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MAINTENANCE COSTS OF STORMWATER CONTROL MEASURES (SCMS) IN NORTH CAROLINA

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Maintenance Costs of Stormwater Control Measures (SCMs) in North Carolina

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Abstract

Title: Maintenance Costs of Stormwater Control Measures (SCMs) in North Carolina

With increasing urbanization the need for stormwater control measures (SCMs) to meet federal and state regulations grows. Maintenance is necessary and typically required by state and local regulations to ensure SCMs remain functional and continue to mitigate the impacts of urbanization. In addition to functional drivers, SCMs are maintained for aesthetic appeal. Previous research has quantified maintenance costs for SCMs in North Carolina but (1) this study is dated, (2) there remains a lack of data regarding costs for routine, preventative/proactive, and restorative maintenance, and (3) the relationship between a SCM's location within a parcel and its maintenance frequency has not been evaluated. North Carolina State University (NCSU) partnered with the Stormwater Consortium (SC) of the Water Resources Research Institute of the University of North Carolina (WRRI) to answer these questions. While maintaining the interviewees' anonymity, NCSU interviewed (1) representatives from the WRRI-SC communities, (2) private contractors who have been certified through the NCSU Stormwater BMP Inspection & Maintenance workshop series, and (3) staff from two state entities. A standard set of questions was developed, including (but not limited to): how many practices are maintained, the characteristics of the maintained practices (e.g., age), the location of the maintained practices with respect to the parcel, the types of maintenance tasks needed for a particular SCM, the frequency of and time spent on each maintenance task, and the costs associated with each task.

Quantifying maintenance costs for SCMs was difficult; factors such as maintenance access and SCM location greatly impact costs. Additionally, record keeping prevented maintenance costs from easily being identified. The investigators found private contractors or multiple municipal departments usually maintain municipal SCMs. Despite limited participation in the study, routine and restorative maintenance costs were quantified for the following SCMs: wet ponds, stormwater wetlands, dry ponds, bioretention cells, sand filters, level spreader-filter strips, rainwater harvesting systems, permeable inter-locking concrete pavers (PICP), Contech StormFilters®, ADS BayFilters™, and Contech Filterra systems®. Missing data for infiltration systems, disconnected impervious surfaces (DIS), treatment swales, and other proprietary systems could be the result of a lack of participation from companies who maintain these practices or fewer implementations of these SCMs for stormwater management limited maintenance understanding. Certain tasks such as replacing trees for DeepRoot Silva Cells® or mowing treatment swales and infiltration basins can be estimated using data reported for other SCMs. Interviews with private contractors revealed average annual routine maintenance costs of SCMs with mowing in 2018 ranged from $9,440 per ac of SCM surface area to $16,875 per ac of SCM surface area. Mowing grass was a significant maintenance factor and refers to mowing the landscape surrounding (or inside) the SCM. Factors such as mowing and maintaining vegetative cover increase costs, and these tasks usually occur on a monthly basis.

Maintenance tasks include those set forth by state regulations. We learned that a SCM's location did not impact the level of service (LOS) provided. Interviewees stressed a high LOS is provided to avoid hazardous site conditions, improve water quality, and reflect the interviewee's dedication to their profession. There were differences between routine, proactive, and restorative maintenance costs. However, restorative maintenance costs tend to be much higher than routine and proactive costs, and it is more economical to routinely maintain a practice rather than

waiting to maintain a SCM once it loses functionality. Information from this study will be disseminated through state and national conferences, a journal publication, NCSU workshops, and an Excel based tool.

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Acknowledgements

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1 Introduction

1.1 Background

As urbanization increases so does the need for stormwater control measures (SCMs) to meet federal and state regulations. State and local entities typically require maintenance to ensure these practices mitigate the impacts of urbanization and function in perpetuity per NC DEQ (2020) guidance. Previous research has shown a lack maintenance can result in the deterioration of the water quality and volume reduction performance of SCMs (e.g., Brown and Hunt, 2012; Winston et al., 2016; Bean et al., 2007; Li, 2015; Wardynski and Hunt, 2012). With routine maintenance, biologically active SCMs (e.g., bioretention cells and constructed stormwater wetlands) may have their performance improve over time (Willard et al., 2017; Johnson and Hunt, 2019). In addition to hydrologic and water quality functionality, SCM maintenance is driven by aesthetic needs, as society tends to value more aesthetically pleasing landscapes (Gobster et al., 2007; de Groot, 2005).

1.2 Maintenance Requirements for SCMs

In North Carolina, state regulations require SCM permits holders to enter into a binding operation and maintenance (O&M) agreement (NC DEQ, 2020). Maintenance can be categorized as routine, proactive, or restorative (Table 1). Routine maintenance or general upkeep includes tasks such as collecting trash and mowing. Proactive maintenance is less frequent but helps prevent more costly tasks (e.g., repairing eroding banks versus dredging the resulting deposited sediment). Restorative maintenance includes tasks that returns a SCM's functionality. An example of restorative maintenance is repairing an outlet structure.

Table 1: Examples of routine, proactive, and restorative maintenance (NC DEQ, 2020)

Maintenance	Description
Routine	• Inspections • Trash removal • Sediment removal • Pruning of woody vegetation • Thinning of vegetation • Side slope stabilization • Mowing • Mulching • Testing pavement surface infiltration rate
Proactive	• Controlling weeds and other undesired plants • Cleaning/scraping filter media • Soil testing • Soil aeration • Vegetation replacement • Fertilization • Irrigation • Hose and pipe connections inspected for leaks • Disinfection
Restorative	• Media/soil replacement • Inlet/outlet structure repair • Conveyance system repair • Disease control for vegetation • Denuding overgrown/over-run practices by unwanted species • Embankment, dam, and channel repair due to erosion or rodents • Wound dressing for vegetation • Vacuum sweeping of permeable pavement

Table 2 summarizes common maintenance issues and tasks for SCMs typically found in North Carolina. As of 2021, NC DEQ (2018) has approved 16 practices (12 generic, 4 proprietary) to help meet federal and state stormwater regulations. Each of these practices has specific maintenance requirements (Table 3). Note green roofs are an approved SCM but NC DEQ considers them to be a specialty practice. Green roof maintenance was not included as part of this study.

Table 2: Common maintenance issues and tasks for NC DEQ approved SCMS (NC DEQ, 2020)

SCM element	Issue	Maintenance task
Entire SCM	Trash/debris present	Remove trash/debris
Perimeter of SCM	Areas of bare soil and or erosive gullies; surrounding vegetation (if applicable) is too short or too long	Regrade the soil to remove gully and plant and water ground cover until established; provide one-time fertilizer application
Inlet device (pipe or swale)	Pipe is clogged or damaged (e.g., cracked); erosion occurring in swale	Unclog or replace pipe; regrade swale and provide erosion control devices
Forebay or pretreatment area	Sediment accumulation reducing depth to 75% of original design depth or depth greater than six inches; erosion occurred or riprap displaced; weeds are present; runoff bypassing pretreatment	Identify sediment source and remedy, remove and dispose of sediment; provide additional erosion control devices; remove plants by hand; regrade to direct runoff to pretreatment area
Main treatment area	Visible layer of accumulated sediment; standing water for more than five days after storm event (SCM dependent)	Identify sediment source and remedy, remove and dispose of sediment; replace top few inches of media and revegetate, consult professional if issue persists
Embankment	Shrubs or trees present; rodents present; annual inspection shows need for repair	Remove shrubs or trees; use traps to remove rodents; make necessary repairs
Outlet device	Clogging; device is damaged	Unclog device; repair or place device
Receiving water	Erosion or other signs of damage have occurred	Contact NC Division of Water Resources (NC DWR)

Table 3: Additional specific maintenance tasks for common NC DEQ approved SCMs (NC DEQ, 2020)

SCM	Description	Maintenance tasks specific to SCM
Bioretention cell	Depression filled with sandy media and plants designed to temporarily store and filter runoff	Vegetation pruning and replacement; tree stake/wire removal; flush out underdrain system; mulch replacement; annual soil tests
Wet pond	Depression designed to capture and slowly release runoff over a 2- to 5-day period	Algae, cattail, phragmite and other invasive vegetation removal; remove trees and weeds from floating wetland islands; restoring floating wetland island cables; revegetation
Stormwater wetland	Shallow, vegetation-filled depression designed to capture and slowly release runoff over a 2- to 5-day period, store runoff in shallow pools supporting emergent and riparian vegetation	Algae, cattail, phragmite and other invasive vegetation removal; revegetation
Permeable pavement	Pavement that captures runoff through voids in the surface and filters runoff through underlying aggregate base	Vacuum or sweep surface; bag grass clippings or direct away from surface; weed removal; annual infiltration testing; observation well inspection; surface repair; flush out underdrain system
Sand filter	Surface or subsurface device that percolates runoff through a sand media	Sweep or vacuum adjacent pavement; flush out underdrain system; replace sand media
Rainwater harvesting	Collection device storing rainwater for later use	Inspect and repair all leaks; clean gutters; unclog screens and filters; inspect pump; remove algae; mosquito abatement
Level spreader-filter strip	Exposed buried concrete footer immediately upstream of vegetated area	Unclog and repair flow splitter device; mow and unclog blind swale; repair or replace concrete lip; repair erosion and remove sediment in filter strip
Disconnected impervious surface (DIS)	Practice of directing runoff from built-upon areas to properly sized, sloped, and vegetated pervious surfaces	Unclog gutter system; remove sediment and repair erosion in vegetated area; remove trees or shrubs in vegetated area; remove obstructions at interface of impervious and vegetated area
Contech StormFilter® (proprietary underground SCM)	Proprietary device designed to capture runoff and slowly release via an outlet structure	Mosquito abatement; vacuuming; rinse chambers; install fresh cartridge(s)
ADS BayFilter™ (proprietary underground SCM)	Proprietary device designed to capture runoff and slowly release via an outlet structure	Mosquito abatement; vacuuming; rinse chambers; install fresh cartridge(s)

1.3 SCM Maintenance Costs

Previous research has evaluated the life cycle costs of SCMs with regards to performance, gray infrastructure, and environmental impacts (e.g., Sullivan et al., 2015; Cohen et al., 2012; Mani et al., 2019; Fong et al., 2016; Krieger and Grubert, 2021) but few studies have solely quantified maintenance costs. Weiss et al. (2005) estimated annual O&M costs as a percentage of construction costs for recently installed SCMs in Minnesota (Table 4). These percentages ranged from 0.7% to 178% with bioretention cells and swales costing the least and most amount of money to maintain (relative to construction cost), respectively.

