INTEGRATING MAINTENANCE INTO STORMWATER TREATMENT DESIGN

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ABSTRACT

As today's assortment of best stormwater treatment practices has expanded to include both Low Impact Design techniques and innovative proprietary systems, a great deal of attention has been focused on the topic of system performance and the development of performance evaluation tools. Often missing from the evaluation process, however, is the determination of system longevity and the establishment of required maintenance frequency. All stormwater treatment systems are subject to routine maintenance needs in order to function as designed. Maintenance, like performance, is a function of site-specific variables and therefore must be included in the system design phase. This paper examines factors influencing system longevity, focusing on sediment loading. A design methodology is outlined which uses estimated sediment loading rates from various catchment types to predict system maintenance requirements along with system performance. Central to this methodology is the knowledge of system-specific load capacity, which must be established through laboratory and field research. This design tactic is appropriate for any system utilizing filtration and/or sedimentation as unit processes. The evaluation of maintenance as part of the design process benefits site owners, specifiers, and regulators by establishing the true cost of long-term site compliance at the project onset.

KEYWORDS

Maintenance, Solids Loading, Filter Design, Lifecycle Cost

PRESENTER PROFILE

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1 INTRODUCTION

Today's site design engineer has a number of options available for the treatment of stormwater runoff. Traditional treatment systems such as detention ponds and sand filters are well understood and suitable to a variety of land use applications. When available land is at a premium, engineers may select from a number of innovative sedimentation and filtration systems which may be located below grade. Low Impact Design (LID) techniques integrate stormwater management into the overall site landscaping, combining treatment with aesthetic benefits. Regardless of the technology employed, all stormwater treatment systems share a critical operational component: the need for periodic maintenance. If a treatment system is working as designed, it will remove pollutants from the runoff, storing them within the treatment structure until maintenance is performed. Without periodic maintenance, the system performance will decrease with regard to pollutant removal efficiency, hydraulic capacity, or both.

The cost of maintenance and the frequency at which it is required factor heavily into the lifecycle cost of the treatment system. As such, detailed knowledge of the maintenance implications is required at the design phase of the overall project and is critical information for regulators, specifiers, and site owners. Understanding the failure mechanisms of a given system is crucial to accurate long-term costing, as a finite pollutant removal capacity exists before maintenance is required. Regulatory design guidelines such as the Auckland Regional Council's Technical Publication #10 (ARC, 2003) provide relevant maintenance considerations for a variety of treatment systems. However, maintenance requirements depend not only on the operational mechanism of the system itself, but are largely a function of the pollutant loading generated from the catchment being treated. While these loading rates are difficult to accurately predict at the project inception, historical data measuring pollutant loading rates are available for a variety of land use applications. By combining knowledge of the pollutant loading capacity of the system with estimated loading rates from the catchment, the projected maintenance costs can be integrated into the design phase.

The following discussion examines the influence of various design factors on the maintenance requirements of stormwater treatment systems. While the breadth of treatment options is too great to deal with in specific terms, most systems rely on the unit operations of sedimentation or filtration, or a combination of the two. As such, the concepts outlined are meant to be applicable on a general basis.

2 DESIGN FACTORS INFLUENCING MAINTENANCE

2.1 PRETREATMENT

Pretreatment serves a vital role in the determination of maintenance costs by extending the lifecycle of the primary treatment device. Pretreatment typically focuses on the removal of coarse solids, trash, and debris, and can take place as a separate system upstream in the catchment or as an integrated component of the primary treatment unit. Common separate pretreatment options include catchpit filters and gross pollutant traps (GPTs). Integrated pretreatment may take the form of a forebay to a wet pond or a sedimentation chamber in a sand filter.

Besides extending the operational life of the treatment system, pretreatment benefits maintenance by concentrating bulk pollutants in an accessible location. As the pretreatment unit is usually proportionally smaller than the primary unit, more frequent maintenance of the pretreatment bay is necessary. This is particularly true given that the coarse solids comprise the highest proportion of incoming sediments in terms of total volume (ARC, 2003).

