Physical Assessment of Selected Rain Gardens in Fairfax County, Virginia

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Northern Virginia Soil and Water Conservation District

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Cover:
At first glance, the cover is a picture of a beautiful rain garden. However, the perforated pipe prevents the rain garden to function as expected.

Introduction and Abstract

The use of rain gardens as a component of the overall stormwater management system on newly developed construction sites is a relatively new phenomenon. To justify and promote such use, monitoring of existing rain gardens to assess operational standards is very important. At present, most of such monitoring is concentrated on the chemical performance of these facilities and is based on the analysis of pollutants coming into the rain garden in stormwater and exiting the rain garden through the under drain system. What is missing is adequate monitoring of the physical performance of rain gardens years after the initial installation. Rain gardens function by providing adequate infiltration capacity to allow the incoming runoff to pass through the filter medium inside within a reasonable amount of time. The physical performance of the filter medium might change with time and therefore affect the rain garden's ability to function as a stormwater Best Management Practice (BMP). The main objectives of this study are to determine the infiltration capacity; the relation that capacity has to other physical properties of the filter media such as soil texture, organic matter content, and bulk density; and the compatibility of the actual facilities with the original approved design specifications. In addition, chemical properties of the filter media are also examined to determine the type and level of pollutants retained in the rain gardens and the relationship of those measurements to the land use of the areas draining to the rain gardens.

Rain gardens chosen for this study have been selected randomly among areas within Fairfax County, Virginia. All the rain gardens are designed and built as BMP facilities to provide the water quality improvement requirements of the developments where they are located. To protect the privacy of cooperating landowners, the rain gardens surveyed for this study are designated RG-1 (Rain Garden 1) through RG-20. Nineteen of the rain gardens have an operating age of two to seven years, while the twentieth rain garden was installed in late 2006. Some of the rain gardens are publicly maintained and some are privately maintained. As part of the assessment of each site, soil infiltration capacity, texture, organic matter content, bulk density, nutrient content, and toxicity were measured. Furthermore, each site was surveyed to determine the surface area, ponding depth, planting soil depth and the general state of the facility.

A variety of problems were found with the examined rain gardens. Three of the examined rain gardens failed infiltration tests (had infiltration rates of 0 inches/hour). The failures were due to soil textures in parts of the facilities that deviated far from applicable standards, poor soil structure, and, in one case, the lack of an under drain. More than half of the sites did not have adequate ponding depths. A few sites had smaller surface areas and a few did not meet the planting soil depths mandated in their original designs.

Despite the failure of three sites, most rain gardens had adequate infiltration capacities despite having soil textures that deviated in varying degrees from accepted standards. All soils had more clay, most had less sand, and a large minority had more silt than the levels allowed by the Virginia Stormwater Handbook or Fairfax County Public Facilities Manual (PFM) standard soil mixes. Analysis of the results indicates that a soil mix close

to current standards but allowing slightly less sand, slightly more silt, and significantly more clay is adequate for rain gardens.

Heavy metals were being retained in the rain garden soil at high levels, while nutrients were being retained at low levels. This was expected as the sampled sites were draining areas of impervious material. Runoff from impervious surfaces contains high levels of heavy metals and low levels of nutrients. The heavy metal contents of the rain garden soils were not close to toxic levels.

Other miscellaneous problems were encountered. Some sites had poorly graded inlets which would allow most runoff to bypass the rain garden. Other sites had perforated monitor wells that negated any surface ponding. Several sites had un-approved modifications that quickened draw down time and lessened stormwater filtering.

Publicly maintained rain gardens had fewer design and operating problems than privately maintained rain gardens. Publicly maintained sites generally adhered closer to original designs and were better maintained than sites on private land. More funding and oversight of publicly maintained rain gardens may be responsible for their better performance.

Common problems with the physical design of rain gardens indicate that more construction oversight and training is needed for the builders and inspectors of such facilities. A training regimen to certify contractors and site inspectors may eliminate many of the design problems encountered in the study. Training of private landowners responsible for the maintenance of rain gardens on their property may help to improve the long term care and operational efficiency of the facilities.

This study was supported with funding from the Environmental Protection Agency's Chesapeake Bay Program through the Virginia Department of Conservation and Recreation.

Methodology

Twenty rain garden sites in Fairfax County were chosen to best represent the range of locations and maintenance of older bioretention facilities in the county. To sample the range of locations, the sites were geographically dispersed so as to account for the broad range of natural underlying soils in the county. The drainage areas of the individual sites were also varied to represent the types of runoff that drain to bioretention facilities. The selected sites captured runoff from three types of landscapes:

- 100% vehicle blacktop (parking lots, driveways, roadways).
- A mix of rooftop and grassed land.
- A mix of vehicle blacktop, rooftop and grassed land.

To account for the range in maintenance, both publicly and privately maintained rain gardens were sampled. Publicly maintained rain gardens were sampled at recreation centers, government offices, fire and police stations, and public gardens. Privately maintained rain gardens were sampled at churches, office buildings, and private homes.

All the rain gardens, with the exception of one, were 2-7 years old. The one exception was a rain garden installed in the winter of 2006 which began to permanently pond water immediately after its installation.

At each of the study sites, a full profile of the engineered soil medium was taken, using a two inch bucket augur, and described. The area of the rain garden was calculated, and if it appeared that adequate ponding depths were not provided, the cross section and longitudinal profile of the site were surveyed. All other notable physical features—including the state of inlets and outlets, presence of erosion, condition and types of planting, etc—were recorded. A constant head infiltration test was performed using a double ring infiltrometer attached to two Marriott tubes (Fig. 1). Soil samples were taken at a depth of approximately ten inches using a two-inch bucket augur. Where a strong organic-rich surface layer or a layer with clearly higher clay or silt content than the rest of the engineered soil existed, a second soil sample was collected from it using the same method. All soil samples were sent to A&L Eastern Laboratories in Richmond for analysis. Particle size analysis was performed on the samples and their texture was determined. Total organic matter was measured by combustion. Phosphorous, potassium, copper, and zinc were measured using the Mehlich 3 extraction solution. Total lead content was measured using nitric acid digestion and ICP Emission. Nitrate nitrogen was measured using potassium chloride solution.

Three undisturbed density samples were obtained from each site. The density samples were taken with a slide hammer just below the organic-rich surface layer (where it existed) and stored in aluminum cylinders with plastic caps. The samples were sent to the lab and the undisturbed (field state) bulk density was calculated for each.

Original blue prints for the study sites were obtained and compared to data from the field and lab. The measured infiltration rate; depth, texture and organic matter content of the

Fig 1: In-situ measurements of soil physical properties

engineered soil; area, ponding depth, planting, and all other relevant physical attributes of each rain garden were compared to the original specifications in the blue prints.

The laboratory measurements of phosphorous, potassium, copper, zinc, lead and nitrate were examined to see if the rain gardens were accumulating potentially problematic levels of nutrients or heavy metals.