Table 4: Estimated O&M costs for Minnesota SCMs (Weiss et al., 2005)

SCM	Estimated annual O&M cost (% of construction cost)
Detention basins	1.8 to 2.7
Constructed wetlands	4 to 14.1
Infiltration trenches	5.1 to 126
Infiltration basins	2.8 to 4.9
Sand filters	0.9 to 9.5
Swales	4 to 178
Bioretention cells	0.7 to 10.9
Wet basins	1.9 to 10.2

Erickson et al. (2010) estimated the range of maximum annual cost to remove sediment from SCMs located in Minnesota and Wisconsin was from $500 to $53,000. Based on values from 2005, Erickson et al. (2010) also predicted maintenance costs for SCMs will equal construction costs after 12 years for a $10,000 installation and 25 years for a $100,000 installation.

In New Hampshire, Houle et al. (2013) quantified costs for seven different SCMs for the first 2 to 4 years of operation. These SCMs included vegetated swales (1), wet ponds (1), dry ponds (1), sand filters (1), gravel wetlands (1), porous asphalt (1), and bioretention cells (3). Costs included personnel, materials, and maintenance in terms of yearly impervious watershed treated. Annual O&M costs ranged from $5,634/ac to $19,348/ac, while personnel costs varied between $2,320/ac and $18,681/ac (Table 5).

Table 5: Costs for SCMs in New Hampshire (Houle et al., 2013)

Cost ($/yr-ac[a])	Stormwater control measure (SCM)						
	Vegetated swale	Wet pond	Dry pond	Sand filter	Gravel wetland	Bioretention cell	Porous asphalt
Personnel	5,016	18,681	14,530	17,149	13,047	11,540	2,320
Materials	610	672	672	672	672	672	0
Annual maintenance	5,634	19,348	15,197	17,816	13,714	12,207	6,598

[a] ac refers to the impervious area draining to the SCM

Similar to Houle et al. (2013), Wossink and Hunt (2003) found SCM maintenance costs for SCMs in terms of watershed area treated and a 20-year lifespan (Table 6). These costs for constructed wetlands, wet ponds, sand filters, and bioretention cells were determined through interviews with municipal officials in North Carolina, Maryland, Virginia, and Delaware.

Table 6: Maintenance costs for SCMs in North Carolina (Wossink and Hunt, 2003)

Parameter[a]	SCM				
	Wet ponds	**Stormwater wetlands**	**Sand filters**	**Bioretention cells in clay soils**	**Bioretention cells in sandy soils**
Maintenance costs for 20 yrs ($)	$C=9{,}202x^{0.269}$	$C=4{,}502x^{0.153}$	$C=10{,}556x^{0.534}$	$C=3{,}437x^{0.152}$	$C=3{,}437x^{0.152}$

[a] Note: C = cost and x = watershed area (ac)

Clary and Piza (2017) quantified maintenance costs for green infrastructure through nationwide surveys. In 2015, average annual costs for municipalities to maintain bioretention cells ranged from $0.13 per sf of bioretention cell surface area to $2.30 per sf of bioretention cell surface area. The average total cost varied between $250 per facility to $3,880 per facility. Clary and Piza (2017) also found in 2015 the average annual maintenance cost for bioretention cells was approximately 6% of the facility's capital cost. With regards to permeable pavement, Clay and Piza (2017) found routine maintenance could cost municipalities between $0.25 per sf of permeable pavement to $0.28 per sf of permeable pavement. Restorative maintenance could cost as much as $1.50 per sf of permeable pavement. In 2014, it cost one municipality $1,340 to replenish aggregate for an installation of permeable inter-locking concrete pavers (PICP). Clary and Piza (2017) reported few municipalities use a centralized database to collect and track maintenance costs, and it is difficult to separate costs for SCMs when departments share maintenance responsibilities or the municipality has an ongoing contract with a private maintenance company.

Both US EPA (2019) and MHFD (2017) created calculators to estimate capital and maintenance costs for SCMs. The BMP-REALCOST tool developed by MHFD (2017) allows users to estimate maintenance costs using unit costs for labor and equipment or as a percentage of capital costs. The BMP-REALCOST tool also provides default lifespans for SCMs and calculates restorative maintenance costs as a percentage of initial capital costs. The National Stormwater Calculator uses previous literature and cost curves to estimate maintenance costs for green infrastructure (US EPA, 2019). The cost curves use the SCM's footprint and are either simple, typical, or complex (Table 7). US EPA (2019) bracketed expected O&M costs for the curves using the following conditions:

- Simple: the SCM design criteria is less stringent than current design criteria, the installation site is conducive for construction, and the SCM is privately constructed and maintained in a new development or suitable parcel,
- Typical: the SCM is designed to capture 85% of a storm event, the installation site is somewhat conductive for construction, and the SCM has well defined maintenance requirements, and
- Complex: the SCM design criteria and site conditions are difficult or constrained.

Table 7. Cost curves for the National Stormwater Calculator (US EPA, 2019)

SCM	Simple cost curve	Typical cost curve	Complex cost curve
Disconnected impervious area[a]	y = 0.2142x + 159.75	y = 3.65x + 1922.8	y = 5.7238x + 3806.5
Rainwater harvesting[b]	y = 0.3844x + 61.8	y = 0.7697x + 3564	y = 1.4085x + 4350
Rain garden[c]	y = 0.2717x + 346.08	y = 1.5691x + 3696	y = 4.6378x + 10052
Green roof[d]	y = 0.5421x + 1975.2	y = 2.5009x + 3288	y = 7.5401x + 20824
Street planter[e]	y = 0.5592x + 1928.2	y = 2.7125x + 2580.6	y = 10.357x + 14163
Infiltration basin[f]	y =0.8205x + 1928.2	y = 0.8473x + 3864	y = 3.7531x + 13050
Permeable pavement[g]	y = 2.3502x + 1545	y = 4.7209x + 1800	y = 7.8694x + 3750

Note: y refers to estimated annual maintenance cost
[a] x refers to sf of disconnected impervious area
[b] x refers to gal of cistern storage
[c] x refers to sf of rain garden
[d] x refers to sf of green roof
[e] x refers to sf of infiltration basin
[f] x refers to sf of permeable pavement

Quantifying maintenance costs for SCMs is difficult for a number of reasons (e.g., a lack of organization, SCM maintenance access). Previous efforts in cost quantification did not account for aesthetic appeal or the future cost of maintaining SCMs. There is also limited knowledge differentiating costs among routine, proactive, and restorative maintenance. Entities responsible for maintaining SCMs would benefit from data that quantify these differences. These entities could better allocate resources (e.g., funds) to maintenance and help prevent the loss SCM functionality (e.g., Brown and Hunt, 2012; Winston et al., 2016; Bean et al., 2007; Li, 2015; Wardynski and Hunt, 2012).

2 Objectives

The primary objectives for this study were to (1) build upon the data collected by Wossink and Hunt (2003), (2) determine how the aesthetic appeal of SCMs influences maintenance, and (3) isolate costs for routine, proactive, and restorative maintenance. Secondary objectives for this study included identifying maintenance tasks and the time spent by maintenance crews on these tasks for different types of SCMs. This study focused on the following SCMs:

- Infiltration systems,
- Bioretention cells,
- Wet ponds,
- Stormwater wetlands,
- Permeable pavement,
- Sand filters,
- Rainwater harvesting,
- Level spreader-filter strips,
- Treatment swales,
- Dry ponds,

- DeepRoot® Silva Cells,
- Contech Filterras®,
- ADS BayFilters™, and
- Contech StormFilters®.

Note green roofs are an approved SCM but NC DEQ considers them to be a specialty practice. Green roof maintenance was not included as part of this study.

3 Methods

Maintenance costs were quantified through anonymous interviews with staff from Water Resources Research Institute- Stormwater Consortium (WRRI-SC) communities, private companies who previously attended the NCSU Extension Stormwater BMP Inspection and Maintenance (I&M) certification workshop series, and state entities with active stormwater programs (Table 8). Efforts were made to interview 20 companies who were recently certified through the I&M workshop series; however, many of these companies declined to participate in the study.

Each interviewee was provided with a standard set of questions (Appendix E) and the study's definitions for routine, proactive, and restorative maintenance (Table 1). Example questions included: the level of service (LOS) provided, typical issues experienced, number of practices maintained, frequency of maintenance, average SCM footprint, and typical SCM location within the parcel. Any tasks outside of the defined maintenance categories as well as any differences between in-house and contracted work were included in the results. The lifespans of SCMs were estimated using either the years of service provided or the typical ages of the maintained practices. The data were normalized on an annual basis and the SCM's average footprint. Note that side slopes were included as part of the footprint. A SCM's footprint (rather than age or capital costs) were used because these latter two sets of data were typically not available, while a SCM's footprint can be estimated using field measurements, computer software (e.g., ArcGIS), or orthoimagery (e.g., Google Earth). In addition to identifying costs, the interviewees were asked to evaluate North Carolina's required maintenance tasks (NC DEQ 2020) and provide design recommendations to optimize maintenance. Using typical SCM: watershed size ratios, routine maintenance costs are also presented on a per watershed acre treated basis in Appendix D.

Table 8: Number of conducted interviews

Interviewee	Number of interviews
WRRI-SC communities	9
Private contractors	12
State entities	2

4 Results

4.1 Level of Service Provided and Types of Maintenance

Interviewees described a high LOS as monthly maintenance that includes tasks required by NC DEQ (2020) while a low LOS is maintenance that occurs on a quarterly basis. Interviewees do not provide a low LOS to avoid accruing maintenance costs for clients, reducing the SCM's aesthetic appeal, and causing hazardous conditions (e.g., tall vegetation covering animal burrows along an embankment).

Interviewees stated that, for all SCMs, the location of the practice within the parcel (visible vs. "hidden") did not affect costs. Some proactive tasks were included in routine maintenance. There were large differences between routine and restorative maintenance costs. Interviewees stressed maintenance costs are affected by watershed composition and area, the SCM's size, and access to the site. Restorative maintenance can occur between 2 to 10 years after installation. However, interviewees stated restorative maintenance rarely occurs if a practice is routinely maintained. Proactive maintenance tasks may occur every 1 to 2 years.

