Estimating Post-Construction Costs of a Changing Urban Stormwater Program

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ABSTRACT

Degradation of the nation's waters continues to be a problem and urban runoff is a large contributor to it. New stormwater management policies stress the importance of using stormwater control practices that reduce the quantity and improve the quality of stormwater runoff. The new approaches tend to emphasize small-scale, on-site practices over large scale. Yet to achieve water quality benefits, stormwater control practices must be maintained over time. Maintenance costs of these facilities, however, are poorly understood. A case study of five municipalities around the United States is used to estimate inspection and enforcement costs for each case site. Maintenance activities and costs were collected at the case sites for the following stormwater controls: dry ponds, wet ponds, wetlands, bioretention facilities, sand filters, and infiltration trenches. Cost estimates indicate that inspection and enforcement is not influenced by type. Maintenance cost estimates change depending on the BMP type. Estimated annual post-construction costs applied to a hypothetical 1,000-acre indicate that moving from large-scale to small-scale stormwater controls has a large impact in terms of financial obligation.

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Chapter 1: Introduction

Over the last forty years, philosophies surrounding stormwater management have evolved in ways that have impacted regulations, treatment practices, and the administration of stormwater controls. In the past, as urbanization occurred and populations centers grew, the mitigation paradigm shifted from using pipes and ditches to using detention (Debo & Reese, 2003) to control stormwater and reduce flooding. Finally, in the 2000s, efforts shifted further to include a focus on pollutants. Low impact development (LID) and controlling for quantity and quality at the site level was introduced as a way to meet the standards set forth in the Clean Water Act (Prince George's County, 2000).

The enactment of the Clean Water Act of 1972 was intended to reduce pollutants contaminating our nation's waters and regulate point sources of pollution. Stormwater began to be regulated at the federal, state, and local levels as part of an effort to clean up the nation's waters. Attempts to meet the standards set forth in the Clean Water Act has led to continued improvement in designing and managing stormwater controls. This is due in part to meet increasingly strict water quality and quantity standards. To implement these improvements, there has been a shift from large-scale, off-site stormwater best management practices (BMPs) to smaller-scale and on-site practices. However, knowledge about the post-construction and long-term costs of this change is not well known. This study aims to estimate the post-construction cost of three large-scale, off-site stormwater controls and three small-scale, on-site stormwater controls to better understand the cost of maintaining and managing this change in the composition of stormwater inventory.

1.1 Background

Population growth over the last several decades in the United States has led to increased urban development around the country. An expanding population increases housing demands along with demands for other public services such as schools, transportation, police and fire protection, and retail. To meet these public needs, land must be developed. The construction of buildings, sidewalks, roads, and parking lots results in a loss of pervious ground cover and changes the hydrologic profile of the landscape. The result of this development is increased runoff during a rain event.

Urban stormwater is runoff from rainfall that does not infiltrate due to increased impervious surface in the built environment. Development, human activity, and the subsequent change in land cover impact the quality and quantity of runoff and, ultimately, the water quality of receiving waters (Fletcher, Andrieu, & Hamel, 2013). As the volume of runoff increases, so does the energy with which the water moves through the landscape. Less pervious land surface decreases the time that it takes the water to move through the landscape (time of concentration) and results in higher peak flows. Lower infiltration rates and higher stormflows can cause greater levels of erosion within the channel and overland erosion (Cianfrani, Hession, & Rizzo, 2006). The reduction in infiltration also results in reduced groundwater recharge and decreased surface water base flows (Yang, Bowling, Cherkauer, & Pijanowski, 2011). Flooding is another result of this increase in runoff quantity due to the changes in land covey urbanization (Meierdiercks, Smith, Baeck, & Miller, 2010).

In addition to changing the quantity of water that flows over the land, urbanization has an effect on the type and number of contaminants in the water. Human activity increases the amount of pollutants in our environment, and with increased water flow and decreased infiltration, these pollutants are often picked up and carried into streams and rivers. Of particular concern for regulatory agencies are nitrogen, phosphorus, sediment, heavy metals, and fecal coliform (Hatt, Fletcher, Walsh, & Taylor, 2004). All of these contaminants have a detrimental effect on the health of water systems.

As a result of increased volume of runoff and pollutant loads, a degradation of the water quality and aquatic habitat of receiving water bodies occurs (Alberti et al., 2007). The altered stormwater quantity and quality have a direct impact on stream conditions. Tilburg and Alber (2009) took numerous studies from around the United States that examined the impact of impervious surfaces on aquatic habitats. Their summary of studies showed that even an 8% percent impervious area resulted in the decline of stream conditions. Even a relatively small change in pervious surface (10-15%) leads to conditions such as declines in species diversity, higher fecal coliform counts, and loss of aquatic system function. Schueler, Fraley-McNeal and Cappiella (2009) examined the relationship between impervious cover and stream conditions and found that, since 2003, most studies have either confirmed or at least reinforced the link between the two. Moglen and Kim (2007) provide a dissenting opinion.

Stormwater design recommendations and federal and state policy for urban stormwater have evolved over time as knowledge and perceptions of the consequences of urban stormwater runoff have changed. Prior to the Clean Water Act (CWA), stormwater management arose out of a concern over flooding. For many years, stormwater management practices were designed to address only the adverse effect of localized and downstream flooding that occurred during a storm event. The management objective was to convey runoff from the landscape as quickly as possible into temporary storage facilities. Therefore, stormwater infrastructure relied on pipes and large detention areas such as dry and wet ponds to deliver and temporarily store peak flows during storm events. While they did reduce the effects of localized flooding, these types of stormwater management systems failed to address the volume or quality of stormwater discharges. In the 1970s, the CWA was passed at the federal level, giving the Environmental Protection Agency (EPA) the right to regulate point source pollution. Stormwater was not originally classified as point source pollution, but has since fallen under this distinction with the addition of amendments to the CWA in 1987.

Since the enactment of these amendments, the EPA, and corresponding state agencies are the primary regulatory bodies that implement and enforce stormwater pollution management. Stormwater regulations put into place by these agencies were first directed at large and medium metropolitan areas with a population greater than 100,000 that had a separate sewer and stormwater system. These municipalities fell into what is considered Phase I of the National Pollution Discharge Elimination System (NPDES). In addition to the regulation of stormwater, construction activities that disturbed five or more acres of land were now required to have permits and plans for reducing the effects of rain during construction.

In 1999, the EPA began Phase II of the NPDES municipal separate storm sewer system (MS4) program, which expanded the number of communities that fell under the NPDES. In addition to Phase I communities, smaller communities that were located within a Bureau of Census-defined urbanized area were now required to be permitted. This greatly increased the number of communities required to develop stormwater management programs.

In most cases today, the EPA has delegated municipal-level regulation to the states. States issue stormwater permits to Phase I and II municipalities. MS4 permits require the municipality to commit to activities designed to meet the federal and state stormwater regulations to discharge urban stormwater into state and federal waters. These activities have changed over time as regulations have changed. The implementation of the Phase II NPDES and Total Maximum Daily Limits (TMDLs) encouraged the next generation of stormwater regulations and standards, which placed more emphasis on the treatment of stormwater quality. This change was reflected through stormwater controls such as wetlands and sand filters, which reduced flooding and treated the water as well.

Regulatory requirements continue to undergo change and evolution. In the most recent iteration of stormwater regulations, the focus has been on reducing the total volume of runoff that leaves a site (Brown 2014). In some cases, the explicit management goal is to restore the volume, magnitude, and duration of runoff to conditions that more closely approximate pre-development levels. A recent attempt at a federal stormwater rule included performance standards that were retention based (Brown 2014). While this measure may not come to fruition, it highlights the move by regulatory agencies to move toward more on-site retention of stormwater.

Some state and local stormwater regulatory systems also reflect this change in stormwater management objectives. For example, Virginia recently revised state stormwater regulations to emphasize lowering the total volume runoff to meet revised stormwater quality and quantity requirements (9VAC25-870-66 and 9VAC25-870-63). These new management goals emphasize reduction of stormwater volume by reducing impervious surfaces and infiltrating runoff on site.

In the late 1990s and into 2000, low impact development (LID) was introduced as a new way of controlling stormwater and meeting regulatory requirements (Prince George's County, 2000). LID was seen as a solution designed to help control flooding and address pollutant concerns. Since then, EPA and state agencies have been advocating for the use of LID facilities to meet regulatory requirements (EPA, 2006; EPA, 2013). Using LID facilities over large-scale detention ponds or wetlands is expected to increase the number of BMPs required to treat a given urban land area. Infiltration BMPs, in general, treat a smaller acreage of land than the traditional dry or wet pond. In the past, a development that may have needed only one dry or wet pond may now need to incorporate multiple smaller-scale BMPs to treat the same amount of acreage. Thus, new stormwater management goals can significantly change the municipal stormwater infrastructure by increasing the number of stormwater treatment facilities per acre. Regulatory changes and engineering design work together. Over time, design of stormwater facilities improves as information about performance and impact on receiving waters provide feedback. This feedback loop is vital for designing systems that can meet the regulatory requirements.

Long-term management challenges emerge from changes in size and type of stormwater inventory. Adding to stormwater control practice inventory can increase stormwater management staff and costs. In addition, small-scale BMPs are often owned and maintained by private companies, individuals, or groups, such as homeowner associations. Transfers of ownership over time may impact the management of this inventory. Changes in inventory size, type, and responsibility can impact post-construction stormwater infrastructure management processes and costs in three distinct areas:

- Inspection of public and private stormwater facilities,
- Enforcement on private facilities, and
- Maintenance of stormwater facilities.

Knowledge about these three areas in terms of how municipalities perform these functions and the costs required to do so is relatively unknown, especially when considered within the scope of changes in stormwater practices. Growth in the number and type of stormwater facilities leads to increased monitoring and enforcement needs for these privately maintained and owned BMPs as well as increased monitoring for those under the purview of the municipality. The cost and logistics of running a post-construction stormwater management program are well-documented challenges (GAO, 2007; NRC, 2009). Management expertise is also becoming a problem as water quantity and quality controls require different skill sets. For example, in the past, engineers were taught to control stormwater quantity without concern for quality; now, however, they must take both into consideration. Thus, funding challenges and lack of stormwater management expertise are likely to increase as the inventory continues to change.

The long-term effectiveness and financial sustainability of local stormwater programs are dependent on being able to ensure the adequate functioning of stormwater controls over time. A critical element of an effective program is meeting the financial obligations of operating a post-construction stormwater program. Therefore, additional knowledge is needed about the relationship between stormwater BMP inventory and the activities and costs associated with post-construction management.

For the purposes of this study, post-construction costs and activities have been defined as follows:

- Inspection and enforcement activities and costs (I&E)– These include the activities and subsequent costs required to inspect public and private inventory and to enforce deficiencies on privately maintained facilities.
- Maintenance activities and costs (M)– Individual stormwater control maintenance activities and costs are either scheduled or unscheduled activities and costs that are necessary to maintain the functionality of the BMP over time. These costs may be the result of an inspection, a complaint, or scheduled maintenance that is performed.

1.2 Research Objectives

This study aims to contribute knowledge to academic literature and the stormwater industry about the activities and costs associated with post-construction stormwater management. The objectives of this study are to:

- Estimate the costs incurred during post-construction stormwater management, specifically:
    - Post-construction inspection and enforcement activities and costs at five case study sites across the United States, and
    - Post-construction maintenance activities and costs for the following stormwater control measures at five case study sites across the United States: wet pond, dry pond, wetlands, bioretention, sand filters, and infiltration trenches.
- Compare post-construction inspection and enforcement and maintenance activities and costs of select stormwater control practices to existing engineering and literature cost estimates.
- Compare the costs of servicing stormwater infrastructure due to changes in the size and scope of stormwater inventory.

1.3 Summary of Procedures

A multiple case study approach was chosen to identify management and associated costs of post-construction stormwater programs that include the following functions: inventory management and tracking, monitoring and enforcement, and maintenance. This focus on well-developed programs not only allows for the collection of better data, but also provides insights into the resources and strategies needed for program implementation as regulatory initiatives are being scaled and matured.

The intent of this case study approach is to overcome limitations of data and the survey approach with more exact data and the ability to use various methods for data collection and analysis. Additionally, a mixed method approach will be used for qualitative and quantitative data collection and analysis to identify overall patterns and to understand the data within the context of specific case sites. This will be used for comparing costs between case study sites.

The case study approach requires first the identification of case study sites and then the estimation of costs for meeting the objectives of this study. To address the identified research questions and meet the objectives of this study, the following approach will be used:

1. Documentation and collection of post-construction activities and costs at each of the case study sites, including:
    a. Inspection of public and private inventory; enforcement of private inventory.
    b. Maintenance activities for public and private inventory.
2. Estimation of post-construction costs based on evidence from the case study sites.
3. Comparison of two different development scenarios using current regulatory requirements and varying objectives (maximizing infiltration versus minimizing the number of stormwater controls) with the estimated post-construction costs to gauge the impact of changing stormwater inventory.

1.4 Organization

Chapter 2 provides a discussion of post-construction stormwater management in regard to expected activities, current literature's post-construction cost findings, and limitations of these studies. In addition, the case study and mixed method approaches are described, as is the method for estimating post-construction costs. Chapter 3 offers case site descriptions for the five municipalities examined and includes the processes used at each case site for inspection and enforcement as well as for maintenance. Inspection results are presented as they are used in calculating I&E costs as well as maintenance costs. Chapter 4 estimates I&E costs and provides a comparison with literature and cost tool estimates. Chapter 5 estimates maintenance costs for each BMP type based on the five case studies. These costs are compared against current literature estimates regarding maintenance of the selected BMP types. Chapter 6 combines the estimated inspection and enforcement costs with maintenance costs to project the cost of various hypothetical future scenarios of differing scopes and inventory sizes necessary to comply with Virginia stormwater requirements. And, finally, Chapter 7 is a discussion of future research needs.

Chapter 2: Methods

It is necessary to understand the financial implications of monitoring and maintaining stormwater inventory to ensure adequate funding to meet these needs. This chapter provides a conceptual framework for describing post-construction stormwater management costs. Chapter 2 will present current estimation methodologies, what is presently known about stormwater post-construction costs, and the methods used in this study given data limitations. This chapter will also address the delay in this study from the time of data collection to the publication of this data and its continued applicability given current stormwater regulations and inventory management practices.

2.1 Conceptual Model of Post-Construction Stormwater Costs

Post-construction management of stormwater consists of three primary areas: administration, inspection and enforcement, and maintenance. These three areas are imperative to a properly functioning post-construction stormwater program (Hirschman & Kosco, 2008). Naturally, there are costs associated with each of these three areas. While a conceptual model would include all three of these costs, for the purposes of this study, post-construction costs are estimated for only two categories: 1) Inspection and Enforcement (I&E), and 2) Maintenance. The decision not to estimate administrative costs was due to difficulty in isolating costs specific to post-construction stormwater management. Administrative costs that were collected often included other aspects of a stormwater program such as construction permitting, construction inspection, or management of TMDLs. In addition, it is believed that inspection and enforcement and maintenance are the most sensitive areas to changes in inventory size and facility type. However, administrative costs are defined conceptually along with I&E and maintenance costs.

2.1.1 Administrative Costs

Administrative activities and costs for stormwater management refer to those activities and subsequent costs which are required to adequately manage a post-construction stormwater program. Costs include overhead, staff expenses for management of inventory and overall stormwater program, and equipment for tracking inventory and record-keeping. Overhead costs include physical space for the staff and support staff who manage the stormwater inventory. There is very little information about actual costs in the current literature. This is in part because they are difficult to calculate; most stormwater programs have obligations which include more than just post-construction management of stormwater. As mentioned above, staff may have duties which include administration on the construction side of stormwater, education of the public, and detection of illicit discharges. Determining which costs to assign to post-construction stormwater management can be difficult. This study assumes administrative costs are a function of staff costs for management of the stormwater system, and for inventory and record-keeping, overhead, equipment, and the number of BMPs in the municipality's inventory.

Administrative costs = *f* (staff time spent on record-keeping and management, overhead, equipment, number of BMPs in inventory)

Administrative costs are an important component of post-construction costs, but the difficulty in isolating these costs and a lack of data availability did not allow for estimation at this time. Activity-based costing could be used to assign administrative costs in future studies (Tsai, Chen, Leu, Chang, & Lin, 2013).

2.1.2 Inspection and Enforcement Costs

Inspection and enforcement activities and costs are necessary to determine whether stormwater facilities are functioning properly, to identify maintenance needs, and to meet permit requirements. Inspection and enforcement costs are a function of the following: inspection frequency, staff time to inspect a facility, failure rate of facilities requiring follow-up, staff time for follow-up, transportation costs, and overhead. Inspection frequency can be influenced by the BMP type, local, state, and federal regulations, and MS4 permit requirements for that specific municipality.

The amount of time it takes staff to inspect a facility is influenced by the size and type of the BMP. It is also influenced by the requirements of that municipality. There is no literature on the difference in inspection time based upon the type of stormwater control measure; however, it is expected that a greater number of components to inspect leads to increased inspection time, which would directly influence staff time. This would seem to indicate that staff time to inspect would be different depending on the type of BMP. Overhead costs include physical space required by the staff to accomplish the inspection and enforcement process, this is in addition to the overhead for staff that is performing administrative activities.

> Inspection and Enforcement costs = *f* (inspection frequency, staff time to inspect a facility, failure rates, staff time to follow up, transportation, overhead)

2.1.3 Maintenance Costs

Maintenance activities and costs are necessary to keep BMP facilities functioning properly, correct design flaws, and fix deficiencies that occur due to neglect or the passage of time. For this study, these costs are considered either scheduled or unscheduled. Scheduled maintenance activities are expected, they ensure stormwater quantity and quality on a scheduled basis. Some examples of scheduled activities include mowing around the BMP, removal of litter and debris, and management of vegetation. Scheduled maintenance is performed on a somewhat regular basis and can be thought of as "routine". Unscheduled maintenance would include any maintenance that is unexpected or only occurs as a result of observed deficiencies in the stormwater BMP; they are "non-routine" activities. For example, dredging of ponds is an expected maintenance activity, but does not occur on a scheduled basis. Thus, it would be considered unscheduled for the purpose of this study and for classification of activities in this study. Both types of maintenance are discussed below.

Maintenance activity recommendations vary among the BMP types. While there are a multitude of design manuals published by various agencies and groups, many states and local programs have similar recommendations. EPA has published recommendations for expected maintenance activities; below is a brief description of the type of BMPs that are the focus of this study as well as EPA's recommendations for their maintenance.

Maintenance costs are a function of the maintenance activity costs and the frequency with which activities are performed. Activity costs are a function of labor and machinery costs.

Frequency is determined by whether it is a scheduled or an unscheduled activity. If the activity is unscheduled, frequency is determined by the inspection frequency and the failure rate.

$$\text{Maintenance costs} = f\,(\text{maintenance activity, frequency})$$

Activity costs are a function of the labor, materials, and equipment to accomplish a maintenance task. Labor and materials are a function of the type of BMP and the size of the BMP. For example, the cost to mow a pond is dependent upon whether it is a dry or wet pond and on how many acres are mowed. The removal of sediment is also dependent upon these two factors, the type of BMP and the size of the BMP. Other maintenance costs may only change with the BMP type. Maintenance activities by BMP type are discussed below.

2.1.3.1 Stormwater Ponds

Dry and wet ponds fall under the designation of stormwater ponds. Dry ponds detain and hold water only after a storm event. Wet ponds, on the other hand, always contain water and provide more water quality control. Maintenance concerns and practices for dry and wet ponds are shown in Table 2-1 and Table 2-2, respectively.

Table 2-1: Typical Maintenance Activities for Dry Ponds

Maintenance Activity	Frequency
• Repair undercut or eroded areas • Mow side slopes • Manage pesticide and nutrients • Remove litter and debris	Standard maintenance
• Seed or sod to restore dead or damaged ground cover	Annual maintenance (as needed)
• Remove sediment from the forebay	5- to 7-year maintenance

• Monitor sediment accumulations and remove sediment when the pond volume has been reduced by 25 percent	25- to 50-year maintenance

(Source: City of San Francisco & Hydroconsult Engineers, 2014)

Table 2-2: Typical Maintenance Activities for Wet Ponds

Maintenance Activity	**Frequency**
• Repair undercut or eroded areas	As-needed maintenance
• Clean and remove debris from inlet and outlet structures • Mow side slopes	Monthly maintenance
• Manage and harvest wetland plants	Annual maintenance (if needed)
• Remove sediment from the forebay	5- to 7-year maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic	20-to 50-year maintenance

(Source: EPA BMP Factsheets in City of San Francisco & Hydroconsult Engineers, 2014)

2.1.3.2 Wetlands

Land costs aside, constructed wetlands are one of the most cost-effective methods for treating and detaining stormwater (Erickson, Kang, Weiss, Wilson, & Gulliver, 2009).They do, however, require a large amount of land of a type. Maintenance for constructed wetlands, as detailed by EPA in Table 2-3, is more extensive than for stormwater ponds.

Table 2-3: Regular Maintenance Activities for Wetlands

Maintenance Activity	Frequency
• Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season	One-time
• Repair undercut or eroded areas	As-needed maintenance
• Clean and remove debris from inlet and outlet structures • Mow side slopes	Frequent (3-4 times/year) maintenance
• Supplement wetland plants if a significant portion have not established (at least 50% of the surface area) • Harvest wetland plants that have been "choked out" by sediment build-up	Annual maintenance (if needed)
• Remove sediment from the forebay	5- to 7-year maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic	20- to 50-year maintenance

(Source: EPA BMP Factsheets in City of San Francisco & Hydroconsult Engineers, 2014)

2.1.3.3 Bioretention

Bioretention facilities are intended to facilitate infiltration and evapotranspiration of stormwater runoff and filtration. Treatment of water is accomplished through nutrient uptake by plants and through soil filtering and storage (Davis, Hunt, Traver, & Clar, 2009). Bioretention facilities use soil and plant material to filter and then treat stormwater. Expected maintenance activities and their frequency follow in Table 2-4.