The undisturbed bulk density measurements were compared to the soil texture to see if compaction had occurred during construction or operation of the rain gardens.

Results and Discussions

1. Evaluation of the physical performance of individual rain gardens

The physical properties of planting media as measured in this study include in-situ measurements of infiltration rates, laboratory measurements of the bulk density of undisturbed soil samples, and particle size analysis. Results of these measurements are presented in Table 1 and will be discussed below.

1.1 Infiltration rate

In this study, the most relevant test related to the physical performance of the rain gardens was the infiltration test. Failure to infiltrate water negates the function of the rain garden. Among the twenty rain gardens that were investigated, three rain gardens failed infiltration testing. Two rain gardens, RG-2 and RG-10, showed zero infiltration during infiltrometer tests conducted over several hours. A third rain garden, RG-4, had water ponding on top from rainfall days earlier. This precluded an infiltration test but indicated that the infiltration rate was zero. A fourth rain garden, RG-12, was ponded over two thirds of its surface, but an infiltration test was performed on the dry portion and the results were good. This suggests that the ponding at RG-12 might be due to another problem such as a malfunctioning under-drain. The infiltration rates for the remaining sixteen rain gardens were 0.47 inches/hour and higher.

1.2 Soil particle size analysis and organic matter

The characteristics most closely linked with infiltration in rain gardens are planting soil texture (% sand, silt, clay) and organic matter content. The planting media in rain gardens is engineered, meaning sand, topsoil and compost are mixed in specific proportions. In Fairfax County, two textural standards have applied in recent years; that proposed by the Virginia Stormwater Management Handbook - Volume 1, Edition 1, and that proposed by the current Fairfax County Public Facilities Manual (PFM), Chapter 6, Section 6-1307 . The Virginia Stormwater Handbook was published in 1999 and based on Prince George's County, MD standards. The recommendations within it were not legally binding. The amendments to the Fairfax County PFM standards were adopted by the County in 2007. The plans for nearly all the examined rain gardens were submitted and approved when the Virginia Stormwater Handbook represented the current standards in bioretention design, and all plans for sites investigated in this study were approved before adoption of the new amendments to the PFM. Comparisons to the Virginia Stormwater Handbook and PFM are made simply to show how closely the surveyed rain gardens adhered to both the widely accepted standards of the time at which they were built and the present county codes.

The Virginia Stormwater Handbook standard states that the rain garden planting soil must consist of 50% sand, 30% topsoil and 20% organic compost by volume. The topsoil must consist of loamy sand, sandy loam or loam with less than 5% clay. The current Fairfax County PFM codes require the planting soil to consist of 60-75% sand, 10-35% top soil, and 5-15% organic compost by volume. The topsoil must be in the silt loam, loam, sandy loam, or loamy sand textural classes and have less than 8% clay. Laboratory particle size

Table 1: Physical properties of Individual rain gardens

Site Code	Remarks	**Sand** (%) (dry weight)	**Silt** (%) (dry weight)	**Clay** (%) (dry weight)	Soil texture	Organic matter (%)	Bulk Density (g/cm^3)	Infiltration Rate (in/hour)
RG-1		79.00	12.00	9.00	Loamy Sand	3.8	1.87	8.59
RG-2	Thin silty layer	17.00	59.00	24.00	Silt Loam	1.4		0.00
	Rest of garden	57.00	25.00	18.00	Sandy Loam	1.4	1.32	
RG-3		84.00	12.00	4.00	Loamy Sand	4.4	1.43	4.35
RG-4	0.00 to 15.00"	74.00	16.00	10.00	Sandy Loam	5.7	No data	0.00
	Below 15.00"	48.00	28.00	24.00	Sandy Clay Loam	NA		
RG-5		47.00	34.00	19.00	Loam	5.5	1.73	8.24
RG-6		43.00	32.00	25.00	Loam	2	2.10	13.67
RG-7		76.00	18.00	6.00	Loamy Sand	2.4	1.57	6.37
RG-8		73.00	18.00	9.00	Sandy Loam	5	1.22	14.72
RG-9		71.00	19.00	10.00	Sandy Loam	1.1	1.40	3.23
RG-10		43.00	35.00	22.00	Loam	1.3	1.65	0.00
RG-11		77.00	13.00	10.00	Sandy Loam	4.7	1.29	-
RG-12		83.00	12.00	5.00	Loamy Sand	4.7	1.43	0.96
RG-13		49.00	28.00	23.00	Sandy Clay Loam	2.7	2.06	4.64, 9.55
RG-14		75.00	17.00	8.00	Sandy Loam	3.5	1.23	5.43, 9.18
RG-15		72.00	22.00	6.00	Sandy Loam	10	0.84	9.04
RG-16		47.00	35.00	18.00	Loam	1.7	1.50	9.21
RG-17		75.00	11.00	14.00	Sandy Loam	2	1.57	0.47
RG-18		67.00	21.00	12.00	Sandy Loam	4.2	1.77	4.64
RG-19		57.00	25.00	18.00	Sandy Loam	3.2	1.59	0.79
RG-20						4.7		

analysis results are reported as percentages of dry weight and exclude organic matter, so the two standards were converted to weight to allow for direct comparison to the field measurements. The comparisons are found on the Soil mix table in Table 2.

Table 2: Standard soil mix according to Virginia SWM Handbook and Fairfax County PFM

Virginia SWM Handbook mandated mix			PFM mandated mix		
Mineral particles size distribution	Sand	≥81%	Mineral particles size distribution	Sand	≥71%
	Silt	≤17%		Silt	≤26%
	Clay	≤2%		Clay	≤3%
Organic matter		≥1.5%	Organic matter		≥1.5%

None of the rain gardens sampled met all of the Stormwater Handbook's planting soil requirements but most of them had a more than adequate infiltration rate. For every site, clay content was above the maximum; seventeen sites had too little sand; twelve sites had too much silt; and three sites had too little organic matter (Table 1). For the PFM, all sites had too much clay; eight sites had too little sand; seven sites had too much silt; and three sites had too little organic matter. However, non-compliance with Stormwater Handbook or PFM requirements had little effect on the infiltration capacities of most rain gardens considering that only three sites failed infiltration tests.

Compared to the other rain gardens, the three failed sites contained soil that deviated further from the Stormwater Handbook and PFM requirements than most. RG-2 consisted mostly of sandy loam, but a pervasive thin layer of silt loam (17% sand, 59% silt, 24% clay) was found at the surface. The silt loam layer had strong platy texture and would likely have very slow infiltration. RG-4 also had good sandy loam planting soil, but the depth of the planting soil was only 15". The unaltered soil below consisted of sandy clay loam (48% sand, 28% silt, 24% clay), was highly dense and likely contained shrinking-swelling clays and very little organic matter. Since the rain garden was equipped with neither an under-drain nor a gravel filter, water perched on top of the subsoil and saturated the rain garden. RG-10 appeared to consist of mixed natural soil with little or no sand or compost added. The texture was loam and, the organic matter content was low.

