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National Management Measures to Control Nonpoint Source Pollution from Urban Areas

Management Measure 5: New Development Runoff Treatment

November 2005

MANAGEMENT MEASURE 5
NEW DEVELOPMENT RUNOFF TREATMENT

5.1 Management Measure

By design or performance (a) reduce the postdevelopment loadings of total suspended solids (TSS) so that the average annual TSS loadings[a] are no greater than the predevelopment loadings, or (b) reduce the average annual TSS loadings by a minimum of 80 percent of the influent concentration of TSS[b].

Maintain the postdevelopment average volume and peak runoff rates at levels that are similar to predevelopment[c] levels or, through planning and/or design, control offsite discharges of runoff to prevent erosive impacts to downstream channels or shorelines.

Maintain discharge temperatures in runoff at levels similar to predevelopment levels or at levels that will protect aquatic communities from the thermal impacts of runoff.

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[a] In general, calculations of average annual TSS loadings will be based on TSS loadings from all storms below or equal to a predetermined maximum storm size. The most commonly used upper threshold that states use to calculate annual average TSS loadings is the 2-year, 24-hour storm. However, some states have recently reevaluated the benefits of controlling the 2-year versus the 1-year, 24-hour storm and, as a result, have adopted standards that require the control of all storms less than or equal to the 1-year, 24-hour storm.

EPA interprets predevelopment conditions to mean those conditions that exist prior to the current land use. In situations where the previous land use has resulted in unacceptable erosion and significant sediment movement offsite, a baseline reference condition can be used (e.g., the typical TSS loading rates from forested sites or meadows in the area). Average annual TSS loading calculations also should be based on the TSS discharge concentrations that occur after the site has been permanently stabilized.

[b] It is anticipated that the total TSS reductions will be calculated based on all reductions achieved through a system of structural and nonstructural management practices. The intent of this guidance is to promote the implementation of runoff management programs that protect receiving waters from increases of suspended solids that may, on an individual or cumulative basis, threaten or impair surface waters. Management practices and systems of practices should be selected based on achievement of water quality standards throughout the receiving watershed. TSS loading reduction goals therefore should be determined by assessing the capacity of the receiving water body to assimilate TSS from all contributing sources. EPA acknowledges that, in some jurisdictions, reducing 80 percent of the influent TSS concentration is not reasonable due to the presence of significant concentrations of colloidal particles. EPA also understands that treatment of these particles in many cases is not necessary to protect receiving waters and meet state or local water quality standards. In such cases, design or performance requirements should protect receiving waters from impairment from TSS loadings above the ambient TSS in receiving waters that are not due to anthropogenic sources.

[c] As with the TSS element of the measure, term *predevelopment* refers to runoff rates and volumes that exist on-site immediately before the planned land disturbance and development activities occur. Predevelopment is not intended to be interpreted as that period before any human-induced land disturbance activity has occurred. Watershed managers need to determine an appropriate reference or management condition as an objective to achieve. Also, for the purposes of this element of the management measure, the term *similar* is defined as “resembling though not completely identical.”

5.2 Management Measure Description and Selection

5.2.1 Description

During the development process, both the existing landscape and hydrology are altered. As development occurs, the following changes are likely to occur:

- Soil porosity decreases due to removal of vegetation and compaction of topsoil by construction equipment;
- Impermeable surfaces (paving and rooftops) increase (see Introduction);
- Artificial conveyances such as pipes and concrete channels are constructed;
- Slope angles become less acute;
- Vegetative cover decreases; and
- Surface roughness decreases.

These changes result in increased runoff volume and velocity, which may lead to accelerated erosion of streambanks, steep slopes, and unvegetated areas (Novotny, 1991). The grading of urbanized areas can increase the downward slope to a water body and destroy riparian buffer zones, or developers may level a site to facilitate construction activities. Destruction of in-stream and riparian habitat, increases in water temperature, streambed scouring, and downstream sedimentation of streambed substrates, riparian areas, and estuarine habitats may occur.

Everyday activities that occur after development may cause the discharge of pollutants in runoff that can have harmful effects on waters and habitat. Pollutants related to vehicle petroleum and coolant leaks and overflows, tire and brake wear, pet waste, pesticides, and fertilizers can be carried into estuaries, streams, rivers, and lakes through runoff. Soils and sediment can constitute a significant fraction of the solids on urban surfaces. Weather related erosion and transport of eroded soil (e.g., by wind and rain) increases solids in urban areas. Other sources of solids on urban surfaces are wear of automotive parts (brake pads, tires), combustion products from diesel- and gasoline-fueled engines, fireplaces, construction sites, and industrial facilities. An extensive discussion of these pollutants is presented in Chapter 1.

The goals of the new development runoff treatment management measure are to:

- Retain the predevelopment or pre-disturbance hydrological conditions of both surface and ground water;
- Remove suspended solids and associated pollutants entrained in runoff that result from activities occurring during and after development;
- Decrease the erosive potential of increased runoff volumes and velocities associated with development-induced changes in hydrology;

- Preserve natural systems, including in-stream habitat, riparian areas, and wetlands; and
- Reduce the thermal impacts that result from impervious surfaces and treatment devices with large amounts of surface exposed to sunlight such as wet ponds.

Several issues require clarification to fully understand the scope and intent of this management measure. The watershed protection (3), site development (4), and new development runoff treatment (5) management measures are intended to be used together within a comprehensive framework to reduce nonpoint source pollution. Applied on-site and throughout watersheds, these three management measures can be used together to provide increased watershed protection and help prevent erosion, flooding, and increased pollutant loads generally associated with poorly planned development. Implementation of the watershed protection and site development management measures can help achieve the goals of the new development runoff treatment management measure.

5.2.1.1 Pollutants and total suspended solids

Many pollutants bind to and are entrained in sediment or particulate loadings. Particulates include suspended, settleable, and bedload solids. Metals, phosphorus, nitrogen, hydrocarbons, and pesticides are commonly found in urban sediments. The correlation between total suspended solids (TSS) and specific pollutants may vary (URS Greiner Woodward Clyde, 1999).

TSS is a measure of the concentrations of sediment and other solid particles suspended in the water column of a stream, lake, or other water resource. TSS is an important parameter because it quantifies the amount of sediment entrained in runoff. This information can be used to link sources of sediments to the resulting sedimentation in a stream, lake, wetland, or other water resources. As shown previously, TSS is also an indirect measure of other pollutants carried by runoff, because nutrients (phosphorus), metals, and organic compounds are typically attached to sediment particles. For these reasons TSS was selected as the prime or sole parameter associated with the first element of this management measure.

Sansalone and Buchberger (1997) found that the relative proportional mass of heavy metals (Zn, Cu, Pb) in highway runoff and snowbank samples increased with decreasing particle size. This effect was attributed to the increase in surface area binding sites that were present with smaller particles. In another study, Sansalone et al. (1998) observed that the greatest mass of contaminants in highway runoff is found on particles in the 425 to 850 micron (μm) range. Because average particle size varies across the U.S., it makes sense to address the particle size that most effectively captures the highest percentage of associated pollutants.

The quantity and size range of the suspended particles measured and reported as TSS at any given time depends on many factors including:

- The composition and extent of the sources of suspended solids in the watershed;
- The magnitude and duration of storms or dry weather periods preceding the sampling;

- Flow velocity, turbulence, and other conditions that promote the suspension of solids in the water column; and
- The sampling techniques employed.

Generally, individual particles found in a TSS sample are 62 µm (0.062 µm) or less in diameter and classified as either silts or clays (Table 5.1). Solids greater than 62 µm can also be found in the water column if conditions are turbulent enough to keep them in suspension.

Table 5.1: Sediment particle size distribution (shaded classes are found in a typical urban TSS sample).

General Class	Class Name	Diameter (µm)
Sand	Very coarse sand	2000–1000
	Coarse sand	1000–500
	Medium sand	500–250
	Fine sand	250–125
	Very fine sand	125–62
Silt	Coarse silt	62–31
	Medium silt	31–16
	Fine silt	16–8
	Very fine silt	8–4
Clay	Coarse clay	4–2
	Medium clay	2–1
	Fine clay	1–0.5
	Very fine clay	0.5–0.24
	Colloids	< 0.24

Erosion and entrainment of solids in runoff occur primarily during rainfall. Rainfall varies in magnitude through time, with large rainstorms occurring less frequently than small showers. Collectively, all the rainfall occurring during the year contributes to the annual sediment yield from a site. In order to focus on typical annual yields, however, the management measure states that yield calculations are to be based on the average annual TSS loadings from all storms less than or equal to the two-year, 24-hour storm. Setting this threshold eliminates the need to calculate or integrate the impacts of larger infrequent storms into the average annual sediment yield calculation.

The annual TSS loadings can be calculated by adding the TSS loadings that can be expected during an average one-year period from precipitation events less than or equal to the two-year, 24-hour storm. Removal of 80 percent of TSS can be achieved by reducing, over the course of the year, 80 percent of these loadings.

Critics of the TSS standard suggest that the sampling and analysis protocols employed for this measure do not fully capture the entire range of particle sizes found in some kind of samples. More specifically, TSS protocols tend to under-sample larger solids and therefore yield lower-than-actual values for management practice pollutant removal efficiency. However, under-sampling the larger particles that would easily settle out in a runoff treatment control results in higher overall removal rates of solids and fewer solids discharged to surface waters.

There are alternatives to the TSS method, including turbidity and suspended sediment concentration (SSC). Monitoring turbidity in urban runoff is advantageous because the measurements can be conducted in situ using continuous methods (e.g., Secchi disk). It should be noted, however, that using turbidity as a surrogate for TSS may be appropriate only in instances where a strong statistical correlation has been established, such as in low-energy environments like lakes and estuaries. This correlation should be established on a case-by-case basis if turbidity is to be used as a surrogate.

The SSC method is used by the U.S. Geological Survey (USGS) as the standard for determining concentrations of suspended material in surface water samples (USGS, 2000). Gray et al. (2000) examined the comparability of SSC and TSS measurements. SSC and TSS are the predominant analytical methods used to quantify concentrations of solid-phase material in surface waters. SSC values are obtained by measuring the dry weight of all the sediment from a known volume of a water-sediment mixture. TSS data are produced by several methods, most of which involve measuring the dry weight of sediment from a known volume of a subsample of the original. Analysis of paired SSC and TSS data showed bias in the relationship between SSC and TSS. In samples where sand-size material was greater than nearly a quarter of the dry sediment mass, SSC values tended to be higher than corresponding paired TSS values.

According to Gray, the SSC method produces relatively reliable results for natural water samples, regardless of the amount or percentage of sand-size material in the samples. SSC and TSS are not comparable and should not be used interchangeably. Rather, the authors suggest using the SSC analytical method to enhance the accuracy and comparability of suspended solid-phase concentrations of natural waters (Gray et al., 2000). More information about the SSC analytical method can be found at http://www.astm.org/ by searching for standard number ASTM D 3977-97, *Standard Test Method for Determining Sediment Concentration in Water Samples* (ASTM International, 2002).

5.2.1.2 Runoff

Runoff management programs have traditionally focused on reducing or preventing induced flooding from new development. Performance standards were typically developed to control large storms, e.g., 50- or 100-year storms. Although the control of these large storms is still essential, it has become apparent in the last 20 years that a broad range of storms must be managed to prevent streambed and streambank erosion. Recent research points to the need to control total discharge volumes and rates so that they do not result in stream channel degradation. As a result, some states and local governments have developed performance requirements that are intended to prevent stream channel erosion as well as flooding of downstream properties.

This management measure was written to address the control of both peak runoff rates and average runoff volumes with the intent to maintain postdevelopment runoff characteristics at predevelopment levels. Even though EPA recommends that structural runoff controls be designed to control all storms less than or equal to the two-year, 24 hour storm, state and local governments should determine the locally appropriate storm size threshold to control based on local hydraulics, hydrology, meteorology and other regional and local factors. Watershed managers also should consider the development and implementation of volume and peak discharge performance standards to address problems associated with the frequency and duration of erosive flows (MacRae and Rowney, no date). The use of low-impact development (LID) techniques may be one way to achieve these goals (Prince Georges' County, Maryland, Department of Environmental Resources, 2000a, 2000b).

5.2.2 Management Measure Selection

This management measure was selected because of the following factors:

- Removal of 80 percent of TSS is assumed to control heavy metals, phosphorus, and other pollutants.

- Several states and local governments have implemented a TSS removal treatment standard of at least 80 percent. Table 5.2 presents TSS reduction standards and design criteria for select state and local runoff management programs.

- Analysis has shown that constructed wetlands, wet ponds, and infiltration basins can remove 80 percent of TSS, provided they are designed and maintained properly. Other practices or combinations of practices can also be used to achieve the goal.

- A number of flood control practices can control postdevelopment volume and peak runoff rates and maintain predevelopment hydrological conditions, which will reduce or prevent streambank erosion and stream scouring. Table 5.3 presents peak discharge and volume standards and design criteria for select local runoff management programs.

- Urban streams often experience elevated temperatures due to an increase in impervious areas and a decrease in vegetative cover that would normally provide shading for wetlands and stream channels. Many of the practices presented in this management measure and throughout this guidance, such as infiltration practices, riparian buffers, and urban forestry, help to lower stream temperatures. Practices such as retention ponds may contribute to temperature elevation and should not be used in areas with temperature-sensitive fish or macroinvertebrates unless the other measures are taken to counteract this effect (i.e., plant vegetation to shade ponds, wetlands, or channels).

Table 5.2: Select local and state programs with TSS performance standards (adapted from Watershed Management Institute [WMI], 1997a).

Community/State	Standard	Criteria
Olympia, WA	80 percent removal of suspended solids.	Treat runoff volume of six-month, 24 hr storm
Orlando, FL	Reduce average annual TSS loading by 80 percent.	Treat first half-inch of runoff or the runoff from the first inch of rainfall, whichever is greater.
Winter Park, FL	Reduce average annual TSS loading by 80 percent.	Treat the first inch of runoff by retention.
Baltimore Co., MD	Remove at least 80 percent of the average annual TSS loading.	Treat the first half-inch of runoff from the site's impervious area.
South Florida Water Management District	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 1.0 to 2.5 inches times percent impervious area.

Table 5.2 (continued).

Community/State	Standard	Criteria
Delaware	Remove at least 80 percent of the annual TSS loading.	Treat the first inch of runoff by approved management practices.
Florida	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 0.5 to 1.5 inches depending on the practice.
New Jersey	80 percent reduction in TSS.	Treat runoff volume of a storm of >1.25inches in two hours or the one-yr, 24-hr storm.
South Carolina	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 0.5 to 1.0 inch depending on the practice.

Table 5.3: Select local programs with peak discharge and/or runoff volume performance standards (adapted from WMI, 1997a).

Community/State	Peak discharge	Volume
Alexandria, VA	Postdevelopment rate cannot exceed predevelopment rate for two-yr and 10-yr, two-hr storm.	None
Austin, TX	Postdevelopment rate cannot exceed predevelopment rate for two-, 10-, 25-, and 100-yr, 24-hr storm.	None
Bellevue, WA	Postdevelopment rate cannot exceed predevelopment rate for two- and 10-yr, two-hr storm.	Multiple release rates for detention systems.
Olympia, WA	Postdevelopment rate cannot exceed predevelopment rate for two-yr and 100-yr, 24-hr storm.	Must infiltrate all of the 100-yr vol. on-site if percolation rate greater than 6 inches per hr.
Orlando, FL	Postdevelopment rate cannot exceed predevelopment rate for 25-yr, 24-hr storm.	In closed basins, retain runoff from 100-yr, 24-hr storm.
Washington, DC	Postdevelopment rate cannot exceed predevelopment rate for two-, 10-, and 100-yr, 24-hr storm.	None
Clark Co., WA	Postdevelopment rate cannot exceed predevelopment rate for two-, 10- and 100-yr, 24-hr storm.	Post-development vol. cannot exceed predevelopment vol. for two-yr, 24-hr storm.
SW Florida Water Management District	Postdevelopment rate cannot exceed predevelopment rate for 25-yr, 24-hr storm.	Post-development vol. cannot exceed predevelopment vol. for 25-yr, 24-hr storm.

General Performance Standards for Storm Water Management in Maryland

To prevent adverse impacts from runoff, the Maryland Department of the Environment (MDE, 2000) developed 14 performance standards for development sites. These standards apply to any construction activity disturbing 5,000 or more square feet of land. The following standards are required at all sites where runoff management is necessary:

- Site designs shall minimize runoff generation and maximize pervious areas for runoff treatment.
- Runoff generated from development and discharged directly into a jurisdictional wetland or waters of the State of Maryland shall be adequately treated.
- Annual ground water recharge rates shall be maintained by promoting infiltration through the use of structural and nonstructural methods. At a minimum, the annual recharge from postdevelopment site conditions shall mimic the annual recharge from predevelopment site conditions.
- Water quality management shall be provided through the use of structural and nonstructural controls.
- Structural management practices for new development shall be designed to remove 80 percent and 40 percent of the average annual postdevelopment TSS and total phosphorus loads, respectively. It is presumed that a management practice complies with this performance standard if it is sized to capture the prescribed water quality volume, designed according to the specific performance criteria outlined in the Maryland Stormwater Design Manual (MDE, 2000), constructed properly, and maintained regularly.
- On the Eastern Shore, the postdevelopment peak discharge rate shall not exceed the predevelopment peak discharge rate for the 2-year frequency storm event. On the Western Shore, local authorities may require that the postdevelopment 10-year peak discharge not exceed the predevelopment peak discharge if the channel protection storage volume (Cp_v) is provided. In addition, safe conveyance of the 100-year storm event runoff control practices shall be provided.
- To protect stream channels from degradation, Cp_v shall be provided by 12 to 24 hours of extended detention storage for the 1-year storm event. Cp_v shall not be provided on the Eastern Shore unless the appropriate approval authority deems it necessary on a case-by-case basis.
- Runoff to critical areas with sensitive resources may be subject to additional performance criteria or may need to use or restrict certain management practices.
- All management practices shall have an enforceable operation and maintenance agreement to ensure the system functions as designed.
- Every management practice shall have an acceptable form of water quality pretreatment.
- Redevelopment, defined as any construction, alteration, or improvement exceeding 5,000 square feet of land disturbance on sites where existing land use is commercial, industrial, institutional, or multi-family residential, is governed by special sizing criteria depending on the increase or decrease in impervious area created by the redevelopment.
- Certain industrial sites are required to prepare and implement a storm water pollution prevention plan (SWPPP) and file a notice of intent (NOI) under the provisions of Maryland’s Storm Water NPDES general permit. The SWPPP requirement applies to both existing and new industrial sites.
- Runoff from land uses or activities with higher potential for pollutant loadings, sometimes referred to as hotspots, may require the use of specific structural runoff control and pollution prevention practices. In addition, runoff from a hotspot land use may not be infiltrated without proper pretreatment.
- In Maryland, local governments are usually responsible for storm water management review authority. Prior to design, applicants should always consult with their local reviewing agency to determine if they are subject to additional storm water design requirements. In addition, certain earth disturbances may require NPDES construction general permit coverage from MDE.

Delaware Urban Runoff Management Model

The Delaware Department of Natural Resources and Environmental Conservation (2005) developed the Delaware Urban Runoff Management Model (DURMM) to quantitatively estimate how "green technology" management practice designs achieve pollutant removal and flow reductions. Green technology includes the following management practices:

- Conservation site design
- Source area disconnection
- Biofiltration swales/grassed swales
- Terraces
- Bioretention structures
- Infiltration practices

These green technologies address some of the drawbacks of traditional runoff controls, including the following:

- Ponds and wetlands do not necessarily protect against streambank erosion
- Ponds and wetlands do not recharge groundwater.
- Ponds and wetlands require substantial land area
- Ponds and wetlands require significant maintenance.
- Discharges from multiple structural practices can overlap, resulting in downstream flooding.
- Discharges can elevate stream temperatures and sometimes contain high levels of algae.

DURMM provides a quantitative approach to define the benefits of conservation design and quantifies runoff reductions and pollutant reductions from filter strips, biofiltration and grassed swales, terraces, bioretention structures, and infiltration trenches. It also quantifies runoff reductions from source area disconnection. The Delaware Department of Natural Resources and Environmental Conservation is also developing a companion document specifically focused on riparian buffer system design.

