Critical assessment of stormwater treatment and control selection issues - Implications and recommendations for design standards.

Analyse critique des solutions de traitement et de contrôle des eaux pluviales : implications et recommandations pour des normes de dimensionnement

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RESUME

Des travaux de recherche pour la Water Environment Research Foundation (WERF) et le National Cooperative Highway Research Program (NCHRP) ont conduit au développement d'une méthodologie basée sur des procédés unitaires pour la sélection et la conception de MPGs par le biais de l'application de principes d'ingénierie scientifiquement solide. Ces travaux recommandent l'utilisation d'une conception de procédé unitaire fondamental combiné et d'une méthodologie de données de performances d'observation qui mettent l'accent sur l'importance de l'adéquation des objectifs de qualité de l'eau requis. Cet article recommande une modalité d'application des résultats de ces travaux pour le développement de normes ou exigences pour répondre aux permis de charges quotidiennes maximales totales et de système d'élimination de rejets des polluants dans les eaux pluviales. Des exemples sont fournis.

ABSTRACT

Research efforts for Water Environment Research Foundation (WERF) and the National Cooperative Highway Research Program (NCHRP) have resulted in the development of a unit processes based methodology for BMP selection and design through the application of basic scientifically sound engineering principals. The efforts recommend using a combined fundamental unit process design and observational performance data methodology that emphasizes the importance of matching desired water quality goals. This paper recommends how the research findings of these efforts should be applied to the development of design standards/requirements for addressing Total Maximum Daily Loads (TMDLs) and National Pollutant Discharge Elimination System (NPDES) Stormwater Permits. Examples are presented.

KEYWORDS

Best Management Practice, Design, Stormwater Design Standards, Stormwater Treatment, Unit Processes

1 INTRODUCTION

Research conducted by the authors under the Water Environment Research Foundation (WERF) project “Critical Assessment of Stormwater Treatment and Control Selection Issues” (Strecker et. al, 2005) and the United States National Cooperative Highway Research Program (NCHRP) project “Evaluation of Best Management Practices for Highway Runoff Control” (Huber et. al., in publication) sought to advance the state of the practice of stormwater design through the application of basic scientifically sound engineering principals using a combined fundamental unit process design and observational performance data methodology. The research findings have been incorporated into guidance manuals aimed at both the design of highway runoff controls and, in the case of the WERF guidance documents, stormwater treatment approaches.

The intent of these manuals is to provide a means for better applying research on the relationship between design and performance that specifically emphases the importance of matching water quality goals to fundamental unit processes. To that end, the research discussed in this paper has integrated findings from a number of sources including work by the authors conducted as part of the International Stormwater Best Management Practices Database project (Strecker, et. al., 2005 and www.bmpdatabase.org) as well as the above referenced projects.

It is important to recognize that this effort focuses on separated stormwater systems. Much of the efforts in Europe and other parts of the world have been on addressing combined sewer systems. While many of the recommendations in this paper would also apply to combined sewerage systems, in this paper we are focused on separated systems.

To date in the United States and in many other locations around the world, the requirements for BMPs (stormwater treatment controls) has been primarily focused on the size of a storm that one must treat and much less attention has been paid to the types of controls that should be employed such that specific pollutants of concern are addressed. The effort of setting the treatment storm size in many cases has not been established utilizing a unit processes based approach. For example, many standards have been set by analyzing the 24-hour rainfall statistics without consideration of the fact that storms rarely end at midnight and even more importantly that storms can arrive back-to-back and therefore a design based upon a 24-hour storm basis may result in storage (volume) based-systems that are quickly overwhelmed by back-to-back storms. In addition, many of the BMPs employed are really not affected as much by the size of a storm, but are more “flow-through” (rate) based and therefore it is more appropriate to set the sizing of these systems by analysis of precipitation time series such as hourly or 15-minute data sets.