Table 2-4: Typical Maintenance Activities for Bioretention Areas

Maintenance Activity	Frequency
• Re-mulch void areas • Treat diseased trees and shrubs • Mow turf areas	As needed
• Water plants daily for two weeks	At project completion
• Inspect soil and repair eroded areas • Remove litter and debris	Monthly
• Remove and replace dead and diseased vegetation	Twice per year
• Add mulch • Replace tree stakes and wires	Once per year

(Source: EPA BMP Factsheets in City of San Francisco & Hydroconsult Engineers, 2014)

2.1.3.4 Infiltration

Infiltration devices are typically trenches or drains that capture runoff via gravity and are depressed compared to the local ground surface. Suggested maintenance activities and their frequency are shown in Table 2-5. Infiltration practices have historically had a high rate of failure compared to other stormwater management practices (Lowndes, 2000). One study conducted in Prince George's County, Maryland, revealed that less than half of the infiltration trenches investigated (of about 50) in the study were functioning properly, and less than one-third still functioned properly after five years (Gallie, 1992 in Lowndes, 2000). This highlights the need for regular maintenance and inspection.

Table 2-5: Typical Maintenance Activities for Infiltration Trenches

Maintenance Activity	Frequency
• Remove sediment and oil/grease from pretreatment devices and overflow structures	Standard maintenance

Maintenance Activity	Frequency
• If bypass capability is available, it may be possible to regain the infiltration rate in the short term by using measures such as providing an extended dry period	5-year maintenance
• Total rehabilitation of the trench should be conducted to maintain storage capacity within 2/3 of the design treatment volume and 72-hour exfiltration rate limit • Trench walls should be excavated to expose clean soil	Upon failure

(Source: EPA BMP Factsheets in City of San Francisco & Hydroconsult Engineers, 2014)

2.1.3.5 Filtration

For the purposes of this study, sand filters are the primary filtration BMP. Sand filters consist of layers of sand through which the stormwater filtrates. They provide water quality control by removing suspended solids (Barrett & Borroum, 2004). EPA lists all sand filter maintenance as occurring annually (Table 2-6). Some of these activities, such as the removal of sediment, may not require action every year.

Table 2-6: Typical Maintenance Activities for Filtration BMPs

Maintenance Activity	Frequency
Check to see that the filter bed is clean of sediments and the sediment chamber is no more than one-half full of sediment; remove sediment if necessary	Annually
Make sure that there is no evidence of deterioration, sailing, or cracking of concrete	Annually
Inspect grates (if used)	Annually
Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion	Annually
Repair or replace any damaged structural parts	Annually
Stabilize any eroded areas	Annually

Ensure that flow is not bypassing the facility	Annually

(Source: EPA BMP Factsheets in City of San Francisco & Hydroconsult Engineers, 2014)

Based upon recommendations, maintenance activities are more frequent for bioretention, infiltration, and filtration facilities. This study uses the terms "scheduled" and "unscheduled" for the different types of maintenance occurring. Table 2-7 lists maintenance for each BMP type and classifies them for this study. Scheduled maintenance occurs with regular frequency while unscheduled maintenance occurs as the result of an inspection or complaint.

Table 2-7: Scheduled and Unscheduled Maintenance Activities by BMP Type

BMP Type	Scheduled Maintenance	Unscheduled Maintenance
Dry Ponds	• Repair undercut or eroded areas • Mow side slopes • Manage pesticide and nutrients • Remove litter and debris	• Seed or sod to restore dead or damaged ground cover • Remove sediment from the forebay • Monitor sediment accumulations, and remove sediment when the pond volume has been reduced by 25 percent
Wet Ponds	• Clean and remove debris from inlet and outlet structures • Mow side slopes • Manage and harvest wetland plants	• Repair undercut or eroded areas • Remove sediment from the forebay • Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic
Wetlands	• Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season • Clean and remove debris from inlet and outlet structures • Mow side slopes • Supplement wetland plants if a significant portion have not	• Repair undercut or eroded areas • Remove sediment from the forebay • Monitor sediment accumulations and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or

BMP Type	Scheduled Maintenance	Unscheduled Maintenance
	established (at least 50% of the surface area) • Harvest wetland plants that have been "choked out" by sediment build-up	the wetland becomes eutrophic
Bioretention	• Water plants daily for two weeks • Inspect soil and repair eroded areas • Remove litter and debris • Remove and replace dead and diseased vegetation • Add mulch • Replace tree stakes and wires • Mow turf areas	• Re-mulch void areas • Treat diseased trees and shrubs
Sand Filters	• Inspect grates (if used) • Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion • Ensure that flow is not bypassing the facility	• Check to see that the filter bed is clean of sediments and the sediment chamber is no more than one-half full of sediment; remove sediment if necessary • Make sure that there is no evidence of deterioration, sailing, or cracking of concrete • Repair or replace any damaged structural parts • Stabilize any eroded areas
Infiltration Trenches	• Remove sediment and oil/grease from pretreatment devices and overflow structures	• If bypass capability is available, it may be possible to regain the infiltration rate in the short term by using measures such as providing an extended dry period • Total rehabilitation of the trench should be conducted to maintain storage capacity within 2/3 of the design treatment volume and 72-hour exfiltration rate limit • Trench walls should be excavated to expose clean soil

2.2 Current Knowledge About Post-Construction Costs

Discussions about stormwater control costs fall into two broad categories: up-front costs and post-construction costs. Up-front costs include design and permitting costs along with installation and construction costs; essentially, they are costs required to design, build, and implement a functioning BMP. It is important to note that stormwater BMP construction costs for more conventional types of stormwater control practices such as ponds, detention basins, and wetlands are better understood than those for newer LID control methods (Brown & Schueler, 1997; Lampe, Andrews, Glass, & Jefferies, 2004; Wossink & Hunt, 2003). It is also worth noting that construction costs for smaller-scale practices are documented but the studies are not as prevalent as for more traditional facilities (Brown & Schueler, 1997; MacMullan & Reich, 2007).

There is a large body of literature that provides design criteria for stormwater BMPs that includes suggestions for long-term operation and maintenance. Design criteria tends to come from state or other research institutes (Pomeroy, Postel, O'Neill, & Roesner, 2008; Prince George's County, 2000; U.S. Environmental Protection Agency (EPA), 2004; United States Government Accountability Office (GAO), 2007) and acts to ensure that facilities are designed to fit the needs of the site based on topography, land cover, and rainfall. It is acknowledged by the these design manual, as well as other studies, that all stormwater BMPs require long-term operation and maintenance to ensure their functionality as a water quantity or quality maintenance feature (Hunt, Lord, & Smith, 2005). Whole- or life-cycle cost studies have combined up-front costs, including land costs, with post-construction cost estimates in an attempt to understand the full cost of stormwater BMPs (Duffy et al., 2008; Sample et al., 2003).

2.2.1 Review of Previous Research and Cost Tools

Regardless of the BMP type, there are limited post-construction cost estimates. Many cost estimates rely primarily on assumed cost estimates and survey-based reported data (Bruce & Barnes, 2008; Erickson et al., 2009; Houdeshel, Pomeroy, Hair, & Goo, 2009; Houle, Roseen, Ballestero, Puls, & Sherrard, 2013). There are only a few studies including actual operation and management costs (Barrett, 2005; California Department of Transportation (CALTRANS), 2004; Houle et al., 2013; Hunt et al., 2005; King & Hagan, 2011; Minton, 2003; Wossink & Hunt, 2003). In addition, there are also some cost tools which estimate post-construction costs (Houdeshel et al., 2009; Olson, Roesner, Urbonas, & Mackenzie, 2010). Post-construction cost literature is categorized in this study as survey-based costs studies, site-specific cost studies, and cost tools.

2.2.1.1 Survey-based cost studies

Erickson, et al. (2009) surveyed 28 municipalities in Minnesota about post-construction activities and costs. The survey gathered information on many aspects of a stormwater program: from inventory and tracking, to construction permits and inspections, to post-construction maintenance. This survey asked local municipalities to use their best professional judgment to estimate time spent on routine maintenance activities for the following BMP types: wet ponds, dry pond, constructed wetlands, surface sand or soil filter, infiltration basins or trenches, rain gardens, porous pavements, filter strips or swales, underground sedimentation devices, and underground filtration devices. Annual estimated staff hours for maintenance ranged from 1-4 hours for most BMP types, with slightly higher estimates, 1-6 hours for rain gardens and 1-9 hours for wetlands. They also asked for survey responders to rate the complexity of maintenance activities. Those BMPs that were considered to require more complex maintenance were wetlands, porous pavements, and surface sand and soil filters. For actual maintenance costs, the study used estimates from previous literature (Erickson et al., 2009; Wossink & Hunt, 2003).

2.2.1.2 Site-specific cost studies

CALTRANS (2006) is often cited in studies that include I&E costs for post-construction estimation; several studies which include a component of post-construction maintenance in their cost estimation use the CALTRANS data. CALTRANS costs are based on projects implemented in California that were retrofit BMPs. Detailed records were kept regarding all post-construction activity, including inspection for the following BMPs: six sand filters, five extended detention basins, nine biofiltration facilities, four infiltration devices, and one wet basin. The data are limited by geography, and what is described as "state of the art" design, construction, and maintenance for that time. CALTRANS (2006) provides maintenance estimates that were adjusted from actual maintenance activities and costs, meaning the detailed actual costs were adjusted based upon expert opinion. These BMPs were followed for a year. Narayanan and Pitt (2006) use CALTRANS to estimate life-cycle costs. Barrett (2005) offers a comparison of structural BMP performance and uses CALTRANS costs.

An extensive study by Houle et al. (2013), looked at seven BMPs, following them for two to four years after implementation. This study tracked time, activities, and costs for these seven BMPs. Costs are discussed in detail in chapters 4 and 5; however, they found that LID facilities did not see a higher maintenance cost burden than traditional facilities. King & Hagen (2011) estimate costs as a percentage of construction costs and per impervious area treated. They used various methods to develop their costs. They looked at literature estimates, cost tools, actual project cost data, interviewed stormwater staff in Maryland, spoke with economists inside and outside of Maryland and used best profession judgement in their final numbers. They estimated that routine (scheduled) annual maintenance and intermittent (unscheduled) annual maintenance. Costs ranged from 0% to 3% of construction costs

Minton (2003) conducted a survey of municipalities in western Oregon, western Washington, and Austin, Texas, to help estimate I&E costs for the San Francisco area. While they collected actual I&E data and estimated I&E costs, their use of a survey method did not allow for them to specify what was included in these inspection costs. Minton estimated either an annual inspection cost and/or the number of inspections per full time employee (FTE). Maintenance costs are not detailed; they used an estimate of $1000/year per BMP.

Wossink and Hunt (2003) survey municipal stormwater employees in North Carolina, Delaware, and Virginia. There were 15 individual BMP sites surveyed about wetlands, 13 sites about wet ponds, 12 sites for sand filters, and 18 sites for bioretention facilities. This study developed cost curves based upon interviews asking about costs for specific tasks that are expected to occur for a type of BMP. They estimated costs for three different sizes of BMPs: small, medium and large, for dry ponds, wet ponds, and wetlands. The results are presented for comparison in Chapter 5.

2.2.1.3 BMP cost tools

A cost tool by EPA along with the Water Environmental Research Foundation (WERF) was developed to estimate life-cycle costs and provide a comparison of LID and traditional BMPs (Houdeshel et al., 2009). This tool estimates life-cycle costs for the following BMP types: curb-contained bioretention, extended detention basin (dry pond), green roof, in-curb planter vault, permeable paver, rain garden, retention pond (wet pond), and swale. The WERF tool allows the user to indicate a level of maintenance (low, medium, high). This tool uses a set of activities that are expected to occur for each BMP type and includes both scheduled and unscheduled activities. Unit costs and hours are assigned to each activity based upon the level of maintenance chosen. The user can define maintenance as low, medium, or high. As the level of maintenance increases, the inspection frequency increases as do most of the other maintenance activities. Unfortunately, this cost tool is unable to capture the tradeoff between higher attention and lower attention on overall maintenance needs. Cost data to populate the tool came from a myriad of sources that included literature at the time of development and expert opinion.

Another cost tools recently developed is the BMP REALCOST tool (Olsen, Urbonas, and Mackenzie, 2010). The authors interviewed seven stormwater utilities located near Denver, Colorado, and asked for expert opinion on frequency and costs for post-construction management. While it is assumed that the managers are familiar with these costs, there is a lack of specificity in the I&E costs and the data is limited in applicability by geography. This cost tool includes inspections as part of administrative costs. Administrative costs are a function of the inspection cost (a constant) and then a portion of the maintenance costs. Inspection costs for the BMPs in our study and in this cost tool are estimated at $19 - $28/BMP annually (2014 $). The BMP REALCOST tool estimates maintenance costs by BMP type by relating annual maintenance costs to the size of the BMP. As with their I&E cost limitations, the BMP REALCOST tool data is based upon a limited geographical area and relies on expert opinion. In addition, the BMP REALCOST tool assumes a proactive maintenance approach versus a reactive approach. However, a survey of stormwater managers in Minnesota by (Erickson et al., 2009) found that most maintenance is reactive, not proactive. The cost tool does offer a wide range of BMPs and can compare traditional and LID facilities.

The above literature and cost tools are used for comparing estimates from our case sites (Table 2-8). This study aims to overcome some of the limitations in these studies in the following ways: through a broader scope of geographical sites, collection of actual inspection and enforcement costs, collection of inspection and enforcement process, and BMP types.

Table 2-8: Summary Table of Literature and Cost Tools

Source	**Description**	**Cost Estimates**
California Department of Transportation (CALTRANS), 2004	Retrofit stormwater BMPs in California. Detailed records were kept regarding all post-construction activity, including inspection for the following BMPs: 6 sand filters; 5 extended detention basins; 9 biofiltration facilities; 4 infiltration devices; and 1 wet basin. Limited geographic application and what is described as "state of the art" design, construction, and maintenance for that time period may limit the applicability of these costs to other areas and time periods.	Includes inspection and maintenance costs.
Erickson et al., 2009	Survey from 28 municipalities in Minnesota.	Estimated maintenance staff hours and complexity of maintenance activities.
Houdeshel et al., 2009	The WERF cost tool allows the user to indicate a level of maintenance (low, medium, high). Cost estimates are based upon expert opinion and previous literature.	Includes inspection and maintenance costs, with costs dependent upon the level of maintenance.
Houle et al., 2013	Actual cost data from seven BMPs; following them for two to four years after implementation.	Estimated inspection and maintenance costs.

Source	Description	Cost Estimates
King & Hagan, 2011	Actual cost data, literature estimates, cost tool estimates, interviews, and best professional judgement were all used to estimate on a per acre of impervious area.	Estimated post-construction costs all together. This estimate combined operating, implementation, and maintenance cost.
Minton, 2003	Conducted a survey of municipalities in western Oregon, western Washington, and Austin, Texas, to estimate I&E costs for the San Francisco area. Interviews by phone and email of local governments and development/engineering firms. This study estimated either an annual inspection cost and/or the number of inspections per full time employee (FTE).	Estimated inspection and maintenance costs.
Olson et al., 2010	Cost Tool Estimates - Interviewed seven stormwater utilities located near Denver, Colorado, and asked for expert opinion on frequency and costs for post-construction management. While it is assumed that the managers know the costs, there is lack of specificity for I&E costs.	This cost tool includes inspections as part of administrative costs.
Wossink & Hunt, 2003	Survey of municipalities in North Carolina, Delaware, and Virginia.	Cost curves developed based upon expert opinion.

2.2.2 Data Availability

Many municipalities are just beginning to keep detailed records about post-construction I&E, and maintenance activity, much less tracking costs of those specific activities associated with a particular BMP. Even though this study tried to identify municipalities that were keeping better records, this study revealed that even within well-developed post-construction stormwater programs, costs and cost relationships are incomplete and highly contextual. Data and records kept by local programs differ between municipalities. Data is not always organized similarly across municipalities, and even within a municipality, different record-keeping is employed by the various departments. Additionally, records might be incomplete or maintenance might be performed by different departments within the municipality. For example, public works might do all mowing while stormwater staff correct structural problems and a third party is responsible for vegetation. As mentioned, all of these costs are also highly contextual. There are different inspection procedures, maintenance agreements, and requirements based upon the municipality's regulatory environment and their MS4 permit.

There are even shorter histories for newer BMP types, such as smaller-scale on-site detention facilities, than for more traditional BMPs like dry ponds. Many of the newer BMPs are also privately owned, which creates another obstacle to adequate data availability. Thus, a municipality may not have information about the long-term cost obligations for those BMPs because the municipality is not responsible for maintaining them.

Many post-construction costs studies, recommendations, and cost tools do not include actual cost data Thus, a different approach is required to gain insight into post-construction stormwater costs and the implication of changes in the nature of future stormwater inventories.

2.3 Methodology for Estimating Costs

A case study with a multi-type mixed analysis approach is used to identify costs and causal relationships. Inspection and enforcement (I&E) and maintenance (M) costs make up the definition of post-construction costs in this study. These cost categories are influenced by the activities undertaken by the municipality, which are dictated by regulatory requirements, as well as the type and size of the inventory. This study gathered data on costs, and where costs were not available, activities or other methods are used to estimate costs. Each municipality as well as the various cost classifications had differing levels of detail. The case study and mixed method approaches accommodated these differences and allowed for the maximum level of detail to be collected.

2.3.1 Case Study Method

The case study method was used because it provided better opportunities to obtain relevant, detailed data than did the survey approach. The larger survey method also does not account for the rules and procedures, unique to each location, which influence costs. Most cost studies have used survey approaches or studies based on only one geographical area, which hinders the quality and applicability of the results. In addition, many studies that do include costs rely on a few well-known studies for estimating post-construction costs, which may be limited in accuracy or relevancy. This study aims to overcome some of these shortcomings through a case study approach across a wider geographical area. The advantage of the case study approach is that it enables us to look at program components and try to understand their influence on costs.

2.3.1.1 Selection of Case Study Municipalities

The identification of potential case study municipalities with post-construction stormwater programs began with the definition of the type of municipality from which to collect data. First and foremost, municipalities with an established inspection and enforcement program as well as a maintenance program were needed. However, there is no set list of municipalities that meet these criteria or an existing overall program evaluation or ranking to draw upon. Therefore, the identification of potential case study sites was achieved in several ways. Discussions with industry and government officials, discussions with other researchers in stormwater management, and research documents were used to identify an initial list of municipalities. Twelve municipalities were on our initial list.

Screening of these 12 municipalities was conducted based on their willingness to participate, and on the following criteria:

- Inventory type: Because of the changing nature of stormwater regulations and programs, it was important to identify programs with a diverse mix of BMPs in their public and private inventory. For this study, it was necessary to have an adequate number of dry ponds, wet ponds, wetlands, sand filters, bioretention facilities, and infiltration trenches.

- Age of inventory: To understand maintenance costs over time and long-term, it was desirable that municipalities not only had inventory that fell within our categories but also that these BMPs had a range of ages.
- Record availability and accessibility*:* In order to minimize errors and reduce the time and cost to collect raw data, the data had to be readily available. Additionally, the following data was required in electronic format:
    - Inspection costs associated with post-construction program.
    - Inspection results of public and private BMP inventory.
    - Enforcement costs associated with a post-construction program.
    - Scheduled maintenance activities and costs, either on individual BMP or by type.
    - Unscheduled maintenance and costs, including type of maintenance and cost, with records on bmp inspections, failure rates, and remediation activities or costs.
    - Information on individual bmp characteristics including age, drainage size, and characteristics, etc.

After the two-step screening process, sites that failed to meet the case study selection criteria or did not respond to phone and email contact were removed from the list.

Detailed data collection occurred at four municipalities; a fifth municipality provided data at an aggregate level. Data pertaining to individual BMP characteristics, such as age, drainage size, etc., was not available in electronic format for the majority of the case sites. Case site descriptions and details about inventory, inspection and enforcement processes, maintenance processes, and inspection results are discussed in Chapter 3.

2.3.2 Multi-Type Mixed Methods

Johnson, Onwuegbuzie, and Turner (2007) define multi-type mixed analysis as analysis using qualitative and quantitative data and analysis. According to Cresswell and Plano Clark (2007)strengths of mixed method analysis include intuitive sense and efficiency in design. Using this method allows each data type to be collected and analyzed separately if needed.

Powell et al. (2005) discuss using quantitative and qualitative assessment to determine life-cycle costs of stormwater facilities. They suggest quantitative data such as land acquisition, construction, operation and maintenance, and salvage value. The qualitative data includes effectiveness of managing stormwater and the benefits of that type of management. While this study does not use these exact definitions for helping to determine post-construction costs, this points to the need for both types of assessment. The limitations in obtaining quantitative data further necessitated the use of various methods for gathering a complete picture of the post-construction liability for a municipality.

In this study, the goal for the mixed data collection and analysis was to provide evidence for the other. This can also be referred to as triangulation. Due to the nature of the data limitation, parallel and concurrent analyses were conducted. The qualitative and quantitative data simultaneously informed the other. Inconsistencies found during analysis may indicate the need for further analysis to clarify the discrepancy between the expected and observed pattern (Cresswell & Plano Clark, 2007). The advantage to using both types of data and analysis in this study is that it allowed for more credible validation than either does on its own. Collecting the data concurrently, weighting the data types equally, and merging the data during analysis allowed for causal relationships and patterns to emerge that might not have occurred had only one type of data or analysis been used.

2.3.3 Estimating Inspection and Enforcement Costs

Data collection and inspection cost analysis took several forms. Interviews with stormwater staff and inspection and enforcement documents were used to determine the activities undertaken and costs incurred by each municipality. Explanatory variables such as inventory size and diversity and inspection procedures were used for comparison across the case sites and to understand costs. Data was gathered with the assumption that procedures lead to activities, which lead to costs. Where possible, budget estimations or actual inspection costs were obtained.

We attempted to collect the following data at each case site:

1. Inventory Size – The number of BMPs inspected has a direct correlation to the inspection cost. This data will also be used for inventory management.