4.2 General Design Recommendations to Improve Maintenance

Interviewees recommended all SCM designs include: maintenance access wide enough for heavy equipment (at least 8 ft), gradual side slopes (preferably no steeper than 4:1), pretreatment, and irrigation systems for newly planted vegetation. When appropriate, interviewees suggested designers use gate valves rather than slide valves, install valves inside outlet structures, enforce the topsoil and or compacted layers specified in the design plans, install the outlet structure close to the bank, and ensure the initial vegetation selection is appropriate for the site conditions. These recommendations would help improve maintenance accessibility, reduce the risk of clogging, and increase the survival rate for vegetation. Additional recommendations include using wetland vegetation instead of sod if level spreader-filter strips are located in shady or wet areas, converting dry ponds with wet bottoms into wetlands, including an underdrain in level spreader-filter strips to help dewater the level spreader, ensuring cleanout caps for underdrains are visible, and not placing emergency spillways in line with (on top of) outlet pipes.

4.3 General Maintenance Issues and Costs

The interviewees explained typical maintenance issues include: lack of access, trash, nuisance vegetation, clogged outlet structures, erosion, poor vegetation health, mulch displacement, clogged media, degraded mulch, damaged cleanouts, incorrect outlet structure elevations, and rodents. Certain issues such as lack of access and poor vegetation health can be prevented by designing SCMs with maintenance in mind (e.g., maintenance access, clog-free outlet structures) and providing thorough construction oversight. Additionally, stabilizing the practice's watershed can help reduce trash and clogging issues.

4.4 Costs for Annual Inspections by Licensed Professionals

In 2018, the average cost for a licensed professional engineer (P.E.) or registered landscape architect (R.L.A.) to provide an annual inspection was $705. Note these inspection costs are dependent upon location and the regulating municipality. Also in 2018, the cost for a private contractor to visit a SCM without performing any work was at least $75.

4.5 Private Contractors: Wet Ponds

Eight private contractors provided routine/proactive and restorative maintenance costs for wet ponds in 2018. Typical routine tasks include those listed in Table 2 and Table 3 as well as the following: backfilling animal burrows, trapping rodents, and water quality testing (e.g., pH, hardness). On a monthly basis, the interviewees were maintaining wet ponds between 10 and 28 years old that have an average footprint of 0.50 ac (Table 9). The ponds were typically located along the back or sides of a property. The average annual cost to maintain wet ponds without mowing the pond's surrounding landscape was $6,360 per ac of pond surface area. As expected, mowing the wet pond's surrounding landscape increased the average annual cost to $9,440 per ac of pond surface area. Interviewees tended to mow the surrounding landscape to ensure typical landscaping activities (e.g., fertilizing) did not negatively impact the wet pond and the immediate upstream watershed remained stable. Henceforth with and without mowing will refer to whether or not a SCM's surrounding landscape is mowed. The landscapes around most wet ponds were mowed. The interviewees reported their companies maintained between 10 and 1,500 wet ponds throughout the state. Note these routine costs include labor, equipment, and materials.

Table 9: 2018 Routine maintenance costs and characteristics for wet ponds

Parameter	Mean	Median	Range
Age (yr)	16	16	10 to 28
Typical footprint (ac[a])	0.50	0.50	0.25 to 0.75
Maintenance frequency	Monthly	-	8 to 21 times per yr
Time spent on tasks (hr)	2	1	0.25 to 6
Number of employees maintaining SCM	3	2	1 to 9
Routine costs without mowing[b] ($/ac[a])	6,360	4,600	4,000 to 9,600
Routine costs with mowing[b] ($/ac[a])	9,440	8,800	5,400 to 15,200

[a] ac refers to wet pond surface area
[b] refers to mowing the wet pond's surrounding landscape

Reported costs from 2018 and Equation 1 can be used to estimate the amount of funds needed to routinely maintain a wet pond in the future. Based on these data routinely maintained wet ponds have a life span of at least 30 years. The annual increase in maintenance costs is dependent upon the current economy, maintenance company's business model, and the wet pond's accessibility. Therefore those responsible for maintaining wet ponds may want to use a higher annual increase in price (r) as a factor of safety.

$C = (P * A) * (1 + r)^n$ **Equation 1**

Where:
C= future annual cost of routine wet pond maintenance ($)
P= 2018 cost of routine maintenance (with mowing the surrounding landscape: $9,440/ac; without mowing the surrounding landscape: $6,360/ac)
A= surface area of wet pond (ac) (typ. 0.50 ac)
r= annual increase in pricing (decimal)
n= number of years since 2018

Contractors also provided 2018 costs for proactive maintenance tasks (Table 1). Interviewees stressed activities such as forebay sediment accumulation and tree removal are dependent upon the drainage area or the site (e.g., degree of access provided), available disposal locations, and the volume of sediment or number of trees that need to be removed. The average cost of sediment removal was $63 per cy of sediment or $56,250 per ac of forebay surface area (Table 10). With respect to nuisance trees, the average removal cost was $1,038 per tree or $8,600 per total ac of trees covering the wet pond embankment. The average cost to replace vegetation was $4 per plug or $7 per linear foot of pond's surface area at normal pool elevation (NPE). Note these miscellaneous costs include labor, equipment, materials, and disposal fees.

Similar to sediment and tree removal, muskrat or beaver trapping is dependent upon the number of animals present in the pond and the location of the practice. For instance, contractors reported it was more difficult to trap rodents in a neighborhood than at a commercial site. Typical trapping fees include a $250 set up fee, $100 per beaver captured, and $40 per muskrat captured (Table 10). Pond additions such as beneficial bacteria and dye cost $2,000 per ac of pond surface area and $1,000 per ac of pond surface area, respectively. Contractors estimated adding fat head minnows to a pond cost $50. Interviewees did not state how often these proactive maintenance tasks occur.

Table 10: 2018 Proactive maintenance costs for wet ponds

Task	Mean	Median	Range
Forebay sediment removal ($/cy)	63	63	60 to 65
Forebay sediment removal ($/ac[a])	56,250	56,250	12,500 to 100,000
Tree removal ($/ac[b])	8,600	7,400	2,000 to 20,000
Tree removal ($/tree)	1,038	1,038	575 to 1,500
Vegetation replacement ($/plug)	4	4	3 to 5
Vegetation replacement ($/plant)	11	11	8 to 15
Vegetation replacement ($/lf[c])	7	-	-
Muskrat removal ($/muskrat)	40 plus $250 setup fee	-	-
Beaver removal ($/beaver)	100 plus $250 setup fee	-	-
Beneficial bacteria ($/ac[d])	2,000	-	-
Dye ($/ac[d])	1,000	-	-
Fat-head minnows ($)	50	-	-

[a] ac refers to wet pond forebay surface area
[b] ac refers to total surface area of trees covering the wet pond embankment
[c] lf refers to wet pond perimeter at normal pool elevation (NPE)
[d] ac refers to wet pond surface area

Entities responsible for maintaining wet ponds can also use Equation 2 to estimate additional expenses that are not included in routine maintenance tasks.

$$C = (P * U) * (1 + r)^n \qquad \textbf{Equation 2}$$

Where:
C= future cost of maintenance task ($)
P= reported cost of maintenance task ($, Table 10)
U= unit of measure associated with SCM and maintenance task (if applicable)
r= annual increase in pricing (decimal)
n= number of years since 2018

For example, the estimated cost to remove 100 cy of sediment from a forebay in 2027 with an annual price increase of 1% would equal $6,890 (Equation 3).

$$C = (\$\,63/cy\ sediment * 100\ cy\ sediment) * (1 + 0.01)^{2027-2018} \qquad \textbf{Equation 3}$$
$$C = \$6{,}890$$

Much like sediment and tree removal, restorative costs in 2018 were heavily dependent upon site location and the severity of the issue (Table 1). The average cost to repair an inlet or outlet was $2,600 while the cost to replace a riser was roughly $15,000 (Table 11). Dredging a pond was approximately $100 per cy of sediment removed or $120,000 per ac of pond surface area. The average cost to repair embankments was $2,780 while the cost to replace rip-rap aprons was approximately $5,000. The contractors reported the cost to repair pipe concrete cradles was roughly $15,000, and the average cost to repair a concrete pipe joint was $3,750. Note these costs include labor, equipment, materials, and disposal (as applicable). Future restoration costs can be estimated using Equation 2 and Table 11. Interviewees stated restorative maintenance costs for wet ponds, stormwater wetlands, dry ponds, and sand filters were identical. Therefore, restorative maintenance cost information will only be presented here and not repeated in subsequent sections.

Table 11: 2018 Restorative maintenance costs for wet ponds, stormwater wetlands, dry ponds, and sand filters

Task	Mean	Median	Range
Inlet/outlet repair ($)	2,600	2,750	1,200 to 3,700
Riser replacement ($)	15,000	-	-
Dredging ($/ac[a])	118,800	120,000	26,400 to 210,000
Dredging ($/cy[b])	100	-	-
Embankment repair ($)	2,780	2,500	1,200 to 3,700
Replace rip-rap apron ($)	5,000	-	-
Repair pipe concrete cradle ($)	15,000	-	-
Repair pipe joint ($)	3,750	3,750	2,500 to 5,000

[a] ac refers to wet pond, stormwater wetland, dry pond, and sand filter surface area
[b] cy refers to sediment removed

4.6 Private Contractors: Stormwater Wetlands

Five private contractors provided routine, proactive, and restorative maintenance costs for stormwater wetlands in 2018. Due to the similar designs, routine tasks for wetlands are comparable to wet ponds; however, the time to complete these activities tends to be longer for wetlands (Table 12). Contractors also commented removing invasive vegetation is more difficult in a wetland than in a wet pond. The maintained wetlands were at least 10 years old and had an average footprint of 0.40 ac. Comparable to wet ponds, these wetlands are mostly located on the sides or back of the property. The average annual cost to maintain wetlands with and without mowing on a monthly basis was $10,950 per ac of wetland surface area and $8,150 per ac of wetland surface area, respectively. Unlike wet ponds, constructed stormwater wetlands tend not to have perimeter mowing needs. Proactive and restorative costs for wetlands in 2018 are summarized in Table 10 and Table 11, respectively. Interviewees stated restorative maintenance costs for wet ponds and stormwater wetlands were similar. The number of wetlands maintained by the companies range between 25 and 600. Note these costs include labor, equipment, and materials. Annual routine maintenance costs for stormwater wetlands can be estimated using Table 12 and Equation 4, and entities responsible for maintenance should assume the average lifespan of wetlands is at least 20 years.