Additional information on green technology BMPs or DURMM can be obtained by contacting Delaware's Division of Soil & Water Conservation at 302-739-4411.

5.2.3 General Categories of Urban Runoff Control

Structural practices to control urban runoff rely on several basic mechanisms:

- Infiltration;
- Filtration;
- Detention/retention; and
- Evaporation.

5.2.3.1 Infiltration practices

Infiltration facilities are designed to capture a treatment volume of runoff and percolate it through surface soils into the ground water system. This process:

- Reduces the total volume of runoff discharged from the site, which, in turn, decreases peak flows in storm sewers and downstream waters;

- Filters out sediment and other pollutants by various chemical, physical, and biological processes as runoff water moves through the bottom of the infiltration structure and into the underlying soil; and

- Augments ground water reserves by facilitating aquifer recharge. Groundwater recharge is vital to maintain stream and wetland hydrology. During dry weather, ground water recharge helps to assure baseflow necessary for survival of biota in wetlands and streams.

Treatment effectiveness depends on whether the facility is sited on-line or off-line, and on the sizing criteria used to design the facilities. Online systems receive all of the runoff from an area. Off-line practices receive diverted runoff for treatment and isolate it from the remaining fraction of runoff, which must still be controlled to prevent flooding. Off-line infiltration practices prevent all of the TSS and other pollutants contained in the volume of runoff infiltrated from exiting the site. Thus, the total annual load reduction depends on how much of the annual volume of runoff is diverted to the infiltration structure. On-line infiltration practices, on the other hand, have lower treatment effectiveness, averaging approximately 75 percent removal of TSS (WMI, 1997b).

The overall hydrologic benefits of infiltration practices may also vary depending on site characteristics and the frequency and intensity of storms. Holman-Dodds et al. (2003) modeled the potential for infiltration techniques to reduce the adverse hydrologic effects of urbanization. The study indicated that the greatest reductions in flow are achievable when rainfall is limited and relatively frequent, and when soils are relatively porous.

Infiltration facilities require porous soils (i.e., sands and gravels) to function properly. Generally, they are not suitable in soils with 30 percent or greater clay content or 40 percent or greater silt/clay content (WMI, 1997b). They are also not suitable:

- In areas with high water tables;
- In areas with shallow depth to impermeable soil layers;
- On fill sites, which have low permeability, or on steep slopes;
- In areas where infiltration of runoff would likely contaminate ground water;
- In areas where there is a high risk of hazardous material spills; or

- Where additional groundwater could form sinkholes.

Special protection for ground water is needed when runoff is used as a drinking water source in urban areas (see Management Measure 3—Watershed Protection). Certain types of infiltration facilities, called Class V injection wells, may be regulated as part of the federal Underground Injection Control (UIC) Program, authorized by the Safe Drinking Water Act. Class V wells discharge fluids underground. Class V wells include French drains, tile drains, infiltration sumps, and percolation areas with vertical drainage. Dry wells, bored wells, and infiltration galleries are all Class V wells. Class V wells do not include infiltration trenches filled with stone (with no piping), or excavated ponds, lagoons, and ditches (lined or unlined, without piping or drain tile) with an open surface. Compliance with federal regulations may include submitting basic inventory information about the drainage wells to the state or EPA and complying with specific construction, operation, permitting, and closure requirements (USEPA, 2003). Any questions regarding the applicability of the UIC regulations to a storm water facility should be directed to federal or state UIC contacts. This information is available at http://www.epa.gov/safewater/uic.html.

The effect of infiltration practices on ground water quality is unclear, but a few studies exist that indicate potential ground water quality concerns from infiltrating urban runoff (Pitt, et al., 1994; Fischer, no date; Ging et al., 1997, Morrow, 1999). For example, Fischer (no date) studied the effects of infiltration of urban runoff on ground water quality in the New Jersey Coastal Plain. He found that although many pollutants were removed from runoff before reaching the water table, elevated concentrations and occurrences of certain compounds and ions indicated contributions from urban runoff, implying that infiltration practices could have a detrimental effect on ground water quality. Conversely, Fischer hypothesized that infiltrating runoff would have the beneficial effect of diluting other compounds frequently present in ground water.

Pitt et al. (1994) summarized the potential for 25 pollutants to contaminate ground water, categorizing each as low, low/moderate, moderate, or high. Of these 25 pollutants, only one, chloride, has a high potential, and only fluoranthene and pyrene have a moderate potential. Nitrate, a highly soluble and mobile contaminant, was categorized as having a low/moderate potential for contamination, and the other 21 pollutants had low potential.

Heavy metals and hydrocarbons may pose a low risk of contamination, but several studies have indicated that concentrations of these pollutants decrease rapidly with depth (Barraud et al., 1999; Legret et al. 1999). Similarly, Dierkes and Geiger (1999) found that polycyclic aromatic hydrocarbons (PAHs) in highway runoff were removed in the top four inches of soil.

The presence of volatile organic compounds (VOCs) in ground water is another concern. A USGS study (Ging et al., 1997) analyzed the occurrence and distribution of VOCs in ground water in south-central Texas. Although less than 50 percent of the samples taken had VOC detections, 28 VOCs were detected in samples from 89 wells. Based on the results of this study, VOC contamination in ground water appears to be associated with urban development (Ging et al., 1997).

VOC contamination has also been detected in the ground water of the Lower Illinois River Basin. In 1996, water samples collected from 60 wells in the basin were sampled and analyzed for VOCs. There were only six VOC detections in more than 4,300 analyses of the ground water samples (although at least three of these detections may have been caused by well disinfection practices). Additionally, a VOC was detected in one sample from deep glacial drift, indicating that shallow aquifers may be more susceptible to VOC contamination than deep aquifers. Based on these results, the authors concluded that VOC contamination does not appear to be a major concern for ground water quality in rural areas of the Lower Illinois River Basin (Morrow, 1999).

Several studies have found that the potential for ground water contamination, particularly from heavy metals and hydrocarbons, is low when porous pavement and stone-filled subsurface infiltration beds are used. These systems provide treatment through adsorption, filtration, sedimentation, and biodegradation before runoff reaches the underlying soil (Balades et al., 1995; Legret and Colandini, 1999; Newman et al., 2002; Pratt et al., 1999; Swisher, 2002).

5.2.3.2 Filtration practices

Filtration practices are so named because they filter particulate matter from runoff. The most common filtering medium is sand, but other materials, including peat/sand combinations and leaf compost material, have been used. Filtration systems provide only limited flood storage; therefore, they are most often implemented in conjunction with other types of quantity control management practices. Most filtration techniques require a forebay or clarifier to remove larger particles in runoff from clogging the filter media.

Biofiltration refers to practices that use vegetation and amended soils to retain and treat runoff from impervious areas. Treatment is through filtration, infiltration, adsorption, ion exchange, and biological uptake of pollutants.

5.2.3.3 Detention/retention practices

Runoff *detention* facilities provide pollutant removal by temporarily capturing runoff and allowing particulate matter to settle prior to release to surface waters. Dry detention runoff management ponds are one type of detention facility. Peak flows are reduced in drainage systems/receiving waters downstream of detention facilities.

Runoff *retention* facilities are used to capture runoff, which is subsequently withdrawn or evaporated. Therefore, peak flows and total flow volume can be reduced in downstream drainage systems/receiving waters. Wet runoff management ponds are one type of retention facility. These retention facilities can be designed to accept flow from receiving streams/drainage systems offline.

Both detention and retention facilities can use biological uptake as a mechanism for pollutant removal. Runoff management ponds can be designed to control the peak discharge rates, thereby reducing excessive flooding and downstream erosion in reaches of the drainage system/receiving stream immediately downstream. At some point downstream, however, runoff flow that is not retained will increase the volume of total flow, thereby increasing the risk of flooding and erosion if the receiving stream at that point does not have a stable channel and riparian area or floodplain.

Constructed wetlands are engineered systems designed to employ the water quality improvement functions of natural wetlands to treat and contain surface water runoff pollution and decrease pollutant loadings to surface waters. They can be designed with extended detention to control runoff peak flow and volume. Where site-specific conditions allow, constructed wetlands and retention basins should be located to minimize the impact on the surrounding areas (e.g., in upland areas of the watershed). Ponds, constructed wetlands, and other structural management practices degrade the functions of natural buffer areas and natural wetlands, and they may also interrupt surface water and ground water flow when soils are disturbed for installation. Therefore, the placement of structural management practices in natural buffers and natural wetlands should be avoided where possible.

5.2.3.4 Evaporation practices

Runoff detention and retention facilities and other practices that temporarily store runoff can also evaporate it. Evaporation from runoff detention and retention areas such as rooftops, streets, basins, and ponds can be an important mechanism for runoff management in warm, dry climates.

5.3 Management Practices

Management practices to control urban runoff can be classified in seven categories. The following practices are described for illustrative purposes only. EPA has found these practices to be representative of the types of practices that can be applied successfully to achieve the new development runoff treatment management measure. As a practical matter, EPA anticipates that the management measure can be achieved by applying one or more management practices appropriate to the source(s), location, and climate. Thus, practices that by themselves do not achieve 80 percent TSS removal can be combined with other practices to achieve 80 percent removal (such that x + y + z = 80 percent). This is the “treatment train” approach, in which several types of practices are used together and integrated into a comprehensive runoff management system (WMI, 1997b). The seven categories include:

- Infiltration practices;
- Vegetated open channel practices;
- Filtering practices;
- Detention ponds or vaults;
- Retention ponds;
- Wetlands; and
- Other practices such as water quality inlets.

5.3.1 Infiltration Practices

These practices capture and temporarily store runoff before allowing it to infiltrate into the soil over several days. Design variants include:

- Infiltration basins;
- Infiltration trenches; and
- Pervious or porous pavements.

To prevent premature clogging, these practices must not receive drainage from a construction activity or site. Infiltration practices can be placed in service after the construction activity is complete or the site is stabilized.

5.3.1.1 Infiltration basins

Infiltration basins (Figure 5.1) are impoundments created by excavation or creation of berms or small dams. They are typically flat-bottomed with no outlet and are designed to temporarily store runoff generated from adjacent drainage areas (from 2 to 50 acres, depending on local conditions). Runoff gradually infiltrates through the bed and sides of the basin, ideally within 72 hours, to maintain aerobic conditions and ensure that the basin is ready to receive runoff from the next storm. Infiltration basins are often used as an off-line system for treating the first flush of runoff flows or the peak discharges of the two-year storm.

The key to successful operation is keeping the soils on the floor and side slopes of the basin unclogged to maintain the rate of percolation. This is usually much easier said than done. For example, Schueler (1992) reported infiltration basin failure rates ranging from 60 to 100 percent

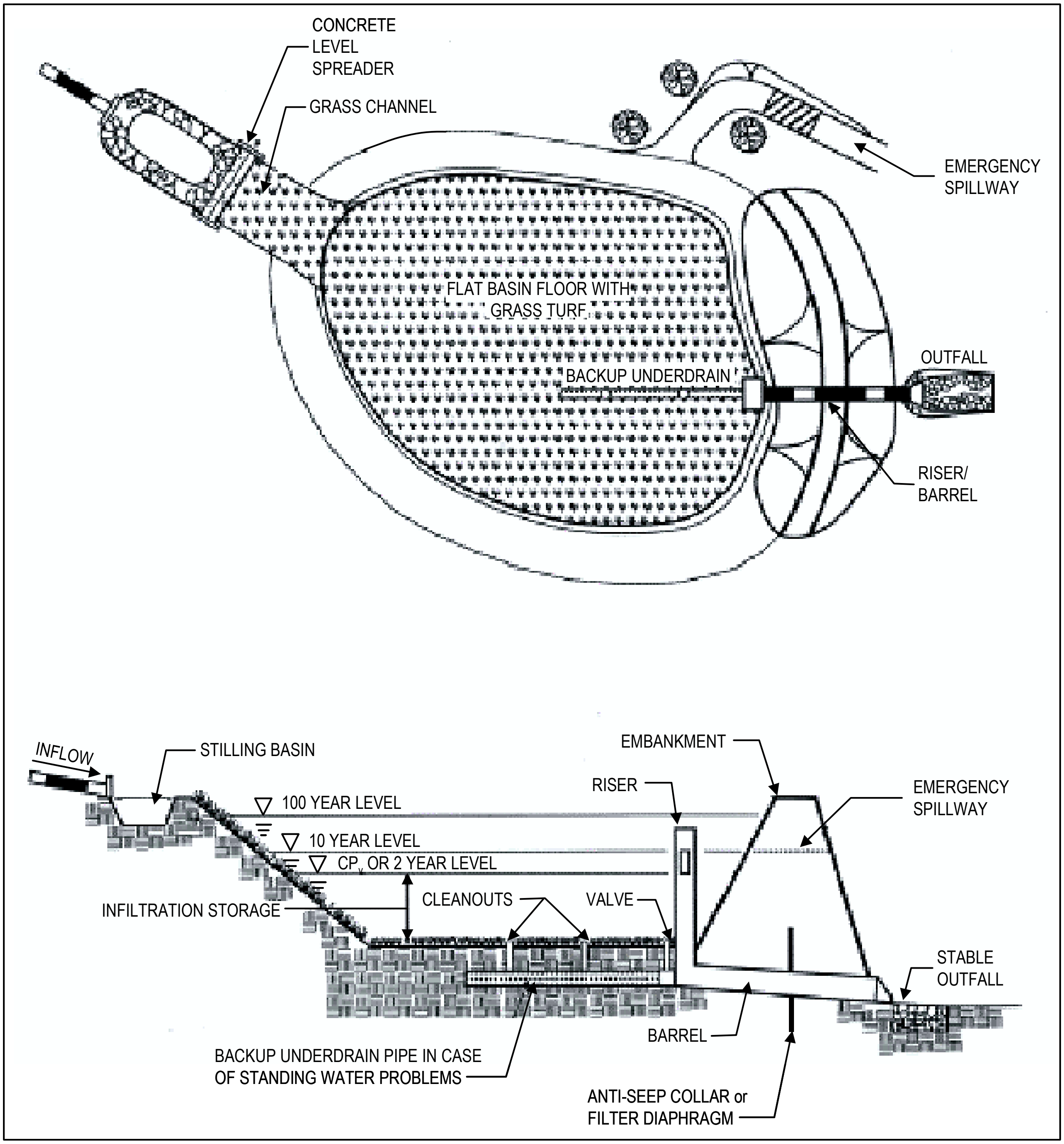

Figure 5.1: Schematic of an infiltration basin (MDE, 2000).

in the mid-Atlantic region. To help keep sediment out of the basin, incoming runoff should be pretreated using vegetated filter strips, a settling forebay, or other techniques. Grasses or other vegetation should also be planted and maintained in the basin. If soil pores become clogged, the basin bottom should be roughened or replaced to restore percolation rates.

5.3.1.2 Infiltration trenches

Infiltration trenches (Figure 5.2) are shallow (2- to 10-feet deep) excavated ditches with relatively permeable soils that have been backfilled with stone to form an underground reservoir. The trench surface can be covered with a grating or can consist of stone, gabion, sand, or a grass-covered area with a surface inlet. Runoff diverted into the trench gradually infiltrates into the subsoil and, eventually, into the ground water. Trenches can be used on small, individual sites or for multi-site runoff treatment. Pretreatment controls such as vegetated filter strips should be incorporated into the design to remove sediment and reduce clogging of soil pores. More expensive than pond systems in terms of cost per volume of runoff treated, infiltration trenches are best-suited for drainage areas of less than 5 to 10 acres, or where ponds cannot be used.

Variations in the design of infiltration trenches include dry wells, which are pits designed to control small volumes of runoff (such as rooftop runoff) and exfiltration trenches. A typical dry well design includes a perforated pipe 3 to 4 feet in diameter that is installed vertically in deposits of gravely/sandy soil. Rock is then backfilled around the base of the well. An exfiltration trench is an infiltration trench that stores runoff water in a perforated or slotted pipe and percolates it out into a surrounding gravel envelope and filter fabric. Dry wells and other infiltration practices that involve subsurface drainage may be regulated by EPA's Underground Injection Control Program. See the EPA's Underground Injection Control Program Web site at http://www.epa.gov/safewater/uic.html for more information.

5.3.1.3 Pervious or porous pavements

Pervious pavement has the approximate strength characteristics of traditional pavement but allows rainfall and runoff to percolate through it. The key to the design of these pavements is the elimination of most of the fine aggregate found in conventional paving materials. There are two types of pervious pavement, porous asphalt and pervious concrete (WMI, 1997b). Porous asphalt has coarse aggregate held together in the asphalt with sufficient interconnected voids to yield high permeability. Pervious concrete, in contrast, is a discontinuous mixture of Portland cement, coarse aggregate, admixtures, and water that also yields interconnected voids for the passage of air and water. Underlying the pervious pavement are a filter layer, a stone reservoir, and a filter fabric. Stored runoff gradually drains out of the stone reservoir into the subsoil. Figure 5.3 shows several types of porous pavement. More information about pervious pavement can be found at http://www.gcpa.org/pervious_concrete_pavement.htm (Georgia Concrete & Products Association, 2003).

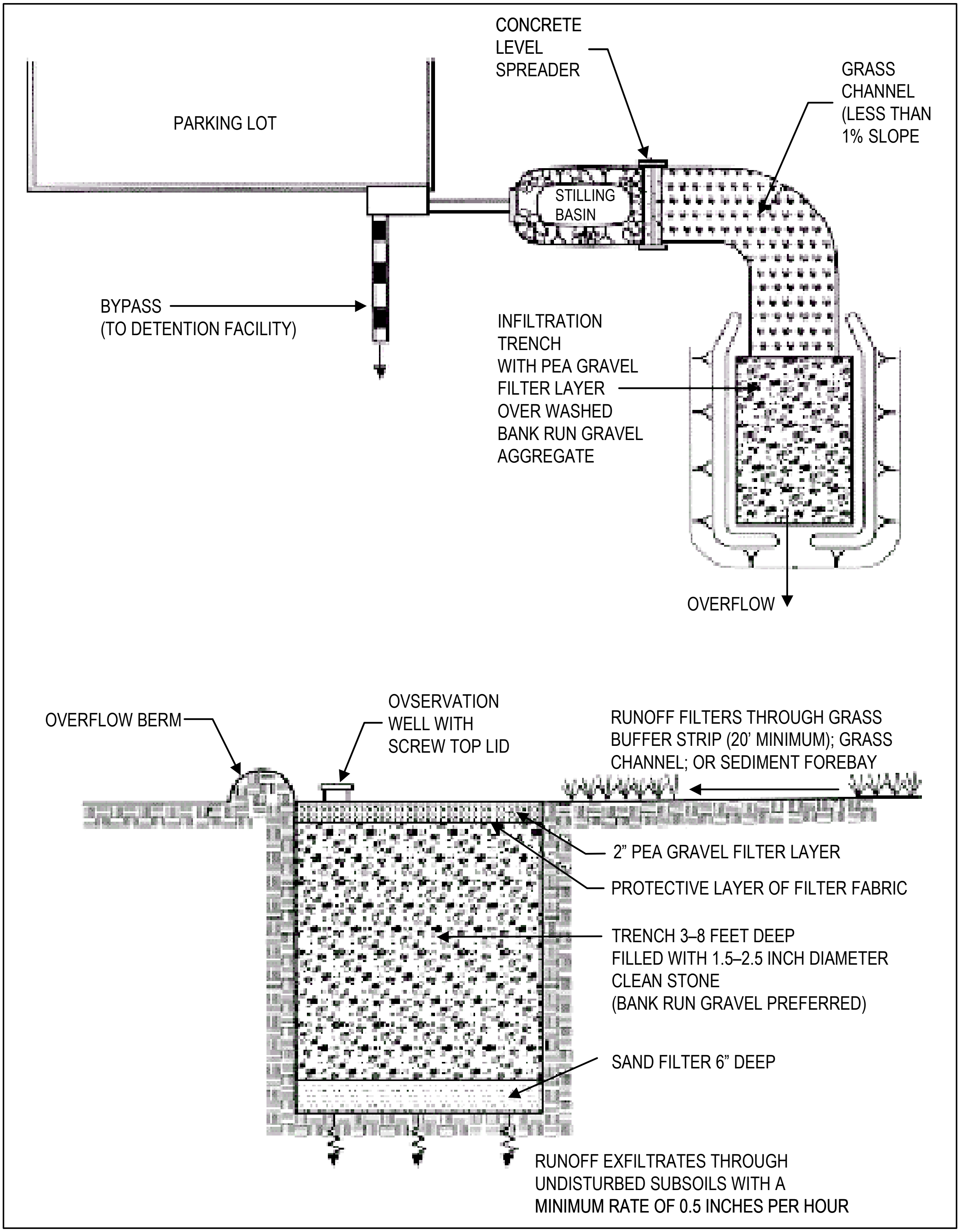

Figure 5.2: Schematic of an infiltration trench (MDE, 2000).