2. Inventory Diversity – Inspection costs may differ depending on the type of BMP. Examples of inspection criteria are found in Appendix A.
3. Staff Devoted to Inspections – Number of full-time employees (FTE) to complete inspection process.
4. Inspection Costs – The yearly cost to inspect all public and private BMP inventory.
5. Description of Inspection and Enforcement Procedure – A narrative of the inspection procedure was necessary for comparison between municipalities including such things as the inspection frequency and follow-up. Inspection frequency refers to how often BMPs are inspected by the municipality. Frequency may differ between publicly and privately maintained BMPs. Many municipalities conduct multiple site visits to ensure that BMPs that failed inspections are corrected.
6. Percentage of Failure to Comply - BMPs that failed to pass inspection and failed to respond to notification by the municipality determined the number of enforcements that are actionable.

Inspection and enforcement costs were converted to 2014 dollars for comparison purposes. The Consumer Price Index (CPI), from the data year or an average of the CPIs if multiple years of data were collected, was used to convert all case site data into 2014 dollars. An annual inspection and enforcement cost per BMP was calculated.

$$\text{Present Value Inspection and Enforcement Cost} = \sum_{t=1}^{T} \frac{C_T}{(1+i)^t}$$

Where,

C = Inspection and Enforcement Cost_{jmn}

t= 1, ., ., T

T = frequency of inspection and enforcement

i =discount rate, 5%

j = type of bmp

m = municipality

n = responsible party.

The per BMP unit cost includes staff time to inspect a facility, staff time to follow-up, transportation, and overhead. Frequency refers to inspection occurrence. This frequency of inspection often depends on the whether the facility is publicly maintained or privately maintained. Present value is calculated annualized over the inspection period (with 5% discount rate). The present value of costs is spread equally over the total inspection period resulting in an annualized cost.

2.3.4 Estimating Maintenance Costs

Maintenance records kept by the municipality were the primary source of data. These records, combined with actual costs per BMP, if available, or expert opinion, form the basis of scheduled maintenance costs. Unscheduled maintenance costs are defined as costs that are the result of failed inspections requiring corrective action. Unscheduled costs may also be referred to as remediation costs, non-routine costs, or corrective costs.

For privately maintained facilities, access to data concerning unscheduled or corrective maintenance is all that was available. Regarding all BMP types at all municipalities, the following data was collected where available:

1. BMP Type – Maintenance activities are highly dependent on the type of BMP and the necessary maintenance to keep them functioning.
2. Responsible Maintenance Party – Privately and publicly maintained BMPs may have different maintenance costs due to competition and/or economies of scale. For example, a municipality that contracts out all maintenance costs may have slightly lower costs than privately maintained BMPs. Conversely, privately maintained BMPs may be able to take advantage of changes in technology and increased competition among maintenance businesses.
3. Maintenance Activities – Data about scheduled and unscheduled activities was collected.
4. Maintenance Costs – Maintenance costs by activity and by BMP, where available, was collected.

Individual maintenance costs have not been studied in great detail. Some of the costs from our case sites are tied directly to a stormwater facility; for others we have aggregate information. For unscheduled maintenance costs, present value is calculated and annualized over the inspection period (with 5% discount rate). A discount rate of 5% was used to convert to an annualized payment. The Consumer Price Index (CPI), from the data year or an average of the CPIs if multiple years of data were collected, was used to convert all case site data into 2014 dollars. An annual maintenance cost per BMP was calculated using the following formula:

Annual BMP Maintenance Costs = Annual Scheduled Maintenance Costs + Present Value of Unscheduled Maintenance Costs

Annual Scheduled Maintenance Costs = (C * F)

Where,

C = Average Scheduled Maintenance Cost_{jmn}

F= Maintenance Frequency_{jmn}

j = type of bmp

m = municipality

n = responsible party.

Present Value of Unscheduled Maintenance Costs = $\sum_{t=1}^{T} \frac{C_T F}{(1+i)^t}$

Where,

C = Average Unscheduled Maintenance Cost_{jmn}

t= 1, ., ., T

T = Frequency of Inspection

F = Inspection Failure Rate

i = Discount rate, 5%

j = type of bmp

m = municipality

n = responsible party.

In addition to estimating costs, we will compare public and private maintenance activities to see if there is an impact by ownership and activities. We will also examine inspection results for differences in failure rates for different types of BMPs. These conclusions will help inform cost and management obligations as inventory changes. Using the estimates from I&E and maintenance, we can run various inventory scenarios to understand how a change in inventory might impact long-term management and cost of stormwater facilities (Table 2-9).

Table 2-9: Summary of Annual Post-Construction Costs

	Annual Post-Construction Costs
Inspection and Enforcement Costs	Present Value Inspection and Enforcement Cost = $\sum_{t=1}^{T} \frac{C_T}{(1+i)^t}$ Where, C = Inspection and Enforcement Cost$_{jmn}$ t= 1, ., ., T T = frequency of inspection and enforcement *i* =discount rate, 5% j = type of bmp m = municipality n = responsible party.
Maintenance Costs	Annual BMP Maintenance Costs = Annual Scheduled Maintenance Costs + Present Value of Unscheduled Maintenance Costs Annual Scheduled Maintenance Costs = (C * F) Where, C = Average Scheduled Maintenance Cost$_{jmn}$ F= Maintenance Frequency$_{jmn}$ j = type of bmp m = municipality n = responsible party. Present Value of Unscheduled Maintenance Costs = $\sum_{t=1}^{T} \frac{C_T F}{(1+i)^t}$

	Annual Post-Construction Costs
	Where, C = Average Unscheduled Maintenance $Cost_{jmn}$ $t = 1, ., ., T$ T = Frequency of Inspection F = Inspection Failure Rate i = Discount rate, 5% j = type of bmp m = municipality n = responsible party.

2.3.5 Current Regulatory Environment

There is a lag between the time of data collection (2011-2012) and the publication of the estimation of post-construction costs in this study (2016). While it is not ideal, the scenarios facing most municipalities are similar in the present to how they were at the time of data collection. It is likely that better data may now be available as many of the municipalities were in the process of improving their record-keeping at the time of data collection. In addition, enforcement costs may now be higher as several of the MS4s were developing or planning to develop stormwater ordinances, which would provide them with greater legal power to pursue non-compliant privately-owned facilities. However, in general, the stormwater policies in effect at the federal level and at most state levels were either similar to current requirements, or the current requirements are even more strict.

At the federal level, there was an attempt to make a national stormwater rule. The Chesapeake Bay Foundation (CBF) sued EPA after the NRC's 2009 report showed that stormwater programs had failed to meet the directive under the Clean Water Act (Brown 2014). The work leading up to meeting the requirement from the CBF lawsuit showed EPA pursing a retention-based national performance standard. While this rule is not moving forward currently, it is indicative of stormwater regulations increasing push to small-scale BMPs. Thus, while there has been a lapse from the time of data collection till publication, it is believed that this trend toward small-scale on-site stormwater controls will continue.

Chapter 3: Case Site Descriptions

The five case sites examined in this study represent municipalities that are urban and suburban. The municipalities' stormwater programs varied in inventory size and duration of program, with four sites being Phase I and one being a Phase II municipality. These five case sites represent geographical locations in the South, Midwest, West, and East. The geographical location likely impacts the type of BMPs constructed, but that is outside of the purview of this study. Instead, the BMPs that make up the inventory are presented as a piece of the story for that municipality. This chapter provides a description of the case sites along with a discussion about their maintenance, inspection, and enforcement processes. The inventory make-up at the time of data collection (2011-2012) as well as the inspection results used in calculating maintenance costs are presented where available by BMP type for each municipality. This information can be used to compare BMP types within a municipality and costs across case sites.

3.1 MS4–1: Case Site Description

MS4-1 is located in the Mid-Atlantic region. This site is considered a suburban municipality with a medium- to large-sized stormwater inventory and is a Phase I municipality. The municipality is roughly 400 square miles; stormwater inventory consists of a little over 1,350 publicly owned BMPs and around 3,200 privately owned and maintained stormwater controls. There are approximately 30 subwatersheds within the geographic region for which the municipality is responsible. There has been a considerable effort by the municipality to map these watersheds and the stormwater controls within each watershed over the last few years (Stormwater Manager MS4-1, 2009, 2010).

At the time of data collection, this municipality received funding through a general budget and thus was often competing with other local government services such as police, fire, and school. According to county officials, a relatively wealthy tax base has allowed for them to continue to maintain their level of service and to improve where possible (Stormwater Manager MS4-1, 2009, 2010). However, rising costs due to inventory changes, more stringent regulations at the state level, and decreased budgets as a result of a slowdown in the economy influence the level of service (Stormwater Manager MS4-1, 2009, 2010)

MS4-1 has recently completed an overview of the BMPs in their inventory, both public and private, as part of the process of managing the stormwater in the responsible area. Inventory growth is expected for both public and private facilities. Small-scale BMPs are being utilized in residential areas where redevelopment is taking place and most inventory growth is expected to occur here. Thus, small-scale facilities are preferred over those that control for larger acreage. Additional regulations are pushing for pre-development levels of runoff, which will require more intensive facilities at these sites (Stormwater Manager MS4-1, 2009, 2010).

Table 3-1 includes all BMP types in MS4-1's inventory, with BMPs evaluated in this study highlighted in grey. As is evident from Table 3-1, this municipality's public inventory is primarily dry ponds at this time. Private inventory, however, is more diversified with large numbers of rooftop detention, wet and farm ponds, underground detention, and infiltration trenches. For this municipality, public inventory that is LID or small-scale is often used for demonstration to encourage the adoption of practices by residential and commercial developers. Both public and private inventory that are LID or small-scale are newer facilities.

Table 3-1: MS4-1 - Public and Private Inventory, 2009.

BMP Type	Public	Private	Total
Dry Ponds	1,233	523	1,756
Wet Ponds	14	296	310
Rooftop Detention	1	514	515
Farm Ponds	1	474	475
Underground Detention	51	473	524
Infiltration Trenches	37	428	465
Sand Filters	1	197	198
Manufactured BMPs	4	136	140
Bioretention	15	92	107
Tree Box Filter	3	50	53
Parking Lot Detention	--	42	42
Vegetative Swales	1	2	3
Wetlands	1	2	3
Permeable Pavers	2	--	2
Total	1,364	3,229	4,593

3.1.1 MS4-1: Inspection and Enforcement Procedure

Inspection frequency differs depending on whether a BMP is maintained by the municipality or by commercial or residential entities (Table 3-2). The municipality uses a third-party or private inspection crew for all inspections. The type of BMP dictates the frequency of the inspection.

Table 3-2: MS4-1 - Public and Private BMP Inspection Frequency by Type

BMP Type	Inspection Frequency
Public – State-Regulated Dams	Yearly
Public - Non-Regional Ponds	Once every two years
Public – Regional Ponds	Yearly
Public – LID Facilities (Bioretention, Infiltration Trench)	Yearly
Public – LID Facilities (Bioretention, Infiltration Trench)	Monthly for the first year and then every six months
Private – All BMP Types	Once every five years

Inspection teams consist of at least two people to ensure the safety of the individuals. Public facilities are given a ranking from 1 to 3, with 3 being the most critical. This allows for priority to be established for fixing deficiencies. Inspection data was not available for public facilities, but private inspection results were available. Dry and wet pond inspections were detailed and covered aspects from the dam embankment to the inlet and outlet and all areas in between. For the other BMP types, inspection components were more general. This would indicate a longer inspection time spent on ponds versus the other BMP types. However, tracking of time to inspect was not available. For examples of MS4-1's inspection forms and data, see Appendix A.

After inspections are conducted on private facilities, the owners are notified of any deficiencies through certified mail. Owners are then required to submit "Maintenance Activity Reports" and show proof of work to remedy the problems. This proof of work ranges from pictures to copies of contracts for work performed. If owners fail to respond to the initial letter, they receive follow-up letters. Enforcement on private facilities beyond the second letter is minimal at the time of data collection.

Based upon conversations with municipality employees, pre-enforcement consists of three letters, the last including a threat of turning the matter over to the legal department. These letters are sent 45 days after the inspection and each subsequent letter follows the same 45-day waiting period. Four recent cases have been sent for legal action. An additional 190 cases are being considered for further legal action. Enforcement on private inventory is carried out by roughly one-third of one full-time position. Staff is exploring other enforcement options given current ordinances and maintenance agreements. However, at the time of data collection, local ordinance language did not support strong enforcement procedures (Stormwater Manager MS4-1, 2009, 2010).

3.1.2 MS4-1: Maintenance Activities and Inspection Results

At MS4-1, regular maintenance is conducted on public facilities by either the municipality or a third party depending on the type of stormwater control. Maintenance on public small-scale or LID facilities was contracted to a third party outside of the municipality. This was in part because most of these sites were demonstration sites and held to the highest standards. For the remainder of the public facilities, maintenance was provided by the municipality. MS4-1's public stormwater control facilities are primarily dry and wet ponds. Expected maintenance of public facilities is listed below for MS4-1 (Table 3-3). These activities are those undertaken by the municipality or a third party and are the activity and frequency used for calculating costs in Chapter 5.

Table 3-3: MS4-1 Expected Activities for Public Stormwater BMPs

BMP Type	Scheduled and Unscheduled Activity
Sand Filter	N/A

BMP Type	Scheduled and Unscheduled Activity
Bioretention	Scheduled maintenance: • Weeding - Monthly for the first 3 years, as needed after that • Watering - As needed to ensure survival • Replenish mulch - Late winter • Plant maintenance - Late winter • Flush the underdrain - Annually, or as needed by inspection Unscheduled maintenance: • Reseeding and replanting - As needed per inspection • Repair erosion - As needed per inspection • Remove sediment and debris from control structures, grates, inlets - As needed per inspection
Infiltration Trench	Scheduled maintenance: • Flush the underdrain - Annually, or as needed by inspection Unscheduled maintenance: • Weeding - As needed per inspection • Repair erosion - As needed per inspection • Remove sediment and debris from control structures, grates, inlets - As needed per inspection
Non-Regional Dry and Wet Ponds	Scheduled maintenance: • Mowing • Minor sediment and debris removal • Sediment removal • Cleanout • Other maintenance Unscheduled maintenance: • Sediment removal

Source: MS4-1 internal documents and budgets (2010)

MS4-1 provides guidelines for private facility scheduled maintenance (Table 3-4) but does not collect data on it. However, it does collect data on the unscheduled maintenance of private facilities, which occur once every five years. Data on the inspection deficiencies in these facilities provided evidence of the types of maintenance activities actually performed (Table 3-5 through Table 3-8). Deficiencies in dry and wet ponds were included if the deficiency was found in 20% or more of the inspections. The other facility types have a summary table regardless of the percentage failure; the available data by BMP type is based upon the items inspected by MS4-1 for each type of stormwater facility. Full details of inspection results are provided in the appendix.

Table 3-4: MS4-1 Private Maintenance Recommendations by BMP Type

BMP Type	Recommended Maintenance
Dry Ponds	• Sediment removal needed with accumulation and interference with volume capacity. • Removal of trees or other shrub vegetation growth on the dam embankment. • Erosion corrected as needed. • Correct visible damage to any of the mechanical equipment if present. • Remove blockage (trash, debris, or sediment) to the low flow orifice, forebay, or concrete trickle ditch. • Remove animal burrows on dam embankment. • Correct standing water if present longer than 72 hours after a rain event.
Wet Ponds and Wetlands	• Sediment removal needed with accumulation and interference with volume capacity. • Removal of trees or other shrub vegetation growth on the dam embankment. • Erosion corrected as needed. • Correct visible damage to any of the mechanical equipment.
Sand Filters	• Sediment removal needed with the accumulation of too much sediment to properly treat and drain runoff. • Remove excessive oil and debris. • Perform routine maintenance as suggested.

BMP Type	Recommended Maintenance
Infiltration Trench	• Remove trash, vegetation, or other debris from gravel surface. • Remove woody vegetation from trench. • Correct visible damage to any of the mechanical equipment. • Correct standing water if present longer than 48 hours after a rain event. • Maintenance required if runoff no longer infiltrates into but flows across the trench.
Bioretention	• Replant vegetation that becomes discolored, wilted, or dies. • Correct erosion problems present on the berms or slopes. • Remove blockage from the overflow riser or grate. • Correct standing water if present longer than 72 hours after a rain event.

Source: Internal budget projections and justification, 2009 and 2010

Table 3-5: MS4-1 Private Inspection Results – Dry Ponds

	Total Inspected *	% of Total (250)
Maintenance is needed based on this visual condition assessment	221	88%
Trees were noted on the dam	87	35%
Shrubbery and other types of low-growing vegetation were noted on the dam	60	24%
Scrub brush and other types of viney material were noted on the dam	51	20%
The low-flow orifice is blocked	89	36%
Other – Riser	108	43%

	Total Inspected *	% of Total (250)
The low-flow ditch system is blocked with silt and sediment	76	30%
Other – Impoundment Area	74	30%
Inflow pipe(s) blocked	57	23%
Other – Inflow pipes	63	25%

*Inspection results from 2007- 2009

Table 3-6: MS4-1 Private Inspection Results – Wet Ponds

	Total Inspected *	% of Total (187)
Maintenance is needed based on this visual condition assessment	158	84%
Trees were noted on the dam	79	42%
Shrubbery and other types of low-growing vegetation were noted on the dam	52	28%
Other – Riser	59	32%
The lake is showing signs of significant sedimentation and/or poor health	38	20%
Other – Impoundment area	45	24%
Inflow pipe(s) blocked	40	21%
Other – Inflow Pipe	57	30%

*Inspection results from 2007- 2009

Table 3-7: MS4-1 Private Inspection Results – Sand Filters

	Total Inspected *	% of Total (117)
General routine and preventive maintenance is recommended	51	44%
Structural repair is recommended	13	11%
Functional repair/renovation is recommended	7	6%
Refurbishment (i.e. cleaning and/or repairing) is recommended	39	33%
Silt removal is recommended	48	41%
Other	37	32%

	Total Inspected *	% of Total (117)
No additional maintenance is needed	27	23%

***Inspection results from 2007- 2009

Table 3-8: MS4-1 Private Inspection Results – Infiltration Trenches

	Total Inspected *	% of Total (258)
Inspection could not be performed	4	2%
General routine and preventive maintenance recommended	78	30%
Replacement of trench is recommended	75	29%
Refurbishment (i.e. cleaning and/or repairing) of trench is recommended	131	51%
Other	90	35%
No additional maintenance is needed	29	11%

*Inspection results from 2007- 2009

3.2 MS4-2: Case Site Description

The second site, MS4-2, is also located in the Mid-Atlantic region. This area is densely populated, is the suburb of a major metropolitan area, and has public and private stormwater facilities that number over 4,000 (Table 3-9). This municipality has funding from a specific fee that is charged based on type of residential property (single or multiple, attached, detached, etc.). The stormwater fees have changed over the years to reflect increased funding needs. Since 2001, all private residential BMPs have been placed into the public inventory to ensure proper maintenance.

There has been an effort to convert residential BMPs installed prior to 2001 into public inventory, allowing for maintenance responsibility to be taken over by the municipality. However, while this municipality is working to move all residential facilities into the purview of the public sector, a majority of the older facilities and more traditional BMPs are still maintained by HOAs or other groups. Commercially owned BMPs remain the responsibility of the private owner (Table 3-9).

Table 3-9: MS4-2 – Public and Private Inventory by BMP Type as of 2011.

Stormwater Facility Type	Private	Public	Total
Aquafilter	5	3	8
Aquaswirl	7	1	8
Baysaver	46	62	108
BayFilter	0	4	4
Bioretention	77	37	114
Bioswale	0	1	1
Bayseparator Flowsplitter	0	1	1
Dryswale	6	0	6
Flowsplitter	291	329	620
Infiltration Trench	296	274	570
Infiltration Basin	33	27	60
Dry Pond	332	292	624
Wet Pond	82	117	199
Constructed Wetland	62	54	116
Porous Pavement	4	0	4
Rain Garden	0	1	1
Oil/Grit Separator	400	323	723
Underground Sandfilter	122	62	184
Surface Sandfilter	188	190	378
Stormceptor	153	75	228
Stormfilter	56	36	92
Underground Storage	240	72	312
V2B1	2	0	2
Vortechnics	1	1	2
Total	2,403	1,962	4,365

Note: grey shading indicates BMPs evaluated in this study.

3.2.1 MS4-2: Inspection and Enforcement Procedure

All BMPs, regardless of responsible party, are inspected by an outside contractor. The results of these inspections are input into asset management software where a work order is generated. If the stormwater facility is publically maintained, the work order is sent to the municipality's third-party contractor to be completed. If the BMP is privately maintained, a letter is generated and emailed to the appropriate contact. To ensure that proper and adequate maintenance was performed on private BMPs that required correction, follow-up inspections are conducted while the corrective maintenance is occurring and a final inspection. It is not possible to know the total number of inspections required for follow-up, this study assumes at least one follow-up inspection is the facility failed the initial inspection.

Privately maintained BMPs are divided into two groups: above-ground facilities and below-ground facilities. Above-ground facilities that fail an inspection receive an emailed letter and are given 60 days to respond. Underground facilities that fail an inspection receive an emailed letter and are given 45 days to respond. Facilities that fail to respond and properly fix their deficiencies are fined. This municipality works diligently with private owners and the hired contractors to ensure that maintenance is completed and done adequately. Inspection results are listed in the section below.

3.2.2 MS4-2: Maintenance Activities and Inspection Results

A third-party inspected and maintained the public facilities for this municipality. Maintenance data provided by the municipality refers to those activities which were triggered either by an inspection or a complaint. All maintenance is considered unscheduled because it was performed only when deficiencies were noted. Inspections of public facilities occurred yearly. Inspection results for public facilities are listed as overall percentage failure (Table 3-10). This data spans three years, from 2008 to 2010. Each facility was inspected once per year. Public failure rates range from 27% to 68%, with the highest failure rates occurring in wet ponds. Sand filters had similarly high failure rates compared to the three remaining BMPs, which each had around a 30% failure rate.

