Chapter 1
Introduction to Stormwater Runoff Processes

Background

Water flowing over the land during and immediately following a rainstorm is called stormwater runoff. The runoff passing a particular point is equal to the total amount of rainfall upstream of that point less the amounts of infiltration, transpiration, evaporation, surface storage, and other losses. The amount of these losses is a function of climate, soils, geology, topography, vegetative cover and, most importantly, land use.

In an undeveloped area, stormwater runoff is managed by nature through the hydrologic cycle. The cycle begins with rainfall. Rain either stands where it falls and evaporates or it is absorbed into the ground near the surface, to feed trees and vegetation, ultimately to be returned to the atmosphere by transpiration; or it percolates deeply into the ground replenishing the groundwater supply. The remainder of the rainfall collects into rivulets. This collected runoff increases in quantity as it moves down the watershed, through drainageways, streams, reservoirs and to its ultimate destination, rivers and then the sea. Evaporation from the sea surface begins the cycle again.

This simple explanation of the hydrologic cycle belies its complexity. Nature's inability to accommodate severe rainfalls without significant damage, even in undeveloped areas, is very apparent. Nature's stormwater management systems are not static but are constantly changing. Streams meander, banks erode, vegetation changes with the seasons, lakes fill in with sediment and eventually disappear. The stripping of ground and tree cover by fire can change an entire system, forcing new natural accommodations throughout the system.

The volume of stormwater runoff is governed primarily by infiltration characteristics and is related to the land use, soil type, topography, and vegetative cover. Thus, runoff is directly related to the percentage of the area covered by roofs, streets, and other impervious surfaces. Water intercepted by vegetation and evaporated or transpired is lost from runoff. A small portion of the water that infiltrates into the soil and groundwater is delivered to the stream as delayed flow and does not contribute directly to peak stormwater runoff. Impervious surfaces normally contribute almost all of the total rain immediately to stormwater runoff.

There are four distinct yet interrelated effects of land use changes on the hydrology of an area:

1) Changes in peak flow characteristics; 2) changes in total runoff; 3) changes in water quality; and 4) changes in the hydrologic amenities (Leopold, 1968). The hydrologic amenities are what might be called the appearance or the impression that the river, its channel, and its valleys leaves with the observer.

Of all land use changes affecting the hydrology of an area, urbanization is the most forceful. As an area becomes urbanized, the peak rate of runoff and volume of runoff increase. These effects are caused by 1) a reduction in the opportunity for infiltration, evaporation, transpiration, and depression storage; 2) an increase in the amount of imperviousness; and 3) modification of the surface drainage pattern, including the associated development of stormwater management facilities.

As land is developed, the impervious surfaces that are created increase the amount of runoff during rainfall events, disrupting the natural hydrologic cycle. Without stormwater controls, the increased runoff can erode stream channels, increase pollutant loadings, cause downstream flooding, and prevent groundwater recharge. The increased runoff can degrade water quality in all types of waters, including those classified as water supply watersheds, shellfish areas, and nutrient-sensitive waters. Protecting these waters is vital for a number of reasons, including the protection of fish and wildlife habitat, human health, recreation, and drinking water supplies.

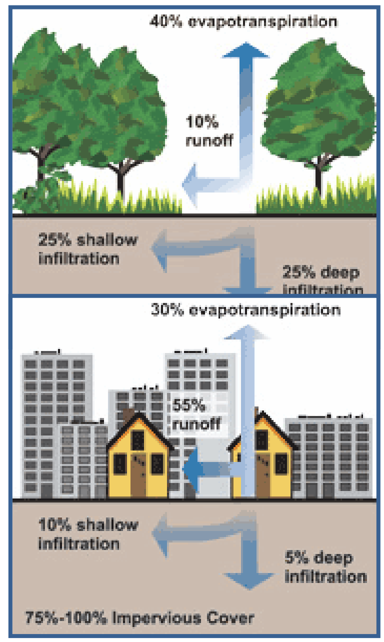

Figure 1 Stormwater runoff in natural and urban areas (Source: EPA)

The management of all water pollution sources is a stated goal of the 1987 amendments to the Clean Water Act. To fulfill the requirements of the Clean Water Act, the Mississippi Department of Environmental Quality (MDEQ) has examined water pollution within the State and has developed permit programs to address that pollution. Some of the programs have resulted in the promulgation of specific stormwater regulations to address overall water pollution issues. In addition, there are several county and local governments that have also implemented stormwater regulations to address specific local water pollution issues. Most of these programs attempt to protect, maintain, and restore water uses to the surface waters through the use of narrative-based effluent limitations in the form of “best management practices” (BMPs).

