COMPARISON OF STORMWATER QUALITY TREATMENT GUIDELINES AND CRITICAL STRUCTURAL BEST MANAGEMENT PERFORMANCE FACTORS AND PARAMETERS TO CONSIDER

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ABSTRACT

Provisions to protect source water have become an important consideration in urban development in North America. In the United States, Phase I and Phase II of the U.S. Environmental Protection Agency's (EPA's) stormwater program require owner/operators to address stormwater runoff pollution issues. The program relies on National Pollutant Discharge Elimination System (NPDES) permits to implement programs and practices to control polluted stormwater runoff. To assist regional and local governments with meeting NPDES requirements, state governments developed stormwater quality and quantity management guidance manuals. The guidance manuals for stormwater quality management focused on traditional structural Best Management Practices (BMPs) such as swales, ponds and porous pavement. Due to lack of studies at the time, little or no guidance was provided for manufactured BMPs. As such regional and locals governments were left to use their best judgement to establish sizing guidelines for manufactured BMPs.

While climate, geology and hydrogeology change with location, the physical laws and considerations governing BMP effectiveness do not change. BMP performance is complex in nature and warrants more detailed consideration than most current guidelines provide. There exists a need for clear, concise, consistent and detailed stormwater guidelines to be adopted across the nation to facilitate proper BMP evaluation and design.

This paper examines stormwater quality treatment guidelines considered by regional and local governments. Sample design criteria are presented and discussed. Key BMP performance factors and parameters relevant to sizing manufactured devices are suggested.

INTRODUCTION

In 1972, Congress passed what is currently referred to as the Clean Water Act (CWA). The Act established the National Pollutant Discharge Elimination System (NPDES) program. Early efforts under the NPDES program focused on non-stormwater discharges from industries and municipal wastewater treatment plants. As it became more evident that diffuse resources can create impacts on water quality, the United States Environmental Protection Agency (USEPA) expanded the NPDES program to cover stormwater discharges (US EPA, 2000).

In 1990, the CWA was revised to address stormwater discharges. The CWA defined municipal and industrial stormwater runoff discharge as "point source" and called for a two phase permitting strategy. NPDES Phase I of the USEPA stormwater permitting program was established in 1990 and affected all discharges related to 10 categories of industrial activity, any discharge from a large or medium municipal separate storm sewer system (MS4) generally serving populations of 100,000 or greater, and construction activities disturbing 5 acres of land or greater. NPDES Phase II of the program was signed into law in December 1999. It requires operators of MS4s in urbanized areas and operators of small construction sites that disturb equal to or greater than 1 (one) and less than 5 (five) acres of land to apply and obtain an NPDES permit for stormwater discharges (US EPA, 2000).

Since the revision of the CWA in 1990, numerous states have published guidance manuals identifying design criteria for traditional structural best management practices (BMPs), such as grass swales, porous pavement, extended detention basins, sand filters, constructed wetlands, and retention ponds. Due to lack of studies at the time, little guidance was provided for manufactured BMPs.

Leading up to and following the Phase II final ruling, numerous manufactured BMP technologies were developed and are now being applied to meet NPDES Phase II requirements. However, different performance claims and design methodologies for the various technologies are making it difficult for regional and local governments to set design criteria for manufactured stormwater devices. Since state government manuals only provide design guidelines for traditional structural BMPs, regional and local governments are left to use their best professional judgement and set what they consider appropriate design criteria for manufactured BMPs. These design criteria vary depending on the region, county or municipality. The design criteria tend to be general and can be counterproductive to achieving effective BMP application and performance. There exists a need to adopt clear, concise, consistent and detailed stormwater guidelines across the nation to facilitate effective BMP performance.

COMPARISON OF GUIDELINES

A comparison of sample stormwater quality treatment guidelines from regions and municipalities is presented in Table 1. This section discusses potential weaknesses of the guidelines presented in Table 1 and how BMP performance can be affected. The discussion focuses on total suspended solids (TSS) removal from stormwater runoff.

Table 1. Examples of Design Criteria from Regional and Local Governments for

Stand Alone Manufactured BMPs

Sample Design Criteria	Particle Size Distribution	Ave. Annual Percent TSS Removal	Design Flow Rate	Scour Prevention	Reference
Wayne County, MI	75 microns (µm)	80%	10 yr storm	Must bypass internally after 10 yr storm	(Wayne County, MI, 2003)
Municipality of Anchorage, AK	Greater or equal to 100 µm Less than 100 µm	80% 25%	2 yr 6 hr storm	Bypass required after the 2 yr 6 hr storm	(MOA, 2005)
City of Sacramento, CA	n/a	80%	2 yr 6 hr storm	n/a	(City of Sacramento, CA, 2000)
City of Minneapolis, IN	75 to 2400 µm	100% of 2400 µm or greater	10 yr storm	n/a	(City of Minneapolis, MN, 2004)

Note: Parameters not addressed in the guideline are noted as “n/a”.