Some clear patterns do exist between the rain gardens that failed infiltration tests and those that did not. With the exception of the organic matter content of RG-4, the failed sites missed all of the requirements of the Stormwater Handbook and PFM standards. An organic matter test was only performed for the planting soil of RG-4. Had the subsoil below 15" been tested, it likely would have had insufficient organic matter to meet either standard. Of the sites with adequate infiltration, only one site failed to attain any of the Stormwater Handbook requirements, while all attained at least one of the PFM requirements. As shown in the Table 3, the clay and silt contents of the failed sites were significantly higher, and the sand and organic matter contents were significantly lower

Table 3: Comparison between the texture and organic matter (OM) content of individual sites and standardized soil mixes

Site Code	Measured Texture (dry weight)			Measured Organic Matter	Δ Between Measured and Stormwater Handbook Textures & OM (by percentage points)				Δ Between Measured and PFM Textures & OM (by percentage points)			
	Sand (%)	Silt (%)	Clay (%)	% of total weight	ΔSand	ΔSilt	ΔClay	ΔOM	ΔSand	ΔSilt	ΔClay	ΔOM
RG-1	79	12	9	3.8	-2	-5	7	2.3	8	-14	6	2.3
RG-2	17	59	24	1.4	-64	42	22	-0.1	-54	33	21	-0.1
	57	25	18	1.4	-24	8	16	-0.1	-14	-1	15	-0.1
RG-3	84	12	4	4.4	3	-5	2	2.9	13	-14	1	2.9
RG-4	74	16	10	5.7	-7	-1	8	4.2	3	-10	7	4.2
	48	28	24	NA	-33	11	22		-23	2	21	
RG-5	47	34	19	5.5	-34	17	17	4	-24	8	16	4
RG-6	43	32	25	2	-38	15	23	0.5	-28	6	22	0.5
RG-7	76	18	6	2.4	-5	1	4	0.9	5	-8	3	0.9
RG-8	73	18	9	5	-8	1	7	3.5	2	-8	6	3.5
RG-9	71	19	10	1.1	-10	2	8	-0.4	0	-7	7	-0.4
RG-10	43	35	22	1.3	-38	18	20	-0.2	-28	9	19	-0.2
RG-11	77	13	10	4.7	-4	-4	8	3.2	6	-13	7	3.2
RG-12	83	12	5	4.7	2	-5	3	3.2	12	-14	2	3.2
RG-13	49	28	23	2.7	-32	11	21	1.2	-22	2	20	1.2
RG-14	75	17	8	3.5	-6	0	6	2	4	-9	5	2
RG-15	72	22	6	10	-9	5	4	8.5	1	-4	3	8.5
RG-16	47	35	18	1.7	-34	18	16	0.2	-24	9	15	0.2
RG-17	75	11	14	2	-6	-6	12	0.5	4	-15	11	0.5
EG-18	67	21	12	4.2	-14	4	10	2.7	-4	-5	9	2.7
RG-19	57	25	18	3.2	-24	8	16	1.7	-14	-1	15	1.7
RG-20	89	8	3	4.7	8	-9	1	3.2	18	-18	0	3.2
	64	**23**	**14**	**3.7**	**-21**	**12**	**12**	**-0.2**	**-24**	**10**	**12**	**-0.2**
	Total Averages				**Average of Non-Attainers**							

than the average for all sites. The differences between the two standardized sand, silt and clay percentages and the measured percentages in the failed sites was also much higher than the average difference for all non-attaining sites. However, other sites that performed well on their infiltration tests had soil mix data similar to those of the failed sites. For instance, RG-6 had a very similar sand and silt content and a slightly higher clay content than RG-4 and RG-10, but its infiltration rate was 13.7inches/hr. The soil mix is certainly important—almost certainly the prime determinant of whether a rain garden infiltrates or not—but it does not seem to be the only factor.

1.3 Soil Structure

One of the additional factors that may determine whether a rain garden passes an infiltration test is its structure. Structure refers to the way that soil particles are physically put together. A well structured soil has lots of pore space, and much of the pore space consists of macropores – pores large enough to allow for the quick passage of water and air. Higher sand content increases macroporosity, as does organic matter. Sand particles are large, and therefore the pore space between particles tends also to be large. Organic matter increases macroporosity by causing the clumping of surrounding soil particles into small aggregates with macropores between them. Aside from extrapolating from particle size analysis and organic matter tests, structure can also be measured by measuring bulk density or visually examining the soils.

As stated before, the failed rain gardens did have less sand and organic matter than the averages for all sites. This suggests that the structure of the failed gardens was poor compared to the average, but other rain gardens that had similar soil mix data infiltrated water very well. The average bulk density of a soil varies according to its texture, so direct comparisons cannot often be made from one soil to another. However, general ideal and compacted densities are well known for each textural type. Bulk density tests revealed no clear patterns between the failed and functioning sites. RG4, one of the failed sites, could not be tested for bulk density as it was constantly underwater. Nine sites were compacted beyond the ideal, but of the nine only one was a failed site – RG10. Three sites were compacted above levels that are considered restrictive to root growth, but none of these were the failed sites. The density tests showed that a high proportion of the sites had soil that was extremely compacted. This led us to believe that the bulk density sampler may have been compacting the soil during sample extraction, thus leaving the value of some of the density measurements questionable.

A visual inspection is a more qualitative way to examine soil structure, but it can be very instructive. Of the three rain gardens that failed to infiltrate, all three appeared to be poorly structured in all or part of the soil. Similar problems were not found with the functioning rain gardens. RG-2 was well structured and textured throughout except for a thin layer of silt loam at the top of the rain garden. The silt loam had a very strong platy structure. Platy structure consists of aggregates that resemble overlapping discs, similar to reptile scales. Soils with this structure have very slow infiltration rates because the water must spread out laterally across the face of each disk before finding the larger pores along the disc's edge. Platy structure is common in compacted soils. Soil compaction in RG-2 might have happened due to the possible use of machinery inside the facility during the construction work. RG-4 had natural soil underlying the rain garden 15" below the surface. This soil, in addition to containing some shrinking-swelling clay, was very dense and poorly structured. It is likely that this soil was highly disturbed during the construction of the buildings, parking lots and sidewalks found at the site. When disturbed by heavy machinery, the naturally occurring soil layers are mixed together and the natural structure is obliterated. The soil is laid back down and compacted to create a strong base for foundations. This system works well for construction, but is highly impaired when it comes to infiltrating rainwater.

The soil at RG-10 appeared to be crusted on the surface. Crusting occurs when the surface soil is bare and directly exposed to the force of rainfall or runoff. Rain drops and fast runoff carry enough force to break down the soil aggregates into their individual particles of sand, silt and clay. The loose soil particles and moisture create a muddy slurry on the surface that clogs pores and hardens into a brittle crust when dry. This crust can prevent future infiltration.

