5.0 Description and Performance of Storm Water Best Management Practices

A storm water best management practice (BMP) is a technique, measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of storm water runoff in the most cost-effective manner. BMPs can be either engineered and constructed systems ("structural BMPs") that improve the quality and/or control the quantity of runoff such as detention ponds and constructed wetlands, or institutional, education or pollution prevention practices designed to limit the generation of storm water runoff or reduce the amounts of pollutants contained in the runoff ("non-structural BMPs"). No single BMP can address all storm water problems. Each type has certain limitations based on drainage area served, available land space, cost, pollutant removal efficiency, as well as a variety of site-specific factors such as soil types, slopes, depth of groundwater table, etc. Careful consideration of these factors is necessary in order to select the appropriate BMP or group of BMPs for a particular location.

5.1 Goals of Storm Water Best Management Practices

Storm water BMPs can be designed to meet a variety of goals, depending on the needs of the practitioner. In existing urbanized areas, BMPs can be implemented to address a range of water quantity and water quality considerations. For new urban development, BMPs should be designed and implemented so that the post-development peak discharge rate, volume and pollutant loadings to receiving waters are the same as pre-development values. In order to meet these goals, BMPs can be implemented to address three main factors: flow control, pollutant removal and pollutant source reductions.

5.1.1 Flow Control

Flow control involves managing both the volume and intensity of storm water discharges to receiving waters. Urbanization significantly alters the hydrology of a watershed. Increasing development leads to higher amounts of impervious surfaces. As a result, the response of an urbanized watershed to precipitation is significantly different from the response of a natural watershed. The most common effects are reduced infiltration and decreased travel time, which significantly increase peak discharges and runoff volumes. Factors that influence the amount of runoff produced include precipitation depth, infiltrative capacity of soils, soil moisture, antecedent rainfall, cover type, the amount of impervious surfaces and surface retention. Travel time is determined primarily by slope, length of flow path, depth of flow and roughness of flow surfaces. Peak discharges are based on the relationship of these parameters, and on the total drainage area of the watershed, the time distribution of rainfall, and the effects of any natural or manmade storage (USDA/NRCS, 1986).

High flow rates of storm water discharges can cause a number of impacts to receiving streams (see section 4.3), and may also increase the pollutant concentrations in storm water runoff. High velocity runoff can detach and transport significant amounts of suspended solids and associated pollutants such as nutrients and metals from the urban landscape. In addition, high flow rates in drainage channels and receiving waters can erode stream banks and channels, further increasing suspended solids concentrations in waters that receive storm water discharges. In order to reduce the pollutant concentrations in runoff and receiving water impacts associated with high storm water flow rates, BMPs that provide flow attenuation are frequently implemented.

In areas undergoing new development or redevelopment, the most effective method of controlling impacts from storm water discharges is to limit the amount of rainfall that is converted to runoff. By utilizing site design techniques that incorporate on-site storage and infiltration and reduce the amounts of directly connected impervious surfaces, the amount of runoff generated from a site can be significantly reduced. This can reduce the necessity for traditional structural BMPs to manage runoff from newly developed areas. There are a number of practices that can be used to promote on-site storage and infiltration and to limit the amount of impervious surfaces that are generated. However, the use of on-site infiltration can be limited in certain areas due to factors such as slope, depth to the water table, and geologic conditions.

- *Site design features* such as providing rain barrels, dry wells or infiltration trenches to capture rooftop and driveway runoff, maintaining open space, preserving stream buffers and riparian corridors, using porous pavement systems for parking lots and driveways, and using grassed filter strips and vegetated swales in place of traditional curb-and-gutter type drainage systems can greatly reduce the amount of storm water generated from a site and the associated impacts.

- *Street construction features* such as placing sidewalks on only one side of the street, limiting street widths, reducing frontage requirements and eliminating or reducing the radius of cul-de-sacs also have the potential to significantly reduce the amount of impervious surfaces and therefore the amount of rainfall that is converted to runoff.

- *Construction practices* such as minimizing disturbance of soils and avoiding compaction of lawns and greenways with construction equipment can help to maintain the infiltrative capacity of soils.

There are several guides that contain useful information regarding development practices that can limit the impacts associated with storm water runoff (Delaware DNREC, 1997; US EPA, 1996b; Center for Watershed Protection, 1998).

In areas that are already developed, flow control can be more complicated. Since a drainage infrastructure already exists, retrofitting these systems to provide flow control can be prohibitively expensive. Regional storm water management systems can be used to manage runoff in these areas, but space considerations and high capital costs can limit their usefulness. Depending on site-specific constraints, however, there are a number of practices that can be incorporated on-site to reduce runoff volumes from these areas. Down spouts can be disconnected from the storm drain system and this rainfall can instead be collected and stored on a property in rain barrels to be used for watering lawns and landscaping during inter-event periods. Infiltration and retention practices such as bioretention areas and infiltration trenches can be constructed to capture runoff from rooftops, lawns and driveways and reduce the volume of runoff discharged to storm sewers. Curb-and-gutter systems can be replaced with grassed swales or wetland channels to provide temporary ponding of runoff. Storm water from commercial areas and golf courses can be collected and stored in ponds and subsequently be used for irrigation. Storm water reuse can help to maintain a more natural, pre-development hydrologic balance in the watershed (Livingston et al, 1998). Parking lots can also be used as short-term storage areas for ponded storm water, and bioretention facilities placed around the perimeter of parking lots can be used to infiltrate this water volume.

Where the generation of runoff cannot be avoided, end-of-pipe structural BMPs may be implemented to decrease the impacts of storm water discharges to receiving streams. However, BMPs are limited in their ability to control impacts, and frequently cause secondary impacts such as increased temperatures of discharges to receiving streams. BMPs that can be designed to provide significant flow attenuation include grassed swales, vegetated filter strips, detention and retention basins, wetland basins, and wetland channels and swales. These BMPs can also provide the added benefit of removing pollutants such as suspended solids and associated nutrients and metals from storm water runoff.

The environmental aspects of storm water quantity control must be carefully balanced against the hazard and nuisance effects of flooding. Large or intense storm events or rapid snowmelt can produce significant quantities of runoff from urban areas with high levels of imperviousness. This runoff must be rapidly transported from urbanized areas in order to prevent loss of life and property due to flooding of streets, residences and businesses. This is frequently accomplished by replacing natural drainage paths in the watershed with paved gutters, storm sewers or other artificial means of drainage. These drainage systems can convey runoff at a faster rate than natural drainage paths, allowing rapid transport of runoff away from areas where flooding is likely to occur. However, as large quantities of runoff are conveyed rapidly from the urban landscape and discharged to receiving streams, downstream areas can flood. Following urbanization, large volumes of runoff can be produced from even small storm events due to the high amounts of impervious surfaces. As a result, flooding of streams that receive runoff can occur much more frequently following urbanization due to this excessive amount of runoff production. Therefore, design of storm water drainage systems must always balance flood protection with ecological concerns.

In highly urbanized and densely populated cities, little opportunity exists for retrofitting storm drainage systems with BMPs to provide water quantity control due to flooding considerations. The large area of impervious surfaces in heavily urbanized areas produce large quantities of runoff. Rapid conveyance by the storm drain system is frequently the only option that exists in order to prevent flooding of yards, streets and basements. In these areas, the most appropriate BMPs are those that limit the generation of pollutants or remove pollutants from the urban landscape. With this principle in mind, a unique opportunity exists in newly developing areas or in more sparsely populated suburban areas to use BMPs that control runoff at the point of generation, instead of trying to manage it at the point of discharge to the receiving stream. When rainfall is managed as a *resource* instead of as a waste stream requiring treatment, future problems with quantity control may be avoidable. When rainfall is managed at the site level by promoting the concepts of conservation design, and by providing on-site storage, infiltration and usage of rainfall for irrigation of the urban landscape, the need for traditional curb-and-gutter storm drainage system can be reduced. As a result, the need for constructing and maintaining capital-, land- and maintenance-intensive regional BMPs to manage large flows from developed watersheds may be reduced. Nuisance flooding of downstream areas can also be limited by reducing the overall volume of water draining from a watershed. Limiting the discharge of large volumes of storm water to urban streams can help to prevent the degradation of these streams to the point of being non-supporting of a designated use.

5.1.2 Pollutant Removal

Urbanized areas export large quantities of pollutants during storm events. The high population of pollutant sources in urbanized areas contribute large quantities of pollutants that accumulate on streets, rooftops and other surfaces. During rainfall or snowmelt, these pollutants are mobilized and transported from the streets and rooftops into the storm drain system, where they are conveyed and ultimately discharged to waterways. In order to reduce the impacts to receiving waters from the high concentrations of pollutants contained in the runoff, BMPs can be implemented to remove these pollutants.

Properly-designed, constructed and maintained structural BMPs can effectively remove a wide range of pollutants from urban runoff. Pollutant removal in storm water BMPs can be accomplished through a number of physical and biochemical processes. The efficiency of a given BMP in removing pollutants is dependent upon a number of site-specific variables, including the size, type and design of the BMP; the soil types and characteristics; the geology and topography of the site; the intensity and duration of the rainfall; the length of antecedent dry periods; climatological factors such as temperature, solar radiation, and wind; the size and characteristics of the contributing watershed; and the properties and characteristics of the various pollutants.

Pollutant removal in urban storm water BMPs can occur through the following mechanisms:

Sedimentation

Sedimentation is the removal of suspended particulates from the water column by gravitational settling. The settling of discrete particles is dependent upon the particle velocity, the fluid density, the fluid viscosity, and the particle diameter and shape. Sedimentation can be a major mechanism of pollutant removal in BMPs such as ponds and constructed wetlands. Sedimentation can remove a variety of pollutants from storm water runoff. Pollutants such as metals, hydrocarbons, nutrients and oxygen demanding substances can become adsorbed or attached to particulate matter, particularly clay soils. Removal of these particulates by sedimentation can therefore result in the removal of a large portion of these associated pollutants. The main factor governing the efficiency of a BMP at removing suspended matter by sedimentation is the time available for particles to undergo settling. Fine particulates such as clay and silt can require detention times of days or even weeks to settle out of suspension. Therefore, it is important to evaluate the settling characteristics of the particulates in runoff before BMP design in order to determine the detention time necessary for adequate settling to occur. The overall efficiency of a BMP in removing particulates by settling is also dependent upon the initial concentration of suspended solids in the runoff. In general, runoff with higher initial concentrations of suspended solids will have a greater removal efficiency. In addition, some particles, such as fine clays, will not settle out of suspension without the aid of a coagulant. As a result there is usually a minimum practical limit of approximately 10 mg/l of TSS, below which additional TSS removal can not be expected to occur (UDFCD, 1992).

Flotation

Flotation is the separation of particulates with a specific gravity less than that of water. Trash such as paper, styrofoam "peanuts" used for packaging, and other low-density materials can be removed from storm water by the mechanism of flotation. If the inlet area of the BMP is designed to allow for the accumulation of floatable materials, then these accumulated materials can periodically be manually removed from the BMP. Significant amounts of floatables can be removed from storm water in properly designed BMPs in this manner. In addition, oils and hydrocarbons will frequently rise to the surface in storm water BMPs. If the BMP is designed with an area for these materials to accumulate, then significant removals of these pollutants can occur. Many modular or drop-in filtration systems incorporate an oil and grease or hydrocarbon trap with a submerged outlet pipe that allows these contaminants to accumulate and to be periodically removed.

Filtration

Filtration is the removal of particulates from water by passing the water through a porous media. Media commonly used in storm water BMPs include soil, sand, gravel, peat, compost, and various combinations such as peat/sand, soil/sand and sand/gravel. Filtration is a complex process dependent on a number of variables. These include the particle shape and size, the size of the voids in the filter media, and the velocity at which the fluid moves through the media. Filtration can be used to remove solids and attached pollutants such as metals and nutrients. Organic filtration media such as peat or leaf compost can also be effective at removing soluble nutrients from urban runoff.

Infiltration

Infiltration is the most effective means of controlling storm water runoff since it reduces the volume of runoff that is discharged to receiving waters and the associated water quality and quantity impacts that runoff can cause. Infiltration is also an important mechanism for pollutant control. As runoff infiltrates into the ground, particulates and attached contaminants such as metals and nutrients are removed by filtration, and dissolved constituents can be removed by adsorption. However, infiltration is not appropriate in all areas.

Adsorption

Adsorption, while not a common mechanism used in storm water BMPs, can occur in infiltration systems where the underlying soils contain appreciable amounts of clay. Dissolved metals that are contained in storm water runoff can be bound to the clay particles as storm water runoff percolates through clay soils in infiltration systems.

Biological Uptake

Biological uptake of nutrients is an important mechanism of nutrient control in storm water BMPs. Urban runoff typically contains significant concentrations of nutrients. Ponds and wetlands can be useful for removing these nutrients through biological uptake. This occurs as aquatic plants, algae, microorganisms and phytoplankton utilize these nutrients for growth. Periodic harvesting of vegetation in BMPs allows for permanent removal of these nutrients. If plants are not harvested, however, nutrients can be re-released to the water column from plant tissue after the plants die.

Biological Conversion

Organic contaminants can be broken down by the action of aquatic microorganisms in storm water BMPs. Bacteria present in BMPs can degrade complex and/or toxic organic compounds into less harmful compounds that can reduce the toxicity of runoff to aquatic biota.

Degradation

BMPs such as ponds and wetlands can provide the conditions necessary for the degradation of certain organic compounds, including certain pesticides and herbicides. Open pool BMPs can provide the necessary conditions for volatilization, hydrolysis and photolysis of a variety of organic compounds to take place.

5.1.3 Pollutant Source Reductions

Source reduction is an effective non-structural way of controlling the amounts of pollutants entering storm water runoff. A wide range of pollutants are washed off of impervious surfaces during runoff events. Removing these contaminants from the urban landscape prior to precipitation can effectively limit the amounts of pollutants contained in the storm water runoff. Source reduction can be accomplished by a number of different processes including: limiting applications of fertilizers, pesticides and herbicides; periodic street sweeping to remove trash, litter and particulates from streets; collection and disposal of lawn debris; periodic cleaning of catch basins; elimination of improper dumping of used oil, antifreeze, household cleaners, paint, etc. into storm drains; and identification and elimination of illicit cross-connections between sanitary sewers and storm sewers.

5.2 Types of Storm Water Best Management Practices

There are a variety of storm water BMPs available for managing urban runoff. Regardless of the type, storm water BMPs are most effective when implemented as part of a comprehensive storm water management program that includes proper selection, design, construction, inspection and maintenance. Storm water BMPs can be grouped into two broad categories: structural and non-structural. *Structural* BMPs are used to treat the storm water at either the point of generation or the point of discharge to either the storm sewer system or to receiving waters. *Non-structural* BMPs include a range of pollution prevention, education, institutional, management and development practices designed to limit the conversion of rainfall to runoff and to prevent pollutants from entering runoff at the source of runoff generation. The descriptions in this section provide summary information on a variety of commonly used structural and nonstructural storm water BMPs. Information provided includes a general description of the technology or practice, important components and factors to incorporate into BMP design and planning, and the positive and negative aspects of the technology or practice. In addition, maintenance considerations for structural BMPs are discussed. Quantitative performance data for BMPs are not included in this section. These data are included in section 5.5, "Effectiveness of BMPs in Managing Urban Runoff."

5.2.1 Structural BMPs

There are a wide variety of structural BMPs in use for storm water management. Structural BMPs include engineered and constructed systems that are designed to provide for water quantity and/or water quality control of storm water runoff. Structural BMPs can be grouped into several general categories. However, the distinction between BMP types and the terminology used to group structural BMPs is an area that needs standardization. In particular, the terms "retention" and "detention" are sometimes used interchangeably, although they do have distinct meanings. Storm water detention is usually defined as providing temporary storage of a runoff volume for subsequent release (WEF/ASCE, 1992). Examples include detention basins, underground vaults, tanks or pipes, and deep tunnels, as well as temporary detention in parking lots, roof tops, depressed grassy areas, etc. Retention is generally defined as providing storage of storm water runoff without subsequent surface discharge (WEF/ASCE, 1992). With the strict interpretation of this definition, retention practices would be limited to those practices that either infiltrate or evaporate runoff, such as infiltration trenches, wells or basins. However, retention is also commonly used to describe practices that retain a runoff volume (and hence have a permanent pool) until it is displaced in part or in total by the runoff event from the next storm. Examples include retention ponds, tanks, tunnels, and underground vaults or pipes, and wetland basins. For purposes of this document, and in being consistent with the definitions and terminology used in the ASCE National Stormwater BMP Database, structural BMPs have been grouped and defined as follows:

- Infiltration systems capture a volume of runoff and infiltrates it into the ground.

- Detention systems capture a volume of runoff and temporarily retain that volume for subsequent release. Detention systems to not retain a significant permanent pool of water between runoff events.

- Retention systems capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Retention systems therefore maintain a significant permanent pool volume of water between runoff events.

- Constructed wetland systems are similar to retention and detention systems, except that a major portion of the BMP water surface area (in pond systems) or bottom (in meadow-type systems) contains wetland vegetation. This group also includes wetland channels.

- Filtration systems use some combination of a granular filtration media such as sand, soil, organic material, carbon or a membrane to remove constituents found in runoff.

- Vegetated systems (biofilters) such as swales and filter strips are designed to convey and treat either shallow flow (swales) or sheetflow (filter strips) runoff

- Minimizing directly connected impervious surfaces describes a variety of practices that can be used to reduce the amount of surface area directly connected to the storm drainage system by minimizing or eliminating traditional curb and gutter. This is considered by some to be a non-structural practice, but is has been included under the structural heading in this report due to the need to design and construct alternative conveyance and treatment options.

- Miscellaneous and vendor-supplied systems include a variety of proprietary and miscellaneous systems that do not fit under any of the above categories. These include catch basin inserts, hydrodynamic devices, and filtration devices.

5.2.1.1 Infiltration Systems

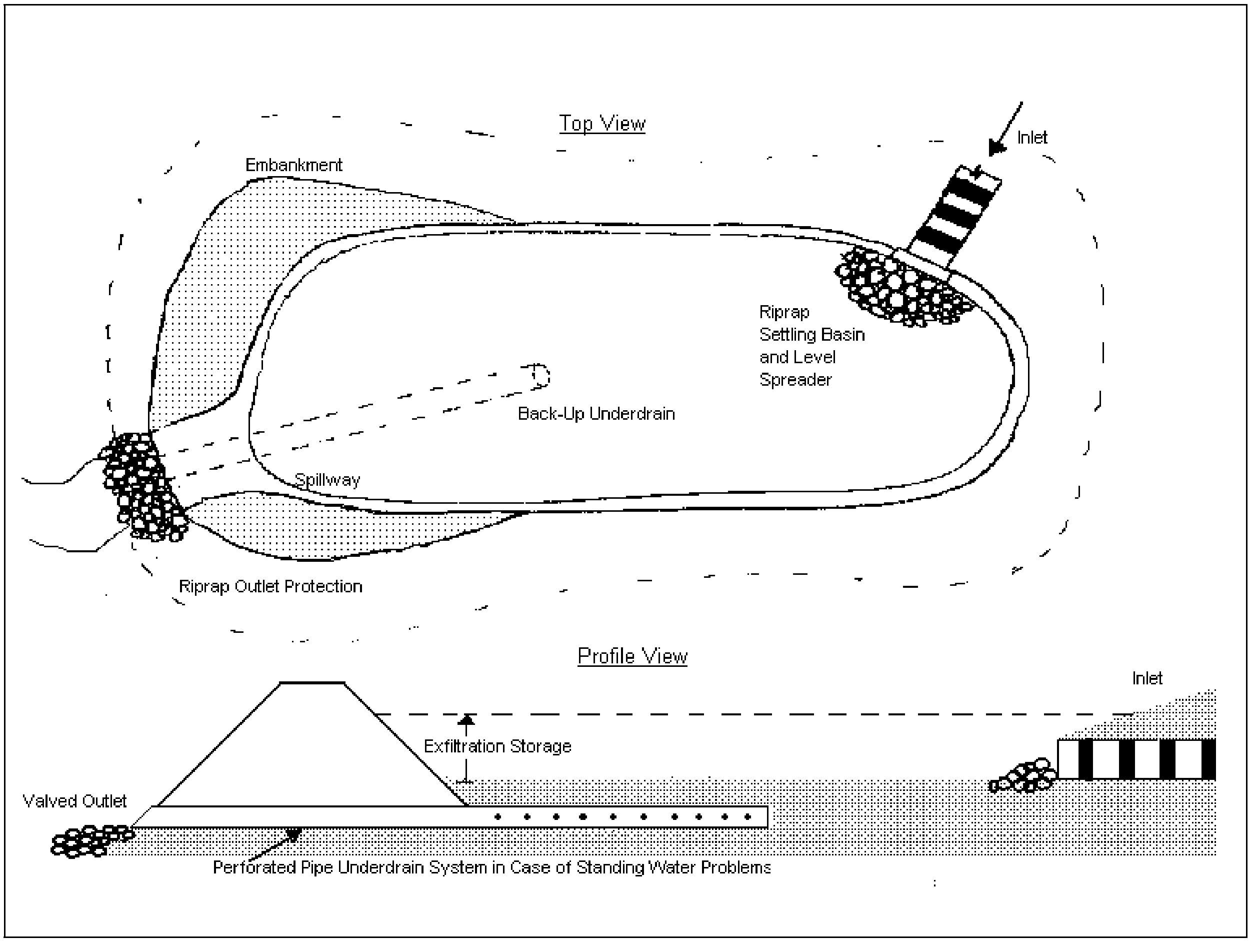
Infiltration systems include infiltration basins, porous pavement systems, and infiltration trenches or wells. An infiltration BMP is designed to capture a volume of storm water runoff, retain it and infiltrate that volume into the ground. Infiltration of storm water has a number of advantages and disadvantages. The advantages of infiltration include both water quantity control and water quality control. Water quantity control can occur by taking surface runoff and infiltrating this water into the underlying soil. This reduces the volume of water that is discharged to receiving streams, thereby reducing some of the potential impacts caused by an excess flow as well as increased pollutant concentrations in the receiving stream. Infiltration systems can be designed to capture a volume of storm water and infiltrate this water into the ground over a period of several hours or even days, thereby maximizing the infiltrative capacity of the BMP. Infiltration can have many secondary benefits such as increasing recharge of underlying aquifers and increasing baseflow levels of nearby streams. Infiltration BMPs can also provide water quality treatment. Pollutant removal can occur as water percolates through the various soil layers. As the water moves through the soil, particles can be filtered out. In addition, microorganisms in the soil can degrade organic pollutants that are contained in the infiltrated storm water.

Although infiltration of storm water has many benefits, it also has some drawbacks. First, infiltration may not be appropriate in areas where groundwater is a primary source of drinking water due to the potential for contaminant migration. This is especially true if the runoff is from a commercial or industrial area where the potential for contamination by organics or metals is present. Also, the performance of infiltration BMPs is limited in areas with poorly permeable soils. In addition, infiltration BMPs can experience reduced infiltrative capacity and even clogging due to excessive sediment accumulation. Frequent maintenance may be required to restore the infiltrative capacity of the system. Care must also be taken during construction to limit compaction of the soil layers underlying the BMP. Excessive compaction due to construction equipment may cause a reduced infiltrative capacity of the system. Plus, excessive sediment generation during construction and site grading/stabilization may cause premature clogging of the system. Infiltration systems should not be placed into service until disturbed areas in the drainage have been stabilized by dense vegetation or grasses.

Infiltration Basins

Infiltration basins are designed to capture a storm water runoff volume, hold this volume and infiltrate it into the ground over a period of days. Infiltration basins are almost always placed off-line, and are designed to only intercept a certain volume of runoff. Any excess volume will be bypassed. The basin may or may not be lined with plants. Vegetated infiltration systems help to prevent migration of pollutants and the roots of the vegetation can increase the permeability of the soils, thereby increasing the efficiency of the basin. Infiltration basins are typically not designed to retain a permanent pool volume. Their main purpose is to simply transform a surface water flow into a ground water flow and to remove pollutants through mechanisms such as filtration, adsorption and biological conversion as the water percolates through the underlying soil. Infiltration basins should be designed to drain within 72 hours in order to prevent mosquito breeding and potential odor problems due to standing water and to ensure that the basin is ready to receive runoff from the next storm (US EPA, 1993a). In addition to removing pollutants, infiltration basins are useful to help restore or maintain pre-development hydrology in a watershed. Infiltration can increase the water table, increase baseflow and reduce the frequency of bankfull flooding events. A diagram of a typical infiltration basin is shown below.