When water quality is considered for BMP standards, it is usually focused on total suspended solids (TSS) as a surrogate for other pollutants of concern. Most BMP “acceptance” or “approval” efforts (Washington State Department of Ecology, 2004) and Technology Acceptance Reciprocity Partnership, 2003) have focused almost exclusively on TSS and percent removals being demonstrated. First, percent removal as a measure of BMP performance has become increasingly discredited (Strecker et. al. 2001; 2004) due to the fact that BMPs have demonstrated an ability to achieve a relatively consistent effluent quality and therefore percent removal is a function of how “dirty” the inflow is. Probably even more problematic then this is the fact that there are many other pollutants of concern, only some of which are to varying degrees associated with fine particulates. Rarely, if ever, have design standards been developed that properly address the pollutants of concern (i.e., to meet a pollutant specific TMDL or specifically address receiving water impairments.)

Research findings should be applied to the development of design standards and guidance that are targeted to the pollutants and parameters of concern. Fundamentally it is critical that when developing design guidance, one should consider the pollutants of concern, their form, and how they arrive (e.g. runoff rates and volumes) to then determine what the physical, biological, and/or treatment processes that would be required to address the concerns. The potential physical impacts, including stream instability, of runoff should also be addressed where these are an issue.

This paper briefly presents examples of how this work is being applied in projects, including the Lake Tahoe Total Maximum Daily Load (TMDL) effort and a number of large Southern California large scale development projects.

2 RECOMMENDED APPROACH FOR SETTING STORMWATER DESIGN STANDARDS

We have developed a recommended 7-step process for the selection and design of BMPs (Strecker, et. al.2005) as shown in Figure 1. This same process is applicable for the development of design standards and/or requirements at the municipal, regional, or state level. Certainly the more localized the level, the greater ability to target the BMP requirements to local conditions. The following sections provide our recommended approach for applying this methodology for setting design standards or requirements for stormwater management systems.

2.1 Problem definition

In this initial phase of the development (or revision of existing standards) of design standards, we recommend that a list of objectives be developed for the design standards that list the desired outcomes for projects that utilize the standards, including new development. Re-development, and/or required retrofit projects. Table 1 lists potential objectives that one should consider in the development of stormwater BMP design standards.

2.2 Characterize range of site conditions and constraints

The next step in the development of design standards is to characterize the range of site conditions and constraints that will be faced by BMP treatment projects within the applicable area as well as the “pollutants and parameters of concern.” This step is critical for the identification of appropriate solutions to runoff management problems for the local area. Site conditions can significantly influence runoff treatability and hydraulic and hydrologic controls. Through careful characterization of the hydrologic, geologic, and anthropogenic factors that may affect urban runoff quantity and quality, as well as the specific pollutants that should be addressed, the applicable Fundamental Process Categories (FPCs) available for runoff management practices that meet the identified project objectives can be identified. Note that we are not advocating that design standards be developed on a regional basis to address every pollutant of concern for all of the applicable watersheds. On the other hand, we are recommending that the standards should address those pollutants and parameters that are problematic in many, if not most, of the watershed and those that are known to generally be of concern in urban runoff. That is, we recommend that design standards be developed such that one would expect that most TMDLs or other pollutants that are listed as impairing water bodies would be addressed.

2.3 Identify applicable fundamental process categories

In the development of BMP requirements few have seldom assessed what unit operations and processes (UOP) would need to be included in "approved" BMPs based on an understanding of water quality (chemistry) and quantity. Most existing requirements and BMP guidance focuses the design process on selecting "BMPs" that are expected to or have been shown in some manner to treat a surrogate pollutant such as total suspended solids (TSS) consistent with some stipulated performance measure (e.g., 80% TSS removal) with little attention paid to the unit treatment operations and processes (UOPs) that occur within those BMPs or the achievable effluent quality. The recommended approach advocated for development of BMP requirements is to identify the UOPs that will address the pollutants of concern, their phases (i.e. dissolved vs. particulate), based on their chemistry (i.e. metal species), or based on their granulometric characteristics (i.e. size, specific gravity) and then require that projects individually select the components of a treatment system to meet design requirements based on those UOPs. This recommendation is key to the success or failure of the UOP design, the operation and the maintenance of the UOP.