Table 12: 2018 Routine maintenance costs and characteristics for stormwater wetlands

Parameter	Mean	Median	Range
Age (yr)	14	15	10 to 18
Typical footprint (ac[a])	0.40	0.50	0.25 to 0.50
Maintenance frequency	Monthly	-	-
Time spent on tasks (hr)	2	2	1 to 2
Number of employees maintaining SCM	2	2	1 to 4
Routine costs without mowing[b] ($/ac[a])	8,150	9,200	4,600 to 9,600
Routine costs with mowing[b] ($/ac[a])	10,950	11,600	5,400 to 15,200

[a] ac refers to stormwater wetland surface area
[b] refers to mowing the stormwater wetland's surrounding landscape

$$C = (P * A) * (1 + r)^n \qquad \textbf{Equation 4}$$

Where:
C= future annual cost of routine maintenance ($)
P= 2018 cost of routine maintenance (with mowing the surrounding landscape: $11,600/ac; without mowing the surrounding landscape: $9,200/ac)
A= surface area of stormwater wetland (ac) (typ. 0.50 ac)
r= annual increase in pricing (decimal)
n= number of years since 2018

4.7 Private Contractors: Dry Ponds

Five contractors provided maintenance costs for dry ponds in 2018 and reported maintenance tasks are comparable with wet pond and stormwater wetland maintenance activities. On average, the dry ponds were 14 years old and had a footprint of 0.42 ac (Table 13). These SCMs are also located on sides or back of the property. In general, the dry ponds were maintained on a monthly basis, and the average annual cost to maintain dry ponds with and without mowing was $11,320 per ac of dry pond surface area and $6,920 per ac of dry pond surface area, respectively. Dry ponds almost always require perimeter mowing. Contractors reported miscellaneous proactive and restorative costs for dry ponds in 2018 were comparable to those of wet ponds (Table 10; Table 11). The interviewees reported their companies maintain between 50 and 75 dry ponds. Note these costs include labor, equipment, and materials. Annual routine maintenance costs for dry ponds can be estimated using Table 13 and Equation 5, and entities responsible for maintenance should assume the average life span for dry ponds is at least 20 years. Proactive and restorative costs can be estimated using Equation 2, Table 10, and Table 11. Note interviewees stated restorative maintenance costs for wet ponds and dry ponds were similar.

Table 13: 2018 Routine maintenance costs characteristics for dry ponds

Parameter	Mean	Median	Range
Age (yr)	14	15	10 to 18
Typical footprint (ac[a])	0.42	0.50	0.25 to 0.50
Maintenance frequency	Monthly	-	4 to 21 times per yr
Time spent on tasks (hr)	1	1	0.17 to 2
Number of employees maintaining SCM	3	4	1 to 9
Routine costs without mowing[b] ($/ac[a])	6,920	6,000	5,400 to 9,600
Routine costs with mowing[b] ($/ac[a])	11,320	10,400	6,600 to 18,000

[a] ac refers to dry pond surface area
[b] refers to mowing the dry pond's surrounding landscape

$$C = (P * A) * (1 + r)^n$$ **Equation 5**

Where:
C= future annual cost of routine maintenance ($)
P= 2018 cost of routine maintenance (with mowing the surrounding landscape: $11,320/ac; without mowing the surrounding landscape: $6,920/ac)
A= surface area of dry pond (ac) (typ. 0.42 ac)
r= annual increase in pricing (decimal)
n= number of years since 2018

4.8 Private Contractors: Bioretention Cells

Four contractors provided maintenance costs for mulched and grassed bioretention cells in 2018. Routine maintenance issues for these SCMs are included in Table 2 and Table 3. Contractors commented these practices tend to be smaller and have an average footprint of 0.17 ac (Table 14). Typically, the cells were 14 years old, were located throughout the parcel, and were maintained on a monthly basis. The average annual cost to maintain mulched bioretention cells with and without mowing was $12,400 per ac of bioretention surface area and $11,867 per ac of bioretention surface area, respectively. As expected, annual costs to maintain grassed cells increased; the average cost with and without mowing was $15,600 per ac of bioretention surface area and $13,467 per ac of bioretention surface area, respectively. Similar to wet ponds, companies maintain between 15 and 500 bioretention cells across the state. Note these costs included labor, materials, and equipment. Annual routine maintenance costs can be estimated using Table 14 and Equation 6, and entities should assume bioretention cells have a lifespan of at least 15 years.

Table 14: 2018 Routine maintenance costs and characteristics for bioretention cells

Parameter	Mean	Median	Range
Age (yr)	14	15	10 to 15
Typical footprint (ac[a])	0.17	0.13	0.05 to 0.25
Maintenance frequency	Monthly	-	8 to 21 times per yr
Time spent on tasks- mulched (hr)	1	1	0.25 to 3
Number of employees maintaining SCM-mulched	3	2	1 to 9
Routine costs without mowing[b]- mulched ($/ac[a])	11,867	12,000	9,200 to 14,400
Routine costs with mowing[b]- mulched ($/ac[a])	12,400	12,000	12,000 to 14,400
Time spent on tasks- grassed (hr)	1	1	1 to 1.5
Number of employees maintaining SCM-grassed	3	2	1 to 9
Routine costs without mowing[b]- grassed ($/ac[a])	13,467	12,000	9,200 to 19,200
Routine costs with mowing[b]- grassed ($/ac[a])	15,600	12,000	10,800 to 24,000

[a] ac refers to bioretention cell surface area
[b] refers to mowing the bioretention cell's surrounding landscape

$$C = (P * A) * (1 + r)^n$$ **Equation 6**

Where:
C= future annual cost of routine maintenance ($)
P= 2018 cost of routine maintenance (mulched with mowing the surrounding landscape: $12,400/ac; mulched without mowing the surrounding landscape: $12,000/ac; grassed with mowing the surrounding landscape: $15,600/ac; grassed without mowing the surrounding landscape: $13,467/ac)
A= surface area of bioretention cell (ac) (typ. 0.17 ac)
r= annual increase in pricing (decimal)
n= number of years since 2018

The contractors also provided proactive maintenance costs for bioretention cells in 2018 (Table 15). On average the cost to replace and dispose of mulch was $80 per cy of mulch while media testing costs $183 per test (Table 14). With respect to vegetation, the average cost to purchase and plant a 1 gal or a 3 gal to 5 gal plant was $17 per plant and $43 per plant, respectively. On average, any vegetation smaller than 1 gal cost $3 per plant. Contractors did not provide the unit cost associated with planting a 3 gal plant. Contractors also estimated planting a tree cost $325 per tree. Costs to remove trees are summarized in Table 10. Note these costs include labor, materials, equipment, and disposal. Proactive maintenance costs can be estimated using Equation 2 and Table 15.

Table 15: 2018 Proactive maintenance costs for bioretention cells

Task	Mean	Median	Range
< 1 gal plant replacement ($/plant)	3	4	2.75 to 4
1 gal plant replacement ($/plant)	17	15	12 to 25
3 gal to 5 gal plant replacement ($/plant)	43	35	30 to 70
Tree replacement ($/tree)	325	300	100 to 600
Mulch replacement ($/cy[a])	80	75	40 to 150
Media testing ($/test)	183	200	150 to 200

[a] cy refers to mulch replaced

Comparable to other SCMs, restorative costs for bioretention cells in 2018 were heavily dependent upon site location, access, and the severity of the issue. The average cost to completely restore a bioretention cell was $455,213 per ac of bioretention surface area while the cost to replace media was $77 per ton of media or $300 per hr of work (Table 16). Note these costs include labor, materials, and disposal. The cost to flush out and camera underdrains was at least $20 per lf of underdrain and $250 per hr of work, respectively. The costs to repair embankments, inlets, outlets, and conveyance systems for bioretention cells are summarized in Table 11. Note these costs include labor, equipment, materials, and disposal. Restorative maintenance costs can be estimated using Equation 2 and Table 16.

Table 16: 2018 Restorative maintenance costs for bioretention cells

Task	Mean	Median	Range
Replace media ($/ton[a])	77	80	25 to 125
Replace media ($/hr[b])	300	-	-
Complete restoration ($/ac[c])	455,213	480,000	300,000 to 585,640
Camera underdrains ($/hr[b])	250	-	-
Flush out underdrains ($/lf[d])	20	-	-

[a] ton refers to media replaced
[b] hr refers to time complete work
[c] ac refers to bioretention cell surface area

4.9 Private Contractors: Sand Filters

Five contractors provided maintenance costs for above and below ground sand filters in 2018. The average age and footprint for above sand filters was 10 years and 0.22 ac, respectively (Table 17). Above ground sand filters are generally maintained on a monthly basis where the annual routine costs with and without mowing were $16,875 per ac of sand filter surface area and $13,281 per ac of sand filter surface area, respectively. Contractors reported routine costs for underground sand filters are dependent upon the sand filter's location. Additionally, the interviewees stated underground sand filters limited accessibility contributed to higher maintenance costs than costs associated with above ground sand filters. Maintenance typically occurs on a quarterly basis, and the average footprint for these underground practices is 0.20 ac. The average cost for residential underground sand filters was $73,086 per ac of sand filter surface area while the average cost for commercial below ground practices was $91,207 per ac of sand filter surface area. The interviewees reported their companies maintain between 7 and 30 sand filters (above and below ground). Note these costs include labor, materials, and equipment. Annual routine maintenance costs can be estimated using Table 17 and Equation 7, and entities should assume sand filters have a lifespan of at least 15 years.