Figure 5-1. Infiltration Basin



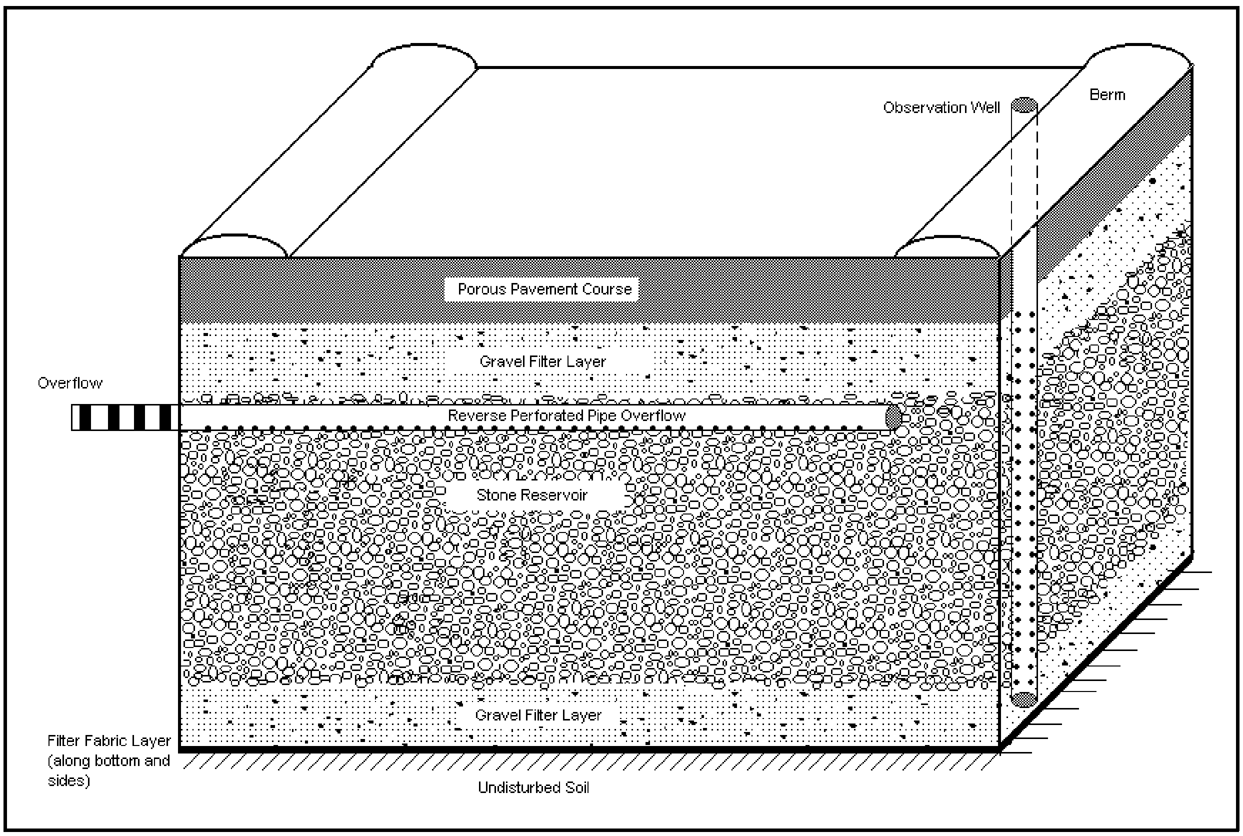
Source: Adapted from Schueler et al, 1992

Porous Pavement Systems

Porous pavement is an infiltration system where storm water runoff is infiltrated into the ground through a permeable layer of pavement or other stabilized permeable surface. These systems can include porous asphalt, porous concrete, modular perforated concrete block, cobble pavers with porous joints or gaps or reinforced/stabilized turf (Urbonas and Strecker, 1996). Permeable pavement can be used in parking lots, roads and other paved areas and can greatly reduce the amount of runoff and associated pollutants leaving the area. Porous pavement systems are suitable for a limited number of applications. Typically, porous pavement can only be used in areas that are not exposed to high volumes of traffic or heavy equipment. They are particularly useful for driveways and streets and in residential areas, and in parking areas in commercial areas. Porous pavement is not effective in areas that receive runoff with high amounts of sediment due to the tendency of the pores to clog. Porous pavements require maintenance including periodic vacuuming or jet-washing to remove sediment from the pores. Paved areas should be clearly marked to indicate that a porous pavement system is in use and to prevent frequent use by equipment, to prevent excess traffic volume, to limit the use of de-icing chemicals and sand, and to prevent resurfacing with non-porous pavement.

The performance of porous asphalt has been historically very poor in the mid-Atlantic region. However, many of these failures can be attributed to lack of proper erosion and sediment controls during construction or lack of contractor experience with installation of porous pavement systems. Porous concrete systems in use in Florida have performed very well (Florida Concrete and Products Assn., 1993). When properly designed and maintained, porous pavement systems can be an effective means of managing urban storm water runoff. Porous pavement systems are particularly useful for overflow parking areas that are not used on a daily basis. A diagram of a porous asphalt pavement system is shown below.

Figure 5-2. Porous Pavement System

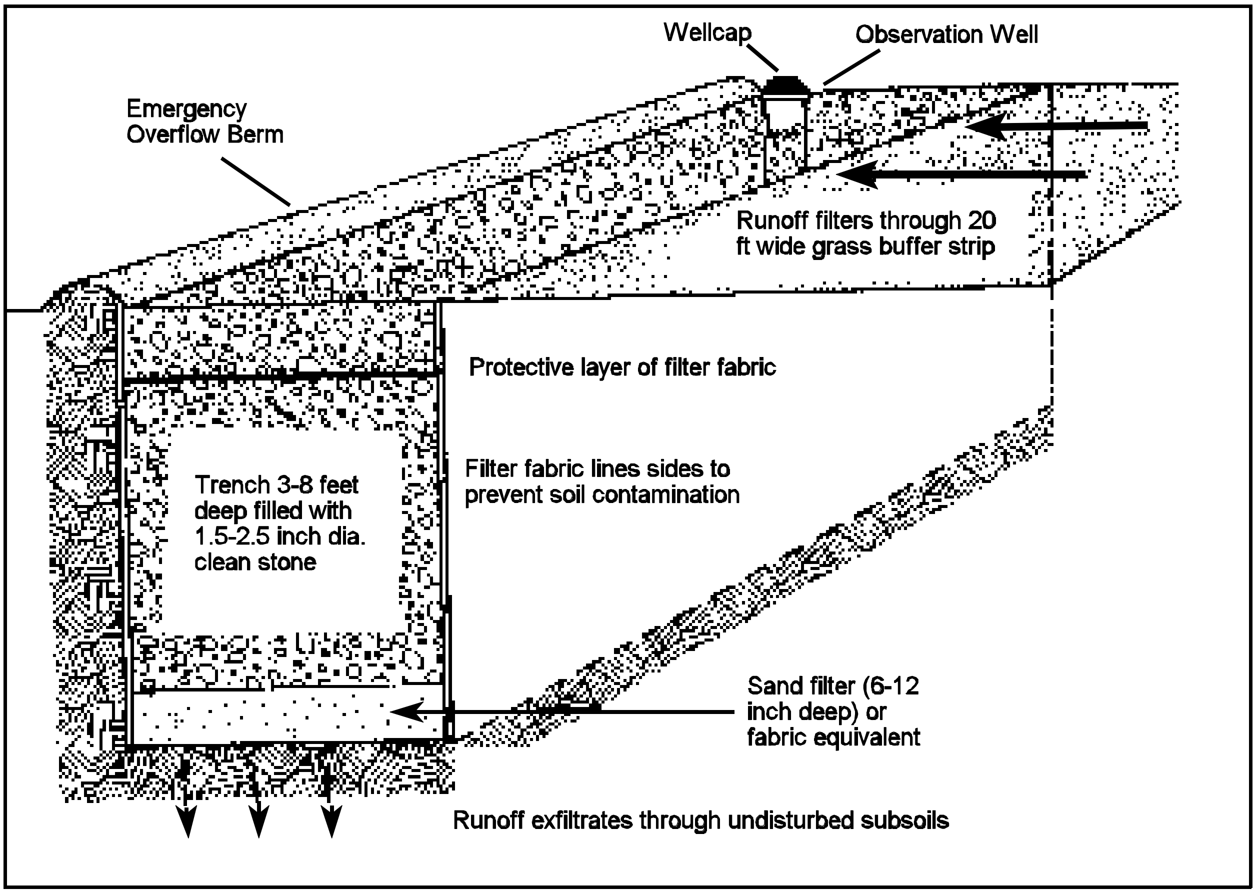


Source: Adapted from Schueler, 1987.

<u>Infiltration Trenches and Wells</u>

An infiltration trench or well is a gravel-filled trench or well designed to infiltrate storm water into the ground. A volume of storm water runoff is diverted into the trench or well where it infiltrates into the surrounding soil. Typically infiltration trenches and wells can only capture a small amount of runoff and therefore may be designed to capture the first flush of a runoff event. For this reason, they are frequently used in combination with another BMP such as a detention basin to control peak hydraulic flows. Infiltration trenches and wells can be used to remove suspended solids, particulates, bacteria, organics and soluble metals and nutrients through the mechanisms of filtration, absorption and microbial decomposition. They are also useful to provide groundwater recharge and to increase base flow levels in nearby streams. As with all infiltration practices, the possibility for groundwater contamination exists and must be considered where groundwater is a source of drinking water. A diagram of an infiltration trench is shown below.

Figure 5-3. Infiltration Trench



Source: Schueler et al, 1992.

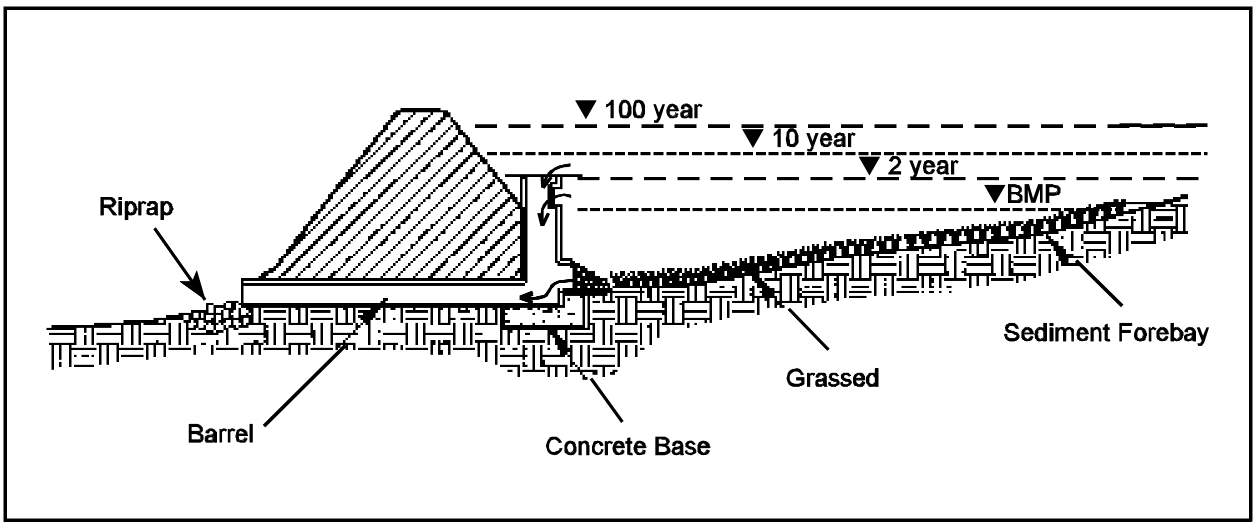
5.2.1.2 Detention Systems

Detention systems are BMPs that are designed to intercept a volume of storm water runoff and temporarily impound the water for gradual release to the receiving stream or storm sewer system. Detention systems are designed to completely empty out between runoff events, and therefore provide mainly water quantity control as opposed to water quality control. Detention basins can provide limited settling of particulate matter, but a large portion of this material can be re-suspended by subsequent runoff events. Detention facilities should be considered mainly as practices used to reduce the peak discharge of storm water to receiving streams to limit downstream flooding and to provide some degree of channel protection. There are several types of detention facilities used to manage storm water runoff, including detention basins and underground vaults, pipes and tanks.

Detention Basins

Detention basins are designed to intercept a volume of storm water, temporarily impound the water and release it shortly after the storm event. The main purpose of a detention basin is quantity control by reducing the peak flow rate of storm water discharges. They are designed to not retain a permanent pool volume between runoff events. and most basins are designed to empty in a time period of less than 24 hours. The treatment efficiency of detention basins is usually limited to removal of suspended solids and associated contaminants due to gravity settling. The efficiency can be increased by incorporating a forebay or pre-settling chamber for the accumulation of coarse sediment, facilitating periodic cleaning in order to prevent washout by subsequent runoff events. Detention basins can limit downstream scour and loss of aquatic habitat by reducing the peak flow rate and energy of storm water discharges to the receiving stream, but their removal of pollutant of potential water quality concern can be limited. A diagram of a typical detention basin is shown below.

Figure 5-4. Detention Basin



Source: NVPDC, 1992.

Underground Vaults, Pipes and Tanks

Underground detention facilities, such as vaults, pipes and tanks, are designed to provide temporary storage of storm water runoff. Significant water quality improvements should not be expected in underground detention facilities. They should mainly be used for providing storage to limit downstream effects due to high peak flow rates. Like detention basins, underground detention systems are designed to empty out between runoff events so that storage capacity is available for subsequent runoff events. In addition, studies are being conducted to evaluate the usefulness of in-system detention (storing runoff temporarily in the storm drainage system through the use of valves, gates, orifices, etc.), although these evaluations are in the preliminary stages and are only useful in certain cases (Lake Barcroft Watershed Improvement District, 1998). This is a potential alternative for retrofitting existing storm drains in the upper portions of the drainage system to delay the peak discharge rate and provide a limited amount of additional temporary storage volume. However, a careful analysis of the storm drainage system is necessary in order to prevent flooding in the upper reaches of the drainage area.

5.2.1.3 Retention Systems

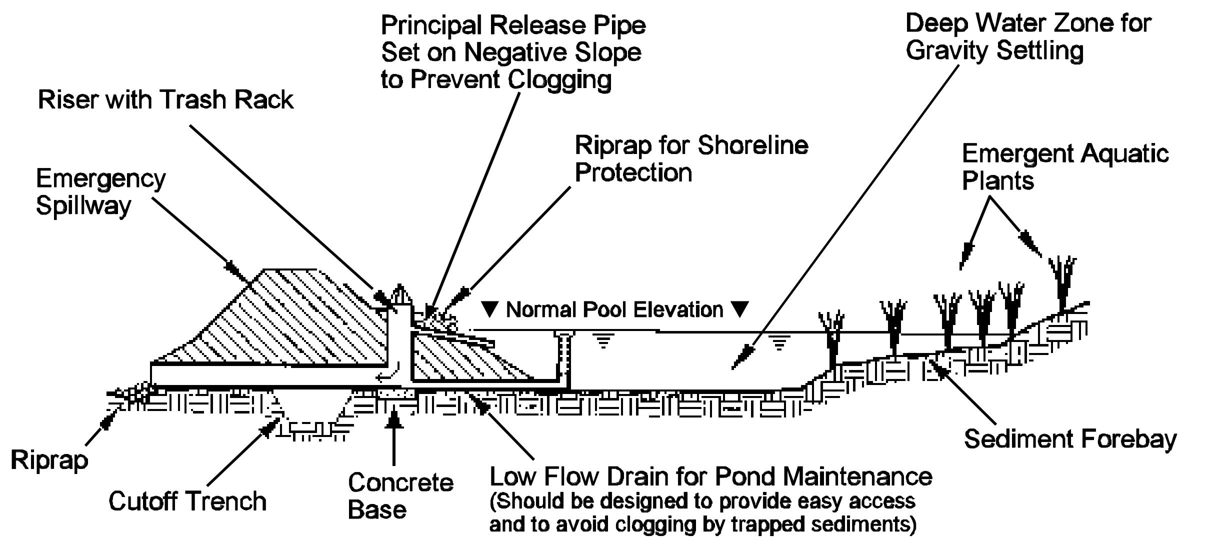
Retention systems include wet ponds and other retention systems such as underground pipes or tanks. Retention systems are designed to capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Retention systems can provide both water quantity and quality control. The volume available for storage, termed the water quality volume, is provided above the permanent pool level of the system. The main pollutant removal mechanisms in retention systems is sedimentation. By retaining a permanent pool of water, retention systems can benefit from the added biological and biochemical pollutant removal mechanisms provided by aquatic plants and microorganisms, mimicking a natural pond or lake ecosystem. Also, sediments that accumulate in the pond are less likely to be re-suspended and washed out due to the presence of a permanent pool of water. In addition to sedimentation, other pollutant removal mechanisms in retention systems include filtration of suspended solids by vegetation, infiltration, biological uptake of nutrients by aquatic plants and algae, volatilization of organic compounds, uptake of metals by plant tissue, and biological conversion of organic compounds.

<u>Retention Ponds</u>

Retention ponds (also known as wet ponds) are designed to intercept a volume of storm water runoff and to provide storage and treatment of this runoff volume. Water in the pond above the permanent pool level is displaced in part or completely by the runoff volume from subsequent runoff events. Retention ponds, when properly designed and maintained, can be extremely effective BMPs, providing both water quality improvements and quantity control, as well as providing aesthetic value and aquatic and terrestrial habitat for a variety of plants and animals.

Pollutant removal in retention ponds can occur through a number of mechanisms. The main mechanism is the removal of suspended solids and associated pollutants through gravity settling. Aquatic plants and microorganisms can also provide uptake of nutrients and degradation of organic contaminants. Retention basins that incorporate an aquatic bench around the perimeter of the basin that is lined with aquatic vegetation can have an added pollutant removal efficiency. This littoral zone can aid in pollutant removal efficiency by incorporating mechanisms found in wetland systems. These mechanisms include removal of sediment by filtration by aquatic plants, removal of metals and nutrients through biological uptake by aquatic vegetation and degradation of organic contaminants. If the bottom of the pond is not lined, then infiltration can occur aiding in the maintenance of local groundwater supplies. A diagram of a typical wet pond is shown below.

Figure 5-5. Retention Pond



Source: NVPDC, 1992.

<u>Retention Tanks, Tunnels, Vaults and Pipes</u>

Retention systems other than ponds include surface tanks and underground vaults, pipes and tunnels. These systems are not as prevalent as typical wet ponds, and therefore little information is contained in the literature about their design, applicability and usefulness.

5.2.1.4 Constructed Wetland Systems

Constructed wetland systems incorporate the natural functions of wetlands to aid in pollutant removal from storm water. Constructed wetlands can also provide for quantity control of storm water by providing a significant volume of ponded water above the permanent pool elevation. Constructed wetland systems have limits to their application. A water balance must be performed to determine the availability of water to sustain the aquatic vegetation between runoff events and during dry periods. In addition, a sediment forebay or some other pretreatment provision should be incorporated into the wetland system design to allow for the removal of coarse sediments that can degrade the performance of the system. Also, construction sediment should be prevented from entering constructed wetlands, as the resulting sediment loading can severely degrade the performance of the system. Constructed wetlands are particularly appropriate where groundwater levels are close to the surface because groundwater can supply the water necessary to sustain the wetland system.

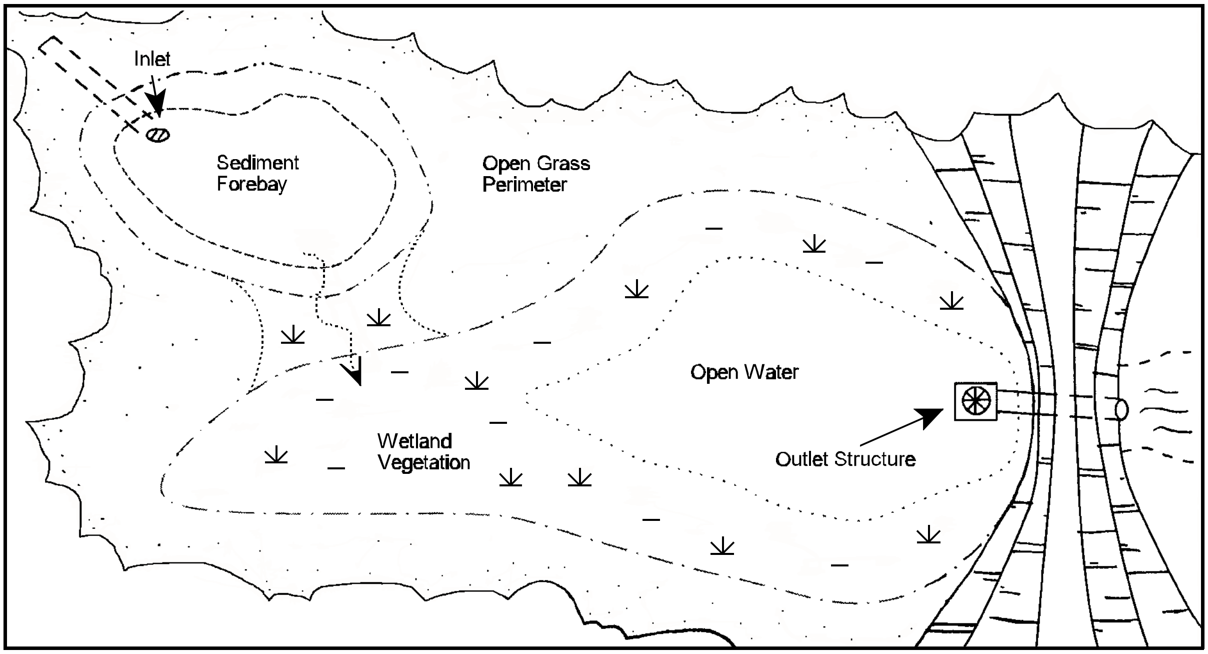
Storm water runoff should not be intentionally routed to natural wetlands without pretreatment due to the potentially damaging effects runoff can have on natural wetland systems. In addition, natural wetlands that receive storm water runoff should be evaluated to determine if the runoff is causing degradation of the wetland, and if so measures should be taken to protect the wetland from further degradation and to repair any damage that has been done. In addition, local permitting authorities should be consulted prior to designing and maintaining constructed wetland systems in order to determine if any local regulations apply to their use or maintenance.

Wetland Basins and Wetland Channels

Wetland basins and channels are any of a number of systems that incorporate mechanisms of natural wetland systems for water quality improvement and quantity control. A wetland channel is designed to develop dense wetland vegetation and to convey runoff very slowly (Urbonas and Strecker, 1996). Generally, this rate is less that 2 feet-per-second at the 2-year peak flow. Wetland basins may be designed with or without an open water (permanent pool) component. Wetland basins with open water are similar to retention ponds, except that a significant portion (usually 50 percent or more) of the permanent pool volume is covered by emergent wetland vegetation. Wetland basins without open water are inundated with water during runoff events, but do not maintain a significant permanent pool. Wetland basins of this type, also known as a wetland meadow, support a variety of wetland plants adapted to saturated soil conditions and tolerant of periodic inundation by runoff.

Pollutant removal in wetlands can occur through a number of mechanisms including sedimentation, filtration, volatilization, adsorption, absorption, microbial decomposition and plant uptake. In addition, wetlands can provide for significant water storage during runoff events, thus supplying water quantity control as well. A diagram of a typical storm water wetland system is included below.

Figure 5-6. Constructed Wetland System

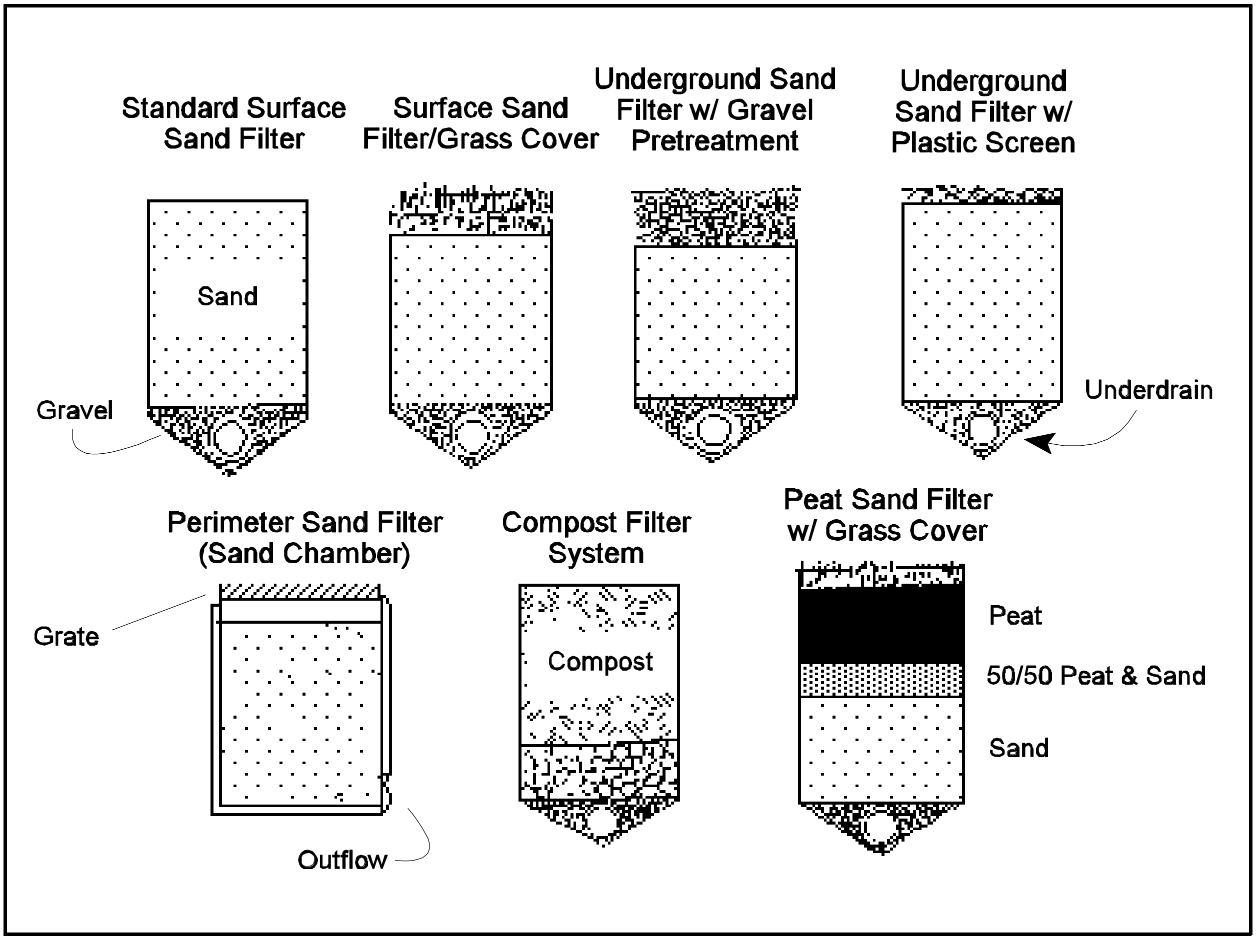


5.2.1.5 Filtration Systems

A filtration system is a device that uses a media such as sand, gravel, peat or compost to remove a fraction of the constituents found in storm water. There are a wide variety of filter types in use. There are also a variety of proprietary designs that use specialized filter media made from materials such as leaf compost. Filters are primarily a water quality control device designed to remove particulate pollutants. Quantity control can be included by providing additional storage volume in a pond or basin, by providing vertical storage volume above the filter bed, or by allowing water to temporarily pond in parking lots or other areas before being discharged to the filter. Media filters are commonly used to treat runoff from small sites such as parking lots and small developments, in areas with high pollution potential such as industrial areas, or in highly urbanized areas where land availability or costs preclude the use of other BMP types. Filters should be placed off-line (i.e., a portion of the runoff volume, called the water quality volume, is diverted to the BMP, while any flows in excess of this volume are bypassed) and are sometimes designed to intercept and treat only the first half inch or inch of runoff and bypass larger storm water flows. A benefit of using filters in highly urbanized areas is that the filter can be placed under parking lots or in building basements, limiting or eliminating costly land requirements. However, placing filters “out of sight” may have implications for continued maintenance and performance. Media filters should use a forebay or pre-settling chamber to remove a portion of the settleable solids prior to filtration. This helps to extend the life of the filter run and prevent clogging of the filter media by removing a portion of the coarse sediment. Also, care must be taken to prevent construction site sediments and debris such as fines washed off of newly paved areas from entering the filter, as these can cause premature clogging of the filter.