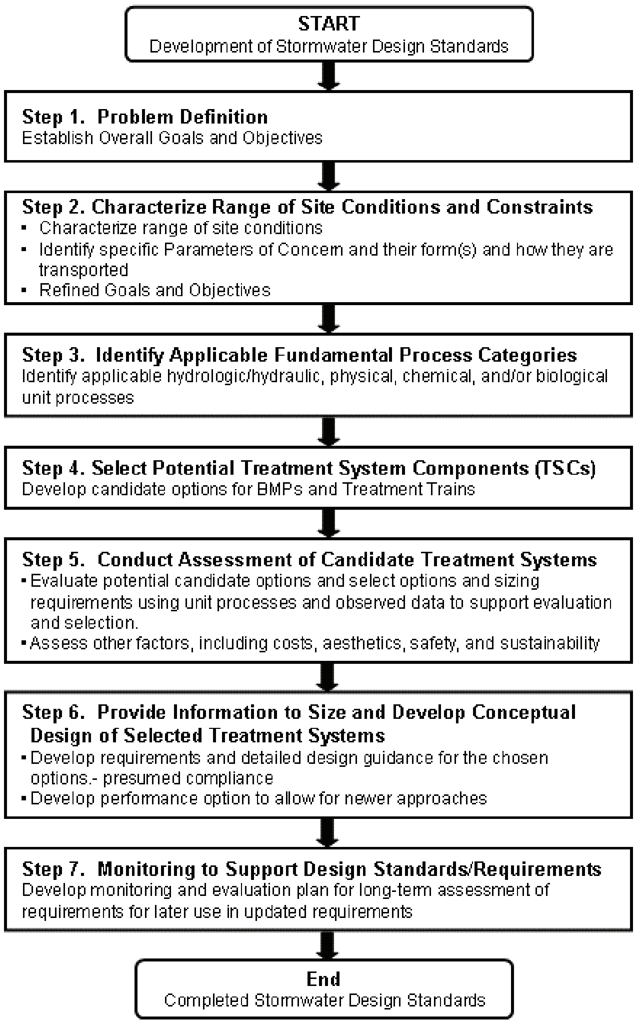

Figure 1. 7 Step Process for Development of Design Standards for Stormwater BMPs

Many stormwater pollutant control mechanisms are similar to fundamental unit operations and processes (UOPs) used to remove various constituents found in wastewater (Metcalf and Eddy, 2002). However, experience over the last decade has demonstrated that there continues to be a significant gap in knowledge between stormwater treatment system design/analyses and fundamental unit operations and processes that can demonstrate treatment viability as a function of the physical and chemical characteristics of stormwater loadings. This knowledge requires identification of treatment mechanisms and rates, partitioning of pollutants between dissolved and particulate forms (e.g. heavy metals for example), physical-chemical characteristics of transported particulate matter, and the management of residuals separated through treatment operations. It is also important to factor into treatment effectiveness evaluations of their effect on downstream hydraulic conditions.

Category	Typical Objectives of Urban Runoff Management/Stormwater Treatment Systems
Hydraulics	Manage flow characteristics upstream, within, and/or downstream of BMP
Hydrology	Mitigate floods; improve runoff characteristics (peak shaving)
Water Quality	Reduce downstream pollutant loads and concentrations of pollutants
	Improve/minimize downstream temperature impact
	Achieve desired pollutant concentration in outflow
	Remove litter and debris
Toxicity	Reduce acute toxicity of runoff
	Reduce chronic toxicity of runoff
Regulatory	Comply with NPDES permit
	Meet local, state, or federal water quality criteria
Implementation	Function within management and oversight structure
Cost	Minimize capital, operation, and maintenance costs
Aesthetic	Improve appearance of site and avoid odor or nuisance
Maintenance	Operate within maintenance, and repair schedule and requirements
	Design system to allow for retrofit, modification, or expansion
Longevity	Achieve long-term functionality
Resources	Improve downstream aquatic environment/erosion control
	Improve wildlife habitat
	Achieve multiple use functionality
Safety, Risk and Liability	Function without significant risk or liability
	Function with minimal environmental risk downstream
	Contain spills
Public Perception	Clarify public understanding of runoff quality, quantity and impacts on receiving waters

