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Editorial
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Evolving Bioretentiontechniques for Urban Storm water Treatment

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Urban stormwater running off streets, parking lots, driveways, and construction sites contains various pollutants such as sediment, oil and grease, heavy metals, toxic organic chemicals (e.g., pesticides), nutrients, and pathogens (Table 1) and needs to be treated before discharged to receiving waters [1,2]. Different treatment structures have been employed, including detention ponds, storm water wetlands, sand filters, bioretention cells, and level spreaders (e.g., vegetative filter strips, swales, permeable pavements, and green roofs). Of these storm water best management practices, bioretention is to collect storm water into a vegetated land depression and allow it to infiltrate through the underlying filter layer (typically a mixture of soil, sand, and compost) into the ground. Bioretention removes pollutants from storm water by sedimentation, filtration, sorption, microbial transformation, and plant uptake [3,4]. The more or less constructed land depression is termed "bioretention area", "bioretention cell", or "rain garden." If engineered overflow features such as a weir or under drain pipe are installed, the structure is then called "bioretention basin" or "biofilter" [5].

The bioretention technique was developed in 1992 by the Department of Environmental Resources, Prince George's County, Maryland [3].As illustrated in Figure 1, a bioretention system consists generally of an inflow structure (e.g., swales, pipes, curb openings, gutter downspouts) that collects storm water, a depressive orientation for water ponding, a thin mulch layer on the depression surface, a filter media layer to treat infiltrating storm water, water-tolerant plants growing in the filter media, and optional appurtenances for overflow (e.g., pipe, weir) and outlet (e.g., under drain - perforated pipes in a sand/gravel sump layer underneath the bioretention media).The water ponding zone, the mulch and vegetation zone, the filter zone, and the drainage zone of such a "rain garden" function in combination to reduce runoff, purify storm water, and recharge groundwater.

Although bioretention is not suitable for treatinga large drainage area (e.g., >1 ha) and the treatment structure takes space [3,11], this low impact development (LID) technique has become a most popular stormwater best management practice in the U.S. and is rapidly being adopted by other countries [11].The effectiveness of a bioretention system is, however, influenced by its location, size, water ponding depth, bioretention media composition and thickness, and vegetation. Commonly, a bioretention structure is installed in areas with a slope gradient less than 20% and the high seasonable water table deeper than 1.8 m [3]. A natural soil infiltration (water percolation) rate greater than 6 mm hr^{-1} is desirable and otherwise, engineered soils by mixing on-site soil, sand, and compost are needed to construct the 90-150 cm thick bioretention layer. The water ponding depth should limit to 15-30 cm such that all runoff water is able to infiltrate into the ground within 48 hours after a storm [11]. An overflow pipe connecting to an existing drainage network or a reinforced overflow area is necessary for a bioretention structure, especially for those with disturbed soils. An under drain buried in a gravel bed underneath the bioretention layer is essential if the natural soil infiltration rate is low (e.g., <6 mm hr^{-1}) [12]. This feature, however, may significantly increase the construction cost, which can be largely estimated from the equation

$$C = 249V^{0.99} \quad (1)$$

where C is the permitting, design, and construction cost (US \$) and V is volume (m^3) of water treated by the facility [13]. The stormwater treatment capacity of a bioretention unit is determined by its size, which is typically designed according to the drainage area to be treated. Runoff from a drainage area can be calculated by the equation

$$Runoffdepth(cm) = \frac{(P-0.2S)^2}{P+0.8S} \quad (2)$$

Where P is precipitation of a storm event (typically use 2.54 cm) and S is a coefficient by 1000/CN – 10, where CN is curve number indicating water infiltration extent as related to land cover and soil properties. For impervious surface, CN = 98 [14]. To vegetate a rain garden, native perennial grasses and shrubs that are water-tolerant and provide additional aesthetic benefits should be selected [3,4,12].

Starting from its invention, bioretention has been evolving for improvement in water infiltration and pollutant removal efficiency. The infiltration rate of a bioretention device can maintain for years without significant degradation [15]. If the on-site soil contains more than 30% of clay (e.g., fine loam or heavier texture), mixing with sand and organic materials is necessary to improve the infiltration rate. Prince George's County, MD has recommended a mix consisting by volume of 50% sand, 30% topsoil, and 20% well-aged wood fines or composted leaf mulch. Delaware is using a formula of 1/3 sand, 1/3 peat moss, and 1/3 double-shredded mulch. The filter media specification in North Carolina is 85-88% sand, 8-12% silt and clay, and 3-5% organic material [11]. The performance of a bioretention structure in removing

