatment must be part of the design of the BMP. Pretreatment serves to remove sediment or debris that may otherwise impair the proper function of BMPs resulting in clogging of filter media, infiltration beds, or in extreme cases clogging of inflow, outflow, and overflow structures. Accordingly, the design and installation of properly sized pretreatment and attentive inspection and maintenance of pretreatment devices must be completed.

In addition to pretreatment practices, the watershed upstream of post construction BMP should be stabilized prior to placing the BMP in operation. This is particularly true of filter or infiltration BMPs. Placing a filtering or infiltration BMP into operation while the upstream watershed is not stabilized will likely result in clogging or fouling of the BMP which may then require replacement or complete reconstruction. This requirement dictates that careful coordination between the construction erosion control plan, the site construction phasing, and BMP construction be considered in the earliest stages of the project design and construction.

Filtration practices may fail due to clogging which often results in standing water or bypass of the filter. Filters will generally clog from the top down. Therefore, 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 roto-tilling the top six inches of fiiter media, to the removal and replacement of a sediment layer at the top six to eight inches of filter media, to removal and replacement of the entire media bed (Gulliver, 2010).

Sedimentation Device Maintenance

Sedimentation BMPs include wet ponds, dry ponds, and stormwater wetlands. Some of these BMPs may be quite large and detain significant volumes of water. As such, maintenance of these devices may require dredging or otherwise removing large quantities of sediment. It should be noted that these BMPs may require large embankments, or even dams, with complex outflow devices or spillways. Accordingly, the design of such BMPs should provide ample room and the required property rights for access and maintenance. It should also be kept in mind that given the size of these BMPs, large equipment may be required to perform such maintenance.

Common or routine maintenance of various types of ponds will generally include facility inspection, inflow pipe inspection, cleaning of forebays or otherwise removing sediment, vegetation maintenance including mowing, and disposal of sediment. Structural repairs to outlet structures may be required on occasion as may dredging of the pond. Annual routine maintenance costs for wet ponds in North Carolina were found to vary from $1,920 to $3,090, depending upon the size of the pond (Hunt, 2005b). If major dredging or reconstruction is required, the annual costs will greatly exceed these numbers.

Planting Maintenance

Many BMPs, such as bio-retention and organic filters, make extensive use of plantings and landscaping. These plantings may be quite extensive and represent a large investment. Accordingly, much of the same sort of maintenance required for any landscaped area will be required for these BMPs, including replacement of dead plants, weeding, pruning, thinning, staking, and wound dressing. Care should also be taken to help ensure that all plantings become established. This may include watering, fertilization, liming, and amendment of the filter media.

Mulch is used at many bio-retention facilities and should be considered as a maintenance item. Mulch may become infested with vectors, sediment laden, or may float and displace. Accordingly, it is recommended that mulch be removed and replaced approximately once every two to three years (Hunt, 2005a).

Invasive species should be identified and immediately removed. These species can escape cultivation and begin reproducing in the wild, causing significant damage to native ecosystems. This is ecologically significant because some species out-compete indigenous species and begin to replace them in the wild (MSD, 2009). Further excessive plant growth may impede the function of outflow and overflow devices, therefore particular care should be taken in these areas to ensure proper function of the BMP. In many localities a reliance on native plantings will increase plant survivorship and reduce the need for plant replacement. The deep root systems of native plants will also help aerate the filer media and enhance infiltration.

Standing water present in many BMPs presents a potential for the hatching and breeding of mosquitoes. This 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, will serve to provide many natural predators to mosquitoes and help reduce their appearance.

CASE STUDIES

Understanding of the maintenance burden associated with stormwater BMPs is critical not only to the stormwater management performance of these practices, but also to the proper budgeting and allocation of resources by municipalities, public agencies, and private stakeholders. This maintenance burden will be influenced by factors that include BMP type, practice design, stakeholder class, climate and other regional influences, and BMP maintenance approach (active versus passive). The case studies described in the following section of this paper examine these facets as well as different stakeholder approaches to gain understanding of BMP maintenance burdens across three distinctive geographic areas of the United States.

