

Review of Vegetative Biofilter Stormwater Control Measures DR-18-06, January 2018

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Watershed Protection Department
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Introduction

There are three generalized types of vegetative biofilter stormwater control measures that may be used for stormwater management: grass swales, vegetative filter strips and buffers, and bioretention cells. General considerations associated with each type of vegetative biofilter are reviewed in this paper.

Grass Swales

Grass swales, also known as grassed waterways, have traditionally been used as a low cost stormwater conveyance practice in low-to-medium density residential developments (e.g., half acre lots). It is now generally recognized that vegetated grass swales have a number of desirable attributes with respect to total stormwater management (MDE 2000, ASCE 1998, CRC 1996, and Yu 1993). These attributes include:

- 1) slower flow velocities than pipe systems that result in longer time of concentration and corresponding reduction of peak discharge;
- 2) the ability to disconnect directly-connected impervious surfaces such as driveways and roadways, thus reducing the computed runoff curve number (*CN*) and peak discharge;
- 3) filtering of pollutants by grass media;
- 4) infiltration of runoff into the soil profile, thus reducing peak discharges and providing additional pollutant removal; and
- 5) uptake of pollutants by plant roots (phytoremediation).

The dry swale consists of an open channel that has been modified to enhance its water quality treatment capability by adding a filtering medium consisting of a soil bed with an underdrain system (CRC 1996). The dry swale is designed to temporarily store the design water quality volume (V_{wQ}) and allow it to percolate through the treatment medium. The system is designed to drain down between storm events within approximately 24 hours. The water quality treatment mechanisms are similar to bioretention practices except that the pollutant uptake is likely to be more limited since only a grass cover crop is available for nutrient uptake.

The wet swale also consists of a broad open channel capable of temporarily storing the V_{wQ} but does not have an underlying filtering bed (CRC 1996). The wet swale is constructed directly within existing soils and may or may not intercept the water table. Like the dry swale, the V_{wQ} within the wet swale should be stored for approximately 24 hours. The wet swale has water quality treatment mechanisms similar to stormwater wetlands, which rely primarily on settling of suspended solids, adsorption, and uptake of pollutants by vegetative root systems.

Vegetative Filter Strips (VFS)

VFS and buffers are areas of land with vegetative cover that are designed to accept runoff as overland sheet flow from upstream development. They can be constructed or existing vegetated buffer areas can be used. Dense vegetative cover facilitates sediment attenuation and pollutant removal. Unlike grass swales, VFS are effective only for overland sheet flow and provide little treatment for concentrated flows. Grading and level spreaders can be used to create a uniformly sloping area that distributes the runoff evenly across the filter strip (Haan et al. 1994, Hayes et al. 1984, Barfield and Hayes 1988, and Dillaha et al. 1989).

VFS have been used to treat runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They can also be used as the “outer zone” of a stream buffer or as pretreatment to a structural practice. VFS are often used as pretreatment for other structural practices, such as infiltration basins and infiltration trenches, because VFS are most effective when combined with another practice (Magette et al. 1989).

Bioretention

The bioretention concept was originally developed by the Prince George's County (PGC), Maryland, Department of Environmental Resources in the early 1990's as an alternative to traditional stormwater control structures (Clar et al. 1993, 1994). Bioretention is a practice that manages and treats stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. The method combines physical filtering and adsorption with biological processes. The system consists of a flow regulation structure, pretreatment filter strip or grass channel, sand bed, pea gravel overflow curtain drain, shallow ponding area, surface organic layer of mulch, a planting soil bed, plant material, a gravel underdrain system, and an overflow system.

Design Considerations

The general design considerations associated with the use of vegetative biofilter stormwater control measures include design flow volumes and rates, flow regulation, and pretreatment. The filter bed and media considerations, vegetation type and inspection, and maintenance issues are specific to each biofilter type.

The design flow volumes and rates are typically determined by the design objectives for the site. Design objectives can include (Clar et al. 2004):

- 1) traditional use flow conveyance;
- 2) water quality control on small sites or in a treatment system approach;
- 3) reducing the impact of development on the hydrologic regime alterations of a site;

- 4) addressing groundwater recharge concerns;
- 5) reducing impacts to stream channel erosion; and
- 6) controlling peak discharge for the 2-, 10- and 100-yr storms.

