Memorandum

To: MIDS Work Group
From: Barr Engineering Co.
Subject: Selected Pretreatment Practices
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Project: 23621050

Stormwater runoff that is treated by water quality best management practices (BMPs) to remove nutrients and suspended sediments are required to pass through pretreatment prior to entering a primary infiltration BMP. Pretreatment allows coarser sediments (coarse silts and sands) to be removed in an easy-to-maintain pretreatment BMP, extending the life and reducing maintenance considerations for the primary BMP.

The MPCA directed Barr to provide a summary of the performance and design considerations associated with two common pretreatment BMPs: (1) vegetated filter strips and (2) flow-through structures. This memorandum provides a summary of our research and experience with these pretreatment practices.

After reviewing a draft of this memorandum, the MIDS Work Group asked that a statement be included to indicate that the MIDS calculator could be updated in the future to quantify the pollution removal from pretreatment BMPs. However, additional analysis would be needed to ensure that accurate removal is then given to the downstream BMP since the pollutant removal at the downstream BMP may include pretreatment BMP pollutant removal.

Vegetated Filter Strips

Overview

Vegetated filter strips are a pre-treatment BMP designed to remove solids from stormwater runoff. The vegetation can consist of natural to established vegetation communities, and can range from turf grass to woody species with native grasses and shrubs. Because of the range of suitable vegetation communities, vegetated filter strips can be easily incorporated into landscaping plans; in doing so, they can accent adjacent natural areas or provide visual buffers within developed areas. They are best suited for treating runoff from roads, parking lots, and roof downspouts.

Their primary function is to slow runoff velocities and allow sediment in the runoff to settle or be filtered by the vegetation. By slowing runoff velocities, they help to attenuate flow and create a longer time of concentration. Filter strips do not significantly reduce runoff volume; however, there are minor losses due to infiltration and depression storage.

Filter strips are most effective if they receive sheet flow and the flow remains uniformly distributed across the filter strip. Channelized flow significantly reduces their effectiveness because flow velocities are minimally reduced and the effects of filtration through plant stems and accumulated thatch on the ground surface is lost.

Permit Applicability

As stated in the Minnesota Stormwater Manual, vegetated filter strips are included in the "Infiltration/Filtration" category of the MPCA Construction General Permit and will usually require such a permit as part of the overall construction project. Properly designed vegetated filter strips also satisfy permit requirements for pre-treatment for certain stormwater quality BMPs. Retrofits are cases in which construction of a vegetated filter strip may not require a MPCA Permit, although the permit's standards may still provide design guidelines. Additional permits may be necessary depending on the jurisdiction and the proposed location of the vegetated filter strip.

Retrofit Applicability

The ability to retrofit a site to incorporate a vegetative filter strip is highly dependent on existing conditions and how well they conform to design requirements. As noted in the overview and design guidelines, vegetated filter strips are much more effective if they receive sheet flow and if the filter strip has a low gradient; therefore, a retrofit may require additional grading or repaving to create sheet flow and/or create a grade suitable for effective pretreatment. The availability of space for the filter strip will impact its effectiveness, particularly if the available space is smaller than design guidelines stipulate. In such cases, the pretreatment needs should be evaluated to determine if a potentially undersized filter strip is the most appropriate pretreatment option.

Cold Climate Suitability

During the winter season, vegetated filter strips can become covered in snow and ice, causing runoff to find an alternate flow path or possibly flow on top of ice-covered ground and away from the filtering ability of the vegetation. Furthermore, the frozen ground eliminates the minor benefit of infiltration.

Special Receiving Waters Suitability

The Minnesota Stormwater Manual provides design restrictions for filtration methods for special receiving waters in the state, and Table 12.FIL.1 is reproduced here for easy reference as Table 1.

Table 1. Design Restrictions for Special Waters from Minnesota Stormwater Manual

Table 12.FIL.1 Design Restrictions for Special Waters					
BMP Group	Stormwater Management Category				
	A Lakes	B Trout Waters	C Drinking Water	D Wetlands	E Impaired Waters
Filtration	Some variations RESTRICTED due to poor P removal, combined with other treatments	PREFERRED	PREFERRED	OK	PREFERRED for non-nutrient impairments

Table 1 was prepared for filtration practices in general; however, the restrictions hold true for vegetated filter strips specifically. While the design of filter strips can utilize a variety of vegetation communities, native vegetation with robust root systems should be used immediately adjacent to water bodies to provide additional bank stabilization and provide natural cover for habitat.

