

CRITICAL COMPONENTS FOR SUCCESSFUL PLANNING, DESIGN, CONSTRUCTION AND MAINTENANCE OF STORMWATER BEST MANAGEMENT PRACTICES

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Abstract

This paper presents a common nomenclature for structural stormwater best management practices (BMPs) and reviews the several critical elements that must be addressed to ensure that BMPs meet watershed protection goals. A set of key planning, design and implementation elements is reviewed. The paper documents some of the many possible pitfalls that planners, designers, and local officials are faced with during the BMP implementation process. Several real world examples of successful and failed BMP implementation are cited as illustrations. The old adage, "the devil is in the details," is illustrated to alert stormwater management practitioners to critical components throughout the BMP implementation process.

Introduction

This paper presents a series of suggestions to help implement successful stormwater management best management practices (BMPs). A nomenclature is introduced to understand the context of how planning, design, and construction decisions vary depending on which stormwater practice is being discussed. Next, a series of BMP performance factors are presented to help the reader understand the complex nature that governs BMP effectiveness. Finally, several planning, engineering, construction and maintenance considerations are reviewed that identify specific measures to help engineers, plan reviewers, and regulators implement successful BMPs.

Background

Stormwater BMPs are commonly grouped into one of two broad categories, as so-called "structural" management measures or as "non-structural" measures. For purposes of discussion, structural measures are those that consist of a physical device or practice that is installed to capture and treat stormwater runoff for a prescribed precipitation amount, frequently referred to as either the "water quality volume" or "first flush" volume. Structural BMPs include a wide variety of practices and devices, from large-scale retention ponds and constructed wetlands, to small-scale underground treatment systems, and manufactured devices. Non-structural practices are generally defined as the operational and/or behavior-related practices that attempt to minimize the contact of pollutants with stormwater runoff.

Over the years, there has been a great deal of confusion and uncertainty regarding BMP nomenclature. For example, one person may use the term "wet pond" to describe a retention pond. Another may use the term "retention pond" to describe an infiltration basin because runoff is "retained" within the pond until it is infiltrated into the ground. Both are technically correct, since a wet pond "retains" runoff in a permanent pool and an infiltration basin "retains" runoff within the underlying soils of a basin. This confusion arises

because stormwater practitioners do not have a consistent BMP nomenclature whereby everyone knows what everyone else is talking about. To help provide a consistent basis for comparison and discussion of BMPs, many organizations, state agencies and others are developing naming conventions for the most common stormwater treatment practices. Table 1 lists some of the various widely accepted structural practices and provides a brief description of each. As illustrated in Table 1, the so-called structural practices can be grouped into one of six major categories as ponds, wetlands, infiltration practices, filters, open channels, and other practices. While Table 1 certainly cannot be offered as the "standard" for BMP nomenclature, it recently has been adopted in a series of statewide programs in Vermont, New York, Maryland, and Georgia. Figure 1 illustrates four of the more widely applied of these structural BMPs.

Another area of particular interest and concern to stormwater managers is the question of how effective BMPs actually will be in meeting watershed protection goals, such as helping to achieve total maximum daily load (TMDL) targets or implementation as part of EPA's Phase II Stormwater Program. This raises the question, what watershed management objectives are BMPs being designed to solve? In general, stormwater management measures are called upon to meet one or more of four major watershed planning objectives, including:

- Promoting groundwater recharge
- Reducing pollutant loading to receiving waters
- Minimizing or eliminating accelerated stream channel erosion
- Minimizing or eliminating flooding

The management objective along with any site constraints will dictate which practice, or suite of practices, is employed for implementation. For example, the typical dry detention pond or underground vault does little to reduce pollutant loading, but can be reasonably effective in meeting channel protection and flood control goals (Winer, 2002). Infiltration practices certainly promote groundwater recharge, but rarely are capable of meeting flood control objectives. This paper will concentrate on those components that go into the successful planning, design and implementation of BMPs to reduce pollutant export to receiving waters.

All of the structural stormwater management measures have some capability to remove pollutants, but their effectiveness varies widely depending on the type of practice, design characteristics, site characteristics, target pollutant constituents, and construction and maintenance factors. Watershed managers are increasingly aware that there are limitations and uncertainty to structural BMP effectiveness. Consequently, there is frequently a need to also employ a suite of "non-structural" practices to help meet watershed protection goals. While the uncertainty of the effectiveness of non-structural practices is probably an order of magnitude higher than that of structural BMPs, many practitioners recognize the need to do both.