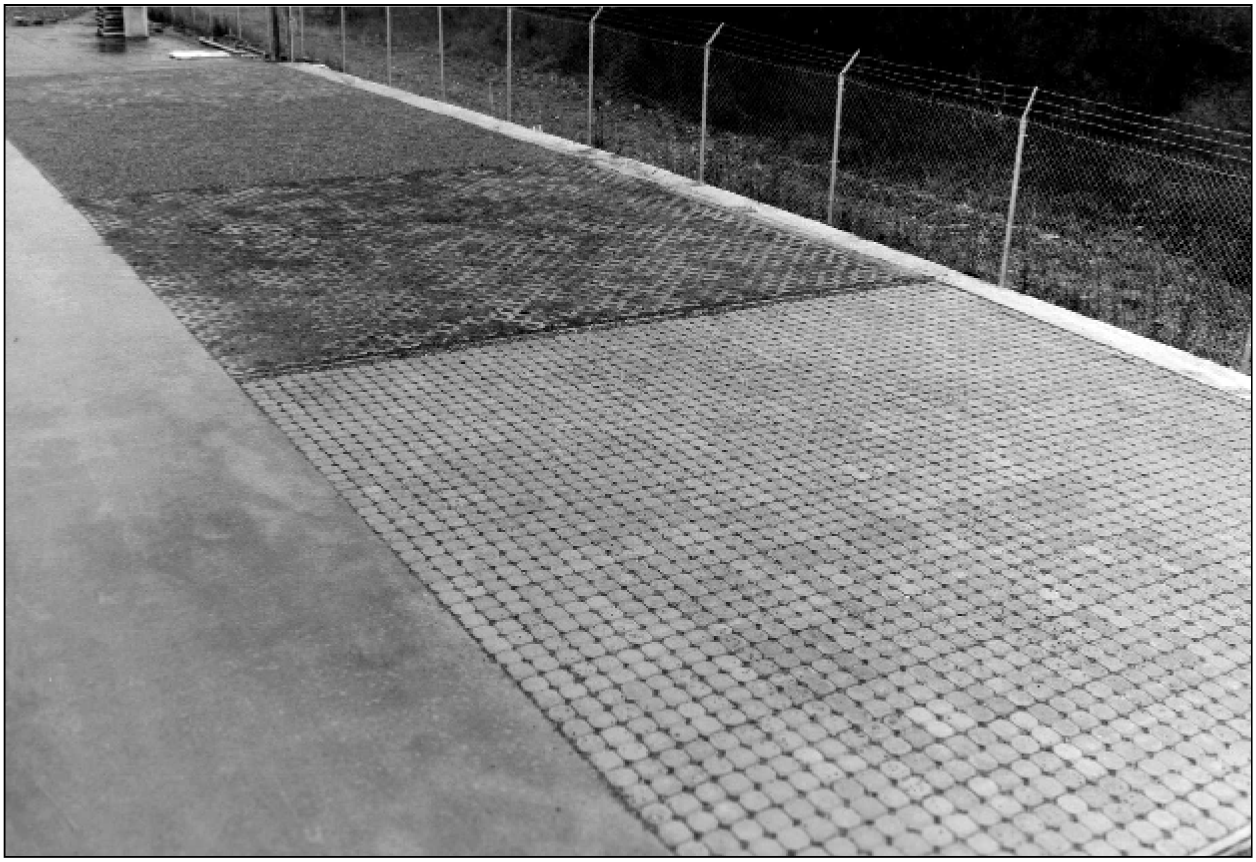

Figure 5.3: Photo showing several types of pervious modular pavement installations.

Modular pavement consists of individual blocks made of pervious material such as sand, gravel, or sod interspersed with strong structural material such as concrete. The blocks are typically placed on a sand or gravel base and designed to provide a load-bearing surface that is adequate to support personal vehicles, while allowing infiltration of surface water into the underlying soils. They usually are used in low-volume traffic areas such as overflow parking lots and lightly used access roads. An alternative to pervious and modular pavement for parking areas is a geotextile material installed as a framework to provide structural strength. Filled with sand and sodded, it provides a completely grassed parking area. More information about concrete pavers can be found at http://www.concretenetwork.com/concrete/porous_concrete_pavers/ (Concretenetwork.com, 2003).

Some states no longer promote the use of porous pavement because it tends to easily clog with fine sediments (Washington Department of Ecology, 1991). If this type of pavement is installed, a vacuum-type street sweeper should be used regularly to maintain porosity. Frequent washing with a high-pressure jet of water can also keep pores clear of clogging sediments. Sites where pervious pavement is to be installed must have deep, permeable soils, slopes of less than 5 percent, and no heavy vehicle traffic.

The City of Kinston, North Carolina, installed a permeable pavement parking lot as a demonstration and research project and to meet the daily parking needs of city employees (Hunt and Stevens, 2001). The final parking lot design included 26 stalls; 20 of the stalls were

The Bath Club Concourse Storm Water Rehabilitation Project, Florida

The Bath Club Concourse is located on a small barrier island community in North Redington Beach, Florida. A combination roadway and parking area, which connects Bath Club Circle and Gulf Boulevard, was previously an impervious slab of concrete pavement. The concourse could not absorb falling rain, which caused runoff to flow directly into a single storm sewer. The sewer would then carry pollutants directly to Boca Ciega Bay. In August 1990, the Water Management District and the town agreed to construct a stormwater rehabilitation project using pervious concrete pavement at the Bath Club Concourse (USEPA, 1999).

The main objective of the rehabilitation project was to reduce nonpoint source pollutant loading by reducing the volume of runoff discharging directly into Boca Ciega Bay. A second objective was to demonstrate an innovative way to treat or improve the quality of runoff in highly urbanized areas, where it can sometimes be difficult or expensive to manage runoff because of land constraints.

To maximize infiltration of runoff and reduce the amount of untreated runoff discharged directly into storm sewers, drainage was directed toward two pervious concrete parking areas. These areas were separated by an unpaved island in the center of the concourse, which also provides infiltration. Engineers installed two 150-foot under-drains to maximize infiltration by allowing subsurface soils to drain beneath the parking areas.

The rehabilitation project resulted in a significant reduction of direct discharge of runoff from the site. Estimates indicate that these improvements resulted in a 33 percent reduction in total on-site runoff volume. Additionally, the volume of surface runoff discharging directly to Boca Ciega Bay was reduced by nearly 75 percent. Overall removal efficiencies for the project, which are based on the pollutant removal efficiency of the under-drain/filter system, indicate that the project can remove 73 percent of lead (Bateman et al., no date). Other removal efficiencies and additional information about the project are available at http://www.stormwaterauthority.org/assets/103BFloridaRetrofits.pdf.

constructed using a concrete block paver filled with and overlaying sand, while the other six were constructed using a plastic grid paver with sandy soil and Bermuda grass. Monitoring results from a two-year study showed a 3- to 5-time reduction in peak runoff for storms greater than 0.5 inches based on calculated runoff coefficients (using the rational method). Of 48 rainstorms, only 11 (less than 25 percent) resulted in runoff generated from the parking lot The researchers found that annual maintenance to scarify the surface of the lot with a street sweeper helps to maximize permeability of the pavement. More information about the study, including several design recommendations, can be found at http://www5.bae.ncsu.edu/programs/extension/wqg/issues/101.pdf.

Brattebo and Booth (2003) examined the long-term effectiveness of permeable pavement by testing four commercially available permeable pavement systems for six years of regular parking use. The systems included the following:

- A flexible plastic grid system with virtually no impervious area, filled with sand and planted with grass;
- An equivalent plastic grid, filled with gravel;
- A concrete block lattice with approximately 60 percent impervious coverage, filled with soil and planted with grass; and

- Small concrete blocks with approximately 90 percent impervious coverage, with the spaces between blocks filled with gravel.

At the end of the study, none of the systems showed major signs of wear. The pavements infiltrated nearly all rainwater, generating almost no surface runoff. The researchers compared the quality of infiltrated water to surface runoff from an asphalt area and found significantly lower levels of copper and zinc in the infiltrated water. Motor oil was not detected in infiltrated water but was detected in 89 percent of samples of surface runoff from asphalt. Measurements of infiltrated rainwater from five years earlier showed significantly higher concentrations of zinc and lower concentrations of copper and lead.

5.3.2 Vegetated Open Channel Practices

Vegetated open channels are explicitly designed to capture and treat runoff through infiltration, filtration, or temporary storage.

A vegetated swale is an infiltration practice that usually functions as a runoff conveyance channel and a filtration practice. It is lined with grass or another erosion-resistant plant species that serves to reduce flow velocity and allow runoff to infiltrate into ground water. The vegetation or turf also prevents erosion, filters sediment, and provides some nutrient uptake benefits. These practices are also known as biofiltration swales. Check dams are often used to reduce flow velocity. When used, sediment that collects behind check dams should be removed regularly.

Two types of channels are typically used in residential landscapes:

- *Grass channels*. These have dense vegetation, a wide bottom, and gentle slopes (Figure 5.4). Usually they are intended to detain flows for 10 to 20 minutes, allowing sediments to filter out.

- *Dry swales*. As with grass channels, runoff flows into the channel and is subsequently filtered by surface vegetation (Figure 5.5). From there, runoff moves downward through a bed of sandy loam soil and is collected by an underdrain pipe system. The treated water is delivered to a receiving water or another structural control. Dry swales are used in large-lot, single-family developments and on campus-type office or industrial sites. They are applicable in all areas where dense vegetative cover can be maintained. Because of a limited ability to control runoff from large storms, they are often combined with other structural practices. They should not be used in areas where flow rates exceed 1.5 feet per second unless additional erosion control measures, such as turf reinforcement mats, are used.

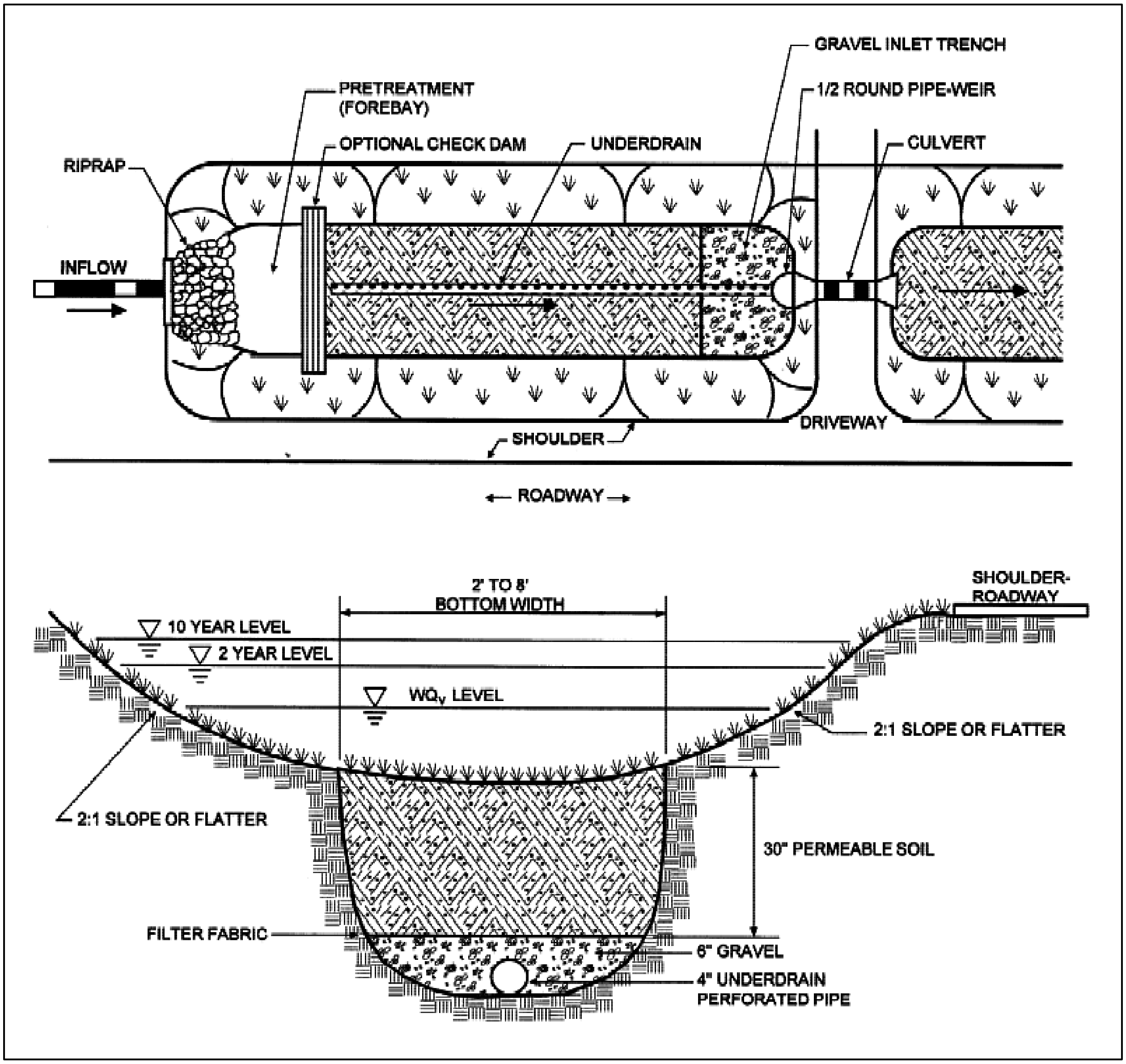

Figure 5.4: Schematic of a grass channel (Claytor and Schueler, 1996).

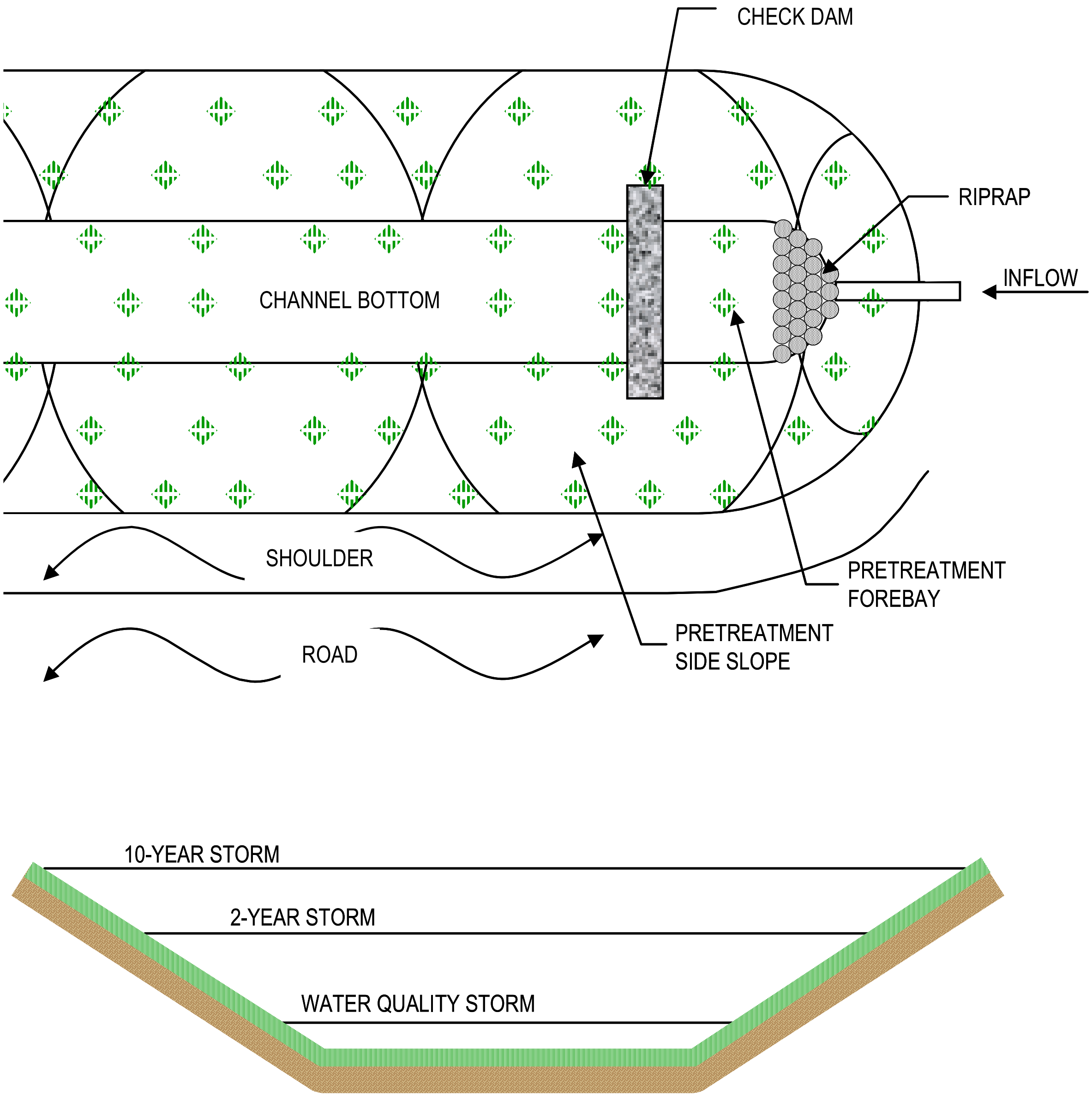

Figure 5.5: Schematic of a dry swale (adapted from MDE, 2000).

In a research study conducted by J.F. Sabourin and Associates (1999), two grass swale/perforated pipe systems and one conventional curb-and-gutter system were compared. Flow monitoring results indicate that much less water reached the outlet of the perforated pipe systems than the conventional system. Peak flows and total runoff volumes from the outlet of the perforated pipe/grass swale system were 2 to 6 percent of those of the conventional system, and total runoff volumes were 6 to 30 percent of conventional system volumes. Water quality monitoring results indicate that for most elements, concentrations measured in the perforated pipes were the same or lower than in the conventional system. Chloride concentrations were found to be higher in the perforated pipe system, most likely from the use of road salt. However, a loading analysis indicated that the perforated pipes released significantly fewer pollutants than the conventional system.

The authors also performed video inspections of the swale/perforated pipe sewershed. These inspections revealed a few interesting issues that can affect the performance of perforated pipe systems. Several unauthorized sanitary sewer connections had been made by some residents, and several raccoons were found living inside the pipes. Both can contribute to nutrient and pathogen problems in receiving waters.

J.F. Sabourin and Associates concluded that infiltration capacities of grass swales are optimum when they allow for proper drainage and hold enough moisture for sustaining grass and plant life. Exfiltration tests indicated that runoff volumes can be reduced by 40 to 60 percent by grass swales and perforated pipe drainage systems. With a direct connection, peak outflows can be 45 percent of the inflow.

5.3.3 Filtering Practices

Filtering practices capture and temporarily store runoff and pass it through a filter bed of sand, organic matter, soil, or other media. Filtered runoff may be collected and returned to the conveyance system, or allowed to exfiltrate into the soil. Design variants include:

- Surface sand filter;
- Underground sand filter;
- Organic filter;
- Pocket sand filter; and
- Bioretention areas.

