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ABSTRACT

Many stormwater management manuals and guidance documents have stated the importance and estimated frequency of maintenance for stormwater best management practices (BMPs), but few have documented the actual frequency and intensity of maintenance required to maintain a desired level of performance and efficiency. Increased attention to mass balance, numerical goals, total maximum daily loads (TMDLs), and non-degradation requirements has created the need for more emphasis on BMP maintenance in order to meet permitting and reporting requirements. The purpose of this paper is to advance short and long-term maintenance considerations so as to develop more realistic maintenance plans. To do so, we conducted a national literature search for maintenance costs and developed, distributed, analyzed the results of a detailed municipal public works survey.

The specific goals of the survey were to identify and inventory stormwater BMP O&M efforts and costs. Survey questionnaires were sent to 106 cities with 28 responses received. The survey related to the following topics: number of BMPs in the city, frequency of BMP inspections, average staff-hours spent per routine inspection/maintenance, complexity of BMP maintenance, most frequent causes of performance deterioration within BMPs, and cost of non-routine maintenance activities.

The results of the survey revealed that most (89%) cities perform routine maintenance once per year or less. Staff-hours per year ranged from one to four hours for most stormwater BMPs and but were significantly more for rain gardens (one to sixteen hours per year) and wetlands (one to nine hours per year). The most common causes of performance deterioration were sediment buildup and litter/debris for most stormwater BMPs. Respondents indicated that the removal of accumulated sediment incurred the largest cost of all BMP maintenance activities.

SURVEY RESULTS AND DISCUSSION

Inspection Frequency

As listed in Table 1, the majority (89%) of cities conduct routine maintenance actions once a year or less. Inspection frequency varies significantly due to stormwater BMP accessibility and management strategy (proactive vs. reactive).

Table 1: Frequency of routine inspection and maintenance activities.

Stormwater BMP Type	Number of Responses (n)	Less than once	Once per year	Twice per year	More than twice
		Percentage of Responses			
Wet Ponds	27	52%	44%	0%	4%
Dry Ponds	23	52%	48%	0%	0%
Constructed Wetlands	16	38%	56%	6%	0%
Surface Sand or Soil Filter	9	67%	33%	0%	0%
Infiltration Basins or Trenches	17	18%	76%	0%	6%
Rain Gardens	19	21%	42%	16%	21%
Porous Pavements	12	25%	50%	8%	17%
Filter Strips or Swales	12	58%	33%	0%	8%
Underground Sedimentation Devices	16	13%	56%	31%	0%
Underground Filtration Devices	9	44%	56%	0%	0%
Average		**39%**	**50%**	**6%**	**6%**

Staff Hours

For most stormwater BMPs, staff-hours per activity range from 1 to 4 hours as listed in Table 2. Constructed wetlands and rain gardens may require more staff-hours (typically between 1 and 16 hours) for inspection and maintenance because vegetation management can be significant in these practices.

Table 2: Staff-hours spent on routine maintenance actions.

Stormwater BMP Type	Number of Responses (n)	Staff-hours				
		Max.	75th %tile	Median	25th %tile	Min.
Wet Ponds	24	120	3.5	2	1	0.5
Dry Ponds	19	5	2	1	0.5	0.5
Constructed Wetlands	14	60	9.5	1.5	1	0
Surface Sand or Soil Filter	7	3	2	1	0.5	0.5
Infiltration Basins or Trenches	17	60	2	1	0.5	0.5
Rain Gardens	13	80	16	1	1	0.5
Porous Pavements	9	6	4	2	1	0.5
Filter Strips or Swales	11	30	1.75	1	0.5	0.5
Underground Sedimentation Devices	14	360	3	1.25	1	0.5
Underground Filtration Devices	7	5	3.5	1	0.75	0.5

Maintenance Complexity

For most stormwater BMP types, most respondents indicated that maintenance was minimal or simple (i.e., stormwater professional is occasionally needed), as listed in Table 3. Maintenance was viewed as moderate to complex most often for constructed wetlands (47%) and porous pavements (46%). Porous pavements are a fairly new technology, which may explain the more frequent requirement for evaluation by stormwater professionals.