Pollutants	U.S.	Korea	France	Italy	Australia
TSS, mg L^{-1}	20-2890 (80)	15-1021	49-498	15-377	39
BOD_5, mg L^{-1}	4-14	23-130	15-141	NA	NA
COD, mg L^{-1}	20-275 (40)	45-369	48-964	11-281	NA
NO_3^--N, mg L^{-1}	0.71-1.14	0.14-6.1	NA	NA	0.4
NH_4^+-N, mg L^{-1}	NA	NA	NA	NA	0.04
Kjeldahl N, mg L^{-1}	0.4-20 (2.1)	1.4-23.9	NA	NA	1.1
PO_4^{3-}-P, mg L^{-1}	NA	0.70-6.44	NA	NA	0.01
Total P, mg L^{-1}	0.02-4.3 (0.3)	1.2-10.2	NA	NA	0.07
Pb, µg L^{-1}	10-1200 (15)	10-490	70-520	6-23	6
Zn, µg L^{-1}	10-330 (60)	NA	250-3800	28-124	100
Cu, µg L^{-1}	10-400 (50)	NA	30-190	1-53	10

TSS: total suspended solids; COD: chemical oxygen demand; BOD_5: 5-day biological oxygen demand; NA: data not available

Table 1: Concentrations of pollutants in urban stormwater runoff [2,6-10]. Values in the parentheses represent an average or typical level.

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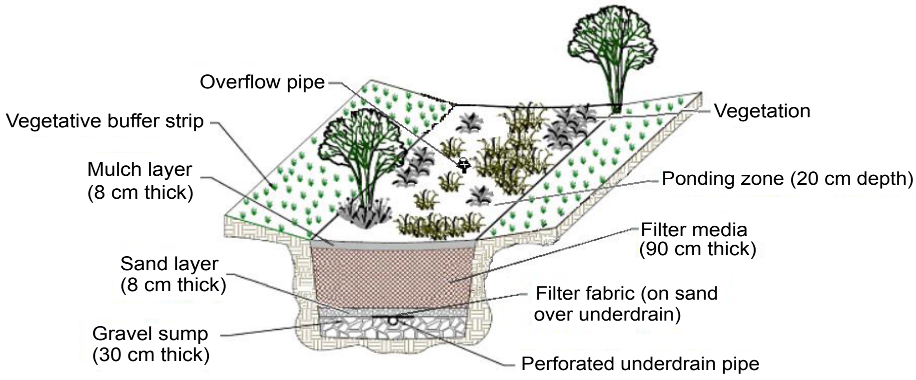

Figure 1: Diagram of a typical bioretention basin (Adopted from VADCR, 2011) [5].

pollutants from storm water, however, is a function of the storm water chemistry and filter media chemistry [16].Through bioretention, 81-98% of the metal ions Cu^{2+}, Pb^{2+}, and Zn^{2+} and more than 90% of the suspended particulates, oil/grease, and bacteria in storm water (Table 1) would be removed [3,17,18]. Nevertheless, nutrient removal through bioretention is widely variable [19]. If bioretention media low in N and P are used and proper vegetation is maintained, 70-83% of the total P, 60-80% of NH_4^+, and 30-70% of the total Kjeldahl N would be removed from storm water [17,20, 21]. Otherwise, a bioretention unit may act as a nutrient source [17,22]. Especially for nitrate (NO_3^-), a generally-designed bioretention unit demonstrates fairly limited purification capacity (e.g., a removal rate as low as 13%) [23]. If an anoxic zone is included at the bottom with 18 mass% chopped newspaper as electron donor, however, a bioretention unit can remove up to 80% NO_3^- mass from the storm water inflow [24].

To improve the performance of a bioretention facility in removing N and dissolved P, specially formulated infiltration media and varied media layering have been tested. U.S. researchers are investigating to use industrial byproducts such as flue gas desulfurization gypsum, drinking water treatment residuals, steel slag, and iron-coated sand to trap dissolved P in runoff water [25]. A variety of cellulose-based organic materials such as wood bark, wood chips, leaf compost, wheat straw, and newspaper were evaluated for promoting N removal from storm water through enhanced denitrification [24]. Primary laboratory studies at University of Delaware indicated that zero-valent iron facilitated reduction of NO_3^- to NH_4^+ under aerobic conditions but to N_2 and N_2O under anaerobic conditions, while wood biochar strongly adsorbed NH_4^+ and therefore, filter media containing biochar and zero-valent iron in specific layer configuration were promising in storm water N removal [26]. Hsieh et al. [27] found that the filter media configuration with a highly permeable layer over a less permeable layer formed an anoxic zone in laboratory bioretention columns and improved NO_3^- removal by denitrification. Further research is warranted to confirm these findings in field bioretention practices.

In addition to filter media composition and configuration, other design parameters including maximum pooling depth, minimum filter media thickness, under drain configuration, and vegetation selection have to be optimized in bioretention practices [11]. Optimization of a bioretention design for desirable infiltration or nutrient removal requires intensive knowledge of the local climate, hydrology, and soil type, as well as financial status. Research-based guidelines with adaption to local conditions should be developed.

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