5.3.3.1 Filtration basins and sand filters

Filtration basins are impoundments lined with a filter medium such as sand or gravel. Runoff drains through the filter medium and through perforated pipes into the subsoil. Detention time is typically four to six hours. Sediment-trapping structures are often used to prevent premature clogging of the filter medium (NVPDC, 1980; Schueler et al., 1992).

Sand filters are usually two-chambered practices: the first is a settling chamber and the second is a filter bed filled with sand or another filtering medium. As runoff flows into the first chamber, large particles settle out and finer particles and other pollutants are removed as runoff flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and multi-chambered treatment train (Robertson et al., 1995). All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging site designs (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter). The following are design variations for sand filtration devices:

(1) *Surface sand filter*. The surface sand filter (Figure 5.6) is an aboveground filter design. Both the filter bed and the sediment chamber are aboveground. The surface sand filter is designed as an off-line practice; only the water quality volume is directed to the filter. The surface sand filter is the least-expensive filter option and has been the most widely used.

(2) *Underground sand filter*. The underground sand filter (Figure 5.7) is a modification of the surface sand filter, where all of the filter components are underground. Like the surface sand filter, this practice is an off-line system that receives only flows from small rainstorms. Underground sand filters are expensive to construct but consume very little space. They are well-suited to highly urbanized areas, and often included in groups of practices known as "ultra-urban BMPs."

(3) *Perimeter sand filter*. The perimeter sand filter (Figure 5.8) also includes the basic design elements of a sediment chamber and a filter bed. In this design, however, flow enters the system through grates, usually at the edge of a parking lot. The perimeter sand filter is the only filtering option that is on-line; all flow enters the system, but a bypass to an overflow chamber prevents system flooding. One major advantage of the perimeter sand filter design is that it requires little hydraulic head and thus is a good option in areas of low relief.

(4) Organic media filter. Organic media filters (Figure 5.9) are essentially the same as surface filters, with the sand replaced with or supplemented by another medium. Two examples are the peat/sand filter (Galli, 1990) and the compost filter system. It is assumed that these systems will provide enhanced pollutant removal for many compounds because of the increased cation exchange capacity achieved by increasing organic matter content.

(5) *Multi-chambered treatment train*. The multi-chambered treatment train (Figure 5.10) is essentially a "deluxe sand filter" (Robertson et al., 1995). This underground system consists of three chambers. Runoff enters into the first chamber where screening occurs, trapping large sediments and releasing highly volatile materials. The second chamber provides settling of fine sediments and further removal of volatile compounds and floatable hydrocarbons through the use of fine bubble diffusers and sorbent pads. The final chamber provides filtration by using a sand and peat mixed medium for reduction of the remaining pollutants. The top of the filter is covered by a filter fabric that evenly distributes the water volume and prevents channelization. Although this practice can achieve very high pollutant removal rates, it might be prohibitively expensive in many areas. It has been implemented only on an experimental basis.

(6) *Exfiltration/partial exfiltration.* In exfiltration designs, all or part of the underdrain system is replaced with an open bottom that allows infiltration to the ground water. When the underdrain is present, it is used as an overflow device in case the filter becomes clogged. These designs are best applied in the same soils where infiltration practices are used.

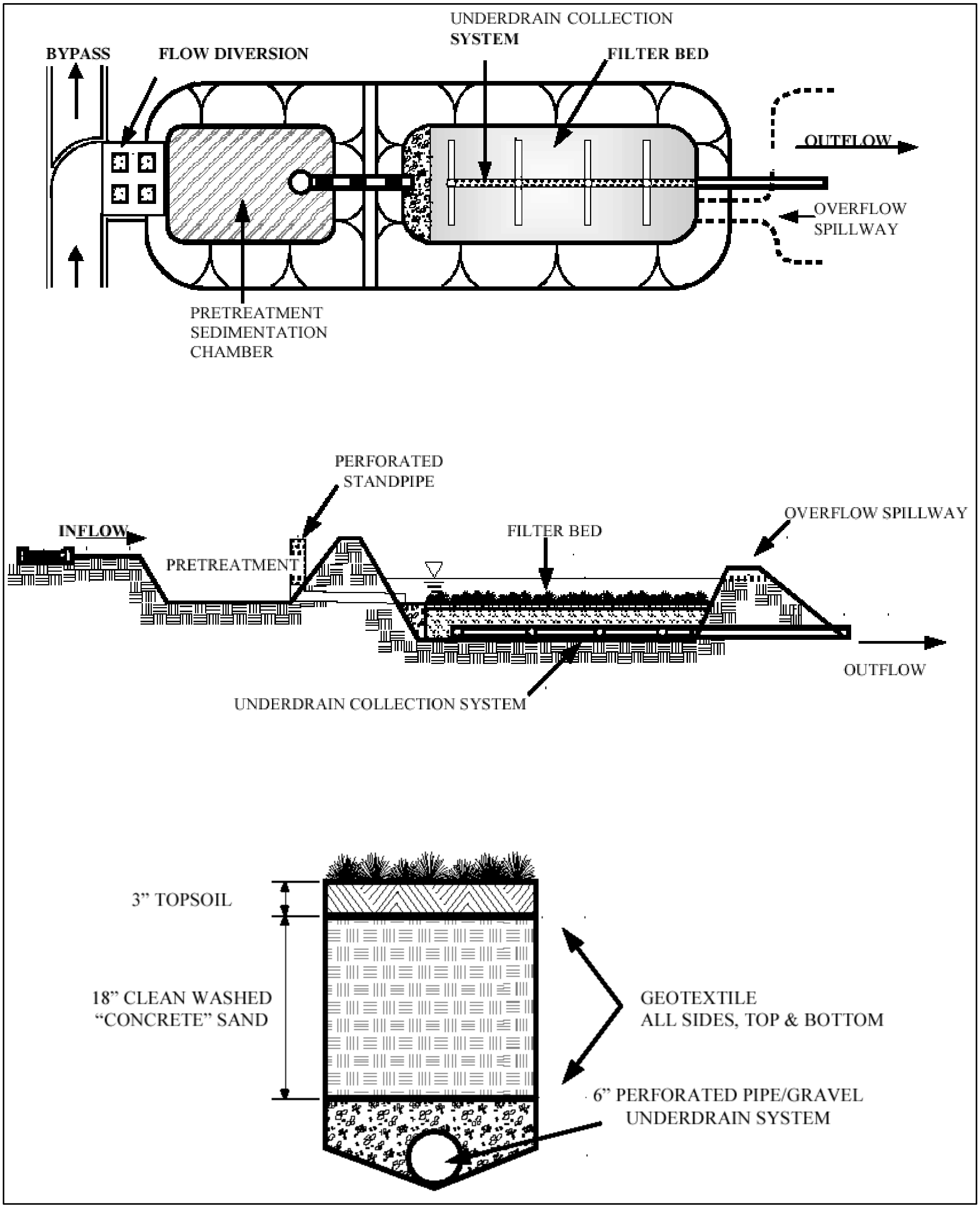

Figure 5.6: Schematic of a surface sand filter (MDE, 2000).

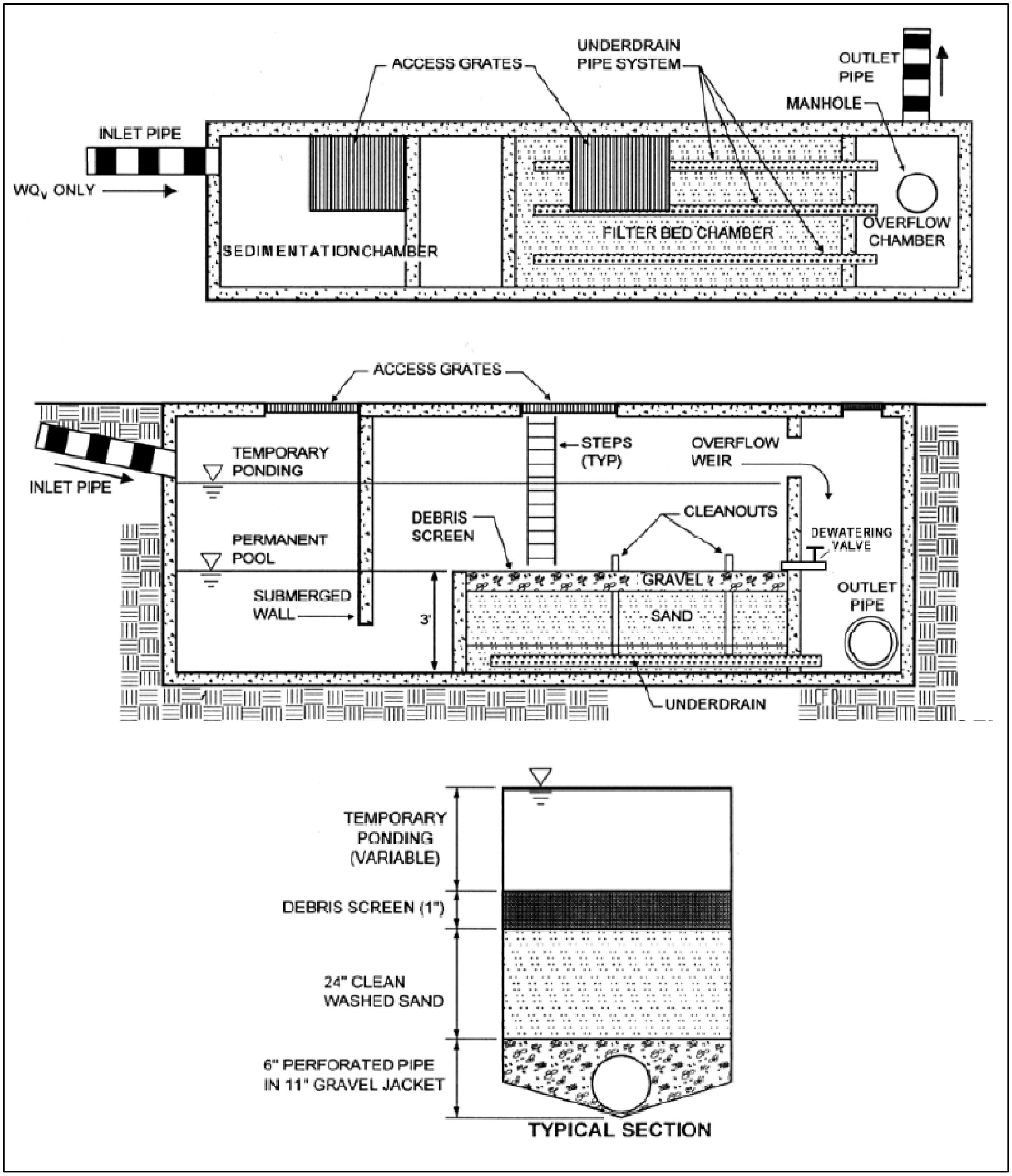

Figure 5.7: Schematic of an underground sand filter (MDE, 2000).

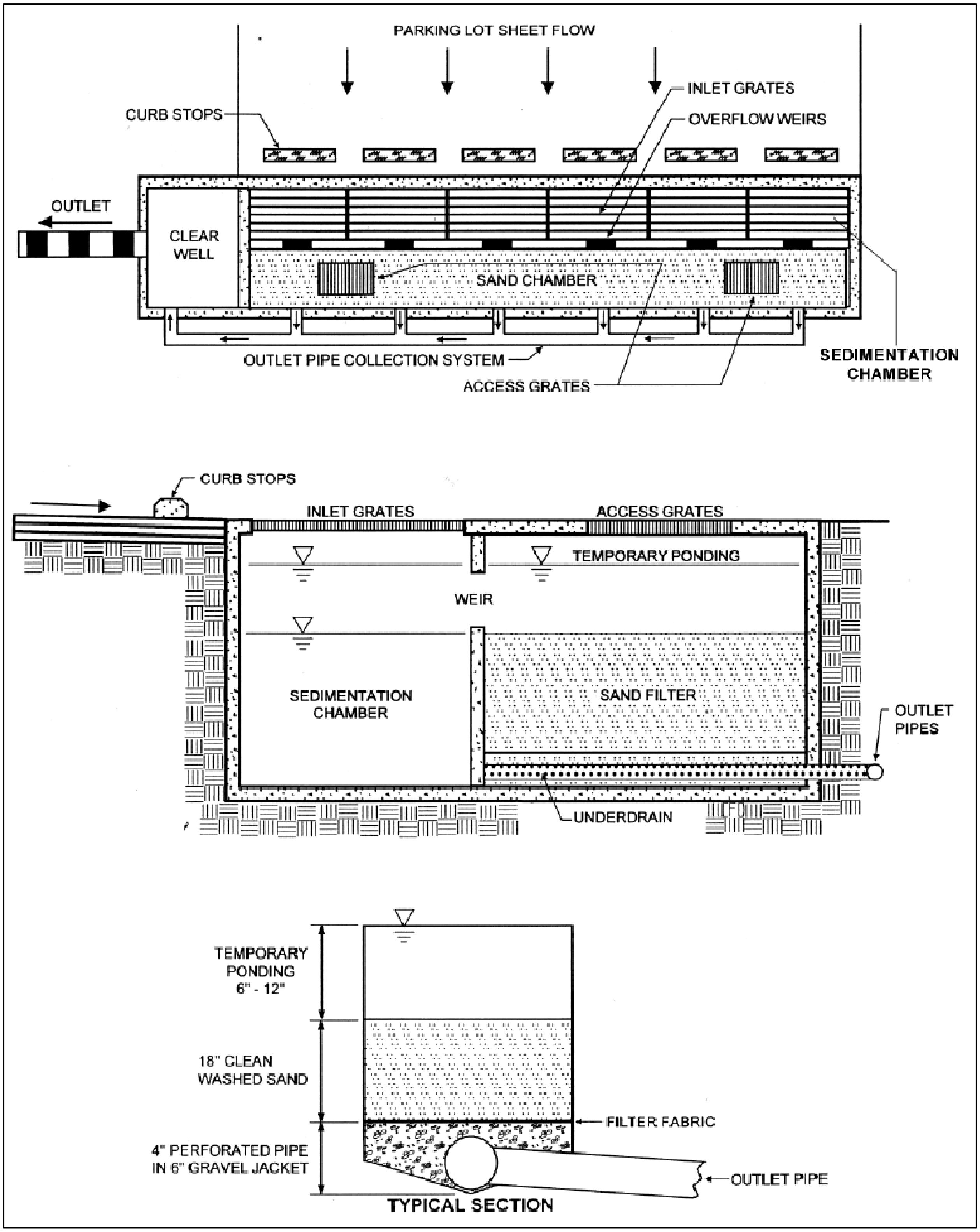

Figure 5.8: Schematic of a perimeter sand filter (MDE, 2000).

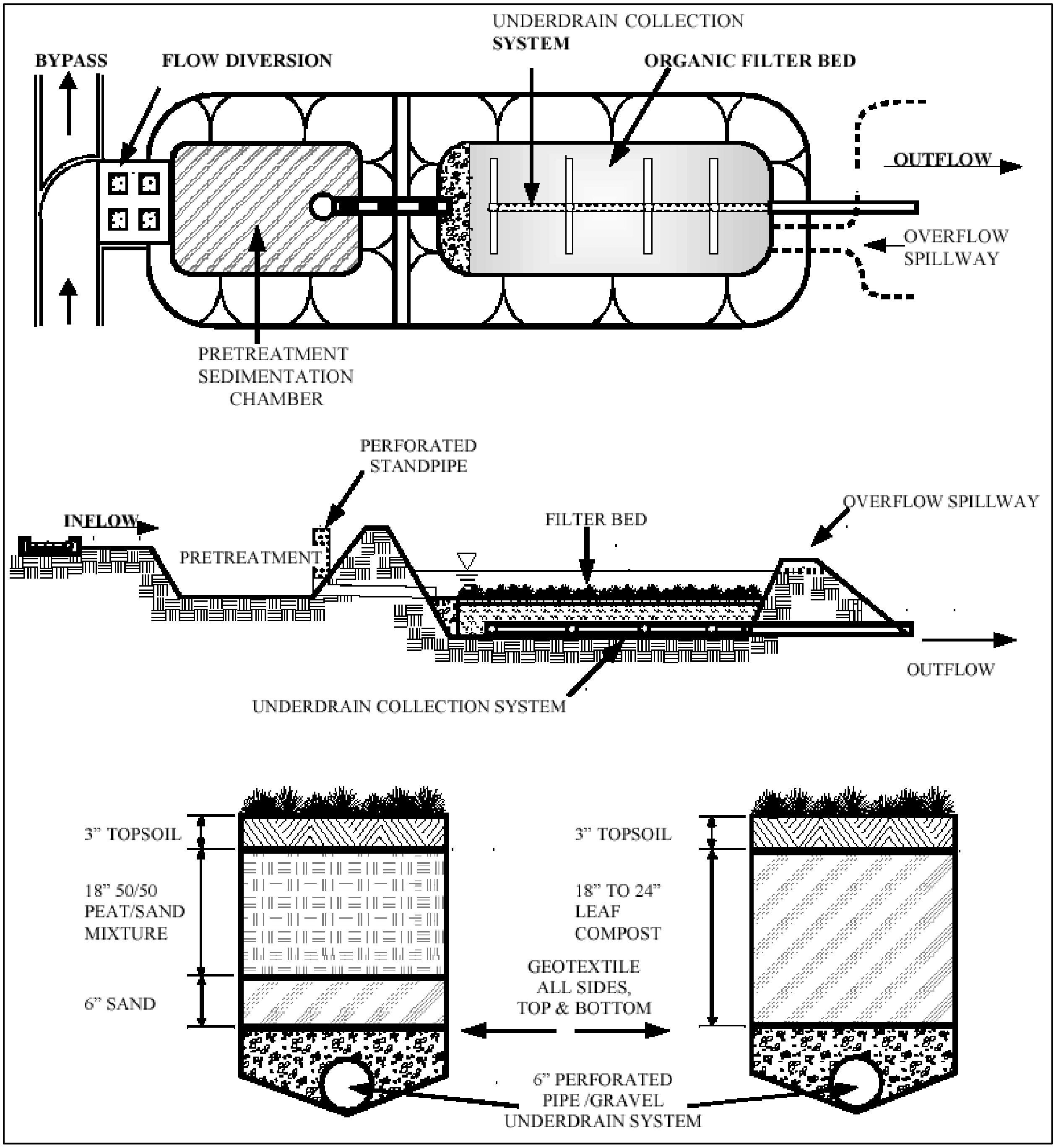

Figure 5.9: Schematic of an organic media filter (MDE, 2000).

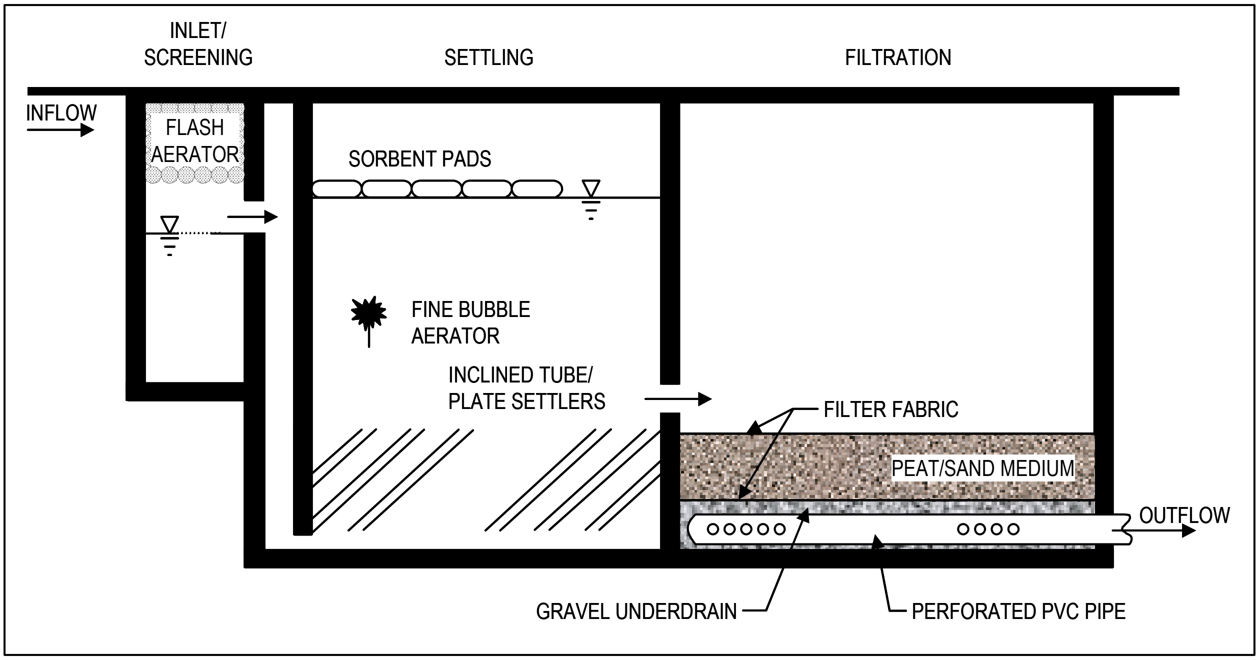

Figure 5.10: Schematic of a multi-chambered treatment train (Pitt, 1996).