Introduction to BMPs

Stormwater BMPs are implemented as a way of treating or limiting pollutants and other damaging effects of stormwater runoff. There are two major categories of BMPs: non-structural and structural. The management of stormwater runoff through non-structural BMPs is the preferred method of reducing pollution from developing urban and suburban areas. In cases where the preferred methods are not feasible or sufficient, or where stormwater controls are being used to retrofit existing development, engineered or structural BMPs are viable solutions to reducing pollution. Both non-structural and structural BMPs are discussed in more detail in the following sections.

Non-Structural BMPs

Non-structural BMPs are typically passive or programmatic and tend to be source control or pollution prevention BMPs that reduce pollution in runoff by reducing the opportunity for the stormwater runoff to be exposed to the pollutants. In many circumstances it may be easier and less costly to prevent the pollutants from entering the drainage system rather than to control them with end-of-pipe structural BMPs. Used properly, the non-structural BMPs can be very effective in controlling pollutants and in greatly reducing the need for structural BMPs. In addition, non-structural BMPs tend to be less costly and easier to design and implement. Typically, the measures do not require maintenance but do require administrative resource commitments to ensure that they are continually implemented. Non-structural BMPs normally do not have technical or engineering designs associated with them. Some typical non-structural BMPs are listed below:

- Public education and participation.
- Land use planning and management (vegetative controls, reduced impervious areas, disconnected impervious areas).
- Material use controls (housekeeping practices, safer alternative products, pesticide and fertilizer use).
- Material exposure controls (material storage control, vehicle-use reduction).
- Illegal dumping controls (storm drain stenciling, household hazardous waste collection, used oil collection).
- Spill prevention and cleanup (vehicle spill control, above ground tank spill control).
- Connection controls (illicit connection detection, removal, and prevention, leaking sanitary sewer control).
- Street and storm drain maintenance (roadway cleaning, catch basin cleaning, vegetation controls, storm drain flushing, roadway/bridge maintenance, drainage channel, and creek maintenance).

Structural BMPs

Structural BMPs refer to physical structures designed to remove pollutants from stormwater runoff, reduce downstream erosion, provide flood control, and promote groundwater recharge. Structural BMPs typically require engineering design and engineered construction. The several types of structural BMPs vary greatly in their design, and they each have advantages and disadvantages relative to each other. Some structural BMPs provide considerable stormwater quantity handling capability through the use of infiltration and/or detention/retention facilities (e.g., infiltration devices, constructed stormwater wetlands, wet detention basins). Others provide many types of pollutant removal mechanisms such as sedimentation, filtration, microbial action, and plant uptake (e.g., bioretention, constructed stormwater wetlands). Some BMPs provide high levels of both stormwater quantity handling and pollutant removal ability. In addition, structural BMPs can be divided into those that help reduce the pollutants or quantity of stormwater entering a collection system (e.g., permeable pavement, filter strips, green roofs), and those that treat the stormwater at the “end of pipe” (e.g., sand filter, constructed stormwater wetlands, wet detention basins). The following structural BMPs are discussed in detail within this design manual:

- Bioretention
- Sand Filter
- Stormwater Wetlands
- Wet Detention Basin
- Filter Strip
- Grassed Swale
- Infiltration Devices
- Restored Riparian Buffer
- Dry Extended Detention Basin
- Permeable Pavement Systems
- Rooftop Runoff Management

Selecting the Right BMP

Selecting the most appropriate BMPs for a development is an art as well as a science, if done correctly. This section provides the link between stormwater regulatory requirements and physical site constraints, as well as issues of cost and community acceptance.