From the textural and organic matter findings, the fact that 16 out of 20 rain gardens investigated, despite not conforming to the established planting soil standards, had adequate infiltration rates is an important conclusion. In recent years there has been a tendency to gradually increase the sand portion of the soil mixture at the expense of finer particles, particularly clay. The main reason for this is the widespread view that finer particles might migrate downwards and eventually clog the system. This study shows that this hypothesis is not entirely correct. The texture of the planting soil in rain gardens RG-5, RG-6, RG-13 and RG-16 was loam or sandy clay loam with clay contents ranging from 18% to 25% and a sand content less than 49%, yet all had high infiltration rates. On the other hand, the three sites that failed infiltration tests (RG-2, RG-4, RG-10) had planting soil textures of loam, sandy clay loam or silt loam with clay contents between 22% and 24% and sand contents below 48%. The poor structure of these three rain gardens may account for why they failed to infiltrate and the rain gardens with similar soil mixes did not.

2. Evaluation of the chemical properties of planting media in each individual rain garden

Although the main objective of this study is to assess the physical performance of a number of operating rain gardens, certain soil chemical properties have also been measured and analyzed. A properly functioning rain garden will remove large portions of the suspended and dissolved metals and nutrients traveling in runoff before releasing the filtered runoff into the underlying natural soil or the under-drain. As a result, nutrients and pollutants should accumulate in the planting soil of the rain garden. A larger than normal concentration of either would indicate that the rain garden is functioning as intended. The accumulation of nutrients and pollutants also raises a concern that, in the long run, the planting soil could become toxic to plants and people. Rain Gardens that drain impervious surfaces tend to accumulate heavy metals such as zinc, copper and lead; but not nutrients. Rain gardens draining areas of lawn or playing fields tend to accumulate nutrients, but not heavy metals. Therefore, the reasons for measuring these chemical properties are to assess the:

- Existing nutrient load of the planting soil within the rain garden.
- Relationship between the dominant nutrient and heavy metal loads in the planting soil and the type of land use within the facility's drainage area.

Results of Chemical measurements are presented in Table 4. The chemical properties analyzed include nitrate, phosphorous, potassium, and heavy metals including lead, copper and zinc. For each chemical, the concentration in parts-per-million (ppm) and a qualitative rating ranging from very low (VL) to very high (VH) are given. With the exception of lead, the measurements represent the amount of the chemical that is plant available, not the total measure. Lead is measured by its total concentration in the soil. Many pollutants and nutrients bind strongly to the surfaces of clay and organic matter and become unavailable to plant uptake. Plant available measurements are therefore lower than total concentrations.

The ratings are for agricultural purposes. A "high" or "very high" rating indicates that any further additions of copper or zinc by fertilizer application will not result in increased crop yields. Conversely, a "low" or "very low" rating means that additions of the nutrients will result in increased yields. There is no direct connection to toxicity, but the ratings can be used to get a general idea of what the rain gardens are removing from stormwater and storing in their planting soil.

2.1 Nitrate, phosphorous, and potassium

Nitrate, phosphorous and potassium were found at generally low levels in the tested rain gardens. Of 29 total soil samples (some sites were sampled more than once), there were 25 low or very low readings for potassium, 24 for phosphorous and 22 for nitrate. This is a clear indication that the type of the land use within the rain gardens' drainage area determines the dominant nutrients (pollutants) within the planting soil. Most of the rain gardens were draining mainly impervious surfaces that would not have been subject to fertilizer application. Two sites, both publicly maintained, did test "high" or "very high" for both nitrate and phosphorous. One site, RG-8, was completely grassed and the other, RG-15, was in a public garden that drained both impervious and pervious surfaces. It is likely that the RG-8 was directly fertilized during routine maintenance to help the grass grow. RG-15 likely received fertilizer in the runoff it drained from the pervious portions of the public garden. No other site tested "high" or "very high" for more than one of the three nutrients.

2.2 Heavy Metals

Soil samples from all of the surveyed rain gardens were tested for lead, copper and zinc. For fifteen of the sampled sites, drainage areas consisted of only impervious surfaces, while the remainder of the drainage areas were mainly impervious but had small inclusions of grassed lawn. Due to the nature of the drainage areas, it was expected that

Table 4: Chemical properties of individual rain gardens

Site Code	OM (%)	Nitrate (ppm)	Phosphorus (ppm)	Potassium (ppm)	Lead (mg/kg)	Copper (ppm)	Zinc (ppm)
RG-1	3.8 (M)	1 (VL)	10 (VL)	37 (VL)	11	1.5 (M)	2.2 (L)
RG-2	1.4 (L)	2 (VL)	10 (VL)	78 (L)	7	2.1 (H)	1.1 (L)
RG-3	3.2 (M)	2 (VL)	214 (VH)	66 (L)	5	1.1 (M)	3.8 (H)
RG-4	5.7 (H)	1 (VL)	18 (L)	76 (L)		0.7 (L)	3.1 (M)
RG-5	5.5 (H)	4 (VL)	15 (L)	70 (L)	25	4.2 (VH)	4.3 (H)
RG-6	2.0 (L)	9 (L)	16 (L)	60 (L)	22	2.5 (H)	7.1 (H)
RG-7	2.4 (L)	3 (VL)	24 (L)	69 (L)	11	1.7 (H)	3.6 (H)
RG-8	5.0 (H)	39 (H)	282 (VH)	63 (L)	14	1.7 (H)	18.3 (VH)
RG-9	1.1 (L)	4 (L)	17 (L)	41 (L)	8	3.3 (VH)	1.6 (L)
RG-10	1.3 (L)	10 (L)	17 (L)	54 (VL)	21	1.7 (H)	2.7 (M)
RG-11	4.7 (M)	17 (M)	43 (M)	80 (L)	13	1.4 (M)	4.6 (H)
RG-12	4.7 (M)	3 (VL)	25 (L)	125 (H)	13	0.7 (L)	4.1 (H)
RG-13	2.7 (M)	7 (L)	6 (VL)	47 (L)	18	4.0 (VH)	6.7 (H)
RG-14	3.5 (M)	2 (VL)	14 (L)	44 (VL)	13	1.1 (M)	3.1 (M)
RG-15	9.9+ (VH)	27 (H)	103 (VH)	96 (L)	17	2.5 (H)	21.4 (VH)
RG-16	3.4 (M)	13 (M)	13 (VL)	46 (VL)	15	3 (H)	3.5 (H)
RG-17	2.0 (L)	3 (VL)	14 (L)	54 (L)	9	1.7 (H)	2.8 (M)
RG-18	3.9 (M)	5 (L)	11 (VL)	75 (L)	<5	2.2 (H)	1.5 (L)
RG-19	1.7 (L)	10 (L)	14 (L)	55 (L)	15	1.4 (M)	0.8 (VL)
RG-20	4.7 (M)	5 (L)	24 (L)	51 (L)	6	1.1 (M)	6.1 (H)

Rating categories:
(VL): Very Low
(L): Low
(M): Medium
(H): High
(VH): Very High

the heavy metal content would be high, and for the most part, the results followed this pattern. Out of the 29 soil samples, 17 zinc readings and 22 copper readings came back as high or very high. Conversely, zinc and copper were rated low or very low 7 times and 2 times respectively. Lead content ranged from <5ppm to 34 ppm. No rating was applied to lead as it is not a plant nutrient.