5.3.3.2 Media filtration units

Similar to wastewater treatment technology, passive filtration units can be used to capture pollutants from runoff. Media filtration practices commonly use trenches filled with sand or peat. Other media, including types of crushed rock and composted leaves, can also be used. A basin collects the runoff and gradually routes discharge through cartridges filled with filter media. An emergency bypass prevents system flooding during large rainstorms. According to the Unified Sewerage Agency of Washington County in Oregon (WEF, 1998), composted leaf media trap particulates, adsorb organic chemicals, and remove 90 percent of solids, 85 percent of oil and grease, and 82 to 98 percent of heavy metals through cation exchange from leaf decomposition. Similar types of systems with various filter media are available commercially.

Performance of a Compost Storm Water Treatment System in Hillsboro, Oregon

A compost storm water treatment facility was constructed to treat runoff from 3.9 acres of 5-lane arterial road and 70.1 acres of mixed residential land use in Hillsboro, Oregon (FHWA, no date). The system consists of a discharge pipe that conveys runoff from the drainage area into a forebay. Runoff then flows over a wooden baffle into two consecutive cells filled with Portland leaf compost material. After runoff filters through the compost medium, it is discharged to a rock drainbed separated from the compost by a layer of filter fabric.

Monitoring of the effluent between 1991 and 1994 showed average mass balance pollutant removals of 81 percent for oils and grease, 84 percent for petroleum hydrocarbons, 58 percent to 94 percent for nutrients, and 68 percent to 93 percent for metals. See Table 5.4 for additional pollutant removal results. More details on the design and performance of this study are available at http://www.fhwa.dot.gov/environment/ultraurb/5mcs5.htm.

Table 5.4: Pollutant removal efficiencies for the compost storm water treatment facility from 1991 to 1994.

Parameter		1991-1992	1992-1993	1993-1994
Turbidity	Combined	84.2 %	78.4 %	78.4 %
	First Flush	93.4 %	85.3 %	81.4 %
Total Suspended Solids	Combined	94.8 %	88.5 %	86.0 %
	First Flush	98.3 %	91.4 %	89.0 %
Chemical Oxygen Demand	Combined	66.9 %	76.3 %	74.0 %
	First Flush	89.5 %	82.1 %	79.8 %
Total Phosphorus	Combined	40.5 %	53.2 %	65.5 %
	First Flush	67.3 %	68.9 %	72.9 %
Total Kjeldhal Nitrogen	Combined	55.9 %	50.5 %	66.7 %
	First Flush	84 %	60.8 %	69.0 %
Iron	Combined	89 %	95.5 %	79.6 %
	First Flush	94 %	97.5 %	82.9 %
Chromium	Combined	61.2 %	74.5 %	64.3 %
	First Flush	92.4 %	80.8 %	72.8 %
Copper	Combined	66.7 %	63.5 %	64.1 %
	First Flush	83.7 %	73.9 %	70.7 %
Lead	Combined	N/A	85.1 %	81.4 %
	First Flush	N/A	89.0 %	84.0 %
Zinc	Combined	88.3 %	75.8 %	79.9 %
	First Flush	92.8 %	83.1 %	83.1 %

5.3.3.3 Bioretention systems

Bioretention systems (Figure 5.11 and Figure 5.12) are suitable to treat runoff on sites where there is adequate soil infiltration capacity and where the runoff volumes that are not infiltrated do not present a safety or flooding hazard. Typical applications for bioretention include parking areas with or without curbs, traffic islands, and swales or depressed areas that receive runoff from impervious areas.

Bioretention system designs are very flexible, can be adapted to a wide range of commercial, industrial, and residential settings, and can be linked in series or combined with structural devices to provide the necessary level of treatment depending on expected runoff volumes and pollutant loading. A common technique is to use bioretention areas to pre-treat sheet flow before it is channelized or collected in an inlet structure.

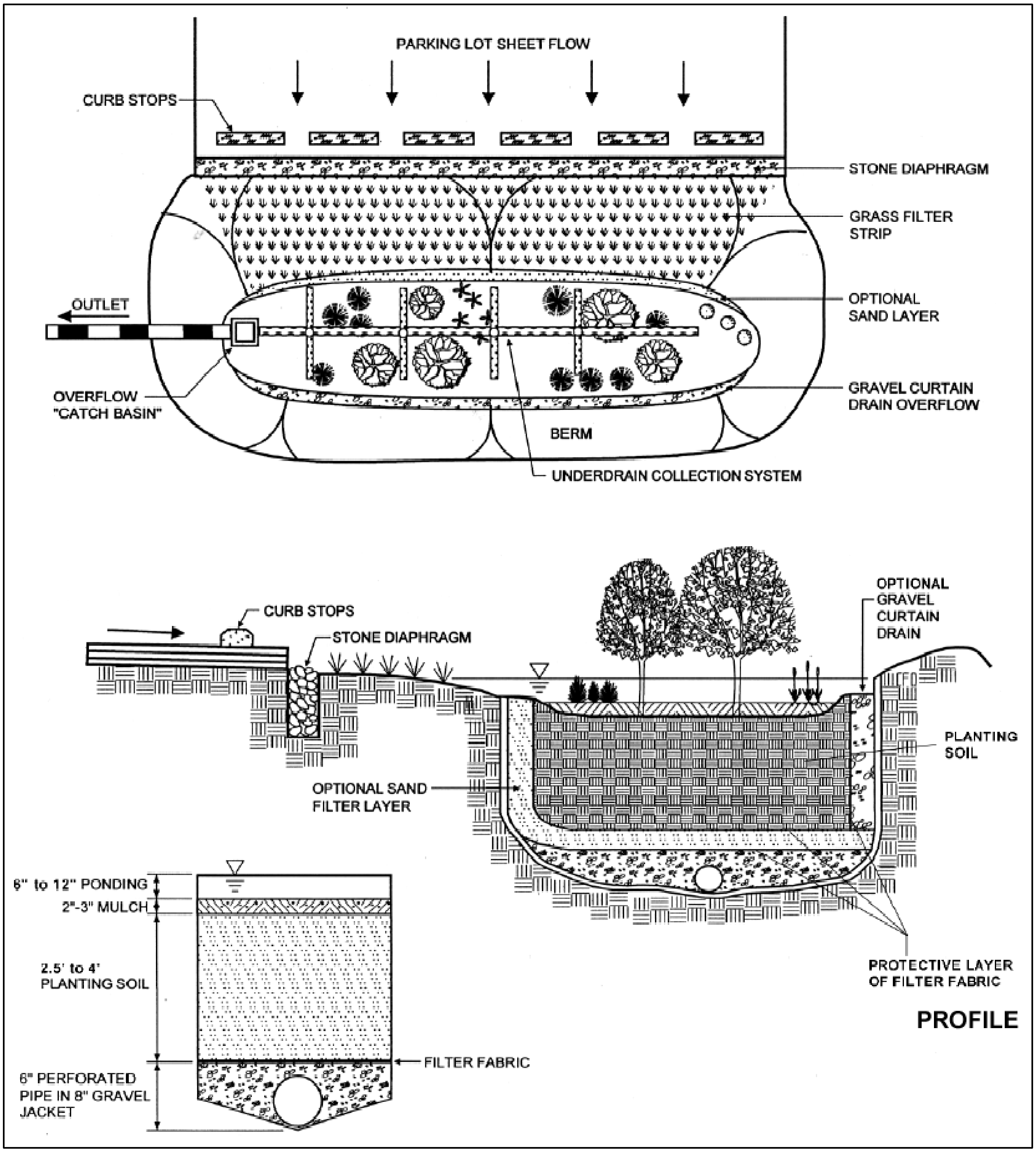

Figure 5.11: Schematic of a bioretention system (MDE, 2000).

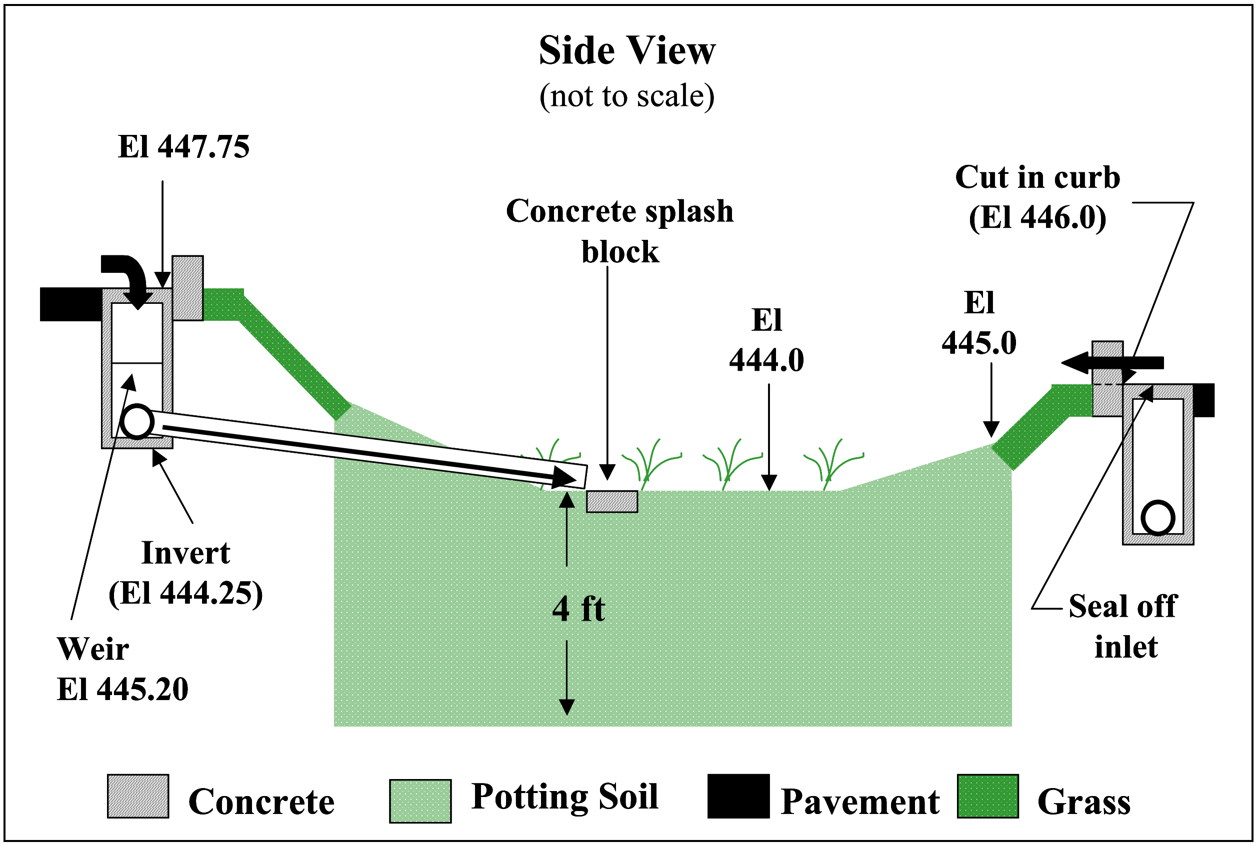

Figure 5.12: Schematic of a bioretention parking lot island (Traver, 2003).

Bioretention should not be used in areas:

- With mature trees;
- With slopes greater than 20 percent;
- With a water table within 6 feet of the land surface;
- With easily erodible soils;
- Below outfalls;
- Where concentrated flows are discharged; or
- Where excavation or cutting will occur.

To determine the appropriate design of the bioretention area with respect to the amount of runoff it receives, Prince George's County, Maryland, Department of Environmental Resources (1993), suggests a design based on a four-day maximum ponding period (appropriate for the Mid-Atlantic region). This four-day period is based on hydrologic, horticultural, and maintenance constraints such as plant tolerance of flooded conditions and mosquito-breeding concerns. Other considerations include infiltration rates for the root zone, sand layer, and in-situ material.

There is some flexibility with respect to size, shape, and placement of vegetation within the bioretention area. Other elements that should be incorporated into the design of the bioretention system include curb openings, a ponding area suitable to handle runoff from larger storms, amended planting soil that provides the desired infiltration rate, and an under-layer sand or gravel bed or underground perforated pipe that facilitates infiltration.

Regular maintenance, including soil pH testing, mulching and repairing eroded areas, inspecting vegetation, ensuring that runoff is infiltrating as designed, and checking for damage caused by large storms, will help to ensure the longevity of bioretention areas. More information about the design, operation, and maintenance of bioretention systems can be found in Coffman and Winogradoff (1999) or Prince George's County, Maryland, Department of Environmental Resources (1993).

As for the performance of bioretention areas, in one research study, simulated runoff was pumped continuously into an area of 5.3 m^2 in six bioretention cells, and effluent samples were collected from the perforated drainpipes underlying the bioretention media. All six bioretention facilities showed greater than 99 percent removal efficiency for oil and grease. Total lead removal efficiency decreased when the TSS level in the effluent increased because lead was adsorbed onto the surface of the solids. TSS removal ranged from 72 to 99 percent, and lead removal rates ranged from 80 to 100 percent. For total phosphorus, the removal efficiency was found to be highly variable, ranging from 37 to 99 percent. Nitrate-nitrogen and ammonium-nitrogen removal efficiencies ranged from 2 to 7 percent and 5 to 49 percent, respectively. Overall, the bioretention cells contributed significantly to water quality improvement (Hsieh and Davis, 2003).

The developer of Somerset Community, a typical suburban development in Prince George's County, Maryland, incorporated bioretention areas into each lot to control runoff quantity and quality. The bioretention areas eliminated the need for a wet pond, allowed the development of six extra lots, and resulted in a cost savings of more than $4,000 per lot. Somerset residents have enthusiastically accepted their bioretention areas, are actively maintaining them, and have lodged few complaints. Safety issues and mosquitoes have not been a problem (Daniels, 1995, and Curry and Wynkoop, 1995).

The Inglewood Demonstration Project in Largo, Maryland, involved retrofitting an existing parking facility with bioretention areas and comparing the pollutant removal efficiency of a bioretention cell in a laboratory setting to that of a comparable facility constructed in a parking lot. This study showed the feasibility of retrofitting an existing parking facility and demonstrated the consistency of laboratory and field pollutant removal performance. Results showed that the runoff temperature was lowered 12 degrees Celsius, lead levels were lowered 79 percent, zinc levels were lowered 78 percent, and numerous other pollutant levels were also considerably reduced. The retrofit cost $4,500 to construct, while usual methods would have cost $15,000 to $20,000 and involved fewer environmental benefits and higher maintenance costs. Also, bioretention areas offer the ancillary benefit of aesthetic enhancement. It is interesting to note that a drought occurred after the installation of the plants, and although many of the other plants in the parking lot died or experienced severe drought stress, those in the bioretention facility survived because of the retained water supply (USEPA, 2000a).

Using Landscaped Rain Gardens to Control Runoff

The city of Maplewood, Minnesota is seeking to improve drainage in its older neighborhoods through the use of rain gardens. A successful pilot project, which was implemented in 1995, was the starting point for the current citywide rain garden initiative. Rain gardens from the pilot project have prevented runoff from flowing out of the area, containing 100 percent of the flow. City officials decided to expand the project when they recognized the aesthetic and environmental benefits resulting from the pilot project rain gardens.

The city is focusing on demonstration, education, and outreach to convey the benefits of using rain gardens for runoff management, rather than requiring homeowners to participate. Although rain gardens can be a solution for people who are opposed to adding curbs and gutters to their streets, some are concerned that rain gardens may attract and breed mosquitoes. Before beginning a street improvement project for a specific neighborhood, the city holds neighborhood meetings and distributes a comprehensive educational mailing and questionnaire to homeowners. These materials contain a fact sheet that explains the purpose of rain gardens, how they are designed, how they work, their benefits, and the plants best suited for a variety of hydrologic conditions. A questionnaire is also included to ascertain existing drainage problems and to determine whether the homeowner would be willing to agree to use a rain garden.

Once a homeowner has decided that they want a rain garden, they choose the location and size. The city works with homeowners to make these types of decisions and to help them comply with restrictions on garden placement caused by existing trees, natural drainage, or the presence of gas and water mains and other utilities. Homeowners may choose from three standard rain garden sizes (12-foot by 24-foot, 10-foot by 20-foot, and 8-foot by 16-foot) and from one of six different garden themes, including an easy shrub garden, easy daylily garden, sunny garden, sunny border garden, butterflies and friends garden, Minnesota prairie garden, and shady garden.

To begin construction, the city's contractor excavates a gently sloping depression to collect the water. Rain garden depths vary depending on garden size and topography. The contractor digs a sump 42 inches wide and 3 feet deep at the deepest part of the garden to accommodate a geotextile filter fabric bag, which is filled with clean crushed rock. The sump promotes rapid infiltration to reduce the standing time of water in the rain garden. After the infiltration sump is in place, the contractor adds at least 8 inches of bedding material (typically a mixture of salvaged topsoil and clean organic compost) and covers the area with 3 to 4 inches of shredded wood mulch. Residents are provided with all necessary plants and a landscape plan at no additional cost. However, many Minnesota municipalities charge residents a street assessment to cover a percentage of the project cost.

The city's rain garden street improvement project typically costs 75 to 85 percent of a traditional curb and gutter project. Costs are kept low because most of the existing street material is recycled to use as the base aggregate. Additionally, plants are obtained at a reasonable cost and residents are responsible for the planting. Other long-term savings, which are difficult to quantify, result from the reduced demand on the city's downstream sewer infrastructure, which is not characteristic of conventional storm systems. The city may also be able to reduce the need for downstream storm sewer system upgrades and construction, including detention and treatment facilities designed to prevent pollution, erosion, and flooding problems.

More information about Maplewood's rain garden project is available from Chris Cavett, Assistant City Engineer, at 651-770-4554 or chris.cavett@ci.maplewood.mn.us (Terrene Institute, 2001).

5.3.4 Detention and Retention Practices

5.3.4.1 Detention ponds and vaults

These practices temporarily detain runoff to ensure that the postdevelopment peak discharge rate is equal to the predevelopment rate for the desired design storm (e.g. two-, 10-, or 25-year). These practices may also be used to provide temporary extended detention to protect downstream channels from erosion (e.g., 24-hour extended detention for a one-year storm).

Extended detention (ED) ponds (Figure 5.13) are an example of this type of facility. ED ponds temporarily detain a portion of urban runoff for up to 24 hours after a storm, using a fixed orifice to regulate outflow at a specified rate and allowing solids and associated pollutants time to settle out. ED ponds are normally dry between storm events and do not have any permanent standing water. These basins are typically composed of two stages: an upper stage, which remains dry except after larger storms, and a lower stage, which is designed for typical storms. Enhanced ED ponds are equipped with plunge pools or forebays near the inlet, a micropool at the outlet, and an adjustable reverse-sloped pipe as the ED control device (NVPDC, 1980; Schueler et al., 1992). Most ED ponds use a riser with an anti-vortex trash rack on top to control large floating solids.

Detention tanks and vaults are underground structures used to control peak runoff flows. They are usually constructed out of concrete (vaults) or corrugated metal pipe (tanks). Underground detention can also be achieved by retrofitting the over-capacity storm drain pipes with baffles. The baffles allow water to be stored in the pipes so it can be released at a slower rate. Pretreatment structures such as water quality inlets and sand filters can be used to treat runoff and remove trash and debris.