While there are certainly several options available to watershed managers, the reality is that many practices, both structural and non-structural, may simply be infeasible or impractical in certain situations. Furthermore, there are other considerations, such as cost, unintended environmental consequences, neighborhood acceptance, or maintenance burden that will affect the ultimate selection and implementation of any given stormwater management strategy. The remainder of this paper will focus on those factors affecting structural BMP performance and longevity. This is not to underestimate the role of non-structural BMPs in the stormwater manager's toolbox, but simply to acknowledge that data in this arena is currently under-represented in the literature.

Table 1: Naming Convention of Common Structural Stormwater Management Practices for Water Quality Management and Treatment (Adapted from CWP, 2002)

BMP Group	Practice Name	Practice Description
Ponds	Dry Detention Pond	Dry ponds or vaults are generally designed to temporarily detain runoff from a set of defined storm frequencies to provide peak flow attenuation for flood control purposes.
	Dry Extended Detention Pond	Ponds that treat a prescribed water quality volume through extended detention, a design option that holds runoff over a fixed detention time.
	Wet Pond	Ponds that provide storage for a water quality volume in a permanent pool.
	Wet Extended Detention Pond	Ponds that treat a water quality volume by detaining runoff above the permanent pool for a specified minimum detention time.
	Multiple Pond System	A group of inter-connected ponds that collectively treat a water quality volume.
Wetlands	Shallow Marsh	Constructed wetlands that provide water quality treatment primarily in a wet shallow marsh.
	Extended Detention Wetland	Wetland systems that treat a portion of a water quality volume by detaining storm flows above the marsh surface.
	Pond/ Wetland System	Wetland systems that treat a portion of a water quality volume in a permanent pool of a wet pond that precedes the shallow marsh wetland.
	Gravel Wetland	Wetland systems composed of wetland plant mats grown in a gravel matrix.
Infiltration	Infiltration Trench	Infiltration practices that store a water quality volume in the void spaces of a gravel trench or within a chamber or vault before being infiltrated into underlying soils.
	Infiltration Basin	Infiltration practices that store a water quality volume in a surface depression, before being infiltrated into underlying soils.
Filters	Surface Sand Filter	Filtering practices that treat stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a sand matrix.
	Underground Sand Filter	Filtering practices that treat stormwater as it flows through an underground sediment chamber and then into a sand-matrix filtering chamber.
	Perimeter Sand Filter	Filters that incorporate a shallow sediment chamber and a sand filter bed as parallel vaults.
	Organic Filter	Filtering practices that use an organic medium such as compost in the filter, or incorporate organic material in addition to sand (e.g., peat/sand mixture).
	Bioretention	Practices that incorporate shallow depressions with vegetation that treat stormwater as it flows through a soil matrix.
Open Channels	Dry Swale	Open vegetated channels or depressions explicitly designed to detain and promote the filtration of stormwater runoff into a prescribed underlying soil media.
	Wet Swale	Open vegetated channels or depressions with wetland vegetation designed to retain water or intercept groundwater for water quality treatment.
	Grass Channel	Open vegetated channels or depressions designed to convey and detain a water quality volume at a very slow maximum velocity with a minimum residence time.
Other Practices	Hydrodynamic Devices and Swirl Concentrators	Hydrodynamic solids separation devices characterized by an internal structure that creates a swirling vortex.
	Oil and Grit Separator	Flow separation devices designed to remove pollutants from stormwater runoff through gravitational settling and trapping.
	Filter Strips	Vegetated areas with prescribed dimensions and slopes, designed to treat sheet flow runoff from adjacent surfaces and remove pollutants through filtration and infiltration (a.k.a., grass filter strips, filter strips, and forested buffers).

Pollutant Removal Effectiveness

What are the characteristics or criteria that govern BMP pollutant removal effectiveness and how can one be reasonably certain that BMPs will meet watershed management objectives? These are key questions that watershed managers need to address in order to reliably predict benefits of stormwater implementation.