Design to Reduce Hydrologic Regime Alterations

An important design objective is to reduce the adverse impact of the hydrologic regime alteration due to the development of a site. Land use change, especially land development activities, may alter the hydrologic regime. The creation of impervious areas, in particular hydraulically-connected impervious areas, can greatly alter the rainfall-runoff relationship relative to pre-development conditions and produce larger volumes of runoff and higher peak discharge rates. Vegetative biofilters such as grass swales incorporated into a rural road design can be used to replace a traditional curb and gutter road section approach. Grassed swales can be used in some development conditions to reduce the amount of impervious surfaces, as well as to disconnect directly connected impervious surfaces.

“Urban Hydrology for Small Watersheds: TR-55” published by the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA 1986) provides convenient procedures that allow the design engineer to readily calculate the potential reduction in runoff volume achieved by reducing the total volume of impervious area. This procedure uses the well-known runoff curve number (*CN*) method. A number of publications (PGC 1997, EPA 2000a, and EPA 2000b) that describe the Low Impact Development (LID) design approach to stormwater management have documented the use of runoff curve number (*CN*) method.

Design to Provide Water Quality Management

Currently, the great majority of local jurisdictions simply require that stormwater control measures be sized to provide peak discharge control of the 2-, 10- and 100-yr storms, and assume that this approach provides an adequate level of water quality management. Vegetative biofilters can be sized based on the volume of runoff to be treated. A number of States in the Mid-Atlantic region, including Maryland (MDE 2000), have adopted a target rainfall event for estimating the design Water Quality Volume (V_{wQ}) for sizing vegetative biofilters. This event targets capturing 90% of the annual runoff volume (90% rule) and is based on the data reported in the literature (Guo and Urbonas 1995, and Urbonas et al. 1990). Some jurisdictions are currently using other sizing guidelines, such as the capture and treatment of the first ½ inch of runoff. This criteria may be acceptable for lower impervious areas but will have decreased pollutant capture efficiencies for a higher impervious areas and a lower capture percentage of the annual runoff volume. Two simple methods, the Short Cut Method and Small Storm Hydrology, can be utilized to estimate V_{wQ} . Both rely on computing a volumetric runoff coefficient (*Rv*) and multiplying this by the rainfall volume to obtain a runoff volume in watershed inches.

The peak rate of discharge is needed for the sizing of off-line diversion structures and to design grass swales. Conventional NRCS methods underestimate the volume and rate of runoff for rainfall events less than 2 inches. This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff bypasses the filtering treatment practice due to an inadequately sized diversion structure, or leads to the design of undersized grass channels.

A procedure that can be used to estimate peak discharges for small storm events was developed by Pitt (1994) and relies on the volume of runoff computed using the Small Storm Hydrology Method and utilizes NRCS TR-55 Graphical Peak Discharge Method. This procedure has been documented (MDE 2000).

Design to Maintain Groundwater Recharge Rate

Groundwater recharge criteria have been developed in some jurisdictions (MDE 2000) to maintain existing groundwater recharge rates at development sites. Maintaining recharge may help to preserve existing water table elevations, thereby maintaining the hydrology of streams and wetlands during dry weather. The volume of recharge (V_{Re}) that occurs on a site depends on slope, soil type, vegetative cover, precipitation, and evapo-transpiration. Sites with natural ground cover such as forest and meadow have higher recharge rates, less runoff, and greater transpiration losses under most conditions. Because development increases impervious surfaces, a net decrease in recharge rates is inevitable. The use of vegetative biofilters to help maintain groundwater recharge is a relatively new design objective and there is little data available on the success of this approach.

Flow Regulation

Vegetative biofilters are all primarily in-line stormwater treatment practices. Typically used as the first stage of the treatment train, their purpose is generally to address groundwater and water quality control for small headwater areas. Wet and dry grass swales can receive runoff from concentrated sources such as pipe outfalls, as well as from lateral sheet flow along the length of the practice. The isolation/diversion structure within the drainage network is the preferred method for diverting concentrated flows prior to entering these treatment practices.

The filter strip, which receives runoff through sheet flow from impervious or pervious surfaces, is most commonly designed as an on-line practice. It may be possible, through site grading and other design techniques, to provide an overflow diversion that bypasses larger flows around the facility. However, since the filter strip drainage area is limited by the flow path, the volume of high flow runoff will not generally be excessive and there should be little need to design the system as an off-line practice.