Water Quality Benefits

Properly designed vegetated filter strips slow runoff velocities and allow sediment in the runoff to settle or be filtered by the vegetation. In addition to filtering solids, vegetated filter strips can also remove portions of other pollutants in runoff, including small particulates, hydrocarbons, heavy metals and nutrients such as phosphorus and nitrogen. The removal mechanisms include sedimentation, filtration, adsorption, infiltration, biological uptake and microbial activity.

The water quality benefit of a vegetated filter strip is dependent on the length of flow through the BMP, the effectiveness in achieving sheet flow and avoiding channelized flow, and the characteristics of the contributing watershed. Studies have examined the effectiveness of vegetated filter strips in treating runoff from urban settings, including highways and parking lots; however, these studies have been too few in number or have too many varying characteristics (watershed variables and vegetated filter strip design) to determine strong correlations between design components and specific water quality benefits.

Water Quantity Benefits

Vegetated filter strips are not a primary means of water quantity control; however, there are minor volumetric losses from infiltration and evapotranspiration.

Design Considerations

There are five critical components for an effective vegetative filter strip design:

- Contributing drainage area
- Type of vegetation
- Filter strip length
- Filter strip slope
- Filter strip soils

Vegetated filter strips are most effective for storm events up to the 1- to 2-year event. The effectiveness of filter strips is reduced for flow depths that exceed one inch and flow velocities that exceed 0.5 feet per second.

The flow length leading to the vegetated filter strip is a primary design factor because if the flow length is too long, there is a greater chance that the sheet flow will become concentrated flow and require additional design to re-establish sheet flow entering the vegetated filter strip. The flow length into the vegetated filter strip should be limited to 75 feet from impervious surfaces and 150 feet from pervious surfaces.

Vegetated filter strips are most effective if the vegetation is healthy and dense. Grasses are most effective in shorter filter strips while woody species may be suitable for longer filter strips.

A properly designed filter strip length is dependent on the slope, the underlying soils, and the type of vegetation to be used. Filter strips that are too short will have reduced effectiveness. Filter strips with steeper slopes will require more length to be equally effective as a filter strip with a lower slope; slopes less than 5% are most effective. The current state of Minnesota guidelines are consistent with other published guidelines. Table 2 below is a copy of Table 12.BIOS.9 from the Minnesota Stormwater Manual.

Table 2. Vegetated Filter Strip Design Criteria from the Minnesota Stormwater Manual

Table 12.BIO.9 Guidelines for Filter Strip Pre-treatment Sizing								
Parameter	**Impervious Parking Lots**				**Residential Lawns**			
Maximum Inflow Approach Length (ft.)	35		75		75		150	
Filter Strip Slope	≤2%	>2%	≤2%	>2%	≤2%	>2%	≤2%	>2%
Filter Strip Minimum Length	10’	15’	20’	25’	10’	12’	15’	18’

Construction

One significant benefit of vegetated filter strips is that construction is relatively inexpensive since it is limited to grading and vegetation establishment. Maintaining sheet flow in the filter strip is critical to its effectiveness; therefore, construction must result in an evenly graded site. Care should also be taken to avoid excessive compaction in the filter strip area to maintain healthy soils for a healthy vegetation community; and to preserve the infiltration capacity of the soils.

Maintenance

If designed properly and if they receive sheet flow, vegetated filter strips require minimal maintenance; however, more maintenance is required of vegetated filter strips that receive channelized flow from the contributing watershed or concentrated flow from curb cuts. Systems that redistribute concentrated or channelized flow into sheet flow may require periodic maintenance to ensure the redistribution system maintains its design function. Depending on the contributing watershed characteristics, common maintenance needs include periodic removal of accumulated sediment and debris (particularly at the upstream end of the filter strip) and monitoring to ensure channels or preferential flow paths have not developed. Contributing watersheds with high sediment concentrations require more frequent maintenance in the vegetated filter strip to manage sediment build-up. Maintenance may also include mowing, trimming or burning the plant community, depending on specific needs of the vegetation.