Despite the higher than normal concentrations of heavy metals in the rain gardens, none of the sites appear to be nearing toxicity. The EPA considers soil to be lead contaminated when it reaches 400ppm in bare soil where children play and 1,200ppm in non-play area bare soil (1). It also is considered safe to eat produce grown in soil with as much as 300ppm lead (2). None of the lead readings for any of the sites approaches these toxic levels.

As for copper and zinc, both are essential plant and human micronutrients. Only in excess do they pose a pollution problem. The preponderance of "very high" or "high" ratings for these two metals sounds alarming, but the ratings are for agricultural purposes, not toxicity. The recommended upper limit for daily human ingestion is 10mg for copper (3) and 40 mg for zinc (4). From the lab results, the highest concentration of copper is 6.3mg/kg and the highest concentration of zinc is 51.1mg/kg. One would have to ingest 1.59 kg of rain garden soil per day to reach the limit for copper intake and 0.78kg per day to reach the limit for zinc intake. Of course, the lab measurements are of plant available zinc and copper. The total amount of these metals is higher, but even if one assumes that the lab measures represent only 10% of the metals that would be absorbed into the system upon ingestion, one would still need to consume 159mg and 78mg of soil per day to induce copper and zinc toxicity. Neither amount seems at all likely.

3. Field survey and observations

As part of this study each individual rain garden was surveyed separately. The main objectives for the survey were to determine the compatibility of the properties of the existing rain gardens with their original designs that were approved by the County, and to assess the present maintenance conditions of the rain gardens. All the rain gardens investigated in this study are designed as BMP (best management practice) facilities. BMP facilities are meant to control the water quality of a specific volume of stormwater runoff. The volume to be treated determines the rain garden's total surface area and ponding depth. The intensity of the treatment determines the depth of the planting soil. The necessary surface area, ponding depth, and planting soil depth are specified in the rain garden's original design. In order to be properly functioning, a rain garden must be compatible with its original design assuming that the original approved design is adequate. Deviation from the original design during construction, or a lack of maintenance which leads to eventual deviation, means that the rain garden is not meeting its mandated volume or water quality requirements. To see if BMP requirements were met, the field survey included:

- Measuring the approximate dimensions of each individual rain garden to determine its existing surface area.

- Preparing a longitudinal profile, and on selected sites, a cross section of the rain garden to determine the ponding depth. This was particularly applied to rain gardens where the overflow from the rain garden was through structures such as drop inlets or pipe outlets.
- Measuring the depth and describing the planting soil profile inside each rain garden.
- Making notes of the existing maintenance conditions and additional features not compatible with the original design of the rain garden.

The comparisons of the field measurements to the original design specifications are presented in Table 5. Analysis and explanation are provided below.

3.1 Ponding depth

The ponding depth on top of the planting soil is one of the most important components of any rain garden, as it strongly affects the volume of runoff that is treated. To avoid having different ponding depths for different rain gardens, the ponding depth is usually designed at 6.0 or 12.0 inches depending on whether the first 0.5 or 1.0 inch of runoff is to be treated. For the rain garden to be able to accommodate the intended volume of runoff, the ponding depth should be greater than or equal to that specified in the original plans.

To determine whether an adequate ponding depth exists, a longitudinal profile of the rain garden was surveyed. The profile measured the ground surface elevations of the rain garden as well as the elevation of the overflow structure. The differences between the ground surface elevations and the overflow elevation are equal to the ponding depth. The measured ponding depth was compared to the specifications on the original design to see if it was adequate.

Based on the analysis of the surveyed profiles, 13 out of the 20 rain gardens did not have the proper ponding depth. In the worst cases almost none or very little ponding was provided at all. This was the case for RG-2, RG-7, RG-10, RG-11, and RG-14, or almost 25% of the sites investigated. In less severe cases, some portions of the rain garden would feature the required ponding depth, while other parts would not (Fig. 2); or all parts of the rain garden would have ponding, but the depth would not be deep enough to satisfy the requirements set forth in the original plans (Fig.3). This is the case for RG-4, RG-8, RG-9, RG-12, RG-15, RG-18, RG-19, and RG-20. In cases where the facility has no ponding depth or the ponding depth is not adequate, smaller storms would not create the volume of runoff necessary to cause surface ponding and outflow through the overflow structure. During these storms, the rain gardens would filter all the runoff that flows into the rain garden. However, during larger storms where ponding does occur, the rain gardens would quickly fill to the level of the overflow. After that point, subsequent runoff entering the rain garden would almost immediately be channeled untreated into the overflow. This is especially true for the facilities with almost no ponding depth. During

Fig. 2: Example of a longitudinal profile of a rain garden (RG-7) showing almost no ponding depth