Filter types in common use include surface sand filters such as the “Austin” sand filter and underground vault filters such as the “D.C.” sand filter and the “Delaware” sand filter. There are a number of variations of these basic designs in common use. In addition, there are a number of proprietary filtering systems in use. There are also a number of variations in the types of filtration media that are in use in media filters. Designs may incorporate features such as a layer of filter cloth or a plastic screen, a gravel layer, a peat layer, a compost layer, a layer of peat or a peat/sand mixture. Typical variations in filtration media are shown below.

Figure 5-7. Filter Media

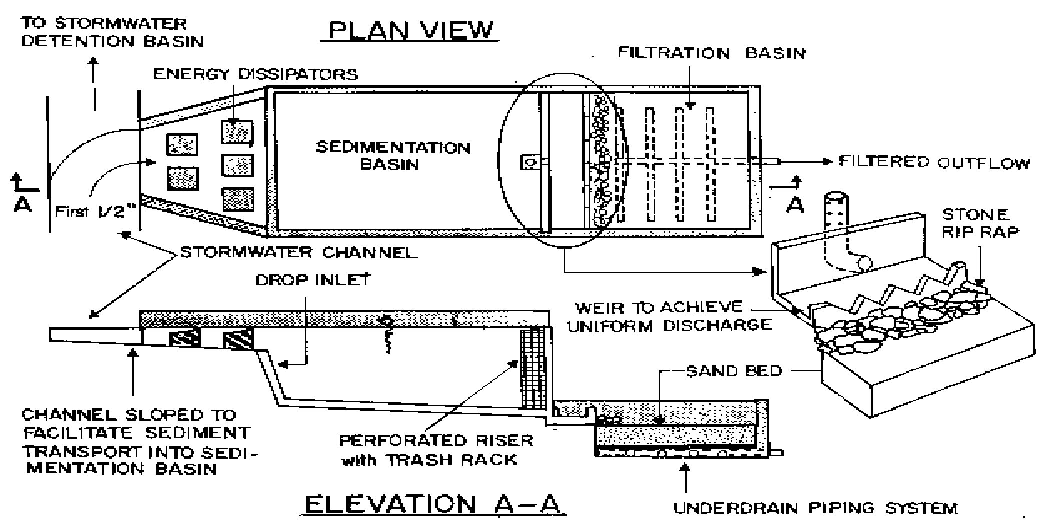


Source: Claytor and Schueler, 1996

<u>Surface Sand Filter</u>

The surface sand filter was developed in Florida in 1981 for sites that could not infiltrate runoff or were too small for effective use of detention systems. The city of Austin, Texas took the development of filter technology further in the mid-1980's. The surface sand filter system usually incorporates two basins. Runoff first enters a sedimentation basin where coarse particles are removed by gravity settling. This sedimentation basin can be either wet or dry. Water then flows over a weir or through a riser into the filter basin. The filter bed consists of sand with a gravel and perforated pipe under-drain system to capture the treated water. The surface of the filter bed may be planted with grass. Additional storage volume is provided above the filter bed to increase the volume of water that can be temporarily ponded in the system prior to filtration. This two-basin configuration can help to limit premature clogging of the filter bed due to excessive sediment loading. There are several design variations of the simple surface sand filter. Austin uses two variations, termed the partial and the full sedimentation-filtration systems. A diagram of the Austin surface sand filter is shown in Figure 5-8.

Figure 5-8. Austin Full Sedimentation-Filtration System

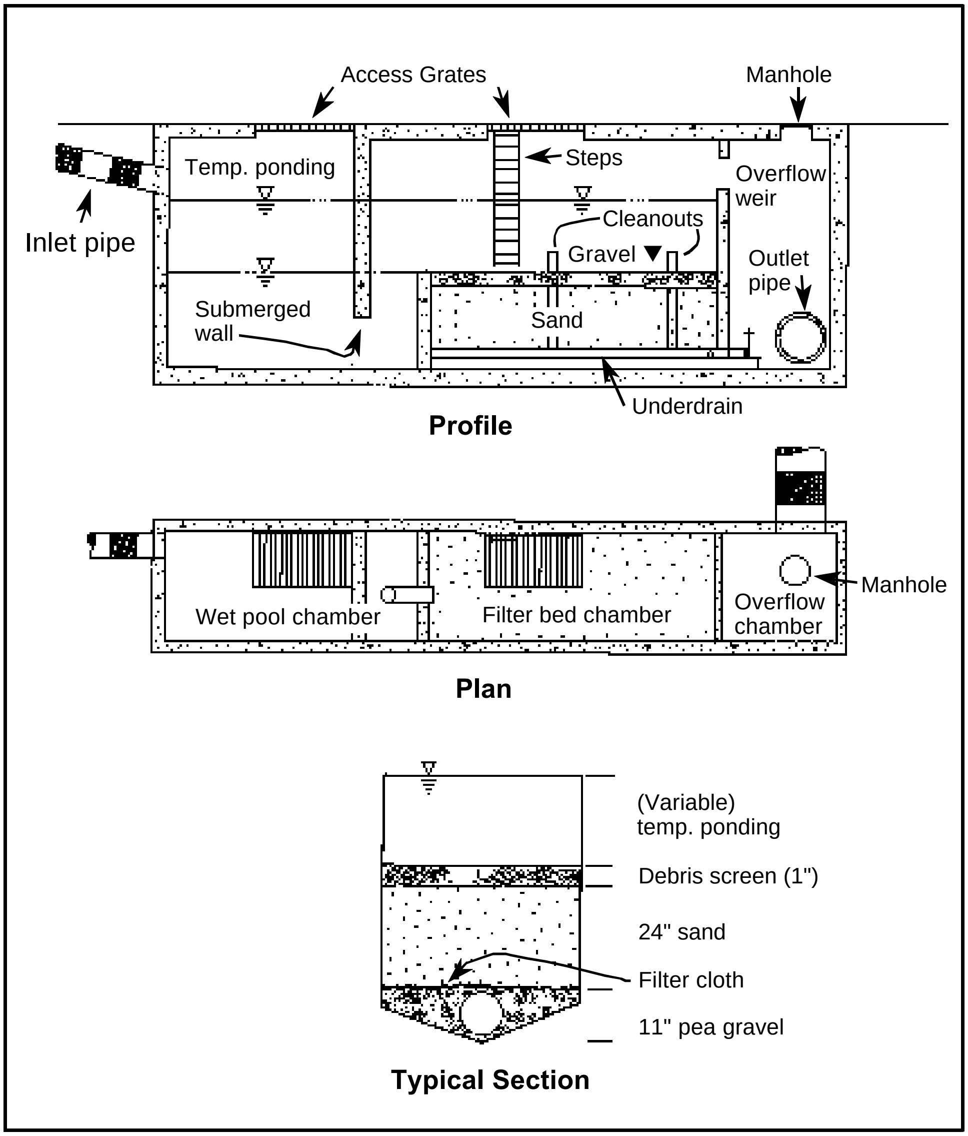


Source: Bell, 1998

Underground Vault Sand Filter

The underground vault sand filter was developed by the District of Columbia in the late 1980's. This filter design incorporates three chambers. The first chamber and the throat of the second chamber contain a permanent pool of water and functions as a sedimentation chamber and an oil and grease and floatables trap, as well as provides for temporary runoff storage. A submerged opening or inverted elbow near the bottom of the dividing wall connects the two chambers. This submerged opening provides a water seal that prevents the transfer of oil and floatables to the second chamber which contains the filter bed. During a storm event, water flows through the opening into the second chamber and onto the filter bed. Additional runoff storage volume is provided above the filter bed. Filtered water is collected by a gravel and perforated pipe under-drain system and flows into the third chamber, which contains a clearwell and a connection to the storm drain system. Overflow protection can be provided by placing the filter off-line, or by providing a weir at the top of the wall connecting the filter chamber with the clearwell chamber to serve as an overflow. A schematic of the "D.C. Sand Filter" is shown below.

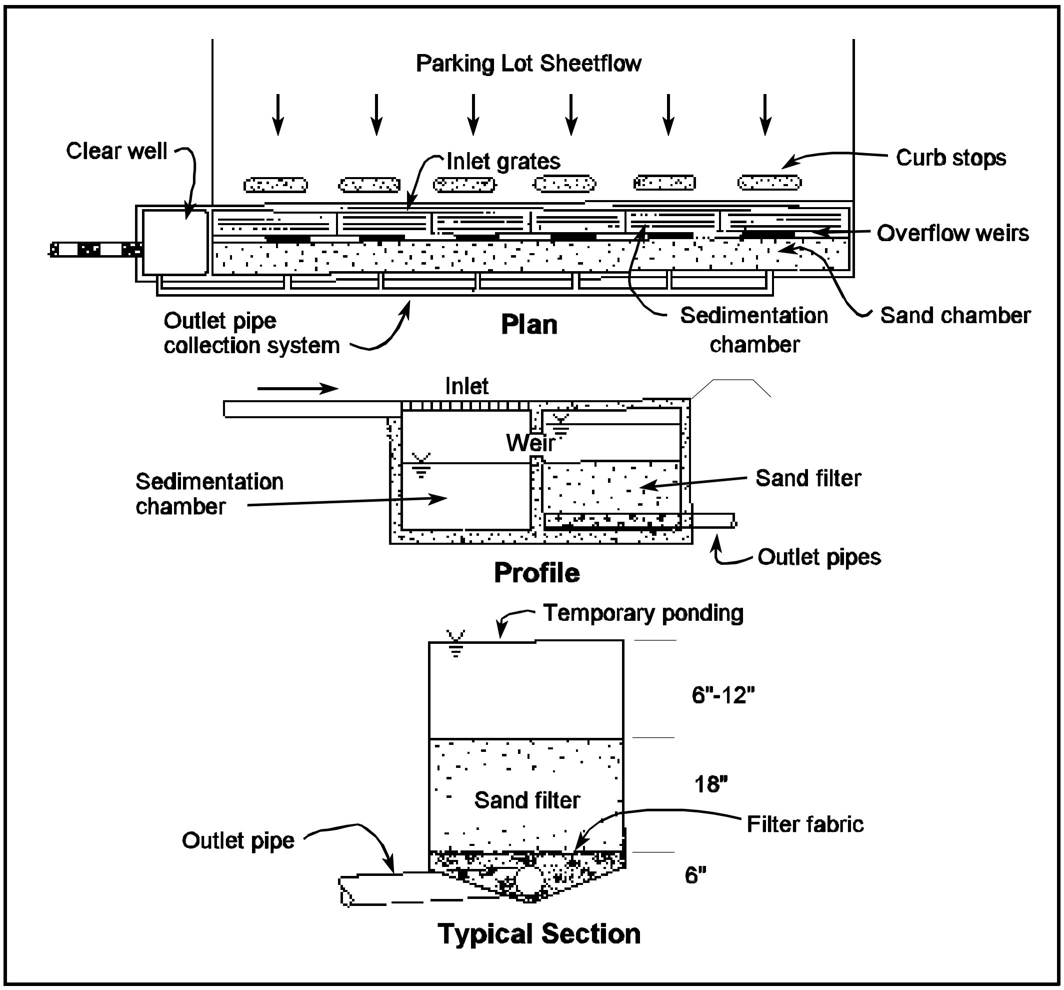
Figure 5-9. Underground Vault Sand Filter



Source: Claytor and Schueler, 1996.

Another underground vault sand filter, also termed a "perimeter" sand filter because it is particularly suited for use around the perimeter of parking lots, was developed in Delaware by Shaver and Baldwin and is known as the "Delaware Sand Filter." This system contains two chambers and a clearwell. Storm water runoff enters the first chamber, which serves as a sedimentation chamber. Water then flows over a series of weirs and into the second chamber which contains the filter media. Additional storage volume is provided by water temporarily ponding in both chambers. Filtered water is collected by a series of gravel and perforated pipe under-drains, and flows into a clearwell that contains a connection to the storm drain system. A schematic of the Delaware Sand Filter is shown below.

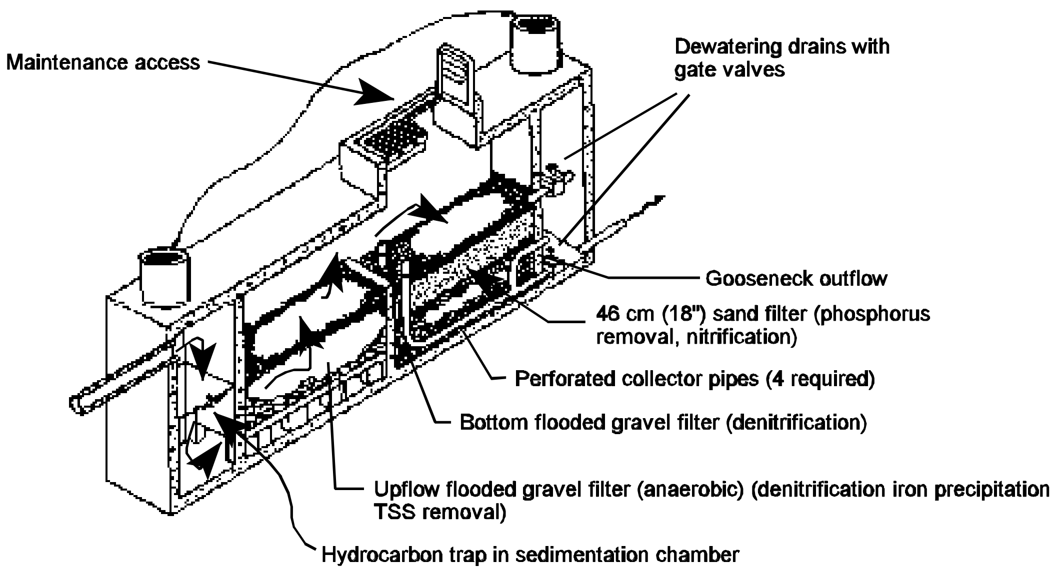
Figure 5-10. Delaware Sand Filter



Source: Shaver and Baldwin, 1991

In addition to the three basic filtering systems (D.C., Austin, and Delaware), there are a number of variations in use. The city of Alexandria, Virginia has developed a compound storm water filtering system (Bell, 1998). This design incorporates an anoxic filtration zone in a permanently flooded gravel layer in the filter. This anoxic zone aids in nitrogen removal by anoxic denitrification. Another configuration uses an upflow anaerobic filter upstream of the sand filter to enhance phosphorus removal by precipitating more iron on the sand filter. A diagram of the Alexandria Compound Filtration System is shown below.

Figure 5-11. Alexandria Compound Filter



Source: Bell, 1998.

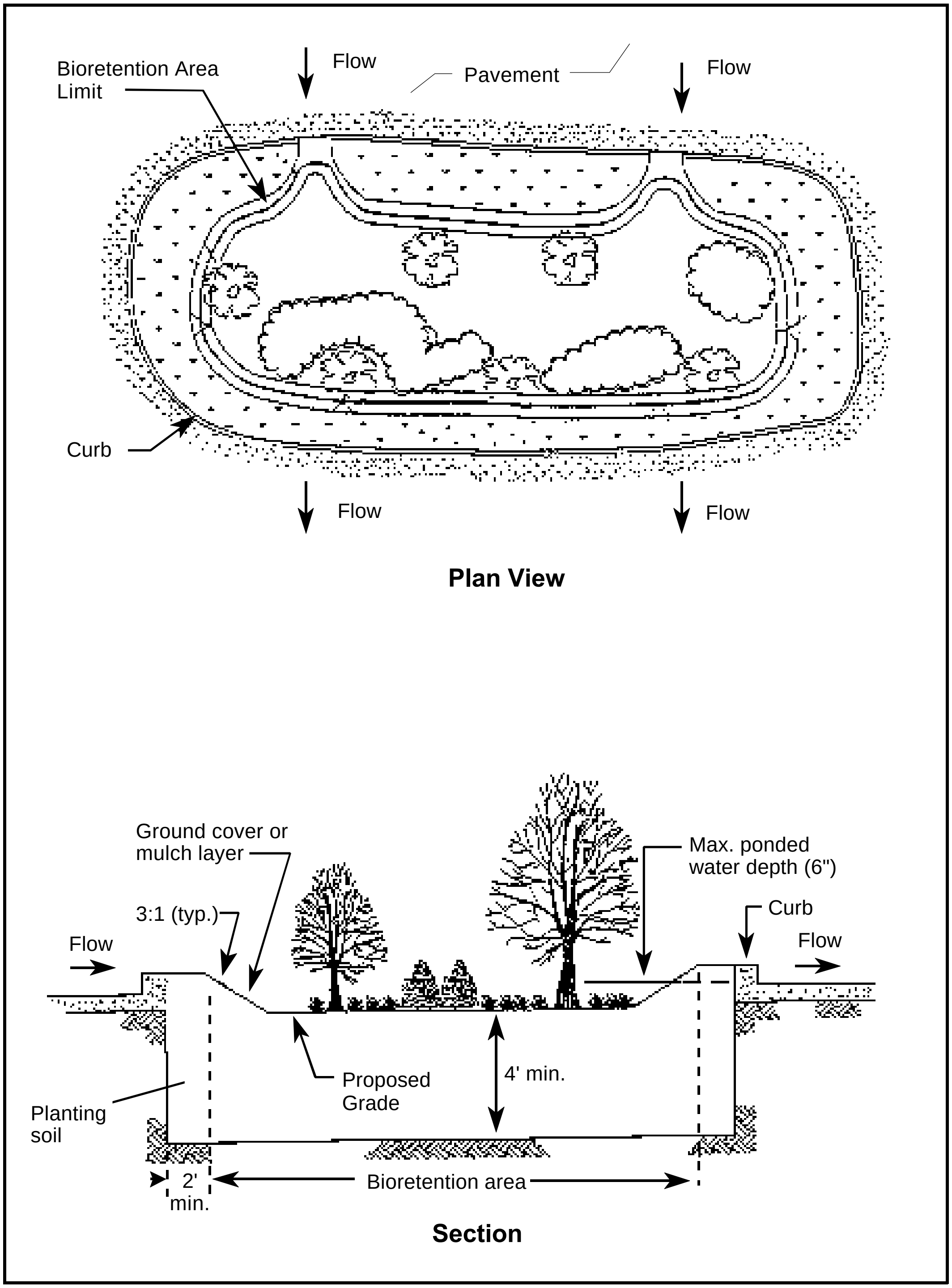
Filters that use an organic filtration media, such as peat or leaf compost, are useful in areas where additional nutrient or metal control is desirable due to the adsorptive capacity, its ion-exchange capability, and is ability to serve as a medium for the growth of a variety of microorganisms. However, peat must be carefully selected (fibric and/or hemic peat should be used, not sapric) and one must question the environmental consequences of destroying peat bogs to obtain filtration media when other technologies are available.

There are a number of references available that contain information on the design and selection of filtering systems for storm water treatment (Urbonas, 1999; Bell, 1998; Claytor and Schueler, 1996; Galli, 1990b; MDE, 1998; NVPDC, 1996a).

Biofiltration/Bioretention Systems

Bioretention systems are designed to mimic the functions of a natural forest ecosystem for treating storm water runoff. Bioretention systems are a variation of a surface sand filter, where the sand filtration media is replaced with a planted soil bed. Storm water flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by a number of processes including adsorption, filtration, volatilization, ion exchange and decomposition (Prince George’s County, MD, 1993). Treated water is allowed to infiltrate into the surrounding soil, or is collected by an under-drain system and discharged to the storm sewer system or directly to receiving waters. When water is allowed to infiltrate into the surrounding soil, bioretention systems can be an excellent source of groundwater recharge. A diagram of a typical bioretention area is shown below.

**Figure 5-12. Bioretention System
Traffic Island**



Source: Prince George's County, 1993.

The components of a bioretention system include:

- *Grass Buffer Strips* - runoff enters the bioretention area as sheet flow through the grass buffer strips. The buffers reduce the velocity of the runoff and filter particulates from the runoff.

- *Ponding Area* - The ponding area provides for surface storage of storm water runoff before it filters through the soil bed. The ponding area also allows for evaporation of ponded water as well as allows for settling of sediment in the runoff.

- *Organic Mulch Layer* - The organic mulch layer has several functions. It protects the soil bed from erosion, retains moisture in the plant root zone, provides a medium for biological growth and decomposition of organic matter, and provides some filtration of pollutants.

- *Planting Soil Bed* - The planting soil bed provides water and nutrients to support plant life in the bioretention system. Storm water filters though the planting soil bed where pollutants are removed by the mechanisms of filtration, plant uptake, adsorption and biological degradation.

- *Sand Bed* - the sand bed underlies the planting soil bed and allows water to drain from the planting soil bed through the sand bed and into the surrounding soil. The sand bed also provides additional filtration and allows for aeration of the planting soil bed.

- *Plants* - Plants are an important component of a bioretention system. Plants remove water though evapotranspiration and remove pollutants and nutrient through uptake. The plant species selected are designed to replicate a forested ecosystem and to survive stresses such as frequent periods of inundation during runoff events and drying during inter-event periods.

In addition to providing for treatment of storm water, bioretention facilities, when properly maintained, can be aesthetically pleasing. Bioretention facilities can be placed in areas such as parking lot islands, in landscaped areas around buildings, the perimeter of parking lots, and in other open spaces. Since local regulations frequently require site plans to incorporate a certain percentage of open landscaped area, additional land requirements for bioretention facilities are often not required. The layout of bioretention facilities can be very flexible, and the selection of plant species can provide for a wide variety of landscape designs. However, it is important that a landscape architect with proper experience in designing bioretention areas be consulted prior to construction to insure that the plants selected can tolerate the growing conditions present in bioretention facilities. Bioretention facilities can be adapted easily for use on individual residential lots. Prince George's County, MD has developed the concept of "rain gardens" which are small bioretention systems for use in single or multi-lot residential areas. They provide an easily maintainable, aesthetically pleasing, and effective means of controlling runoff from residential areas. By disconnecting down spouts and placing a series of bioretention areas throughout a residential area, the volume of storm water runoff produced and requiring subsequent management can be significantly reduced.

Additional design information on bioretention facilities can be found in *Design Manual for Use of Bioretention in Stormwater Management* (Prince George's County, 1993) and in *Design of Stormwater Filtering Systems* (Claytor and Schueler, 1996).