Table 17: 2018 Routine maintenance costs and characteristics for sand filters

Parameter	Mean	Median	Range
Age- above ground (yr)	10	10	5 to 12
Typical footprint- above ground (ac[a])	0.22	0.22	0.02 to 0.33
Maintenance frequency- above ground	Monthly	-	4 to 21 times per yr
Time spent on tasks- above ground (hr)	1	1	0.25 to 1.50
Number of employees maintaining SCM- above ground	2	2	1 to 9
Routine costs without mowing[b]- above ground ($/ac[a])	13,281	14,262	5,400 to 78,407
Routine costs with mowing[b]- above ground ($/ac[a])	16,875	16,951	9,600 to 24,000
Age- underground (yr)	10	9	8 to 10
Typical footprint- underground (ac[a])	0.20	0.20	0.01 to 0.50
Maintenance frequency- underground	Quarterly	-	4 to 21 times per yr
Time spent on tasks- underground (hr)	1	1	0.25 to 1.5
Number of employees maintaining SCM- underground	4	4	3 to 4
Routine costs without mowing[b]- underground, residential ($/ac[a])	73,086	74,407	4,000 to 145,200
Routine costs without mowing[b]- underground, commercial ($/ac[a])	91,207	78,407	4,000 to 223,028

[a] ac refers to sand filter surface area
[b] refers to mowing the sand filter's surrounding landscape

$$C = (P * A) * (1 + r)^n$$ **Equation 7**

Where:
C= future annual cost of routine maintenance ($)
P= 2018 cost of routine maintenance (above ground with mowing the surrounding landscape: $16,951/ac; above ground without mowing the surrounding landscape: $14,262/ac; underground, residential: $74,407/ac; underground, commercial: $91,207/ac)
A= surface area of sand filter (ac) (typ. 0.22 ac above ground; typ. 0.20 ac underground)
r= annual increase in pricing (decimal)
n= number of years since 2018

Proactive maintenance costs for above and underground sand filters in 2018 were limited to confined space training ($250 per person) and forebay sediment removal ($65 per cy of sediment). On average, restoring above and underground sand filters was $665 per cy of sand while skimming and refreshing sand filter media was $5 per sf of sand. Restorative costs relating to underdrains, embankment, inlet, and outlet repairs are summarized in Table 11 and Table 16. Proactive and restorative costs for above ground sand filters can be estimated using Equation 2,

Table 11, and Table 16. Note interviewees stated restorative maintenance costs for wet ponds and above ground sand filters were similar.

4.10 Private Contractors: Level Spreader- Filter Strips

Private contractors commented level spreader-filter strips are usually located immediately downstream of outlet structures to provide diffuse flow or immediately upstream to serve as pretreatment devices. Given these typical uses, contractors tend to lump together routine and proactive maintenance costs for level spreader-filter strips with the other practice's maintenance costs. Examples of SCMs incorporating level spreader-filter strips include wet ponds, stormwater wetlands, and bioretention cells. If a level spreader-filter strip is a standalone practice then annual routine/proactive costs with and without mowing in 2018 were at least $160 per lf of level spreader length and $34 per lf of level spreader length, respectively (Table 18). Annual routine maintenance costs can be estimated using Table 18 and Equation 8, and entities should assume level spreader-filter strips have a lifespan of at least 20 years. Note NC DEQ no longer promotes level spreader-filter strips for stormwater management but many of these SCMs were installed from 2000 to 2015.

Table 18: 2018 Routine maintenance costs and characteristics for level spreader-filter strips

Parameter	Mean	Median	Range
Age (yr)	18	15	10 to 28
Typical footprint (lf[a])	37	40	20 to 50
Maintenance frequency	Monthly	-	8 to 12 times a yr
Time spent on tasks (hr)	0.5	0.5	-
Number of employees maintaining SCM	2	1	1 to 4
Routine costs without mowing[b] ($/lf[a])	34	8	5 to 90
Routine costs with mowing[b] ($/lf[a])	160	-	-

[a] lf refers to level spreader length

[b] refers to the level spreader-filter strip's surrounding landscape

$$C = (P * LF) * (1 + r)^n$$ **Equation 8**

Where:
C= future annual cost of routine maintenance ($)
P= 2018 cost of routine maintenance (with mowing the surrounding landscape: $160/lf; without mowing the surrounding landscape: $34/lf)
LF= length of level-spreader (lf) (typ. 40 lf)
r= annual increase in pricing (decimal)
n= number of years since 2018

Restorative costs for level spreader-filter strips in 2018 were dependent upon the level spreader material. On average the cost to repair a concrete level spreader was $163 per lf of level spreader length while the cost to replace a filter strip with sod was at least $2 per sf of filter strip or $70 per lf of level spreader length (Table 19). The minimum cost to replace a filter strip with grass seed was $0.11 per cy of seed. While seed and straw was the clearly less expensive option, most contractors agree that it was a far less reliable "fix" than sod. Costs to restore a concrete or rock level spreader and filter strip was $180 per lf of level spreader length and $178 per lf level spreader length, respectively. Note these costs include labor, materials, equipment, and disposal. Restorative costs can be estimated using Equation 2 and Table 19.

Table 19: 2018 Restorative maintenance costs for level spreader-filter strips

Task	Mean	Median	Range
Repair concrete level spreader ($/lf[a])	163	163	126 to 200
Replace filter strip- sod ($/sf[b])	2	-	-
Replace filter strip- sod ($/lf[a])	70	-	-
Replace filter strip- grass seed ($/cy[c])	0.11	-	-
Restore- concrete level spreader and filter strip ($/lf[a])	180	126	100 to 315
Restore- rock level spreader and filter strip ($/lf[a])	178	140	80 to 315

[a] lf refers to level spreader length
[b] sf refers to filter strip surface area
[c] cy refers to grass seed volume

4.11 Private Contractors: Other SCMs

Participants in this study did not maintain infiltration basins, DIS, and treatment swales. However, the interviewees did provide some data for permeable pavement, rainwater harvesting, Contech StormFilters®, ADS BayFilters™, and Contech Filterras®. Possible reasons for a lack of data for some of these SCMs are: (1) companies who maintain practices like infiltration basins did not participate in our study and (2) private contractors may not have had access to specialty maintenance equipment (e.g., street sweeper). Certain tasks such as replacing trees for DeepRoot Silva Cells® or mowing treatment swales, infiltration basins, and DIS can be estimated using data reported for other SCMs (e.g., Table 13 and Table 15).

For above ground rainwater harvesting systems maintained on a monthly basis, annual costs in 2018 ranged from $1,500 per cistern to $1,800 per cistern. Maintenance tasks for rainwater harvesting includes water quality testing (e.g., pH, alkalinity) and inspecting for leaks. Annual routine maintenance costs for above ground rainwater harvesting systems can be estimated using Equation 2 and an annual maintenance cost of $1,800 per cistern. Note only one interviewee maintained rainwater harvesting systems.

Routine maintenance costs for permeable inter-locking concrete pavers (PICP) in 2021 ranged between $0.68 and $1.05 per sf of PICP surface area (Table 20). Maintenance costs were impacted by the type of equipment used to improve (or restore) surface infiltration rates. Maintenance costs for other types of permeable pavement (e.g., permeable concrete, porous asphalt) could be estimated using these data. Note these costs include labor, materials, equipment, and disposal. Annual routine costs as well as restorative costs can be estimated using Equation 9 and inputs from Table 20. Similar to rainwater harvesting, only one interviewee maintained PICP.

Table 20. 2021 Routine and restorative maintenance costs for permeable inter-locking concrete pavers (PICP)

Type	Minimum	Additional area[b]
Routine- street sweeping (first 1,000 sf)[a]	$1/sf	$0.05/sf
Routine- street sweeping, regenerative air, re-chipping (first 4,000 sf)[a]	$0.38/sf	$0.30/sf
Restorative- vacuum, re-chipping (first 4,000 sf)[a]	$0.70/sf	$0.65/sf
Restorative- lift and replace/reset pavers, setting bed, joint fill (first 50 sf)[a]	$20/sf	$20/sf (> 50 sf) $12/sf (> 500 sf)

[a] sf of PICP surface area
[b] beyond initial surface area noted in the first column

$$C = (P * SF) * (1 + r)^n$$ **Equation 9**

Where:
C= future annual cost of maintenance ($)
P= 2021 cost of maintenance
SF= surface area of permeable pavement
r= annual increase in pricing (decimal)
n= number of years since 2021

Per the manufacturer if an upstream sump is routinely maintained, ADS BayFilters™ cartridges can last between 4 to 6 years. Cartridges do not need to be replaced if the accumulated sediment has not exceeded the top of the system's PVC manifold. For a minimum of 4 hours, pressure jetting and vacuuming out the accumulated sediment in 2021 cost between $1,600 to $2,400. Businesses engaged in such efforts are those that maintain sewer lines. If BayFilter™ cartridges need to be replaced, the cost in 2021 was at least $800 per cartridge.

Per the manufacturer, the expected routine maintenance frequency for Contech StormFilters® is between 2.5 years to 4 years. The cost to mobilize, remove the cartridges, clean and vacuum the vault, dispose of the vacuumed material, furnish and install new cartridges, and recycle or reuse old cartridges in 2021 was between $300 per cartridge and $700 per cartridge. In terms of watershed area treated, the annual cost in 2021 to maintain StormFilters® was roughly $1,400 per ac. For Contech Filterras®, routine maintenance occurs on an annual basis. In 2021, the annual cost to mobilize, remove and replace the top 3 in of mulch, prune and weed the vegetation, and remove and dispose of accumulated trash, debris, and sediment was between $750 and $1,500. Annual routine maintenance costs for ADS BayFilters™, Contech StormFilters®, and Contech Filterras® can be estimated using Equation 2 and the provided data. Note only interviewee each maintained BayFilters™, StormFilters®, and Filterras®.

4.12 WRRI-SC: SCM Maintenance

With the exception of one WRRI-SC community, private contractors and or multiple city departments maintain municipal SCMs. Table 21 summarizes the routine/proactive maintenance costs provided by the WRRI-SC communities. As expected, average costs were higher for heavily vegetated SCMs and or SCMs requiring mowing. Note the contractors responsible for maintaining municipal SCMs were asked to participate in the study, and the provided costs were calculated in the same manner as those provided by the private contractors.