From the author's experience there are at least six separate variables that govern BMP pollutant removal effectiveness. These include:

1. The estimated pollutant removal capability of the practices themselves, based on prior monitoring
2. The contributing drainage area that is physically directed to one or more BMPs
3. The fraction of the annual rainfall that is effectively captured by practices
4. The criteria that are employed for the design and implementation of new BMPs
5. The construction inspection and enforcement capabilities of watershed managers and/or agencies to ensure that the design criteria are applied and implemented
6. The maintenance performance of BMPs over the long term

While several of these variables are self explanatory, it is worth a brief explanation to describe them in greater detail. The estimated pollutant removal capability of specific BMPs is simply the pollutant removal efficiency that has been calculated from monitoring data of actual field studies of BMP performance. Generally, quoted removal efficiencies are based on the median removal values from a dataset of performance monitoring studies. There are several factors that will govern the pollutant removal of a given practice, including inflow concentration, internal geometry, storage volume, and several site characteristic parameters such as soil type/sediment particle size, catchment size, watershed land use, and percent impervious. Two of the most extensive datasets available are the National Pollutant Removal Database for Stormwater Treatment Practices, 2nd Edition (Winer, 2000), and the US EPA/ASCE National Stormwater BMP Database (www.bmpdatabase.org).

Unfortunately, watershed load reduction is not necessarily a direct function of the BMP removal efficiency because often a portion of a watershed cannot be captured by stormwater BMPs. Watershed managers must account for watershed areas and loads that do not drain directly to structural BMPs.

The next important factor is the fraction of the annual rainfall and resulting runoff that cannot be effectively treated by structural BMPs. The pollutant removal rates for most BMPs represented in pollutant removal databases are specific to a certain prescribed runoff volume. If BMP sizing criteria in a given watershed is either higher or lower than the norm, watershed managers may need to adjust removal estimates accordingly. Furthermore, the flow path, depth, area, and topographic complexity within a BMP site can influence performance. For example, it has been surmised that pond and wetland geometry is an equally important parameter to design volume in defining pollutant removal performance (Schueler, 1992 and Strecker, et al., 1992). Designs that do not consider internal geometry criteria or ignore "short-circuiting" possibilities are likely to be less effective.

The final two factors that govern BMP effectiveness relate to the quality of construction and the maintenance performed over time. Many structural BMPs have unique and often subtle design features that facilitate pollutant removal. For example, shallow marsh wetlands must have shallow water depths and complex topographical features to maximize pollutant removal. Filtering practices must be constructed within very tight elevation tolerances to ensure proper inflow and distribution across the surface area of the

practice. Even small variances in the construction of these facilities can result in significant impacts to pollutant removal performance.

Finally, long-term maintenance must be performed to achieve the stated pollutant removal estimates established from prior monitoring studies. While there is not a great deal of research documenting BMP effectiveness over time, at least one study of a constructed wetland in Minnesota found a significant reduction in pollutant removal ten years after initial construction, primarily as a result of a lack of maintenance (Oberts, 1997). Furthermore, the vast majority of facilities being evaluated in BMP performance studies are less than three years old (Winer, 2000). The net result should be that watershed managers and those developing watershed loading assessments should be prepared to discount pollutant removal effectiveness in relationship to anticipated maintenance.

Planning for BMP Implementation

It all starts with planning. Remember the six P's? *Poor Planning Produces Piss Poor Performance!* Well, it could not be any more appropriate than for stormwater BMP implementation. Stormwater practitioners must understand the broad watershed management objectives, site-specific physical limitations, and a host of other issues to select and locate the most effective BMP system. The selection of appropriate stormwater practices involves a combination of the process of elimination and the process of addition. Typically, no single practice will meet all of the stormwater management objectives at a given site. Instead, a series of practices are generally required. Certain practices can be eliminated from consideration, based on one limiting factor, but several practices may ultimately "survive" the elimination process. The most appropriate practices are those that are technically feasible, achieve the benefits for watershed protection, can be most easily maintained, and meet budget constraints of the owner.

The basic considerations for arriving at the most appropriate practice or suite of practices are governed by a variety of factors, including:

Land use

Which practices are best suited for the proposed land use at the site in question? Conversely, some practices are ill suited for certain land uses. For example, infiltration practices should not be utilized where runoff is expected to contain high levels of dissolved constituents, such as metals or the gasoline additive, MTBE.