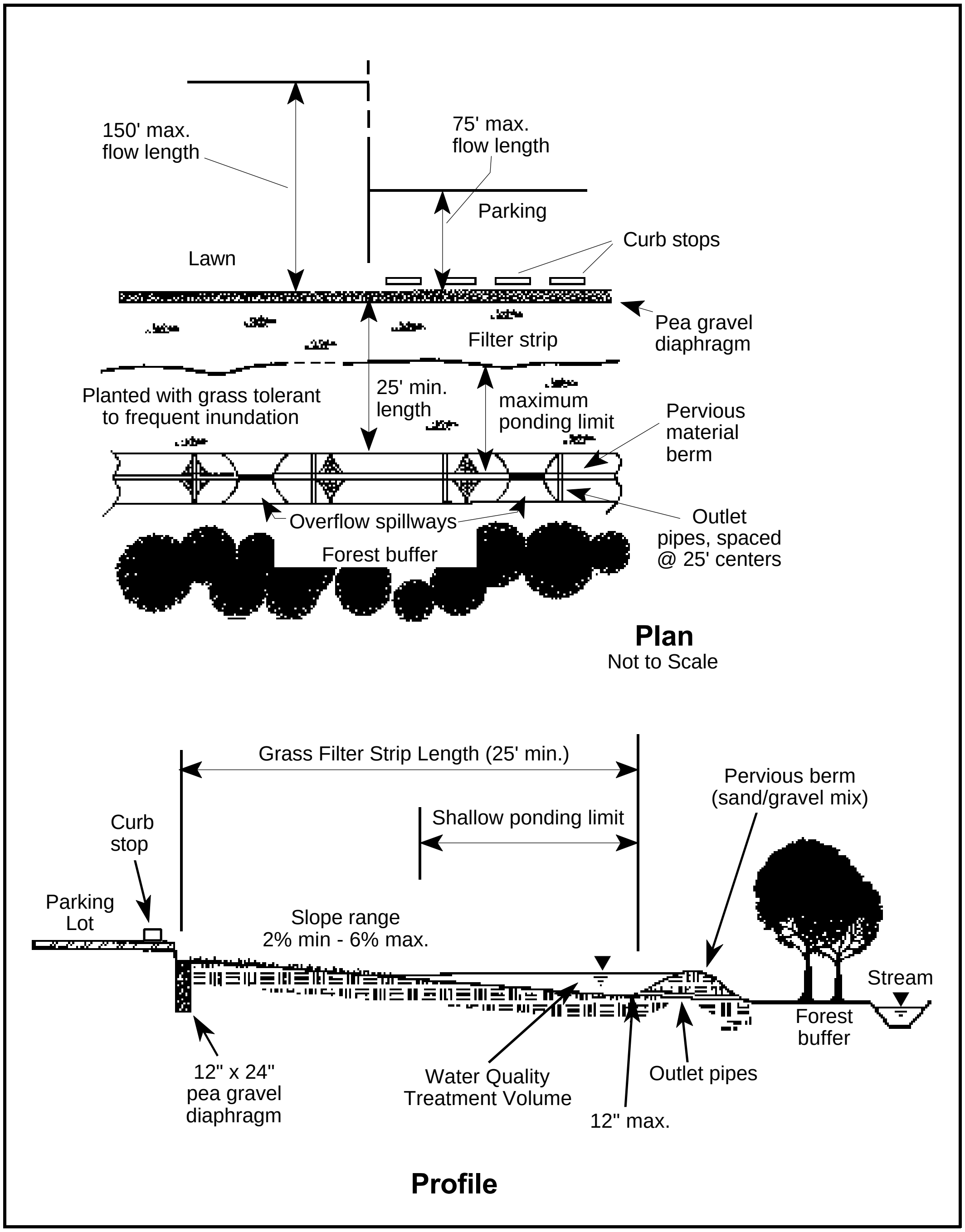
5.2.1.6 Vegetated Systems (Biofilters)

Vegetated systems such as grass filter strips and vegetated swales are used for conveying and treating storm water flows. These BMPs are commonly referred to as *biofilters*, since the grasses and vegetation "filter" the storm water as it flows. Open channel vegetated systems are alternatives to traditional curb-and-gutter and storm sewer conveyance systems. By conveying storm water runoff in vegetated systems, some degree of treatment, storage and infiltration can be provided prior to discharge to the storm sewer system. This can help to reduce the overall volume of storm water runoff that is generated from a particular drainage area.

<u>Grass Filter Strips</u>

Grass filter strips are densely vegetated, uniformly graded areas that intercept sheet runoff from impervious surfaces such as parking lots, highways and rooftops. Grass filter strips are frequently planted with turf grass, however alternatives that adopt any natural vegetated form such as meadows or small forest may be used. Grass filter strips can either accept sheet flow directly from impervious surfaces, or concentrated flow can be distributed along the width of the strip using a gravel trench or other level spreader. Grass filter strips are designed to trap sediments, to partially infiltrate this runoff and to reduce the velocity of the runoff. Grass filter strips are frequently used as a "pretreatment" system prior to storm water being treated by BMPs such as filters or bioretention systems. Grass filter strips can also be used in combination with riparian buffers in treating sheet flows and in stabilizing drainage channel banks and stream banks. In semi-arid climates, grass filter strips may need to be irrigated to maintain a dense stand of vegetation and to prevent export of unstabilized soil. A diagram of a grass filter strip is shown below.

Figure 5-13. Grass Filter Strip



Source: Claytor and Schueler, 1996.

Vegetated Swales

Vegetated swales are broad, shallow channels with a dense stand of vegetation covering the side slopes and channel bottom. Vegetated swales are designed to slowly convey storm water runoff, and in the process trap pollutants, promote infiltration and reduce flow velocities. Vegetated swales can be either wet or dry. Dry swales are used in areas where standing water is not desired, such as in residential areas. Wet swales can be used where standing water does not create a nuisance problem and where the groundwater level is close enough to the surface to maintain the permanent pool in inter-event periods. Wet swales provide the added benefit of being able to include a range of wetland vegetation to aid in pollutant removal.

5.2.1.7 Minimizing Directly-Connected Impervious Surfaces

Minimizing directly-connected impervious surface areas involves a variety of practices designed to limit the amount of storm water runoff that is directly connected to the storm drainage system. Runoff is instead directed to landscaped areas, grass buffer strips, and grassed swales to reduce the velocity of runoff, reduce runoff volumes, attenuate peak flows, and encourage filtration and infiltration of runoff (UDFCD, 1992). By incorporating these principles into site designs, the size and number of conventional BMPs such as ponds and constructed wetland systems can be significantly reduced.

Minimizing directly connected impervious surfaces incorporates both non-structural and structural control measures. Discussions in this section address the structural measures that can be incorporated into existing urbanized or newly developed areas to minimize the amount of runoff discharged to the storm drain system. Additional discussion on non-structural practices that can be used to minimize runoff generation in new developments is included in Section 5.2.3 "Low Impact Development Practices."

The Denver *Urban Storm Drainage Criteria Manual* (UDFCD, 1992) identifies the following three levels of minimizing directly connected impervious areas:

- *Level 1*: Runoff generated from impervious surfaces such as rooftops, driveways and parking lots is directed to flow over vegetated areas before flowing to a storm sewer system. This increases the travel time of runoff and promotes the removal of suspended solids by sedimentation and filtration.
- *Level 2*: Street curb-and-gutter systems are replaced by grassed swales and pervious street shoulders. Conveyance systems and storm sewer inlets are still used to collect runoff at downstream intersections and crossings.
- *Level 3*: In addition to incorporating Levels 1 and 2, swales are oversized and driveway and street crossing culverts are configured to use the grassed swales as detention basins having the capacity to capture runoff volume for a design storm (2-, 5-, 10- or 100-year runoff).

Practices that reduce the amount of directly connected impervious surfaces can easily be incorporated into site design plans during the planning stages of development projects. Using these practices can result in significant development cost savings due to the decreased need for drainage infrastructure and large end-of-pipe structural BMPs such as ponds and constructed wetlands. These practices can also limit secondary impacts from structural BMPs, such as temperature increases from retention ponds. Minimizing directly connected impervious areas can also be applied to existing urbanized areas through retrofit. Practices that can be used in retrofit instances include disconnecting rooftop downspouts from the storm drain system, use of on-site retention and infiltration to limit the amount of runoff leaving the site and replacing traditional curb-and-gutter systems with grassed swales and wetland channels. Additional discussion on practices that minimize runoff generation is included in Section 5.2.3.

5.2.1.8 Miscellaneous and Vendor-Supplied Systems

There are a wide variety of miscellaneous and proprietary devices that are used for urban storm water management. Many of these systems are “drop-in” systems, and incorporate some combination of filtration media, hydrodynamic sediment removal, oil and grease removal, or screening to remove pollutants from storm water. A few of the systems available include:

- BaySaver
- CDS Technologies
- Hydrasep®
- Storm*ceptor*®
- StormFilter™
- StormTreat™ System
- Vortechs™.

A thorough evaluation of vendor-supplied systems was not conducted in this report. Readers are encouraged to contact the product vendors to obtain information regarding these systems.

One of the main problems facing the use of proprietary devices is the lack of peer-reviewed performance data for these systems. Several vendor-supplied storm water treatment systems are being evaluated through EPA’s Environmental Technology Verification (ETV) program. With financial assistance from the ETV program, the Civil Engineering Research Foundation (CERF) established the Environmental Technology Evaluation Center, commonly known as “EvTEC, ” in 1998. EvTEC is a private sector program designed to utilize networks of experts, testing facilities and stakeholders to evaluate technologies dealing with a variety of environmental problems. One of the EvTEC projects is a collaborative effort with the Washington Department of Transportation (WSDOT) to verify the performance of innovative storm water BMPs under field operating conditions. These evaluations, which are scheduled to begin in 1999, are expected to provide comparable, peer-reviewed data on the performance of these systems (CERF, 1998).

5.2.2 Non-Structural BMPs

Non-structural BMPs include institutional and pollution-prevention type practices designed to prevent pollutants from entering storm water runoff or reduce the volume of storm water requiring management. Non-structural BMPs can be very effective in controlling pollution generation at the source, which in turn can reduce or eliminate the need for costly end-of-pipe treatment by structural BMPs. Non-structural BMPs discussed in this report include education and source controls, recycling and maintenance practices.

5.2.2.1 Education, Recycling and Source Controls

Public education can be an effective means of reducing the amounts of non-point source pollutants entering receiving streams. The public is often unaware that the combined effects of their actions can cause significant non-point source pollution problems. Proper education on day-to-day activities such as recycling of used automotive fluids, household chemical and fertilizer use, animal waste control and other activities can significantly reduce non-point source pollutant loadings to urban streams. The main components of a public education program include:

Automotive Product Disposal

Discharge of automotive fluids such as motor oil and antifreeze to the land or storm drains can cause significant water quality problems. "Do-it-yourself" automobile mechanics often incorrectly assume that materials that are dumped into storm drains will receive treatment at a wastewater treatment plant prior to discharge. Education on appropriate recycling and disposal techniques for these materials can help to reduce pollutant loadings to streams. Education programs should identify the location of community automotive products recycling centers. In addition to impacts associated with dumping used oil and antifreeze, potential runoff pollutant sources from home automobile maintenance activities include dirt, cleaners, oils and solvents from car washing, leaking fluids such as brake and transmission fluid and gasoline spills. To reduce impacts from these activities, the following practices should be used:

- all spills or leaks should be cleaned up using a dry absorbent such as cat litter or commercially available absorbents and disposed of appropriately;
- car washing should be done away from storm drains using biodegradable cleaners, or at a commercial carwash;
- all used fluids should be recycled or disposed of appropriately;
- all fluid leaks should be repaired as soon as possible to reduce loss to the environment.

Commercial and Retail Space Good Housekeeping

Commercial and retail areas can contribute significant pollutant loadings to runoff. The biggest contributor of pollutant is usually impervious surfaces used for vehicle parking, storage and maintenance areas, which can contribute sediment, metals and hydrocarbons. Other sources include raw material and finished product storage areas, pesticides and fertilizers from grounds maintenance, and rooftop runoff. Good housekeeping practices include using porous pavement or modular paving systems for vehicle parking lots; limiting exposure of materials and equipment to rainfall; spill cleanup, using dry cleanup techniques instead of wet techniques; and limiting direct runoff of rooftops to storm drains.

General Community Outreach

A main problem associated with identifying and controlling nonpoint source pollution is that the public is generally unaware of the sources and control measures for urban nonpoint source pollutants. Information dissemination is a critical need of most local storm water programs. Information that explains the sources of nonpoint source pollution, control measures available and the steps homeowners and commercial owners can do to reduce impacts of their activities can help to increase the public awareness of the need to control nonpoint source pollution. A few of the techniques available for providing educational materials to the public include television, radio and newspaper announcements, distribution of flyers, community newsletters, workshops and seminars, conducting teacher training programs at schools, and supporting citizen-based watershed stewardship groups and volunteer monitoring programs.

Industrial Good Housekeeping

Industrial areas can contribute significant loadings of toxic pollutants to storm water runoff. Therefore, educational programs that inform industrial site owners and operators about pollution prevention and source control programs to reduce nonpoint source pollutant can significantly reduce the amounts of pollutants discharged from industrial areas. Pollution prevention practices include minimizing or eliminating exposure of materials and products to rainfall by storing inside or under cover, spill cleanup, minimizing pesticide/herbicide and fertilizer use, and minimizing discharges of equipment wash water to storm drains.

Storm Drain Inlet Stenciling

Since storm drains frequently discharge runoff directly to water bodies without receiving any type of treatment, storm drain stenciling programs that educate residents not to dump materials into storm drains or onto sidewalks, streets, parking lots and gutters can be effective at reducing nonpoint source pollution associated with illegal dumping. Residents are frequently unaware that materials dumped down storm drains may be discharged to a local water body. Therefore, stenciling the inlets can be a simple yet effective means of alerting residents of this fact. The Northern Virginia *Nonstructural Urban BMP Handbook* (NVPDC, 1996b) contains a useful discussion on developing a storm drain stenciling program.

Pesticide/Herbicide Use

Due to their high aquatic toxicity, pesticides and herbicides can be a significant source of water quality impairment in urban streams. Pesticide usage in the United States was estimated at more than 1.2 billion pounds of active ingredients in 1995 (US EPA, 1997b). Of this total, agricultural usage constituted 939 million pounds (77 percent), commercial, industrial and government usage accounted for 150 million pounds (13 percent) and home and garden usage accounted for 133 million pounds (11 percent). A significant portion of these applications find their way into storm water runoff and ultimately into receiving streams through spray drift, transport by soils, solubilization by runoff, and by spillage, dumping and improper disposal of containers and residuals. Education on the proper methods of application, application rates and alternatives to pesticides can help to reduce the amount of pesticides that are carried by urban runoff. Alternatives to pesticides, such as in integrated pest management program and pesticide alternatives such as insecticidal soap or natural bacteria, can also reduce the need for pesticides.

Fertilizer Use

A significant amount of nutrients in urban runoff results from misapplication of fertilizer to the urban landscape. Residential lawn and garden maintenance and maintenance of landscape and turfgrass at golf courses, schools and commercial areas uses significant amounts of fertilizers containing nitrogen and phosphorus. Since most fertilizers are water soluble, over-application or application before rainfall events can allow significant quantities to be carried away by storm water runoff. Education on proper application of fertilizers can help to reduce the quantities of nutrients reaching receiving waters.

Household Hazardous Material Disposal

A variety of hazardous and potentially harmful chemicals and materials are improperly used and disposed of by residential homeowners. Materials such as paints and thinners, cleaning products, wood preservatives, driveway sealants and a variety of other miscellaneous household chemicals can find their way into storm water if improperly used, stored or disposed of. Education on usage and holding an annual or semi-annual community household hazardous waste collection program can help to reduce the amounts of these materials that enter storm water runoff.

Lawn Debris Management

Lawn debris such as grass trimmings and leaves require proper management in order to reduce impacts to urban streams. Grass trimmings and leaves can be carried away by runoff and can find their way into streams where they rapidly decompose and release nutrients. Grass trimmings and leaf litter can be controlled by composting or by community curbside collection programs. Composted yard debris can be an excellent source of mulch for residential landscape and gardens. Use of mulch can greatly reduce the need for inorganic fertilizers, which helps to keep nutrient loadings to streams to a minimum.

Pet Waste Disposal

Pet waste can cause significant loadings of bacteria, nutrients and oxygen demanding substances to urban runoff. Pet waste deposited on yards, sidewalks and streets can be carried by runoff into storm drains. As an example, it is estimated that 11,445 pounds of dog waste are generated in the Four Mile Run watershed in northern Virginia each day.[2] 378 pounds of BOD, 39 pounds of total phosphorus and 189 pounds of total nitrogen are washed off into Four Mile Run and its tributaries annually as a result of this pollution load (NVPDC, 1996b). In many areas,

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[2] This estimate was calculated based on the total waste load generated by the dog population in the area, not the waste load deposited on yards, sidewalks and streets.

regulations exist prohibiting the deposit of pet waste on public property. However, it is often very difficult to enforce these laws. Community education on the impacts associated with pet waste and alternative disposal methods such as flushing and disposal in the trash can help to reduce impacts associated with pest waste. A particularly useful method of controlling pet waste is for communities to provide pet waste receptacles in parks and other public areas for pet owners to deposit droppings from their pets.

Illicit Discharge Detection and Elimination

Illicit discharges to storm sewers can be a significant source of pollutants in urban storm water. A study conducted in Sacramento, California indicated that slightly less than one-half of the water discharged from a municipal separate storm sewer system was not directly attributable to precipitation runoff (US EPA, 1993b). A major source of illicit discharges to storm drain systems are direct connections of sanitary sewer piping to the storm drain system. In addition to direct connections, seepage and sewage from leaking sanitary sewer lines can find their way into storm drains, especially in areas where storm drains run parallel to the sanitary sewer lines. Spills can also be collected by storm drain inlets.

Detection and elimination of illicit connections and discharges can significantly reduce the concentrations of bacteria, nutrients and oxygen demanding substances contained in storm water discharges. Several methods exist for detection and elimination of illicit cross-connections. Useful indicators of the presence of cross connections include dry weather flows in storm sewer lines and biological indicators that indicate the presence of human fecal matter in storm drain outfalls. Once illicit connections are detected, excavation and correction of the illicit connections are necessary. In addition to detection and elimination of existing cross-connections, plans for new development should be carefully reviewed and inspections should be conducted during construction in order to prevent future cross-connections from being placed. Storm drain stenciling programs and a public spill reporting system can help to educate the public on proper procedures for managing spills to prevent discharge to the storm sewer system.

5.2.2.2 Maintenance Practices

Maintenance programs are necessary in order to reduce the pollutant contribution from the urban landscape and to ensure that storm water collection and treatment systems are operating as designed. Major maintenance practices that can be used include:

Catch Basin Cleaning

Catch basins naturally accumulate sediment and debris such as trash and leaf litter. In order to ensure their continued effectiveness, catch basins need to be periodically cleaned. This can be done by manual means, or by using a vacuum truck.

Street and Parking Lot Sweeping

Urban streets and parking lots can accumulate large amounts of pollutants that can be washed off during storm events. Streets and parking lots comprise a significant portion of the total impervious area within a developed watershed, and a large percentage, if not the entire area, of streets and parking lots are usually directly connected to the storm drain system. In an investigation conducted by Bannerman (Bannerman et al, 1993), data on runoff volumes from streets and parking lots collected during 4 years from two urbanized areas in Wisconsin indicated that 54 percent of the total runoff volume from residential areas was due to direct runoff from streets and parking lots, and that 80 percent of the total runoff volume from commercial areas was due to direct runoff from streets and parking lots. A breakdown of the runoff volumes based on source area is shown in Table 5-1.

Table 5-1. Percent Runoff Volumes Contributed by Source Area in Two Urbanized Areas of Wisconsin

Land Use	**Source Area Percent Runoff Contribution**					
	Feeder Streets	Collector Streets	Arterial Streets	Parking Lots	Total % due to roads and parking lots	Total Other %*
Residential	34	20	--	--	54	46
Commercial	--	10	21	49	80	20

* Other land uses include lawns, driveways, rooftops and sidewalks
Source: Adapted from Bannerman et al, 1993

Furthermore, Bannerman found that runoff from streets and parking lots contributed a significant portion of the total runoff pollutant loading. Table 5-2 summarizes the pollutant load contributions based on land uses, and indicates the total contaminant contribution in the urbanized area attributable to runoff from streets and parking lots.

Table 5-2. Contaminant Load Percentages in Two Urbanized Areas of Wisconsin

Contaminant	Percent Contribution by Source Area						Total Contaminant Contribution by Streets and Parking Lots
	Residential		*Commercial*		*Industrial*		
	Streets	**Parking Lots**	**Streets**	**Parking Lots**	**Streets**	**Parking Lots**	
Total Solids	76	--	57	31	20	60	**78**
Suspended Solids	80	--	68	27	25	55	**80**
Total Phosphorus	58	--	56	28	19	29	**54**
Dissolved Phosphorus	46	--	50	27	18	11	**39**
Dissolved Copper	73	--	50	39	16	73	**82**
Total Copper	78	--	60	32	22	67	**85**
Total Zinc	80	--	45	32	9	30	**49**
Fecal Coliform	78	--	82	10	10	19	**71**

Source: Adapted from Bannerman et al, 1993

Based on these data, streets and parking lots can contribute significant pollutant loadings to urban runoff. Therefore, sweeping programs that can remove a portion of these materials from streets and parking lots may significantly reduce the pollutant load contributions to urban runoff.

Road and Ditch Maintenance

Road and street surfaces undergo breakdown due to frictional action of traffic, freeze-thaw breakdown, frost heaving, and erosion of road subbase. Failure to correct deteriorating pavement can allow exposure of unstabilized subbase material to erosive forces of water and subsequent increases in suspended solids concentrations. The same process occurs in roadside ditches where high runoff rates cause channelization and erosion. Roadside ditches also accumulate sediment and debris from the road surface, which enters runoff during rainfall events. Maintenance of roads and cleaning and stabilization of ditches can help to reduce pollutant loadings from these sources. In roadside ditches, reducing the length and slope of ditch runs and reducing the velocity of runoff by using check dams can help to prevent excessive channelization and erosion.

Road Salting and Sanding

Road salting and sanding can contribute large quantities of sediment and salts to runoff. Highway maintenance programs in areas where road icing is a problem frequently apply large quantities of sand, salt, and coal ash to prevent icy road surfaces. Snowmelt can carry a large portion of these materials into the storm drainage system and ultimately to receiving streams. High salt concentrations can have significant impacts on receiving streams. In addition, road salt can contain cyanide, which may cause acute or chronic toxicity to aquatic organisms. Alternative deicing products such as acetates, formates and agricultural residues can be used if impacts due to traditional deicing products are significant.

Sediment and Floatables Removal from BMPs

Sediment and floatables removal is an important component of maintenance for BMPs that are designed for sediment capture. Removal of accumulated sediment is important so that the BMP continues to operate efficiently. Accumulation of excess sediment in pond and constructed wetland systems can lead to reduced storage capacity, short-circuiting and re-suspension of previously settled particles. All of these can lead to decreased efficiency of the BMP. Floatables in BMPs can accumulate and block outlet structures leading to changes in BMP hydraulics. Floatables can cause aesthetic impacts, and floating material such as algal scum and other debris can lead to odor problems. Sediment removal is also needed periodically in filtration systems. Sedimentation chambers require periodic cleanout of sediments and floatables (including accumulated oil) and filter beds will accumulate a sediment layer on the surface that will decrease the filtration rate of the system over time. Periodic removal of this sediment layer and a portion of the filtration media is necessary in order to restore the filtration capacity of the system. Sediments also accumulate in infiltration basins. The accumulation of sediments, particularly sediments from construction activities and improperly stabilized soil, will lead to a rapid reduction of the infiltrative capacity of infiltration basins, trenches and wells.

The frequency of sediment removal in BMP types can vary widely. Some BMPs require sediment removal every two or three years, while others may not need maintenance for more than 20 years. The frequency that sediment must be removed depends greatly on the land use and degree of soil stabilization in the contributing watershed. BMPs that receive runoff from a watershed that has significant construction activities will accumulate sediment at a rate much faster than a watershed with little or no construction activity. In addition, watersheds with dense, well established vegetation will contribute less sediment than sparsely vegetated watersheds. Also, watersheds in arid or semi-arid regions, which frequently are subject to high intensity rainfall and highly erosive storm water flows will produce large quantities of solids requiring frequent removal from BMPs. Table 5-3 summarizes maintenance requirements and frequency for different structural BMP types.

Vegetation Maintenance

Vegetative BMPs such as constructed wetlands, grassed filter strips, vegetated swales, and bioretention facilities require periodic vegetation maintenance to enhance performance. Grassed filter strips and vegetated swales require a dense stand of vegetation in order to function properly and to prevent export of sediment from unstabilized planting areas. Several seasons of planting and re-seeding of sparsely vegetated areas may be needed in order to reach optimum performance. Constructed wetland systems frequently require re-planting of wetland vegetation in areas where original plantings failed to become established. Once wetland systems are functioning, periodic vegetation harvesting is necessary to remove excess vegetation and stored nutrients. Invasive species also need to be periodically removed to promote growth of beneficial wetland vegetation. Grassed filter strips and vegetated swales require periodic mowing to remove excess vegetation and stored nutrients. Mowing of these systems should not be done too close to the ground, as dense vegetation is needed for optimum performance.

General BMP Maintenance

BMPs require a variety of periodic maintenance activities in order to enhance performance. In addition to sediment removal and vegetation maintenance, periodic maintenance and repair of outlet structures is needed, filtration media need to be periodically replaced, and eroded areas need to be repaired, to name a few. Table 5-3 summarizes general maintenance activities and frequency for a few BMP types. The actual maintenance schedule varies considerably based on site-specific conditions, and the values given should be used only as a general guideline for established residential or commercial areas without significant inputs of construction sediment or other sediment loadings.