For several reasons, no one BMP is best for every site. First, different BMPs are better suited for different aspects of stormwater treatment and control (sediment removal, nutrient removal, and volume control). One particular BMP might not provide all of the required treatment goals of the regulations that apply to a site. Additionally, each site has unique features, such as slope, soils, size, and development density that encourage the use of some types of BMPs and eliminate the use of other types of BMPs. Issues of cost and community acceptance are also vital to consider in the BMP selection process.

General BMP Selection Guidance

Prior to selecting a structural BMP, a designer should first consider if it is possible to reduce the impervious surfaces on the site. Reducing impervious surfaces can minimize or eliminate the need for structural BMPs. Strategies for reducing impervious surfaces are discussed in depth in Chapter 2.

If structural BMPs will be required, the following process is recommended for selecting the appropriate one to use:

- First, determine the treatment the primarily stormwater treatment and control requirement (e.g., sediment control, nutrient control, volume control).
- Second, determine which BMPs will meet the treatment requirements and create a “short list.”

- Third, see which of the "short list" BMPs will be appropriate for the physical site characteristics.
- Fourth, consider other factors such as construction cost, maintenance effort, community acceptance, and wildlife habitat.

When a site has a lot of physical constraints and the regulatory requirements are stringent, it can be especially challenging to find a BMP that will fit the bill. In this case, it may be necessary to modify the BMP design for the site characteristics (see individual BMP chapters) or to provide a combination of BMPs that are suitable for the site, in series, to provide the required level of stormwater treatment.

Getting even further into the art of good BMP design requires blending the BMP into the natural environment to make it an aesthetic enhancement rather than a thing to hide (especially in areas with considerable pedestrian traffic such as residential, commercial, and office locations). This often requires collaboration between various professions such as civil engineers and landscape architects.

When siting BMPs within a site, they should conform to the natural features of the landscape such as drainage swales, terraces, and depressions. Many of the more "natural" BMPs can readily achieve these goals, such as filter strips, grassed swales, and restored riparian buffers. Other natural-looking BMPs such as bioretention and stormwater wetlands can be blended right into natural areas of site designs, or even create new, small-sized natural areas within normally barren portions of the site, such as parking lots, walking areas, and outdoor plazas.

MDEQ recommends reintroducing runoff from impervious surfaces into the natural environment as close to the surface as possible. Ideally, impervious surfaces should be hydrologically divided so that runoff is delivered in smaller volumes that can be accommodated by smaller, less expensive and less obtrusive BMPs. In general, MDEQ recommends against constructing large "end-of-pipe" facilities because of their high cost, maintenance requirements, consumption of land, and disruption of the landscape.

Reducing Impervious Surfaces

Most stormwater rules provide an option to meet certain low-density development criteria and then typically no engineered stormwater controls will be required. Keeping the percent impervious surface low when possible is the preferred method of stormwater control. In addition, reducing the percentage of impervious cover in a high-density development will reduce the size of BMPs that are needed.

Some of the options for reducing impervious surfaces are listed below and discussed in the *Planning* and *Site Design* sections of Chapter 4. The local planning jurisdiction will usually determine the flexibility that exists to try them.

- *Narrower Residential Streets*
- *Green Parking/Shared Parking*
- *Eliminating (or Minimizing) Curbs and Gutters*

- *Open Space Design*
- *Traditional Neighborhood Developments*
- *Mixed-use Developments*

Chapter 2 of this manual provides general information on site-design principles that address reducing impervious surfaces. Chapter 4 provides specifics on *Planning* and *Site Design* practices for reducing impervious surfaces.

Comparison of BMP Treatment Capabilities

If the low-density option is not chosen, then one or more structural BMPs will be needed. For structural BMPs, one or more of the following general requirements will apply:

- There will be a volume of stormwater that must be captured and treated prior to release (typically first 1 inch or first 1.5 inches of rainfall).
- The post-construction peak stormwater discharge rate must be reduced to no greater than the pre-construction peak stormwater discharge rate (usually for the 2-year, 24-hour storm).

Table 1-1 presents the total suspended solids (TSS), nitrogen (N), and phosphorus (P) removal efficiencies of the various BMPs discussed in this manual. These removal efficiencies assume that the BMPs are designed in accordance with the design requirements presented in Chapter 4. The removal efficiencies presented are in accordance with the September 8, 2004, memorandum *Updates to Stormwater BMP Efficiencies* from the North Carolina Department of Environment and Natural Resources (DENR), Division of Water Quality (DWQ) Stormwater Unit (DWQ, 2004).