Table 21: 2018 Routine maintenance costs without mowing the surrounding landscape for WRRI-SC SCMs

Stormwater control measure (SCM)	Mean	Median	Range
Wet ponds ($/ac[a])	2,957	2,390	1,053 to 5,997
Stormwater wetlands ($/ac[a])	3,122	1,874	940 to 7,800
Dry ponds ($/ac[a])	6,045	-	-
Bioretention cells ($/ac[a])	3,295	3,478	1,237 to 6,353
Above ground sand filters ($/ac[a])	3,200	-	-

[a] ac refers to SCM surface area

4.13 State Entities: SCM Maintenance

Similar to WRRI-SC interviewees, state entities maintain SCMs using more than one department, and SCM characteristics (e.g., surface area) are not easily identifiable. This makes quantifying costs difficult, if not impossible; state entities were not able to contribute data to the study.

5 Discussion

Despite a limited number of interviewees, maintenance costs were quantified for most of the NC DEQ (2018) approved SCMs. Efforts to recruit interviewees included emails, phone calls, and presentations at the ongoing NCSU BMP I&M workshop series. A lack of participation was attributed to current or lack thereof recording keeping methods, reluctance to disclose information as maintenance costs are highly site (and business-) specific, or concerns about competitive pricing (Clary and Piza, 2017). Interviewees quantified maintenance costs in terms of the SCM's surface area rather than the SCM's watershed characteristics (e.g., watershed area, percent imperviousness) or construction costs. Construction costs and watershed characteristics are not readily available to most SCM permit holders. However, permit holders can estimate the surface area of a SCM using field measurements or computer software (e.g., Google Earth, ArcGIS). To ensure the Excel based tool summarizing these project results is user-friendly, the tool will use a SCM's surface area to quantify maintenance costs.

The differences in how maintenance costs were defined prevents comparisons among the project results and previous literature for most SCMs (Houle et al., 2013; Wossink and Hunt, 2003; Weiss et al., 2005). Using data summarized in Table 14, the estimated annual maintenance costs in North Carolina for a 0.17 ac mulched bioretention cell in 2018 ($2,040) is roughly $1,600 less than the cost estimated using US EPA (2019)'s typical cost curve for rain gardens ($3,696). Additionally, the cost of street sweeping 1,000 sf of PICP in North Carolina in 2021 ($1,000) is approximately $5,500 less that the cost estimated using US EPA (2019)'s typical cost curve for permeable pavement ($6,520.90). Based on these limited comparisons, it appears maintenance costs for one region are not applicable for estimating the maintenance costs associated with SCMs in another region.

Costs for routine and proactive maintenance were easier to quantify than restorative maintenance costs. A SCM's footprint and proximity to resources (e.g., disposal site) affected restorative costs more than routine or proactive costs. Interviewees stressed routinely maintained SCMs rarely needed restorative maintenance. This latter type of maintenance is usually triggered when property owners of a SCM receive a notice of violation (NOV). Determining the money saved by routinely maintaining a practice versus waiting to maintain a SCM until it no longer functions properly is difficult. However, these data can help make the necessary assumptions for these calculations. Table 22 includes the projected savings for some generic SCMs if 2018 routine and restorative maintenance costs steadily increase at 1%, and the practice needs restorative maintenance 10 years after installation. Note a cost increase of 1% was arbitrarily chosen as the rate of maintenance costs increasing is dependent upon the maintenance company's business model, current economy, and the accessibility of the practice. The project results suggest 10 years is an appropriate length of time before restorative maintenance should occur.

With the exception of stormwater wetlands and level spreader-filter strips, it appears to be more economical to provide routine maintenance rather than restorative maintenance (Table 22). However, these cost estimations do not include the fees (fines) associated with out-of-compliance SCMs and the likely need to hire a PE or RLA to design and/or verify that an SCM has been restored. The savings between routinely and restoratively maintaining a level spreader-filter strip is most likely caused by the minimal difference between routine and restorative maintenance costs in 2018 for this SCM. Regardless of the type of SCM, permit holders should continue to routinely maintain SCMs to remain in compliance with environmental regulations and avoid creating hazardous conditions for the surrounding community.

Table 22. Routine vs. restorative maintenance costs 10 years after installation

SCM[a]	Total routine maintenance costs[e]	Restorative maintenance costs[f]	Difference
Wet ponds[b]	$109,191 per ac	$132,555 per ac	$23,364 per ac
Stormwater wetlands[b]	$134,175 per ac	$132,555 per ac	-$1,621 per ac
Dry ponds[b]	$130,937 per ac	$132,555 per ac	$1,618 per ac
Bioretention cells[c]			
Mulched	$143,429 per ac	$530,219 per ac	$386,790 per ac
Grassed	$180,443 per ac	$530,219 per ac	$349,775 per ac
Level spreader-filter strips[d]			
Concrete level spreader	$1,851 per lf	$199 per lf	-$1,652 per lf
Rock level spreader		$197 per lf	-$1,654 per lf

[a] Routine costs associated with mowing the surrounding landscape (if applicable)
[b] Costs in terms of ac of SCM surface area; restorative maintenance- dredging
[c] Costs in terms of ac of SCM surface area; complete restoration
[d] Costs in terms of lf of level spreader
[e] Sum of routine maintenance costs from 2018 to 2028 in terms of ac of SCM surface area
[f] Cost of restoring SCM in 2028 in terms of ac of SCM surface area

Figure 1 summarizes the average annual routine maintenance costs with mowing in 2018 for the detention based SCMs. High costs for maintaining grassed bioretention cells and above ground sand filters can be attributed to the additional time spent mowing the SCM. Also, it appears vegetation impacts annual costs; bioretention cells and stormwater wetlands have (often, modestly) higher maintenance costs than their counterparts (dry ponds and wet ponds, respectively). Annual routine maintenance costs may influence which SCMs are implemented for stormwater management. Wet ponds have the lowest annual maintenance cost among detention based SCMs; however, as environmental awareness increases the number of SCMs with lower total nitrogen (TN) and total phosphorus (TP) effluent concentrations (e.g., bioretention cells) may increase (NC DEQ, 2018). Moreover, a recent study submitted to the NC Legislature on SCM resilience indicates that practices that employ more vegetation (i.e., CSW's and bioretention) are more resilient to stressors like large storm events than those with minimal vegetation (e.g., wet ponds and sand filters).

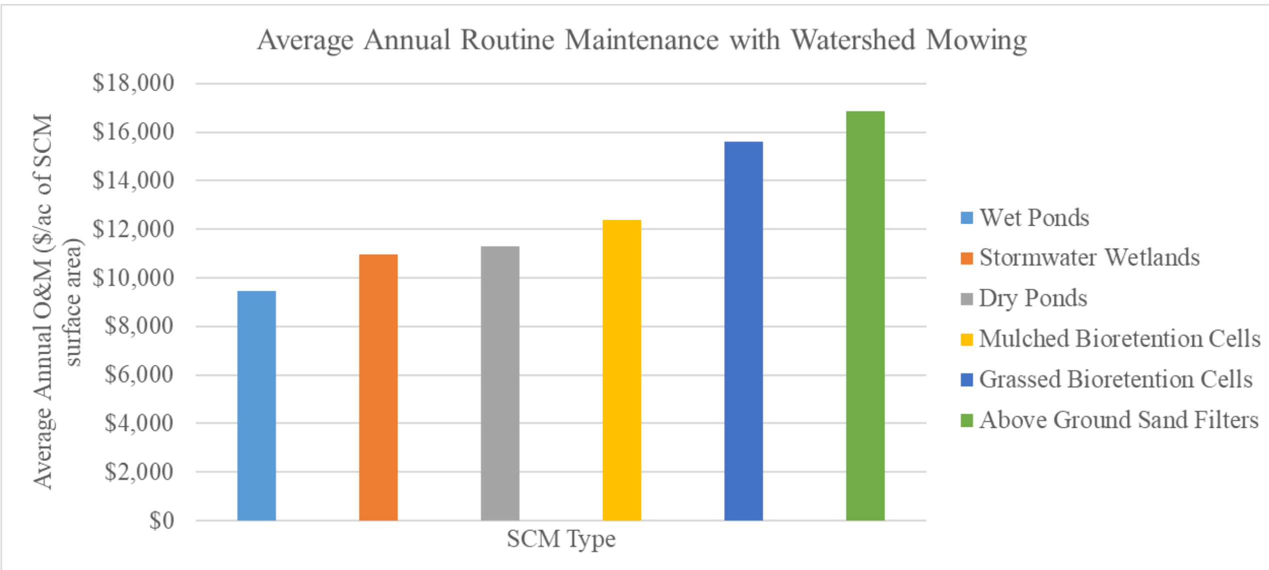

Figure 1: Private contractor average annual routine maintenance with mowing costs in 2018

6 Summary and Conclusions

Quantifying maintenance costs for SCMs is difficult; factors such as maintenance access and SCM location greatly impact costs. Additionally, record keeping can prevent maintenance costs from easily being identified. Routine, proactive, and restorative maintenance costs were quantified for: wet ponds, stormwater wetlands, dry ponds, bioretention cells, sand filters, level spreader-filter strips, rainwater harvesting systems, PICP, Contech StormFilters®, ADS BayFilters™, and Contech Filterras®. Certain tasks such as replacing trees for DeepRoot Silva Cells® or mowing treatment swales, infiltration basins, and DIS can be estimated using data reported for other SCMs. Routine and restorative maintenance costs for various SCMs can be estimated using the provided equations. Appendix C provides an example of how to use these equations and project results.

Interviews with private contractors revealed average annual routine maintenance costs with mowing in 2018 range from $9,440 per ac of SCM surface area to $16,875 per ac of SCM surface area (Figure 1). Multiple departments or private contractors usually maintain SCMs owned by municipalities or state entities. Factors such as mowing and vegetative cover increase costs, and maintenance usually occurs on a monthly basis. Maintenance tasks include those set forth by NC DEQ (2020), and a SCM's location does not impact the LOS provided. Interviewees stressed a high LOS is provided to avoid hazardous site conditions, improve water quality, and reflect the interviewee's dedication to their profession. Restorative maintenance costs tend to be much higher than routine and proactive costs, and it is more economical to routinely maintain a practice than waiting to maintain a SCM once it loses functionality. In addition to maintenance costs, interviewees provided design recommendations to optimize SCM maintenance. These suggestions included providing maintenance access wide enough for equipment (at least 8 ft), gradual side slopes (preferably no steeper than 4:1), pretreatment, and irrigation systems for newly planted vegetation. Interviewees also suggested enforcing topsoil and or compacted layers specified in the design plans and ensuring the initial vegetation selection is appropriate for the site conditions. These recommendations have the potential to reduce clogging, increase vegetation survival rates, and reduce maintenance costs.