2.2 SOLIDS LOADING CAPACITY

As Total Suspended Solids (TSS) is the primary pollutant of focus for most stormwater treatment systems, solids accumulation should be the corresponding indicator of maintenance needs in typical applications. In sedimentation systems, solids accumulation will take place in sumps and dedicated sedimentation chambers, often concentrating in pretreatment forebays as discussed earlier. Direct measurement of sediment levels as part of routine system inspection is the most straightforward way to anticipate maintenance needs. However, these measurements are often difficult to make, especially when access to the sediment storage location is hindered. In underground sedimentation systems, confined space entry restrictions often prohibit direct sediment measurement. Well-designed systems will therefore incorporate an inspection access so sediment levels can be measured from the surface. Accumulated solids depth is typically quantified using a calibrated stadia rod—at a defined depth, the solids capacity of the system has been met and maintenance is required. If maintenance is not performed, subsequent storm events will not be treated to design standards, and at worse the system becomes a pollutant source as high flows resuspend accumulated material, transporting it directly to the receiving body. Routine inspection is a straightforward means of anticipating maintenance requirements but must be coupled with knowledge of the system solids storage capacity to be effective.

Filtration systems accumulate sediment on the filter surface, as well as within the bulk media volume (depending on the media type and configuration). As such, direct measurement of the sediment level is not as simple as in sedimentation systems. While a number of visual indicators exist to cue maintenance, evidence of bypass is usually the most readily noticed. At this point, however, diminished flows are actually being filtered, and water quality is not controlled to design standards. It is therefore especially important to understand the solids loading capacity of the filtration system. The solids capacity depends not only on the filtration media, but on the filter configuration and operational flow rate of the system. This is particularly true for complex filtration systems such as rain gardens, where the media surface is usually covered in vegetation and visual indicators other than evidence of bypass are not readily apparent.

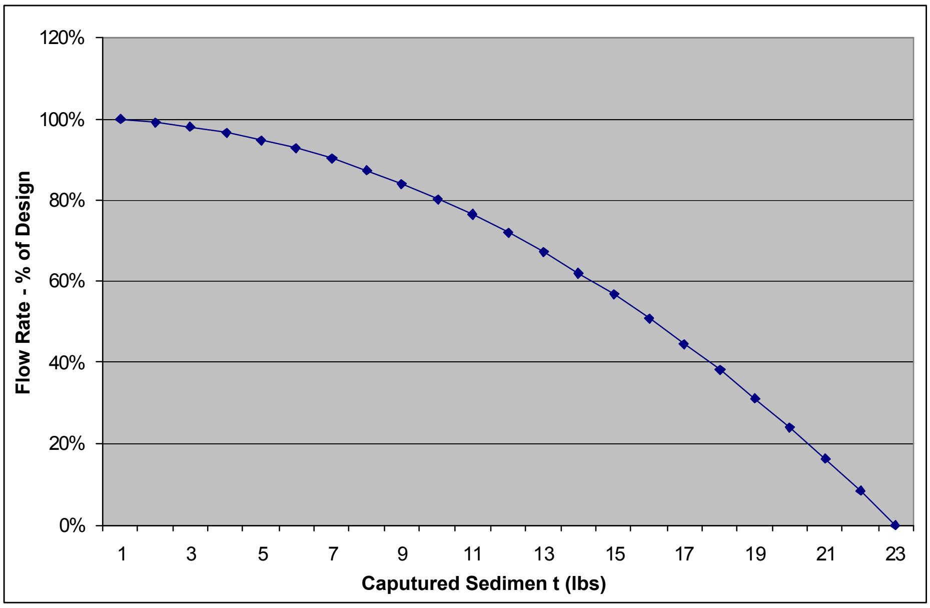
2.3 FLOW CONTROL

Flow control plays an important role in the sizing of stormwater treatment systems, and control mechanisms vary widely depending on the treatment technology employed. Invariably, however, hydraulic flow controls influence the rate of sediment accumulation, as lower system flow rates allow finer particles to settle out or promote higher filtration efficiencies.