The criterion “percent removal” of a pollutant on its own is an unclear measure of BMP performance. For TSS, the percent removal is a function of influent concentration. Therefore, as influent concentration increases, the removal efficiency also increases. Poor removal efficiencies are observed at lower contaminant concentrations and for many constituents there is a minimum concentration necessary to achieve reduction (USEPA, 2002). As such, the percent removal alone may not reflect the actual BMP performance. Large, dense particles, such as sand, settle faster than smaller, less dense particles, such as silts and clays. From a water quality perspective, 80 percent TSS removal of large particles (e.g., 150 µm) would not achieve the same water quality outcome as 80 percent TSS removal of a finer gradation (e.g. 20 to 150 µm). Influent characteristics must be defined in order to understand the context of the removal efficiencies and to establish clear treatment goals. Otherwise, “80% TSS removal” by itself is meaningless.

One influent characteristic to consider is particle size distribution (PSD). PSD is an important design consideration for water quality improvement due to its sediment pollutant availability (Wong et al., 2000). Finer particles such as clays (<2 µm) and silt (<63 µm) have high surface areas and typically adsorb a higher fraction of pollutants (Wong et al., 2000). A number of researchers have found that smaller particles tend to be more susceptible to being mobilized during storm events and the concentration of metals was found to increase with decreasing particle size (Sartar et al., 1974 in USEPA, 2002). Hence, water quality can be improved by targeting removal of the finer particle fraction in stormwater. While particle size(s) are considered in three out of the four sample design specifications presented in Table 1, the reasons they were chosen are unclear. The specified particle sizes do not cover the range of PSD typically found in urban stormwater. The USEPA’s National Urban Runoff Program (NURP) found that the particle gradation in stormwater ranged from 1 to 1000 µm (Burton & Pitt, 2002). As such, if only a certain particle range is specified for removal (e.g. 75 µm), then the water quality outcome would be much different than if 1 to 1000 µm was targeted for removal. This demonstrates the need for water quality treatment objectives to be identified in order to determine whether the PSD design criteria is appropriate or adequate. Conversely, the absence of a PSD removal target results in unclear BMP performance objectives which can potentially lead to the selection and application of inappropriate BMPs.

The volume of particles suspended within fluid also affects BMP performance. It has been observed that the more particles suspended within the fluid, the faster the rate of settling. However, this relationship is non-linear since observations indicate the rate of settling will bottom out (Stahre and Urbonas, 1990 in USEPA, 2002). To help put "percent removal" into context, another influent characteristic to consider is the typical range of TSS concentration found in stormwater (e.g. 100 to 300 milligrams per litre, mg/L). An 80% TSS removal translated from this reference influent concentration would provide a better picture of the water quality outcome achieved.

Another important influent characteristic to consider is stormwater flow patterns. Stormwater quality design guidelines for traditional structural BMPs are based on annual rainfall runoff volume rather than a design storm. Prior to the introduction of water quality considerations, hydrologic design methods focused on flood event hydrology (USEPA, 2002). Therefore, storms ranging from 1 or 2 year (channel protection), 10 or 25 year (overbank flood protection) and the 100 year (extreme flood protection) were used as a design basis for quantity management of stormwater (USEPA, 2002). Stormwater professionals are realizing that small storms dominate watershed hydrologic parameters typically associated with water quality management issues and BMP design (USEPA, 2002; ASCE & WEF, 1998). USEPA (2002) recognized that in any given area, most frequently recurrent rainfall events are small (less than 1 inch or 25 millimetre of daily rainfall). These small storms are responsible for the majority of annual urban runoff and groundwater recharge. Therefore, the use of the "small storm" (those with a return frequency under six months) approach should dominate design of BMPs for pollutant removal (USEPA, 2002). An understanding of the characteristics of storms that make up the majority of the annual rainfall runoff volume is important in the design and optimization of BMPs (ASCE & WEF, 1998).

Requiring infrequent high flows to be treated for water quality management is counterproductive to the removal of TSS in stormwater. Influent particle size and the hydraulic characteristics of the BMP during runoff events will directly affect the pollutant settling ability. The larger the stormwater loading rate or hydraulic loading rate, the lower the removal of the sediment by settling (SGC, 2004; USEPA, 2002; Minton, 2002). Since smaller, less dense particles require more time to settle, high loading rates would inhibit or reduce capture of these fine particles. In addition, turbulence and circular currents can re-suspend particles in a water column. Re-suspension of sediment deposited will lower sediment removal efficiency over the long term (USEPA, 2002). In Table 1, scour prevention is addressed in only 2 of the 4 sample design guidelines. Since stormwater flow is intermittent and highly variable, scour prevention is an important consideration in any BMP design. The optimal solution is to design a treatment system that treats the majority of the flows (small storms) and provides the system with protection against high flows such that re-suspension and scouring is prevented. As a result, the design flow and scour prevention criteria presented in Table 1 may not be appropriate or sufficient for stormwater quality design since infrequent high flows in a settling process can result in sediment loss or scouring.