Fecal coliform reduction is currently regulated as a narrative requirement rather than a quantitative requirement. Effort must be made to reduce fecal coliform levels in sensitive waters. The current main mechanism for reducing fecal coliform in stormwater BMPs is through exposure to UV light (sunlight), which happens regularly in devices containing areas that become temporarily inundated with stormwater. Fecal coliforms can be deposited and exposed to UV light. Additionally, in bioretention cells, fecal coliforms can be reduced by filtration, drying events between storms, and sedimentation. Some scientists also believe predation from other microbes can significantly reduce fecal coliform numbers (Hathaway and Hunt, 2008). BMPs are ranked relatively for fecal coliform removal in Table 1-1.

Table 1-1
BMP Ability for Stormwater Quantity Control

	Quantity Control	TSS Removal Efficiency	TN Removal Efficiency	TP Removal Efficiency	Fecal Removal Ability	High Temperature Concern
Bioretention without IWS*	Possible	85%	35%	45%	High	Med
Bioretention with IWS* *Coastal Counties*	Possible	85%	60%	60%	High	Med
Bioretention with IWS* *Non-Coastal Counties*	Possible	85%	40%	45%	High	Med
Stormwater wetlands	Yes	85%	40%	40%	Med	High
Wet detention basin	Yes	85%	25%	40%	Med	High
Sand filter	Possible	85%	35%	45%	High	Med
Filter strip	No	25-40%	20%	35%	Med	Low
Grassed swale	No	35%	20%	20%	Low	Low
Restored riparian buffer	No	60%	30%	35%	Med	Low
Infiltration devices	Possible	85%	30%	35%	High	Low
Dry extended detention basin	Yes	50%	10%	10%	Med	Med
Permeable pavement system	Possible	0%	0%	0%	Low	Med
Rooftop runoff management	Possible	0%	0%	0%	Low	Med

*IWS = Integrated water system

Comparison of BMP Site Constraints

The basic nature of stormwater BMPs often places them in low-lying areas and next to existing waterways, which can put them at odds with other regulations. The designer must always be aware of other regulations when siting BMPs. A non-exhaustive list of possible environmental regulatory issues is provided below:

– Jurisdictional wetlands
– Stream channels
– 100-year floodplains
– Stream buffers
– Forest conservation areas

- Critical areas
- Endangered species

BMPs should also be sited in a manner that avoids the following types of infrastructure:

- Utilities
- Roads
- Structures
- Septic drain fields
- Wells

A BMP will not work unless it is sited appropriately. It is very important to visit the site and obtain information about the size of the drainage area, soils and slopes, as well as depth to groundwater table and bedrock.

The various site considerations for siting BMPs are presented in Table 1-2 below. Each of these considerations is discussed below.

The **size of drainage area** is a primary consideration in selecting a BMP. Some BMPs will work only with a drainage area that is sufficient to provide a permanent pool of water. Other BMPs, such as bioretention areas and sand filters, are specifically designed to handle smaller flows and could easily become overwhelmed if sited at the outlet of a large drainage area.

The **space required** for a BMP is another important consideration, particularly if the site does not have a lot of space to accommodate a BMP. It is important to note, however, that some of the BMPs that require a small space are relatively expensive (i.e., sand filter) or do not have high treatment capabilities (i.e., grassed swale).

The **head required** (elevation difference) will also affect the BMP selected. In areas of low relief, excavations are often required for basins, which can be expensive. In addition, some devices require several feet of hydraulic head, which may not be available in low-relief areas.

Steep slopes will affect the BMP selection process. Larger BMPs, such as wet detention basins and extended detention wetlands, may not fit well on a site where there is not a relatively flat area to site them or may result in an impractically large embankment height. Also, steep slopes may create excessive water velocities for some systems (e.g., filter strips, swales, restored riparian buffer). When an entire site has steep slopes, it may be best to provide a number of smaller BMPs that can fit into the existing contours of the site.

A **shallow water table** can limit some types of BMP systems. For example, bioretention areas require a minimum depth to groundwater of 2 feet; otherwise, the bioretention area will actually function as a stormwater wetland.