Table 5-3. Recommended BMP Maintenance Schedules

<table>
<tr><th>BMP</th><th>Activity</th><th>Schedule</th></tr>
<tr><td rowspan="3">Retention Pond / Wetland[1]</td><td>• Cleaning and removal of debris after major storm events
• Harvest excess vegetation
• Repair of embankment and side slopes
• Repair of control structure</td><td>Annual or as needed</td></tr>
<tr><td>• Removal of accumulated sediment from forebays or sediment storage areas</td><td>5-year cycle, or as needed</td></tr>
<tr><td>• Removal of accumulated sediment from main cells of pond once the original volume has been significantly reduced</td><td>20-year cycle (although can vary)</td></tr>
<tr><td>Detention Basin</td><td>• Removal of accumulated sediment
• Repair of control structure
• Repair of embankment and side slopes</td><td>Annual or as needed</td></tr>
<tr><td>Infiltration Trench[1]</td><td>• Cleaning and removal of debris after major storm events
• Mowing[4] and maintenance of upland vegetated areas
• Maintenance of inlets and outlets</td><td>Annual or as needed</td></tr>
<tr><td rowspan="2">Infiltration Basin[2]</td><td>• Cleaning and removal of debris after major storm events
• Mowing[4] and maintenance of upland vegetated areas</td><td>Annual or as needed</td></tr>
<tr><td>• Removal of accumulated sediment from forebays or sediment storage areas</td><td>3- to 5-year cycle</td></tr>
<tr><td>Sand Filters[3]</td><td>• Removal of trash and debris from control openings
• Repair of leaks from the sedimentation chamber or deterioration of structural components
• Removal of the top few inches of sand and cultivation of the surface when filter bed is clogged (only works for a few cycles)
• Clean-out of accumulated sediment from filter bed chamber
• Clean out of accumulated sediment from sedimentation chamber</td><td>Annual or as needed</td></tr>
</table>

1. Modified from Livingston et al (1997)
2. Modified from Livingston et al (1997), based on infiltration trench requirements
3. Modified from Claytor and Schueler (1996)
4. Mowing may be required several times a year, depending on local conditions

Table 5-3. Recommended BMP Maintenance Schedules (continued)

BMP	Activity	Schedule
Bioretention[1]	• Repair of eroded areas • Mulching of void areas • Removal and replacement of all dead and diseased vegetation • Watering of plant material	Bi-Annual or as needed
	• Removal of mulch and application of a new layer	Annual
Grass Swale[2]	• Mowing[4] and litter and debris removal • Stabilization of eroded side slopes and bottom • Nutrient and pesticide use management • De-thatching swale bottom and removal of thatching • Discing or aeration of swale bottom	Annual or as needed
	• Scraping swale bottom, and removal of sediment to restore original cross section and infiltration rate • Seeding or sodding to restore ground cover (use proper erosion and sediment control)	5-year cycle
Filter Strip[3]	• Mowing[4] and litter and debris removal • Nutrient and pesticide use management • Aeration of soil in the filter strip • Repair of eroded or sparse grass areas	Annual or as needed

1. Modified from Prince George's County (1993)
2. Modified from Livingston et al (1997)
3. Modified from Livingston et al (1997) based on grass swale recommendations
4. Mowing may be required several times a year, depending on local conditions

5.2.3 Low-Impact Development Practices

There are a number of low-impact development practices that can be used at the site level. While these practices often do not produce direct removal of pollutants from runoff, they can significantly reduce runoff volumes that are generated, reduce the impacts associated with runoff and reduce the need for conventional structural BMPs. There are a number of practices that are in use, and therefore an exhaustive summary has not been included in this document. However, a few of the more common practices in use are presented briefly in the following sections.

Minimizing Impervious Areas

Minimizing the amount of impervious surfaces that are created in a new development can greatly reduce the volume of storm water runoff that is generated. There are many opportunities that exist for reducing impervious surfaces, including:

- limiting the number, length and radius of cul-de-sacs;

- using porous pavement or modular block pavers in parking areas and low-traffic areas;
- reducing the width of streets;
- placing sidewalks on only one side of the street;
- reducing frontage requirements to lessen paved surface areas.

Although the above practices can reduce the amounts of impervious surfaces that are created, there will still be a great deal of impervious surfaces that must be included into a site plan such as rooftops, streets, driveways and lawns. To limit the impacts associated with runoff from these surfaces, it is important to limit the amount of areas that are directly connected to the storm drainage system. This can be accomplished by providing on-site retention and infiltration to collect rooftop and driveway runoff, and through the use of BMPs such as grassed swales, vegetated filter strips and wetland channels in place of traditional curb-and-gutter systems.

Directed Growth

Directed growth involves placing controls on land use through mechanisms such as master planning and zoning ordinances. Local governments may utilize these mechanisms in order to protect sensitive areas from development and to target growth to areas that are more suitable for development where it is easier to control the impacts associated with runoff. Directed growth can be a complex process, and must balance a number of factors such as economic considerations, local laws and ordinances, secondary impacts such as increased traffic and population in certain areas, as well as the availability of public utilities such as sewage treatment and drinking water service, and schools, hospitals and fire stations. Nevertheless, with careful planning and consideration, directed growth can help to reduce impacts associated with development of an area.

Sensitive Area Protection

Sensitive area protection is an important component of conservation design. Sensitive areas include the areas adjacent to streams, wetlands and natural drainage channels, cold water fisheries, shellfish beds, swimming beaches, recharge areas, and drinking water supplies. These areas are particularly susceptible to degradation by storm water runoff. Preservation of these areas and incorporation of stream and wetland buffers into site plans can help to preserve the integrity of these areas.

Open Space Preservation

Preservation of open space such as forested areas and meadows can help to reduce the impacts associated with development of an area. Open space preservation helps to reduce the generation of runoff, and can reduce the overall impact that results from development of an area by limiting the amount of impervious areas that are created. Open space allows the preservation of buffers and natural drainage corridors, and retains the natural storm water filtering, retention and infiltration effects of these areas. Open space can also increase the aesthetics of a development, and make the area more desirable to potential home buyers.

Minimizing Soil and Vegetation Disturbance

Soil and vegetation disturbance can significantly increase the amount of runoff that is generated from a site and the concentrations of pollutants that are transported by the runoff. Disturbed soil areas are particularly susceptible to erosion during storm events. Vegetation helps to stabilize soil and prevent detachment and transport by flowing water. By minimizing the area that is disturbed to only areas undergoing active construction (often termed "fingerprinting"), erosion of soil can be minimized. In addition, disturbance of soil and vegetation should be limited to only those areas that are necessary. Disturbing soil by excavation, grading and compaction reduces the infiltrative capacity of the soil, creating additional runoff that must be managed. Maintaining naturally vegetated areas minimizes the amount of increased runoff that is produced.

5.3 BMP Selection

BMP selection is a complex process. There are a number of competing factors that need to be addressed when selecting the appropriate BMP or suite of BMPs for an area. It should be stressed that BMPs should be incorporated into a comprehensive stormwater management program. Without proper BMP selection, design, construction and maintenance, BMPs will not be effective in managing urban runoff. BMP selection can be tailored to address the various sources of runoff produced from urbanized areas. For example, a particular suite of BMPs may be developed for use on construction sites and new land development, where opportunities exist for incorporating BMPs that are focused on runoff prevention, reducing impervious surfaces and maintaining natural drainage patterns. In established urban communities, a different suite of BMPs may be more appropriate due to space constraints. In these areas, BMPs may be selected to focus on pollution prevention practices along with retrofit of the established storm drain system with regional BMPs. *Site suitability* for selecting a particular BMP strategy is key to successful performance. Most BMPs have limitations for their applicability, and therefore cannot be applied nationwide. A few considerations to incorporate into BMP selection are:

- drainage area;
- land uses;
- average rainfall frequency, duration and intensity;
- runoff volumes and flow rates;
- soil types;
- site slopes;
- geology/topography;
- availability of land;
- future development/land use in watershed;
- depth to groundwater table;
- availability of supplemental water to support vegetative BMPs;
- susceptibility to freezing;
- safety and community acceptance;
- maintenance accessability;
- periodic and long-term maintenance/rehabilitation needs.

In addition to site-specific applicability requirements, factors such as BMP cost, local regulations or requirements, aesthetics, the experience of a developer or contractor with a particular design, and competing receiving water considerations such as temperature and nutrient levels should be addressed. The combination of these factors make selection of appropriate BMPs a difficult task, and one that should be done only by an experienced storm water practitioner. This is especially true in established urban areas, where knowledge of local factors that affect design and performance is needed. BMP use in arid and semi-arid climates also presents unique challenges. The availability of water to support vegetative and open pool BMPs such as retention ponds and wetland systems is of primary concern in these areas. Without adequate water sources, these systems may not function properly and may become public nuisances. A designer with adequate experience in designing BMPs for arid climates should be consulted in these instances. In addition to arid climates, BMP use in areas where freezing conditions can be encountered presents design problems. In cold climates, design modifications may be needed to adjust for freezing and spring snowmelt (Caraco and Claytor, 1997). Given the variety of local considerations that exist, developing a matrix of BMP applicability is outside of the scope of this report. There are several references that readers should consult to obtain additional information on BMP selection, including *Fundamentals of Urban Runoff Management* (Horner et al, 1994), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs* (Schueler, 1987), *A Watershed Approach to Urban Runoff: Handbook for Decisionmakers* (Terrene Institute, 1996), *Urban Targeting and BMP Selection* (Terrene Institute, 1990), *Guidance Specifying Management Measures for Sources on Nonpoint Source Pollution in Coastal Waters* (US EPA, 1993a), *Handbook Urban Runoff Pollution Prevention and Control Planning* (US EPA, 1993c), *Municipal Wastewater Management Fact Sheets: Storm Water Best Management Practices* (US EPA, 1996e), *Design and Construction of Urban Stormwater Management Systems* (WEF and ASCE, 1992), and *Urban Runoff Quality Management* (WEF and ASCE, 1998).

5.4 Monitoring BMP Effectiveness

Monitoring the effectiveness of BMPs can be done in a number of ways. Since urban runoff frequently contains pollutants that can contribute to water quality impacts to receiving streams, the ability of a BMP to remove pollutants from runoff is often of concern. The typical method for measurement of the pollutant removal efficiency of a BMP system is to collect and analyze *water quality samples*. This can be accomplished by measuring the concentration of a target parameter or group of parameters in an inflow sample or set of samples and comparing these values to samples collected from the outflow of the BMP. The reduction in concentrations or loading across the BMP can be termed the pollutant removal efficiency.

In addition to monitoring the pollutant removal efficiency of BMPs, it is important to *monitor the hydraulic performance* of the BMP. A major problem associated with urban runoff is the total volume and flow rate of water that is discharged to the storm sewer system or the receiving stream. To evaluate the effectiveness of BMPs in reducing these impacts, hydraulic parameters such as the reduction in peak discharge rate, reduction in total volume discharged, and the time effects of discharges are frequently measured. To do this, measurement of flow rates and water volumes into and out of the system are conducted by using flow monitoring equipment.

Since the ultimate goal of BMPs is to protect or improve the quality of receiving streams, another method of evaluating the effectiveness of BMPs is to *evaluate the quality of waters receiving runoff*. Measures of water quality such as pollutant levels, pH, dissolved oxygen and other parameters can give an indication as to the effectiveness of a given BMP or group of BMPs. Evaluation of the contaminant levels present in sediments of receiving waters is also an important measure of BMP effectiveness. In addition, measures of aquatic habitat and stream channel morphology can give an indication as to the effectiveness of BMPs in controlling impacts or improving channel or habitat quality. Another measure to evaluate the effectiveness of BMPs is to measure the organisms that live in the receiving stream. Biological indicators such as macroinvertebrate counts, fish counts, and aquatic plant surveys can indicate the overall health of the receiving stream and indicate, over time, the effectiveness of BMPs. A potential problem with in-stream indicators is that it is sometimes difficult to isolate the impacts or improvements attributable to one particular variable. Since there are potentially a number of different factors that can influence a stream such as the amount of riparian cover, the existence of point source discharges, seepage from on-site disposal systems, as well as urban runoff, in can be very difficult to isolate impacts or improvements attributable to one particular stressor. Therefore, many years of data, collected both before and after a BMP implementation, may be needed to indicate a change. In spite of these shortcomings, in-stream monitoring and evaluation of the cumulative effects in a watershed as a result of BMP implementation is a very important measure of BMP effectiveness.

5.4.1 Water Quality Monitoring of BMPs

BMP monitoring can be conducted for a number of reasons, and the type of monitoring conducted and the instrumentation or equipment used can vary greatly depending upon the parameters of interest. BMP monitoring and data analysis is a complex process, and therefore a thorough explanation of all of the available monitoring practices and procedures is not included here. An important point to emphasize with respect to BMP monitoring is that consistent data reporting is needed in order to compare data between studies. Consistent reporting of BMP design parameters and watershed parameters as well as consistent monitoring methods and data analysis protocols is key to conducting data comparisons. It is recommended that individuals conducting BMP monitoring use the data reporting protocols developed by the American Society of Civil Engineers (ASCE) for the National Stormwater BMP Database (Urbonas and Strecker, 1996). These protocols are included with the database software, and are also available from the ASCE website.[3]

The following discussion includes a description of the most common methods used to evaluate BMP performance. Readers are encouraged to consult various monitoring manuals that

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[3] The website address is http://www.asce.org/peta/tech/nsbd01.html

are available and papers that are contained in the literature for more detailed information on BMP monitoring and data analysis. Recommended references include *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (US EPA, 1997c), *NPDES Storm Water Sampling Guidance Document* (US EPA, 1992c), and *Stormwater NPDES Related Monitoring Needs* (Torno, 1995).

BMPs are frequently evaluated by collecting inflow and outflow samples and comparing concentrations of pollutants. Samples can be collected in a number of different ways. The most common way is by collecting flow- or time-weighted composite samples from inflow and outflow points and measuring the concentrations of a targeted group of parameters in these samples. Composite samples can be collected by using automatic samplers, or by collecting a series of discrete samples and manually compositing. Composite samples are useful for determining an overall average or "event mean" concentration for a particular sampling point, and are commonly used to evaluate BMP performance. However, composite samples cannot be used to evaluate any trends in pollutant concentrations over time or varying flow rates. In order to conduct these types of evaluations, it is necessary to collect a series of discrete grab samples either by an automatic sampler or by collecting grabs manually. By collecting a series of discrete time-weighted or flow-weighted samples, a "pollutograph" of concentration versus time or flow rate can be prepared, which can give insight into the performance of the BMP under various hydraulic loadings. Sample results can then be combined mathematically to determine representative event mean concentrations. Manual grab samples are also used for collecting samples that are not amenable to collection by automated equipment, such as microbiological samples, samples for oil and grease evaluation, and samples for volatile organic compounds analysis.

BMP monitoring frequently incorporates measurements of water flow rates and volumes into and out of the system. Flow rates are frequently determined by using a combination of a primary control device (weir, flume or orifice) that is calibrated to discharge water according to a known relationship based on the depth of the water flowing over or through the device, along with a secondary control device (bubbler, pressure transducer, float, etc.) that is used to measure the depth of water flowing through or over the primary control device. A digital recorder is frequently used to record the depth of water measured by the secondary control device and to calculate the flow rate through the primary control device based on a pre-determined relationship between water depth and flow rate. The digital recorder can be used to log this flow data for subsequent retrieval and analysis, and can activate automated sampling equipment to collect samples at pre-determined flow rates or times. By using a configuration such as this, flow-weighted samples or discrete samples can be collected automatically, reducing or eliminating the need for personnel to be on-site during an event.

In addition to measuring surface runoff contributions to BMPs, measurement of the contribution of groundwater and subsurface flow may be necessary for BMPs that have a significant groundwater contribution. Constructed wetland systems that are close to or at groundwater level are a good example of BMPs where measurement of groundwater flows may be necessary.

BMP monitoring programs also frequently incorporate measurements of rainfall depths, intensities and duration by using a rain gauge. Additional meteorological monitoring equipment can measure parameters such as air temperature, solar radiation, humidity, atmospheric pressure and wind speed and direction, which can aid in interpreting BMP performance data. Other instruments such as continuous pH, dissolved oxygen, and conductivity meters are also frequently incorporated into BMP monitoring programs in order to measure parameters of interest.

BMP monitoring programs can also include measurements of the atmospheric deposition rates of pollutants by using wet deposition and dry deposition sampling equipment. Atmospheric deposition can contribute significant loadings of pollutants to storm water BMPs, especially to BMPs that have a large surface area such as ponds or constructed wetlands.

Analysis of data collected from BMP monitoring programs can be conducted in a number of ways. Some of the most common methods used to measure effectiveness are measures of pollutant removal efficiency based on event mean concentrations (EMC). An event mean concentration can be determined directly from a flow-weighted composite sample. Estimations of pollutant removal efficiency in use include the efficiency ratio, the summation of loads, and the regression of loads. These methods are defined as follows (from Martin and Smoot, 1986 and reported by Strecker, 1995):

- The efficiency ratio (ER) is defined in terms of the average event mean concentration of pollutants from inflows and outflows:

$$ER = 1 - \frac{Average\ outlet\ EMC}{Average\ inlet\ EMC}$$

- The summation of loads method is based on the loads of pollutants removed during monitored storms:

$$SOL = 1 - \frac{\sum\ of\ outlet\ loads}{\sum\ of\ inlet\ loads}$$

- The regression of loads method defines the efficiency ratio as the slope of a simple linear regression of inlet loads and outlet loads of pollutants. The equation is:

$$Loads\ in = \$ \cdot Loads\ out$$

where β equals the slope of the regression line, with the intercept constrained at zero.

The above are only a few of the methods available for computing BMP pollutant removal efficiency. The selection of method can have a large impact on the reported removal efficiency. As a result, reported removal efficiency is not always comparable between studies due to differences in the way that pollutant removal was calculated. Additional work is needed in this area in order to standardize BMP data analysis and reporting.

5.4.2 Receiving Stream Assessments

Receiving stream assessments are an important means of determining the effectiveness of BMPs. The health of the biological community and the quality of the habitat present in the stream can be strong indicators of the effectiveness of BMPs. There are a number of biological indicators that can be used to evaluate streams, and a discussion of these methods is not within the scope of this document. Readers are encouraged to consult available documents for additional information on this subject, and for recommendations on developing biological criteria programs. Recommended readings include *Biological Criteria Technical Guidance for Streams and Small Rivers* (US EPA, 1996c) and *Restoring Life in Running Waters: Better Biological Monitoring* (Karr and Chu, 1998).

Physical habitat and fish and macroinvertebrate diversity indices have been identified as suitable indicators to assess the effectiveness of storm water controls (Center for Watershed Protection, 1996). EPA's *Rapid Bioassessment Protocols for Use in Streams and Rivers* (US EPA, 1997f) can be used to survey biological communities. In addition, many local and state environmental protection agencies have developed monitoring protocols for streams within their geographic area. Readers are encouraged to contact county and state environmental agencies to obtain more information regarding stream assessments. In addition to surveys of biological communities, measures of stream habitat are also useful for determining the effectiveness of BMPs. Some available methods for assessing habitat include:

- Physical habitat assessment component of EPA's Rapid Bioassessment Protocols;
- The Rapid Stream Assessment Technique (RSAT);
- The Ohio EPA's Qualitative Habitat Evaluation Index (QHEI);
- The Rosgen Stream Classification.

EPA used several receiving stream assessment methods in its 1998 field work at one BMP site. Findings from these assessments will appear in a supplement to this report.

5.5 Effectiveness of BMPs in Managing Urban Runoff

There has been a great deal of storm water and BMP monitoring data collected by a number of organizations. However, most of these data have focused on characterization of pollutants in runoff, and not on the effectiveness of various control measures. Several nation-wide monitoring programs have been conducted to characterize pollutants in urban storm water runoff and to evaluate the performance of storm water BMPs. The major federal monitoring programs that have been conducted are listed in Table 5-4.

Table 5-4. Sources of Storm Water Runoff and BMP Monitoring Data

Data Source	Year	Type of Monitoring Conducted
"208 Studies" under FWPCA Amendments of 1972	late 1970's	Limited storm water quality data
Nationwide Urban Runoff Program (NURP)	1978-83	Storm water quality data collected at 81 outfalls at 28 cities for a total of 2,300 storm events as well as some BMP data
Federal Highway Administration (FHWA)	1970's - 80's	Storm water runoff loadings from highways at 31 sites in 11 states
USGS Urban Storm Studies*	1970's - 90's	Rainfall, runoff and water-quality data for areas throughout the United States
Phase I NPDES Municipalities (260 permittees)	1990's	Storm water and BMP monitoring data for 5 representative sites during a minimum of 3 storm events

* USGS prepared a database that includes rainfall, runoff and water-quality data for 717 storms from 99 stations in 22 metropolitan areas throughout the United States, including much of the data collected during the NURP program, in the mid-1980's (Driver et al, 1985)

The USGS has been collecting urban rainfall and runoff data for several decades. In the 1970's and early 1980's, monitoring programs were conducted to collect water quality data in addition to rainfall and runoff data in order to characterize the pollutants present in storm water runoff and to evaluate the impacts attributable to wet weather discharges. The major programs included the Nationwide Urban Runoff Program (NURP) conducted by EPA and USGS and the FHWA evaluation of runoff from highways. Data from these evaluations indicated that urban storm water runoff was contributing significant levels of pollutants to the nations waters, and that control of urban runoff was warranted. However, these investigations also indicated that there was insufficient data available to quantify the degree of impacts attributable to urban runoff and to evaluate the effectiveness of various runoff control practices.

In addition to the major federal investigations, some data has been published in the professional literature. A number of bibliographies have been prepared that include storm water BMP-related literature. These include the ASCE Urban BMP Effectiveness Bibliography, and the National Highway Runoff Water-Quality Data and Methodology Synthesis Bibliography compiled by USGS and FHWA. The Center for Watershed Protection (CWP) has prepared a database containing BMP performance data for 123 structural BMPs (Brown and Schueler, 1997a). The

FHWA and ASCE are currently developing databases of published highway and urban BMP effectiveness data. In addition to data in the published literature, a large amount of data has been collected by various cities and municipalities as part of the storm water permitting program under the Phase I NPDES program for storm water discharges. To date, EPA has not undertaken a concerted effort to collect and evaluate this data. In addition to published data sources, a number of states, counties and cities have collected a significant amount of monitoring data for their own use. The extent of this data is not currently known, but several county and city storm water programs have collected a great deal of potentially useful BMP monitoring data. An effort to collect and evaluate these data may provide more useful information on the effectiveness of various control measures.

The effectiveness of BMPs can be measured in various ways. Non-structural BMPs deal mainly with pollution prevention and limiting the amounts of pollutants that are carried away by runoff. Their effectiveness is best measured in terms of the degree of change in people's habits following implementation of the management program or by the degree of reduction of various pollutant sources. It is oftentimes very difficult to measure the success of non-structural BMPs in terms of pollution reduction and receiving stream improvements. Structural BMPs can be measured in terms in the reductions of pollutants discharged from the system and by the degree of attenuation of storm water flow rates and volumes discharged to the environment. Various physical, chemical and biological evaluation methods exist for determining the pollutant removal efficiency of structural BMPs. The following sections summarize existing data on the pollutant removal efficiency of a variety of BMPs.

5.5.1 Controlling Pollution Generation

The literature on the effectiveness of BMPs in controlling the generation of pollutants is not very extensive. Pollution prevention type BMPs such as street sweeping, public education and outreach, collection of lawn debris, etc., are conceptually very effective means of controlling the generation of pollutants that can enter storm water runoff. However, it is often very difficult to develop a representative means of monitoring or evaluating their effectiveness. Additional work in this area is needed in order to measure the effectiveness of these controls. Effectiveness data and information for pollution prevention BMPs that has been identified is presented in the following sections.

Education and Outreach

Evaluating the performance of education and outreach programs is difficult. There is little quantitative data in the literature that measures the effectiveness of these programs in improving water quality. Information exists on how educational programs have been implemented and what their success rate has been as far as changing the habits of a select group of people, but data linking implementation with improvements in water quality are scarce. Nevertheless, educational programs are a valuable component of a comprehensive storm water management program. Surrogate measures of the effectiveness of education and outreach programs include:

- numbers of flyers distributed per given time period;
- number of radio or television broadcasts;
- number of public workshops held per year;
- the percentage of storm drains that have been stenciled;
- the number of volunteer monitoring and stewardship groups that have been formed.

A literature review by ASCE (Strecker and Quigley, 1998) did not identify any published studies that contained quantitative information evaluating the effectiveness of Education and Outreach BMPs in improving water quality.

Recycling and Source Controls

Evaluating the effectiveness of recycling and source control programs can be measured in terms of the quantities of materials that are being recycled, but it is often difficult to determine water quality improvements as a result of these programs. Measures of effectiveness include:

- surveys that evaluate how many residents have changed habits such as picking up pet waste and composting lawn debris;
- volumes of materials such as used oil and antifreeze that are recycled;
- the volume and types of materials collected during community household hazardous waste collection days;
- the number of illicit cross connections that have been detected and eliminated;
- the total curb miles of streets that are swept annually and the quantity of materials removed; and
- reductions in pesticide and fertilizer usage.

Monitoring of storm water quality to evaluate the effectiveness of source control programs is possible, however very few studies have been conducted. The difficulty stems from isolating the impacts of a particular source control program on the overall water quality draining from the watershed. The ASCE bibliography identified one study that potentially contains quantitative information about the effectiveness of recycling automotive products as a BMP (Horner et al, 1985). Additional data are needed in this area in order to evaluate the effectiveness of recycling and source controls.

Maintenance Practices

Maintenance practices are a necessary part of any municipal storm water program. In addition to maintenance of storm water management infrastructure and BMP maintenance, a range of municipal maintenance activities impact the quality of storm water runoff. As with other non-structural control practices, data evaluating the effectiveness of maintenance practices at reducing the impacts associated with storm water discharges are scarce.