Physical feasibility factors

Are there certain physical constraints at a project site that restrict or preclude the use of particular practices? This involves an assessment of existing onsite structures, soils, drainage area, depth to water table, slope or head constraints at a particular site. For example, stormwater wet ponds generally require a drainage area approaching 25 acres unless groundwater interception is likely. They can also consume significant land area.

Watershed factors

What watershed protection goals are needed within the watershed that the site drains to? This set of factors involves screening out those practices that might be in conflict with overall watershed protection strategies. For example, practices that contribute to thermal loading should be restricted in cold-water fisheries.

Stormwater management control capability

What is the capability of a particular stormwater practice or suite of practices to meet the multiple objectives of water quality control, channel erosion mitigation and/or flood control? Certain practices have limited capabilities to manage a wide range of storm frequencies. For example, the filtering practices are generally limited to water quality treatment and seldom can be utilized to meet large storm management objectives.

Pollutant removal capability

How do each of the stormwater management options compare in terms of pollutant removal? Some practices have a better pollutant removal potential than others or have a better capability to remove certain pollutants. For example, stormwater wetlands provide excellent total suspended solids (TSS) removal but only modest total nitrogen (TN) removal.

Environmental and maintenance considerations

Do the practices have important environmental drawbacks or a maintenance burden that might influence the selection process? Some practices can have secondary environmental impacts that would preclude their use in certain situations. Likewise, some practices require frequent maintenance and operation that is beyond the capabilities of the owner. For example, infiltration practices are generally considered to have the highest maintenance burden because of a high failure history.

Key Planning Considerations

Choosing the right BMP

While designers and reviewers alike may be familiar with the list of selection criteria cited above, many still select BMPs primarily based on a single factor, cost. This is particularly true in the private sector, where cost seems to be the overriding selection criteria. This includes the cost to design as well as the capital costs of construction. Design firms submit competitive bids to clients and tend to select BMPs that are easy and quick to design. The easiest designs are those that involve the implementation of proprietary products, where vendors provide sizing computations and ready-drawn cad files. As a result, many sites end up with "stormwater in a can" as the proposed BMP, yet in general, these practices provide no groundwater recharge, little or no channel protection or flood control benefits, and often do little to remove pollutants of concern. One example is from Lake George, New York, where a propriety product was installed to help mitigate fecal coliform delivery to a downstream swimming beach. Unfortunately, this product had no documented capabilities to remove bacteria and as it turned out, actually exported bacteria to the beach (West, et al., 2001). Apparently, the right conditions existed in the system for bacteria reproduction.

In this climate of intense competition and modest profit margins, developers are increasingly unwilling to weigh other factors beyond cost in the BMP selection process unless forced by regulatory agencies. Another preferred practice has historically been the standard dry detention pond. In some jurisdictions, however, the dry pond no longer meets required water quality performance criteria. For example, Massachusetts requires an 80% total suspended solids (TSS) removal rate as part of the statewide stormwater policy. The dry pond is not rated to remove this percentage and therefore developers frequently turn to the wet pond as a substitute. The problem is that wet ponds are being proposed in several applications where they likely will not function. In one example in Mattapoisett, Massachusetts, the engineer and developer of a five-acre condominium project are implementing a 5,000 square foot, four-foot deep wet pond with a drainage area of 4.3 acres, where the groundwater elevation is below the pond bottom

for most of the year (Rizzo Associates, 2002). At best, one should expect to see eutrophic conditions at this pond and frequent complaints from homeowners living nearby.

Site Surveys and Physical Investigations

A comprehensive site survey and physical investigations are perhaps the two most important BMP planning considerations. At a minimum, a soils test and a simple site visit should be performed at all sites. Aside from flat terrain, site soils and groundwater elevation are the most common limiting factors inhibiting successful BMP implementation. Only a few of the filtering systems and the proprietary products can be implemented in most soil conditions. Other practices such as ponds and wetlands must have soils suitable for embankment construction and water retention. All infiltration practices must have soils with appropriate percolation rates and separation between groundwater. Even open channels rely on either porous soils for infiltration, or impermeable soils for retention. Poor underlying soils are perhaps the greatest single factor leading to infiltration system failure. For example, approximately 55% of infiltration trenches installed in one Maryland county had failed within five years of construction, most as a result of poor underlying soils (Galli, 1992). In Massachusetts and several other states, at least a two-foot separation distance is required between the seasonal high groundwater elevation and the bottom of any infiltration facility (MADEP/CZM, 1997). Failure to document water table elevations can lead to potential groundwater contamination and inadequate treatment where groundwater mounds-up into the bottom of infiltration facilities.