In filtration systems, flow control and maintenance interval are directly related. Flow is controlled by the permeability of the filtration media, typically measured as infiltration rate in systems such as sand filters and rain gardens. During the operational lifespan of the filtration system, sediment is captured by the filtration media as runoff flows through the pore spaces in the media matrix. This media has a limited capacity to trap sediment—over time, accumulated sediment occludes the filter, reducing the matrix permeability and overall flow capacity of the system. Figure 1 illustrates the decrease in flow through a filter media as removed sediment accumulates. Periodic maintenance must be performed in order to restore the system to its initial state. In anticipation of solids loading, design standards often require that a factor of safety be applied to the infiltration rate of the media or infiltrating substrate when sizing the system (Ecology, 2003). Thus, the system is sized at a flow rate that is less than its initial hydraulic capacity.

Safety factors are suitable in systems where the permeability and infiltration rate of the filter media can be specified. However, a large number of proprietary filter systems are available, with filtration media ranging from porous concrete and specialized minerals to blends of organic and inorganic materials. Typically, these media formulations are proprietary in nature, and their permeabilities and/or infiltration rates are not commonly disclosed. How then can the system be sized such that the hydraulic design capacity is maintained throughout the entire filter lifecycle?

One solution is to utilize a flow control other than the permeability of the media as part of the initial design. By applying an external flow restriction, the hydraulic capacity of the system is maintained at a constant rate regardless of the gradual accumulation of sediment in the media matrix, as illustrated in Figure 2. As sediment builds up over time, the permeability of the filter media will become reduced to the point that the external flow control no longer governs. Hydraulic capacity is then reduced, and some portion of the design flow is bypassed, indicating a need for maintenance. The net effect is the same as applying a safety factor to the infiltration rate of a sand filter.



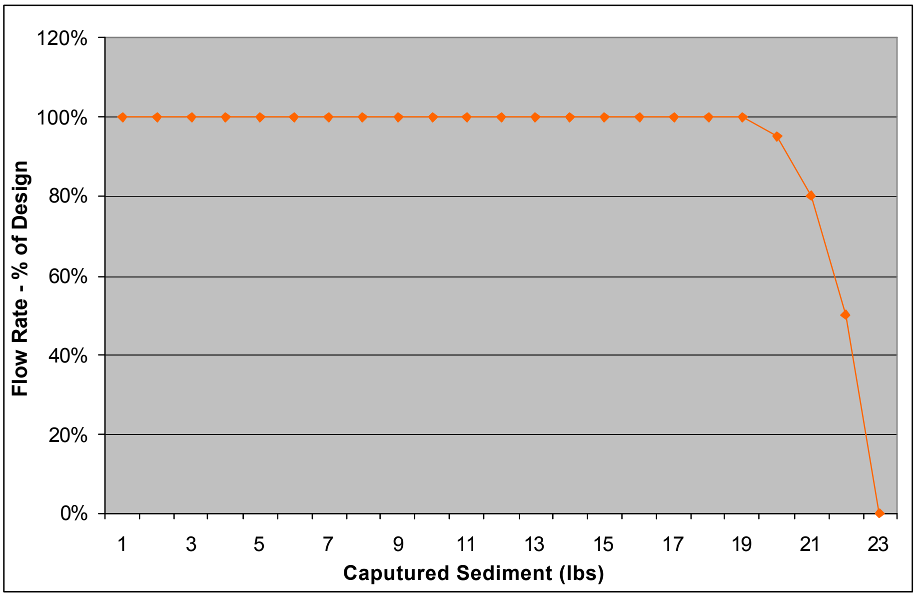


Figure 1: Decrease in Operational Filter Flow Rate as Captured Sediment Accumulates

Figure 2: Filter with Flow Control Maintains Design Flow Rate. Once Sediment Accumulation Restricts Flow to Beneath Controlled Design Rate, Maintenance is Required.

3 SOLIDS-BASED DESIGN METHODOLOGY

To better predict the maintenance requirements of its stormwater filtration system, the StormFilter, Stormwater360 has developed a sizing methodology that measures system loading capacity relative to anticipated solids loading rates. The resulting output specifies the predicted system maintenance interval in months, allowing designers the flexibility to balance lifecycle costs with system size.