A **shallow depth to bedrock** can greatly limit BMP options. Shallow bedrock can restrict the use of infiltration systems, prevent the excavation of basins, and limit the hydraulic functions of certain BMPs. The BMP options in this scenario may be limited to filter strips, restored riparian buffers, and rooftop runoff management.

High sediment input can limit the longevity of certain BMPs, especially sand filters, bioretention, infiltration systems, stormwater wetlands, and permeable pavement. These BMPs should not be placed in locations where high sediment loads are expected upstream in the future (typically from future development). Alternatively, high sediment loads that might adversely affect BMPs can be overcome by providing filter strips and sediment basins in up-gradient areas.

Poorly drained soils are another BMP siting consideration. For example, poorly drained soils may exclude the use of any system relying on infiltration, such as bioretention areas without an underdrain (however, this problem can be corrected with the use of an underdrain.) Poorly drained soils may be very well suited, however, for BMPs that retain water, such as a wet detention basin or a stormwater wetland.

Table 1-2
Possible Siting Constraints for BMPs

BMP	Size of Drainage Area*	Space Required	Head Required	Works with Steep Slopes?	Works with Shallow Water Table?	Works with Shallow Depth to Bedrock?	Works with High Sediment Input?	Works with Poorly Drained Soils?
Bioretention without IWS	S	High	Med	Y	N	N	N	Y
Bioretention with IWS	S	High	Med	Y	N	N	N	N
Stormwater wetlands	S-L	High	Med	N	Y	N	Y	Y
Wet detention basin	M-L	High	High	N	Y	N	Y	Y
Sand filter	S	Low	Med	Y	N	N	N	Y
Filter strip	S	Med	Low	N	Y	Y	N	Y
Grassed swale	S	Low	Med	Y	Y	N	N	Y
Restored riparian buffer	S-M	Med	Low	N	Y	Y	N	Y
Infiltration devices	S-M	High	Low	N	N	N	N	N
Dry extended detention basin	S-L	Med	High	N	N	N	Y	Y
Permeable pavement system	S-M	N/A	Low	N	N	N	N	Y
Rooftop runoff management	S	Variable	Low	Y	Y	Y	Y	Y

* S = small, M = medium, L = large drainage area

Comparison of BMP Costs and Community Acceptance

Construction costs and operation and maintenance efforts for each of the BMPs are listed in Table 1-3. However, it is important to note that some of the lowest cost or lowest maintenance-level BMPs also have some of the lowest treatment capabilities. Using low-cost BMPs could result in a need for additional BMPs to achieve the requirements, thereby increasing costs and maintenance requirements. In addition, several of the lowest cost BMPs may be difficult to integrate into the natural features of a site or may be the least desirable from an aesthetic or safety point of view. Often, a slightly more expensive or maintenance intensive BMP may be a better choice for overall site design.

Sometimes, community and environmental factors seem the least important; however, they can have a big impact on the public perception and acceptance of a site development. For instance, a prospective homeowner may think twice before buying a lot or home bordering a large, fenced-in, dry extended detention basin with a large corrugated metal riser pipe and occasional mosquito outbreaks after storms. However, if the BMP were designed as a bioretention device or a stormwater wetland, it could serve as an aesthetic amenity on the site, possibly with birds, frogs, and fish. Table 1-3 provides information on each BMP's safety concerns, community acceptance, and wildlife habitat.

Table 1-3
Cost, Community and Environmental Issues for BMPs

	Construction Cost	Maintenance Level	Safety Concerns	Community Acceptance	Wildlife Habitat
Bioretention	Med-High	Med-High	N	Med-High	Med
Stormwater wetland	Med	Med	Y	Med	High
Wet detention basin	Med	Med	Y	Med	Med
Sand filter	High	High	N	Med	Low
Filter strip	Low	Low	N	High	Med
Grassed swale	Low	Low	N	High	Low
Restored riparian buffer	Med	Low	N	High	Med-High
Infiltration device	Med-High	Med	N	Med-High	Low
Dry extended detention basin	Low	Low-Med	Y	Med	Low
Permeable pavement system	Med-High	High	N	Med	N/A
Rooftop runoff management	Med	Med	N	High	Low