Flow-Through Structures

Overview

Flow-through water quality treatment structures are commonly used for pretreatment to remove coarse sediment (i.e., coarse silts, fine sands and larger particles) and floatables (i.e., debris and oil). These structures vary greatly in size and can include the following categories that are discussed in greater detail below:

- Underground Storage Structures
- Hydrodynamic Separators
- Sump Catch Basins or Manholes

Pretreatment Considerations

Pretreatment is a required stormwater management practice for infiltration practices intended to extend the life of downstream BMPs. Flow-through structures are intended to remove a significant amount of coarse silts and sands during low flows; their removal efficiency often is significantly reduced at high flows. Frequent maintenance and cleaning is required as these structures are prone to exhibit washout during high flows, where the previously-accumulated sediment is resuspended and carried out of the structure. Washout concerns can be mitigated through:

- Frequent maintenance
- Appropriate sizing
- High-flow bypass
- Scour-reducing screens, baffles or protective measures

Permit Applicability

Many communities have water quality goals that target a specific reduction in total suspended solids (TSS). Because flow-through structures cannot effectively remove clays and most silts, these BMPs cannot meet water quality goals without additional downstream primary treatment. If sized appropriately, flow-through structures can effectively extend the life of downstream primary treatment systems by removing coarser sediments.

Similarly, flow-through structures cannot remove dissolved phosphorus. Many communities have specific phosphorus reduction goals that are not possible to meet with use of these structures alone. While these structures alone do not meet the stormwater runoff volume performance goals or the stormwater runoff phosphorus removal performance goal developed as part of MIDS, flow-through structures do qualify as pretreatment under the MPCA Stormwater Construction Permit.

Retrofit Applicability

Flow-through structures are often used in retrofit situations or in denser development (or redevelopment) where surface treatment is not feasible or cost-effective due to competing land demands. Flow-through structures generally have a smaller footprint than other treatment approaches and due to their placement underground, their use can allow the surface to be used for other purposes, such as parking or greenspace.

Sump catch basins and manholes are a relatively common BMP; however, testing has shown that these BMPs are prone to washout, limiting their effectiveness. Sump catch basins and manholes that have already been constructed present a unique opportunity for retrofit with porous baffles that can prevent or limit washout (e.g., SAFL Baffle[1]). If the characteristics of the existing sump catch basin or manhole are consistent with the design considerations for the installation of porous baffle retrofit, a retrofit may effectively, and inexpensively, improve the removal efficiency of the BMP.

Cold Climate Suitability

According to the Minnesota Stormwater Manual, flow-through structures are appropriate for usage in Minnesota and other cold climates. They are placed belowground, often below the frostline. Flow-through structures are particularly effective at capturing sediment from late-winter or early-spring snowmelt events that are often sediment-laden.

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[1] SAFL Baffle was developed by the University of Minnesota St. Anthony Falls Laboratory (SAFL)

Water Quality Benefits

Flow-through structures can remove nutrients that are attached to larger particles (coarse silts and sands) or nutrients that are attached to floating trash or debris. These BMPs are not effective at removing dissolved nutrients or nutrients attached to silts or clays.

Water Quantity Benefits

Flow-through structures do not promote volume reduction; however, stormwater reuse could be incorporated into the design, allowing reuse of the permanent pool in the BMP.

General Descriptions

Underground Storage Structures

Underground storage structures (also called underground settling devices) typically contain multiple chambers to remove sediment and floatables. The first chamber serves as a forebay, promoting settlement of suspended sediment, generally coarse silts and sands in a permanent pool with a minimum depth of 4 feet. The second chamber serves a skimming function, removing oils, grease, and floating debris. A baffle or submerged inverted pipe separates the second and third chambers, trapping floatables. The third chamber can be used for additional settlement of large particles, before the cleaner water is discharged from the structure.

A permanent pool totaling 400 cubic feet per acre of tributary impervious surface should be provided throughout the entire structure. The footprint of these systems is generally much larger and they are typically more expensive than hydrodynamic separators.

Hydrodynamic Separators

Due to the large size required to remove suspended solids in the underground storage structures, smaller-footprint proprietary systems have become more commonly used. The internal components of these devices create flow patterns and flow conditions that help remove suspended sediments during low flow conditions. Several of these hydrodynamic separators have been full-scale tested by the St. Anthony Falls Laboratory (SAFL) at the University of Minnesota, including BaySaver, CDS, Downstream Defender, ecoStorm, Environment 21, Stormceptor, and the Vortechs System (Wilson et al, 2009).