Studies conducted during the NURP project indicated that street sweeping was generally not an effective BMP. This is mainly due to the fact that street sweepers remove only the coarse particles on streets, and are not generally effective at removing the fine particles. It is the "fines" that frequently contain the highest fractions of pollutants, especially metals. In fact, the NURP study report from Winston-Salem reported that street sweeping could actually increase the concentrations of select pollutants by removing the surface "armoring" of coarse particles, which during normal runoff events inhibit the removal of fine surface loads (Noel et al, 1987). Likewise, NURP studies conducted in Long Island, New York, Champaign, Illinois and Bellevue, Washington found little or no benefit of street sweeping programs. A study in Durham, New Hampshire, which evaluated the effectiveness of pavement vacuum cleaning, indicated that this technology was effective at removing BOD and fecal streptococci bacteria. It was thought that these contaminants were mainly associated with the coarser sediments, which this technology was able to effectively remove. Although the NURP data indicated that street sweeping was not an effective BMP for improving water quality, the usefulness of street sweeping programs cannot be discounted. Improvements in sweeper technology have occurred since the NURP studies were conducted, and today's sweepers may be more efficient at removing fine particulates. Regardless, sweeping programs can remove a significant amount of dirt and debris from streets and parking lots. However, obtaining data linking sweeping programs to water quality improvements may be difficult due to the variety of pollutant sources present in urban areas.

Data on other maintenance practices are likewise scarce. Practices such as catch basin cleaning, street pavement repair, and ditch maintenance are all necessary components of a storm water management program. However, data that indicate their effectiveness may be difficult to obtain due to the lack of appropriate evaluation methodologies and the difficulty associated with isolating water quality improvements attributable to these practices. The ASCE bibliography identified two NURP studies that included evaluating the effectiveness of catch basin cleaning as a storm water BMP (Lake Hills and Surrey Downs, Bellevue, Washington).

5.5.2 Controlling Pollution Discharges

There has been a great deal of published data documenting the efficiency of BMPs in removing pollutants from storm water. Much of this data provides useful insights into the performance of various types of storm water BMPs. For the purposes of this study, *efficiency* has been used to describe the ability of the management practice to remove pollutants from runoff. *Effectiveness* refers to the actual improvements in water quality, habitat or other parameters as a result of implementing the management practice. Most of the data contained in the literature reports efficiency of a BMP. Little of the available data can be used to evaluate actual effectiveness.

Brown and Schueler (1997a) documented the pollutant removal efficiency of commonly used and innovative urban storm water BMPs. The number of monitoring reports of various BMP categories included in this study are summarized in Table 5-5.

Table 5-5. Monitoring Studies for BMP Categories

BMP Type	Number of Studies
Detention Basins	8
Retention Basins	35
Wetland Systems	36
Filtration Systems	15
Swales and Filter Strips	20
Other	4

Evaluation of the existing BMP monitoring data gives an indication of the information gaps that exist in BMP monitoring studies that have been performed to date. Commonly used BMPs that are seldom monitored include infiltration trenches, infiltration basins, bioretention practices and filter strips. The reason for the limited number of monitoring studies for these practices is due to the difficulty involved in collecting inflow and outflow samples to calculate pollutant removals. Bioretention practices and filter strips frequently accept runoff as sheet flow, which must be concentrated in order to collect a representative sample. Infiltration practices and bioretention practices can discharge water through a large surface area into surrounding soil layers, and therefore collection of a representative “outflow” sample is problematic. There are also a number of innovative and infrequently used BMPs that are seldom monitored. These include sand filters, vegetated filter strips, filters with organic media, wetland channels and swales.

In addition to a general lack of monitoring data for certain types of BMPs, there is also a lack of performance data for all BMP types for certain parameters. While BMP monitoring studies typically monitor for parameters such as total phosphorus, total lead, and total suspended solids, there is little monitoring data available for parameters such as bacteria, dissolved metals and hydrocarbons. Table 5-6 summarizes the frequency with which selected parameters have been monitored in BMP performance studies (Brown and Schueler, 1997a).

Table 5-6. Extent of Monitoring for Selected Pollutants in BMP Performance Studies

Parameter	Percent Monitored
Total Phosphorus	94
Total Lead	94
Total Suspended Solids	92
Total Nitrogen	70
Soluble Nitrogen	70
Total Zinc	67
Soluble Phosphorus	60
Organic Carbon	55
Total Copper	42
Bacteria	19
Total Cadmium	15
Total Dissolved Solids	13
Dissolved Metals	10
Hydrocarbons	9

Review of the existing BMP monitoring data gives an indication of the pollutant removal efficiency of various BMPs. Several efforts have been conducted to attempt to evaluate the range of pollutant removals that can be expected to occur in various BMP designs. Evaluation of these data can give an indication of the range of pollutant removals expected, however arriving at a fixed numerical "percent removal" for each BMP type or category is a difficult task. The main problem associated with comparing BMP performance data is the variety of techniques that are used to compute performance, as well as the variation in the ways that samples are collected and in the parameters that are measured in the samples. Performance calculations are further complicated by the errors that result from measuring flow rates and volumes of storm water that pass through the BMP. A study conducted by USGS evaluated 23 flow measurement techniques in order to determine potential differences in reported flows. Average percent differences between reported total storm volumes were in many cases greater than 25 percent over a range of storms (Strecker, 1998). With errors of this magnitude, calculation of pollutant loadings and loadings reductions can be complicated significantly.

Efficiency of a BMP can be related to the removal of individual pollutants on both an event basis and on a long-term basis. Frequently, the statistical rigor with which BMP sampling data are analyzed is poor or even nonexistent. Most BMP performance data are reported as event mean concentrations (EMCs). An EMC can either be determined directly from a flow-weighted composite sample, or calculated based on a series of discrete samples. While an EMC may be an appropriate method for determining the reduction in pollutant concentrations for an individual event, an EMC may not give an indication of the long-term performance of the BMP or the performance for runoff events of varying intensity and volume. A more appropriate means of determining the long-term performance of a BMP may be to do a statistical evaluation of inflow and outflow loadings over a range of storm event sizes and durations. Samples must also account for the seasonality of performance that results with certain BMP types such as ponds and constructed wetlands. The selection of the method used can have a significant impact on the reported performance. Additional work to standardize BMP monitoring protocols and to standardize calculations for performance is needed in order to make BMP monitoring data comparable from site to site.

BMP performance can vary considerably based on differences in the design criteria and performance standards for which the BMP was designed. Comparing pollutant removal efficiency for similar BMP types with very different performance goals may result in widely disparate efficiency estimations. In addition to differences in performance goals, variations in watershed parameters can cause significant differences in performance among otherwise similar BMPs. In most cases, parameters such as the size of the drainage area, the level of watershed imperviousness, the duration and volume of runoff entering the BMP, and the land use of contributing drainage areas are not easily comparable from study to study. In addition, differences in BMP design parameters such as the ratio of the BMP volume to the contributing drainage area, the retention time in the BMP, the physical dimensions and the construction of the BMP further complicate direct comparisons between BMP monitoring data. Also, a great deal of variability exists in the performance of each BMP due to event and seasonal variations.

Despite these shortcomings, some general ranges of expected BMP efficiency have been compiled from the literature. Documents that summarize BMP efficiency information include the CWP's National Pollutant Removal Performance Database (Brown and Schueler, 1997a), the Terrene Institute's report *The Use of Wetlands for Controlling Stormwater Pollution* (Strecker et al, 1992), as well as a variety of articles and documents contained in the professional and scientific literature. In addition, the ASCE National Storm Water BMP Database is expected to provide BMP monitoring studies in a format that will facilitate evaluation and comparison of BMP performance data. Readers are encouraged to consult the variety of referenced information resources for more detailed BMP performance data than is presented in this report. Table 5-7 presents expected pollutant removal efficiencies for various BMP types (US EPA, 1993c). The values found in this table give an indication of the expected overall pollutant removal efficiency for a properly sited, designed, sized, constructed and maintained BMP. The sections that follow Table 5-7 summarize the actual performance data contained in the literature on pollutant removal efficiencies for selected BMP types.

Table 5-7. Structural BMP Expected Pollutant Removal Efficiency

BMP Type	Typical Pollutant Removal (percent)				
	Suspended Solids	Nitrogen	Phosphorus	Pathogens	Metals
Dry Detention Basins	30 - 65	15 - 45	15 - 45	< 30	15 - 45
Retention Basins	50 - 80	30 - 65	30 - 65	< 30	50 - 80
Constructed Wetlands	50 - 80	< 30	15 - 45	< 30	50 - 80
Infiltration Basins	50 - 80	50 - 80	50 - 80	65 - 100	50 - 80
Infiltration Trenches/ Dry Wells	50 - 80	50 - 80	15 - 45	65 - 100	50 - 80
Porous Pavement	65 - 100	65 - 100	30 - 65	65 - 100	65 - 100
Grassed Swales	30 - 65	15 - 45	15 - 45	< 30	15 - 45
Vegetated Filter Strips	50 - 80	50 - 80	50 - 80	< 30	30 - 65
Surface Sand Filters	50 - 80	< 30	50 - 80	< 30	50 - 80
Other Media Filters	65 - 100	15 - 45	< 30	< 30	50 - 80

Source: Adapted from US EPA, 1993c.

Infiltration Systems

Infiltration systems can be considered 100 percent effective at removing pollutants in the fraction of water that is infiltrated, since the pollutants found in this volume are not discharged directly to surface waters. Quantifying the removal efficiency of infiltration systems, therefore, can perhaps best be determined by calculating the percent of the average annual runoff volume that is infiltrated, and assuming 100 percent removal of the pollutants found in that runoff volume. Since collecting samples of runoff once it has been infiltrated can be very difficult, little field data exist on the efficiency of infiltration for treatment of storm water. Since infiltrated water does not leave the BMP as a discrete flow, there is no representative way of collecting a true outflow sample. Infiltration systems can be monitored by installing a series of wells around the perimeter of the BMP for collecting samples. However, this can add significant costs to any monitoring effort. Table 5-8 summarizes the available field data on the efficiency of infiltration practices in treating storm water. Reported removal efficiencies are based on the results of three studies that evaluated the performance of infiltration trenches and two studies that evaluated the efficiency of porous pavement systems.

Table 5-8. Pollutant Removal Efficiency of Infiltration Practices

Parameter	Median or Average Removal Efficiency (percent)	Number of Observations
Total Phosphorus	65	5
Ammonia-Nitrogen	83	3
Nitrate	82	3
Total Nitrogen	83	2
Suspended Solids	89	2
Organic Carbon	82	1
Lead	98	1
Zinc	99	1

Source: Brown and Schueler, 1997a

Conceptually, infiltration should provide significant pollutant removal for a wide variety of storm water pollutants. As water moves through the underlying soil layers, suspended particulates and associated pollutants should be filtered out. In addition, pollutants can be adsorbed by soil particles and microorganisms in the soil can degrade organic pollutants. There is little data available, however, regarding the potential mobility of metals and hydrocarbons that enter groundwater due to infiltration of storm water. This may be a particular problem in areas with extremely high soil permeabilities (such as coastal areas), where pollutants can rapidly enter underlying aquifers with insufficient contact time for breakdown or adsorption of contaminants. Consequently, additional data gathering to target the behavior of these pollutants is warranted.

The success of infiltration systems has been mixed. In same areas, infiltration has been applied successfully, while in others infiltration systems have clogged in a very short time. Many failures can be attributed to contractor inexperience, to compaction of soil by construction equipment and to excess sediment loading during construction activities, and to improper design and siting. In order to apply infiltration successfully, the following guidelines should be applied:

- Permeability of soils must be verified. A percolation rate of 0.5 inches per hour or more, and an soil layer of 4 feet or more is essential (Cahill, 1994).
- Construction site runoff must be kept from entering the recharge bed, and the infiltration system should not be placed into service until all disturbed land that drains to the system has been stabilized by vegetation. Strict erosion and sediment controls during any construction or re-landscaping is a must to prevent clogging of the system.

- A sedimentation basin or chamber placed before the infiltration system to remove a portion of the sediment can help to extend the life of the infiltration system.
- Use of filter fabric between the recharge bed and soil interface (in porous pavement and infiltration trench systems) can prevent the migration of soil into the recharge bed.
- Construction traffic should be directed away from the infiltration bed before and during construction to prevent compaction of underlying soil layers and loss of infiltrative capacity.
- Porous pavement systems should be clearly marked to prevent use by heavy vehicles and resurfacing with non-porous pavement.
- A basin drain should be provided so that the basin can be drained and maintenance performed if the basin becomes clogged.

Readers are encouraged to consult the ASCE/WEF manual of practice (WEF and ASCE, 1992) for additional guidelines on using infiltration systems.

Retention Basins (wet ponds)

Retention basins can be very effective systems for removing pollutants from storm water. Retention basins provide quiescent conditions with long retention times that allow a large fraction of suspended solids and associated pollutants such as metals, nutrients and organics to be removed by sedimentation. In addition, degradation of organic compounds by microorganisms and uptake of nutrients by aquatic vegetation can provide additional water quality benefits. Retention basins have been one of the most widely-monitored storm water BMP types, mainly due to their prevalence and relative ease of monitoring in comparison to other BMP types. In arid regions, artificial or decorative lakes can function as retention basins. However, as with all other BMP types, the available monitoring data are not always comparable from study to study due to variations in procedures, protocols and methods. Although the mechanisms taking place in retention basins are fairly well known, additional data are needed in order to determine what the important design parameters are and to determine what event, seasonal and long-term performance variances exist. Table 5-9 summarizes the pollutant removal efficiency of retention basins systems. Reported removal efficiencies are based on data contained in 35 studies evaluating retention basins.

Table 5-9. Pollutant Removal Efficiency of Retention Basins

Parameter	Median or Average Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	34	-12	90	20
Total Phosphorus	46	0	91	44
Ammonia-Nitrogen	23	-107	83	14
Nitrate	23	-85	97	27
Organic Nitrogen	23	2	34	6
Total Nitrogen	30	-12	85	24
Suspended Solids	70	-33	99	43
Bacteria	74	-6	99	10
Organic Carbon	35	-30	90	29
Cadmium	47	-25	54	5
Chromium	49	25	62	5
Copper	55	10	90	18
Lead	67	-97	95	34
Zinc	51	-38	96	32

Source: Brown and Schueler, 1997a

The wide range of variability in reported removal efficiencies of retention systems is due to a number of factors. Watershed variables such as the area draining to the pond, the percent imperviousness and land use of the watershed, the design features of the basin such as surface area and depth of permanent pool, and hydraulic and hydrologic parameters such as rainfall intensity, rainfall volume, length of antecedent dry periods, time of concentration and peak inflow rate can have a large impact on the efficiency of a particular retention system. Studies that contain data on the efficiency of retention systems sometimes report only pollutant removal statistics, but fail to report the relationship to the hydraulics of the system. A thorough evaluation of the hydraulics of the system is needed in order to properly evaluate the efficiency of ponds. This evaluation should also include a measure of the expected suspended solids settling characteristics of the pond influent through a settling velocity column test or particle size distribution analysis, which can shed light on the observed efficiency of the pond in removing sediments and associated pollutants. Greb and Bannerman (1997) reported that the influent particle size distribution plays a significant role in the overall solids removal efficiency. Perhaps the greatest parameter influencing pond efficiency is retention time. Studies indicate that residence times on the order of 14 days may be necessary to allow for sufficient removal of sediment and associated pollutants and to meet receiving water standards (Rushton and Dye, 1993). In fact, Florida requires that the permanent pool volume of ponds treating runoff from new land use activities must provide a minimum residence time of 14 days.

While retention systems can be very effective at removing pollutants from storm water, there are some potential problems associated with these systems. During periods of intense runoff, the retention time in the pond can decrease, resulting in decreased efficiency. In addition, previously removed sediments can be re-suspended, resulting in a net export of pollutants from the pond. This is one of the reasons that negative removals are frequently reported for pond systems for parameters such as suspended solids and associated contaminants such as nutrients and metals. Also, changes in water chemistry such as increased or decreased pH, alkalinity and hardness can occur in the pond, which can effect the solubility of metals that are present in pond sediments and the behavior of various nutrient species. This can also affect the chemistry of the receiving waters, since the aquatic toxicity of certain metal species is dependant on hardness. There is also evidence that anaerobic bottom sediments promote more soluble forms of phosphorus and some metals, which can increase their release to the water column (Rushton and Dye, 1993).

Perhaps the greatest problem is the increased temperature of discharges that occur from storm water retention systems. Retention ponds can have a significant surface area, and during summer months elevation of the temperature of water in the pond can occur. When this warm water is displaced during the next runoff event, the elevated temperature can cause detrimental impacts to the receiving waters, including loss of sensitive species and downstream shift of trophic status (Galli, 1988). Ponds can also fail to function properly in the winter time when the surface of the pond freezes. Water entering the pond can flow over the ice surface directly to the outlet structure. This short circuiting can limit the retention time of storm water entering the ponds and reduce the sedimentation efficiency. Outlet structures are also prone to freezing in the winter time, which can cause serious flooding problems. In order to prevent cold-weather problems with wet ponds, several design features can be incorporated in ponds that are used in cold climates. Readers are encouraged to consult the *Stormwater BMP Design Supplement for Cold Climates* published by CWP (Caraco and Claytor, 1997) for additional information regarding BMP designs for cold climates.

Retention systems also present a potential hazard to nearby residents and children, can often become populated with large number of waterfowl, and can be breeding grounds for mosquitoes and odor producers if not designed and maintained properly. Large ponds also can present a danger of downstream flooding and risk of catastrophic loss of life and property in the event of an embankment or outlet structure failure. Several pond failures have occurred that are attributable to piping around outlet structures and eventual failure of embankments due to poor installation. Careful adherence to design and construction standards is necessary and inspections during construction should be conducted to ensure that ponds are installed correctly.

In addition to relating performance to measures of pollutant reduction across the BMP, evaluations that measure effluent from BMPs and compares these values to receiving water criteria can provide useful data. One such study was conducted in Florida, and it was determined that effluent from 22 wet detention facilities was in most cases in compliance with class III Florida state water quality standards. The ponds evaluated in this study were permitted by Florida and met the required state design criteria. Parameters analyzed in samples included eight metal species, six nutrient species, turbidity, TSS, temperature, dissolved oxygen, pH and conductivity. The constituents that were in compliance 100 percent of the time included un-ionized ammonia, iron, manganese (class II standard) and nickel. All other analyzed parameters, with the exception of dissolved oxygen, were in compliance greater than 65 percent of the time, with most in compliance greater than 79 percent of the time. Dissolved oxygen was in noncompliance 64 percent of the time (Carr and Kehoe, 1997). The results of this study indicate that evaluation of constituents in BMP effluent and comparison with water quality standards may be an effective measure of BMP effectiveness. In many cases, data of this nature may be more useful than data that indicates percent removal of a targeted group of constituents across the BMP. It is also important to note that the Florida study found that concentrations of constituents (with the exception of dissolved oxygen) in samples collected at these systems did not vary significantly between samples collected immediately before the outflow weir and after the outflow weir. Therefore, sampling before the weir, where more convenient, does not significantly alter sample results. This may be useful where the BMP discharges through an outflow structure where samples are not easily collected (such as in a manhole or other confined space).

In addition to treating runoff, retention systems can be adapted for storm water reuse. Florida is actively seeking reuse of storm water runoff for reuse as irrigation water. Reuse of storm water reduces the volume of water and the amount of pollutants discharged to receiving streams. In addition, reuse of storm water as irrigation water can help to recharge aquifers and restore pre-development hydrologic conditions. Also, significant financial incentives exist for reuse as irrigation in areas where water rates are high. However, the health risks of storm water reuse have not been thoroughly investigated. Additional research in this area is warranted to determine if a risk of exposure to potentially harmful microorganisms or other health risks exist. Livingston et al (1998) presented a discussion of storm water reuse opportunities and discussed design considerations for sizing ponds for reuse. Readers are encouraged to consult this reference for additional information on storm water reuse.

There are a number of design features that can be included in retention system designs to increase their effectiveness, reduce maintenance burdens and reduce impacts to receiving waters. These include:

- A broad, flat aquatic bench around the perimeter of the pond planted with emergent wetland vegetation;

- A permanent pool volume that provides a long residence time to promote maximum removal of suspended solids;
- An irregular pool shape that increases sinuosity of flow paths;
- A sediment forebay for removal of coarse sediments and ease of maintenance;
- A submerged reversed-slope pipe or other non-clogging low-flow orifice;
- Concrete, rather than corrugated metal risers and outlet structures;
- Preservation of riparian cover along drainage channels to limit temperature increases;
- Maintenance access to forebays and inlet and outlet structures for removal of sediments and repairs.

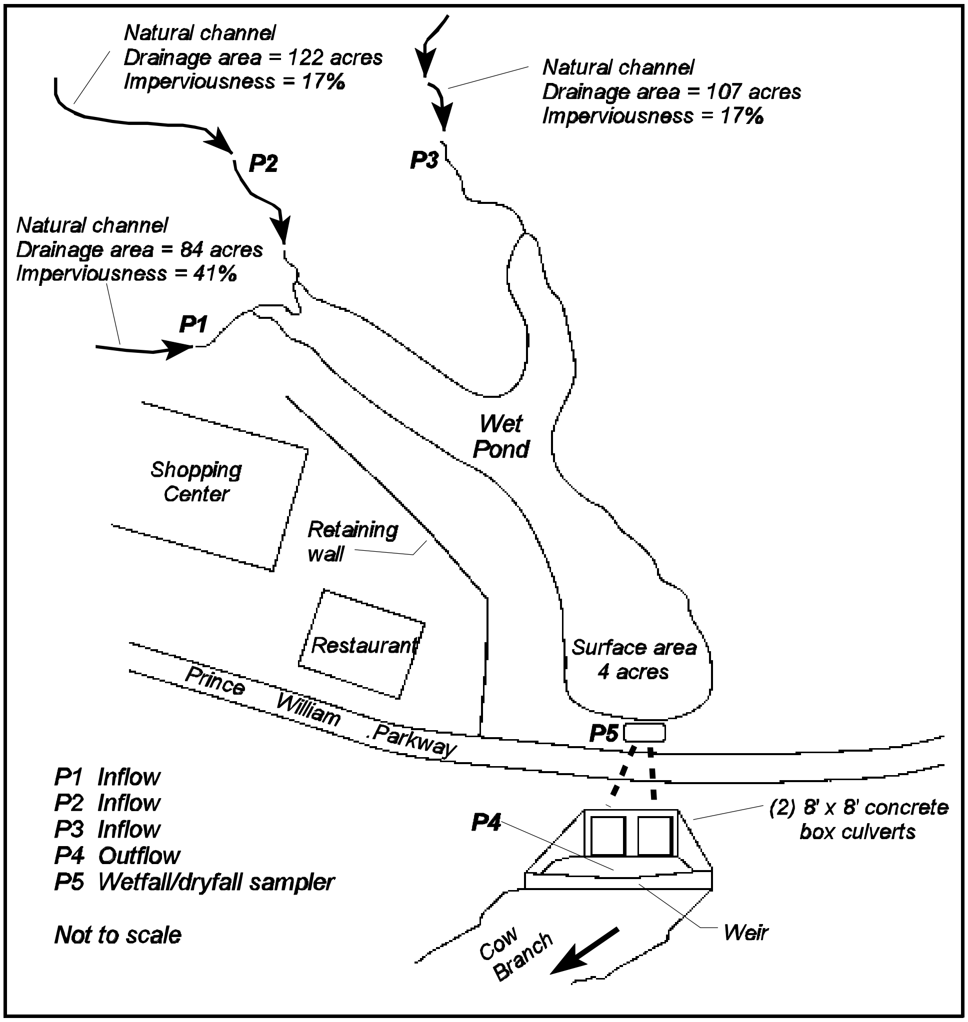
Prince William Parkway Regional Wet Pond

In 1998 EPA conducted sampling activities at a retention system in Prince William County, Virginia. The Prince William Parkway Wet Pond is a regional wet pond located adjacent to a major county road in Dale City. The pond has a surface area of 4 acres, and has a total volume of approximately 25 acre-feet at the permanent pool level. The pond is approximately 1,000 feet in length, 260 feet wide at its widest point, and was constructed by placing an earthen dam in what appears to previously have been a natural drainage channel. The discharge is to Cow Branch, a tributary of Neabsco Creek. The contributing drainage area to the pond is approximately 310 acres. The land use of the watershed is approximately 20 percent commercial, 30 percent forested, 40 percent open land, 5 percent residential (mostly lots less than 1 acre) and 5 percent from other sources. The pond is designed to control up to the 100-year storm event for the fully developed watershed conditions. There are a total of 5 discrete inflow points to the wet pond. Three of these points were natural drainage channels (identified as P1, P2 and P3), while the 4th and 5th points were concrete channels. Points P1, P2 and P3, which represent a majority of the contributing drainage area, were monitored during the course of the study period. The contributing drainage area and percent imperviousness of these sub-basins are:

Sub-Basin	Area (acres)	Imperviousness (%)
P1	84	41
P2	122	17
P3	107	17

The other two inflow points, which conveyed runoff from a small segment of Prince William Parkway, were not monitored and their contributions of both storm flow and pollutant loadings were considered negligible due to the small drainage area in comparison to the overall watershed area. The outflow of the pond occurs through a pair of 8 by 8-foot concrete box culverts. A concrete V-notch weir is installed at the outflow of the pond. See Figure 5-14.

Figure 5-14. Prince William Parkway Regional Wet Pond



During May through October 1998, rainfall and hydrologic data were collected for 14 storm events and water quality samples were collected during 10 storm events at the pond. In addition, samples of atmospheric deposition (dryfall) and precipitation (wetfall) were collected for a number of storms. The following tables summarize a portion of the analytical data collected during the study period and the corresponding flow volume at each of the sampling points. Wetfall volumes were determined by multiplying the total storm rainfall depth by the surface area of the pond. A detailed presentation of the sampling results and an analysis of the sampling data will be included in a supplement to this report.