These systems are primarily applicable where space is limited and there are no other practical alternatives. Concrete vaults are relatively expensive and are often used to control small flows where system replacement costs are high. Corrugated metal pipe systems are less expensive and are often used to control larger volumes of runoff in parking lots, adjacent to rights-of-way, and in medians. These systems should be located where maintenance can be conducted with minimal disturbance.

Underground detention structures provide runoff quantity control but do not provide significant water quality control without modifications. Corrugated metal pipe systems can work in conjunction with infiltration to provide additional runoff treatment. This is accomplished by adding perforations to the pipe to allow it to store the water until it can be released into the soil (FHWA, no date).

5.3.4.2 Retention ponds

These practices use a permanent pool, extended detention basin, or shallow marsh to remove pollutants and can include:

- Micropool extended detention ponds;
- Wet ponds;
- Wet extended detention ponds; and
- Multiple pond systems.

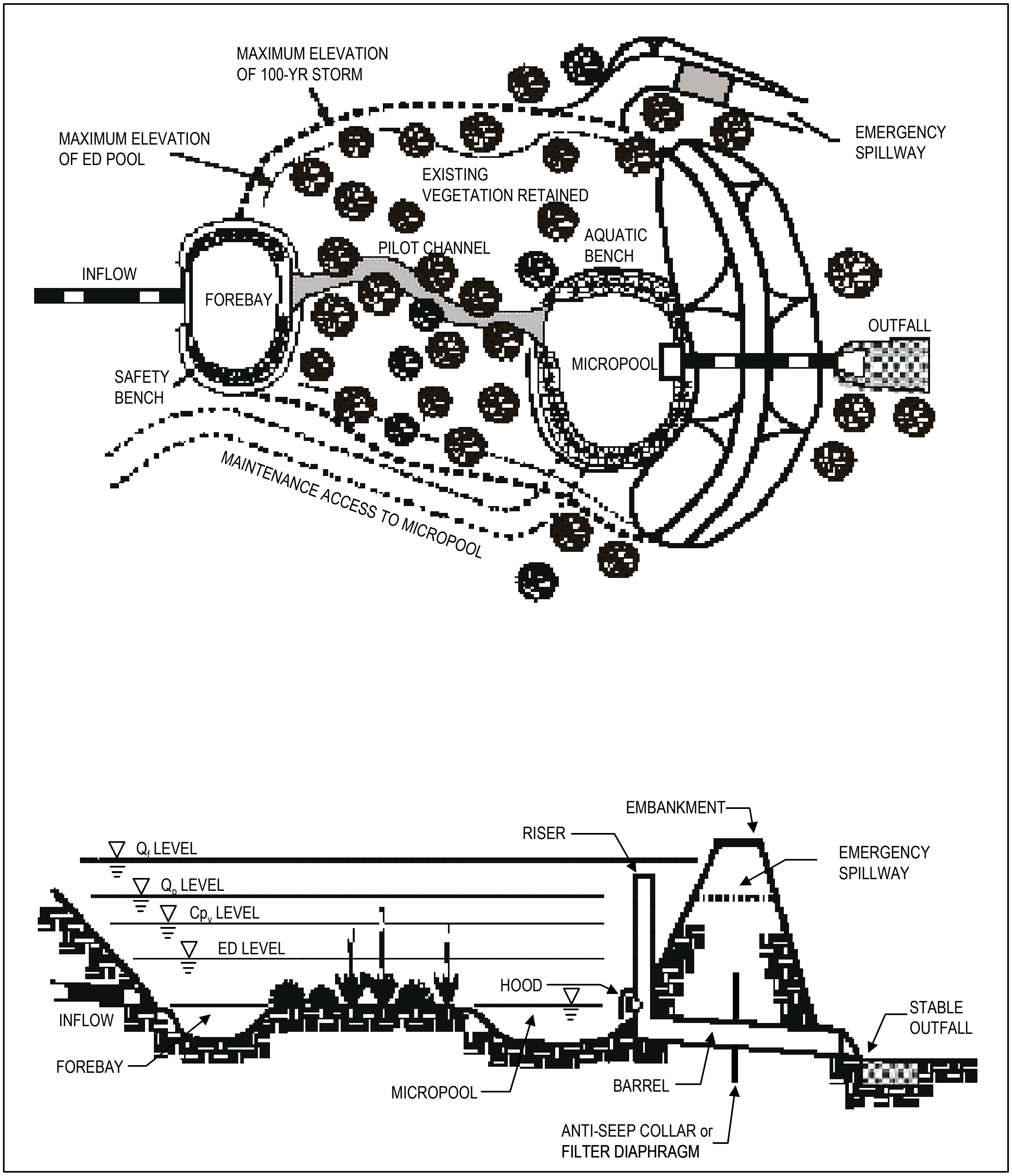

Figure 5.13: Schematic of a dry extended detention pond (MDE, 2000).

Ponds (Figure 5.14) are basins designed to maintain a permanent pool of water and temporarily store runoff (ED wet pond), which is released at a controlled rate. Ponds allow particulates to settle and can provide biological uptake of pollutants such as nitrogen or phosphorus. Enhanced designs include a forebay to trap incoming sediment where it can easily be removed. Often, a

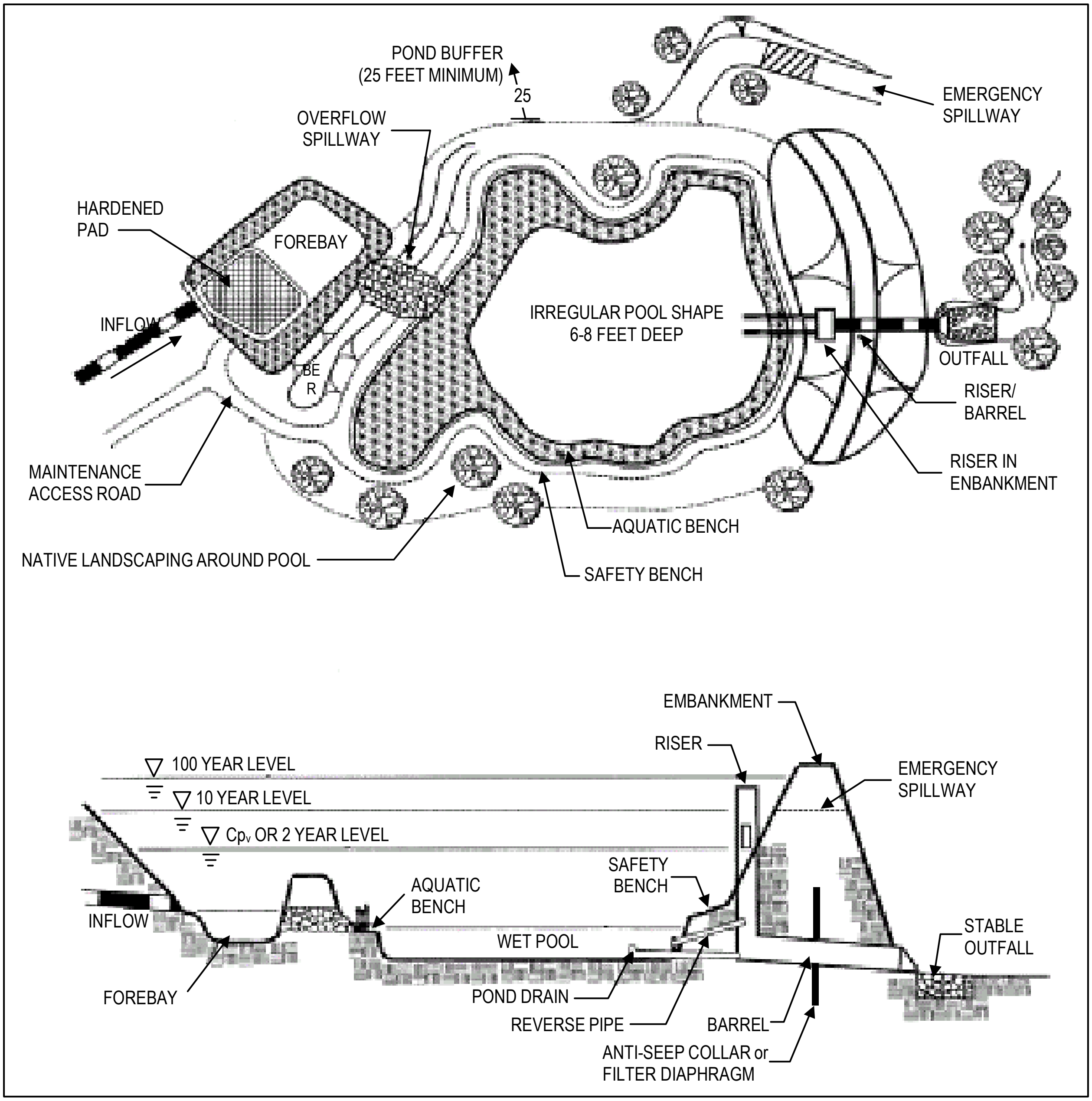

Figure 5.14: Schematic of a wet pond (MDE, 2000).

fringe wetland is installed around the perimeter of the pond to increase the habitat, aesthetic, and pollutant removal values of the facility. An outlet riser, sometimes combined with an anti-vortex trash device, is a common design modification. The design of wet ponds should account for the infiltration of ground water when the wet pond intercepts the water table. Table 5.5 presents several design considerations for ponds.

Table 5.5: Design considerations for ponds and wetlands (MDE, 2000).

Design Consideration	Ponds	Wetlands
Watershed Design Requirements		
Streams in intensely developed areas	Drainage area may limit the applicability of ponds except for pocket ponds.	Drainage area may limit the applicability of ponds except for pocket wetlands.
Cold-water streams	An offline design is recommended. Maximize shading of open pool areas.	An off-line design is recommended. Maximize shading of open pool areas.
Streams in sparsely developed areas	Require additional storage to ensure adequate downstream channel protection.	Require additional storage to ensure adequate downstream channel protection.
Aquifer protection	May require a liner depending on soil type.	May require a liner depending on soil type.
Reservoir protection	Require additional storage to ensure adequate downstream channel protection.	Require additional storage to ensure adequate downstream channel protection.
Shellfish beach located downstream	Provide moderate bacteria removal. Should be designed to prevent geese problems. Should provide permanent pools.	Provide 48-hr extended detention for maximum bacterial die-off.
Terrain Factors		
Low relief	The maximum normal pool depth should be 4 feet (dugout).	Wetlands are suitable for low-relief areas.
Karst	Require a poly or clay liner and geotechnical tests.	Require a poly or clay liner and geotechnical tests.
Mountainous	Embankment heights are restricted.	Embankment heights are restricted.
Physical Feasibility		
Soils	Depending on pond type, they may or may not require a liner or testing.	Certain soils may require a liner.
Water table	Must be at least 2 feet above water table if near a potentially contaminated "hotspot" or if underlain by an aquifer. Pocket ponds by definition are below the water table.	Must be at least 2 feet above water table if near a potentially contaminated "hotspot" or if underlain by an aquifer.
Drainage area	Minimum drainage area is 10 to 25 acres depending on type of pond. Pocket pond has a 5-acre maximum.	Minimum of 25 acres except pocket wetlands, which have a 5-acre maximum.
Site slope	Slopes should always be less than 15%	Slopes should be less than 8%.
Head	A 6- to 8-foot head is needed for all ponds except pocket ponds, which require a 4-foot head.	A 3- to 5-foot head is needed for most wetlands except pocket wetlands, which require a 2- to 3-foot head.
Ultra urban	Only pocket ponds are practical.	Pocket wetlands are sometimes practical; all others impractical.
Runoff Treatment Suitability		
Ground water recharge	No	No
Channel protection	Yes	Yes
Runoff Treatment Suitability (continued)		
Ground water recharge	No	No
Channel protection	Yes	Yes
Water quantity control	Yes	Yes
Large space requirements	Less space	More space
Community and Environmental Factors		
Maintenance	Easier	More difficult
Community acceptance	More acceptable	Less acceptable
Affordability	More affordable	Less affordable
Wildlife habitat	Yes	Yes

Used in combination with on-site and nonstructural practices, regional ponds are an important component of a runoff management program. The costs and benefits of regional, or off-site, practices compared to on-site practices should be considered as part of a comprehensive management program. For example, regional ponds can be located to treat runoff from existing development, and will result in overall net reductions on pollutant loads for the watershed (Fairfax County Environmental Coordinating Committee, 2002). Regional facilities can incorporate more advanced treatment technologies than on-site facilities (Maupin and Wagner, 2003). They can also provide community recreation and wildlife benefits, reduce peak and total flow, and be easier to maintain than dispersed controls. The City of Fairfax, Virginia, found that maintenance costs for a regional pond were about one-sixth those of on-site ponds (Fairfax County Environmental Coordinating Committee, 2002). Maintenance responsibilities and liability for regional runoff facilities belong to the municipality (Maupin and Wagner, 2003).

A study of 43 wadeable streams in Austin, Texas, showed that several indicators of stream health (ephemeroptera-plecoptera-trichoptera (EPT) richness and percent EPT abundance) were higher in streams with storm water ponds protecting 60 to 95 percent of their catchments than in streams with no storm water controls (Maxted and Scoggins, 2004). This trend was only significant in fully developed watersheds (having greater than 40 percent impervious cover). In watersheds with less than 40 percent impervious cover, storm water ponds had no significant impact on EPT richness or percent EPT abundance. The researchers attributed the lack of effects of storm water ponds to urban development in the reference watersheds and to the nature of the biological index used to gauge stream health, which was not tailored to the specific environmental conditions of the Austin area.

Research has shown that storm water ponds can increase property values. A survey in Columbia, Maryland, found that 75 percent of homeowners felt that permanent bodies of water such as storm water ponds added to real estate values. Seventy-three percent were willing to pay more for property located in a neighborhood with storm water control basins designed to enhance fish or wildlife uses (Adams et al., 1984; Tourbier and Westmacott, 1992; USEPA, 1995). Residents of a Champaign-Urbana, Illinois, neighborhood with storm water ponds stated that lots adjacent to a wet pond were worth an average of 21.9 percent more than comparable non-adjacent lots in the same subdivision. The same survey revealed that 82 percent would in the future be willing to pay a premium for a lot adjacent to a wet pond (Emmerling-DiNovo, 1995). In Alexandria, Virginia, condominiums alongside a 14-acre runoff detention pond sold for $7,500 more than comparable units not adjacent to the pond (USEPA, 1995).

Regional ponds do not, however, provide protection in contributing drainage systems, including upstream tributaries. These can experience damage from increased peak flow and flow volume. In addition, placement of regional ponds in low-lying areas may harm natural wetlands, and the ponds may create safety and liability issues. Siting ponds or other structural management practices within natural buffer areas and wetlands degrades their functions and may interrupt surface water and ground water flow when soils are disturbed for installation.

5.3.4.3 Constructed wetlands

Constructed wetlands (Figure 5.15) are engineered systems designed to treat runoff. They are typically designed to provide some of the functions of natural wetlands, e.g., wildlife habitat, in

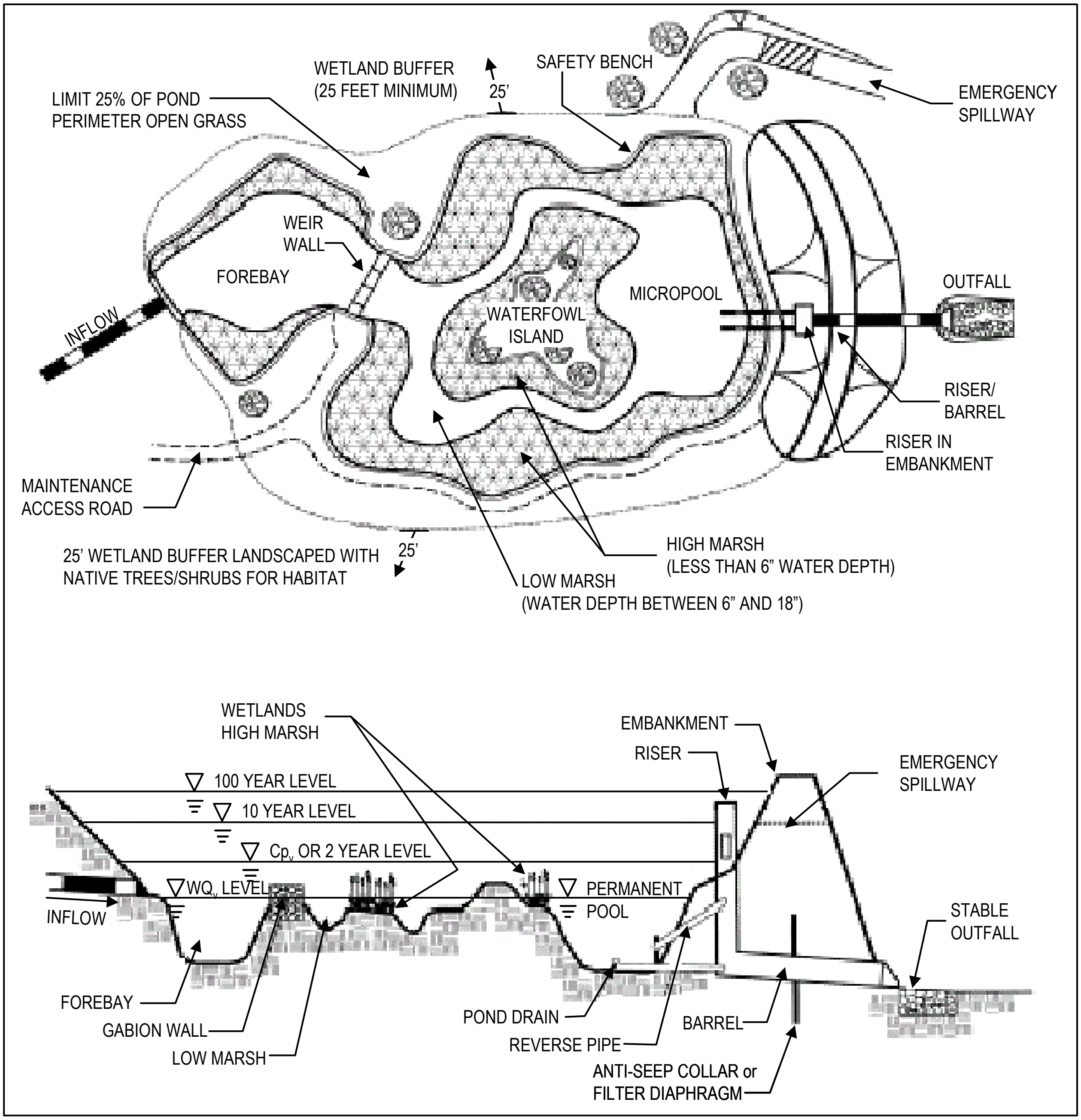

Figure 5.15: Schematic of a shallow wetland (MDE, 2000).

addition to controlling runoff volumes and pollutant loadings. There are many variations of constructed wetlands, such as shallow wetlands, extended detention wetlands, pond/wetland systems, and small isolated "pocket" wetlands. Constructed wetlands may contain some or all of the following elements: shallow vegetated areas, permanent pools, sediment forebays, transition areas, and weirs. Designs are intended to slow flow through the wetlands and provide maximum contact with wetland vegetation.

It should be noted, however, that constructed wetlands rarely replicate the functions of natural wetlands and should not be used for compensatory mitigation of natural wetlands and buffers.

Furthermore, constructed wetlands should be designed to receive periodic maintenance to ensure the wetland continues to function as designed.

Constructed wetlands are feasible at most sites and drainage areas where there is enough rainfall and/or snowmelt to maintain a permanent pool. In areas with highly permeable soils, other impermeable barriers, such as synthetic liners or clay, sometimes can be used to maintain enough water or moisture to support the wetland. Constructed wetlands should be located contiguous to existing wetlands wherever possible, unless there is concern about contaminants that may pose a threat to wildlife. Although it is technically feasible to construct a wetland on a small site (less than 1 acre), alternative control strategies should be considered when land constraints are present.