Similar to underground storage structures, hydrodynamic separators include a permanent pool for sedimentation and a solid baffle or inverted outlet pipe to provide skimming to trap floatables. These systems vary in size and may contain several chambers.

The manufacturers of the hydrodynamic separators provide product-specific design guidance, but rarely do the guidelines include considerations for high flows and associated washout.

Sump Catch Basins and Manholes

A sump is a standard catch basin or manhole constructed with part of the structure located below the outlet, creating a permanent pool. Catch basins and manholes are not made for pretreatment of storm water; however, they can potentially function as pretreatment structures when the bottom of the structure is significantly below the invert of the outlet pipe. Similar to the proprietary hydrodynamic devices, standard catch basins and manholes with deep sumps have a smaller footprint than an underground storage structure. Sumps are generally less expensive are more readily available than the hydrodynamic separators.

Standard sumps have one chamber and sedimentation occurs due to flow patterns resulting from water plunging into the sump. Sedimentation in standard sumps occurs in the permanent pool. Sumps should be designed with a permanent pool of at least three feet. The outlet from the sump sometimes incorporates an inverted pipe to allow skimming of floatables such as debris and oil.

As with proprietary systems, washout is a concern with sump catch basins and manholes (Saddoris et al., 2011; Howard et al., 2012). To mitigate the effects of washout, the University of Minnesota developed a porous baffle, called the SAFL Baffle, to modify the flow characteristics through sump manholes and reduce resuspension of previously-accumulated sediment. Full-scale testing determined that the SAFL Baffle proved quite effective at reducing resuspension and washout while adding very little head loss (Howard et al., 2012).

The SAFL Baffle was tested with sump manholes and sump catch basins. Sump catch basins (receiving flow through a grate above and from an inlet pipe) present a different flow pattern than a sump manhole which does not receive flow from above. Based on research performed at SAFL, washout and resuspension is mitigated when the drainage area of the inflow pipe is at least three times greater than the drainage area of the grate above the catch basin. High flows from an inlet grate into a catch basin can plunge deeper into the sump and cause washout when horizontal flows from an inlet pipe are too low (McIntire et al., 2012). Therefore, porous screen/baffle retrofits, such as SAFL Baffle, are not recommended for headwater catch basins or when the depth of the sump is less than three feet.

Design Considerations

General Guidance

Flow-through structures should be selected and designed to maximize suspended sediment removal given the treatment drainage area and its land use characteristics, available space for the structure, and presence of other stormwater BMPs in series. Design assistance of proprietary systems is generally provided by the manufacturer of the flow-through system.

All flow-through structures have some propensity to washout during high flow conditions. Installation of a high-flow bypass can mitigate washout, essentially designing the systems to function as offline treatment devices, primarily treating low flows.

Design Assistance Using SHSAM

The Saint Anthony Falls Laboratory (SAFL) of University of Minnesota has performed extensive full-scale testing of many different types of flow-through structures to determine their removal efficiency functions that can assist the designer in selecting the appropriate type of flow-through structure and size the selected structure to meet the sediment removal goals. In 2012, ASTM International developed standards in testing removal efficiency of hydrodynamic separators (ASTM C1746/C1746M–12). The standard is primarily based on the testing conducted at the University of Minnesota. In addition to sediment removal, SAFL performed testing to determine the propensity for sediment washout under high flows for different structures.

The results of SAFL's full-scale testing were used to build a computer program to predict the removal efficiency and washout for various flow-through devices under different conditions. The program is called SHSAM (Sizing Hydrodynamic Separators And Manholes). SHSAM can be downloaded for free at https://www.barr.com/WhatsNew/SHSAM/SHSAMapp.asp. SHSAM is a computer program for predicting the amount of suspended sediments removed from stormwater runoff by a given hydrodynamic separator/standard sump over a given period of time, e.g., 15 years. SHSAM is comprised of a simple continuous runoff model, a generic sediment removal response function, and a generic sediment washout function. Table 3 summarizes the flow-through structures available for water quality modeling by SHSAM and whether the model is able to determine sediment removal efficiency and/or washout.