Table 3-10: MS4–2 – Public Inspection Results by BMP Type

BMP Type - Public Facilities	Percentage Failure, Inspections Spanning 2008 – 2010
Dry Ponds (201)	27%
Wet Pond (117)	68%
Wetland (54)	30%
Bioretention (35)	31%
Sand Filter (219)	63%
Infiltration Trench (273)	30%

Private maintenance was performed by the owner of the facility. While scheduled maintenance may have occurred, attempts to collect this data were not successful. However, the inspection results give an indication of the unscheduled maintenance that was needed. Overall failure rates are listed below in Table 3-11.

Table 3-11: MS4-2 – Percentage Failure by BMP Type for Private Facilities

BMP Type - Private	**Percentage Failure, Inspections Spanning 2008 – 2010**
Dry Ponds with Sand Filter (112)	77%
Wet Pond (99)	71%
Wetland (62)	45%
Bioretention (78)	51%
Sand Filter (273)	50%
Infiltration Trench (299)	45%

3.3 MS4-3: Case Site Description

The third site, MS4-3, chosen for data collection is in the Gulf Coast region. This area is a densely populated Phase I municipality. A stormwater utility provides funding for this program. This municipality's most recent data for collection is from 2011. In 2011, MS4-3 had 843 publicly maintained stormwater facilities, of which the majority are sand filters and dry ponds (Table 3-12). In addition, these facilities are mostly residential. Most residential facilities are maintained publically while commercial ponds are privately maintained. Private facilities number over 6,000 and the majority of them are also dry ponds and sand filters.

Table 3-12: MS4-3 - Public and private inventory of BMP types.

BMP Type	**Public**	**Private**	**Total**
Bioretention (Includes biofiltration, rain gardens, sedimentation only, vegetation filter)	94	176	270
Dry Ponds (Flood detention)	216	3,152	3,368

BMP Type	Public	Private	Total
Infiltration Trenches (Infiltration basin or trench, retention/infiltration)	7	34	41
Sand Filters (Filtration only, sedimentation/filtration/irrigation, sedimentation/sand filter)	425	2,027	2,452
Wet Ponds (Retention/irrigation, wet ponds)	96	287	383
Other	5	489	494
Total	843	6,165	7,008

3.3.1 MS4-3 - Inspection and Enforcement Procedure

Public facilities, mostly residential, are inspected yearly by in-house staff to determine the maintenance needs of the facilities. Failures or problems found during inspection are rated from 0 to 9. This indicates the seriousness of the problem and drives maintenance priority. Initial and follow-up inspections are performed by municipal inspectors. At the time of data collection, which was 2010, there were five inspectors listed. However, based upon inspection records provided by the municipality, three of those inspectors performed fewer than 20 inspections. The other two inspected 434 and 386 BMPs per year. An average inspection rate for a full-time employee (FTE) would seem to be around 400 BMPs per year for public facilities.

Commercial and private facilities are inspected every three years by four primary inspectors. Three of the inspectors averaged approximately 500 facilities per year, ranging from 435 to 663 facilities. The other inspector is listed as having inspected 1,255 facilities. Due to the fact that this number is significantly higher, it is possible more than one person performed these inspections. An attempt to clear up this number was unsuccessful. Thus, the higher number was disregarded and an average from the other three inspectors was used for private facilities.

When privately maintained facilities do not comply with the required maintenance within 60 days, further follow-up occurs. An extension is granted or a second notice-of-violation (NOV) is sent. If a second NOV is sent, there is a mandatory re-inspection fee of $100. This municipality mentioned that it works hard to get compliance instead of prosecution (Stormwater Manager MS4-3, 2011). Inspectors, through follow-up inspections, make an effort to ensure problems found during an inspection are corrected (Stormwater Manager MS4-3, 2011).

3.3.2 MS4-3: Maintenance Activities and Inspection Results

Table 3-13 is a summary of actual activities performed by the municipality on BMPs for which they are responsible (publicly maintained). These facilities and the activities were identified through the inspection process, which occurred during fiscal year (FY) 2010. MS4-3's fiscal year spanned July 2009 through June 2010. While costs were not available, details about actual maintenance activities performed can inform the stormwater community regarding the types of maintenance needed over time.

Inspection results of publically maintained stormwater BMPs were given a rating of 0 through 9, which corresponds to the severity of the problem. A rating of 3 or above is considered actionable, with a rating of 9 being the most severe and requiring immediate attention. Table 3-13 does not take into account the severity of the maintenance required, but rather if any rating at all was above a zero, indicating that maintenance was needed or would be needed in the near future. It is assumed that even those receiving a score of 1 or 2, while not actionable in the current year, would become actionable as time progressed. They are included because this data is only from one year of inspections; thus, over the course of several years, the issue would require maintenance.

Table 3-13: MS4-3, Public BMP Inspection Failures, FY 2010

BMP Type (No of Inspections)	Dry Pond (215)	Wet Pond (97)	Bioretention (94)	Sand Filter (425)	Infiltration Trench (8)
Sedimentation Build-Up	12%	23%	26%	31%	50%
Erosion	5%	11%	7%	12%	13%
Standing Water	5%	23%	11%	8%	13%
Inlet Blocked	6%	11%	13%	14%	50%
Outlet Blocked	7%	6%	14%	3%	0%
Riser Pipe/ Trash Rack	2%	4%	17%	12%	13%
Trash	8%	19%	5%	12%	38%
Mowing Needed	5%	13%	7%	9%	13%
Total Inspection Failure	21%	35%	26%	36%	50%

Data collection of scheduled private maintenance activities was attempted, but was not successful. As a result, the activities listed in Table 3-14 are considered unscheduled only. Unlike public inspections, private inspections for this municipality were not rated on a scale of severity. Instead, the inspection simply indicated whether maintenance was needed.

Table 3-14: MS4-3, Private BMP Inspection Failures, FY 2010

BMP Type (No of Inspections)	Dry Pond (1331)	Wet Pond (158)	Bioretention (67)	Sand Filter (793)	Infiltration Trench (19)
Excessive Vegetation Growth	9%	9%	0%	25%	5%
Sedimentation Build-Up	9%	3%	3%	30%	16%
Trash & Debris	7%	9%	3%	16%	0%
Structural Integrity/Soil Erosion	6%	5%	0%	10%	32%
Standing Water	4%	27%	1%	9%	0%
Total Inspection Failure	16%	16%	10%	35%	32%

3.4 MS4-4: Case Site Description

This municipality, MS4-4, is a suburb of a larger metropolitan area and is the only Phase II municipality in this study. The political environment is one where there is considerable coordination between the larger metropolitan municipality and its suburbs. At the time of data collection, development had slowed due to the recession, but most growth in stormwater facilities in this area was from new development rather than redevelopment (Stormwater Staff MS4-4, 2011). This municipality is helping to set standards that are being adopted by surrounding municipalities. Initial contact occurred in May 2011 and travel to the municipality occurred in June 2011. Soon after the June 2011 visit to this municipality, its stormwater division was drastically reorganized. Final data was collected in December 2011 due to this change.

This municipality had initial funding from a sales tax initiative, which allowed for the establishment of many of the larger capital projects the municipality now maintains. Wetlands and regional ponds were developed from this initial funding, which was available for eight years (the initial sales tax was renewed twice). There is also a 10-year-old stormwater utility. A stormwater ordinance is in place that gives the municipality the authority to ensure that privately maintained BMP maintenance problems are addressed by the owner.

This municipality has around 40 public BMPs (Table 3-15), which are part of its infrastructure. This inventory grew by about 20-25% during the previous few years, although public BMP growth is waning because development has slowed down due to the reduction in economic activity (Stormwater Staff MS4-4, 2011). Privately maintained facilities account for the majority of the stormwater infrastructure and number around 200.

Table 3-15: MS4-4 – 2011 Stormwater Inventory.

BMP Type	Public	Private	Total
Dry Pond	0	107	107
Wet Pond	4	53	57
Underground Vault	0	6	6
Native Vegetation	0	2	2
Rain Garden	1	4	5
Bioretention	10	9	19
Extended Detention Wetland	10	1	11
Media Infiltration Practice	0	1	1
Native Grass Swale	7	10	17
Turf Grass Swale	0	4	4
Forebay	3	2	3
Stream Corridor	5	1	6
Total	40	200	240

Note: grey shading indicates BMPs evaluated in this study.

3.4.1 MS4-4: Inspection and Enforcement Procedure

Inspection procedures vary depending on who is responsible for the maintenance (public or private) as well as the age of the BMP. Public facilities are visually inspected monthly during the spring, summer, and into the fall. A maintenance crew, a group of eight including a manager, is responsible for public inspections.

Private facilities are inspected yearly during their first three years of operation to ensure that the BMP is well established. After three years of yearly inspections, privately maintained BMPs are inspected once every three years from then on. One inspector manages the municipality's 200 private facilities. The inspector works continually with landscaping contractors and BMP owners to ensure that problems found during inspection are addressed. This may mean multiple meetings and multiple follow-up inspections occur to resolve an issue. The smaller number of private BMPs and the close relationship between the inspector, property owners, and local landscapers has resulted in a 100% deficiency resolution rate.

3.4.2 MS4-4: Maintenance Activities and Inspection Results

Activity data for public facilities was available in detail for this Phase II municipality. This municipality had the most detailed activity and cost records of all the sites visited. They were the most proactive in terms of maintenance and they performed maintenance on schedule. They conducted multiple inspections during the year to identify any deficiencies. This municipality did not have any publicly maintained sand filters or dry ponds.

Scheduled and unscheduled maintenance activities for stormwater facilities include the following:

- Debris and/or Sediment Removal
- Erosion Repair/Control
- Grading and Backfilling
- Invasive Vegetation Removal
- Mowing/Weed Eating
- Pesticide Application
- Plant Maintenance
- Prescribed Burning
- Trash Removal
- Tree Removal
- Water Control Structure Repair
- Watering

- BMP Rehab

3.5 MS4-5: Case Site Description

The final case study site is located in the Pacific Northwest. MS4-5 is a co-permittee with two other entities, and together they manage stormwater on a watershed basis. This municipality has also been under MS4 regulations for over 15 years. Unfortunately, data provided by the municipality is primarily aggregate data. Original discussions indicated the ability to gather raw data, but changes in personnel and staff during the course of the data collection resulted in less data than originally anticipated. Total public inventory for MS4-5 is 1,200 BMPs with the vast majority being bioretention (Table 3-16). The municipality did not provide private inventory details.

Table 3-16: MS4-5: Public inventory, 2011.

BMP Type	Public	Private	Total
Dry Pond	42	N/A	N/A
Wet Pond	35	N/A	N/A
Wetlands	4	N/A	N/A
Vegetative Swales	99	N/A	N/A
Infiltration Basin	7	N/A	N/A
Sand Filters	13	N/A	N/A
Green Street Cells (Bioretention)	1,000	N/A	N/A
Total	1,200	N/A	N/A

Note: grey shading indicates BMPs evaluated in this study.

3.5.1 MS4-5: Inspection and Enforcement Procedure

Public facilities are inspected four times per year by a staff of three full-time employees. These three FTE inspect 1,200 facilities, leading to an inspection rate of 400 BMPs/FTE. Private facilities' inspection frequency is between every one to five years depending on the type of facility. BMPs that fall into the LID category are inspected more frequently. No information was provided about enforcement of private facilities.

3.5.2 MS4-5: Maintenance Activities and Inspection Results

Individual BMP activities were not provided by this municipality. Instead, general activities (Table 3-17) and aggregate cost data were supplied. This included public maintenance budget amounts for FY 2011. The cost data is presented in the cost section below. MS4-5 categorizes its facilities as either traditional or LID. In this case, they defined traditional BMPs as: Dry Ponds, Wet Ponds, Wetlands, Vegetative Swales, Infiltration Basins, and Sand Filters. LID facilities were Bioretention/Green Street Cells. For this municipality, the traditional facilities numbered 200 and the LID are approximately 1,000.

Table 3-17: MS4-5 – Scheduled Maintenance Activities

BMP Type	Maintenance Activities
Traditional Facilities	Vegetation Maintenance, Sediment Removal, and Residuals Disposal
LID Facilities	Vegetative Maintenance, Removal of Sediments, Garbage, Organic Debris

This municipality provided aggregate deficiency results from private inspections for FY 2009-2010 (Table 3-18). However, no activity or cost data were available for this municipality's privately maintained BMPs. They did provide some details about the percentage of private facilities where a deficiency was observed during inspection.

Table 3-18: MS4-5 - Private Inspection Aggregate Results

BMP Type	Inspections	Observed Deficiencies	Percentage
Dry Pond	4	2	50%

Wet Pond	6	1	17%
Sand Filter	11	2	18%
Infiltration Trench	5	1	20%

3.6 Summary of Case Sites and Data Collection

The five case sites selected for this study had varying levels of available data (Table 3-19). While each case site had distinct processes for inspection and enforcement and for maintenance, there are a lot of similarities across the case sites. Maintenance processes are classified as either reactive or proactive. For this study, proactive public maintenance process were programs who used a schedule for maintenance versus those who used the inspection process to indicate maintenance needs. For MS4-1 they use a combination of proactive and reactive. Costs available at the time of data collection were expert opinion and budget estimates. These budget estimates were more in-line with what would be considered proactive or scheduled especially for the smaller-scale facilities such as bioretention. The expert opinion was an estimate of annual costs per BMP, so it was treated as occurring regularly or as scheduled.

Table 3-19: Summary of Case Study Sites

	MS4-1	**MS4-2**	**MS4-3**	**MS4-4**	**MS4-5**
MS4 designation	Phase I	Phase I	Phase I	Phase II	Phase I
Size of Public Inventory	1364	1962	843	40	1200
Size of Private Inventory	3229	2403	6165	200	N/A
Inspection Process	Public – Yearly Private – once every five years	Public – Yearly Private – once every three years	Public – Yearly Private – once every three years	Public – Monthly Private – yearly for first three years, then every three years	Public – Quarterly Private – between yearly and once every five years.

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Public Maintenance Process	Hybrid	Reactive	Reactive	Proactive	Proactive

3.6.1 INSPECTION AND ENFORCEMENT DATA COLLECTION

Inspection results were collected for over 3,000 BMPs at these five municipalities. This includes publicly maintained and privately maintained facilities. The four Phase I municipalities inspect between 1,000 and 2,000 publicly maintained facilities each year. The Phase II municipality inspects fewer than 100 public facilities, but has nearly a monthly inspection frequency for these facilities. Private inspections by the five municipalities range from just over 600 to just over 2,000 facility inspections yearly. The frequency of these private inspections has a significant impact on the cost of inspections. It is important to note that inspections were expected to be completed annually whether a facility was publicly or privately maintained. It is expected that private facilities are inspected by the owner or business on a yearly basis and then once every three to five years by the municipality. However, no municipalities had much knowledge as to whether or not private annual inspections were actually occurring. Inspection results are presented in full in Chapter 4.

3.6.2 MAINTENANCE DATA COLLECTION

Over 700 data points were collected on maintenance costs or actual maintenance activities. Maintenance data for public and private facilities varied. Activity data was robust for those municipalities which provided inspection results, but often cost data was not as detailed. Where costs could not be tied to specific activities, expert opinion or aggregate cost data was used. Table 3-20 provides a summary of the collected data.

Table 3-20: Maintenance Data Collection Summary

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Maintenance – Public	Activities and budget estimates	N/A	N/A	Activities and averages by BMP type	Activities and expert opinion
Unscheduled Maintenance (Inspections) – Public	N/A	Activities and cost averages by BMP type	Activities, expert opinion for average costs	N/A	N/A
Scheduled Maintenance – Private	N/A	N/A	N/A	N/A	N/A
Unscheduled Maintenance (Inspections) – Private	Activities and cost averages by BMP type	Activities, no cost data	Activities, no cost data	N/A	Percentage failure, but no actual activities or cost data

Chapter 4: Post-Construction Inspection and Enforcement Costs

Post-construction inspection activities are those performed during regular inspections on public and private facilities. Post-construction enforcement activities are activities performed during required follow-up to ensure that any deficiencies found are corrected. All of the above responsibilities are required by regulating agencies and are necessary for ensuring the functionality of facilities and the fulfillment of their permit requirements. The purpose of this chapter is to estimate an annual post-construction inspection and enforcement cost per stormwater facility based upon evidence gathered from the case sites.

Inspection and enforcement (I&E) costs were intertwined for most of the municipalities studied, and thus costs are presented as a total cost for post-construction inspection and enforcement. Annual costs are determined by multiplying the unit cost for the specific time, type of BMP, and municipality times the frequency of inspection. The unit cost is assumed to include the influencing factors identified in the conceptual model: staff time to inspect, staff time to follow-up, transportation costs, and overhead.

$$\text{Present Value Inspection and Enforcement Cost} = \sum_{t=1}^{T} \frac{C_T}{(1+i)^t}$$

Where,

C = Inspection and Enforcement Cost_{jmn}

t= 1, ., ., T

T = frequency of inspection and enforcement

i =discount rate, 5%

j = type of bmp

m = municipality

n = responsible party.

Annualized costs are calculated based upon the frequency of the inspection costs. Frequency of costs are determined by either the frequency inspections and follow up. Net present value is calculated with a discount rate of five percent and then an annualized payment is calculated. Cost are calculated for 2014 dollars for comparison across case sites and rounded. Available data from the case sites differed both in its source and its reliability. Table 4-1 lists the data source for each municipality as well as the confidence that this data includes all aspects of I&E costs. The cost data for municipalities using a third-party for I&E has a higher level of confidence as this data is believed to fully reflect staff time, overhead, and transportation costs. In-house inspection cost data is believed to underestimate costs and may only include staff time. All costs data collected is discussed for each municipality.

Table 4-1: Data source and confidence of data for I&E costs

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Data Source	Expert opinion from 3rd party costs	3rd party cost data	n/a	Only public costs available, internal cost data	Only public cost data available, expert opinion
I&E Costs Include	Staff time, transportation, overhead	Staff time, transportation, overhead	n/a	Staff time	Staff time
Calculated as:	Annual per BMP	Annual per BMP	n/a	Annual per BMP	Annual per BMP
Confidence of Data Source	High	High	n/a	Low	Low

4.1 Annual Inspection and Enforcement Costs

4.1.1 MS4-1 – I&E Costs

At MS4-1, public and private inspection costs are based on the expert opinions of the stormwater manager and staff. They estimate an annual BMP inspection cost of $380 for public facilities and $850 for private facilities in 2014 dollars. It is assumed that this number includes the staff time to inspect, transportation costs, and overhead. The frequency of the occurrence of these costs differs depending on the ownership of the facilities and thus how often they are inspected: public facilities were inspected every year and private facilities were inspected once every five years. Therefore, the annualized cost for private facility inspections was estimated to be $150 per facility per year in 2014 dollars. MS4-1's inspections are performed by a third party.

The equivalent of five FTE perform inspections on roughly 1,331 public facilities and 642 private facilities per year. This means that one FTE can inspect and follow up with 395 individual facilities in one year. The inspection cost data for public inspections and private I&E is thought to be a reliable estimate. This municipality uses a third-party for inspections and thus the full measure of costs associated with I&E would be accounted in this figure.

4.1.2 MS4-2 – I&E Costs

I&E costs in 2014 dollars at MS4-2 were estimated to be $550 annually per public BMP. Private I&E costs are $770 per BMP, assuming an overall follow-up rate of 53.6%. This percentage of follow-up is based upon inspection results provided by the municipality. These costs are based on actual money spent on inspection services. For public facilities this includes one initial inspection. For private facilities this includes initial inspection for all inventory and in-progress inspections and final inspections for those BMPs found to have a deficiency. The total money spent on inspections is weighted by the overall failure rate of private facilities that would require more than one inspection. Thus, staff time to inspect, staff time to follow up, overhead, and transportation costs are part of this number. Annualized costs for private facilities, inspected once every three years, is $140 per BMP. Both public and private estimates are believed to be reliable.

4.1.3 MS4-3 – I&E Costs

Neither actual nor average inspection costs were provided by MS4-3, but some information regarding inspections was collected. This municipality employs five full-time inspectors who are responsible for inspecting approximately 6,000 private BMPs once every three years. During the data collection period, this amounted to 411 inspections per FTE per year. Three crews, made up of roughly five persons each, provide inspection and maintenance for the public inventory. Publicly maintained inventory includes over 800 facilities.

4.1.4 MS4-4 – I&E Costs

For private facilities at MS4-4, inspection costs equaled the salary and overhead of one inspector. This municipality followed up with private facilities until they were in compliance, so the number above would also include enforcement costs. Unfortunately, the municipality was not willing to disclose the inspector's salary and benefits, nor the typical cost of work equipment and gas. However, all private inventory (200 facilities at time of data collection) I&E is completed by a single FTE.

MS4-4's public average yearly inspection costs from 2010 were provided by BMP type and are reported in Table 4-2. They refer to public facility inspections that were performed in-house by the municipality. Average inspection costs for public facilities range from $39 to $94 annually, with dry and wet ponds incurring higher costs. The inspections were performed monthly along with some maintenance. These reported costs likely only consist of labor and do not include transportation costs or overhead; therefore, this cost estimate is believed to be too low. Additionally, while MS4-4's estimates indicate a difference in inspection costs by BMP type, the sample size is small. It does however, indicate that at this particular MS4, larger-scale facilities have higher inspection costs.

Table 4-2: MS4-4 - Public Average Annual Inspection Costs, 2010

BMP Type (Number of Samples)	Average Yearly Inspection Costs
Bioretention (8)	$39
Dry Pond (1)	$51
Wet Pond (1)	$94
Wetland (8)	$43
Average	$57

4.1.5 MS4-5 – I&E Costs

Publicly maintained traditional and LID facilities at MS4-5 were inspected four times per year by in-house inspectors. The municipality staff estimated yearly inspection costs per facility to be $150 (FY 2011); this is approximately $40 per inspection. Further details about what these inspection costs included were not provided. This estimate is relatively low and may not account for overhead and transportation since the inspections are performed in-house. Data regarding private inspection costs on an annual per BMP basis was not provided.