Table 5-10. Summary of Prince William Parkway Regional Wet Pond Sampling Data

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
6/01/98										
Total Kjeldahl Nitrogen (mg/l as N)	---	---	---	0.95	---	---	---	1.1	0.67	ND (0.1)
Ammonia (mg/l as N)	---	---	0.97	0.39	---	---	0.39	0.37	0.61	ND (0.1)
Nitrate/Nitrite (mg/l as N)	---	---	0.45	0.52	---	---	0.13	0.18	0.18	ND (0.01)
Biochemical Oxygen Demand (mg/l)	---	---	4	7	---	---	4	3	---	---
Chemical Oxygen Demand (mg/l)	---	---	ND (20)	ND (10)	---	---	ND (10)	ND (10)	---	---
Total Organic Carbon (mg/l)	---	---	7	9.1	---	---	5.4	6.5	2.2	ND (1)
Phosphorus (mg/l)	---	---	0.02	ND (0.01)	---	---	0.02	0.03	ND (0.01)	ND (0.01)
Total Orthophosphate (mg/l)	---	---	ND (0.01)	---	---	---	ND (0.01)	---	---	ND (0.01)
Total Suspended Solids (mg/l)	---	---	266	---	---	---	48	---	---	---
Total Dissolved Solids (mg/l)	---	---	46	---	---	---	65	---	---	---
Volatile Suspended Solids (mg/l)	---	---	26	---	---	---	14	---	---	---
Chloride (mg/l)	---	---	4	---	---	---	13	---	---	---
Alkalinity (mg/L)	---	---	5	---	---	---	26	---	---	---
Hardness (mg/l as CaCO3)	---	---	35	---	---	---	35	---	---	---
Runoff Volume (gallons)	201,800		619,700		152,500		1,071,000		61,000	
6/11/98										
Total Kjeldahl Nitrogen (mg/l as N)	---	---	5.6	1.12	---	---	9.52	9.52	2.24	8.96
Ammonia (mg/l as N)	---	---	ND (1)	ND (1)	---	---	ND (1)	ND (1)	ND (1)	ND (1)
Nitrate/Nitrite (mg/l as N)	---	---	0.53	0.59	---	---	0.13	0.16	0.18	0.42
Biochemical Oxygen Demand (mg/l)	---	---	---	3.65	---	---	6.9	2.8	---	---
Chemical Oxygen Demand (mg/l)	---	---	45.6	26	---	---	27.6	27.2	---	---
Total Organic Carbon (mg/l)	---	---	9.35	7.91	---	---	9.35	6.47	3.58	3.58
Phosphorus (mg/l)	---	---	0.25	0.051	---	---	0.25	0.017	0.044	0.038
Total Orthophosphate (mg/l)	---	---	0.094	---	---	---	0.062	---	ND (0.01)	---
Total Suspended Solids (mg/l)	---	---	14	---	---	---	8	---	---	---
Total Dissolved Solids (mg/l)	---	---	49	---	---	---	62	---	---	---
Volatile Suspended Solids (mg/l)	---	---	3	---	---	---	3	---	---	---
Alkalinity (mg/L)	---	---	13.2	---	---	---	24	---	---	---
Hardness (mg/l as CaCO3)	---	---	18	---	---	---	26	---	---	---
Runoff Volume (gallons)	244,500		849,400		242,200		1,434,000		81,500	

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
6/12/98										
Total Kjeldahl Nitrogen (mg/l as N)	8.96	11.8	8.96	2.8	---	---	1.68	8.4	5.04	---
Ammonia (mg/l as N)	1.12	ND (1)	ND (1)	ND (1)	---	---	ND (1)	ND (1)	1.12	---
Nitrate/Nitrite (mg/l as N)	1	0.88	0.57	0.61	---	---	0.15	0.12	0.66	---
Biochemical Oxygen Demand (mg/l)	4.3		2.5	2	---	---	3.7	40.8	---	---
Chemical Oxygen Demand (mg/l)	36.4	47.2	106	14	---	---	27.2	20.4	---	---
Total Organic Carbon (mg/l)	5.83	10.2	5.83	5.83	---	---	10.2	10.2	4.37	---
Phosphorus (mg/l)	0.1	0.049	0.82	0.08	---	---	0.18	0.04	0.046	---
Total Orthophosphate (mg/l)	0.038	---	0.099	---	---	---	0.099	---	---	---
Total Suspended Solids (mg/l)	18	---	53	---	---	---	9	---	---	---
Total Dissolved Solids (mg/l)	90	---	37	---	---	---	65	---	---	---
Volatile Suspended Solids (mg/l)	6	---	6	---	---	---	6	---	---	---
Alkalinity (mg/L)	13.9	---	9.7	---	---	---	24	---	---	---
Hardness (mg/l as CaCO3)	28	---	20	---	---	---	28	---	---	---
Runoff Volume (gallons)	162,400		237,600		191,700		631,000		36,000	
6/13/98										
Total Kjeldahl Nitrogen (mg/l as N)	---	---	ND (1)	7.84	---	---	1.68	17.4	---	---
Ammonia (mg/l as N)	---	---	ND (1)	1.12	---	---	ND (1)	ND (1)	---	---
Nitrate/Nitrite (mg/l as N)	---	---	0.2	0.25	---	---	0.28	0.29	---	---
Biochemical Oxygen Demand (mg/l)	---	---	5.9	2.5	---	---	3.9	ND (2)	---	---
Chemical Oxygen Demand (mg/l)	---	---	32.8	25.2	---	---	22.8	20.8	---	---
Total Organic Carbon (mg/l)	---	---	4.37	4.37	---	---	5.83	5.83	---	---
Phosphorus (mg/l)	---	---	0.35	---	---	---	0.091	0.17	---	---
Total Orthophosphate (mg/l)	---	---	0.097	---	---	---	ND (0.1)	---	---	---
Total Suspended Solids (mg/l)	---	---	31	---	---	---	8	---	---	---
Total Dissolved Solids (mg/l)	---	---	245	---	---	---	54	---	---	---
Volatile Suspended Solids (mg/l)	---	---	6	---	---	---	4	---	---	---
Alkalinity (mg/L)	---	---	5.2	---	---	---	22	---	---	---
Hardness (mg/l as CaCO3)	---	---	10		---	---	24	---	---	---
Runoff Volume (gallons)	166,700		411,600		136,000		765,000		43,500	

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
6/15/98										
Total Kjeldahl Nitrogen (mg/l as N)	3.92	2.24	8.4	13.4	---	---	21.3	5.6	---	---
Ammonia (mg/l as N)	---	2.8	1.12	9.52	---	---	16.8	6.16	---	---
Nitrate/Nitrite (mg/l as N)	0.23	0.21	0.2	0.35	---	---	0.29	0.31	---	---
Biochemical Oxygen Demand (mg/l)	4.25	3.8	4.05	2.7	---	---	1.8	4	---	---
Chemical Oxygen Demand (mg/l)	18.4	24	22	66.4	---	---	21.6	17.2	---	---
Total Organic Carbon (mg/l)	7.11	19	4.47	9.75	---	---	5.79	20.3	---	---
Phosphorus (mg/l)	0.072	---	0.2	---	---	---	0.069	---	---	---
Total Orthophosphate (mg/l)	0.017	---	ND (0.01)	---	---	---	ND (0.01)	---	---	---
Total Suspended Solids (mg/l)	ND (4)	---	21	---	---	---	ND (4)	---	---	---
Total Dissolved Solids (mg/l)	61	---	58	---	---	---	19	---	---	---
Volatile Suspended Solids (mg/l)	ND (4)	---	5	---	---	---	ND (4)	---	---	---
Alkalinity (mg/L)	10	---	4.2	---	---	---	ND (20)	---	---	---
Hardness (mg/l as CaCO3)	18	---	10	---	---	---	24		---	---
Runoff Volume (gallons)	841,600		1,260,900		719,600		3,097,500		176,000	
6/17/98										
Total Kjeldahl Nitrogen (mg/l as N)	1.05	1.06	---	---	0.55	---	0.75	0.97	---	---
Ammonia (mg/l as N)	0.32	0.26	---	---	ND (0.1)	---	ND (0.1)	ND (0.1)	---	---
Nitrate/Nitrite (mg/l as N)	0.33	0.33	---	---	0.12	---	0.19	0.2	---	---
Biochemical Oxygen Demand (mg/l)	4	4	---	---	---	---	6	4	---	---
Chemical Oxygen Demand (mg/l)	ND (10)	ND (10)	---	---	ND (10)	---	ND (10)	26	---	---
Total Organic Carbon (mg/l)	8.8	9	---	---	7.5	---	8	7.9	---	---
Phosphorus (mg/l)	0.12	---	---	---	0.11	---	0.13	---	---	---
Total Orthophosphate (mg/l)	ND (0.01)	---	---	---	ND (0.01)	---	ND (0.01)	---	---	---
Total Suspended Solids (mg/l)	ND (4)	---	---	---	19	---	8	---	---	---
Total Dissolved Solids (mg/l)	142	---	---	---	121	---	79	---	---	---
Volatile Suspended Solids (mg/l)	ND (4)	---	---	---	ND (4)	---	ND (4)	---	---	---
Alkalinity (mg/L)	26	---	---	---	13	---	10	---	---	---
Hardness (mg/l as $CaCO_3$)	24	---	---	---	---	---	12	---	---	---
Runoff Volume (gallons)	129,400		215,200		162,500		554,500		31,500	

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
6/23/98										
Total Kjeldahl Nitrogen (mg/l as N)	0.22	---	1.44	6.1	1.15	0.3	0.76	0.51	---	---
Ammonia (mg/l as N)	0.12	---	0.2	0.5	0.14	0.13	0.31	ND (0.1)	---	---
Nitrate/Nitrite (mg/l as N)	0.23	---	0.4	0.42	0.15	0.14	0.21	0.17	---	---
Biochemical Oxygen Demand (mg/l)	ND (2)	---	ND (2)	6	ND (2)	23	ND (2)	52	---	---
Chemical Oxygen Demand (mg/l)	ND (10)	---	31	15	34	ND (10)	ND (10)	ND (10)	---	---
Total Organic Carbon (mg/l)	3.1	---	4.4	7.7	4.7	7.4	3.2	3.8	---	---
Phosphorus (mg/l)	0.06	---	0.02	---	ND (0.01)	---	0.04	---	---	---
Total Orthophosphate (mg/l)	0.03	---	ND (0.01)	---	ND (0.01)	---	ND (0.01)	---	---	---
Total Suspended Solids (mg/l)	19	---	33	---	29	---	10	---	---	---
Total Dissolved Solids (mg/l)	47	---	79	---	64	---	69	---	---	---
Volatile Suspended Solids (mg/l)	9	---	16	---	13	---	11	---	---	---
Alkalinity (mg/L)	6	---	13	---	7	---	14	---	---	---
Hardness (mg/l as $CaCO_3$)	8	---	20	---	10	---	19	---	---	---
Runoff Volume (gallons)	1,207,300		1,064,200		756,800		3,499,000		199,000	
6/24/98										
Total Kjeldahl Nitrogen (mg/l as N)	0.73	---	0.71	---	0.7	---	0.53	---	---	---
Ammonia (mg/l as N)	0.22	---	0.22	---	0.16	---	0.55	---	---	---
Nitrate/Nitrite (mg/l as N)	0.4	---	0.61	---	0.27	---	0.32	---	---	---
Biochemical Oxygen Demand (mg/l)	3	---	4	---	3	---	2	---	---	---
Chemical Oxygen Demand (mg/l)	ND (10)	---	ND (10)	---	14	---	ND (10)	---	---	---
Total Organic Carbon (mg/l)	3.8	---	4	---	5.6	---	3.1	---	---	---
Phosphorus (mg/l)	0.05	---	0.1	---	0.05	---	0.12	---	---	---
Total Orthophosphate (mg/l)	ND (0.01)	---	ND (0.01)	---	ND (0.01)	---	ND (0.01)	---	---	---
Total Suspended Solids (mg/l)	ND (4)	---	57	---	54	---	8	---	---	---
Total Dissolved Solids (mg/l)	45	---	48	---	69	---	51	---	---	---
Volatile Suspended Solids (mg/l)	4	---	5	---	6	---	3	---	---	---
Alkalinity (mg/L)	6	---	6	---	12	---	8	---	---	---
Hardness (mg/l as $CaCO_3$)	8	---	11	---	17	---	15	---	---	---
Runoff Volume (gallons)	293,200		682,400		290,400		1,415,000		80,000	

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
7/31/98										
Total Kjeldahl Nitrogen (mg/l as N)	1.3	1	2.7	---	---	---	1.2	---	---	---
Ammonia (mg/l as N)	1	1.1	0.74	---	---	---	0.96	---	1.5	---
Nitrate/Nitrite (mg/l as N)	1.51	1.51	1.81	---	---	---	0.13	---	---	---
Biochemical Oxygen Demand (mg/l)	6	26	27	6	---	---	5	---	---	---
Chemical Oxygen Demand (mg/l)	16	ND (10)	106	---	---	---	ND (10)	---	---	---
Total Organic Carbon (mg/l)	11	11	20	---	---	---	8.1	---	---	---
Phosphorus (mg/l)	0.05	---	0.36	---	---	---	0.09	---	---	---
Total Orthophosphate (mg/l)	0.03	---	ND (0.1)	---	---	---	ND (0.01)	---	ND (0.01)	---
Total Suspended Solids (mg/l)	9	---	51	---	---	---	11	---	---	---
Total Dissolved Solids (mg/l)	92	---	115	---	---	---	90	---	---	---
Volatile Suspended Solids (mg/l)	9	---	16	---	---	---	7	---	---	---
Alkalinity (mg/L)	17	---	15	---	---	---	25	---	---	---
Hardness (mg/l as $CaCO_3$	40	---	52	---	---	---	36	---	---	---
Runoff Volume (gallons)	79,400		436,900		32,000		593,000		33,500	

Constructed Wetland Systems

Constructed wetlands can be effective BMPs for removing pollutants from urban storm water. The main mechanism of pollutant removal in wetland systems is sedimentation (Strecker et al, 1992). Other pollutant removal mechanisms include filtration by aquatic vegetation and by underlying soil and gravel in systems where subsurface flow is present, biological conversion of organic compounds by microorganisms, uptake of nutrients by aquatic plants and algae, uptake of metals by plant tissue, adsorption of metals by clay soils, and volatilization of hydrocarbons and volatile organics. While the literature contains hundreds of references to constructed wetlands systems, very few quantitative studies have been conducted with sufficient rigor to provide good estimates of performance. Strecker's evaluation of the literature on wetland treatment systems identified only 17 reports that discussed the results of research on a functioning wetland system (of 140 reviewed reports). This indicates that there is a general lack of thorough, scientifically-defensible evaluations on the performance of wetland treatment systems. As a result, there is a wide range of variability in reported efficiency data. Table 5-11 summarizes the pollutant removal efficiency of constructed wetland systems based on Strecker's evaluation of published studies.

Table 5-11. Pollutant Removal Efficiency of Constructed Wetland Systems

Parameter	Median Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	23	-30	78	12
Ortho-Phosphate	28	-109	93	7
Total Phosphorus	46	-120	97	37
Ammonia-Nitrogen	33	-86	62	15
Nitrate	46	4	95	18
Organic Nitrogen	7	-36	39	7
Total Nitrogen	24	-20	83	11
Suspended Solids	76	-300	98	26
Bacteria	78	55	97	3
Organic Carbon	28	-31	93	15
Cadmium	69	-80	80	6
Chromium	73	38	98	3
Copper	39	2	84	10
Lead	63	23	94	17
Zinc	54	-74	90	16

Sources: Strecker at al (1992); Organic Carbon, Bacteria and Metals from Brown and Schueler, 1997a

Evaluation of wetland performance is problematic because the basic mechanisms taking place in wetland systems are not well understood. Wetlands are complex ecosystems, and variations in design and watershed factors can have a significant impact on performance. As a result, data collected from various sites are not always comparable.

Due to the limited amount of comparable data that is available on the performance of storm water wetland systems, it is difficult to arrive at any meaningful relationships indicating the important factors in wetland system design. Strecker indicated that perhaps the greatest factor influencing performance of constructed wetlands is the hydrology of the watershed and the inflow hydraulics. Other factors having a major influence on performance are wetland size and volume, the design of the inlet and outlet structures, flow patterns through the system, vegetational community structure, seasonal productivity and decay of wetland plants, and changes in evapotranspiration rates. In addition, the presence of subsurface flows can complicate wetland performance evaluations.

Strecker recommends that an important evaluation step in determining wetland performance is to compare runoff volumes with storage volumes and contact surface area of the wetland. However, he was unable to conduct this evaluation due to the lack of consistent reporting of rainfall statistics, watershed imperviousness, land uses, flow volumes, capacity and surface areas for contact. In order to ensure the comparability of future data reporting for wetland systems, it is recommended that a standardized set of monitoring protocols be adopted for all future monitoring efforts.

An important factor in the variation of reported efficiency is the wide range of designs that are used in constructed wetland systems. A few design variations include:

- ponds with an emergent wetland area on the pond perimeter;
- shallow wetlands with subsurface flow;
- wetland channels;
- pond-wetland systems;
- extended detention wetlands.

Although the design of a particular systems is dependent upon a number of site-specific variables, there are some important design factors that should be incorporated in wetland system designs including:

- a pre-settling chamber for removal of heavy sediments and to limit disturbance of the wetland to remove accumulated sediments;
- adjustable level control at the outlet by means of an adjustable weir or orifice;
- design the flow path to limit short circuiting and dead space and to maximize detention time;
- a broad, densely planted aquatic bench;
- selection of planting species to produce a dense stand of vegetation for filtration and nutrient uptake;
- periodic harvesting of excess vegetation to prevent nutrient release and to remove undesirable species.

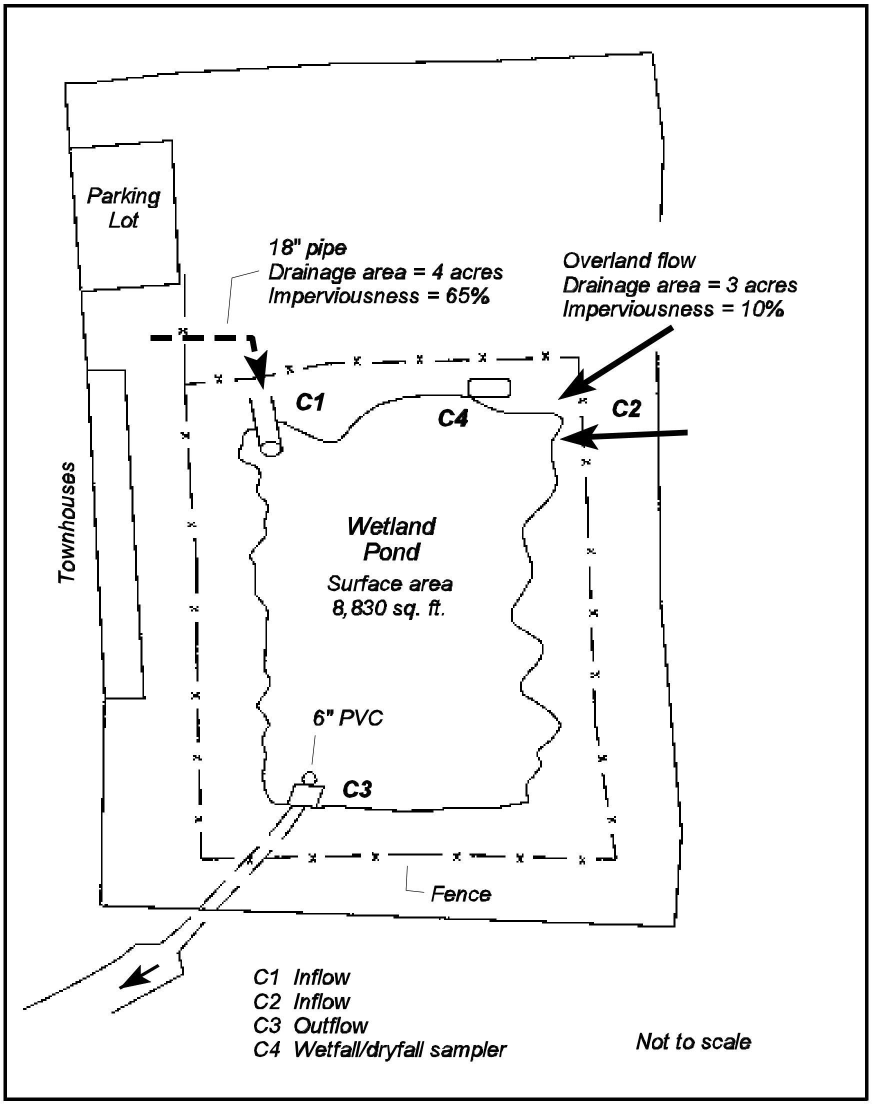
Crestwood Marsh Constructed Wetland

In 1998 EPA conducted sampling activities at a constructed wetland in Manassas, Virginia. The Crestwood Marsh is located in a residential area and was originally constructed as a dry detention basin, but conditions at the site were such that a wetland system formed on its own. The outlet structure was modified in 1995 to provide an extended detention time of 24 hours within the wetland. As a result of this modification, the system has developed into a shallow emergent marsh and contains a variety of wetland species. The wetland has a surface area of

8,830 ft^2. The water quality detention volume of the wetland is 2,524 ft^3, and the flood control volume above the water quality volume is 3,523 ft^3. The area draining to the wetland is a 7-acre townhouse community, with the land area consisting of approximately 60 percent townhouses, 30 percent forested and 10 percent open space. The drainage area is estimated to be approximately 40 percent impervious. The constructed wetland is located at the headwaters of a small unnamed stream that drains to Bull Run, within the Occoquan River Watershed.

Flow enters the wetland at the eastern corner through an 18-inch concrete pipe situated flush with the bottom grade (point C1). From this point, water gradually spreads throughout the wetland and drains to the northern corner of the pond and is discharged through a 6-inch PVC outlet pipe (point C3). There is an additional inlet point located at the southwest corner of the wetland, which consists of overland flow from an adjacent area of forested parkland. EPA concentrated the flow at this point in order to allow estimation of flow rates and volumes, and to allow for collection of water quality samples (point C2). See Figure 5-15.

Figure 5-15. Crestwood Marsh Constructed Wetland



During the spring and summer of 1998, storm event sampling was conducted during nine events. Sampling consisted of collecting flow-weighted composite samples as well as recording rainfall depth, and runoff flow rates and volumes into and out of the wetland. In addition to water quality monitoring, atmospheric deposition and wetfall deposition samples were collected during the study period. The water quality sampling data collected during the study period are summarized in the tables below. Additional data, as well as a detailed description of the sampling program, wetland design, and an evaluation of the performance of the wetland will be included in a supplement to this report.