The site visit can reveal limitations that may not appear in topographic surveys or geographic information system (GIS) mapping. For example, specimen trees can be identified, located and avoided in subsequent design plans, underground and surface utilities can be documented, subtle drainage patterns that might have a significant impact on the design can be identified, or design constraints from adjacent property owners might be revealed.

Development of the Stormwater Management Concept Plan

Before developing full-scale engineering construction drawings, designers should prepare a conceptual design that clearly defines the location, type, and approximate size of the practice. At this stage, preliminary hydrologic computations should be performed to arrive at the basic configuration of a facility. Potential permitting issues can be identified and hopefully addressed. Typically, a preliminary cost estimate is developed to give the owner some sense of the ultimate capital costs of implementation. Figure 2 illustrates the level of detail typically found at the conceptual stage. The primary purpose of the conceptual plan is to present the design intent in sufficient detail so owners, reviewers, and regulatory staff can understand the project plans and provide input prior to the development of more expensive engineering construction drawings and specifications.

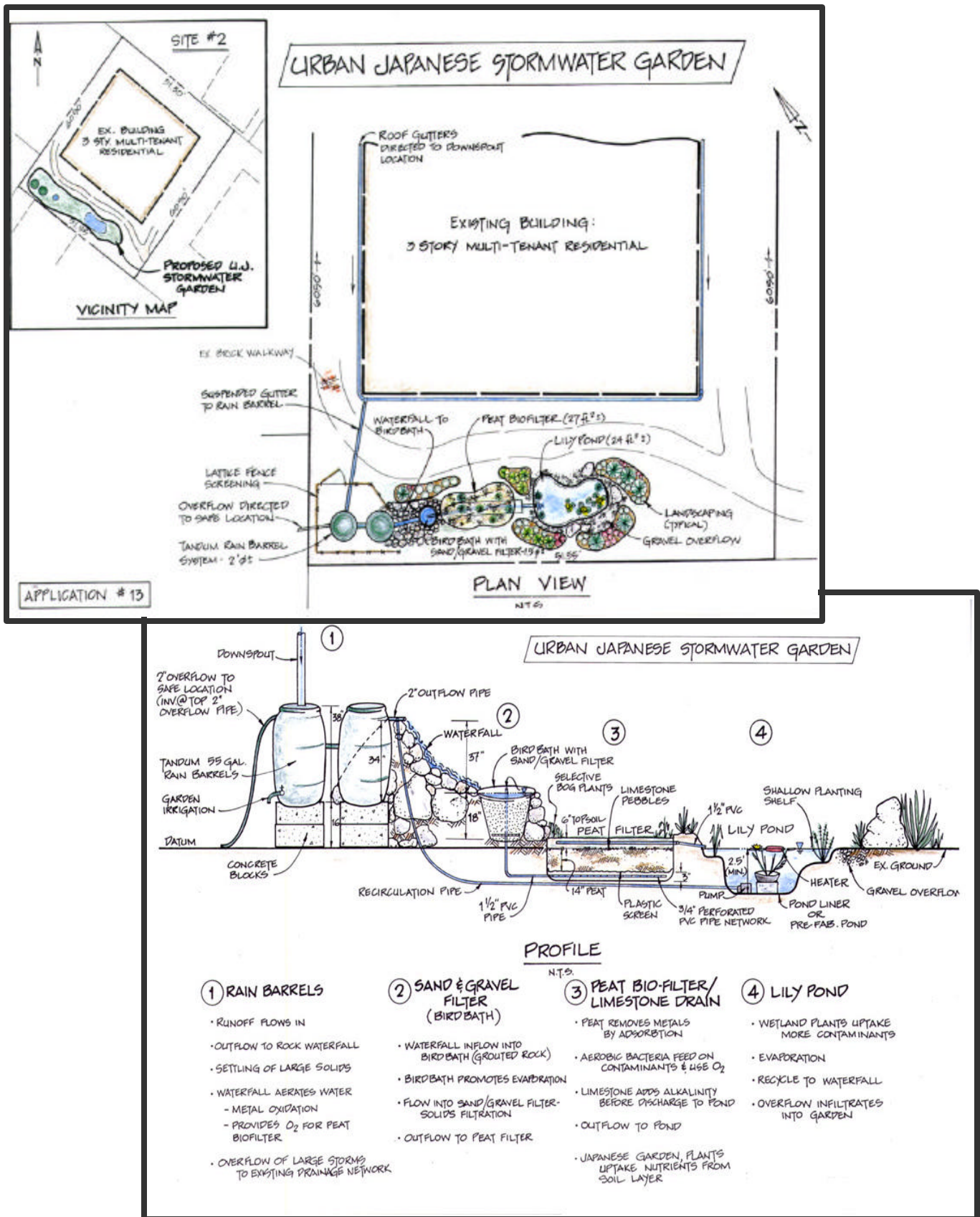


Figure 2: Illustration of a typical stormwater management concept plan (Sourial and Claytor, 2002)(the figure shows the level of detail typical of a stormwater management concept plan)

BMP Design

Assuming an appropriate BMP has been identified and selected in the planning stage, the next opportunity for success or failure is at the design stage. Generally, this stage is where most engineers do all right. Engineers typically have a good education and training background to develop a set of sound construction plans and specifications. However, there are a couple of key considerations that consistently seem to be the vulnerable points in the design process.

Hydrologic and Hydraulic Computations

The development of hydrologic and hydraulic computations is the first point in the design process of a stormwater management system, and the most crucial to get right, since all other design depends on the answers. While the examination of hydrologic methods is beyond the scope of this paper, the following considerations are worth noting:

- Get the rainfall amount right. Many designers rely on the venerable National Weather Service Technical Paper 40 (TP-40), which dates to the early 1960's, to obtain precipitation values for selected storms (NRCS, 1986). While TP-40 is widely referenced in regulatory documents, more recent research is probably more accurate. For example, the Northeast Regional Climate Center at Cornell University has published recent data that is significantly different than those values represented in TP-40 (Wilks and Cember, 1993).
- Estimate a realistic time of concentration. The time of concentration is the single most sensitive hydrologic variable that hydrologists rely upon to estimate peak flow rates. The use of an excessively long overland flow condition can artificially distort the travel time and reduce peak discharge rates.
- Examine land use assumptions to ensure that values are based on current and projected future conditions.
- Examine hydrologic soil group assumptions to make sure they are representative of actual watershed conditions. In one example in the Catskill Mountains of New York, engineers used hydrologic group "C" soils in an attempt to mimic a shallow-shale based soil profile that had large initial infiltration potential and equally large interflow rates, but no relationship to the hydrologic conditions representative of the "C" soil group.
- Utilize appropriate assumptions when performing hydraulic modeling. Many errors occur in describing the storage and outlet conditions of facilities that are very different from what ultimately makes it to the design plan. Examples include: applying large infiltration rates where soil data show modest or poor infiltration, over estimating the storage capacity of a pond, describing an outlet as a single orifice where multiple releases are proposed, getting the invert elevations wrong, or simply ignoring a contributing area in the hydrologic routing to a facility.

Soils and Structural Design

Almost all stormwater designs involve some requirement for soils information and in some cases, reasonably complex geotechnical calculations for soil compaction, seepage diaphragm design or rapid drawdown analyses, for example. Yet few BMP designs incorporate these measures. As a consequence, poor soils analyses ranks as perhaps the most common factor leading to BMP practice failure. Designers and reviewers must involve a reliable soils evaluator or geotechnical engineer in the design process and incorporate their recommendations in the design. Again, according to Galli, (1992), soil limitations ranked among the highest factor contributing to infiltration system failure. Design of infiltration BMPs must include adequate subsurface investigations and reporting.