Table 1. Urban runoff management objectives checklist (adapted from ASCE/EPA, 2002)

Treatment system components (TSCs) include conventional design elements, such as swales, ponds, tanks, etc., but also include pre-treatment devices (e.g., hydrodynamic devices, trash racks, catch basin screens, etc.), custom hydraulic controls (e.g., flow splitters, weirs, orifices, etc.), and tertiary enhancements (e.g., soil amendments, carefully selected vegetative species, incorporation of biological removal mechanisms). All UOPs can be organized according to four fundamental process categories (FPCs): hydrologic/hydraulic controls, physical operations, biological processes, and chemical processes. Table 2 provides a summary of the FPCs, the individual UOPs, and the associated TSCs typically chosen to provide the UOP. When developing design standards, one should include a requirement to include the applicable UOPs in the resulting BMP or BMPs that would then be required.

2.4 Select potential treatment system components (TSCs)

Treatment system components (TSCs) are the fundamental elements of a stormwater treatment system. Each TSC provides at least one unit treatment operation or process. For instance, a dry detention basin is a TSC that provides both sedimentation and detention amongst other unit processes. The integrated unit process design approach recommends that after the potential unit treatment processes that provide water quality or quantity benefits in conjunction with project goals have been identified, the TSCs that include those processes should be selected. For purposes of design requirements, we recommended that the options for addressing design standards include potential combinations of TSCs that one could utilize for meeting the requirements. These could be developed as “packages” that if one utilized would be presumed to meet the overall stormwater management requirements.

It is important to note that many TSCs include multiple unit processes at varying levels of effectiveness. Therefore, the placement of these components in relation to one another in a treatment system must be carefully considered in development of potential packages of BMPs. The design methodology incorporates consideration of five broad categories of treatment system components in the order at which they are typically placed, but not limited to, in a treatment train:

- hydrologic/hydraulic control TSCs,
- pretreatment TSCs,
- conventional TSCs,
- tertiary enhancements, and
- hydraulic enhancement controls.

There are tools in the reference guidance (Strecker, et. al., 2005) to assist users in evaluating the best available information about the performance of TSCs, much of the information about field performance of treatment system components comes from study of wet weather controls that include only one TSC. Many TSCs, however have not been evaluated sufficiently in the field and thus designers must currently rely on pilot scale, laboratory, and theoretical information to evaluate these processes. In many cases models can be quite helpful in these evaluations. For some pollutants, we show how one could apply modelling of fundamental unit processes such as particle settling theory to ascertain the potential performance of BMPs on fine particulates as an example.

2.5 Conduct assessment of candidate treatment systems

This is likely the most critical step in development of design standards that can be accepted by the community (e.g. developers, etc.) subject to design standards. One of the fundamental reasons that design standard development efforts have been controversial, is that those developing the standards have not developed examples of what would result from the design standards including performance, aesthetics, and costs as well as other attributes. In many cases, it has been a “battle” over a storm size that must be treated, with little or no objective and visual information to base a decision upon. Although there are a large number of factors to consider in evaluating potential candidate treatment systems, the two that are focused on in the technical guidance developed are: 1) evaluation of expected performance, and 2) cost considerations. However, we also highly recommend that, for example, in the standards development process that landscape architects be involve in developing schematic visualizations of what potential control measure scenarios might look like so that interested parties can assess those potential effects as well as the space that BMPs may take up. This is particularly applicable for “above-ground” systems.

We believe strongly that one should employ the long-term simulation models such as SWMM to assess the potential performance of candidate stormwater treatment systems when one is developing design standards. The standards themselves should generally be simple (such as use of a design storm or flow rate or use of nomographs with defined TSCs) such that typical land development engineers can implement them readily. However it is critical that proposed standards be tested, including an evaluation of the proposed sizing and hydraulics via long-term simulation modelling combine with performance information for assessing the potential water quality performance of the required TSCs. Performance information is available from the International Stormwater BMP Database Project (see Strecker et. al 2003 and Strecker et al. 2004) and in a series of pollutant fact sheets (available at www.bmpdatabase.org). The fact sheets allow are a tool for those that develop design standards to focus efforts on mechanisms and processes that are pollutant type and form specific and quickly get a summary of the state of the practice for that particular pollutant, including expected wet weather control system performance. We believe that it would be very beneficial to also assess the potential hydrological benefits of potential BMPs and consider allowing “credit” in effect for those BMPs that have been shown to reduce runoff volumes (which in turn also reduces runoff loads). Tools for assessing cost information are available in Strecker (2005). The end of the step is the resulting BMP treatment train designs that would be allowed for use in meeting the communities stormwater design standards.

2.6 Provide information to size and develop conceptual design of selected treatment systems

BMP design involves a myriad of details from hydrologic/hydraulics (e.g. outlet structures) to soil specifications (e.g. to insure that biofiltration system effectiveness is maximized). Extensive hydrologic and hydraulic design guidelines are included in many existing references. The key is to ensure that detention basins for example include an outlet structure that would provide the desired detention of flows while also performing without constant maintenance. An example reference for detailed design information is WERF/ASCE (1998).

2.7 Monitoring to support design standards and requirements

It is recommended that as standards are developed applying the approaches described above that a monitoring program be designed with this development process with the intention of being able to ascertain whether the resulting designs are meeting water quality goals, including whether they are being built according to the design requirements as well as whether resulting designs are achieved predicted results. The referenced WERF and NCHRP manuals both include guidance on monitoring as well as the International BMP Database.

3 APPLICATIONS

There are several examples of where the approaches described above are being applied. These include development of the Lake Tahoe TMDL. For Lake Tahoe, the approach has been used in the development of the TMDLs in an attempt to set a TMDL that is achievable given the current understanding of BMP performance as shown in Figure 2. Note that a bigger BMP is not always a better performer. It is now being utilized to create a spreadsheet based “pollutant crediting” tool, that includes SWMM running in the background, that could be used for assessing and crediting urban retrofit best management practice treatment and source controls. Ultimately, it could serve as the basis for ranking projects and used by land development engineers for determining compliance options for meeting TMDLs and stormwater permit compliance. In Southern California, it has been used to show how New

Development project with a combination of low impact development controls and more traditional BMPs can meet specific TMDLs and water quality criteria.

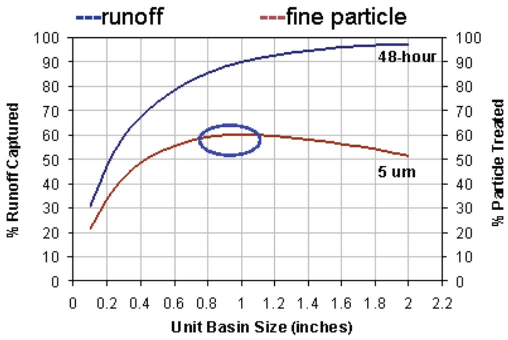

Figure 2. Unit Sizing of BMPs vs. Percent Runoff Captured (treated) and % of 5 micron particles removed at Lake Tahoe

4 SUMMARY

This paper has discussed the need for and recommendations regarding methods for development of stormwater design standards that utilize a more science and engineering based approach that includes consideration of unit processes and observational data.

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