4.2 Staff Time to Inspect and Enforce

During this study, post-construction I&E costs were also examined from the perspective of the required manpower to adequately monitor the municipality's inventory. Data from the municipalities indicating who inspected a specific BMP was used to calculate the total number of BMPs inspected per year per full-time employee (FTE) or the total number of BMPs inspected along with the total inspectors employed was used to calculate an average. Between 400 and 450 BMPs per year of public and private inventory were inspected by third parties at the case study sites. Municipalities that did not use third-party inspectors averaged 400 to 500 BMPs inspected per year. Average time to inspect the inventory ranged from 4.0 hours to 10.4 hours annually per BMP, with an outlier of 12.3 hours for MS4-4's public facilities, which includes maintenance duties. While the I&E cost data has a high degree of variability, the average hours to inspect and enforce as well as the number of BMPs inspected per FTE are more consistent across the MS4s. Excluding MS4-3's public facility inspections, which include maintenance, and MS4-4's private facility inspections, which have intensive follow-up, the number of BMPs inspected per FTE is between 400 and 500 facilities per year. Average hours to inspect and enforce range from 4.0-5.3 hours annually (Table 4-3). The average hours to inspect and enforce is believed to include travel time as well as staff time to perform an inspection and staff time spent on enforcement in the form of follow-up inspections or meetings with private owners.

Table 4-3: Summary of Annual I&E Activities by Case Site

	Respons-ible Party	**MS4-1**	**MS4-2**	**MS4-3**	**MS4-4**	**MS4-5**
Total Yearly Inspect-ions	Public	1,331	1,962	843	40	1,200
	Private	642	801	2,055	200	n/a

	Respons-ible Party	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Inspect-ion Frequency and Party Inspecting BMPs	Public	Yearly; inspected by third party	Yearly; inspected by third party	Yearly; inspected by MS4	Monthly during spring, summer, and early fall; inspected by MS4	Four times per year; inspected by MS4
	Private	Once every five years; inspected by third party	Once every three years; inspected by third party	Once every three years; inspected by MS4	Yearly for the first three years and then once every three years; inspected by MS4	Between one and five years, depending on BMP type; inspecting party
FTE for Inspections and Enforce-ment	Public	5.0	6.0	5. 0 (includes mainten-ance)	8.0 (includes mainten-ance)	3.0
	Private			4.0	1.0	n/a
Number of BMPs Inspected Per FTE	Public	395	461	168.6 (includes mainten-ance duties)	5 (includes all mainten-ance)	400
	Private			513.75	200	n/a
Average Hours to Inspect and Enforce (Based upon FTE = 2,080 hrs/yr)	Public	5.3	4.5	12.3 (includes mainten-ance)	n/a	5.2
	Private			4.0	10.4	N/A

4.3 Significant Findings

I&E cost data is an important part of post-construction stormwater costs. Some of the cost data is believed to not reflect the full-measure of incurred costs. MS4-1 and MS4-2 cost data is believed to include staff time, transportation, and overhead. Therefore, this cost data will be used for comparison for understanding I&E data in this study as well as comparison with other studies and cost tools.

4.3.1 Influence of BMP Type on Costs

The size of the BMP and the difference in components of the various facilities would seem to indicate that inspection lengths are not uniform across BMP types. However, with the exception of MS4-4, that information was not available from the case sites. MS4-4's estimates are also difficult to apply to the other case sites; their sample sizes were very small, their inspection and maintenance procedures are intertwined, and they were more proactive than the other case sites. Ultimately, improved record-keeping and time-tracking surrounding inspections would provide a better idea of whether or not BMP type impacts inspection cost.

One of the initial assumption of this study was that regulations dictate stormwater post-construction activities undertaken by municipalities, which leads to costs. These regulations differ across states, but it is the regulatory requirements which really impact the activities undertaken by the municipality and private owners. Thus, to compare the annual I&E costs per BMP, it is important to consider the inspection frequency and follow-up process. Table 4-4 provides a summary of the costs and processes discussed above for the public BMPs. It is unclear whether the lower annual costs for MS4-4 and MS4-5 is actually due to different processes or if those municipalities reporting in-house costs do not fully account for all costs. For example, those municipalities reporting in-house inspections may only be accounting for labor hours and not factoring in the transportation and overhead associated with inspections, thus resulting in lower reported costs.

Table 4-4: Annual I&E Public Cost per BMP, and I&E Process, 2014$

Case Site	Public Annual Cost/BMP	Inspection Frequency & Follow-Up	In-House or Third-Party
MS4-1	$380	One/year	Third-party inspection
MS4-2	$550	One/year	Third-party inspection
MS4-4	$60	Monthly inspections	In-house inspection
MS4-5	$160	Four/year	In-house inspection

For private BMPs, the frequency of the initial inspection has a significant impact on the annual cost. More data points would be beneficial for applying these costs over a larger geographical area. Additional details about inspections performed by the private owners might result in an increase in these estimated annual costs. Additionally, it is expected that enforcement costs would grow linearly as private inventory grows. However, with respect to the cost to the municipalities shown in Table 4-5, as expected, less frequent inspections of private facilities result in lower overall costs to the municipality. This does not take into account inspections done by the private-owner, but it is unknown if additional inspections are actually occurring.

Table 4-5: Annual I&E Private Cost/BMP, and I&E Process, 2014$

Case Site	Private Annual Cost/BMP	Inspection Frequency & Follow-Up	In-House or Third-Party
MS4-1	$150	Once every five years; includes enforcement by the MS4	Third party inspection; in-house follow-up
MS4-2	$140	Once every three years plus follow-up inspections for compliance	Third party inspection; in-house follow-up

4.3.2 I&E Cost Estimates Compared with Literature

The findings in this study have been compared against the results of five outside sources to provide context and synthesis. Two of the resources reviewed for this study are cost estimation tools: the WERF Cost tool and the BMP REALCOST tool. BMP REALCOST estimated post-construction inspection costs to be $19 to $28 annually with dry ponds and sand filter vaults seeing the higher of these two estimates. This is well below the average cost of inspections found at the case study sites. It estimated one inspection per year with the inspection taking 0.33 hrs. and 0.5 hrs.

The WERF cost tool's inspection estimate includes reporting and information management as part of inspection costs. Table 4-6 provides the WERF tool's ranges for high and low levels of attention to the BMPs. However, this cost tool uses a significantly higher wage rate than the BMP REALCOST tool, and inspection costs do account for BMP type. For comparison purposes, the number of hours is provided as well. Labor hours spent for "high" attention were higher for bioretention versus those for dry and wet ponds receiving the same level of attention. Low-level maintenance attention time is the same for all three BMPs at 0.66 hours annually. So, the WERF tool estimates higher inspection costs for small-scale BMPs.

Table 4-6: WERF Cost Tool, Annual Inventory & Inspection Costs, 2014$

	Bioretention	**Dry Ponds**	**Wet Ponds**
High Attention	$629 6 labor hrs.	$287 4 hrs.	$287 4 hrs.
Low Attention	$22 .66 labor hrs.	$33 .66 hrs.	$33 .66 hrs.

Literature that has been collected on actual post-construction costs indicates a different story than the cost estimation tools above with respect to the amount of time and the eventual cost of BMP I&E. A study performed by Minton (2003) found post-construction BMP inspection costs to range between $64/facility to $297/facility. These numbers are similar to our range of post-construction for public facilities. They did not collect data on inspection frequency nor is there a discussion of if the costs included anything beyond labor costs.

Looking at the number of inspections per full-time employee (FTE), Minton (2003) reported a range of 231 to 433 inspections per FTE. This compares fairly closely with the case sites in this study who saw ranges from 143 inspections (including maintenance duties) to 557 inspections/FTE. This excludes site MS4-4, a Phase II municipality, as their I&E processes are very different from the other municipalities. Shown in Table 4-7 are the specific findings from the survey in Minton's (2003) study of Washington municipalities with costs calculated in 2014$.

Table 4-7: Minton (2003) Inspection Details for Comparison (pg. 4)

Location	**No. of Facilities**	**Inspections per Year**	**Inspection Costs/Facility OR No. of Inspections/FTE**
Bellevue, WA	302 Public 1500 Private	302 Public 750 Private	$64/facility 341/FTE
Clark County, WA	~275	~275	~275/<1 FTE
Federal Way, WA	~650	~650	~$297/facility OR ~325/FTE
King County, WA	850 Commercial	850	$265/facility
Olympia, WA	~300	~150	$257/facility OR 300/FTE
Redmond, WA	~1300	650	433/FTE

The CALTRANS (2004) report is another source referenced by other studies on post-construction costs. Data from the CALTRANS report shows dry and wet ponds requiring the highest number of inspection hours at 13 hours per year and infiltration trenches the lowest at eight hours per year. Inspection costs in 2014 dollars are between $202 and $329 annually (Table 4-8). This falls right in the middle of the range found during this study for public facility inspections at $60 to $550 per year. However, this only includes labor hours, it does not include transportation or overhead.

Table 4-8: CALTRANS Actual Average Annual Inspection Costs

	Sand Filter	**Dry Ponds**	**Wet Ponds**	**Infiltration Trench**	**Bio-filtration Swale**
Labor Hours	12	13	13	8	11
2014$, wage rate of $23.13 in 2010$	$304	$329	$329	$202	$278

Research done by Barrett & Borroum (2004) reported post-construction BMP inspections at 13 hours annually for sand filters. This is very close to the CALTRANS estimate of 12 hours per year. This would be roughly $377 annually in 2014 dollars using the labor wage rate from BMP REALCOST of $23.13. The data from Minton (2003), the CALTRANS (2006) report, and Barrett & Borrum's (2004) research combined with the findings in this study indicate that cost tools such as BMP REALCOST and WERF grossly underestimate the hours and the cost of post-construction BMP inspections (Table 4-9).

Table 4-9: Comparison of Estimates Between Literature and Cost Tools, 2014$

Data Source	**Annual Inspection Hours**	**Annual I and E Cost, 2014$**	**Comments**
Range from MS4-1 - MS4-5 (Licher 2016)	4.0 - 12.3	$ 60- $550	Private costs are likely underestimated as costs by the private owner are not included. Low public costs may not fully account for transportation and overhead.
Minton (2003)	4.8 - 9.0	$64 - $297	Credits range in costs due to intensity of inspection.
Barrett & Borrum (2004)	13.0	$377	Sand filters only
CALTRANS (2006)	8.0 - 12.0	$202 - $329	Range reflects different BMP types
BMP REALCOST Tool (2013)	0.33 – 0.50	$19 - $28	Range reflects different BMP types
WERF Cost Tool	.66 – 6.0	$22 - $629	Range reflects different levels of attention

4.4 Conclusions

Improved recording-keeping and better I&E cost estimates would certainly provide additional valuable information for this study, but there are several conclusions that can be drawn from the data collected.

- BMP type is most commonly discussed only in terms of the frequency of inspections and not in terms of the time it takes to inspect the facilities.
- BMP type and the corresponding difference in inspection frequency were only factors for the first few years of the BMP's life.
- Third-party contracted costs and expert opinion indicate an annual I&E cost range of $380 to $550 per BMP for public facilities and from $140 to $150 per BMP for private facilities.
- Annual I&E hours per BMP range from 4.0 hours up to 12.3 hours depending on the enforcement policy and whether or not maintenance duties are also included. Regardless, these averages are far above estimates provided by cost tools. For private facilities, these hours would be split over the appropriate number of years depending on the frequency of inspection.

Chapter 5: Post-Construction Maintenance Activities and Costs

This chapter identifies and estimates post-construction stormwater maintenance costs from observed data collected at the case study sites and from interviews with stormwater staff. Maintenance costs consist of scheduled and unscheduled maintenance (maintenance done as the result of an inspection). The level of data varies based on the type of stormwater facility, the case site, and the responsible party, a public or private entity.

5.1 Maintenance Costs by BMP Type

The maintenance cost estimates in this report are calculated based upon three types of information: 1) actual data from specific facilities, 2) interviews with experts, and 3) aggregate data provided by the municipalities. Where available, actual maintenance cost data was used. Cost estimates from this study were used to estimate an annual BMP maintenance cost for those municipalities who had inspection data but no cost data. The following equations were used to estimate costs:

Annual BMP Maintenance Costs = Annual Scheduled Maintenance Costs + Present Value of Unscheduled Maintenance Costs

Annual Scheduled Maintenance Costs = (C * F)

Where,

C = Average Scheduled Maintenance Cost_{jmn}

F= Maintenance Frequency_{jmn}

j = type of bmp

m = municipality

n = responsible party.

$$\text{Present Value of Unscheduled Maintenance Costs} = \sum_{t=1}^{T} \frac{C_T F}{(1+i)^t}$$

Where,

C = Average Unscheduled Maintenance Cost$_{jmn}$

t= 1, ., ., T

T = Frequency of Inspection

F = Inspection Failure Rate

i = Discount rate, 5%

j = type of bmp

m = municipality

n = responsible party.

Scheduled maintenance includes those activities which occur as part of a proactive maintenance schedule. Unscheduled maintenance occurs as the result of an inspection and is the sum of maintenance costs to fix the deficiency along with the probability of inspection failure. As detailed in Chapter 2, costs are converted to 2014 dollars for comparison across case sites and rounded and are presented on an annualized per BMP basis. Sources for cost data, frequency (based upon either regular maintenance frequency or inspection frequency), and probability of failure (inspection result with at least one factor being unsatisfactory) are found at the beginning of each discussion of the different BMPs. Private cost data for maintenance was only available for MS4-1 and MS4-2 and only includes maintenance activities that occurred to fix a deficiency found during an inspection thus, unscheduled. MS4-3 did provide inspection results, so unscheduled maintenance activity is available, costs from this study are used with these costs to estimate unscheduled private costs for MS4-3. As discussed in Chapter 3, attempts to collect scheduled maintenance details on private facilities was not successful for any of the case sites. In the discussion for each BMP type, cost estimates only include data with a high degree of credibility. Cost data that was not specific to a BMP type or was believed to be incomplete is not presented.

5.1.1 Dry Ponds

Dry pond maintenance activities and cost data was the most available of all of the BMP data collected as dry ponds make up a large part of many MS4s inventory (Table 5-1). Primary and secondary public cost data was available from MS4-1 and MS4-2. MS4-3 and MS4-5 provided aggregate cost data that was not specific to BMP type and thus it is not included in this analysis. For MS4-2 and MS4-3 their public maintenance is reactive and based upon needs identified during an inspection. For MS4-5, public maintenance activity occurred on a more proactive schedule. MS4-4 did not provide dry pond data. MS4-1 employs a hybrid approach, but did not provide public inspection results and their cost data was based upon budget estimates and expert opinion, thus they are considered scheduled costs for the purpose of this study. Primary private cost data was available for MS4-1. This data is unscheduled as it occurred as the result of a deficiency found during an inspection. Public facility inspection results were available from MS4-2 and MS4-3, while private inspection results were available from MS4-1, MS4-2, MS4-3, and MS4-5. Where inspection data and thus maintenance activity were available, but no cost data was available, the average of unscheduled cost data from this study were used to calculate an annual cost based upon that municipalities inspection failure rate.

Table 5-1: Data source and confidence of maintenance cost data, dry ponds

	MS4-1	**MS4-2**	**MS4-3**	**MS4-4**	**MS4-5**
Dry Ponds – Public Costs	Secondary data from expert opinions and budget estimates	Primary data - average of actual incurred costs for 27 dry ponds.	n/a	n/a	n/a
Dry Ponds - Public Inspections	n/a	Primary data - Based upon 201 inspections	Primary data - Based upon 215 inspections	n/a	n/a

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Dry Ponds – Private Costs	Primary data – average of self-reported costs from 30 dry ponds.	n/a	n/a	n/a	n/a
Dry Ponds – Private Inspections	Primary data – based upon 250 inspections over three years.	Primary data – Based upon 112 inspections.	Primary data – Based upon 1,331 inspections.	n/a	Primary – based upon 4 inspections.

Annual cost estimates for publicly maintained dry ponds ranged from $800 to $2,600 per BMP per year, and from $200 to $700 per BMP per year for privately maintained dry ponds (Table 5-2 and Table 5-3). Annual maintenance costs incurred by public dry ponds is between four and six times the costs of maintenance performed on private dry ponds. The difference in these costs could be due to public ponds being, on average, larger than privately-maintained dry ponds. It is also unknown if scheduled maintenance activities are occurring on private dry ponds. For this study, the costs incurred by private owners reflects only unscheduled maintenance, and thus it is possible that private dry pond maintenance costs may be higher. It is also important to note that the public and private costs shown below are an average of all reported maintenance costs for BMPs classified as dry ponds. For example, MS4-2's maintenance costs for its publicly maintained dry ponds range from $200 to $14,500 per year. This range can be attributed to the size of the facility as well as the maintenance activities required; trash and debris removal versus removal of silt and sediment. Private maintenance costs from MS4-1 similarly range from $300 to $27,500 per year. Again, this is likely influenced by the size of the facility and the severity of the deficiency. Failure rates were much higher for private facilities at both MS4-1 and MS4-2, with the highest failure rate seen in MS4-1's private facilities at 88%. MS4-1 is also the municipality with the longest period of time between inspections.

Table 5-2: Estimated Public Dry Pond Annual Maintenance Costs per BMP

Dry Ponds, Public	MS 4-1	MS 4-2	MS 4-3	MS 4-4	MS 4-5
Scheduled Activity Cost, 2014 $	$2,600	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	1	n/a	n/a	n/a	n/a
Unscheduled Activity Cost, 2014 $	n/a	$3,100	$4,700	n/a	n/a
Probability of Inspection Failure	n/a	0.27	0.2	n/a	n/a
Unscheduled Inspection Frequency	n/a	1	1	n/a	n/a
Annual Scheduled Maintenance Costs	$2,600	n/a	n/a	n/a	n/a
Annualized Unscheduled Maintenance Costs (5%)	n/a	$800	$900	n/a	n/a

Table 5-3: Estimated Private Dry Pond Annual Maintenance Costs per BMP

Dry Ponds, Private	MS 4-1	MS 4-2	MS 4-3	MS 4-4	MS 4-5
Scheduled Activity Cost, 2014 $	n/a	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	n/a	n/a	n/a	n/a	n/a
Unscheduled Activity Cost, 2014 $	$6,300	$4,700*	$4,700*	n/a	$4,700*

Dry Ponds, Private	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Probability of Inspection Failure	0.88	0.77	0.16	n/a	0.5
Unscheduled Inspection Frequency	Once every five years	Once every three years	Once every three years	n/a	Once every three years
Annual Scheduled Maintenance Costs	n/a	n/a	n/a	n/a	n/a
Annualized Unscheduled Maintenance Costs (5%)	$1,000	$1,000	$200	n/a	$700

*Costs were not available for these facilities; instead, the average across case sites is used to estimate annual costs. Average costs for unscheduled dry ponds was $4,700 annually.

5.1.2 Wet Ponds

Maintenance and cost data collected on wet ponds was similar to that of dry ponds (Table 5-4). Public costs specific to wet ponds were available for MS4-1, MS4-2, and MS4-4. Public costs from MS4-3 and MS4-5 were not wet pond-specific and thus were not included in cost estimates. Public inspection results were available for MS4-2 and MS4-3. Unscheduled private cost data was only available from MS4-1. Private inspection data was available for MS4-1, MS4-2, MS4-3, and MS4-5.

Table 5-4: Data source and confidence of wet pond maintenance cost data, wet ponds

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Wet Ponds – Public Costs	Secondary data - from expert opinions and budget estimates	Primary data - average of actual incurred costs for 19 wet ponds.	N/A	Primary data - average based on actual incurred costs at 3 sites	N/A

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Wet Ponds - Public Inspections	N/A	Primary data - Based upon 117 inspections	Primary data - Based upon 97 inspections	N/A	N/A
Wet Ponds – Private Costs	Private: Primary data – average of self-reported costs from 9 wet ponds.	N/A	N/A	NA	N/A
Wet Ponds – Private Inspections	Primary data – based upon 187 inspections over three years.	Primary data – Based upon 99 inspections.	Primary data – Based upon 158 inspections.	N/A	Primary – based upon 6 inspections.

Overall, public wet pond maintenance costs were estimated to be between $1,200 and $4,200 per year and $1,200 to $4,200 per year for private facilities (Table 5-5 and Table 5-6). MS4-2's public BMP cost records reflected some widely varying public maintenance costs that were unscheduled; they ranged from $300 to $11,000 per year. Private maintenance costs specific to MS4-1 ranged from $1,000 to $13,000 annually, so a similarly wide range. As with dry ponds, failure rates were highest at sites MS4-1 and MS4-2.

Table 5-5: Estimated Public Wet Pond Annual Maintenance Costs per BMP

Wet Ponds, Public	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Activity Cost, 2014 $	$2,600	n/a	n/a	$4,200	n/a
Scheduled Activity Frequency	1	n/a	n/a	1	n/a

Wet Ponds, Public	MS 4-1	MS 4-2	MS 4-3	MS 4-4	MS 4-5
Unscheduled Activity Cost, 2014 $	n/a	$2,800	$3,400*	n/a	n/a
Probability of Inspection Failure	n/a	0.68	0.37	n/a	n/a
Unscheduled Inspection Frequency	n/a	1	1	n/a	n/a
Annual Scheduled Maintenance Costs	$2,600	n/a	n/a	$4,200	n/a
Annualized Unscheduled Maintenance Costs (5%)	n/a	$1,900	$1,200	n/a	n/a

*Costs were not available for these facilities; instead, the average found across case sites is used to estimate annual costs. Average unscheduled costs for wet ponds were $3,400 annually.

Table 5-6: Estimated Private Wet Pond Annual Maintenance Costs per BMP

Wet Ponds, Private	MS 4-1	MS 4-2	MS 4-3	MS 4-4	MS 4-5
Scheduled Activity Cost, 2014 $	n/a	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	n/a	n/a	n/a	n/a	n/a
Unscheduled Activity Cost, 2014 $	$6,300	$3,400*	$3,400*	n/a	$3,400*

Wet Ponds, Private	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Probability of Inspection Failure	0.84	0.71	0.21	n/a	0.17
Unscheduled Inspection Frequency	0.2	0.33	0.33	n/a	0.33
Annual Scheduled Maintenance Costs	n/a	n/a	n/a	n/a	n/a
Annualized Unscheduled Maintenance Costs (5%)	$1000	$700	$200	n/a	$200

*Costs were not available for these facilities; instead, the average found across case sites is used to estimate annual costs. Average unscheduled costs for wet ponds were $3,400 annually.