Table 5-12. Summary of Crestwood Marsh Constructed Wetland Sampling Data

Sample Date ➤	06/01/98			06/11/98			06/12/98		
Analytes Location ➤	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**
Runoff Volume (gal)	7,625	No Flow	1,376	9,439	No Flow	3,237	11,621	No Flow	3,903
Total Suspended Solids (mg/l)	41	--	--	18	--	--	70	--	4
Chemical Oxygen Demand (mg/l)	75	--	--	28.4	--	--	37.2	--	--
Total Organic Carbon (mg/l)	13	--	--	5.02	--	--	5.83	--	--
Total Kjeldahl Nitrogen (mg/l as N)	2	--	--	12.3	--	--	5.04	--	--
Total Inorganic Nitrogen (mg/l as N)	0.67	--	--	0.33	--	--	0.47	--	--
Ammonia (mg/l as N)	0.75	--	--	<1	--	--	1.12	--	--
Total Phosphorus (mg/l)	0.12	--	--	0.084	--	--	0.22	--	--
Ortho-Phosphate (mg/l)	<0.01	--	--	0.032	--	--	0.18	--	0.021
Alkalinity (mg/l as $CaCO_3$)	31	--	--	6.8	--	--	4.8	--	4.3
Hardness (mg/l as $CaCO_3$)	--	--	--	--	--	--	14	--	--
Lead	--	--	--	--	--	--	6.9	--	--
Copper	--	--	--	--	--	--	10.1	--	--
Zinc	--	--	--	--	--	--	64.9	--	--
Nickel	--	--	--	--	--	--	6.6	--	--
Aluminum	--	--	--	--	--	--	2690	--	--
Chromium	--	--	--	--	--	--	4.4	--	--

Sample Date ➤	06/14/98			06/16/98			06/23/98		
Analytes Location ➤	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**
Runoff Volume (gal)	7,624	No Flow	No Flow	53,457	6,985	57,216	81,327	6,334	139,390
Total Suspended Solids (mg/l)	44	--	--	<4	19	<4	5	34	6
Chemical Oxygen Demand (mg/l)	64	--	--	12.8	45.6	15.2	<10	24	<10
Total Organic Carbon (mg/l)	14.3	--	--	4.47	9.75	5.79	4.1	7.4	3.1
Total Kjeldahl Nitrogen (mg/l as N)	3.36	--	--	2.8	7.28	17.4	0.57	0.44	0.8
Total Inorganic Nitrogen (mg/l as N)	0.4	--	--	0.2	0.15	0.16	0.81	0.27	0.53
Ammonia (mg/l as N)	1.12	--	--	<1	<1	<1	0.37	0.27	0.32
Total Phosphorus (mg/l)	0.17	--	--	0.078	0.2	0.11	0.2	0.24	0.05
Ortho-Phosphate (mg/l)	0.058	--	--	0.05	0.032	0.026	0.12	0.05	0.05
Alkalinity (mg/l as $CaCO_3$)	6.5	--	--	5.2	20	6.7	11	8	<1
Hardness (mg/l as $CaCO_3$)	--	--	--	--	24	44	20	10	<1
Lead	6.6	--	--	<2	<2	<2	--	--	--
Copper	10.3	--	--	<1	<1	<1	--	--	--
Zinc	68.5	--	--	<2	<2	<2	--	--	--

Analytes	Sample Date ➤ Location ➤	06/14/98 C1	06/14/98 C2	06/14/98 C3	06/16/98 C1	06/16/98 C2	06/16/98 C3	06/23/98 C1	06/23/98 C2	06/23/98 C3
Nickel		<1	--	--	2.3	<1	<1	--	--	--
Aluminum		3450	--	--	<54	3420	<54	--	--	--
Chromium		<1	--	--	2	4.7	<1	--	--	--

Analytes	Sample Date ➤ Location ➤	06/24/98 C1	06/24/98 C2	06/24/98 C3	07/24/98 C1	07/24/98 C2	07/24/98 C3	07/31/98 C1	07/31/98 C2	07/31/98 C3
Runoff Volume (gal)		11,766	7,604	38,353	20,820	9,645	4,579	11,929	761	No Flow
Total Suspended Solids (mg/l)		37	45	<4	68	--	5	30	--	--
Chemical Oxygen Demand (mg/l)		<10	67	18	32	--	<10	27	--	--
Total Organic Carbon (mg/l)		3.6	17	9.2	7.9	--	10.4	12	--	--
Total Kjeldahl Nitrogen (mg/l as N)		0.52	1.28	0.48	1.14	--	0.9	1	--	--
Total Inorganic Nitrogen (mg/l as N)		0.52	0.11	0.15	0.48	--	0.33	0.67	--	--
Ammonia (mg/l as N)		0.18	0.13	0.15	0.46	--	0.22	0.97	--	--
Total Phosphorus (mg/l)		0.11	0.12	0.02	0.15	--	0.83	0.1	--	--
Ortho-Phosphate (mg/l)		0.03	<0.01	<0.01	0.09	--	0.28	0.03	--	--
Alkalinity (mg/l as $CaCO_3$)		7	17	15	2	--	8	4	--	--
Hardness (mg/l as $CaCO_3$)		6	28	17	15	--	--	21	--	--
Lead		--	--	--	18.2	--	--	16.2	--	--
Copper		--	--	--	10.4	--	--	8	--	--
Zinc		--	--	--	75.2	--	--	86.3	--	--
Nickel		--	--	--	10	--	--	11.1	--	--
Aluminum		--	--	--	2430	--	--	1370	--	--
Chromium		--	--	--	7.7	--	--	4.8	--	--

Filtration and Bioretention Systems

Filtration systems are seeing increased usage, especially in ultra-urban environments where space constraints prohibit the use of detention, retention and constructed wetland systems. Filtration systems can provide significant water quality improvements, but only a small amount, if any, water quantity control. It should also be stressed that filters must be placed off-line in order to assure continued functioning, and therefore only provide treatment of a volume of water based on a design storm. Any volume in excess of the design storm is bypassed without treatment.

Limited monitoring data are available on the efficiency of storm water filtering systems. This is mainly due to storm water filters being a relatively new technology, as opposed to more conventional BMPs such as wet ponds and constructed wetland systems. As a result, only a few published monitoring studies are available to evaluate the efficiency of various filter designs. The following Table 5-13 summarizes the pollutant removal efficiencies for storm water filtration systems. Removal efficiencies are based on data collected from 13 monitoring studies.

Table 5-13. Pollutant Removal Efficiency of Storm Water Filtration Systems

Parameter	Median or Average Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	-31	-37	-25	2
Total Phosphorus	45	-25	80	15
Ammonia-Nitrogen	68	43	94	4
Nitrate	-13	-100	27	13
Organic Nitrogen	28	0	56	2
Total Nitrogen	32	13	71	9
Suspended Solids	81	8	98	15
Bacteria	37	36	83	5
Organic Carbon	57	10	99	11
Cadmium	26	N/A	N/A	1
Chromium	54	47	61	2
Copper	34	22	84	9
Lead	71	-16	89	11
Zinc	69	33	91	15

Source: Brown and Schueler, 1997a

Storm water filtration systems can be highly effective at removing pollutants from storm water runoff. They are particularly effective at removing TSS and total phosphorus, although many filters export inorganic nitrogen due to nitrification of ammonia and organic nitrogen in the filter (Bell, 1998). Bell's study reported that significant phosphorus removals can be attributed to reaction and precipitation with sand that contains iron, calcium and aluminum. Although the limited data that are available on storm water filters indicates that their overall performance is good, additional data are needed to evaluate their efficiency, especially data that can be used to evaluate their long-term hydraulic performance and maintenance requirements. For example, Urbonas et al (1997) found that the hydraulic flow-through rate of a sand filter decreased from 3 feet-per-hour per square foot of filter area to less than 0.05 feet-per-hour after only several storms. This rapid decrease in flow-through rate causes a marked decrease in efficiency, since more of the storm flow will be bypassed unless adequate detention storage volume is provided upstream of the filter. Therefore, overall TSS removal rates are significantly lower when this bypass flow is accounted for (for example, Urbonas' evaluation of storms over the 1995 season resulted in only a 15 percent overall TSS removal when bypass flows were taken into account). Due to the potential decrease in efficiency of sand filtration systems, careful consideration of design parameters is needed. Urbonas (1999) presents a thorough discussion of sand filtration design. Readers are urged to consult this reference for information on sand filtration system design.

In order to provide adequate filter functioning, the following basic design and operation guidelines should be followed:

- The filter should be placed off-line;
- A sedimentation chamber or basin should be provided upstream of the filter bed in order to allow for the removal of sediments to extend the length of the filter run between maintenance activities;
- The filter should be sized adequately or else adequate detention facilities should be provided upstream of the filter in order to capture expected storm water flows and to minimize bypasses;
- Care should be taken to limit excessive sediment loadings to the filter during construction or landscaping activities;
- Periodic maintenance to remove accumulated sediments and restore the filter flow-through rate may be necessary in areas with high solids loadings.

As with filtration systems, the available data on the performance of bioretention facilities are limited. Since bioretention facilities incorporate many of the same mechanisms as filtration systems, their performance for removal of parameters such as TSS are expected to be similar. Due to their biological nature, however, bioretention facilities are expected to also provide conditions necessary for uptake of nutrients by vegetation, degradation of organic contaminants by soil microorganisms, and biochemical reactions within the soil matrix and around the root zone of plants. Available data on the efficiency of bioretention facilities (based on laboratory data and one field study) indicates that bioretention can obtain removals on the order of 95-97 percent for metals, 75 percent for total phosphorus, 69 percent for TKN, 79 percent for ammonia, 21 percent for nitrate and 56 percent for total nitrogen (adapted from Bell (1998), average of all reported values).

The following general guidelines should be followed when designing bioretention facilities:

- Water should not be allowed to pond for more than four days in order to prevent mosquito breeding and to prevent adverse effects on plants;
- Plants selected for bioretention should be tolerant to stresses found in urban areas such as pollutants, variable soil moisture, periodic inundation, and high temperatures;

- Native plant species should be used whenever possible (Prince George's County, 1993), and species diversity should be maintained in order to prevent loss of all plants in the event of disease or infestation.
- Plants should be placed with regard to the elevation and moisture level of the planting bed (i.e., more water-tolerant species should be placed in lower areas where water is likely to pond longer);
- A mulch layer should be installed and maintained in order to prevent erosion of soils and to retain soil moisture;
- Where concentrated runoff enters the bioretention system, reinforcement (such as stone stabilization or synthetic erosion protection materials) may be needed to reduce erosion of the mulch layer and disturbance of the planting bed (Claytor and Schueler, 1996).
- The clay content of soils used in bioretention facilities may need to be limited to prevent clogging of the soil bed (Bell, 1998).

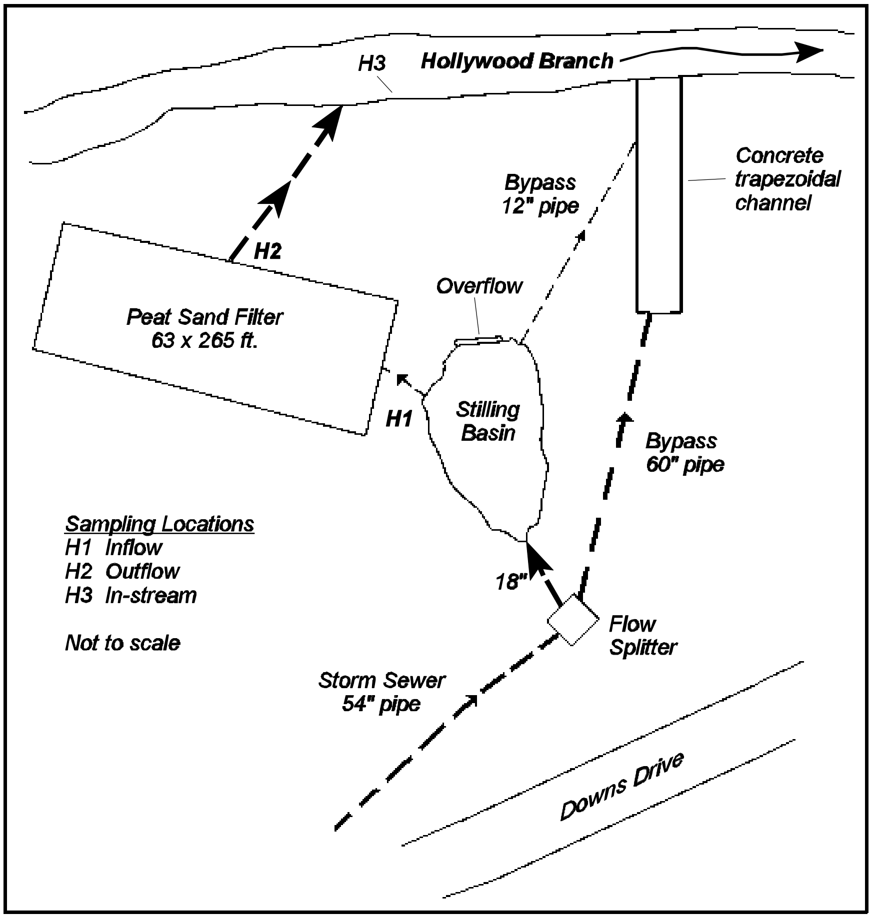
Readers are encouraged to consult *Design Manual for Use of Bioretention in Stormwater Management* (Prince George's County, 1993) and *Design of Stormwater Filtering Systems* (Claytor and Schueler, 1996) for additional information on the bioretention concept.

<u>Hollywood Branch Peat/Sand Filter</u>

In 1998 EPA conducted sampling activities at a peat/sand filter in Montgomery County, Maryland. The Hollywood Branch filter is a surface sand filter with a peat/sand filtration media that was designed based on the Galli paper (1990b). The filter is located in a county park in the Colesville area of Montgomery County and discharges to Hollywood Branch, a first-order stream that discharges into Paint Branch approximately 3,000 feet downstream of the filter. The drainage area covers approximately 140 acres and consists of 73 percent residential, 13 percent industrial and 14 percent other sources. The filter was one of several retrofit projects installed by Montgomery County as part of a watershed restoration effort in the Paint Branch watershed.

The filter is located off-line of the storm drainage system, and is designed to capture the first 0.1 watershed inches of runoff via a flow-splitter located in the storm sewer. This corresponds to a runoff volume of approximately 50,280 ft^3. Any runoff in excess of this amount bypasses the filter and is discharged directly to Hollywood Branch. Runoff from the flow splitter first enters a small stilling basin before being discharged to the filter. The stilling basin functions as a pre-settling chamber to remove coarse sediments in order to prolong the life of the filter. The stilling basin has a volume of 16,940 ft^3 at the permanent pool level, a depth of 3 feet, and length-to-width ratio of approximately 3:1. The edge of the stilling basin is planted with emergent wetland vegetation. Water is discharged from the stilling basin and into the filter through a submerged 18 inch pipe. The filter has dimensions of 265 feet by 63 feet. The filter is designed to pond water to a maximum depth of 2 feet, which corresponds to a volume of 33,880 ft^3. The filter bed is designed to have a minimum infiltration rate of 1.0 inch/hour. The filter bed consists of a 12-inch peat top layer, underlain by a 4-inch sand/peat mix, which is underlain by a 20-inch layer of sand. Water entering the filter is distributed by a series of interconnected 6 inch PVC half-pipes placed along the surface of the filter bed. The filter contains an under-drain system consisting of 6 inch perforated PVC pipes encased in a crushed gravel layer. Filtered water collected in the under-drain system is discharged to Hollywood Branch through a 12-inch concrete pipe. See Figure 5-16.

Figure 5-16. Hollywood Branch Peat/Sand Filter



The monitoring program consisted of recording runoff flow rates and volumes and collecting flow-weighted composite samples from the inflow and outflow of the filter using automatic sampling equipment. A tipping bucket rain gauge was used to record precipitation levels. Flow monitoring and water quality sampling was conducted for five events during the spring and summer of 1998. Baseflow samples were collected from the filter on three occasions. In addition, in-stream sediment samples were collected on one occasion, and bioassessment and physical habitat measurements were also conducted.

The following tables summarize the chemical sampling data collected during this evaluation. Additional information describing the sampling program, additional sampling and assessment data (including sediment, bioassessment and physical habitat assessment) and an analysis of the performance of the filter will be included as a supplement to this report.

Table 5-14. Summary of Hollywood Branch Peat/Sand Filter Storm Event Sampling Data

Sample Dates ➤ Analytes	06/01/98		06/12/98		06/14/98		06/24/98		07/31/98	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Event Volume (gal)	7,597	No flow	68,436	28,470	308,705	149,184	131,744	75,003	151,395	72,537
Total Suspended Solids (mg/l)	--	--	10	< 4	7	17	12	8	38	31
Chemical Oxygen Demand (mg/l)	16	--	25.2	17.6	24	14.4	< 10	11	30	34
Total Organic Carbon (mg/l)	10.4	--	7.29	4.37	4.37	4.37	5.5	6	14	10.4
Total Kjeldahl Nitrogen (mg/l as N)	2	--	7.28	5.6	2.24	11.2	0.91	0.78	1.8	0.68
Total Inorganic Nitrogen (mg/l as N)	1.11	--	0.77	2.14	0.66	2.07	1	1.86	1.13	2.21
Ammonia (mg/l as N)	0.56	--	< 1	< 1	1.68	14.6	0.28	0.16	0.32	< 0.1
Total Phosphorus (mg/l)	0.14	--	0.094	0.16	0.19	0.14	0.19	0.2	0.18	0.15
Ortho-Phosphate (mg/l)	--	--	0.047	0.27	0.23	0.049	< 0.01	< 0.01	0.1	< 0.01
Lead (µg/l)	2.1	--	13.6	2.4	2.3	3.7	2.7	5.6	3.8	8.9
Copper (µg/l)	6.8	--	8.3	2	4.7	1.3	7	4	6.5	11.3
Zinc (µg/l)	17.1	--	40.1	< 2	< 2	< 2	26.8	22.6	43	41.8
Nickel (µg/l)	2.4	--	2.4	22.3	<1	< 1	1.5	4.7	3.2	7.4
Aluminum (µg/l)	< 54	--	488	1360	899	2010	956	2810	497	3450
Chromium (µg/l)	< 1	--	1.4	6.3	< 1	< 1	< 1	4.8	< 1	7.7

Table 5-15. Summary of Hollywood Branch Peat/Sand Filter Baseflow Sampling Data

Sample Dates ➤ Analytes	05/19/98		06/23/98		08/14/98	
	Inflow	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
Total Suspended Solids (mg/l)	< 4	< 4	---	< 4	---	< 4
Chemical Oxygen Demand (mg/l)	< 10	< 10	---	< 10	---	< 20
Total Organic Carbon (mg/l)	< 10	< 10	---	3.5	---	6.6
Total Kjeldahl Nitrogen (mg/l as N)	1.66	19.8	---	0.55	---	1.28
Total Inorganic Nitrogen (mg/l as N)	1.79	0.64	---	0.74	---	0.23
Ammonia (mg/l as N)	0.49	< 0.1	---	< 0.1	---	< 1
Total Phosphorus (mg/l)	0.02	< 0.01	---	0.14	---	0.054
Ortho-Phosphate (mg/l)	0.02	0.02	---	< 0.01	---	0.069
Lead (µg/l)	< 2	< 2	---	---	---	< 2
Copper (µg/l)	< 1	< 1	---	---	---	1.2
Zinc (µg/l)	< 2	< 2	---	---	---	30.5
Nickel (µg/l)	2.3	3.1	---	---	---	2.7
Aluminum (µg/l)	59.8	< 54	---	---	---	1590
Chromium (µg/l)	< 1	--	---	---	---	2.3

Open Channel Vegetated Systems

Open channel vegetated systems are used widely for storm water quality control. However, these systems can be difficult to monitor, especially systems that intercept runoff as sheet flow such as grass filter strips. As a result, data on these types of systems are not as prevalent as other more readily monitored BMP types such as ponds and constructed wetlands. Table 5-16 summarizes the pollutant removal efficiency of open channel vegetated systems. Removal efficiencies are based on data collected from 20 monitoring studies.

Table 5-16. Pollutant Removal Efficiency of Open Channel Vegetated Systems

Parameter	Average or Median Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	11	-45	72	8
Total Phosphorus	15	-100	99	18
Ammonia-Nitrogen	3	-19	78	4
Nitrate	11	-100	99	13
Organic Nitrogen	39	11	86	3
Total Nitrogen	11	-100	99	10
Suspended Solids	66	-100	99	18
Bacteria	-25	-100	0	5
Organic Carbon	23	-100	99	11
Cadmium	49	20	80	6
Chromium	47	14	88	5
Copper	41	-35	89	15
Lead	50	-100	99	19
Zinc	49	-100	99	19

Source: Brown and Schueler, 1997a

Evaluation of available data does not provide a good indication as to the actual performance of these systems. The above data indicate that a wide range in pollutant removal efficiency is reported in the literature for open channel vegetated systems. Since there are a variety of system designs lumped into the above summary, arriving at efficiency estimates for a particular system type given available data is difficult. In general, these types of BMPs should be effective at removing suspended solids and associated pollutants from runoff by sedimentation and by filtration by vegetation, and are certainly effective at slowing the velocity of storm water runoff and for providing detention of runoff if check dams or other structures are incorporated to provide ponding of runoff. However, dense vegetation must be maintained in order to assure proper functioning. In addition, negative removals are frequently reported for sediment and nutrients. If open channel vegetated systems are not properly maintained, significant export of sediments and associated pollutants such as metals and nutrients can occur from eroded soil. In addition, standing water in these systems can be a significant source of bacteria and can provide the conditions necessary for mosquito breeding. Additional data gathering is needed in order to support these assumptions and to quantify the efficiency of these systems.

Open channel vegetated systems can be used as pretreatment devices for other BMPs, or can be used in a "treatment train" approach. For example, grass filter strips are commonly used to accept sheet flow from parking lots in order to pre-treat runoff prior to being treated by a bioretention facility or a filter. Vegetated swales can be used to convey runoff to BMPs such as ponds or constructed wetlands, providing pretreatment of the runoff volume. When used in combination with other BMPs, the overall quality of the treated runoff can be improved and the total runoff volume can be reduced due to infiltration that occurs in the open channel vegetated systems.

Miscellaneous and Vendor-Supplied Systems

Little data exist in the published literature on the efficiency of vendor-supplied systems. Data is frequently available from the vendors, and as more of these systems are installed it is expected that more data will become available. An evaluation of the efficiency of these systems has not been included in this report. The EvTEC program (see section 5.2.1.8) and other evaluation programs should provide useful information that indicates the efficiency of these systems in removing pollutants from runoff.

5.5.3 Controlling Flow Impacts

The removal of pollutants from storm water runoff is an important function of storm water BMPs. However, in many cases receiving water problems are not due to the pollutants contained in storm water, but rather can be attributed to the large flow rates that result in receiving streams that receive storm water discharges. Therefore, in some cases, controlling the volume and flow rate of storm water discharges is as important, if not more important, than removing pollutants prior to discharge. Site-specific parameters will dictate the importance of flow control in preventing degradation of receiving waters.

Evaluating the effectiveness of BMPs in controlling flow impacts is not an easy task. Site-specific variations such as slope, soil types, ground cover, and watershed-imperviousness can greatly impact the hydraulic response of a watershed to rainfall. In addition, receiving water parameters greatly influence the degree of flow control that is necessary in order to prevent degradation. As a result, little information is contained in the literature describing the performance of BMPs at controlling impacts in receiving streams due to excessive storm water flows. The literature that does exist, however, indicates a direct correlation between urbanization and receiving stream degradation. It is not difficult to infer, therefore, that storm water flow is a major contributor to receiving stream degradation, and that control of storm water flow rates and volumes is warranted in order to restore degraded receiving waters and to prevent degradation of receiving waters in newly developing areas. Additional information on the hydrological benefits of BMPs is presented in section 6.3.2 of this report.

Important measures of the effectiveness of BMPs at controlling storm water flows include:

- reductions in peak flow rate across the BMP;
- total storage volume provided in the BMP;
- infiltrative capacity of the BMP;
- retention time in the BMP;
- relationship of post-development hydrologic conditions to pre-development hydrology;
- retention volume necessary for receiving stream channel protection.

Local conditions will dictate the BMP design parameters that are necessary to reduce impacts due to flow. For example, the state of Maryland has developed unified BMP sizing criteria that is designed to provide adequate control of pollutants, limit degradation of streams, provide adequate groundwater recharge, and protect downstream areas from flooding. Additional work is needed in other areas of the country to evaluate the effectiveness criteria necessary to limit flow impacts and to provide adequate BMP sizing standards.

Flow control can be accomplished by using both structural and non-structural practices. Structural BMPs that can provide flow control include retention basins, detention basins, constructed wetlands, infiltration practices, grassed swales and minimizing directly connected impervious surface areas. Filters and bioretention facilities can also be adapted to provide some degree of quantity control if they are used in conjunction with detention basins or other means of providing detention of storm water prior to treatment, such as providing temporary ponding in overflow parking areas. Non-structural BMPs and land-use practices that can help to reduce the volume of storm water runoff discharged to receiving streams should also be considered a vital component of storm water management. Practices that can reduce the impact of storm water runoff due to excessive flows include land use regulations such as zoning, natural area and stream buffer preservation, limits on impervious surfaces, and cluster development. Practices that limit the generation of storm water can be very effective in preventing degradation of streams, and can limit the need for structural storm water controls. Information on development practices aimed at reducing impacts due to site development practices can be found in *Conservation Design for Stormwater Management* (Delaware DNREC, 1997) and in *Green Development* (US EPA, 1996b).

5.6 Conclusions

There are a wide variety of BMPs available to manage storm water runoff. The efficiency of various BMP types has been documented to some degree, but there is still a great need for focused research in certain areas, particularly for newer and innovative structural BMP types, as well as non-structural BMPs. However, due to the complexity involved in isolating the reaction of a complex and highly variable system such as a watershed to one isolated input, evaluations of non-structural BMPs are ambitious tasks. Still, where storm water management is largely driven by the availability of scarce funding, data that indicate the cost-effectiveness of various control strategies are badly needed.

Ultimately, receiving stream morphology, habitat and biological communities may turn out the be the driving factors indicating the success of BMPs at controlling impacts due to storm water flows and the pollutants that they contain. In order for such measures to work, however, it is necessary to isolate the response of a receiving stream system to the implementation of BMPs. Frequently, there are too many variables in a watershed and too many other potential sources of degradation to isolate the improvements (or even to indicate potential negative impacts) of a particular BMP or group of BMPs. For example, Maxted and Shaver (1997) did not observe a significant difference in macroinvertebrate communities between 8 sites with storm water retention ponds and 33 sites with no storm water controls. In addition, the BMPs did not prevent the almost complete loss of sensitive aquatic species. Whether or not these impacts were caused by storm water flows, pollutants or other non-storm water sources was not indicated, and the data to be able to answer these questions may not be forthcoming in the foreseeable future. Therefore, until data are available to indicate that specific BMPs can prevent impacts and prevent degradation of receiving streams in urbanized areas, one should not assume that structural, "end-of-pipe" BMPs are the only answer to the storm water problem.

Available data seem to indicate that urbanization and traditional urban development at almost any level can cause degradation of streams, and that BMPs may be able to mitigate these impacts to a certain level. Accordingly, storm water management should start at the point of runoff generation, and incorporate site planning principles that prevent or minimize the generation of runoff, prevent development in floodplains, preserve natural drainage systems, and avoid disturbing sensitive areas such as wetlands and riparian areas. Where runoff generation cannot be avoided, then properly sited, designed, constructed and operated BMPs can be implemented to attempt to reduce the impacts associated with this runoff. There are data available on the effectiveness of BMPs in reducing pollutant loads, but these data are not comprehensive enough to either characterize the performance of all BMPs in use or to determine if they are actually controlling impacts to receiving waters. Additional data gathering is necessary, but the monitoring and data analysis protocols necessary to do so have not been fully developed. Standardization of monitoring protocols for data transferability is a vital component of successful data evaluation, and is an area that should be actively pursued in the near future.