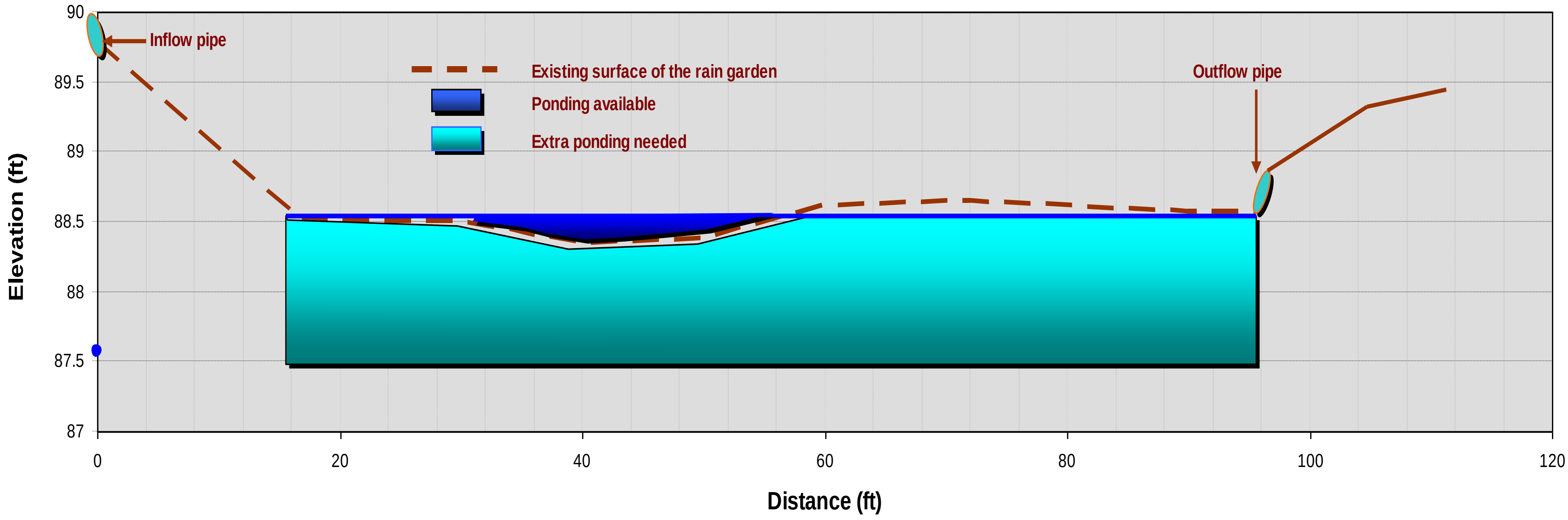
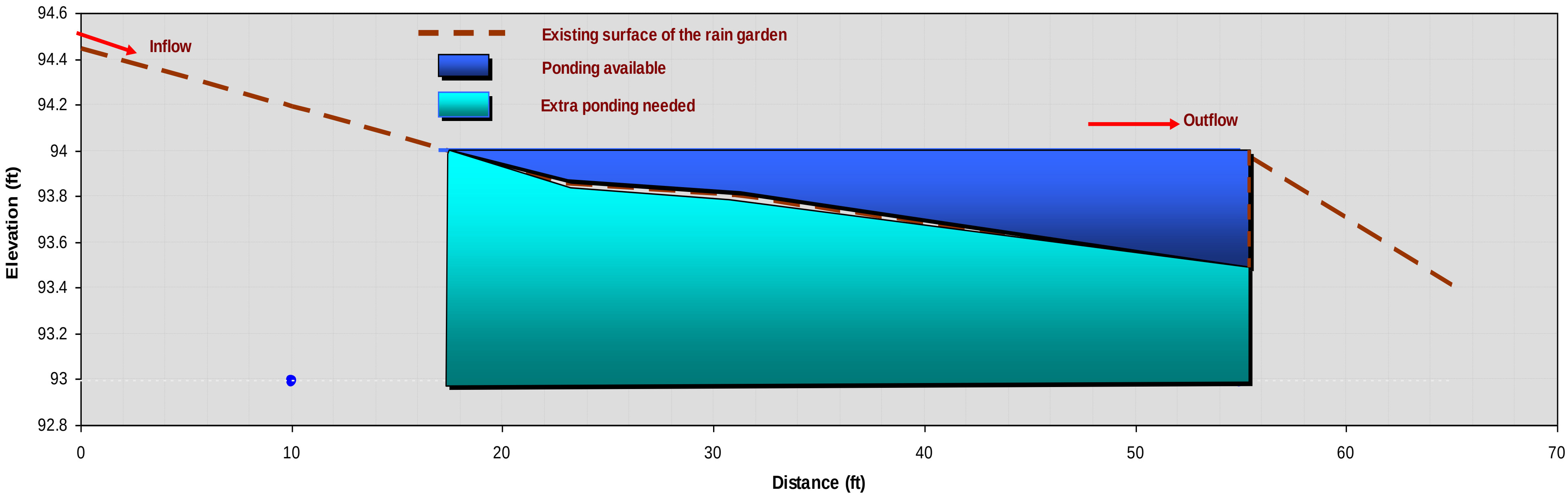


Fig. 3: Example of a longitudinal profile of a rain garden (RG-9) showing inadequate ponding depth



heavy sustained rainfall, the only infiltration and treatment that would occur in these rain gardens would be provided by the small amount of water that could quickly infiltrate into the soil before ponding began to occur.

The reason for inadequate ponding depth can be due to inadequate construction oversight, lack of adequate maintenance, or both.

3.2 Surface area

The surface area for each rain garden was estimated and compared with the original design. The results were generally positive for surface area. Only four sites did not meet their surface area requirements including RG-2, RG-10, RG-11 and RG-17. Several sites were actually larger than originally planned, allowing them to potentially treat a larger volume of runoff than originally designed (Table 5).

3.3 Planting media depth

The depth of the planting soil for each rain garden was measured using a two inch hand auger. Among the 20 sites studied only three - RG-9, RG-16, and RG-17 - did not meet their planting soil depth requirements. Among these sites RG-16 and RG-17 were the worst in that both required 48" of planting soil but provided only 6" and 12" respectively. RG-4 and RG-19 both met their design requirements for soil depth, but the requirements were only 12". All other sites required 30" or more of planting soil (Table 5). The planting soil is responsible for filtering runoff and removing both solid and dissolved nutrients and pollutants. Without the adequate depth, the filtering of the stormwater will be impaired. The Stormwater Handbook suggests and the PFM requires that a rain garden have 2.5 feet of planting soil. The planting media depth not conforming to the facility's original design can be due to inadequate construction oversight.

3.4 Miscellaneous

During the survey, further structural features were identified that would significantly affect the operating efficiency of the rain gardens. For example, RG-11 - a privately maintained facility - had a monitoring well for the under-drain that was perforated (Fig. 4). This allowed the stormwater entering the rain garden or ponding on the surface to bypass the planting soil and flow untreated into the under-drain. It is not clear whether the perforated pipe was part of the original design.

Lack of adequate maintenance was evident at RG-10, a privately maintained facility. Erosion along the embankment is quite evident (Fig. 5). The erosion resulted in the formation of a breach in the berm which provided a path for runoff to exit the rain garden while eliminating nearly all of the designed ponding depth. Evidence of erosion was also found in the planting soil. Large areas of bare soil were evident in the lower lying areas of the rain garden. It appeared that water was preferentially flowing through and eroding the low areas. A surface crust was forming on the bare soil which could affect infiltration (see section 1.3).

Table 5: Comparison between actual field measurements and original design requirements

Site Code	Area (Square Feet)		Ponding Depth (Inches)		Soil Depth (Inches)	
	Design	Actual	Design	Actual	Design	Actual
RG-1	NA	1099.0	NA	>6.0	NA	30.0
RG-2	1997.0	1400.0	6.0	<6.0	36.0	30.0
RG-3	2420.0	2400.0	7.5	≥7.5	30.0	24.0
RG-4	NA	600.0	6.0	<6.0	12.0	15.0
RG-5	2175.0	3000.0	9.0	≥9.0	48.0	56.0
RG-6	2800.0	2800.0	12.0	≥12.0	30.0	30.0
RG-7	2438.0	2500.0	12.0	<12.0	48.0	48.0
RG-8	NA	840.0	NA	<6.0	NA	48.0
RG-9	NA	1100.0	12.0	<12.0	≤30	20.0
RG-10	1753.0	1050.0	8.0	<8.0	36.0	42.0
RG-11	1680.0	600.0	6.0	<6.0	30.0	30.0
RG-12	3920.0	4125.0	6.0	<6.0	36.0	42.0
RG-13	550.0	600.0	6.0	≥6.0	30.0	30.0
RG-14	450.0	470.0	12.0	<12.0	32.0	42.0
RG-15	381.0	3400.0	NA	<6.0	24.0	24.0
RG-16	600.0	1117.0	6.0	≥6.0	48.0	6.0
RG-17	1825.0	825.0	6.0	≥6.0	48.0	12.0
RG-18	2750.0	5200.0	6.0	<6.0	48.0	48.0
RG-19	NA	1750.0	3.8	<3.8	12.0	12.0
RG-20	1450.0	1750.0	12.0	<12.0	≥30	36.0