5.1.3 WETLANDS

Wetlands data was the least available of the BMP types as MS4-4 was the lone municipality that provided actual cost data (Table 5-7). However, this municipality had eight wetlands which it managed in its public inventory. The cost data for these eight wetlands was detailed and provides a good estimate for an annual cost for maintaining a wetland. This cost is used with both public and private inspection data from MS4-2 to estimate costs for MS4-2.

Table 5-7: Data source and confidence of wetland maintenance cost data

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Wetlands Ponds – Public Costs	N/A	N/A	N/A	Primary data - average based on actual incurred costs from 8 wetlands.	N/A

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Wetlands Ponds - Public Inspections	N/A	N/A	N/A	N/A	N/A
Wetlands Ponds – Private Costs	N/A	N/A	N/A	NA	N/A
Wetlands Ponds – Private Inspections	N/A	Primary data – Based upon 54 inspections.	N/A.	N/A	N/A

The average annual maintenance cost for MS4-4's public facilities was $2,200 in 2014 dollars (Table 5-8). The only wetlands inspection data we received came from MS4-2; it indicated failure rates of 30% for public facilities and 45% for private facilities. As a result of the limited data availability, cost information on wetlands is not as robust as that of the other BMP types. However, the estimates for wetlands maintenance shown in Table 5-8 and Table 5-9 are believed to be accurate and representative. MS4-4 does employ a proactive approach to maintenance of these facilities.

Table 5-8: Estimated Public Wetlands Annual Maintenance Costs per BMP

Wetlands, Public	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Activity Cost, 2014 $	n/a	n/a	n/a	$2,200	n/a
Scheduled Activity Frequency	n/a	n/a	n/a	1	n/a
Unscheduled Activity Cost, 2014 $	n/a	$2,200*	n/a	n/a	n/a

Wetlands, Public	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Probability of Inspection Failure	n/a	0.3	n/a	n/a	n/a
Unscheduled Inspection Frequency	n/a	1	n/a	n/a	n/a
Annual Scheduled Maintenance Costs	n/a	n/a	n/a	$2,200	n/a
Annualized Unscheduled Maintenance Costs (5%)	n/a	$700	n/a	n/a	n/a

*Costs were not available for these facilities; instead, the average from MS4-4 is used.

Table 5-9: Estimated Private Wetlands Annual Maintenance Costs per BMP

Wetlands, Private	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Activity Cost, 2014 $	n/a	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	n/a	n/a	n/a	n/a	n/a
Unscheduled Activity Cost, 2014 $	n/a	$2,200*	n/a	n/a	n/a
Probability of Inspection Failure	n/a	0.45	n/a	n/a	n/a
Unscheduled Inspection Frequency	n/a	0.33	n/a	n/a	n/a
Annual Scheduled Maintenance Costs	n/a	n/a	n/a	n/a	n/a

Wetlands, Private	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Annualized Unscheduled Maintenance Costs (5%)	n/a	$300	n/a	n/a	n/a

*Costs were not available for these facilities; instead, the average from MS4-4 is used.

5.1.4 BIORETENTION

Bioretention facilities were used across all the case sites, pointing to their versatility from a geographic standpoint, however there was a general lack of data for these facilities (Table 5-10). Only public maintenance costs were available as a mix of primary and secondary sources and scheduled and unscheduled. Inspection details were available for both public and private facilities for MS4-2 and MS4-3.

Table 5-10: Data source and confidence of bioretention maintenance cost data

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Bioretention – Public Costs	Secondary data - from expert opinions and budget estimates	Primary data - average of actual incurred costs for 7bioretention.	n/a	Primary data - average based on actual incurred costs at 9 sites	n/a
Bioretention - Public Inspections	n/a	Primary data - Based upon 35 inspections	Primary data - Based upon 94 inspections	n/a	n/a
Bioretention – Private Costs	n/a	n/a	n/a	n/a	n/a
Bioretention – Private Inspections	n/a	Primary data – Based upon 78 inspections.	Primary data – Based upon 67 inspections.	n/a	n/a

Public costs ranged from $600 to $2,200 for annual maintenance (Table 5-11). MS4-1's public costs were adjusted downward after conversations with the stormwater manager, who stated that these facilities were the gold standard for maintenance, thus this cost was reduced to $2,200, more in line with average annual costs from MS4-2. Many of them were demonstration sites for public and contractor education and were not representative of actual costs. However, even with the downward adjustment, MS4-1's approach would still be considered proactive and high maintenance, thus higher annual costs.

Private bioretention maintenance costs among the municipalities ranged from $100 to $400 annually (Table 5-12). Despite the fact that bioretention facilities were used at each case site and their use was growing, they still numbered far fewer than the other BMP types. Bioretention facilities tend to be more visible and are newer, suggesting that knowledge of their existence may exceed that of more traditional facilities. The improved visibility and the increased education of private owners, especially HOAs and commercial businesses, could mean that scheduled maintenance is occurring along with unscheduled maintenance. If scheduled maintenance is occurring on private facilities, it is not reflected in these estimates and these estimates would then be too low.

Table 5-11: Estimated Public Bioretention Annual Maintenance Costs per BMP

Bioretention, Public	**MS4-1**	**MS4-2**	**MS4-3**	**MS4-4**	**MS4-5**
Scheduled Activity Cost, 2014 $	$2,200	n/a	n/a	$1,500	n/a
Scheduled Activity Frequency	1	n/a	n/a	1	n/a
Unscheduled Activity Cost, 2014 $	n/a	$2400	$2400*	n/a	n/a
Probability of Inspection Failure	n/a	0.31	0.26	n/a	n/a

Bioretention, Public	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Unscheduled Inspection Frequency	n/a	1	1	n/a	n/a
Annual Scheduled Maintenance Costs	$2,200	n/a	n/a	$1,500	n/a
Annualized Unscheduled Maintenance Costs (5%)	n/a	$700	$600	n/a	n/a

*Costs were not available for these facilities. Average unscheduled costs for bioretention from MS4-2 were $2400 annually.

Table 5-12: Estimated Private Bioretention Annual Maintenance Costs per BMP

Bioretention, Private	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Activity Cost, 2014 $	n/a	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	n/a	n/a	n/a	n/a	n/a
Unscheduled Activity Cost, 2014 $	n/a	$2400*	$2400*	n/a	n/a
Probability of Inspection Failure	n/a	0.51	0.10	n/a	n/a
Unscheduled Inspection Frequency	n/a	0.33	0.33	n/a	n/a
Annual Scheduled Maintenance Costs	n/a	n/a	n/a	n/a	n/a
Annualized Unscheduled Maintenance Costs (5%)	n/a	$400	$100	n/a	n/a

*Costs were not available for these facilities. Average unscheduled costs for bioretention from MS4-2 were $2400 annually.

5.1.5 *SAND FILTER*

Sand filter data was most prevalent in the form of inspection results (Table 5-13). Cost data was available from MS4-1 and MS4-2 for public facilities. Private maintenance cost data was only available as unscheduled maintenance from MS4-1.

Table 5-13: Source of sand filter maintenance data

	MS4-1	**MS4-2**	**MS4-3**	**MS4-4**	**MS4-5**
Sand Filter – Public Costs	Secondary data - from expert opinions and budget estimates	Primary data - average of actual incurred costs for 61 sand filters.	n/a	n/a	n/a
Sand Filter - Public Inspections	n/a	Primary data - Based upon 219 inspections	Primary data - Based upon 425 inspections	n/a	n/a
Sand Filter – Private Costs	Primary data – average of self-reported costs from 24 sand filter.	n/a	n/a	n/a	n/a
Sand Filter – Private Inspections	Primary data – Based upon 117 inspections.	Primary data – Based upon 273 inspections.	Primary data – Based upon 793 inspections.	n/a	Primary data – Based upon 11 inspections.

Public sand filter maintenance costs ranged from $1,200 to $4,500 per year (Table 5-14). Private facility data reflected lower costs with a range of $200 to $800 per year (Table 5-15). MS4-1 had the highest private sand filter inspection failure rate at 77%, while MS4-2 had inspection failure rates over 50% regardless of the ownership and frequency of inspections. However, MS4-3 and MS4-5 showed lower inspection failures.

Table 5-14: Estimated Public Sand Filter Annual Maintenance Costs per BMP

Sand Filter, Public	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Activity Cost, 2014 $	$4,500	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	1	n/a	n/a	n/a	n/a
Unscheduled Activity Cost, 2014 $	n/a	$2,000	$3,800*	n/a	n/a
Probability of Inspection Failure	n/a	0.63	0.36	n/a	n/a
Unscheduled Inspection Frequency	n/a	1	1	n/a	n/a
Annual Scheduled Maintenance Costs	$4,500	n/a	n/a	n/a	n/a
Annualized Unscheduled Maintenance Costs (5%)	n/a	$1,200	$1,400	n/a	n/a

*Costs were not available for these facilities; instead, the average found across case sites is used to estimate annual costs. Average unscheduled costs for sand filters were $3,800 annually.

Table 5-15: Estimated Private Sand Filter Annual Maintenance Costs per BMP

Sand Filter, Private	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Activity Cost, 2014 $	n/a	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	n/a	n/a	n/a	n/a	n/a
Unscheduled Activity Cost, 2014 $	$5,800	$3,800*	$3,800*	n/a	$3,800*
Probability of Inspection Failure	0.77	0.5	0.34	n/a	0.18
Unscheduled Inspection Frequency	0.22	0.33	0.33	n/a	0.33
Annual Scheduled Maintenance Costs	n/a	n/a	n/a	n/a	n/a
Annualized Unscheduled Maintenance Costs (5%)	$800	$600	$400	n/a	$200

*Costs were not available for these facilities; instead, the average found across case sites is used to estimate annual costs. Average unscheduled costs for sand filters were $3,800 annually.

5.1.6 Infiltration Trenches

Infiltration trench cost data was available as secondary and scheduled cost data from MS4-1 (Table 5-16). Public unscheduled cost data was available from MS4-2. Private costs were only available from MS4-1. Inspection data was for public facilities came from MS4-2 and MS4-3. Private inspection data was available from all case sites with the exception of MS4-4.

Table 5-16: Source of infiltration trench maintenance data

	MS 4-1	MS 4-2	MS 4-3	MS 4-4	MS 4-5
Infiltration Trench – Public Costs	Secondary data - from expert opinions and budget estimates	Primary data - average of actual incurred costs for 18 infiltration trench.	n/a	n/a	n/a
Infiltration Trench - Public Inspections	n/a	Primary data - Based upon 273 inspections	Primary data - Based upon 8inspections	n/a	n/a
Infiltration Trench – Private Costs	Primary data – average of self-reported costs from 31 infiltration trench.	n/a	n/a	n/a	n/a
Infiltration Trench – Private Inspections	Primary data – Based upon 258 inspections.	Primary data – Based upon 299 inspections.	Primary data – Based upon 19 inspections.	n/a	Primary data – Based upon 5 inspections.

Annual public maintenance costs for infiltration trenches ranged from $500 to $2,800 per year; this compares with $200 to $600 per year from private facilities (Table 5-17, Table 5-18). Inspection failure rates varied widely. MS4-1 saw failure rates of 89% for private facilities inspected once every five years, while MS4-5 had a 20% failure rate for facilities inspected once every three years.

Table 5-17: Estimated Public Infiltration Trench Annual Maintenance Costs per BMP

Infiltration Trench, Public	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Activity Cost, 2014 $	$2,800	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	1	n/a	n/a	n/a	n/a
Unscheduled Activity Cost, 2014 $	n/a	$1,500	$2,600*	n/a	n/a
Probability of Inspection Failure	n/a	0.3	0.5	n/a	n/a
Unscheduled Inspection Frequency	n/a	1	1	n/a	n/a
Annual Scheduled Maintenance Costs	$2,800	n/a	n/a	n/a	n/a
Annualized Unscheduled Maintenance Costs (5%)	n/a	$500	$1,300	n/a	n/a

*Costs were not available for these facilities; instead, the average found across case sites is used to estimate annual costs. Average unscheduled costs for infiltration trench were $2,600 annually.

Table 5-18: Estimated Private Infiltration Trench Annual Maintenance Costs per BMP

Infiltration Trench, Private	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Scheduled Activity Cost, 2014 $	n/a	n/a	n/a	n/a	n/a
Scheduled Activity Frequency	n/a	n/a	n/a	n/a	n/a

Infiltration Trench, Private	**MS4-1**	**MS4-2**	**MS4-3**	**MS4-4**	**MS4-5**
Unscheduled Activity Cost, 2014 $	$3,700	$2,600*	$2,600*	n/a	$2,600*
Probability of Inspection Failure	0.89	0.45	0.32	n/a	0.2
Unscheduled Inspection Frequency	0.2	0.33	0.33	n/a	0.33
Annual Scheduled Maintenance Costs	n/a	n/a	n/a	n/a	n/a
Annualized Unscheduled Maintenance Costs (5%)	$600	$300	$200	n/a	$200

*Costs were not available for these facilities; instead, the average found across case sites is used to estimate annual costs. Average unscheduled costs for infiltration trench were $2,600 annually.

5.2 Significant Findings

The averages shown in Table 5-19 show the range of cost estimates from the collected data and are the cost estimates with the highest confidence of reflecting actual maintenance costs. These costs are used to uncover patterns and evidence of maintenance cost influencers. The sections below look at the impact of a proactive versus reactive maintenance approach as well as if there is a correlation between inspection frequency and costs. Finally, a cost tools and literature estimates are then used to provide further context for understanding the data presented in Table 5-19. In general:

- Private maintenance costs may underestimate annual costs if scheduled maintenance is occurring.
- Maintenance costs for publicly maintained facilities are higher than private facilities.

- Failure rates are highest for privately maintained dry and wet pond stormwater facilities.

Table 5-19: Summary Table of Estimated Total Annual BMP Maintenance Costs

	MS4-1	MS4-2	MS4-3	MS4-4	MS4-5
Dry Pond – Public	$2,600	$800	$900	n/a	n/a
Dry Pond - Private	$1,000	$1,000	$200	n/a	$700
Wet Pond - Public	$2,600	$1,900	$1,200	$4,200	n/a
Wet Pond - Private	$1,000	$700	$200	n/a	$200
Wetlands - Public	n/a	$700	n/a	$2,200	n/a
Wetlands - Private	n/a	$300	n/a	n/a	n/a
Bioretention - Public	$2,200	$700	$600	$1,500	n/a
Bioretention – Private	n/a	$400	$100	n/a	n/a
Sand Filter - Public	$4,500	$1,200	$1,400	n/a	n/a
Sand Filter - Private	$800	$600	$400	n/a	$200
Infiltration Trench – Public	$2,800	$500	$1,300	n/a	n/a
Infiltration Trench – Private	$600	$300	$200	n/a	$200

5.2.1 MAINTENANCE PROCEDURE

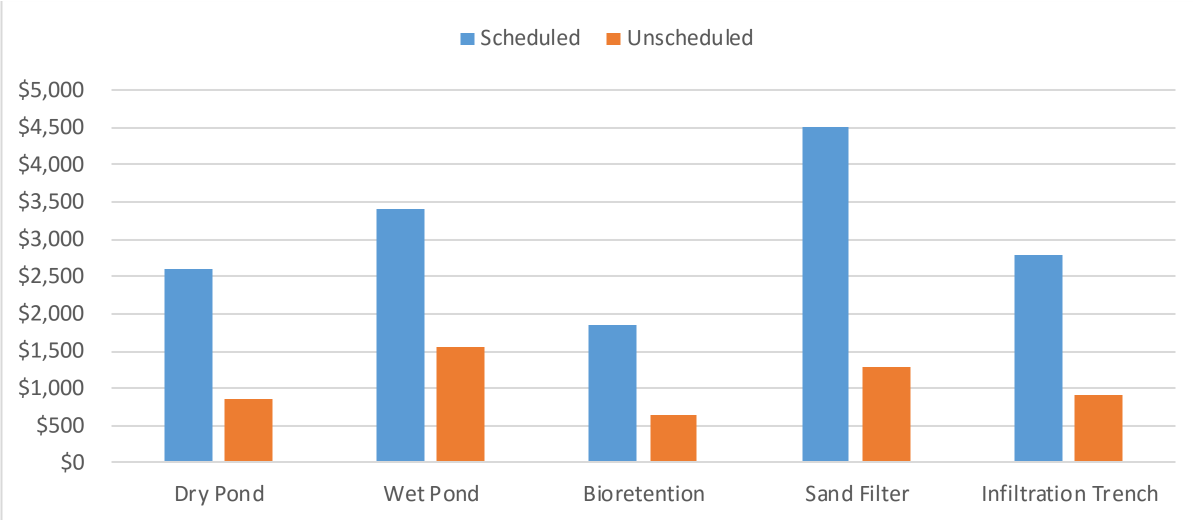
Interviews with stormwater staff from the various municipalities have revealed that regular maintenance is performed on public facilities, but is often limited to aesthetic fixes or is only performed by low-skilled labor (Stormwater Manager MS4-1, 2010; Stormwater Manager MS4-2, 2010). For example, all municipalities regularly mowed and removed trash at all sites.

Other types of regular maintenance occurred in some municipalities as a scheduled event. In this study, scheduled maintenance is considered to be a proactive approach to maintenance and unscheduled activity would be considered a reactive approach for public facilities.

We found that MS4-4 and MS4-5 proactively maintained their facilities, while MS4-2 and MS4-3 reactively performed maintenance on their facilities based upon findings from annual inspections. MS4-1 used a proactive strategy for bioretention and sand filters, and a mostly reactive approach on the rest of its facilities. However, due to the lack of costs for unscheduled activities for MS4-1 and because costs are either budgeted or expert opinion, it is considered to be proactive for the purpose of this analysis.

Cost tools often assume a mostly scheduled (proactive) approach to BMP maintenance. Interviews with stormwater management professionals indicated that they believe a proactive approach is ideal (Erickson et al., 2009). However, it is not clear that this is happening in practice. The rating system employed by some of the case sites, MS4-1 and MS4-3, would indicate that they are not able to meet all maintenance needs and instead focus their energies on the most pressing deficiencies. When comparing the municipalities' average costs incurred by scheduled versus unscheduled maintenance, all BMPs had higher annual maintenance costs when maintained proactively (Figure 5-1). Short-term cost incentives may lead to a reactive approach over proactive approaches for many municipalities and this can be hard to overcome if budget constraints exist. It is not known the impact of a reactive approach over a long time period.

Figure 5-1: Public Costs – Scheduled vs. Unscheduled Annual Maintenance Costs



5.2.2 *Inspection Frequency Impact on Maintenance Costs*

All of the municipalities inspect public facilities more frequently than private facilities. A comparison of public versus private inspection results can indicate whether failure rates change with a change in inspection frequency. This comparison can also give insight into the importance of monitoring facilities as well as the impact of more "regular" maintenance. The most complete data with respect to inspection failure rates came from sites MS4-2 and MS4-3. Their public and private inspection failure rates are shown below in Figure 5-2 and Figure 5-3, respectively. With the exception of sand filters, failure rates were higher for all private facilities at MS4-2. The opposite is true of inspection failure rates at MS4-3. MS4-3 uses a slightly different inspection form for public facilities than for private ones. Rather than a simple yes/no determination as to the existence of a deficiency, as was done by MS4-2, a progressive ranking system is used to identify maintenance needs. It is possible that this graded method influences failure rates to be skewed higher for MS4-3's public BMPs than its private ones. Further research into inspection frequency and its impact on inspection failure would be beneficial.