Table 3: Complexity of maintenance activities.

Stormwater BMP Type	Number of Responses (n)	Maintenance Complexity*			
		Min.	Simple	Mod.	Comp.
Wet Ponds	23	57%	30%	4%	9%
Dry Ponds	21	67%	29%	0%	5%
Constructed Wetlands	15	40%	13%	40%	7%
Surface Sand or Soil Filter	8	63%	0%	25%	13%
Infiltration Basins or Trenches	15	33%	40%	13%	13%
Rain Gardens	17	41%	29%	12%	18%
Porous Pavements	13	46%	8%	38%	8%
Filter Strips or Swales	13	62%	31%	0%	8%
Underground Sedimentation Devices	15	40%	33%	7%	20%
Underground Filtration Devices	10	50%	20%	10%	20%

*Maintenance Complexity is defined as:
Minimal - stormwater professional or consultant is seldom needed
Simple - stormwater professional or consultant is occasionally needed
Moderate - stormwater professional or consultant is needed about half the time
Complicated - stormwater professional or consultant is always needed.

Factors reducing stormwater BMP performance

Sediment buildup and litter & debris accumulation were reported as the most frequent factor reducing performance for most stormwater BMPs and possible factors, as listed in Table 4. Pipe clogging was reported frequently for wet ponds and dry ponds while invasive vegetation was reported frequently for dry ponds, constructed wetlands, rain gardens, filter strips, and swales.

Table 4: Percentage of respondents who indicated the factors listed most frequently for causing deterioration of stormwater BMP performance.

	Number of Responses	Sediment buildup	Litter & Debris	Pipe Clogging	Invasive vegetation	Bank erosion	Groundwater level	Structural problems	Oil spill	Mechanical problems
Wet Ponds	90	26%	19%	21%	10%	11%	7%	7%	0%	0%
Dry Ponds	49	24%	31%	18%	16%	8%	2%	0%	0%	0%
Constructed Wetlands	37	24%	19%	14%	22%	11%	8%	3%	0%	0%
Surface Sand or Soil Filter	10	50%	30%	10%	0%	0%	0%	0%	10%	0%
Infiltration Basins or Trenches	39	36%	21%	10%	5%	5%	13%	5%	3%	3%
Rain Gardens	27	33%	22%	7%	26%	0%	7%	0%	4%	0%
Porous Pavements	9	67%	11%	11%	0%	0%	0%	0%	11%	0%
Filter Strips or Swales	19	21%	26%	5%	26%	11%	5%	5%	0%	0%
Underground Sedimentation Devices	19	58%	21%	11%	0%	0%	5%	5%	0%	0%
Underground Filtration Devices	8	50%	25%	13%	0%	0%	13%	0%	0%	0%

Maintenance Cost

Maintenance for sediment removal, converted to an annual cost, was the most reported and costly maintenance activity. There was also considerable variation in the maintenance costs, as illustrated in Figure 1 for sediment removal. The highest median sediment removal costs were for porous pavement ($1,700/yr) and underground sedimentation devices ($1,000/yr).