Structural design is another key component for many BMPs. Typical examples include: adequate foundation design for pond outlet control structures or underground vaults, retaining wall design for weir walls or large outlet facilities, and concrete slab design for load bearing structures. Many hydrologic and hydraulic engineers are unfamiliar with this component of design to the level of expertise required for some applications. For example, one of the more notable stormwater facilities designed by this author was the Wheaton Branch Retrofit facility constructed in Maryland in the early 1990s (Claytor, 1998). The Wheaton Branch facility design required the modification of a nearly 30-year old riser that wasn't adequately evaluated for structural integrity. As a consequence, the newly constructed facility developed failure cracks that had to be remediated shortly after the facility was finished, at great expense and embarrassment to all parties involved, especially, this author. So the point is, one must recognize that sometimes stormwater design involves detailed structural calculations that involve an experienced structural engineer, do not be bashful in seeking their expertise.

Seeking Adequate Storage Volume

The storage volume design element involves simply making sure a facility is large enough to accommodate the appropriate design criteria. However, one cannot imagine the difficulty that this criteria imposes on BMP designers. For one thing, a site is often simply not big enough to accommodate the required storage, so designers tend to make the "hole in the ground" deeper to accommodate the criteria. Ponds can end up excessively deep and frequently with steep side slopes. Another common problem arises when designing shallow marsh wetlands. Designers are trying to meet the dual objectives of obtaining a minimum water quality volume, while maintaining a shallow marsh system. Invariably, one or the other design objective looses. Two examples illustrate this point. The first was one of the pilot stormwater retrofit projects implemented in Montgomery County, Maryland in the late 1980's. In this facility, the planners and engineers were trying to meet a minimum water quality volume within a limited area constraint. The result was a 2-foot deep permanent pool that was intended to be a shallow marsh and instead resulted in a shallow pond (see Figure 3a). Likewise, for a project completed on Staten Island as part of the "South Richmond Bluebelt Restoration" effort, a shallow marsh stormwater facility was planted with Pickerelweed (*Pontederia cordata*) in 18 inches of water. Unfortunately, Pickerelweed does not typically survive in depths over about 12" (Thunhorst, et al., 1993) and, again, another shallow open water pond was created (see Figure 3b).



Figure 3a: 2-foot deep pond in Montgomery County Maryland (illustrating open water where a shallow marsh should be present)



Figure 3b: 18-inch deep pond in Staten Island, New York (illustrating open water where Pickerelweed should be growing)

BMP Construction and Maintenance

This last area of successful BMP implementation involves the often-grueling process of getting designs constructed properly, and ensuring that practices are maintained over the long term. Construction of BMPs can be a very rewarding process. The satisfaction of seeing a set of design plans mature to a real world facility is very fulfilling. Unfortunately, the construction process is often where the "successful implementation" part of the process breaks down. There seem to be a number of commonalities, as discussed below.

BMP Construction

There are a number of elements that contribute to a successfully constructed facility. Based on the author's experience, it is hard to say whether one element is more crucial than another. However, it is certainly true that any one flawed component can lead to a failed system. The following considerations are worth particular attention:

- Design drawings, details and specifications need to be clear, concise, unambiguous and correct. While there are certainly many places where construction problems can occur, it all starts with the engineering drawings. Engineers must take extra caution to produce plans that are error-free. Details should be easy to interpret and free of vague information. Designers need to consider the "twelve-year old rule." If one's twelve year old child will not understand it, then one is asking for interpretation problems by the contractor. Interpretation problems often lead to contract change orders and usually increase construction costs.
- The design engineer should be involved in the construction process, if possible. Where it is not possible, or preferable to retain the original designer, then an equally qualified engineer, who has design experience with the specific BMPs being constructed, should be involved in the project. "Involved with the project" means that the engineer supervises construction inspections, reviews shop drawings, participates in construction progress meetings, and coordinates directly with the contractor on critical construction issues.
- The contractor should have prior experience building the specific BMPs being proposed. Most construction contracts go to the low bidder. In fact, most municipal laws require that contracts go to the "lowest qualified bidder." The key word is "qualified." Bidding documents should contain specific requirements for contractors to submit prior work experience that are used as part of a "qualified bidder" assessment process. Many construction problems can be attributed to the fact that a contractor has never seen anything like an "underground sand filter" before, for example. Conversely, a qualified contractor can solve many unforeseen problems, often before they become problems.
- Do not start construction in November when working in a cold climate. Many stormwater practices involve earth moving operations, dewatering, and or stream diversions. Winter construction complicates almost everything. A good example was the University Boulevard Retrofit project in Maryland that started in the late fall of 1992 and finished about a year later. The original construction duration was estimated to be 120 days with a anticipated start date in May. But the county procurement process took over six months from the contract award to the "notice to proceed." While the project resulted in a very successful BMP, the construction process was brutal. The contractor could not meet compaction specifications due to excessive soil moisture, construction equipment was routinely mired in muck, concrete curing required tenting, and stabilization of disturbed areas was next to impossible. Not to mention the joy of attending weekly progress meetings in freezing weather (see Figure 4).