NA: Not Available

Fig. 4: Example of a perforated observation well (cleaning well) in one of the surveyed rain gardens (RG-11)

Fig. 5: Example of severe erosion at the rain garden's embankment (RG-10)

In rain gardens RG-10 and RG-18 – both privately maintained - columns of pure sand were installed that reached from the soil surface down to the under-drain and gravel storage layer beneath the planting soil. In RG-10, the sand columns surrounded the two monitoring wells and were included in the original design specifications. In RG-18, 15-inch PVC pipes were filled with sand and buried in the rain garden. These sand columns were not part of the original design and appeared to have been installed after completion of the rain garden, perhaps to alleviate excessively long ponding after large storms. At both of these sites, any water that did pond on the rain garden could be quickly infiltrated through the sand columns rather than through the planting soil, thus negating some of the pollutant filtering capacity of the facility.

RG-20, a privately maintained garden, included a relatively large gravel filled forebay in the original plans. The original forebay did not include an observation well. However the existing forebay has a 6-inch perforated observation well. The observation well was connected to the rain garden's under drain system (Fig. 8). Some runoff did flow directly into the rain garden, but the majority of the runoff flowed into the forebay through an 18-inch stormwater pipe. The infiltration capacity and size of the forebay and the porosity of the perforated pipe are such that only the largest storm would cause it to fill and overflow into the rain garden. Thus the rain garden, despite being well designed, was only being used to treat a small fraction of the runoff coming from the site.

Significant changes in the structural components of the surveyed rain gardens have occurred as a result of unapproved additions or physical deterioration resulting from a lack of maintenance. These changes occurred only within the privately maintained rain gardens. In some cases, the additions may have been made after initial construction to address some perceived problem with the functioning of the rain garden. In any event, the rain gardens no longer match their original plans, and as a result do not provide the storm water quality improvements for which they were designed.

Fig. 7: Example of a modified rain garden where ponding area is directly connected to the gravel sump through a sand column

Fig. 8: Example of a modified forebay where a perforated observation well has been added (RG-20)

Conclusions

1. Among the twenty rain gardens investigated in this study - RG-2, RG-4 and RG-10 - or 15% of the total, failed infiltration tests. One other site, RG-12, was constantly ponded but passed infiltration testing. Failure of these rain gardens can be attributed to:

    a. Poor soil mix: Soil textures within parts of all three failed rain gardens were well off the accepted standards of the Virginia Stormwater Handbook and Fairfax County PFM. Compared to the standards, the soils of the failed sites were high in clay and silt and low in sand and organic matter. The structure of the soil was also poor: one site had platy structure, one had surface crusting and one had dense, compacted, clayey subsoil just below the engineered planting soil. The combination of poor soil texture and structure likely caused the lack of infiltration.
    b. Inadequate design: RG-4 featured dense, clayey subsoil just below the engineered planting soil and 12-15" from the surface. The lack of an under drain allowed water to perch on top of the subsoil and saturate the rain garden. The lack of an under drain was also responsible for the initial failure of RG-15. The garden ponded constantly after its initial installation. The site was soon retrofitted with an under drain and the ponding ceased. For RG-12, the presence of geo-textile fabric between the planting soil layer and the gravel filter and wrapped around the under drain is likely responsible for ponding at the site. The geo-textile can become clogged with fine sediments and result in perched water in the planting soil or a blocked under drain.

2. The results of the particle size analysis for almost all rain gardens differed from the standards established by the Virginia Stormwater Management Handbook and the Fairfax County PFM. Nearly all soil samples were higher in clay and lower in sand when compared to the standards, and about half were higher in silt. The only requirement which was routinely met was organic matter content. However the in-situ infiltration, with the exception of the three failed rain gardens, was high and ranged from 0.5 to 20.4 inches per hour. In recent years there has been a push to increase the sand content of the planting soil, sometimes to as high as 80%-90%, at the expense of finer particles such as silt and clay, with the justification that higher percentages of finer particles will gradually migrate within the planting soil and clog the facility. However, the results of this study indicate that a site with a clay content as high as 25% and a sand content as low as 43% by weight (RG-6) can have an infiltration rate of 13.67 inches per hour years after the start of its operation.

3. After analyzing the soil texture, organic matter and infiltration data from all twenty sites, one can informally formulate a suitable rain garden planting soil mix. A soil with decent structure and a sandy loam or sandier texture, 15% or less clay and 25% or less silt should generally be adequate as a rain garden planting

soil. The organic matter content should be above 1.5% of the total weight of the soil. This mix would not satisfy either the Virginia Stormwater Handbook or Fairfax County PFM standards. The sand and silt contents of this mix do not deviate far from the standards, and the organic matter content is the same, but significantly more clay is allowed. Adhering to either standard almost guarantees a functioning rain garden, but it seems that a soil mix that is close to the standards, but not strictly adhering to them, will perform adequately.

A potential problem with adhering to the standard soil mixtures is that with a very high sand content and very low clay content, the nutrient availability to plants inside the rain garden may be low. This is particularly true when the runoff that passes through the rain garden is low in nutrients, as it commonly is for rain gardens draining impervious surfaces. A higher clay content would allow for increased storage of nutrients that enter the rain garden with infiltrating storm water.

4. The study confirms that the type of pollutants within the planting soil is a function of the dominant land use within the rain garden's drainage area. The source of surface runoff for the majority of the rain gardens in this study is impervious surfaces such as parking lots, roads and rooftops. Runoff from impervious surfaces is usually high in heavy metals and low in nutrients. This is confirmed by high to very high concentrations of heavy metals and low to very low concentrations of nutrients in samples of planting soil taken from the rain gardens. In none of the samples was the heavy metal concentration anywhere close to toxic levels for humans or plants. The operating age of the twenty rain gardens investigated is between two and seven years.

5. Fifteen out of the twenty rain gardens had design features which were not compatible with the original plans that were submitted to the County for permits. The ponding depth and the planting soil depth are two of the most important properties that frequently differed from the original plan. A lack of knowledge about the proper form and function of rain gardens by contractors and a lack of sufficient construction oversight by the County are likely responsible for the design errors. In a few cases, inadequate ponding depth could be the result of poor maintenance. Lack of both adequate ponding depth and planting soil depth affects the expected performance of these facilities. Better training of contractors and site inspectors as to the proper design of a rain garden may alleviate many of the design errors. Following the standard maintenance checklists, such as the one included in the Virginia Stormwater Management Handbook, will also help to ensure that the physical condition of the garden does not deteriorate over time.