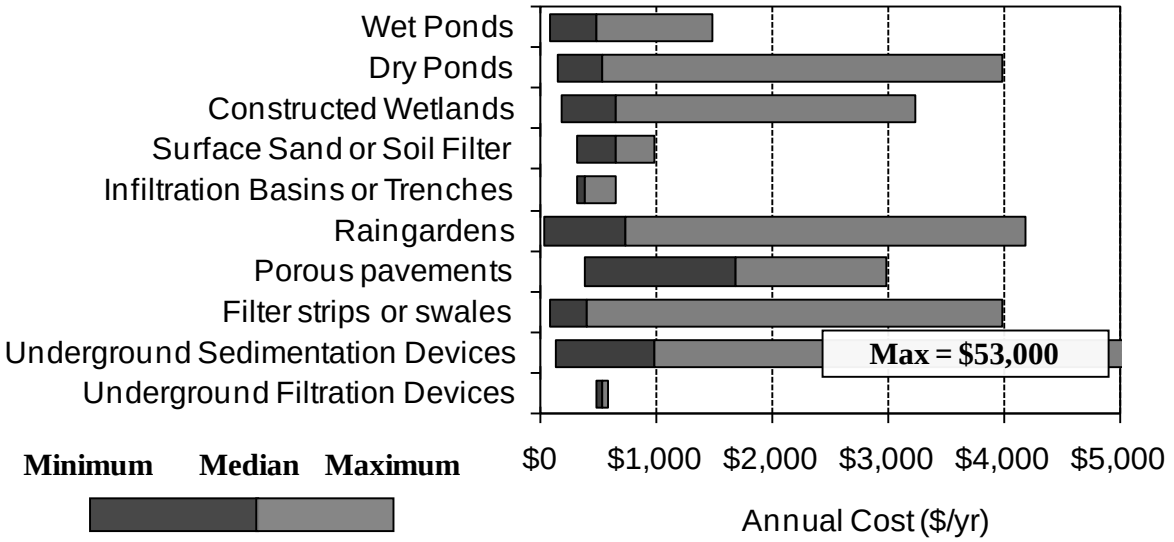

Figure 1: Annual cost of sediment removal for stormwater BMPs

LITERATURE REVIEW ON MAINTENANCE COST

Cost estimates of annual maintenance expenses as a function of construction costs were developed from published literature for dry ponds, wet ponds, constructed wetlands, rain gardens, sand filters, and grassed/vegetative swales (Weiss et al., 2005). These values are compared to U.S. Environmental Protection Agency (USEPA, 1999) expected values as listed in Table 5. Operation and maintenance costs are a substantial portion of life-cycle stormwater BMP costs (Weiss et al., 2005).

Table 5: Expected (USEPA, 1999) and reported (Weiss et al., 2005) annual maintenance cost as a percent of total construction cost for several stormwater BMPs.

Practice	USEPA (1999)	Weiss et al. (2005)
Sand Filters	11% -13%	0.9% - 9.5%
Infiltration Trenches	5% - 20%	5.1% – 126%
Infiltration Basins	1% - 10%	2.8% - 4.9%
Wet Ponds	Not reported	1.9% - 10.2%
Dry Ponds	<1%	1.8% - 2.7%
Rain Gardens	5% - 7%	0.7% - 10.9%
Constructed Wetlands	0.02	4% - 14.2%
Swales	5% - 7%	4% - 178%
Filter Strips	$320/Acre (maintained)	-

CONCLUSIONS

Many communities are struggling to define stormwater BMP maintenance needs without readily available guidelines. As a step towards providing this information, a survey of cities was conducted to quantify the frequency of inspection, level of effort needed for routine maintenance, stormwater BMP deterioration factors, and maintenance complexity. In addition, a nationwide literature review was conducted to estimate maintenance costs for stormwater BMPs.

The results of the survey revealed that most (89%) cities perform routine maintenance once per year or less. The most common causes of performance deterioration were sediment buildup and litter/debris for most stormwater BMPs. Sediment removal is the most costly maintenance activity reported for all stormwater BMPs.

The nationwide literature review resulted in predictive equations for maintenance cost of stormwater BMPs as a function of total construction cost. Maintenance cost is also shown to be a substantial portion of life-cycle cost for all stormwater BMPs and requires serious consideration. As a general rule-of-thumb, mainteannce cost for stormwater BMPs will roughly equal the construction cost (in constant dollars) after 10 years for a $10,000 installation and 20 years for a $100,000 installation (2005 dollars).

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For additional information see:
http://www.safl.umn.edu/research/stormwater.html.

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