The bioretention cell can receive runoff through sheet flow from impervious or pervious surfaces and is generally also designed as an on-line practice. It may also be used as a side channel treatment device by diverting the smaller frequent flows from the channel to the treatment facility (Clar et al. 2004).

Pretreatment

Pretreatment can be provided to extend the functional life of a stormwater control measure, as well as to increase the pollutant removal capability. However, pretreatment is not as crucial for this group of practices as with other larger structural control measures or filter practices. The vegetative element incorporated in the design of vegetative biofilters helps to maintain the infiltration capacity of the soil/media elements. Since the control areas are relatively small, the annual loadings of sediment or other solids and floatables also tend to be correspondingly small (Clar et al. 2004).

Design to Reduce Stream Channel Erosion

Historically, State and local regulatory agencies have used peak discharge control of the 2-yr storm as a surrogate for downstream channel protection. The technical inadequacy of this approach was summarized and documented in a number of reports (McCuen et al. 1987) and by field observations (Jones et al. 1997, Maxted and Shaver 1997, and Stribling 2001). Some new initiatives are being undertaken; Maryland's revised approach uses extended detention strategies for the 1-yr storm (MDE 2000).

Vegetative biofilters are typically assumed to be suitable for small storms in terms of groundwater recharge and water quality management, but are typically assumed to not be suitable for larger storm flows that affect channel stability conditions. However, the introduction of new stormwater management technologies, such as low impact development (LID), is demonstrating the ability of biofilters in conjunction with enhanced design approaches to reduce hydrologic flow modifications. Biofilters as LID components may be able to adequately manage the full spectrum of design storms, ranging from small frequent storms to the 100-yr storm (PGC 1997, EPA 2000a, and EPA 2000b). Sometimes biofilter control measures have to be supplemented with conventional end-of-pipe structural control measures such as ponds; however, the number and size of ponds is usually reduced.

Stability and Selection Considerations

Experience indicates that three factors should be considered in selecting the appropriate biofilter:

- 1) the compatibility of the biofilter with the land use type;
- 2) the compatibility of the biofilter with site conditions such as space consumption, available head, cost, or maintenance considerations;
- 3) the effectiveness of the biofilter design in removing the key pollutants of concern.

Usually, once all three factors are considered, design options are narrowed down. The engineer can then compare the design criteria for the remaining options and select one based on cost and effectiveness (Clar et al. 2004).

Comparative Pollutant Removal Capability

Table 2.1 summarizes the pollutant removal from several studies of biofilter control measures. Biofilters have some similarities with respect to performance. For example, all typically report relatively high removal rates of suspended sediment, ranging from 68% for the grass channel to 90% or more for the dry swale and the bioretention cell.

Some differences have been observed in the comparative ability to remove total phosphorus. Phosphorus removal percentages were highest in the dry swale and bioretention cells, with removal rates of 83% and 70%, respectively. Grass channels, wet swales, and filter strips, were less reliable for phosphorus removal at 10-29 % average removal. Vegetative biofilters display a wide range of total nitrogen removal. The dry swale exhibited a very high removal rate for total nitrogen of 92%.

While all biofilter designs showed at least moderate capacity to remove trace metals such as copper, lead, and zinc, most of the removed metals were most likely already attached to solid

particles. Designs that showed promise in removing dissolved metals include the dry swale and bioretention cell. Pollutant removal rates and mechanisms rely on processes in a generally aerobic environment, as opposed to an anaerobic environment. Filters that go anaerobic tend to release previously captured phosphorous as iron phosphates break down.

Table 2.1 Estimated Pollutant Removal Capability (%) of Biofilters for total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), nitrate (NO₃) and other constituents.

Biofilter	TSS	TP	TN	NO ₃	Other/Comments
Grass Swale ¹	68	29	NA	-25	Metals: Cu (42%); Zn (45%) Hydrocarbons: 65 % Bacteria: Negative
Dry Swale ¹	93	83	92	90	Metals: Cu (70%); Zn (86%)
Wet Swale ¹	74	28	40	31	Metals: Cu (11%); Zn (33%)
Filter Strip ²	70	10	30	0	Metals: 40-50 %
Bioretention	86 ³	71-90 ^{3,4}	43 ⁴	23 ⁴	Metals: Cu (93%), Pb (99%), Zn (99%); COD 97%; Oil & Grease 67%

NA = not applicable, ¹Winer 2000, ²CRC 1996, ³Yu et al. 1999, and ⁴Davis et al. 1998.

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