6. Several rain gardens had physical features that were consistent with their original plans, but these features severely limited the efficiency of the facility. RG-1 had curb inlets that were poorly graded and RG-20 had a large gravel-filled dry well that served as the rain garden's forebay. The result was that most stormwater bypassed the two rain gardens. RG-11 had a perforated monitor well that

prevented surface ponding. In the cases of RG-20 and RG-11, a more intense review of the original plans by the County could have prevented such design errors. For RG-1, better training of the contractors could have eliminated the grading problems.

7. Several of the investigated rain gardens were structurally modified, apparently not in consultation with the County. With the exception of RG-15, all the modified rain gardens are privately maintained. Almost all of the modifications appear to have been done to decrease the length of ponding after a storm. While a maximum draw down duration of 48 hours for rain gardens is acceptable, this may have been considered to be too long by the property owners. Often, a decrease in ponding duration is performed by connecting the ponding area directly to the gravel bed through a sand chamber (RG-18), or perforating the observation well (RG-20). Both of these methods lead to a reduction in the filtering and ponding capacities of the rain garden.

8. Results of this study strongly indicate that the ownership of the rain gardens plays a significant role in the physical performance of the facilities. Publicly maintained rain gardens performed better when compared with privately maintained rain gardens. Publicly maintained facilities likely benefit from having increased oversight during and after construction and higher construction and maintenance budgets. After installation, maintenance crews and other knowledgeable County employees, both on and off-site, can monitor the site and ensure no problems arise. More eyes tend to be trained on pubic sites than private sites. RG-15 provides a good example of this conscientious upkeep. The rain garden failed during installation, but on-site employees immediately installed an under drain that remedied the problem.

   In cases where rain gardens are privately maintained, the neighbors residing around them may be less familiar with the proper BMP design and functioning and may not know who to hire to fix perceived problems. Rain gardens are often thought of as landscaping features, not important stormwater management facilities. As a result, problems in the design or functioning of the rain garden may go unnoticed. On the other hand, proper functioning of the rain garden, such as the ponding of water up to 48 hours after a storm, may be perceived as a malfunction. Landscaping or other companies unfamiliar with rain garden design may be hired to remedy the problems. Efforts to fix the perceived malfunctions (see section 7 above) usually result in a reduction of the rain garden's functioning.

9. In recent years, in order to encourage their use as an effective stormwater management BMP, rain gardens have been promoted as an effective, low tech, low maintenance stormwater management practice. This may have created a mentality that rain gardens are simple structures that require little effort to install and maintain. In reality, rain gardens need to be carefully built and carefully monitored after installation in order to ensure proper performance.

Recommendations

During the last few years the popularity of innovative approaches to site development, such as Low Impact Development (LID), has resulted in the construction of more stormwater management BMP facilities such as rain gardens. More of these facilities are expected to be built in the future because more local jurisdictions are now allowing rain gardens to be used for stormwater detention in addition to conventional BMPs. Based on the conclusions of this study the following recommendations are made to improve and maintain the performance efficiency of rain gardens

1. Improve the construction oversight. Some of the inefficiencies in the performance of rain gardens detected through this study can be contributed to the lack of adequate construction oversight while these facilities are built. This could be mostly due to the lack of site inspectors and contractors familiar with the design and workings of these facilities and the lack of established construction guidelines on how to build these facilities. The following recommendations will help to overcome these construction related problems:

    a. Educate and train site inspectors. It is very important for site inspectors who monitor rain garden construction to understand the significance of these facilities as a stormwater management tool, how they work, and what needs to be inspected during their construction. Regular training by local Departments of Public Works, using industry experts, will help to achieve this goal. A curriculum for these classes needs to be prepared based on the existing needs. Certification will be awarded upon graduation.
    b. Educate the private sector about building and maintaining rain gardens, and if possible, develop a certification program to certify eligible contractors in construction and maintenance of these facilities. The Virginia Department of Conservation and Recreation and qualified local Soil and Water Conservation Districts are in good position to help to develop this program
    c. Develop construction guidelines. The construction guidelines should include the stage during the overall site development when these facilities should be built, how different components of the facility are put in place, and how material quality should be controlled.
    d. Perform post construction inspection. At the end of the construction, before the facility becomes operational, the rain garden should be inspected. Guidelines for post construction inspection should be developed. Facilities that comply with all the post construction inspection guidelines should be certified.

2. Revise the soil mix guidelines. Most of the surveyed rain gardens had adequate infiltration, but none matched the soil textural standards set forth in the Virginia Stormwater Handbook and the Fairfax County PFM. When converted from

volume to weight, the standards reveal themselves to be highly restrictive, especially in terms of the amount of clay allowed. The results of this study show that a less restrictive soil mix with a similar sand and silt content as the two standards, but a significantly higher clay content should be adequate for use in rain gardens.

3. Eliminate the use of geotextile fabric to separate the planting soil from the gravel layer and as a protective wrap around the under drain. The use of geotextile fabric to separate the planting soil media from the gravel filter layer and wrapping the rain garden under drain in geotextile fabric increase the possibility of clogging the facility and should not to be recommended. Instead a 4-6 inch layer of double washed and aggregated pea gravel should act as the transition from the planting soil layer into the underlying gravel filter. Further, instead of wrapping the under drain pipe in geotextile fabric, add a minimum of 4.0 inches of double washed gravel (VDOT # 57) around the pipe to act as the filter.

4. Revise the existing widely promoted post construction maintenance guidelines such as Virginia Stormwater management Handbook table 3.11-6. These guidelines need to be upgraded to cover structural features of the rain gardens in more detail. The present guidelines treat the rain garden simply as a landscape feature and therefore pay a lot of attention to plants and their status without providing guidelines on how to assess the structural performance of the facility. An upgraded maintenance guideline needs to include features such as ponding area and depth, infiltration rate over time, flow patterns within the facility following storms, and others.

5. Educate the owners of privately maintained rain gardens. More and more local jurisdictions transfer the maintenance responsibility of rain gardens to Homeowner Associations (HOA) and private landowners. This often results in unacceptable structural modifications of the facility that results in a reduction of the overall performance or poor maintenance. This is mostly due the fact that homeowners and the private entities that maintain rain gardens are not familiar with purpose and function of these facilities. It would be extremely useful if the local jurisdictions develop a mechanism where - prior to transferring the responsibility of these facilities to private owners - the nature of these facilities, their functions, the maintenance requirements and the owners legal obligations are explained to whomever will be responsible for maintenance. There should be an emphasis that no physical modifications of the facility are allowed unless reviewed and permitted by the local jurisdiction overseeing these facilities.

6. If not already included, revise the existing maintenance agreement between the local jurisdictions and HOAs and homeowners to cover the latter part of recommendation 4.

7. Develop a database of skilled contractors and companies qualified to maintain these facilities in Virginia and surrounding states.

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