Constructed wetland systems can take several forms, including wet ponds with a wetland fringe, swale/ditch wetland depressions, and large-scale constructed wetlands used as mitigation wetlands or treatment wetlands. The choice of wetland designs depends on watershed characteristics, spatial and geomorphic constraints, runoff treatment requirements, and community and environmental factors. These considerations are outlined in Table 5.5.

In the San Diego Creek Watershed in southern California, constructed wetlands are being used as a regional runoff control technique. This approach, called the Natural Treatment System (NTS) Plan, is part of a watershed-wide management effort to meet total maximum daily load (TMDL) requirements for the San Diego Creek, which is impaired by sediment, nutrients, pathogens, heavy metals, and pesticides. The results of water quality modeling that accounted for the combined effects of the 44 planned facilities indicated that the TMDL for total nitrogen in base flows would be achieved, total phosphorus targets would be met in all but the wettest years and the fecal coliform target would be met in the dry season. While the NTS Plan is not meant to meet the TMDL for sediment, it will capture 1,900 tons annually, and the wetlands are estimated to remove 18 percent of the total zinc and 11 percent of the total copper and lead in runoff (Strecker et al., 2003).

New York City Bluebelt

The New York City Department of Environmental Protection (NYCDEP) has taken an innovative approach to solving drainage problems that have long plagued southern Staten Island. Instead of installing a conventional piped storm sewer system that would destroy the existing wetlands through drainage or filling, NYCDEP proposed to use a natural drainage system to convey, store, and filter runoff. The plan involves both preserving and restoring wetlands. In 1991, the agency began purchasing land along wetland corridors, and soon this network of property was termed the Bluebelt, because it mirrors the role a Greenbelt plays for open space areas by protecting water resources. The Bluebelt area is a total of 10,000 acres and includes 16 watersheds.

The constructed wetlands in the Bluebelt range from 0.5 to 2 acres in area and have a permanent pool that ranges from 12 to 24 inches deep. The wetlands are intended to provide water quality, flood control, and flow attenuation benefits for the region. More than 100 management practices were screened for their applicability, and in addition to constructed wetlands, meandering streams and outlet stilling basins were installed. Meandering streams convey runoff in open channels, providing a basis for the establishment and preservation of riparian areas. Outlet stilling basins mitigate the high velocities of runoff exiting conventional pipes. In the past 12 years, approximately half of the 89 planned management practices have been designed (Vokral et al, 2003).

Desert Wetlands

A constructed wetland demonstration project is being tested in the Sonoran Desert to improve the New River, which consists primarily of wastewater from Mexico and agricultural drain water from California's Imperial Valley (Fortner, 2000). Without these two sources of water, the New River would run dry. Near Imperial, California, about halfway along the New River, 68 acres of wetlands were constructed as a demonstration project. These wetlands use a series of six cells to remove sediments and other pollutants from irrigation drain water. A few miles downstream, in Brawley, California, a similar project will treat water that is diverted directly from the New River. The site for this project consists of 7 acres and three cells. The two sites are collectively referred to as the Brawley Constructed Wetlands Demonstration Project.

The project is described as one of the most challenging constructed wetlands projects in the United States and will help researchers determine the best design for treating river and agricultural drain water. Scientists are aware that it will be challenging to construct a wetland to treat a severely impaired waterbody in a desert area. They will monitor the performance of the test sites before additional wetlands are built. Once the data is obtained, the Citizens' Congressional Task Force for the New River (comprised of citizens and representatives from environmental groups, local community organizations, and state and federal agencies) will decide whether to expand the project.

Wetlands and other runoff control systems should not be sited in areas where they disrupt or significantly alter the predevelopment hydrology unless restoration objectives apply. When designing the wetland, a variety of physical characteristics should be used to promote multiple wildlife and habitat functions. For example, an irregular shape increases the perimeter of the system and provides a greater variety of microhabitats along the shoreline. Also, an irregular shoreline can extend the perimeter of a constructed wetland by 10 to 20 percent with no increase in land requirements.

Shallow-water wetlands do not contain a large volume of water per surface area as would a typical wet pond. In general, the wetland should have a shallow slope with a permanent pool in the middle. To enable growth of emergent vegetation, static water depths should not exceed 2 to 3 feet. Depths greater than 2 to 3 feet are conducive to the growth of submerged aquatic vegetation. The use of deeper water (>3 feet) in an area that is easily accessible for small children should be discouraged. No area of the pond should have a depth greater than four feet. In general, 50 percent of the pond should have depths less than one foot, 30 percent should be 1 foot to 2 feet deep, and 20 percent should be 2 to 4 feet deep. Greater depths are allowable for the inflow forebay and around the outlet structure.

The Maryland Department of the Environment (2000) requires that the first inch of runoff from the site must be controlled and released over a 24-hour period to provide water quality treatment, while peak discharge control of the two- and 10-year storms must be provided for water quantity control. Local requirements should be used when designing the treatment capacity of a constructed wetland. Other factors such as steep slopes may necessitate deeper ponds to obtain adequate runoff control.

Individual soil analyses should be done during the site design phase to determine if a clay or plastic liner is needed to maintain a wetland environment. Wetland vegetation cannot usually survive unless a base flow is available to provide a permanent pool to keep plants wet. Rapid infiltration will remove this needed pool. If a liner is needed, it should have at least 1 foot of

The Use of Wetlands to Reduce Fecal Coliform

Unusually high levels of fecal coliform have been found in an area of Laguna Niguel, California. Runoff from a neighborhood is washing into Aliso Creek and then to the Pacific Ocean. In response to a cleanup order issued by state water regulators, city officials built a series of wetlands to filter fecal coliform out of runoff. The natural water treatment system will work in combination with an existing wetland, which has already been proven successful in cleaning waters to a level acceptable for swimming.

Upon completion, water will flow through a series of four stepped ponds, spread out, and remain in the wetlands for hours or days of treatment. It is estimated that it will take a year for all vegetation to grow in and nearly two years to attain maximum removal of bacteria. When the wetlands system is complete, the existing wetland will treat 35 to 40 percent of the runoff and the new wetlands will treat 35 percent of the runoff. The city hopes that the new wetlands will work as well as the existing wetlands in reducing fecal coliform from urban runoff (Vardon, 2000).

clean fill material placed on top of it for wetland plant growth (the fill material will also reduce the potential for puncture).

An island placed in the wetland can extend the length of the flow path that runoff must travel to traverse the pond. This increased flow path enhances the pollution removal function of the constructed wetland. The highest elevation of the island should be above that reachable by storage of the first inch of runoff. Islands in wetlands may attract geese, which can be undesirable in some urban settings, but there are ways to minimize habitat for geese in a constructed wetland. Because most runoff management ponds are fairly small compared with a natural marsh system, they do not provide the long glide path preferred by geese for landing and takeoff. Planting woody vegetation or allowing areas around the pond to grow without mowing also tends to discourage goose residency.

The following are typical elements of a constructed wetland:

(1) *Sediment forebays*. It is important that sediment forebays be placed at all locations where runoff enters the wetland. A forebay is designed for vehicle access to facilitate sediment removal while preventing disturbance of substrate that could disrupt wetland functions. The forebay should constitute approximately 10 percent of the total basin volume and should have a maximum depth of 4 feet. Where there are multiple inlets to the constructed wetland, the total volume of all the forebays should be 10 percent of the basin volume, with individual inlet forebays sized with respect to the percentage of contributing flow they receive. The use of stone riprap in the forebay will reduce the velocity of flow into the wetland portion of the basin and minimize resuspension of deposited sediments. An access to the forebay should be provided for cleanout equipment. An area adjacent to the constructed wetland should be set aside for disposal of the sediments that become trapped and are removed during periodic maintenance.

The cleanout frequency of sediment forebays depends on the sediment load entering the constructed wetland. Each forebay should be inspected annually to ensure cleanout is being conducted as needed. Once the forebay has been filled to approximately 50 percent of its total volume (every 10 to 15 years), sediment should be removed, placed in an appropriate upland location, and stabilized. Costs for sediment forebay maintenance, including periodic inspection and cleaning, should be budgeted as a long-term operating expense if this practice is selected.

(2) *Diversion weir*. Diversion weirs may be needed for designs where the entire runoff volume is not directed to the constructed wetland. This diverted fraction of the runoff is often routed to collection systems or inlets. The amount of rainfall that may be diverted will vary according to local requirements and design objectives.

(3) *Outlet*. As is the case with all ponds having a normal pool of water, algae can clog outlets with small orifices that are needed for extended detention. A below-surface withdrawal structure may reduce or eliminate this problem.

(4) *Transition zone*. The maximum slope of the transition zone on wetland side slopes should be no greater than 10:1 (horizontal:vertical) and should extend at least 20 feet from the design pool of the constructed wetland. This area will be temporarily flooded whenever runoff is temporarily detained. Planting trees in the transition zone enhances nutrient uptake; the shading reduces temperature increases common in open water areas; and the trees provide habitat for wildlife. The transition zone should be mowed no more than once a year in late fall. Optimally, to promote the growth of woody vegetation, the transition area should not be mowed at all unless the pond is an embankment pond, in which case it should be mowed annually to prevent woody vegetation on the embankment.

(5) *Vegetation*. Placement of organic soils on the bottom of the pond will provide faster growth of planted or volunteer vegetation. Constructed wetlands should initially be planted with emergent plants and woody shrubs, and the wetlands should be allowed to succeed to a system dominated by woody shrubs and trees. The emergent wetland plants that are chosen should have tops that rise above the normal pool level.

It is important to consult local ecologists/plant specialists to choose suitable wetland species and to design a landscaping plan with appropriate vegetation density and spacing. Local specialists can also provide information regarding the optimal time to plant vegetation and help to design a maintenance schedule based on vegetation requirements. Native species should be used where feasible because they are well-adapted to local conditions. The USDA has a database (see http://www.plants.usda.gov/) of invasive and noxious species, which should be avoided.

The following specifications are provided as an example and apply to the Mid-Atlantic region (MDE, 2000):

- At least two aggressive species should be planted in the constructed wetland; their purpose is to rapidly spread to other unplanted areas of the wetland. In addition, at least three secondary species should be planted to increase the diversity, wildlife values, and appearance of the wetland. Ideally, plantings should include a mix of perennial and annual species.

- Plants should cover approximately 30 percent of shallow areas, with particular attention paid to areas adjacent to the shoreline. Plants should be spaced 2 to 3 feet apart, and the same species of plants should be planted in a single area to avoid interspecies competition.

- Species that are not recommended for any use in a constructed wetland are *Phragmites australis* (common reed), *Lythrum salicaria* (purple loosestrife), and *Phalaris arundinacea* (reed canary grass). Periodic inspections are important to ensure that exotic or other pest species do not dominate the plant community. In certain situations where there is an initial invasion of an aggressive, undesirable species, selective removal of the plants might be warranted, especially if the plant community that was introduced has not had time to adequately establish itself.

- Depending on site conditions, planting *Typha latifolia* (cattail) may or may not be recommended. Despite the fact that it is considered an exotic species, cattail will eventually dominate the wetland community. Additionally, cattail is an excellent plant for water treatment from a filtration and sedimentation standpoint.

- Planting will be more successful if the water level can be drawn down immediately prior to planting. This drawdown will leave the soils saturated, a condition necessary for the plants, and will improve visibility, especially when a number of people are involved in planting. The potential for damaging previously planted vegetation is reduced if the plants are clearly visible. Upon completion of planting, the outlet structure drain valve should be closed so either storm or base flow can reestablish the normal pool elevation.

- Harvesting wetland plants is only appropriate in areas such as the southern United States where plant growth is the most important mechanism for nutrient uptake. Harvesting is not needed where microbial activity is the dominant pollutant removal mechanism.

Like wet ponds, wetlands can increase adjacent property values. One study in Boulder, Colorado, found that lots located alongside a constructed wetland sold for up to a 30 percent premium over lots with no water view (USEPA, 1995). In Wichita, Kansas, a developer enhanced existing wetlands rather than filling them, and the waterfront lots sell for a premium of up to 150 percent of comparable lots (USEPA, 1995).

5.3.5 Other Practices

Other practices used to control urban runoff have not been studied as extensively as those above but have been used with varying degrees of success. They include:

- Water quality inlets;
- Hydrodynamic devices;
- “Baffle boxes;”
- Catch basin inserts;
- Vegetated filter strips;
- Street surface storage;

- On-lot storage; and
- Microbial disinfection.

In some cases, these practices are used for pretreatment or are part of an overall runoff management system, which is sometimes referred to as a “treatment train.” For example, water quality inlets, catch basin inserts, and vegetated filter strips installed upslope of a wet pond or filtration practice will help remove a portion of the pollutants present in runoff before it enters the pond or filtration practice. These other practices in the treatment train improve runoff quality and can help extend the longevity of the filtration practice and wet pond.

5.3.5.1 Water quality inlets

Water quality inlets are underground retention systems designed to remove settleable solids. There are several water quality inlet designs. In their simplest form, catch basins are single-chambered urban runoff inlets in which the bottom has been lowered to provide 2 to 4 feet of additional space between the outlet pipe and the structure bottom for collection of sediment. Some water quality inlets include a second chamber with a sand filter to provide additional removal of finer suspended solids by filtration. The first chamber provides effective removal of coarse particles and helps prevent premature clogging of the filter medium.

Other water quality inlets include an oil/grit separator. Typical oil/grit separators consist of three chambers. The first chamber removes coarse material and debris; the second chamber provides separation of oil, grease, and gasoline; and the third chamber provides safety relief if blockage occurs (NVPDC, 1980). Although water quality inlets have the potential to perform effectively, they are not recommended because they are usually designed to bypass high flows, which can resuspend captured pollutants and flush them through the water quality inlet. Frequent maintenance and disposal of trapped residuals and hydrocarbons are necessary for these devices to continuously and effectively remove pollutants.

5.3.5.2 Hydrodynamic devices

A variety of engineered hydrodynamic devices, also called swirl separators or swirl concentrators, are available for removing pollutants from runoff. Swirl separators are modifications of the traditional oil-grit separator and include an internal component that creates a swirling motion as runoff flows through a cylindrical chamber. The concept behind these designs is that sediments settle out as runoff moves in this swirling path. Additional compartments or chambers, with or without pads, are sometimes present to trap oil and other floatables. Typically these devices are prefabricated and come in a range of sizes targeted at specific flow rates. At least two technologies are available. One is designed to remove suspended particles, oil, and grease during low flow conditions. The device removes particulate and floatable pollutants from runoff through settling of solids and floating of oils, greases, and litter. Higher runoff flows are diverted around the treatment unit so that scour and increased velocity do not carry the collected pollutants out of the treatment chamber. Maintenance requirements include the periodic removal of oil, greases, and sediments, typically by using a vacuum truck.

A second type of hydrodynamic device uses centrifugal motion to remove litter and debris and, potentially, larger sediment particles from runoff. This technology is designed to capture trash rather than pollutants, and therefore it is most applicable in coastal areas and areas that receive heavy trash loads such as leaf litter, plastics, and cans. Prefabricated units are currently available with capacities up to 300 cubic feet per second (cfs). The devices are constructed so that a vacuum truck can regularly remove the floatable and settleable debris collected in the treatment chamber.

Limited data are available on the performance of these devices, and independently conducted studies suggest marginal fine particle and soluble pollutant removal. Therefore, swirl separators should not be used as a stand-alone practice for new development. Also, these devices require regular maintenance. Communities may reduce maintenance costs by sharing a vactor truck. Swirl separators are best installed on highly impervious sites. These products have application as pretreatment to another runoff treatment practice and in a retrofit situation where space is limited.

5.3.5.3 Baffle boxes

Sediment control devices called "baffle boxes" have been used in Brevard County, Florida, as an "end of pipe" treatment method (England, 1996). They are concrete or fiberglass boxes, typically 10 to 15 feet long and 6 to 8 feet high, which are placed at the end of existing storm drain pipes. The box is divided into multiple chambers by weirs set at the same level as the pipe invert to minimize hydraulic losses. Trash screens are incorporated in the design to remove floating debris. Baffle boxes have been shown to have a removal efficiency of up to 90 percent for sand or sandy clay at entrance velocities of up to 6 feet per second, and 28 percent removal efficiency for fly ash at the same velocity. Baffle box designs can be modified to serve as a retrofit installation at curb or manhole inlets or beneath grates. Regular maintenance, especially removal of sediment and debris, is essential to maintain the effectiveness of this practice.

5.3.5.4 Catch basin inserts

Catch basin inserts consist of a frame that fits below the inlet grate of a catch basin and can be fitted with various trays that target specific pollutants. Typically the frame and trays are made of stainless steel, cast iron, or aluminum to resist corrosion. The trays may contain a variety of media. Often more than one tray is included in the design with the first tray filtering out sediment. Subsequent trays typically address a specific targeted pollutant, (e.g., wood fiber or other absorbent materials for oils and grease, or activated carbon for organics, fertilizers, and pesticides). The device is typically designed to accept the design flow rate of the inlet grate with bypasses as the trays become clogged with debris. The media require routine maintenance for replacement, cleaning, or regeneration. Catch basin inserts are typically used for smaller drainage areas. Usually the media need replacement on a quarterly basis.

The City of Santa Monica installs catch basin inserts that catch trash and debris in areas of high pedestrian traffic. Catch basin screens attach to the face of the curb and block trash from the storm drain, allowing debris to be easily removed by maintenance personnel or a street sweeper. Inserts that also filter hydrocarbons are installed on streets with automotive businesses. The city has found these practices to be effective when they are chosen carefully to suit site characteristics and are carefully installed and maintained (Shapiro, 2003).

5.3.5.5 Alum

Alum, which is an aluminum sulfate salt, can be added to storm water to cause fine particles to flocculate and settle out (USEPA, 2001a). It can help meet downstream pollutant concentration loads by reducing the concentrations of fine particles and soluble phosphorus. Alum can be added directly to or just before a pond or lake inlet, and booms can be used to ensure quiescent settling. When alum is injected into runoff it forms the harmless precipitates aluminum phosphate and aluminum hydroxide. These precipitates combine with heavy metals and phosphorus, causing them to be deposited into the sediments in a stable, inactive state. The collected mass of alum pollutants, precipitates, and sediments is commonly referred to as "floc." Frequent maintenance and disposal of the floc is required for continuous and effective operation.

5.3.5.6 Vegetated filter strips

Vegetated filter strips (VFSs) (Figure 5.16) are areas of land with vegetative cover that are designed to accept runoff as overland sheet flow from upstream development. Dense vegetative cover facilitates sediment attenuation and pollutant removal. Unlike grassed swales, vegetated filter strips are effective only for overland sheet flow and provide little treatment for concentrated flows. Grading and level spreaders can be used to create a uniformly sloping area that distributes the runoff evenly across the filter strip (Dillaha et al., 1989). Vegetated filter strips are often used as pretreatment for other structural practices, such as infiltration basins and infiltration trenches.

Typically, VFSs are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area the practice treats but the length of flow leading to it. As runoff flows over the ground surface, it changes from sheet flow to concentrated flow. Rather than moving uniformly over the surface, the concentrated flow forms rivulets that are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a grassed filter strip.

VFSs should be designed on slopes between 2 and 6 percent. Steeper slopes encourage the formation of concentrated flow. Except in the case of very sandy or gravelly soil, runoff ponds on the surface on slopes flatter than 2 percent, creating potential mosquito-breeding habitat. Filter strips should not be used on soils with high clay content because they require infiltration for proper treatment. Very poor soils that cannot sustain a grass cover crop are also a limiting factor. Filter strips should be separated from the ground water by 2 to 4 feet to prevent contamination and to ensure that they do not remain wet between storms.

The design of VFSs is straightforward because they are not much more than a grassed slope. However, the following design features are critical to ensure that the filter strip provides some minimum amount of water quality treatment:

- A pea gravel diaphragm or stone drop should be used at the top of the slope. The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.