Table 3. SHSAM Flow-Through Structure Modeling

Device	Removal Efficiency Considered	Washout Considered
BaySaver	X	
CDS	X	
Downstream Defender	X	X
ecoStorm	X	X
Environment 21	X	X
Stormceptor	X	X
Vortechs System	X	
Standard Sumps	X	X
Standard Sumps with SAFL Baffle	X	X

In order to assess the performance of hydrodynamic separators and sump manholes, the user of SHSAM should select local weather data and silica sand OK110 particle size distribution (PSD). The silica sand OK110 is a commercial particle size distribution used in testing these devices. This gradation has a median size of 110 microns with 90 percent of particles between 100 and 240 microns, which represents fine sands in stormwater runoff. OK110 does not represent a typical particle size distribution of suspended sediments; rather, it provides an appropriate range of particle sizes that are expected to be removed by flow-through structures. The removal efficiencies achieved by flow-through structures using OK110 are not the removal efficiencies that these devices will achieve for a typical range of suspended sediment particle sizes. OK110 allows the designer to determine how well the pretreatment structure can remove coarse silt and sand which would in turn decrease the maintenance frequency of the downstream primary BMP.

Note that an ASTM standard is currently being developed for a consistent type of particle-size-distribution to be used for testing hydrodynamic separators.

Performance Assessment

The SHSAM software provides a useful tool for assessing the performance of a limited number of hydrodynamic devices and standard sumps. All these devices have been tested based on a mass-balance approach with repeatable results. To assess the performance of hydrodynamic separators which are not included in the SHSAM software, the devices should be evaluated using the testing methods described in ASTM Standards C1746 and C1745. Subsequently, the device performance can be assessed based on the site specific conditions.

Flow-through structures cannot remove fine silts and clays, and thus generally can only remove a small fraction of presumed suspended solids particle size distribution. As such, their primary purpose is pretreatment and removal of coarse silts and sands. If properly designed and maintained, flow-through structures can remove up to 70-80% of coarse silts and sands, which can be represented by OK110 particle size distribution. This removal efficiency for coarse sediment equates to approximately a 20% removal of TSS using a particle size distribution with a broader range of sizes (e.g., EPA NURP particle size distribution). Removal of 20% TSS results in approximately a 10% reduction in total phosphorus. The nutrient loading removal of the downstream primary treatment BMP typically assumes pretreatment; therefore, the nutrient removal from the pretreatment device (such as a flow-through structure) cannot typically be added to the nutrient removal of the downstream primary treatment BMP. Attaining typical TSS and nutrient removal goals will require treatment by a downstream primary BMP. Removing a greater fraction of coarse sediments with pretreatment structures will allow the primary treatment structure to meet or exceed its anticipated design life.

Maintenance

Frequent maintenance of flow-through structures is essential to prevent resuspension of settled particles in subsequent storms. Ideally, structures would be cleaned out after each water quality rain event (described as 0.5 inches of precipitation by the Minnesota Stormwater Manual), although that may not be practical or even necessary, given the drainage area characteristics and resulting sediment load. Manufacturers of hydrodynamic separators recommend a frequency of once a year, which is most effective if it is done before the beginning of winter. However, through frequent inspection of accumulated sediment and screen/baffle clogging over the first two years following installation, a structure-specific maintenance program can be developed. The SHSAM software provides site-specific guidance on frequency of cleaning to mitigate resuspension, which can be implemented during the inspection/monitoring period and modified after obtaining more precise and distinct results on the performance of the device during the inspection/monitoring period. Note that most devices have a maximum capacity of one foot in the sump, i.e., the pretreatment device shall be cleaned before one foot of sediment accumulates in the sump, however, if the sump is shallow (less than three feet), the sump may reach maximum capacity before one foot of sediment accumulation and require more frequent maintenance.

All flow-through structures should be constructed to facilitate access of maintenance vehicles and equipment. Proprietary devices may have additional maintenance requirements that should be followed.

At a minimum, structures and screens/baffles should be fully cleaned once a year. Vacuum trucks can be used to remove accumulated sediment and oils/grease, although compacted sediments may require full dewatering and manual removal of sediments. Currently, sediment removed from flow-through structures is not generally considered to be potentially hazardous and is not subject to testing for proper disposal. All applicable local, state and federal laws should be followed in the disposal of accumulated sediments and floatables, including hydrocarbons.

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