Figure 4: University Boulevard Retrofit project in Maryland – during and after construction
(illustrating the complexity of winter construction on the left and the successfully completed project on the right)

- "Work in the dry." Most BMPs are constructed at the bottom of a drainage system of one kind or another, and projects are not usually completed before at least a few precipitation events. Designers and contractors need to work together to divert storm flows around construction stages to prevent costly delays and/or downstream sediment transport.
- Make sure a professional land surveyor stakes out the project. Many projects end up being constructed with just a small variance from the original design drawings. In most cases, this is all right, but in some it means the difference between a successful project and failure. Shallow marsh wetlands require the maintenance of extremely tight tolerances to foster the different depth zones required for a complex wetland plant community. Filter strips function properly only when sheet flow is maintained. The slightest imperfection in a level spreader will result in concentrated flow. Sand Filters, which also rely on the distribution of flow across a level filter bed, need to be built to within very tight tolerances.
- Provide construction inspections to ensure facilities are built in accordance with approved design plans. This involves a commitment from the approving regulatory agency to develop inspection standards, train personnel on how to perform inspections, and provide enforcement mechanisms for those facilities that are not constructed in accordance with approved plans.

BMP Maintenance

The key to successful BMP implementation is to provide needed maintenance in a manner that ensures that facilities will remain effective over the long term. A successful maintenance program should include at least the following three components:

- Inspection of facilities to identify and document material deficiencies
- Technical resources on how to correct facility deficiencies
- Enforcement provisions on how to deal with owners/operators who are unwilling or unable to correct material deficiencies

In practice, the key to a successful maintenance program is to develop an adequate funding source to perform inspections, correct facility deficiencies, and provide technical capabilities to owners/operators. Adequate funding is perhaps the greatest single hurdle for small municipalities that seek to implement successful stormwater management programs. The few communities that have succeeded have developed

either aggressive fee structures funded by new development, stormwater utilities that collect fees from existing residents and businesses that contribute to stormwater runoff impacts, or stormwater tax systems. While a review of stormwater funding is beyond the scope of this paper, it is generally agreed that the stormwater utility option appears to provide the most reliable source of funding for long-term maintenance implementation.

Conclusion

To summarize, successful implementation of stormwater management BMPs requires careful attention to detail at several stages across the planning, design, construction and maintenance process. As municipalities move into the implementation of EPA's Phase II Stormwater Rule, practitioners should be aware of the several critical elements to successful BMP implementation. From the author's experience, successful programs include a number of key ingredients, such as:

- A comprehensive BMP design criteria that specifies such elements as practice selection, sizing requirements, geometry, landscaping, and maintenance provisions
- A training program for engineers and reviewers on the application of the design criteria
- A well-defined permitting process that includes adequate protections to ensure that facilities are constructed in accordance with approved plans (e.g., review fees, design checklists, surety, enforcement provisions)
- An adequately staffed and trained inspection force to ensure facilities are constructed in accordance with approved plans
- A long-term inspection and maintenance program to ensure facility function over time, and
- A funding source to ensure that above provisions are capable of being implemented

While stormwater BMPs are conceptually relatively easy to understand, they are too often used as a blunt instrument in a watershed manager's toolbox. They are a relatively simple technology that is being applied to help solve a very complex interaction between natural systems and human activities. The unfortunate message is that it may only take one lapse in judgment or lack of training on the part of any one of a variety of individuals, organizations, or institutions to implement a measure that may be partially or wholly ineffective at meeting the challenge of watershed protection. The hopeful message is that, from that author's experience, with thoughtful attention and diligent effort from those involved in the process, stormwater BMPs can be implemented successfully in a variety of applications to help meet a variety of watershed management objectives.

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