Essential to this assessment is knowledge of the solids loading capacities of the individual filter units. These data were established by Contech Stormwater Solutions, the developer of the StormFilter, in its laboratory facility in Portland, Oregon (CONTECH, 2005; SMI, 1999). Laboratory tests were conducted on an individual cartridge basis and were repeated for various media types and gradations. Simulated stormwater runoff was created by mixing water with actual sediment taken from existing StormFilter installations. Actual sediment was chosen to more accurately represent field conditions; of particular importance were the silt-range particulate fraction and the contribution of organic solids. During the tests, simulated stormwater runoff was filtered through the cartridge at design flow rates until the cartridge became entirely occluded. The testing procedure generally consisted of the following steps:

1. Establishing the dry weight of a new StormFilter cartridge.
2. Using the test apparatus (Figure 3), perform simulated filtrations through the cartridge with simulated stormwater runoff at measured flow rates.
3. During simulations, take influent and effluent water quality samples to measure solids concentrations.
4. Continue simulations until flow through the cartridge approaches zero.
5. Using a mass-balance analysis, calculate the sediment removed relative to the flow rate through the filter.

Thus, the solids loading capacity of the individual filter unit was measured. When sizing StormFilter systems to a given catchment area, a discreet number of unit cartridges results. By scaling the unit solids loading capacity to the total system, the solids loading capacity of the entire system can be inferred. The solids loading curve for a perlite cartridge is shown in Figure 4. Implementing flow control to reduce the initial design flow prolongs the maintenance interval, as illustrated by the inset red lines.

In utilizing this data, expected solids loading rates for various catchment areas have been compiled and ordered according to land use application (Table 1). These rates are applied to the specific catchment areas for a given project, yielding an anticipated solids load per annum. This load is then compared with the solids loading capacity of the overall system to predict the required maintenance interval.

As the data used to develop Table 1 is variable in nature, accurate prediction of site runoff is difficult. Every finished site is unique, subject to specific pollutant sources and nuances of land use. Site-specific data should be gathered prior to the design phase where possible. However, even conservative application of these general guidelines aides the long-term viability of the design process. As an example, a system designed to treat 1000-m2 of impervious surface without accounting for site loading rates may be expected to have the same lifecycle, regardless if the area in question is an urban motorway or a residential sidestreet.