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, thirty six (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 inches and 10.3 inches respectively

(NOAA National Climatic Data Center, 2011). This study marks one of the first significant evaluations of stormwater BMPs in a semi-arid 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 alone with site-specific inspection forms were developed for this project to document all maintenance activities and costs. Using this 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 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. The following paragraphs concisely summarize notable study findings with regard to maintenance of these practice types.

Table 1. Caltrans BMP Unit Costs - 1999 USD (Caltrans, 2004)

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

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 due to vegetation management. This included a significant burden associated with non-routine vegetation management for mosquito control. Mosquito fish 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 activates. Because only one wet basin was included in this program, the unit cost developed by this study may not be representatives of other wet basins in Southern California.

Five (5) extended detention basins were included in the study. Similar to the wet basin, the majority of the maintenance burden for these sites was due to 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 ten (10) years based on the criteria that removal should occur when sediment reduces the basin storage volume by 10%.

Six (6) sand filters were constructed, monitored, and maintained under the Pilot Program. The only filter clogging observed was due to cementing of the top layer of sand and not due to 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 ten (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 (9) bio-filtration sites were included in the study. Like the other vegetated practices, vegetation management was the largest maintenance burden for these sites. Irrigation was necessary to establish the vegetation and complete vegetation coverage was found to be difficult to maintain. Damage by burrowing gophers was also a problem at several sites.

A total of four (4) infiltration practices were observed in the Caltrans study. These infiltration practices consisted of two (2) infiltration trenches and two (2) infiltration basins. Routine maintenance was found to be less for the infiltration trenches than for all other BMPs. This 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 as the wet basin and the extended detention basins, with the largest maintenance burden being attributed to vegetation management (Caltrans, 2004).

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 an initiative to understand the maintenance burdens and life cycle costs of stormwater BMPs. When comparing these two studies, regional influence may have an effect on maintenance burdens and costs as the City of Philadelphia has an average annual precipitation of 41.5 inches 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 (9) sites throughout Philadelphia. These sites consisted of bio-retention practices, rain gardens, tree trenches, porous pavements, and subsurface infiltration practices. PWD, working with the consulting firm AKRF, Inc., developed structured maintenance and monitoring protocols which 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 post-storm event maintenance visits by experienced landscaping contractors. Data collection and maintenance tracking is an integral component of this program. Maintenance tracking consists of a database of measurements for sediment levels, water levels, and sink holes 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 post-storm event inspections; and annual reporting with data analysis.

In 2010, the total maintenance cost for the nine (9) monitored sites was recorded as $29,253. Of these total costs, 64% was attributed to routine maintenance activities while the other 36% was expended on special maintenance activities. Labor accounted for 77% of these total costs with the remaining 23% accredited to material costs. Routine removal of sediment and debris represented the largest portion of the total labor cost (23%). Labor costs were found to exceed 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%). Table 2 illustrates ranges of annual unit maintenance costs per impervious drainage area for some general practice types. Unit costs were not developed for individual BMP types due to the small sample size but will be examined in the 2011 annual report. The average unit cost for all BMPs was calculated as $0.50 per square foot of treated impervious area (PWD, 2011).

Table 2. PWD 2010 unit costs by general practice type (PWD, 2011)

BMP Type	*Annual O&M Unit Cost* *(Cost per sf impervious drainage area)*
Bio-retention	$0.29 - $0.92
Subsurface infiltration	$0.01 - $1.03
Vegetated practices	$0.06 - $1.28
Non-vegetated practices	$0.01 - $0.06

Some key performance issues identified in 2010 by PWD include sediment accumulation and erosion, settling and sinkhole formation, porous 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 due to a lack of maintenance access. As in the Caltrans study, this is a concern with regard to the long-term performance of these practices. Settling and sink hole formation occurred at five (5) of the nine (9) PWD monitoring sites in 2010. This was identified as a serious maintenance and safety issue, possibly caused by insufficient compaction of sub-base 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 non-target species, some plants were just not well adapted to site characteristics and BMP types. To address proper vegetation selection, PWD as expanded their maintenance tracking to include a vegetation database to more comprehensively assess species success for different BMP types and site constraints (PWD, 2011).

Minnesota

While the previous case studies described in this paper 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. A municipal public works survey was conducted for twenty-eight (28) Minnesota cities, eight (8) Wisconsin cities, and two (2) Wisconsin counties (Erickson et al., 2010). Average annual rainfall ranges from 30.6 inches in Minneapolis, MN to 34.8 inches in Milwaukee, WI, which falls in 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, over 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 those surveyed, no filters or dry ponds 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 one (1) to four (4) hours for inspection and maintenance. Practices requiring vegetation management, such as constructed wetlands and rain gardens, typically required more staff hours than non-vegetated practices. Wetlands, sand and soil filters, and permeable pavements were identified by the survey as requiring moderate to complex maintenance activities. Maintenance associated with all other BMPs was classified as minimal to simple, meaning a stormwater professional or consultant is needed less than half of the time on site. 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. Through analysis of the survey results, maintenance costs were identified as a significant portion of total BMP life cycle costs. This analysis also revealed an economy of scale effect for maintenance cost of all practices except for rain gardens (Erickson et al., 2010). Further information regarding this study can be found in the publication Erickson et al., 2010.

ASCE/EWRI BMP MAINTENANCE TASK COMMITTEE SURVEY

Two of the stated objectives of the ASCE/EWRI BMP Maintenance Task Committee are to: 1) generate detailed maintenance protocols for each BMP type and 2) generate region-specific guidance for BMP maintenance. As such, the ASCE/EWRI BMP Maintenance Task Committee has resolved to take the UM survey effort, as described in this paper, a step further by broadening the range of survey questions and by expanding its scope to a national level. The reasoning underlying the development of a survey effort is that completion of the two objectives above is based on a fundamental understanding of the current state of BMP maintenance and any problems associated therewith. Many of the questions are similar in nature to the UM survey, but the total number of questions asked was raised from eight to twenty-eight to attempt to capture more detail. The intent of the survey is to collect data from owners and operators of BMPs as well as specialized contractors that regularly perform BMP maintenance. Examples of survey respondents include directors of facility management at colleges and universities, homeowners' associations, directors of environmental quality at U.S. military installations and state transportation agencies, stormwater maintenance contractors, and environmental health and safety officers for manufacturing companies. The focus of the investigation is on structural BMPs as opposed to the newer low impact development (LID) features. This is because less time has elapsed since the shift from structural BMPs to LID causing difficulty in drawing meaningful conclusions about maintenance. Maintenance problems typically occur over long periods of time. Also, LID is still not required in most jurisdictions nationwide, so the prevalence of these features is dwarfed by number of structural BMP installations. A large sample size of varied survey respondents (>100) is desired to provide us with a robust dataset, and to aid in drawing statistical conclusions from the sample. Also, many respondents will have difficulty in answering some of the questions as some of the information requested may not be accessible. A large sample will prevent this from confounding the results. The survey is ongoing and being administered over the internet. It may be accessed at the following web address: http://www.ewri-swi.org/stormwater_bmp_task.html

CONCLUSION

The detailed review of the maintenance guidance and protocols outlined in this paper highlights several of the commonalities among these documents. Each of these documents 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 reviewed. 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 would be expected as these items vary particularly based upon the local permitting and conditions. However, these apparent differences also highlight the need for close local attention to plantings.

Case studies described in this paper 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 few comprehensive studies focused on stormwater BMPs in semi-arid climates, further research and ongoing monitoring are necessary to confirm the study findings with regard to maintenance burdens and BMP unit costs. All study BMPs being retrofit projects located on California State-owned property may have an influence on practice loading rates and thus 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 life cycle 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 (9) sites in 2010, to twenty-one (21) sites in 2011, and again to over forty (40) proposed sites for 2012. Ongoing monitoring and an expanded program scope will only 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 in this paper, sediment accumulation was identified as a significant maintenance burden for all BMPs and vegetation management was recognized as 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 a useful tool for evaluation of current and future maintenance and monitoring studies. The ASCE/EWRI BMP Maintenance Task Committee has developed a survey to increase the body of knowledge related to stormwater facility maintenance. The survey is ongoing, and will provide new perspectives on the issue of stormwater BMP operation and maintenance and the associated costs.

References may be found at: http://www.ewri-swi.org/stormwater_bmp_task.html

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