BMP DESIGN CONSIDERATIONS

At present, stormwater quality guidelines for manufactured BMPs are general and, in some instances, counterproductive to achieving effective performance. In order to promote effective BMP performance, a more systematic design approach needs to be adopted and a detailed guideline be developed by state governments. With this approach, influent characteristics of stormwater must first be understood and identified before solutions can be explored. After stormwater characteristics are identified, treatment objectives can be determined, followed by the development of design criteria or guidelines for design optimization. There is a need for the state government to lead and provide more detailed stormwater quality management guidance to regional and local governments so that water quality improvement can be realistically achieved.

Understanding the characteristics of stormwater is important to the development of treatment objectives and design criteria. This includes PSD of sediment in stormwater runoff, typical sediment concentrations based on land use, constituents of concern in stormwater and its relation to particle size, and regional rainfall patterns or runoff characteristics. Stormwater characterization helps the designer to understand the extent of the pollutant problem so that appropriate solutions can be determined, optimized and applied.

Clear treatment objectives help to facilitate the development of effective solutions. Since a range of physical, chemical and biological processes can occur within stormwater treatment measures, treatment objectives may be grouped into different levels. Similar to wastewater treatment, levels of treatment can be categorized into primary, secondary and tertiary treatment (NSW EPA, 1997). Primary treatment would provide screening for gross pollutants and sedimentation of coarse particles. Secondary treatment would achieve removal of finer particles, and filtration processes would improve the removal of sediment and some nutrients and metals. Tertiary level treatment would provide enhanced sedimentation and filtration as well as biological uptake which would improve retention of nutrients and heavy metals (NSW EPA, 1997). PSD removal goals should be explicitly defined for each level of treatment. By defining a hierarchy of treatment levels, dominant treatment processes are grouped, and treatment goals and solutions become more apparent.

With influent characteristics identified, and treatment levels established, the design criteria for manufactured BMPs can be developed. The design criteria should identify PSD removal targets for each treatment level, concentrations ranges to be expected in the influent, removal efficiencies required with respect to influent characteristics, water quality flow rates to be treated, and bypass to be mandatory for scour prevention. USEPA (2002) recognized that although these large (2 to 100 year) storms may contain significant pollutant loads, their infrequent occurrence would result in a small contribution to the annual average pollutant load. As such, they recognize that designing stormwater quality treatment systems to treat the majority of the annual runoff volume is the more appropriate approach since treatment of the majority of the annual pollutant load would be addressed. The design capacity of the BMP can be determined by analyzing historical rainfall data (15 minute resolution data preferred) to find the flow rate associated with contributing to the majority of the annual runoff volume. To ensure net positive long term removal, the manufactured BMP design must be able to bypass the infrequent high flows. Flows in excess of the design capacity should be bypassed to ensure that re-suspension does not occur during any hydrologic flow condition. The bypass feature must completely isolate excess flows from the treatment chamber such that the surface loading rate in the treatment chamber does not exceed its designed rate. As previously mentioned, turbulence, eddies and high surface loading can reduce particle settling and re-suspend settled material.

CONCLUSION

Since NPDES Phase I and II stormwater ruling, owners/operators are required to address polluted stormwater discharges by treating stormwater runoff from sites one acre in size or greater. As such, the demand for innovative solutions to address stormwater treatment requirements introduced numerous manufactured BMP technologies into the market.

At present, the design challenge in stormwater treatment is achieving a water quality outcome based on general and unclear performance requirements. Stormwater quality and quantity treatment guidance manuals, developed by the state government, are generally focused on design of traditional stormwater BMPs and little guidance is provided for the design and application of manufactured BMPs. As a result, regional and local governments are left to devise what they feel to be appropriate design criteria. The lack of uniformity in performance claims and sizing methodologies between manufactured technologies makes this task challenging. As a result, design criteria vary with location. The design guidelines are often general and at times counterproductive to achieving a stormwater quality outcome due to the focus on quantity treatment rather than quality treatment.

This paper examined examples of regional and local government design criteria for manufactured BMPs. The discussion focused on guidance for TSS removal from stormwater runoff and how it can be improved.

In most case, the design basis or influent characteristics are not clearly defined. The criterion "percent removal" of a pollutant on its own is an unclear measure of BMP performance. PSD removal targets, if identified, do not reflect a clear treatment objective since the PSD typically found in stormwater (i.e. silts and clays) may not be addressed for removal. Additionally, the focus of treating design storms rather than small frequent occurrence storms that contribute to the majority of the stormwater runoff volume can be counterproductive to achieving an improved water quality outcome including particle settling, pollutant retention and scour prevention.

The dynamics of BMP performance is dependent on influent particle size, sediment concentration, constituents of pollutants with respect to particle size, and stormwater runoff characteristics. Removal efficiencies in settling operations change with influent concentration: higher influent concentration result in higher removal efficiencies and lower influent concentrations result in lower removal efficiencies. Experts have determined that finer particles such as clays and silt have high surface areas and typically adsorb a higher fraction of pollutants. Due to more research in this field, stormwater professionals are realizing that small storms dominate watershed hydrologic parameters typically associated with water quality management issues and BMP design.

To achieve an intended water quality outcome, it is necessary to understand the characteristics of the untreated stormwater runoff and quantify treatment objectives before design criteria can be adequately developed.

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