Figure 5-2: MS4-2 Public and Private Inspection Failure Results

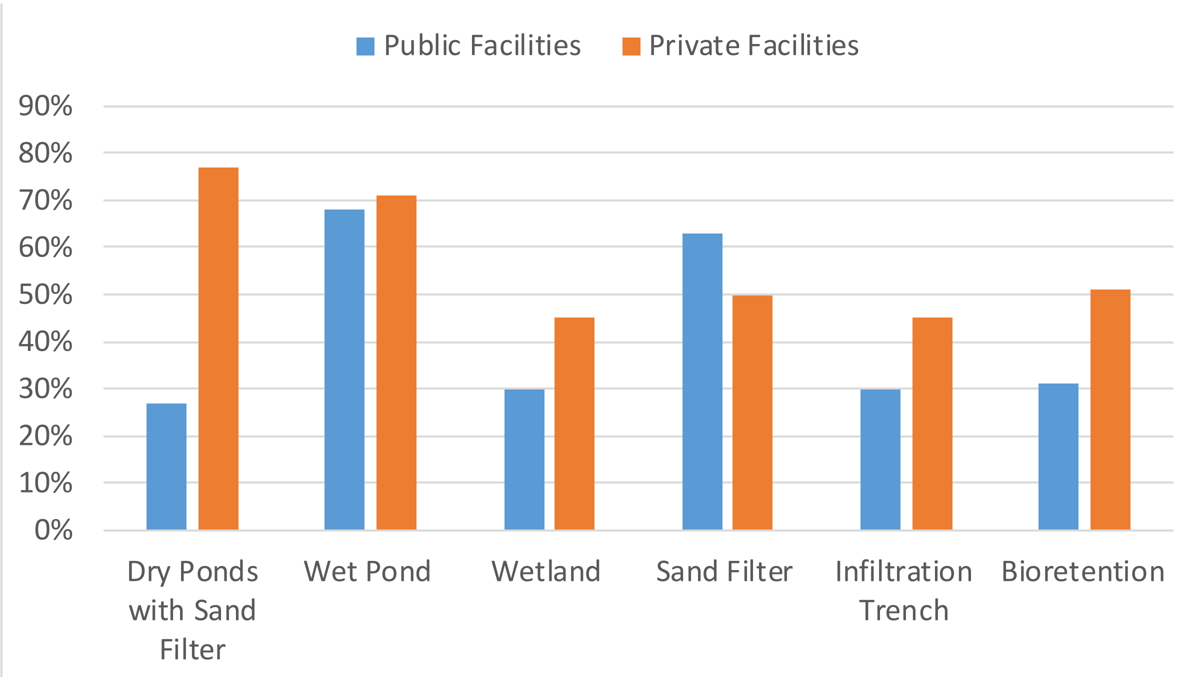
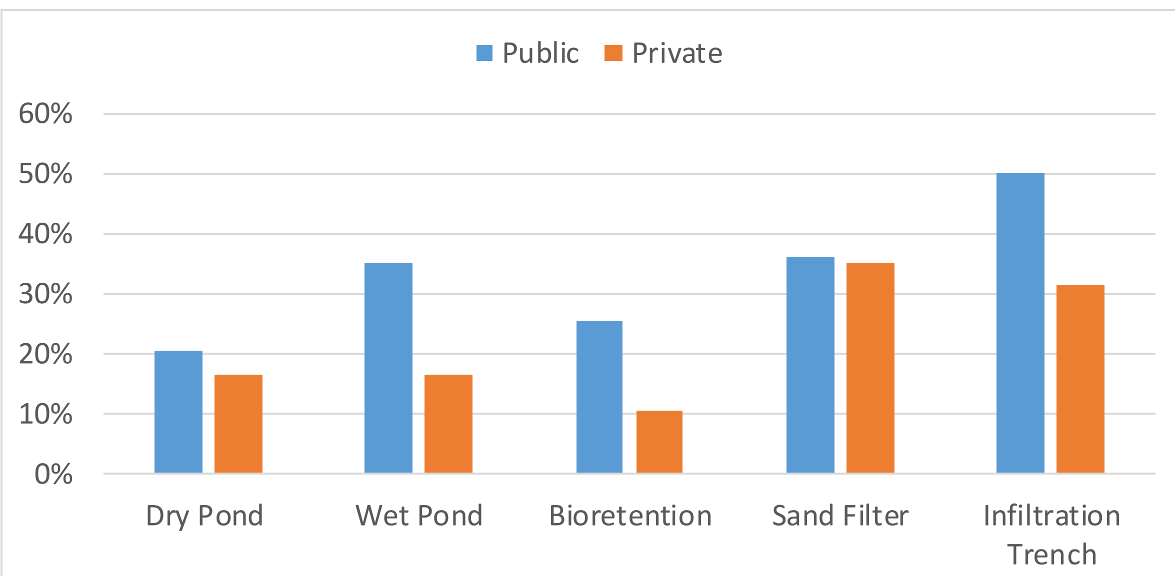


Figure 5-3: MS4-3 Public and Private Inspection Failure Results



5.2.3 COMPARISON WITH LITERATURE AND COST TOOLS

Literature and cost tool maintenance estimates for the same types of BMPs examined in this study are not abundant. The studies we have used in the tables below for comparison were chosen because they are either widely-used cost tools or are studies which attempted to collect actual post-construction maintenance data. The tables below indicate the normalization of the literature's or cost tool's original data for comparison with the data from this study. Where available, a range of low and high costs are provided and all costs are in 2014 dollars and rounded. For this study, maintenance costs are reported on an annual basis per BMP and are representative of an average-size BMP for the specific BMP type. Average sizes are based upon expert opinion of average sizes or defaults from the WERF cost tool:

- Dry Pond: 10 acres
- Wet Pond: 50 acres
- Wetland: 20 acres
- Bioretention: 1 acre
- Sand Filter: 2.5 acres
- Infiltration trench: 0.6 acres

Dry pond normalization used the WERF tool default with a 40% impervious assumption. This resulted in four acres of impervious area (IA). Dry pond estimates from the literature and cost tools show an incredibly wide variation (Table 5-20). The WERF cost tool showed the highest degree of variability depending on the level of attention given to the BMP. The low range of costs from our study are well below those reported both by costs tools and by literature, this came from privately maintained facilities. Either the private cost is underestimating costs or regular maintenance is not occurring. The high range of costs from this study seems more in-line with cost tool and literature estimates, but still on the low end of costs. A more reactive approach to maintenance than suggested by cost tools or studies where proactive and high attention are given to the facilities may be the reason behind these differences.

Table 5-20: Literature and Cost Tool Comparison, Dry Ponds

Dry Ponds	Description of Original Data	Costs - 2014$
Range of Public and Private Maintenance Costs MS 4-1 – MS 4-5	Based upon inspection failure rates and actual maintenance data from five case sites around the United States.	$200 - $2,600
CALTRANS (2006)	Based upon retrofit projects in California. Considered high level of attention. Took actual costs and adjusted them based upon expert opinion. Five dry ponds in this study.	$4,400
King and Hagen (2011)	Actual costs from Maryland counties. Reported cost as $1200 on an IA basis.	$5,100
WERF Cost Tool (Houdeshel et al., 2009)	Costs are expert opinion and literature estimates. Default assumption of 10.0 acres Drainage Area (DA), 40% Impervious Cover (IC), low and high attention	$1,400 - $48,500
BMP REALCOST Tool (Olson, Roesner, Urbonas, & Mackenzie, 2010)	Survey of seven stormwater utilities. Reported costs based on the size of the BMP, per AF.	$2,200

Wet pond normalization used a 40% impervious assumption. The estimates from this study are well below the cost estimates from other studies and from the cost tools (Table 5-21). Again, one explanation may be that municipalities are not performing maintenance activities as frequently as recommended by design manuals and engineers. It may also be that those studies using a IA basis (King & Hagan, 2011) are not scaleable or comparable to this study. As with dry ponds, the WERF tool estimates show a wide range depending on the level of attention.

Table 5-21: Literature and Cost Tool Comparison, Wet Ponds

Wet ponds	Description	Costs -, 2014$
Range of Public and Private Maintenance Costs MS 4-1 – MS 4-5	Based upon inspection failure rates and actual maintenance data from five case sites around the United States.	$200 - $4,200

Wet ponds	Description	Costs -, 2014$
CALTRANS (2006)	Based upon retrofit projects in California. Considered high level of attention. Took actual costs and adjusted them based upon expert opinion. One wet pond in this study.	$24,100
King and Hagen (2011)	Actual costs from Maryland counties. Reported cost as $742 on an IA basis.	$15,600
WERF Cost Tool (Houdeshel et al., 2009)	Costs are expert opinion and literature estimates. Default assumption of 50.0 acres Drainage Area (DA), 40% Impervious Cover (IC), low and high attention.	$1,700 - $12,600
BMP REALCOST Tool (Olson, Roesner, Urbonas, & Mackenzie, 2010)	Survey of seven stormwater utilities. Reported costs based on the size of the BMP, per AF.	$6,100
Wossink & Hunt, (2003)	Survey municipalities in NC, VA, and MD. Cost curve = $9{,}202x^{0.269}$	$17,700

Wetland normalization used the WERF tool default with a 40% impervious assumption. The same trend seen in dry and wet ponds continues for wetlands. Costs are much lower than literature and cost tool estimates (Table 5-22).

Table 5-22: Literature and Cost Tool Comparison, Wetlands

Wetlands	Description	Costs, 2014$
Range of Public and Private Maintenance Costs MS4-1 – MS4-5	Based upon inspection failure rates and actual maintenance data from five case sites around the United States.	$300 - $2,200
BMP REALCOST Tool (Olson, Roesner, Urbonas, & Mackenzie, 2010)	Survey of seven stormwater utilities. Reported costs based on the size of the BMP, per AF.	$4,300

Wetlands	Description	Costs, 2014$
Wossink & Hunt, (2003)	Survey municipalities in NC, VA, and MD. Cost curve = 3,852x^0.484	$10,500

Bioretention normalization used the average drainage area from the WERF tool default (1.0acre DA) with an 80% impervious assumption. For this study our estimated bioretention costs are more in line with cost tools and literature estimates (Table 5-23).

Table 5-23: Literature and Cost Tool Comparison, Bioretention

Bioretention	Description	Costs, 2014$
Range of Public and Private Maintenance Costs (Licher 2016)	Based upon inspection failure rates and actual maintenance data from five case sites around the United States.	$100 - $2,200
CALTRANS (2006)	Based upon retrofit projects in California. Considered high level of attention. Took actual costs and adjusted them based upon expert opinion. Six biofiltration swales in this study.	$3,900
King and Hagen (2011)	Actual costs from Maryland counties. Reported cost as $1500 on an IA basis.	$1,300
WERF Cost Tool (Houdeshel et al., 2009)	Costs are expert opinion and literature estimates. Default assumption of 1.0 acres Drainage Area (DA), 80% Impervious Cover (IC), low and high attention	$706 - $6,500
Wossink & Hunt, (2003)	Survey municipalities in NC, VA, and MD. Cost curve = $3,437x^{0.152.}$	$3,300

Sand filter normalization assumed an 80% impervious cover. This resulted in 2.24 acres of impervious area (IA). The low range of estimates is far below other estimates, but the high range is closer to estimates from cost tools and literature (Table 5-24).

Table 5-24: Literature and Cost Tool Comparison, Sand Filter

Sand Filter	Description	Costs, 2014$
Range of Public and Private Maintenance Costs MS4-1 – MS4-5	Based upon inspection failure rates and actual maintenance data from five case sites around the United States.	$200 - $4,500
CALTRANS (2006)	Based upon retrofit projects in California. Considered high level of attention. Took actual costs and adjusted them based upon expert opinion. Six sand filters in this study.	$4,100
King and Hagen (2011)	Actual costs from Maryland counties. Reported cost as $1600 on an IA basis.	$2,900 - $3,400
Wossink & Hunt, (2003)	Survey municipalities in NC, VA, and MD. Cost curve = $10556x^{0.534}$	$15,300

Infiltration Practices, based upon 1 drainage acre and 80% IC. Cost estimates from literature were closer to the range of the estimates of our study. No cost tools estimated infiltration trench costs (Table 5-25).

Table 5-25: Literature and Cost Tool Comparison, Infiltration Trench

Infiltration Trench	Description	Costs, 2014$
Range of Public and Private Maintenance Costs MS4-1 – MS4-5	Based upon inspection failure rates and actual maintenance data from five case sites around the United States.	$200 - $2,800
CALTRANS (2006)	Based upon retrofit projects in California. Considered high level of attention. Took actual costs and adjusted them based upon expert opinion. Two infiltration trenches in this study.	$3,780
King and Hagen (2011)	Actual costs from Maryland counties. Reported cost as $835-875 on an IA basis.	$400

Comparison with cost tools and literature estimates show that knowledge about post-construction maintenance costs continues to be lacking. Better record keeping, longer histories of BMP maintenance and failures, and an understanding of private maintenance activity would provide much needed information about long-term maintenance of stormwater facilities. However, the cost estimates from this study are much lower than estimates from cost tools and most other studies, especially for large-scale BMPs. This suggests that cost tools and other literature may be over-estimating actual maintenance cost for large-scale BMPs compared with small-scale BMPs. This may be because while design manuals and engineering estimates suggest a certain level of maintenance, the reality is that a more medium or low-level of attention is being paid to facilities. This may hold truer for large-scale facilities who may not need the same level of attention to perform adequately over time.

Chapter 6: Effects of a Changing Stormwater Inventory on Post-Construction Costs

As land becomes more developed and regulations evolve, stormwater inventory has both grown and changed in type. Stormwater policies now stress the use of small-scale, distributed practices that reduce runoff volumes. Evidence from the case sites indicate that inspection and maintenance costs do not change radically based on the type of BMP. Thus, system-wide maintenance costs may be impacted more by policies that increase the number of practices required to treat any given urban area. The objective of this chapter is to estimate the total costs of meeting a regulatory standard using two different approaches. The hypothetical scenarios demonstrate the possible range of costs for two different stormwater management approaches.

6.1 Methods

This chapter uses two different hypothetical urban developments based upon impervious percentages from real-life examples in Selbig and Bannerman (2008). Scenario one is low density residential and scenario two is a mixed-use development with higher residential density. Two different BMP approaches to meeting the same regulatory standards are applied to the two different development scenarios. These two approaches are 1) through maximizing infiltration and 2) through minimizing the number of BMPs in the landscape.

The effects of a change to BMP type in a municipality's inventory are considered through the two hypothetical scenarios. In this example, one development is strictly residential with 28% impervious area, 64% turf, and 8% forested. The second development is a combination of residential and commercial property with 50% impervious area, 48% turf area, and 2% forested.

The Virginia stormwater regulations were chosen as the common regulatory standard to be met, which requires that BMPs meet both a water quality and quantity requirement. For new developments, the total phosphorus load cannot exceed 0.41 pounds per acre per year (9VAC25-870-65). The use of the Runoff Reduction Method (RRM) is used for calculating different BMPs' ability to meet these standards given the phosphorus criteria. Specifically, the RRM "credits the appropriate runoff volume reduction, pollutant concentration reduction or both to meet stormwater quality and quantity standards" (Battiata, Collins, Hirschman, & Hoffmann, 2010). The RRM also takes into account the type of soil, as well as the land cover and the percentage of impervious cover, turf, and forest.

A spreadsheet developed to meet the Virginia standards using the RRM was used with our hypothetical scenarios (Virginia Department of Environmental Quality (DEQ), 2014). As stated in the development scenarios, Virginia's standards are met in two different ways: first, through maximizing infiltration, and, second, through minimizing the number of facilities on the landscape. Bioretention facilities will be used to maximize stormwater infiltration. Wet ponds will be used to minimize the number of BMPs in the landscape. To determine the number of bioretention facilities and wet ponds needed in our scenarios, we assumed wet ponds as having a drainage area of 10 acres, and bioretention a drainage area of 1 acre. This is in line with design manuals, cost tools, and data from the municipalities. For example, EPA (2004) lists wet ponds as being a minimum size of 25 drainage acres and bioretention as being at a maximum of 2 drainage acres. Other design criteria state between 10 acres and 1,000 acres for wet ponds and a maximum of 2.5 acres for bioretention. Thus, the drainage area for wet ponds is on the conservative side and the drainage acres for bioretention facilities is in line with design estimates and with the average of drainage area from MS4-1, which was 0.75 acres with an inventory of 75 facilities.

This study assumes B soils with a 1,000-acre development for each scenario. The RRM is used to determine the number of BMPs needed to meet Virginia's water quality and quantity standards. In the low-density residential scenario, maximizing stormwater infiltration results in the need to treat 254 of impervious acres given the assumptions of the spreadsheet (Virginia Department of Environmental Quality (DEQ), 2014). The 254 impervious acres are exclusively bioretention in this scenario, thus the result is 254 bioretention facilities (Table 6-1). To meet the phosphorus load requirements with wet ponds, it would require treating 280 impervious acres and 116 acres of turf. Resulting in 40 wet ponds to treat the drainage area, based upon the spreadsheet assumptions and our drainage are of 10 acres. In the second development scenario, a mixed residential and commercial 1,000-acre development, the same assumption of B soils is used. For maximum infiltration, 459 acres of impervious area will need to be treated with 459 bioretention facilities (Table 6-1). To meet the phosphorus load requirement using a minimum number of BMPs, all 500 of the impervious acres along with 241 acres of turf would need to be treated. This would require 74 wet ponds.

Table 6-1: Treated Acres for Meeting Phosphorus Load Levels, RRM

1,000-Acre Development with B Soils, Treating All Impervious First	Total Treated Acres for Maximum Infiltration	Total Treated Acres for Minimizing BMPs	Bioretention Facilities Needed (DA = 1)	Wet Pond Facilities Needed (DA = 10)
Development Scenario 1 (Low Residential: 28% Impervious, 64% Turf, 8% Forested)	254 IA	280 IA; 116 Turf	254	40
Development Scenario 2 (Mixed Residential & Commercial: 50% Impervious, 48% Turf, 2% Forested)	459 IA	500 IA; 241 Turf	459	74

DA = Drainage Area; IA = Impervious Acres

Then, inspection and enforcement and maintenance cost estimates from this study are used to estimate the total difference in post-construction costs. This will aid in our understanding of the implication that these changing regulations and thus what a changing stormwater inventory may have on long-term cost and management obligations. Table 6-2 contains a summary of the estimated costs from Chapters 4 and 5 for the two BMP types. For meeting these regulatory requirements only public costs are considered. These costs are multiplied by the number of BMPS needed in each scenario.

Table 6-2: Annual Estimated Cost Ranges, 2014$

	I&E - Low Range	I&E - High Range	Maint - enance - Low Range	Maint- enance - High Range	Total - Low Range	Total - High Range
Wet Pond – Public	$60	$550	$1,200	$4,200	$1,260	$4,750

	I&E - Low Range	I&E - High Range	Maint - enance - Low Range	Maint- enance - High Range	Total - Low Range	Total - High Range
Bioretention – Public	$60	$550	$600	$2,200	$660	$2,750

6.2 Results

The vast difference between these two efforts--maximizing infiltration versus minimizing the number of BMPs used--shows how a change in inventory composition might influence costs. While small-scale facilities provide more infiltration, the annual cost is staggering compared to the cost of using larger-scale facilities. Table 6-3 and Table 6-4 represent the high/low range of costs of bioretention facilities and wet ponds given the number of BMPs needed to meet regulatory standards in the scenarios above. The difference in costs, due to number of BMPs required, highlights how quickly costs could grow.

Table 6-3: Total Annual Cost for 1,000-Acre Development, Development #1

Development #1	I & E Costs - Low	I & E Costs - High	Maint- enance Costs - Low	Maint- enance Costs - High	Total Cost - Low	Total Cost - High
Bioretention – Public	$15,240	$139,700	$152,400	$558,800	$167,640	$698,500
Wet Pond – Public	$2,376	$21,780	$47,520	$166,320	$49,896	$188,100

Table 6-4: Total Annual Cost for 1,000-Acre Development, Development #2

Development #2	I & E Costs – Low	I & E Costs - High	Maint- enance Costs - Low	Maint- enance Costs - High	Total PC - Low	Total PC - High
Bioretention – Public	$27,540	$252,450	$275,400	$1,009,800	$302,940	$1,262,250

Development #2	I & E Costs – Low	I & E Costs - High	Maint-enance Costs - Low	Maint-enance Costs - High	Total PC - Low	Total PC - High
Wet Pond – Public	$4,446	4$0,755	$88,920	$311,220	$93,366	$351,975

These hypothetical developments provide some insight as to how post-construction costs might manifest for municipalities as they grow. This analysis focused only on meeting the phosphorus load requirements. It is meant to demonstrate the overall impact of the change in BMP type may have on post-construction costs.

6.3 Policy Implications

Policy that pushes for small-scale facilities over large-scale facilities may need to rethink the process of inspection and enforcement along with maintenance processes. An inspection process that looks at a sampling of the small-scale facilities to look for component failures may be necessary instead of inspecting each facility. The implications of 1 out of 10 bioretention facilities failing is not the same as the implication of 1 out of 10 wet pond failing to function as designed. In addition, with more facilities to maintain, it is possible that a more reactive maintenance strategy may occur as personnel and budgets are strained. It is still unknown the impact of a proactive versus reactive maintenance strategy has on life-cycle costs. In the past, large-scale residential facilities were maintained by municipalities or other agencies such as homeowner associations or business associations. Depending on the responsible party for these small-scale facilities, education of individuals may be necessary to ensure functionality of systems. These implications have not been discussed in literature.

Chapter 7: Summary and Future Research

As more land is developed and regulations continue to evolve, stormwater inventory has also changed in size and type. This study is concerned with understanding what the long-term management and cost obligations are as a result of these changes; specifically, as smaller-scale facilities are becoming more widely used due to regulatory standards that must be met. Chapter 7 examines the possible long-term consequences of meeting regulatory standards in two ways: through maximizing infiltration or through minimizing the number of BMPs in the landscape. These impacts are examined in a hypothetical scenario using the evidence found at our five case sites. Finally, there is a discussion of future research needed to further the understanding of post-construction stormwater management costs.

Table 7-1 contains a summary of the total annual post-construction management costs for the different BMP types researched for this study. The costs are based on ownership. They range from $240 per year for private bioretention facilities to $5,050 per year for public sand filters. While private costs may not include the total costs required to maintain and monitor a facility, they are often a good estimate of unscheduled costs.

Table 7-1: Annual Estimated Cost Ranges, 2014$

	I&E - Low Range	I&E - High Range	M - Low Range	M - High Range	Total Range
Dry Pond – Public	$60	$550	$800	$2,600	$860 - $3,150
Dry Pond – Private	$140	$150	$200	$1,000	$340 - $1,150
Wet Pond – Public	$60	$550	$1,200	$4,200	$1,260 - $4,750
Wet Pond – Private	$140	$150	$200	$1,000	$340 - $1,150
Wetlands – Public	$60	$550	$700	$2,200	$760 - $2,750
Wetlands – Private	$140	$150	n/a	$300	$440 - $450
Bioretention – Public	$60	$550	$600	$2,200	$660 - $2,750

	I&E - Low Range	I&E - High Range	M - Low Range	M - High Range	Total Range
Bioretention – Private	$140	$150	$100	$400	$240 - $550
Sand Filter – Public	$60	$550	$1,200	$4,500	$1,260 - $5,050
Sand Filter – Private	$140	$150	$200	$800	$340 - $950
Infiltration Trench – Public	$60	$550	$500	$2,800	$560 - $3,350
Infiltration Trench – Private	$140	$150	$200	$600	$340- $750

This research has reconfirmed that the lack of knowledge about post-construction stormwater management costs continues. Initially, this study aimed to estimate the costs and activities associated with inventory tracking, inspections, and enforcement. However, a shortage of data on inventory tracking and the inability to separate such costs from other administrative duties led us to focus on inspection and enforcement only. There still exists a need to understand the costs of tracking and maintaining records for facilities as well as a need to study, in greater detail, costs associated with inspection, enforcement, and maintenance. Below are some of the additional research needs for I&E and maintenance of post-construction stormwater.