7 Recommendations

To help with allocating funds to SCM maintenance, the investigators recommend SCM owners track the following information listed in Table 23 using their existing asset management system, ArcGIS, or Excel (Clary and Piza, 2017). Suggestions for identifying SCM characteristics include using design plans, permits, field visits, or Google Earth. Maintenance costs can be quantified using invoices from private contractors, municipal employees' work schedules and hourly rates, or these project results.

Table 23: Recommended maintenance data to track (Clary and Piza, 2017)

Parameter	Description
	SCM characteristics
Asset ID	If applicable number in asset management system
Facility type	Individual, cluster, or other
SCM coordinates	Decimal latitude and longitude
Name	General SCM name
Type	Type of SCM
Date installed	Date SCM permit transferred to owner
Surface area (ac)	Surface area of SCM including side slopes
SCM sizing	Standard, under-sized, over-sized
Media type	In-situ soils, engineered media, not applicable
Vegetation type	Native grasses, turf, wet pond/wetland/bioretention vegetation
Pretreatment features	List pretreatment features (e.g., forebay)
SCM ownership	Public, private, private-easement, private- homeowners association (HOA)
	Maintenance records
Maintenance ID	Maintenance record number or date of maintenance
Event record type	Annual summary, individual event, other
Work order ID	If applicable asset management system work order ID
Work order description	If applicable asset management system description of work
Maintenance entity	Private contractor, municipal, volunteer, combination
Maintenance narrative	Describe maintenance provided
Total cost ($)	Cost for labor, equipment, and materials
Labor cost ($) and time (hr)	Total labor cost and time spent maintaining/inspecting SCM
Materials description and cost ($)	Materials used during maintenance and total cost
Equipment description and cost ($)	Equipment used during maintenance and total cost

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9 Appendix A: List of abbreviations

ac: acre
BMP: best management practice
cy: cubic yard
DIS: Disconnected impervious surface
ft: feet
gal: gallon
HOA: homeowners association
hr: hour
I&M: inspection and maintenance
lf: linear feet
LOS: level of service
O&M: Operations and maintenance
NC DEQ: North Carolina Department of Environmental Quality
NC DWR: North Carolina Division of Water Resources
NCSU: North Carolina State University
NOV: notice of violation
NPE: normal pool elevation
P.E.: professional engineer
R.L.A.: registered landscape architect
SCM: stormwater control measure
sf: surface area
TN: total nitrogen
TP: total phosphorus
WRRI-SC: Water Resources Research Institute of the University of North Carolina Stormwater Consortium
yr: year

10 Appendix B: Project deliverables

Presentations: 2017 EWRI O&M Conference; 2018 EWRI LID Conference; 2018 NC APWA Stormwater Management Division Fall Conference; 2019 WRRI Annual Conference; 2019 EWRI O&M Conference; 2022 EWRI O&M Conference

Workshops:
NCSU Extension Stormwater BMP Inspection and Maintenance (I&M) certification workshop series; Clemson University LID Hot Topics: Costs, Perceptions and Maintenance of Low Impact Development Practices in Coastal SC

Publications:
Waickowski, S.E., Lord, W.G., & Hunt, W.F. (2021). *Maintenance costs of stormwater control measures (SCMs) in North Carolina*. Manuscript in preparation.

Other:
Stormwater Control Measure Maintenance Cost Calculator. Excel based tool in preparation.

11 Appendix C: Example maintenance cost calculations

2018 Routine maintenance costs and characteristics for wet ponds

Parameter	Mean	Median	Range
Age (yr)	16	16	10 to 28
Typical footprint (ac[a])	0.50	0.50	0.25 to 0.75
Maintenance frequency	Monthly	-	8 to 21 times per yr
Time spent on tasks (hr)	2	1	0.25 to 6
Number of employees maintaining SCM	3	2	1 to 9
Routine costs without mowing[b] ($/ac[a])	6,360	4,600	4,000 to 9,600
Routine costs with mowing[b] ($/ac[a])	9,440	8,800	5,400 to 15,200

[a] ac refers to wet pond surface area
[b] refers to mowing the wet pond's watershed area

$$C = (P * A) * (1 + r)^n$$ **Equation 10**

Where:
C= future annual cost of routine maintenance ($)
P= 2018 cost of routine maintenance (with mowing the surrounding landscape: $9,440/ac; without mowing the surrounding landscape: $6,360/ac)
A= surface area of wet pond (ac) (typ. 0.50 ac)
r= annual increase in pricing (decimal)
n= number of years since 2018

2018 Restorative maintenance costs for wet ponds, stormwater wetlands, dry ponds, and sand filters

Task	Mean	Median	Range
Inlet/outlet repair ($)	2,600	2,750	1,200 to 3,700
Riser replacement ($)	15,000	-	-
Dredging ($/ac[a])	118,800	120,000	26,400 to 210,000
Dredging ($/cy[b])	100	-	-
Embankment repair ($)	2,780	2,500	1,200 to 3,700
Replace rip-rap apron ($)	5,000	-	-
Repair pipe concrete cradle ($)	15,000	-	-
Repair pipe joint ($)	3,750	3,750	2,500 to 5,000

[a] ac refers to wet pond surface area
[b] cy refers to sediment removed

$$C = (P * U) * (1 + r)^n$$ **Equation 11**

Where:
C= future cost of maintenance task ($)
P= reported cost of maintenance task ($)
U= unit of measure associated with SCM and maintenance task (if applicable)
r= annual increase in pricing (decimal)
n= number of years since 2018

Routine cost at Year 2019:

Wet pond surface area = 0.75 ac
Estimated increase in price = 1% (0.01)

$$C = \frac{\$9{,}440}{ac\ of\ wet\ pond} * 0.75\ ac\ of\ wet\ pond * (1 + 0.01)^{2019-2018}$$

$$C = \$9{,}534$$

Year	Estimated cost	Year	Estimated cost	Year	Estimated cost
2018	$9,440	2031	$10,744	2044	$12,227
2019	$9,534	2032	$10,851	2045	$12,349
2020	$9,630	2033	$10,960	2046	$12,473
2021	$9,726	2034	$11,069	-	-
2022	$9,823	2035	$11,180	-	-
2023	$9,922	2036	$11,292	-	-
2024	$10,021	2037	$11,405	-	-
2025	$10,121	2038	$11,519	-	-
2026	$10,222	2039	$11,634	-	-
2027	$10,324	2040	$11,750	-	-
2028	$10,428	2041	$11,868	-	-
2029	$10,532	2042	$11,986	-	-
2030	$10,637	2043	$12,106	-	-

12 Appendix D: Estimated annual routine maintenance costs for treated watershed area

Interviewees did not provide maintenance costs in terms of the watershed area treated by the SCM. Typical watershed areas for some NC DEQ approved SCMs were quantified using previous research conducted in North Carolina (Table 24). Table 25 summarizes the annual routine maintenance costs for some generic SCMs in terms of their smallest and largest typical watershed area.

Table 24. Summary of typical watershed areas for NC DEQ approved SCMs

Stormwater control measure	Watershed area (ac)	Source
Wet pond- Bingham	5.86	Baird (2014)
Wet pond- Raeford	4.79	Baird (2014)
Wet pond- Davis	1,258	Borden et al. (1998)
Wet pond- Piedmont	1,221	Borden et al. (1998)
Wet pond- Pierson	1.25	Hathaway et al. (2007a)
Wet pond- Shade Valley	27.30	Hathaway et al. (2007b)
Wet pond- DOT	32.30	Winston et al. (2013)
Wet pond- Museum	5.86	Winston et al. (2013)
Wetland-Edenton Hospital	600	Bass (2000)
Wetland- Dye Branch	30.89	Hathaway and Hunt (2010)
Wetland- Bruns Ave	15.81	Johnson (2006)
Wetland- Smithfield- Selma	25.95	Johnson (2006)
Wetland- Riverbend	115	Lenhart and Hunt (2011)
Wetland- Centennial Campus	22.49	Line et al. (2008)
Wetland- UNCA	3.71	Line et al. (2008)
Wetland- JEL Wade	588	Mallin et al. (2012)
Wetland- Jack Smith Creek	1,584	Merriman et al. (2016)
Dry pond- MOV1	10.25	Mazer (2018)
Dry pond- MOV2	6.23	Mazer (2018)
Dry pond- WS	2.30	Mazer (2018)
Dry pond- Basin1	15.41	Wissler et al. (2020a)
Dry pond- Basin2	2.00	Wissler et al. (2020a)
Dry pond- HFR	9.81	Wissler et al. (2020b)
Dry pond- PRB	12.50	Wissler et al. (2020b)
Bioretention cell- SCL	0.54	Brown and Hunt (2011)
Bioretention cell- Sand	0.61	Brown and Hunt (2011)
Bioretention cell- G1	0.50	Hunt et al. (2006)
Bioretention cell- G2	0.50	Hunt et al. (2006)
Bioretention cell- C1	0.15	Hunt et al. (2006)
Bioretention cell- Charlotte	0.92	Hunt et al. (2008)
Bioretention cell- Catawba	1.32	Line et al. (2009)
Bioretention cell- Small/Large	0.99	Luell et al. (2011)
Bioretention cell- Graham	1.75	Passeport et al. (2009)
Bioretention cell- L1	0.90	Sharkey (2006)

Stormwater control measure	Watershed area (ac)	Source
Bioretention cell- L2	0.54	Sharkey (2006)
Rainwater harvesting- #6	0.06	DeBusk and Hunt (2014)
Rainwater harvesting- #8	0.10	DeBusk and Hunt (2014)
Rainwater harvesting- #24	0.08	DeBusk and Hunt (2014)
Rainwater harvesting- #28	0.10	DeBusk and Hunt (2014)
Rainwater harvesting- Colonnade	0.52	Wilson et al. (2014)
Level spreader- filter strip- Charlotte	2.15	Hunt et al. (2010)
Level spreader- filter strip- Wilson	3.03	Knight et al. (2013)
Level spreader- filter strip- Catawba	0.86	Line et al. (2009)
Level spreader- filter strip- Apex	1.04	Winston et al. (2011)
Level spreader- filter strip- Louisberg	0.99	Winston et al. (2011)