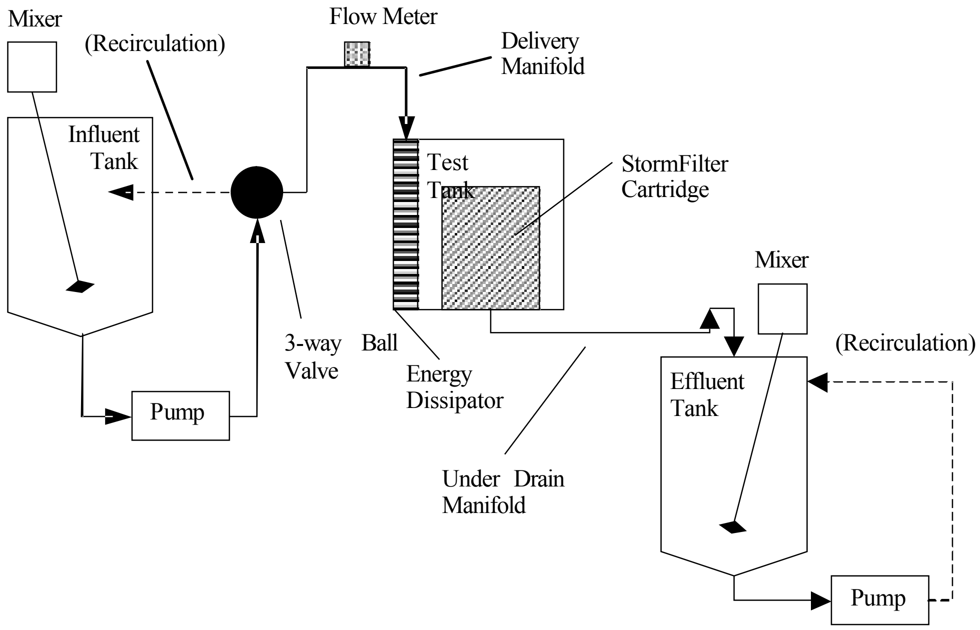


Figure 3: CONTECH Stormwater Solutions Solids Loading Test Apparatus

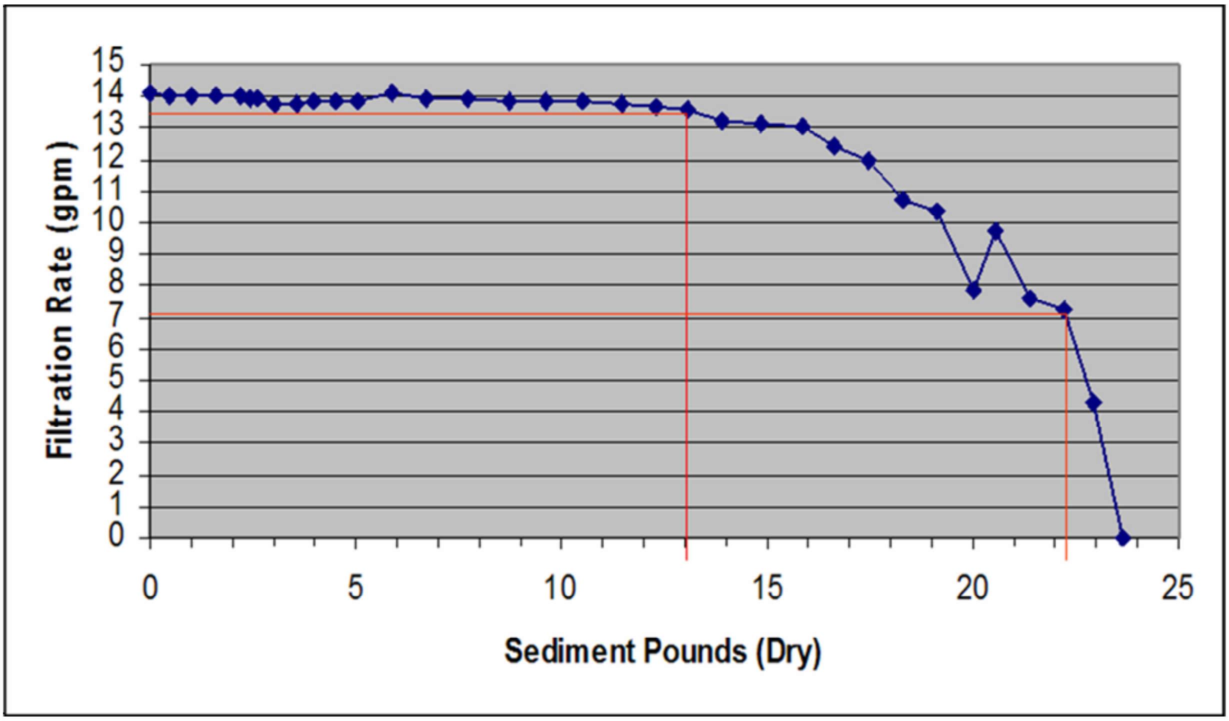


Figure 4: Solids Loading Results for a StormFilter Cartridge Using Perlite Media. Red Lines Illustrate the Influence of Flow Control—As Initial Design Flow is Reduced, System Longevity is Increased

Land Use	TSS (kg/ha/yr)
Road	281 - 723
Commercial	242 - 1369
Residential (low)	60 - 340
Residential (high)	97 - 547
Terraced	133 - 755
Bush	26 - 146
Grass	80 - 588
Roof	50-110 *(1)*
Pasture	103 - 583

Table 1: Recommended Loading Rates for Various Land Use Applications. Taken from Table 4-4, TP #10 (ARC, 2003).

4 CONCLUSIONS

A variety of options are available when selecting and designing stormwater treatment systems. Central to any treatment technology, however, is the determination of maintenance requirements, with regard to both frequency and cost. As these requirements heavily influence the lifecycle cost of the complete treatment system, maintenance details must be evaluated as part of the initial design process. By evaluating the design factors which influence maintenance requirements, Stormwater360 has developed a sizing methodology for its stormwater filtration system, the StormFilter, which predicts the unit maintenance interval using a combination of site-specific and system-specific solids loading data. This approach is appropriate for most stormwater treatment controls and allows regulators, specifiers, and site owners to assess maintenance requirements and costs with relative accuracy before the system is installed. While final site conditions will dictate the actual maintenance requirements, the benefits of this approach are apparent, and the accuracy of the results will increase with use.

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