Inspection and Enforcement Costs

Inspection and enforcement costs will continue to be an important part of post-construction costs and as inventory sizes increase, knowledge about time spent to inspect and then follow-up to ensure that maintenance is adequately completed is necessary. First, better record-keeping is required to track inspection and travel time to understand how the type of BMP influences inspection costs. There is also the need for more information from the private sector about whether they perform inspections outside of those performed by the municipality. It was apparent in talking with the Phase II municipality, MS4-4, that a smaller number of facilities to be managed means municipalities are better able to ensure their compliance. Understanding how enforcement changes as inventory grows can help stormwater managers improve compliance on a larger scale. Interviews with stormwater staff indicates that process and procedure do matter. For the larger municipalities with automated responses, moving from a hard copy notification to an electronic notification was said to greatly increase their private facility response rates. Further inquiry into effective processes to ensure compliance by private owners is needed for meeting the goals of the CWA. In general, better record keeping to capture the full cost of inspection and enforcement is needed. In addition, a review of practices that encourage compliance by private owners would inform municipalities on how to gain compliance as inventory size increases and the ability to personally manage private owners is lost.

None of the municipalities in this study had their inspection results in electronic format that allowed for analysis. Electronic inspection results would allow for municipalities to identify common maintenance issues by BMP type and allow for feedback to engineers to change design requirements, which might lessen maintenance problems. It also allows for an understanding of how well installed BMPs are actually performing.

Maintenance

Electronic record-keeping of maintenance activities on specific BMP types would greatly enhance the knowledge of actual maintenance being performed, the frequency of maintenance activities, and the cost to complete the maintenance. Additional research into private sector maintenance is needed to estimate scheduled costs, not just unscheduled private maintenance costs. The impact of a proactive versus reactive maintenance approach on maintenance costs over time is necessary for long-term planning by municipalities.

The importance of understanding post-construction costs is only expected to grow as development and urbanization continue. Despite the NRC (2009) finding that stormwater maintenance efforts had not been adequate, seven years later there continues to be a dearth of information about how stormwater facilities are performing and how to ensure that funding exists to adequately monitor and maintain existing facilities. This study has shown that a move toward small-scale, on-site retention may result in substantially higher costs due to the sheer number of BMPs required in the landscape. Better record-keeping and analysis of BMPs in the ground would allow stormwater managers to focus on how best to service their inventory within the financial constraints they face.

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Appendix A – Sample Inspection Forms

Condition Assessment Report – Dry Pond

A. Summary of Maintenance Issues

☐ The pond was inaccessible at the time of the condition assessment because _________. Please provide access to the facility and notify the County at [redacted] when it is accessible.

☒ Maintenance is needed based on this visual condition assessment. Maintenance for Stormwater Management facilities governed by conditions in the approved plan of development should be performed. In all cases, maintenance should be performed unless a qualified professional warrants that no maintenance is required.

☐ Other: ____

☐ Other than routine preventative maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

B. Dam Embankment (Includes Separate Emergency Spillway if One Exists)

☒ Trees were noted on the dam. These trees should be removed and replaced with grass. (See picture #'s 1 & 2).

☒ Shrubbery and other types of low growing vegetation were noted on the dam. This material should be removed and replaced with grass. (See picture #'s 1 & 2).

☒ Scrub brush and other types of viney material were noted on the dam. This material should be removed and replaced with grass. (See picture #'s 1 & 2).

☐ Erosion was noted on the dam. Eroded areas should be repaired.

Location(s): _________

☐ Settlement was noted on the dam. Settled areas should be repaired.

Location(s): _________

☐ Piping (i.e. internal cavities due to the outward migration of embankment earth) was noted on the dam. Piping problems should be repaired.

Location(s): _________

☐ Slope slippage was noted on the dam. Slippage problems should be repaired.

Location(s): _________

☐ Animal burrow holes were noted on the dam. Burrow holes should be filled. (See Maintenance Guidelines)

Location(s): _________

☐ Other Items:

____

☐ Other than routine preventative maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

C. Riser (or Control Structure)

☒ The low-flow orifice is blocked. The blockage should be removed. (See picture # 3).

☐ The BMP device is damaged. This device should be repaired.

☐ The BMP device is missing. This device should be replaced. (See attached copy of approved facility plan sheets)

☐ The low-level gate drain appears not to have been exercised within the last year. This drain should be exercised at least annually.

☐ The riser is filled with excess material (debris, trash, rock, etc.) This material should be removed.

☐ The riser is damaged or deteriorated. The riser should be repaired or replaced.

Extent of damage or deterioration:

☒ Other Items:

The lower trash rack is blocked. The blockage should be removed; (See picture # 4)

There is excessive vegetation surrounding the Riser. Remove all vegetation within 10' of the Riser; (See picture # 5).

☐ Other than routine preventative maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

E. Principal Spillway Pipe (PSP)

☐ The PSP is blocked. The blockage should be removed.

☐ One or more of the joints of the PSP are leaking. All leaking joints should be parged.

Location(s): ___________

☐ One or more sections of pipe have settled to a point that it threatens the integrity of the dam. These sections of pipe may need to be replaced.

Location(s): ___________

☐ Other Items:

____

☒ Other than routine preventative maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

F. Outfall Structure

☐ The outfall structure is undermined and/or is rusting inside. This structure should be repaired.

☐ The outfall structure has separated from the main PSP by more than three inches. This structure should be repaired.

☐ Other Items:

____

☒ Other than routine preventative maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

G. Outfall Channel

☐ The outfall channel is blocked. The blockage should be removed.

☐ The outfall channel is eroding. The channel erosion should be repaired.

☐ Other Items:

____

☒ Other than routine preventative maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

H. <u>Impoundment Area</u>

☐ There is heavy vegetation and large debris in the lake or ponding area that could wash down against the riser. This material should be removed.

☐ The lake is showing signs of significant sedimentation and/or poor health (i.e. nutrient overload, excess aquatic vegetation, sever turbidity, etc.). It is recommended that the lake be evaluated by a qualified professional for possible corrective measures.

☐ A ten-foot "un-maintained" riparian buffer has not been provided/ preserved around the lake/wet pond (exclusive of the dam embankment and emergency spillway). A 10' wide riparian buffer is suggested.

☐ The shoreline is showing signs of erosion. The erosion should be repaired.

☒ Silt and sediment have filled in significant portions of the dry pond's BMP or 2-yr SWM volume. It is recommended that this be evaluated by a qualified professional for possible corrective measures. (<u>See picture # 6).</u>

☐ The low-flow ditch system is blocked with silt and sediment. The ditches should be cleaned.

☐ Sections of the low-flow ditch are cracked or have undermined. All damaged sections of the ditch should be repaired.

☐ Other Items:

____

☐ Other than routine preventative maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

I. Infalls (Pipes, channels or streams with significant flows into the subject Stormwater Management Facility)

☒ Infall structure(s) 2 & 3 and/or outflow channels have blockages which should be removed. (See picture #'s 7 & 8).

☐ Infall structure(s) ______________ has/have cracking and concrete spalling occurring. Parging or repair is recommended.

☐ Infall structure(s) ______________ has/have undermining occurring at outlet structure. Please restore underlying support and in the case of concrete pipes, reparge joint(s) if leaking or more than 2" of separation occurs.

☒ Infall structure(s) outlet # 1 has/have erosion and/or blockage(s) which should be corrected / removed. (See picture # 9).

☒ Rip-rap stone appears to be displaced / misaligned at structure 2 & 3 and should be corrected. (See picture #'s 7 & 8).

☒ Other Items:

Infall # 1 has adjacent trees that should be removed; (See picture # 10).

☐ Other than routine preventative maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

Note: To navigate the Infalls, refer to the attached Infall sketch.

J. General

☒ Remove all excess vegetation within 10' around all major structure(s) (e.g. riser, end walls, pipes, channels, etc)

☒ Where sediment and/or debris removal actions are noted, they must be properly disposed. (e.g. flushing this material downstream would not be considered "proper disposal")

☐ Other Items:

____

K. Other Recommended Actions

- ☐ Post warning signs suggested.
- ☐ Install guard rails on all retaining walls over 3’ high.
- ☐ Other Items:

Condition Assessment Report – Wet Ponds

Summary of Maintenance Issues

☒ Condition assessment could not be performed. (*upstream inflow and manhole between Pond* [redacted]

☒ Maintenance is needed based on this visual condition assessment. Maintenance for stormwater facilities governed by conditions in the approved plan of development should be performed. In all cases, maintenance should be performed unless a qualified professional warrants that no maintenance is required.

☐ No maintenance is needed based on this visual condition assessment.

Accessibility

☐ The pond was inaccessible at the time of the condition assessment. Please provide access to the facility.

Dam Embankment (Includes Separate Emergency Spillway if One Exists)

☐ At the time of the condition assessment, the dam was found to be largely over grown. Please cut the dam so that a more thorough condition assessment can be provided.

☒ Trees were noted on the dam. These trees should be removed and replaced with grass.

(*Photo 13*)

☐ Shrubbery and other types of low growing landscaping material were noted on the dam. This material should be removed and replaced with grass.

☐ Scrub brush and other types of viney material were noted on the dam. This material should be removed and replaced with grass.

☐ Erosion was noted on the dam. Eroded areas should be repaired.

Locations:

☐ Settlement was noted on the dam. Settled areas should be repaired.

Locations:

☐ Piping was noted on the dam. Piping problems should be repaired.

Locations:

☐ Slope slippage was noted on the dam. Slippage problems should be repaired.

Locations:

☐ Animal burrow holes were noted on the dam. Burrow holes should be filled in.

Locations:

☐ Other Items:

☐ No maintenance on the dam embankment is needed at this time

Riser

☐ The low-flow orifice is blocked. The blockage should be removed.

☐ The BMP device is damaged. This device should be repaired.

☐ The BMP device is missing. This device should be replaced.

☐ The low-level gate drain appears not to have been exercised within the last year. This drain should be exercised at least annually.

☒ The riser is filled with excess material (debris, trash, rock, etc.) This material should be removed. (*Photo 4*)

☐ The riser is damaged or deteriorated. The riser should be repaired or replaced.

Extent of damage or deterioration:

☐ Other Items:

☐ No maintenance on the riser is needed at this time.

Principal Spillway Pipe (PSP)

☐ The PSP is blocked. The blockage should be removed.

☐ One or more of the joints of the PSP are leaking. All leaking joints should be parged.

Location:

☐ One or more sections of pipe have settled to a point that it threatens the integrity of the dam. These sections of pipe may need to be replaced.

Location:

☐ Other Items:

☐ No maintenance on the principal spillway pipe is needed at this time.

Outfall Structure

☐ The outfall structure is undermined and/or is rusting inside. This structure should be repaired.

☐ The outfall structure has separated from the main PSP by more than three inches. This structure should be repaired.

☐ Other Items:

☐ No maintenance on the outfall structure is needed at this time.

Outfall Channel

☒ The outfall channel is blocked. The blockage should be removed (*Photos 10 and 11*).

☐ The outfall channel is eroding. The channel erosion should be repaired.

☐ Other Items:

Impoundment Area

☐ There is large debris in the lake or ponding area that could wash down against the riser. This material should be removed.

☐ The lake is showing signs of significant sedimentation and/or poor health (i.e. nutrient overload, excess aquatic vegetation, sever turbidity, etc.). It is recommended that the lake be evaluated professionally.

☐ A ten-foot "un-maintained" riparian buffer has not been provided/ preserved around the lake/wet pond (exclusive of the dam embankment and emergency spillway). A 10' wide riparian buffer is suggested.

☐ The shoreline is showing signs of erosion. The erosion should be repaired.

☐ Silt and sediment have filled in significant portions of the dry pond's BMP or 2-yr SWM volume. It is recommended that this be evaluated by a professional.

☐ The low-flow ditch system is blocked with silt and sediment. The ditches should be cleaned.

☐ Sections of the low-flow ditch are cracked or have undermined. All damaged sections of the ditch should be repaired.

☒ Other Items: *Inlet A is severely overgrown with vegetation. There is also blockage downstream from Inlet A due to the vegetation (Photos 5, 6, and 7).*

CONDITION ASSESSMENT REPORT – Wetland

A. Summary of Maintenance Issues

☐ The pond was inaccessible at the time of the condition assessment. Please provide access to the facility and notify the County at [redacted] when it is accessible.

☐ Maintenance is needed based on this visual condition assessment. Maintenance for Stormwater Management facilities governed by conditions in the approved plan of development should be performed. In all cases, maintenance should be performed unless a qualified professional warrants that no maintenance is required.

☐ Other: ____

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

B. Dam Embankment (Includes Separate Emergency Spillway if One Exists)

☐ Trees were noted on the dam. These trees should be removed and replaced with grass.

☐ Shrubbery and other types of low growing vegetation were noted on the dam. This material should be removed and replaced with grass.

☐ Scrub brush and other types of viney material were noted on the dam. This material should be removed and replaced with grass.

☐ Erosion was noted on the dam. Eroded areas should be repaired.

Locations:

☐ Settlement was noted on the dam. Settled areas should be repaired.

Locations:

☐ Piping (i.e. internal cavities due to the outward migration of embankment earth) was noted on the dam. Piping problems should be repaired.

Locations:

☐ Slope slippage was noted on the dam. Slippage problems should be repaired.

Locations:

☐ Animal burrow holes were noted on the dam. Burrow holes should be filled in (See Maintenance Guidelines).

Locations:

☐ Other Items:

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

C. Riser (or Control Structure)

☐ The low-flow orifice is blocked. The blockage should be removed.

☐ The BMP device is damaged. This device should be repaired.

☐ The BMP device is missing. This device should be replaced.

☐ The low-level gate drain appears not to have been exercised within the last year. This drain should be exercised at least annually.

☐ The riser is filled with excess material (debris, trash, rock, etc.) This material should be removed.

☐ The riser is damaged or deteriorated. The riser should be repaired or replaced.

Extent of damage or deterioration:

☐ Other Items:

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

D. Principal Spillway Pipe (PSP)

☐ The PSP is blocked. The blockage should be removed.

☐ One or more of the joints of the PSP are leaking. All leaking joints should be parged.

Location:

☐ One or more sections of pipe have settled to a point that it threatens the integrity of the dam. These sections of pipe may need to be replaced.

Location:

☐ Other Items:

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

E. <u>Outfall Structure</u>

☐ The outfall structure is undermined and/or is rusting inside. This structure should be repaired.

☐ The outfall structure has separated from the main PSP by more than three inches. This structure should be repaired.

☐ Other Items:

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

F. <u>Outfall Channel</u>

☐ The outfall channel is blocked. The blockage should be removed.

☐ The outfall channel is eroding. The channel erosion should be repaired.

☐ Other Items:

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

G. <u>Impoundment Area</u>

☐ There is heavy vegetation and large debris in the lake or ponding area that could wash down against the riser. This material should be removed.

☐ The lake is showing signs of significant sedimentation and/or poor health (i.e. nutrient overload, excess aquatic vegetation, severe turbidity, etc.). It is recommended that the lake be evaluated qualified professional for possible corrective measures.

☐ A ten-foot "un-maintained" riparian buffer has not been provided/ preserved around the lake/wet pond (exclusive of the dam embankment and emergency spillway). A 10' wide riparian buffer is suggested.

☐ The shoreline is showing signs of erosion. The erosion should be repaired.

☐ Silt and sediment have filled in significant portions of the dry pond's BMP or 2-yr SWM volume. It is recommended that this be evaluated by a qualified professional for possible corrective measures.

☐ The low-flow ditch system is blocked with silt and sediment. The ditches should be cleaned.

☐ Sections of the low-flow ditch are cracked or have undermined. All damaged sections of the ditch should be repaired.

☐ Other Items:

____

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

H. <u>Inflow Pipes</u>

☐ The inflow pipe(s) is blocked. The blockage should be removed.

☐ One or more of the joints of the inflow pipe(s) are leaking. All leaking joints should be parged.

Location:

☐ The inflow pipe(s) is undermined and/or is rusting inside. This structure should be repaired.

☐ The inflow pipe(s) has joint separation of more than three inches. This structure should be repaired.

☐ Other Items:

____

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

CONDITION ASSESSMENT REPORT - Bioretention

A. Inspection Items and Recommended Corrective Actions

☐ The facility could not be accessed for inspection because….. Please provide access to the facility and notify the County at [redacted] when it is accessible.

☐ The retention area or a portion of it has been eliminated or could not be located according to approved facility plan as-built information. This retention area should be reinstalled in accordance with the original approved facility plan(s). (See attached copy of approved facility plan).

(Note: If previous County approval or action eliminated the bio-retention system, it is requested that the details of the change and approval be provided to this agency.)

☐ The retention (ponding) area has been covered over with mulch and/or debris causing the facility to be non-functional. The retention area should be restored to the approved facility plan design (See attached copy of approved facility plan).

(See photos _________ & _________)

☐ Drainage to the retention area has been blocked or diverted away from the original design. The retention area drainage design shown in the approved facility plans should be restored to operate according to the approved facility plan (See attached copy of approved facility plan).

☒ The retention area plants, trees or other landscaping material as shown as part of the bio-retention system are missing, removed, or replaced, etc. Please re-establish the correct plantings or landscaping material as shown in the approved facility plan (See attached copy of approved facility plan). Photo #1

☒ Other Items: Check the activation setting for the sump pump, as the sump pump is completely under water. Photo #4

☐ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

B. Summary of the Maintenance Issues

☐ Inspection could not be performed because….. Please provide access to the facility and notify the County at [redacted] when it is accessible.

☒ General routine and preventive maintenance is recommended.

☐ Replacement of bio-retention system is recommended.

☐ Refurbishment (i.e. cleaning and/or repairing) of bio-retention area recommended.

☒ Other Items: Re-establish the correct plantings or landscaping material as shown in the approved facility plan; Check the activation setting for the sump pump, as the sump pump is completely under water.

☐ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

CONDITION ASSESSMENT REPORT – Sand Filter

A. Accessibility

☐ The sand filter was inaccessible at the time of the inspection because….. Please provide access to the facility and notify the County at [redacted] when it is accessible.

B. DC. Sand Filter/ Delaware Sand Filter

☒ Silt and debris have collected in the control chamber(s). This material should be removed (Oil-skim and grit should be removed in the vault by pumping it out and properly disposing of it. Remove discolored sand and replace with clean sand. Trash and debris should also be cleaned out). *See photos 2, 8.*

☐ Silt and debris have collected in the sand filter chamber(s). This material should be removed.

☒ One or more of the structural components have been collapsed/damaged. These elements should be repaired (See attached copy of approved facility plan). The spalling on the inflow pipes should be repaired. *See photos 7, 8.*

☐ Other Items:

____

☐ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

C. Outfall Structure

☐ The outfall structure has separated from the main principal spillway pipe by more than 3”. This structure should be repaired.

☐ The outfall structure is undermined. This structure should be repaired.

☐ Other Items:
____

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

D. Outfall Channel

☐ The outfall channel is blocked. The blockage should be removed.

☐ The outfall channel is eroding. The channel erosion should be repaired.

☐ Other Items:
____

☒ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

E. Summary of Maintenance Issues

☐ Inspection could not be performed because….. Please provide access to the facility and notify the County at [redacted] when it is accessible.

☐ General routine and preventive maintenance is recommended.

☒ Structural repair is recommended.

☐ Functional repair/renovation is recommended. Please review the checked items of Attachment A / Maintenance Guidelines.

☐ Refurbishment (i.e. cleaning and/or repairing) is recommended.

☒ Silt removal is recommended.

☐ Other Items:

☐ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

CONDITION ASSESSMENT REPORT – Infiltration Trench

A. Inspection Items and Recommended Corrective Actions

☐ The trench could not be accessed for inspection. Please provide access to the facility and notify the County at [redacted] when it is accessible.

☐ The gravel trench or a portion of it has been eliminated.

This trench should be reinstalled in accordance with the original approved facility plans (See attached copy of approved facility plan).

(Note: If previous County approval or action eliminated the trench, it is requested that the details of the approval be provided to this agency).

☒ A portion of the gravel trench has been covered over or has silted in causing the trench to be non-functional. The trench should be restored to the approved facility plan condition (See attached copy of approved facility plan). *See photo C-6.*

☐ Drainage to the gravel trench has been blocked or diverted away from the original trench design. The trench drainage design should be restored to the approved facility plan (See attached copy of approved facility plan).

☐ Silt and/or debris have collected in the control structure. This material should be removed and properly disposed of (Power flushing the material downstream would not be considered proper disposal).

☐ Other Items:

____

☐ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

B. Summary of the Maintenance Issues

☐ Inspection could not be performed. Please provide access to the facility and notify the County at [redacted] when it is accessible.

☐ General routine and preventive maintenance is recommended.

☐ Replacement of trench is recommended.

☒ Refurbishment (i.e. cleaning and/or repairing) of trench is recommended.

☐ Other items: ____

☐ Other than your normal routine maintenance, no additional maintenance is needed at this time based on the visual condition assessment.

Appendix B – Sample Calculations

Inspection Costs

$$\text{Present Value Inspection and Enforcement Cost} = \sum_{t=1}^{T} \frac{C_T}{(1+i)^t}$$

Where,

C = Inspection and Enforcement Cost_{jmn}

t= 1, ., ., T

T = frequency of inspection and enforcement

i =discount rate, 5%

j = type of bmp

m = municipality

n = responsible party.

MS4-1 Example, Private Inspections

	Source	**Value**
C	Expert Opinion	$150
T	Interview with stormwater staff	5

Maintenance Costs

Annual BMP Maintenance Costs = Annual Scheduled Maintenance Costs + Present Value of Unscheduled Maintenance Costs

Annual Scheduled Maintenance Costs = (C * F)

Where,

C = Average Scheduled Maintenance Cost_{jmn}

F= Maintenance Frequency_{jmn}

j = type of bmp

m = municipality

n = responsible party.

Present Value of Unscheduled Maintenance Costs = $\sum_{t=1}^{T} \frac{C_T F}{(1+i)^t}$

Where,

C = Average Unscheduled Maintenance Cost_{jmn}

t= 1, ., ., T

T = Frequency of Inspection

F = Inspection Failure Rate

i = Discount rate, 5%

j = type of bmp

m = municipality

n = responsible party.

MS4-1 Example: Dry Ponds, Public, only scheduled maintenance

	Source	**Value**
Cost	Expert Opinion	$2,600

Frequency	Interview with stormwater staff	1

MS4-1 Example: Dry Ponds, Private

	Source	**Value**
C	Average costs for 30 BMPs	$6,300
T	Interview with stormwater staff	5
F	Inspection failure rate for 250 BMPs	88%