Table 25. Estimated range of annual routine maintenance costs for NC DEQ approved SCMs in terms of typically treated watershed area

<table>
<tr><th rowspan="2">Stormwater control measure</th><th colspan="2">Range of annual routine maintenance without mowing per typical watershed area treated ($/ac)[a]</th><th colspan="2">Range of annual routine maintenance without mowing per typical watershed area treated ($/ac)[a]</th></tr>
<tr><th>Mean</th><th>Median</th><th>Mean</th><th>Median</th></tr>
<tr><td>Wet ponds</td><td>3.17 to 3,189</td><td>2.54 to 2,560</td><td>3.06 to 3,080</td><td>2.66 to 2,680</td></tr>
<tr><td>Stormwater wetlands</td><td>2.68 to 1,147</td><td>2.68 to 1,147</td><td>2.41 to 1,032</td><td>2.08 to 890</td></tr>
<tr><td>Dry ponds</td><td>234 to 1,800</td><td>225 to 1,733</td><td>243 to 1,870</td><td>214 to 1,650</td></tr>
<tr><td>Bioretention cells- mulched,</td><td>1,649 to 19,238</td><td>1,314 to 15,333</td><td>1,486 to 17,333</td><td>1,543 to 18,000</td></tr>
<tr><td>Bioretention cells, grassed</td><td>1,673 to 17,524</td><td>1,200 to 13,333</td><td>1,943 to 22,667</td><td>1,543 to 18,000</td></tr>
<tr><td>Above ground rainwater harvesting systems</td><td colspan="2">3,180 to 27,254</td><td>-</td><td>-</td></tr>
<tr><td>Level spreader- filter strips</td><td>259 to 911</td><td>99 to 349</td><td colspan="2">1,056 to 3,721</td></tr>
</table>

[a] with and without mowing refer to mowing the SCM's surrounding landscape

13 Appendix E: List of interviewees questions

SCM O&M Cost Interview:
- Level of Service Provided:
- High and Low Service Defined:

Wet Ponds:
- Number of Practices Maintained:
- Typical Issues:
- Range of SCM Ages or Years of Service:
- Average SCM Footprint/Average Drainage Area:
- Typical SCM Location:
- Routine Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
- Restorative Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
    - In-house or Contractor Perform Work:
- Inspections:
    - Type of Inspection (e.g., monthly, annually):
    - Frequency:
    - Who Conducts Inspection:
    - Cost for Inspection:
- Costs Associated with Removing and Hauling Away Forebay Sediment:
- In-house or Contractor for Tree Removal:
- In-house or Contractor for Vegetation Selection:
- Costs for Vegetation Replacement:
- Equipment Costs:
- Design Recommendations to Ease Maintenance:
- Tasks to Include in NCDEQ Stormwater Manual:
- Factors Improving Maintenance:
- Inspection Tasks Help Maintenance:

Dry Ponds:
- Number of Practices Maintained:
- Typical Issues:
- Range of SCM Ages or Years of Service:

- Average SCM Footprint/Average Drainage Area:
- Typical SCM Location:
- Routine Maintenance Tasks:
  - Tasks:
  - Time Spent on Tasks:
  - Frequency:
  - Number of Employees for Tasks:
  - Cost (labor + equipment) per Visit:
- Restorative Maintenance Tasks:
  - Tasks:
  - Time Spent on Tasks:
  - Frequency:
  - Number of Employees for Tasks:
  - Cost (labor + equipment) per Visit:
  - In-house or Contractor Perform Work:
- Inspections:
  - Type of Inspection (e.g., monthly, annually):
  - Frequency:
  - Who Conducts Inspection:
  - Cost for Inspection:
- In-house or Contractor for Tree Removal:
- Costs Associated with Removing and Hauling Away Forebay Sediment:
- Equipment Costs:
- Design Recommendations to Ease Maintenance:
- Tasks to Include in NCDEQ Stormwater Manual:
- Factors Improving Maintenance:
- Inspection Tasks Help Maintenance:

Bioretention:

- Number of Practices Maintained:
- Typical Issues:
- Range of SCM Ages or Years of Service:
- Average SCM Footprint/Average Drainage Area:
- Typical SCM Location:
- Routine Maintenance Tasks:
  - Tasks:
  - Time Spent on Tasks:
  - Frequency:
  - Number of Employees for Tasks:
  - Cost (labor + equipment) per Visit:
- Restorative Maintenance Tasks:
  - Tasks:
  - Time Spent on Tasks:
  - Frequency:
  - Number of Employees for Tasks:

- Cost (labor + equipment) per Visit:
  - In-house or Contractor Perform Work:
- Inspections:
  - Type of Inspection (e.g., monthly, annually):
  - Frequency:
  - Who Conducts Inspection:
  - Cost for Inspection:
- In-house or Contractor for Tree Removal:
- In-house or Contractor for Vegetation Selection:
- Costs for Vegetation Replacement:
- Costs Associated with Removing and Hauling Away Forebay Sediment:
- Costs for Media Testing:
- Costs for Hauling Away and Replacing Media:
- Costs for Mulch Replacement:
- Equipment Costs:
- Design Recommendations to Ease Maintenance:
- Tasks to Include in NCDEQ Stormwater Manual:
- Factors Improving Maintenance:
- Inspection Tasks Help Maintenance:

Wetlands:

- Number of Practices Maintained:
- Typical Issues:
- Range of SCM Ages or Years of Service:
- Average SCM Footprint/Average Drainage Area:
- Typical SCM Location:
- Routine Maintenance Tasks:
  - Tasks:
  - Time Spent on Tasks:
  - Frequency:
  - Number of Employees for Tasks:
  - Cost (labor + equipment) per Visit:
- Restorative Maintenance Tasks:
  - Tasks:
  - Time Spent on Tasks:
  - Frequency:
  - Number of Employees for Tasks:
  - Cost (labor + equipment) per Visit:
  - In-house or Contractor Perform Work:
- Inspections:
  - Type of Inspection (e.g., monthly, annually):
  - Frequency:
  - Who Conducts Inspection:
  - Cost for Inspection:
- Inspections

    - Type of inspection (e.g., monthly, annually)
    - Frequency
    - Who conducts inspection
    - Cost for inspection
- Costs Associated with Removing and Hauling Away Forebay Sediment:
- In-house or Contractor for Tree Removal:
- In-house or Contractor for Vegetation Selection:
- Costs for Vegetation Replacement:
- Cattail Removal In-house or Contractor:
- Equipment Costs:
- Design Recommendations to Ease Maintenance:
- Tasks to Include in NCDEQ Stormwater Manual:
- Factors Improving Maintenance:
- Inspection Tasks Help Maintenance:

Permanent Pavement:

- Number of Practices Maintained:
- Typical Issues:
- Range of SCM Ages or Years of Service:
- Average SCM Footprint/Average Drainage Area:
- Typical SCM Location:
- Routine Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
- Restorative Maintenance Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
    - In-house or Contractor Perform Work:
- Inspections:
    - Type of Inspection (e.g., monthly, annually):
    - Frequency:
    - Who Conducts Inspection:
    - Cost for Inspection:
- In-house or Contractor Paver Replacement or Pavement Patching:
- In-house or Contractor for Sweeping and Snow Plowing:
- Costs to Replenish Aggregate:
- Equipment Costs:
- Design Recommendations to Ease Maintenance:
- Tasks to Include in NCDEQ Stormwater Manual:
- Factors Improving Maintenance:

- Inspection Tasks Help Maintenance:

Rainwater Harvesting:

- Number of Practices Maintained:
- Typical Issues:
- Range of SCM Ages or Years of Service:
- Average SCM Footprint/Average Drainage Area:
- Typical SCM Location:
- Routine Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
- Restorative Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
    - In-house or Contractor Perform Work:
- Inspections:
    - Type of Inspection (e.g., monthly, annually):
    - Frequency:
    - Who Conducts Inspection:
    - Cost for Inspection:
- In-house or Contractor to Clean Gutters:
- In-house or Contractor to Remove Tank Sediment:
- Equipment Costs:
- Design Recommendations to Ease Maintenance:
- Tasks to Include in NCDEQ Stormwater Manual:
- Factors Improving Maintenance:
- Inspection Tasks Help Maintenance:

Sand Filters/Underground SCMs:

- Number of Practices Maintained:
- Typical Issues:
- Range of SCM Ages or Years of Service:
- Average SCM Footprint/Average Drainage Area:
- Typical SCM Location:
- Routine Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:

- Restorative Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
    - In-house or Contractor Perform Work:
- Inspections:
    - Type of Inspection (e.g., monthly, annually):
    - Frequency:
    - Who Conducts Inspection:
    - Cost for Inspection:
- Costs Associated with Removing and Hauling Away Forebay/Sedimentation Chamber Sediment:
- Costs for Media Testing:
- Costs for Hauling Away and Replacing Media:
- Equipment Costs:
- Design Recommendations to Ease Maintenance:
- Tasks to Include in NCDEQ Stormwater Manual:
- Factors Improving Maintenance:
- Inspection Tasks Help Maintenance:

Level Spreader-Filter Strips:

- Number of Practices Maintained:
- Typical Issues:
- Range of SCM Ages or Years of Service:
- Average SCM Footprint/Average Drainage Area:
- Typical SCM Location:
- Routine Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
- Restorative Maintenance Tasks:
    - Tasks:
    - Time Spent on Tasks:
    - Frequency:
    - Number of Employees for Tasks:
    - Cost (labor + equipment) per Visit:
    - In-house or Contractor Perform Work:
- Inspections:
    - Type of Inspection (e.g., monthly, annually):
    - Frequency:
    - Who Conducts Inspection:

    - Cost for Inspection:
- Costs Associated with Removing and Hauling Away Forebay Sediment:
- Cost for Soil Testing:
- In-house or Contractor for Lip Repair/Replacement:
- Costs for Sod Replacement/Reseeding:
- Equipment Costs:
- Design Recommendations to Ease Maintenance:
- Tasks to Include in NCDEQ Stormwater Manual:
- Factors Improving Maintenance:
- Inspection Tasks Help Maintenance: