1 The Use of Best Management Practices (BMPs) in Urban Watersheds - Executive Summary

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1.1 INTRODUCTION

Diffuse source pollution is one of the most intricate environmental problems with extensive impacts on surface and groundwater quality. It is a major factor impacting the quality of water supply, and the rate at which diffuse source pollutants are generated and delivered to water resources is greatly affected by anthropogenic activities as well as natural processes. The main hydrologic component transporting these pollutants to surface water bodies is runoff, which results from precipitation or snowmelt (Leeds *et al.*, 1993). Stormwater is part of a natural hydrologic process; however, human activities, especially urban development and agriculture, cause significant changes in patterns of stormwater flow from land into receiving waters. Urban runoff can be or is often a significant source of water pollution, causing decline in fisheries, swimming, and other beneficial attributes of water resources (U.S. EPA, 1993). Urban stormwater runoff includes all flows discharged from urban land uses into stormwater conveyance systems and receiving waters; in this context, urban runoff includes both dry-weather non-stormwater sources (e.g., runoff from landscape irrigation, dewatering, and water line and hydrant flushing) and wet-weather stormwater runoff. Water quality can also be affected when runoff carries sediment and other pollutants into streams, wetlands, lakes, estuarine and marine waters, or groundwater. The costs and impacts of water pollution from urban runoff are significant and can include:

- fish kills,
- health concerns of human and/or terrestrial animals,
- degraded drinking water,
- diminished water-based recreation and tourism opportunities,

- economic losses to commercial fishing and aquaculture industries,
- lowered real estate values,
- damage to habitat of fish and other aquatic organisms,
- inevitable costs of clean-up and pollution reduction,
- reduced aesthetic values of lakes, streams, and coastal areas, and
- other impacts (Leeds *et al.*, 1993).

Increased stormwater flows from urbanization have the following major impacts (FLOW, 2003):

- acceleration of stream velocities and degradation of stream channels,
- declining water quality due to washing off of accumulated pollutants from impervious surfaces to local waterways, and an increase in siltation and erosion of soils from pervious areas subject to increased runoff,
- increase in volume of runoff with higher pollutant concentrations that reduces receiving water dilution effects,
- diminished groundwater recharge, resulting in decreased dry-weather flows; poorer water quality of streams during low flows; increased stream temperatures; and, greater annual pollutant load delivery,
- increased flooding,
- combined and sanitary sewer overflows due to stormwater infiltration and inflow,
- damage to stream and aquatic life resulting from suspended solids accumulation, and
- increased health risks to humans from trash and debris which can also endanger and destroy food sources or habitats of aquatic life (FLOW, 2003).

The major categories of stormwater pollutants, their sources, and related impacts are presented in Table 1-1.

Table 1-1. Major Categories of Stormwater Pollutants, Sources and Related Impacts

Stormwater Pollutant	**Major Sources**	**Related Impacts**
Nutrients: Nitrogen, Phosphorus	Urban runoff; failing septic systems; croplands; nurseries; orchards; livestock operations; gardens; lawns; forests; fertilizers; construction soil losses	Algal growth; reduced clarity; lower dissolved oxygen; release of other pollutants; visual impairment; recreational impacts; water supply impairment

Solids: Sediment (clean and contaminated)	Construction sites; other disturbed and/or non-vegetated lands; road sanding; urban runoff; mining operations; logging operations; streambank and shoreline erosion	Increased turbidity; reduced clarity; lower dissolved oxygen; deposition of sediments; smothering of aquatic habitat including spawning sites; sediment and benthic toxicity
Oxygen-depleting substances	Biodegradable organic material such as plant; fish; animal matter; leaves; lawn clippings; sewage; manure; shellfish processing waste; milk solids; other food processing wastes; antifreeze/other de-icing chemicals; other applied chemicals	Suffocation or stress of adult fish, resulting in fish kills; reduction in fish reproduction by suffocation/stress of sensitive eggs and larvae; aquatic larvae kills; increased anaerobic bacterial activity resulting in noxious gases or foul odors often associated with polluted water bodies; release of particulate bound pollutants
Pathogens: Bacteria, Viruses, Protozoans	Domestic and natural animal wastes; urban runoff; failing septic systems; landfills; illegal cross-connections to sanitary sewers; natural generation	Human health risks via drinking water supplies; contaminated shellfish growing areas and swimming beaches; incidental ingestion or contact
Metals: Lead, Copper, Cadmium, Zinc, Mercury, Chromium, Aluminum, others	Industrial processes; mining operations; normal wear of automobile brake pads and tires; automobile emissions; automobile fluid leaks; metal roofs; gutters; landfills; corrosion; urban runoff; soil erosion; atmospheric deposition; contaminated soils	Toxicity of water column and sediment; bioaccumulation in aquatic species and through food chain

Hydrocarbons: Oil and Grease, Polyaromatic hydrocarbons (PAHs) - e.g., Naphthalenes, Pyrenes	Industrial processes; automobile wear; automobile emissions; automobile fluid leaks; waste oil	Toxicity of water column and sediment; bioaccumulation in aquatic species and through food chain; lower dissolved oxygen (DO); coating of aquatic organism gills/impact on respiration
Organics: Pesticides, Polychlorinated biphenyls (PCBs), Synthetic chemicals	Applied pesticides (herbicides, insecticides, fungicides, rodenticides, etc.); industrial processes; nurseries; orchards; lawns; gardens; historically contaminated soils/wash-off	Toxicity of water column and sediment; bioaccumulation in aquatic species and through food chain
Inorganic Acids and Salts (sulphuric acid, sodium chloride)	Irrigated lands; mining operations; landfills; road salting and uncovered salt storage	Toxicity of water column and sediment

(Leeds *et al.*, 1993; MA DEP and MA CZM, 1997; U.S. EPA, 2000)

1.2 THE CONCEPT OF BMPS

The undesirable impacts of stormwater runoff can be controlled by prudent management efforts. Stormwater management encompasses an array of measures that involve careful application of site design principles, construction techniques to prevent sediments and other pollutants from being released and/or entering surface or groundwater, source controls, and treatment of runoff to reduce pollutants and reducing the impact of altered hydrology.

For many years, federal and state regulations for stormwater management efforts were oriented towards flood control with minimum measures directed towards improving the quality of stormwater such as sediments and erosion control and the reduction of pollutants. The U.S. recognized the problem of diffuse pollution many years ago and established provisions in a major amendment to the Clean Water Act in 1987, leading to national programs of action to address the issue. The increased awareness of the need to improve water quality in the last two decades resulted in the concept of best management practices (BMPs) which are measures intended to provide an on-the-ground practical solution to diffuse pollution problems from all sources and sectors (D'Arcy and Frost, 2001). BMPs are technology and education based requirements in the federal stormwater regulations that call for the implementation of controls to reduce the discharge of pollutants to the Maximum Extent Practicable (MEP) in municipal-type stormwater systems (Caltrans, 2002). BMP refers to operational activities, physical controls or educational measures that are applied to reduce the discharge of pollutants and minimize potential impacts upon receiving waters, and accordingly, refers to both structural and nonstructural practices that have direct impacts on the release, transport, or discharge of pollutants.

The proper management of stormwater runoff is necessary to reduce stream channel erosion, pollution, siltation, sedimentation, and local flooding, all of which have adverse impacts on the land, water resources, and the people. The BMP program was increasingly designed in the 1980s primarily to address pollution from wet-weather flow (WWF) and polluted runoff and focused on controlling runoff increases and reducing water quality degradation associated with new development. The goal of these practices is to maintain the predevelopment characteristics as close as possible, even after development of a site, and/or to reduce the impacts to an accepted level. It must be understood in this context that BMPs do not merely act as controls for new development, but these practices equally apply to existing developments as well as areas that have undergone any kind of re-development.

The BMP concept has the following key elements (D'Arcy and Frost, 2001):

- There is a need for guidance that offers practical prevention options.
- The options need to be defined and explicit best practice rather than ill-defined individual interpretations of what is required.
- The options should be describable as best practice, based on research and experience.

Since the development of BMPs, various state and local governments have adopted a profusion of laws, regulations, and policies to encourage or mandate the use of urban BMPs. These BMPs have been developed and refined to mitigate some, if not all, of the adverse impacts associated with any kind of development/re-development activity. The capabilities of each BMP are unique. This needs to be recognized along with its limitations, and these factors, in addition to the physical constraints at the site, need to be judiciously balanced with the overall management objectives for the watershed in question. At a minimum, a BMP program developed for a site should strive to accomplish the following set of criteria:

- Reproduce, as nearly as possible, the natural hydrological conditions in the stream prior to development or any previous human alteration (Schueler, 1987; Young *et al.*, 1996).
- Provide a moderate to high level of removal for most urban pollutants as one of a set of BMPs in the watershed working together to achieve desired receiving-water quality.
- Be appropriate for the site, given physical constraints.
- Be reasonably cost-effective in comparison with other BMPs.
- Have an acceptable future maintenance burden.
- Have a neutral impact on the natural and human environment.

The purpose of this white paper is to provide a general description and insight on the various BMP options, the design considerations involved and the general guidelines for selection, implementation, and monitoring of BMPs to reduce pollutants in urban stormwater from new development and re-development. As the main focus of this white paper is structural BMPs, the various nonstructural practices is discussed only briefly. This white paper however, does not intend to dictate or specify the actual selection of BMPs, but attempts to provide the framework for an informed selection of BMPs for any stormwater management program.

1.3 SUMMARY AND FINDINGS OF THE WHITE PAPER

Chapter 2 provides a general discussion of the most commonly used nonstructural and structural BMPs for the management of urban storm runoff. The introduction defines what a BMP is and describes what structural and nonstructural BMPs are. The chapter discusses how the distinction between structural and nonstructural BMPs is quite clear in many cases, and not entirely so in the case of some other BMPs. Some good examples related to emerging concepts in runoff management are presented, such as better site design and Low-Impact Development (LID) techniques e.g., green roofs (Section 2.1), that focus on the use of both site planning and small-scale treatment approaches. These practices reinforce the growing opinion that a combination of both structural and nonstructural practices in a treatment train approach is almost certainly a better option to meet stormwater management objectives for many project sites. Section 2.2 briefly describes the types of structural BMPs currently being used and recommended by the U.S. EPA's menu of BMPs (U.S. EPA, 2001) and several state agencies. The general advantages and limitations of each of these BMPs are also discussed. Section 2.3 focuses on the major physicochemical and biological processes in BMPs and how they influence the removal of pollutants and mitigate other stressors from stormwater, and section 2.4 presents a brief overview of the factors influencing the performance of these structural BMPs.

In Chapter 3, Structural BMP Design Practices, the factors that need to be considered in designing urban BMPs are discussed. The following eight BMPs commonly used for stormwater treatment in new development are addressed: (i) dry extended-detention ponds; (ii) wet ponds; (iii) stormwater wetlands; (iv) grassed swales; (v) vegetated filter strips; (vi) infiltration trenches; (vii) porous pavement; and, (viii) sand and organic filters. As an introduction, Section 3.1 traces the development of the concept of BMPs from earlier stormwater management measures that first relied heavily on flood and then water quantity control to the current focus on controlling both the quality and quantity of runoff in order to mitigate the impacts to receiving waters. Section 3.2 briefly explains the sizing criteria involved in BMP design considerations and describes the performance objectives of these BMPs. Section 3.3 describes the design considerations for the above-mentioned eight BMPs in detail in separate subsections 3.3.1 - 3.3.8. Each subsection on a specific BMP carries a brief description of the BMP and how it addresses the two issues of stormwater control as well as pollutant removal. Each subsection also has a detailed presentation on the general design considerations including, site suitability, physical specifications, and geometry.

The design and construction of stormwater BMPs is a constantly evolving process in that there does not appear to exist a "100 % fool-proof" design for a single BMP that can achieve the entire spectrum of desirable stormwater benefits in a watershed. A clear understanding of the key mechanisms within a BMP for effluent load reductions and factors that govern these processes is a primary requirement in designing a BMP. On the same note, it must be mentioned that there has been no "exact" or "perfect" design to date. Performance variations in BMPs discussed in Chapter 2 is a fallout of these differences in design characteristics. Chapter 3 identifies the following key issues which need to be addressed in order to improve the design of stormwater BMPs:

- Influent mass loadings should be defined more clearly by considering all associated parameters that include flow rate, pollutant concentrations and their chemical forms, suspended solids and their settling velocities, dissolved solids, and the size apportionment of pollutants in the solid phase.
- Approaches to designing BMPs should focus on frequently-occurring smaller storms; the focus should be on characterizing influent load in such smaller storms and especially the parameters of concern in each watershed.
- BMP design should integrate engineering principles with hydrological characteristics, BMP performance objectives, flow attenuation, and flood control, and should incorporate design features that would enhance the BMP capability in treating the stressor(s) of concern.
- Designers should realize that one BMPs is not adequate to address the above mentioned issues and should consider the use of a treatment train; i.e., a combination of structural and nonstructural BMPs in stormwater treatment programs.

BMP Monitoring, Chapter 4, covers the complexities in developing a BMP monitoring program that yields useful results. Some difficulties and criticisms with current BMP monitoring practices are discussed in Section 4.1. This section identifies many key areas of BMP monitoring programs that require improvement in order for the data of such programs to be widely applicable. Sections 4.2 through 4.5 contain recommendations and explanations of how to ameliorate these deficiencies. Selection of appropriate parameters is covered in Section 4.2. Considerations and difficulties with monitoring nonstructural BMPs and watersheds as a whole are presented in Sections 4.3 and 4.4, respectively. Guidance on the development of a robust structural BMP effectiveness monitoring program is presented in Section 4.5. This section includes information and recommendations on planning, designing, implementing, and evaluating BMP monitoring programs. Methods for data analysis, which is particularly inconsistent between studies, is discussed in subsection 4.5.4. After reading this section, the reader should have a good handle on the problems and complexities associated with BMP effectiveness monitoring programs. The reader should also be equipped with the general knowledge and understanding necessary to develop a successful BMP monitoring program, complete with representative, quality assured, and statistically analyzed results.

BMP monitoring, especially for effectiveness, is a very complex undertaking. The number of variables that affect the resulting efficiency of a BMP is large. This, along with nonuniform sampling and analysis techniques used in current monitoring programs, has led to a wide degree of variability in reported BMP performances. The selection of appropriate pollutants is one of the most fundamental requirements in a robust BMP monitoring program. Due to the large number of variables involved in BMP performance, selecting a reasonable number of suitable parameters is difficult and requires experience and good guidance. Nonstructural BMPs have even more complications with respect to monitoring effectiveness. Without a defined influent and effluent, monitoring programs usually rely on public surveys or watershed monitoring approaches. Watershed monitoring approaches, while seemingly economical when a large number of BMPs require monitoring, is wrought with interferences from outside sources unrelated to BMPs, such as intrusion of contaminated groundwater or the inability to distinguish individual BMP performance. Thus, data from these types of monitoring programs may not be able to produce the results that shed light on the effectiveness of BMPs within the watershed.

Four steps have been outlined to monitor the effectiveness of structural BMPs. This guideline assists in the development of a robust monitoring program from planning and design phases, through the implementation and evaluation phases. A BMP monitoring program should always be initiated with clear goals and specific objectives backed by supporting background information. This foundation will minimize the risk of collecting data that is not useful. Once the goals and objectives are identified, a quality assurance project plan (QAPP) translates objectives into a plan of action. Producing a useful QAPP requires a significant amount of time upfront before any samples are taken. Although it may seem at first to be a tedious exercise, it will likely save time and money in the long run by ensuring the significance of the data collected. Design aspects, such as monitoring approach, parameter and methods selection, specifics on hydraulic, hydrologic, and water quality data collection, and methods of analysis, equipment selection, and quality assurance/quality control measures should all be clearly stated in the QAPP. Hydrologic and hydraulic (H&H) data is one of the most essential components of a well designed monitoring program. Poor quality H&H data will produce errors that will propagate through the rest of the results. Whether the QAPP calls for composite or discrete samples, they should always be flow-weighted or synchronized with flow measurements in some way. Representativeness of the collected samples is another key component that is often overlooked in BMP monitoring programs. Guidelines such as percent capture and minimum number of aliquots should be used to ensure each storm event is accurately represented. Once samples are collected, the chosen method of data analysis must provide useful and unbiased results. For example, percent removal is biased against BMPs with relatively clean influent and may not be useful for watersheds with very high influent loads as the resulting effluent, even with high percent removals, would not meet overall water quality objectives; similarly, any method that produces pollutant concentrations instead of loads will be biased against BMPs that rely on infiltration.

When BMPs are used in stormwater management, many issues need to be addressed to ensure that the BMPs are being used as effectively as possible. Chapter 5, Effective use of BMPs in Stormwater Management, covers these issues. The proper selection of a BMP is one key component to the effective use of BMPs in stormwater management. One must consider regulatory constraints, site factors, the ability of the BMP to provide stormwater quality and quantity control, cost, reliability, maintenance burden, and environmental and community acceptance. Section 5.1 walks through all these considerations and provides useful information in tabular format on many of the commonly used BMPs. Structural BMP placement is currently a “hot-button” issue. Key concerns regarding optimum and appropriate placement options are covered in section 5.2. The chapter is rounded out by a discussion of BMP integration.

An integrated approach to stormwater management appears to be the most effective use of BMPs. When multiple layers of structural and nonstructural BMPs are used in unison, the watershed will reap the largest benefit. The selection of BMPs to be used within such an integrated approach (or as single units) is dependant primarily on applicable regulations and estimated water quality and quantity performance. However, it is once again stressed that instead of relying solely on numerical efficiencies reported in the literature, a much deeper understanding of the factors that control BMP pollutant removal performance is essential to proper selection and design of a BMP. Other factors such as site characteristics, cost, reliability, maintenance requirements, and environmental and community acceptance also need consideration to ensure the chosen BMP performs as desired and expected.

BMP placement is a relatively new issue in stormwater management. Currently, political issues such as regulations that require BMPs for approval of new construction permits often control BMP placement. For this reason onsite placement is the only option. Although, onsite placement of BMPs has its advantages, more uniform sub-regional and regional BMP placement have their advantages as well. Recent efforts to identify optimal BMP placement in watersheds through modeling efforts may uphold or challenge the current focus on onsite placement practices.

Chapter 6 provides information on how to estimate the cost of structural BMPs. Costs of nonstructural BMPs are not included here as they are generally not as easily quantified as structural BMPs due to their indirect nature. Section 6.1 covers BMP cost estimating procedures and discusses four common methods of estimating costs. Section 6.2 contains information on total costs which include both capital (construction and land) and annual operation and maintenance costs. BMPs can present several tangible economic benefits in spite of their high construction (in certain cases), operation, and maintenance costs and these are discussed in Section 6.3. At other times, the use of BMPs can result in reduced infrastructure costs.

The cost of constructing any BMP is variable and can be substantial. The cost of constructing a BMP depends on many factors, including the time of year, site conditions and topography, accessibility of equipment, economics of scale, and government regulations. Several documents have been published that address cost estimation for BMPs, but most of these report only construction costs (Young *et al.*, 1996; Sample *et al.*, 2003). In addition, costs are often documented as base costs and do not include land costs, which is the largest variable influencing overall BMP cost (U.S. EPA, 1999). However, in some areas with minimum landscaping requirements, the implementation of standard practices may mean there are no “extra” land costs. The wide range of cost data reported in the literature indicates that much more information is needed in this area.

1.4 CONCLUSIONS AND RECOMMENDATIONS

The use of BMPs to control and treat urban stormwater runoff has become a common practice in urban watershed management. This has been propagated by ordinances developed by local governments that dictate the use of structural and nonstructural BMPs for new and existing development and to protect surface water quality and mitigate the impacts of stormwater runoff on receiving waters. BMPs demonstrate a wide range of pollutant removal capabilities and their performance is affected by several factors, including the long-term variation in rainfall, BMP design characteristics, processes affecting chemical phase and speciation, and environmental conditions. The pollutant removal performance of BMPs is difficult to interpret beyond generalities due to various inter-related and complex parameters; shortcomings in current BMP related studies include:

- lack of long-term monitoring of the processes in a BMP responsible for export or detention/retention of urban stormwater pollutants,
- absence of, or inadequate monitoring within a BMP for water quality, sediment, and vegetation, which would provide a strong understanding of factors and processes that affect pollutant fate within a BMP, and
- variability in BMP performance results not only due to factors affecting the performance of BMPs, but also the methods used to characterize and calculate BMP effectiveness.

Present and future research initiatives on the implementation of structural BMPs for effective stormwater management resulting in water quality and quantity control should address the following issues:

- BMPs can be more effectively managed with a better understanding of the specific physico-chemical and biological processes and interactions that govern the transformation, immobilization and export of pollutants in stormwater. A national approach, similar to the Nationwide Urban Runoff Program (NURP), which would systemize a large number of investigations into a cohesive, well-controlled, program to learn about various BMP functions, physical mechanisms, biochemistry, and design parameters, is very much needed and in fact is underway (Urbonas, 2000). Also, the interactions among these various processes need to be understood. A knowledge of internal dynamics within a BMP, such as a pond or a wetland, is essential to improve upon BMP design and maintenance considerations.

- The type of pollutants studied should include a more extensive array of priority pollutants such as hydrocarbons, toxic inorganics and pathogens. There is less monitoring data available for pollutants such as dissolved and particulate metal species, hydrocarbons, and bacteria, (U.S. EPA, 1999). Bacteria and viruses are rarely sampled in stormwater studies, but a number of microbial pathogens can be present in stormwater and have been implicated in waterborne disease outbreaks in both humans and fish populations (Rushton, 2002). There is a need to improve existing analytical tools and establish new metrics to detect and estimate the concentrations of these pollutants. Two important research priorities include: (i) the need to develop comprehensive methods to assess the heavy metal bioavailability and other toxics following BMP treatment; and, (ii) the development of meaningful metrics to study stormwater pathogens and their ecological and health impacts. The use of conventional means of assessing water quality by only estimating the fecal coliform (FC) count is not applicable to stormwater (O'Shea and Field, 1992; Rushton, 2002). Stormwater has a wider array of pathogens including bacteria, fungi, viruses, and protozoans such as *Cryptosporidium* and *Giardia* that are not well characterized by existing methods including the FC test.

- With regard to monitoring programs, commonly used BMPs such as infiltration trenches, infiltration basins, bioretention practices, and filter strips are seldom monitored (U.S. EPA, 1999). This could be due to the difficulties associated with collecting inflow and outflow samples from these systems. These systems are widely used, yet their effectiveness has not been well documented; pilot-scale research investigations would be a good approach to assess their effectiveness.

- BMP monitoring should be conducted over a relatively long time period (one yr or more) continuously during dry- and wet-weather flow conditions using an influent-effluent mass balance approach. BMP monitoring and data reporting should be more frequent, (e.g., on a monthly and seasonal basis) rather than estimating annual averages of pollutant removal. This temporal scale approach helps to better assess seasonal factors such as thermal stratification of ponds, plant growth and senescence that influence the performance of BMPs. Also, the investigation of dry- weather/low- flow samples would be the key to ascertain if pollutants are released under low flow conditions.

- The current approach in the use of urban BMPs perceives the effect these practices would have just on water quality. BMPs are best characterized by: (i) how much runoff is prevented; (ii) volume of runoff being treated; and, (iii) the quality of the resulting effluent. In addition, BMP objectives should foremost extend beyond water quality and take into account other media including sediments, vegetation, and benthic invertebrates. The role of vegetation, bacteria, and benthic invertebrates in the accumulation and/or breakdown of pollutants need to be more intensively investigated.

- Most of the commonly used structural BMPs extensively rely on sedimentation as the predominant mechanism to remove pollutants from the water column. What is largely ignored is that these contaminated sediments should be subject to appropriate maintenance practices; they have the potential to either leach the organic and inorganic contaminants into the ground below, or may result in pollutant resuspension during high flows or under unfavorable environmental conditions, which include changes in pH and/or the oxidation reduction potential (ORP). Any BMP research or monitoring program should have in its analytical scheme the sediment speciation for contaminant assessment in order to understand the bioavailability and the potential for pollutant resuspension in the water column.

- A large number of BMP studies at present focus on seasonal, short-term monitoring activities; the long-term performance of BMPs (>5 yr) is uncertain. The pollutant removal capabilities of BMPs are likely limited by a finite capacity of sediment/substrate to sorb and retain pollutants. Numerous research findings infer that the longevity of BMPs is linked to the ability of the substrate to assimilate pollutants and maintenance practices (Schueler *et al.*, 1992), lending credence to the need for an evaluation of the long-term performance of these systems.

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