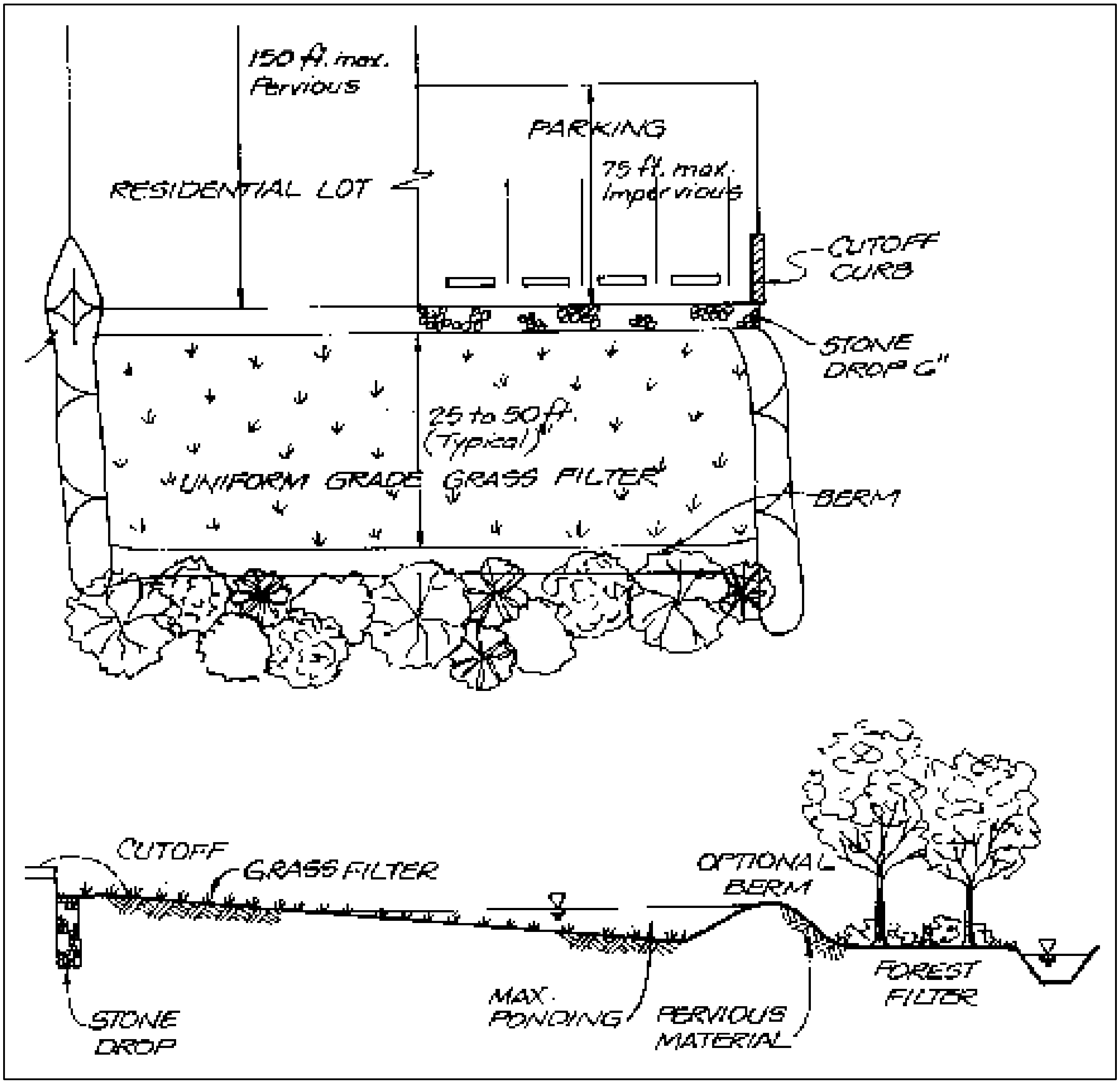

Figure 5.16: Schematic of a vegetated filter strip (Claytor and Schueler, 1996).

- The filter strip should be designed with a pervious berm of sand and gravel at the toe of the slope. This feature provides an area for shallow ponding at the bottom of the filter strip. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm. The volume ponded behind the berm should be equal to the water quality volume. The water quality volume is the amount of runoff that will be treated for pollutant removal in the practice. Typical water quality volumes are the runoff from a 1-inch storm or ½-inch of runoff over the entire drainage area to the practice.

- The filter strip should have a length of at least 25 feet to provide water quality treatment.

- Vegetation must be able to withstand relatively high velocity flows and both wet and dry periods.

- The slope should have a flat top and toe to encourage sheet flow and prevent erosion.

5.3.5.7 Street surface and subsurface storage

Figure 5.17: Runoff pooling on a street surface designed for temporary storage.

Runoff can be temporarily stored on and below the surface of streets in urban areas, as shown in Figure 5.17, to reduce peak flows to the storm sewer system (Carr et al., 1999). Runoff can be retained on and below the street using a combination of berms, flow regulators, and below-surface storage. Berms resemble speed bumps or speed humps but are broader and gentler; they retain water in a shallow pool on the street surface upstream of the berm. In some cases, this type of surface storage is inappropriate because it can result in damage to roadways. An alternative is subsurface storage in tanks or large sewer pipes. Both above- and below-ground storage systems, when combined with flow regulators that allow only a limited amount of runoff to enter the sewer system, mitigate basement flooding, combined sewer overflows, sanitary sewer overflows, and surface flooding. These systems should be designed with public safety in mind to minimize hydroplaning and icing in cold climates.

Two suburban Chicago, Illinois, towns—Skokie and Wilmette—implemented street-surface storage of runoff. The Skokie system has 2,900 flow regulators, 871 berms, 10 off-street storage facilities, 83 subsurface facilities, and several new storm and combined sewers (USEPA, 2000b). Wilmette's runoff storage system is composed of essentially all street storage. These systems have been effective in preventing flooding and overflows and are less expensive than other alternatives such as sewer separation and relief sewers. More information about these studies can be found at http://www.epa.gov/ednnrmrl/publications/reports/epa600r00065/epa600r00065.htm.

5.3.5.8 On-lot storage practices

The term "on-lot storage" refers to a series of practices that are designed to contain runoff from individual lots. The purpose of most on-lot practices is to manage rooftop or parking area runoff. The primary advantage of managing runoff from rooftops and parking lots is to disconnect these impervious surfaces, reducing the effective impervious cover in a watershed.

Johnston et al. (2003) modeled the downstream hydrologic and economic impacts of on-site runoff storage based on flood risk reduction on property values and costs of storm drainage infrastructure. They found that use of reduced runoff practices provided property value benefits due to decreased flood risk of $21,600 to $36,300 per acre using countywide assessed values, or $17,540 to $29,240 per acre using U.S. Census Bureau census block median housing values. Benefits in avoided costs for storm drainage infrastructure (road culverts) totaled $247 to $836 per developed acre.

Although there are many on-lot treatment options, they can all be classified into one of three categories: (1) practices that infiltrate runoff; (2) practices that divert runoff to a pervious area; and (3) practices that store runoff for later use. The best option depends on the goals of a community, the feasibility at a specific site, and the preferences of the property owner.

Rooftop Runoff

Rooftop runoff, particularly in residential areas, generally has low pollutant concentrations compared with other urban sources (Schueler, 1994). Information on green rooftops can be found in Section 4.3.2.2. The practice most often used to infiltrate rooftop runoff is the dry well. In this design, the storm drain is directed to an underground rock-filled trench that is similar in design to an infiltration trench. French drains or Dutch drains can also be used for this purpose. In these designs, the relatively deep dry well is replaced with a long trench with a perforated pipe within the gravel bed to distribute flow throughout the length of the trench. Chamber systems, a widely marketed proprietary product, can be used in a similar manner.

Runoff can be diverted to a pervious area or to a treatment area using site grading or channels and berms. Treatment options can include grassed swales, bioretention cells, or filter strips. The bioretention design can be simplified for an on-lot application by limiting the pretreatment filter and in some cases eliminating the underdrain. Alternatively, rooftop runoff can simply be diverted to pervious lawn areas instead of discharging it directly to the street or a pipe drainage system.

Practices that store rooftop runoff, such as cisterns, chambers, and rain barrels (Figure 5.18), are the simplest designs for on-lot treatment systems. Some of these practices are available commercially and can be applied in a variety of site conditions. Cisterns and rain barrels are particularly valuable in the arid Southwest, where water is at a premium, rainfall is infrequent, and reuse for irrigation can save homeowners money.

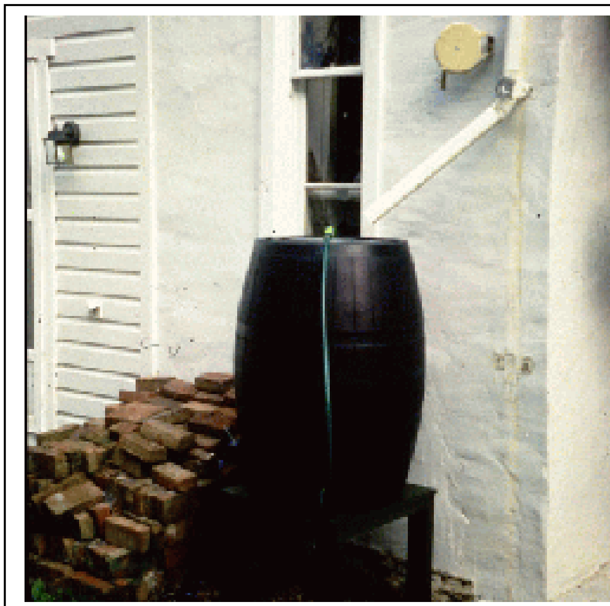

Figure 5.18: A rain barrel that collects runoff from a roof gutter downspout.

Rain barrels typically range in cost from $60 to $135. These prices do not always include the cost of additional parts needed to link the rain barrel to a downspout. These parts generally range in cost from $5 to $18, depending on the manufacturer and the design of the rain barrel (Gardener's, 2001; Jade Mountain, 2000; Midwest, 2001; Spruce Creek, 2001). If homeowners want to save money, they can build their own rain barrel, which costs approximately $15 if recycled drums are available.

Information about building a simple rain barrel is available from the Maryland Green Building Program at http://www.dnr.state.md.us/ed/rainbarrel.html (MDNR, no date). Information is also available in *How to Make a Rain Barrel*, which was published by the city of Ottawa, Ontario (no date). The manual is available by contacting the city of Ottawa toll-free at 866-261-9799, or by e-mailing info@city.ottawa.on.ca.

It is important for municipalities planning to start a rain barrel program to consider water quality issues, climate, algae and mosquito control, homeowner attitudes and willingness, and the protection of home foundations. Rain barrels can be a reliable source of water for garden and lawn watering, but if the water is intended for consumption it is crucial that the roof materials and gutter system be examined for asbestos, lead paint, and bird droppings (Sands and Chapman, 2003).

The Milwaukee Metropolitan Sewerage District (MMSD) undertook a rain barrel project in response to problems with combined sewer overflows. The project involved 40,000 single-family homes with roof areas of approximately 1,200 square feet. Two 90-gallon rain barrels were installed at each home. The MMSD found the reduction in runoff volume attributed to rain barrels to be approximately 243 million gallons. While the effort did not reduce combined sewer overflow volumes for the MMSD, it did result in savings on treatment plant costs and increased environmental awareness. The MMSD plans to continue to incorporate rain barrels into an integrated management plan that might include additional on-lot treatment practices (Sands and Chapman, 2003).

On-lot treatment practices can be applied to almost all sites with very few exceptions (e.g., very small lots or lots with no landscaping). There are currently at least two jurisdictions that offer "credits" in exchange for the application of on-site runoff management practices. In Denver, Colorado, sites designed with methods to reduce "directly connected impervious cover," including disconnection of downspout runoff from the storm drain system, are permitted to use a lower impervious area when computing the required storage of runoff management facilities (DUDFC, 1992). Similarly, new regulations for Maryland allow designers to subtract each rooftop that is disconnected from the total site impervious cover when calculating required storage in runoff management practices (MDE, 2000).

Although most residential lots can incorporate on-lot treatment, the best option for a site depends on design constraints and the preferences of the homeowner. On-lot infiltration practices have the same restrictions regarding soils as other infiltration practices. If other design practices are used, such as bioretention or grassed swales, they need to meet the siting requirements of those sites. Of all of the practices, cisterns and rain barrels have the fewest site constraints. In order for the practice to be effective, however, homeowners need to have a use for the water stored in the practice, and the design must accommodate overflow and winter freezing conditions.

Although these runoff management practices are simple compared with many others, their design needs to incorporate the same basic elements. Pretreatment is important for all of these practices to ensure that they do not become clogged with leaves or other debris. Infiltration practices may

Santa Monica Urban Runoff Program

Santa Monica's comprehensive urban runoff program combines pollution prevention and on-site practices with a runoff recycling program designed to improve water quality and harvest dry weather runoff as a resource. By protecting existing water resources, increasing infiltration on-site, and harvesting runoff for reuse, the city is maximizing the use of storm water as a resource and decreasing the demand for imported water. The city's pollution prevention program protects water quality with education, municipal housekeeping, lawn care and landscaping practices, and an ordinance that requires good housekeeping practices on construction sites. On-site practices are required by the Urban Runoff Pollution Mitigation Ordinance and include infiltration practices, porous pavement, and other low impact development techniques. The city has also installed catch basin inserts and screens to capture trash, debris, and some soluble pollutants. Finally, the Santa Monica Urban Runoff Recycling Facility (SMURRF) harvests and treats dry weather runoff and makes it available for reuse as irrigation water or for indoor toilet flushing (Shapiro, 2003).

be preceded with a settling tank or, at a minimum, a grate or filter in the downspout to trap leaves and other debris. Rain barrels and cisterns also often incorporate some sort of pretreatment, such as a mesh filter at the top of the barrel or cistern.

Both infiltration practices and storage practices should incorporate some type of bypass so runoff from larger storms flows away from the house. With rain barrels or cisterns, this bypass may be a hose set at a high level within the device that directs runoff away from both the device and the building foundation. These practices also include a hose bib set at the bottom of the device so the homeowner can use the stored water for irrigation or other uses by attaching a standard garden hose to the hose bib.

One important design requirement for on-lot infiltration practices is locating the infiltration area sufficiently far from the house (at least 10 feet) to prevent undermining of the foundation or seepage into the basement.

Infiltration practices require regular removal of sediment and debris settled in the pretreatment area, and the infiltration medium needs to be replaced when it becomes clogged. Rain barrels and cisterns require minimal maintenance, but the homeowner must ensure that the hose remains elevated during the winter to prevent freezing and cracking. In addition, the tank requires cleaning approximately once a year.

On the basis of cost per unit area treated, on-lot practices are relatively expensive compared with other runoff storage and treatment options. It is difficult to make this comparison, however, because the cost burden of on-lot practices is borne directly by homeowners. Typical costs are $100 for a rain barrel and $200 for a dry well or French drain. Often, homeowners can reduce costs by creating their own on-lot practice rather than purchasing a commercial product.

Parking Lot Runoff

Standard parking lots typically drain rapidly through curb and gutter systems to prevent flooding. This practice, however, does little to improve water quality or protect receiving waters from high flows during and after storms. Innovative designs for parking lots incorporate pervious areas for drainage, whether at the perimeter or in various islands within the lot. These pervious areas should be designed to infiltrate runoff at rates that prevent excessive ponding, which could appear unsightly or create safety issues and nuisance mosquito habitat. In cases where existing soils have poor infiltration capacity, better-drained soils should be imported or perforated under-drains installed to store infiltrated runoff underground.

The use of large-diameter underground pipes constructed of concrete, corrugated steel, or high-density polyethylene (HDPE) is becoming a more common practice for large parking areas such as shopping malls and mixed-use developments. These underground pipes and vaults as well as chamber systems can store large quantities of runoff that can be reused as needed or released at rates that will not damage natural conveyance systems.

5.3.5.9 Microbial disinfection

Other practices can be used to treat runoff for specific pollutants other than sediment. For instance, in areas where microbial pollution is an issue, runoff can be treated using ozone or ultraviolet light to prevent disease and reduce exceedances of water quality due to pathogen contamination. The City of Encinitas, California, was concerned about the number of public health warnings at its primary seaside attraction, Moonlight Beach, due to high enterococcus and coliform bacteria counts. The main source of the microbial pollution was dry weather runoff from Cottonwood Creek, which discharges at Moonlight Beach. Despite extensive evaluation of the Cottonwood Creek drainage area to identify and reduce bacterial loading, public health warnings continued to be posted. In anticipation of a total maximum daily load for bacteria under development for the region, and to reduce or eliminate the number of beach postings, the City chose to install an ultraviolet (UV) disinfection facility with partial funding from California's Clean Beach Initiative. The UV treatment facility was designed to treat 150 gallons per minute of Cottonwood Creek's dry weather flow, with 15% of the creek's flow diverted around the facility to maintain biological connectivity between upstream and downstream waters. During times of high flow (i.e., during and after storms) and high turbidity, when the system's treatment effectiveness would be reduced, the system is shut down and flow is passed through without treatment. Early monitoring results showed a significant decrease in bacterial counts downstream of the treatment facility, with a removal efficiency of more than 99.9 percent that yielded an effluent quality of 2 bacteria per 100 mL. Filters built into the system were also effective at removing suspended sediment, reducing turbidity from an average of 14.0 mg/L in the influent to 5.0 mg/L in the effluent.

5.4 Performance and Cost Information for Management Practices

Some advantages, disadvantages, and costs of specific runoff control practices described above are listed in Table 5.6. Site-specific information, regional limitations, operation and maintenance burdens, and longevity for these practices are listed in Table 5.7.

Table 5.6: Advantages and disadvantages of management practices (MDE, 2000).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Runoff control ponds			
Wet pond	– Can provide peak flow control – Can serve large developments; most cost-effective for larger, more intensively developed sites – Enhances aesthetics and provides recreational benefits – Little ground water discharge – Permanent pool in wet ponds helps to prevent scour and re-suspension of sediments – Provides moderate to high removal of both particulate and soluble urban runoff pollutants	– Not economical for drainage area less than 10 acres – Potential safety hazards if not properly maintained – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors – Requires considerable space, which limits use in densely urbanized areas with expensive land and high property values – Not suitable for hydrologic soil groups "A" and "B" (USDA-NRCS classification) unless a liner is used – With possible thermal discharge and oxygen depletion, may severely impact downstream aquatic life – Hydrologic damage to stream channels and aquatic habitat is possible due to flow volume.	Moderate to high compared to conventional runoff detention
Infiltration practices			
Infiltration basin	– Provides ground water recharge – Can serve large developments – High removal capability for particulate pollutants and moderate removal for soluble pollutants – When basin works, it can replicate predevelopment hydrology more closely than other BMP options – Basins provide more habitat value than other infiltration systems	– Possible risk of contaminating ground water – Only feasible where soil is permeable and there is sufficient depth to bedrock and water table – Fairly high failure rate – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors – Regular maintenance activities cannot prevent rapid clogging of infiltration basin	Construction cost moderate but rehabilitation cost high

Table 5.6 (continued).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Infiltration trench	– Provides ground water recharge – Can serve small drainage areas – Can fit into medians, perimeters, and other unused areas of a development site – Helps replicate predevelopment hydrology, increases dry weather baseflow, and reduces bankfull flooding frequency	– Possible risk of contaminating ground water – Only feasible where soil is permeable and there is sufficient depth to bedrock and water table – Since not as visible as other BMPs, less likely to be maintained by residents – Requires significant maintenance	– Cost-effective on smaller sites – Rehabilitation costs can be considerable
Concrete grid pavement	– Can provide peak flow control – Provides ground water recharge – Provides water quality control without additional consumption of land	– Requires regular maintenance – Not suitable for areas with high traffic volume – Possible risk of contaminating ground water – Only feasible where soil is permeable, there is sufficient depth to bedrock and water table, and there are gentle slopes	Information not available
Filtering practices			
Filtration basin	– Ability to accommodate medium-size development (3–80 acres) – Flexibility to provide or not provide ground water recharge – Can provide peak volume control	– Requires pretreatment of runoff through sedimentation to prevent filter media from premature clogging	Information not available
Bioretention	– Provides ground water recharge	–	
Open channel practices			
Grassed swale	– Requires minimal land area – Can be used as part of the runoff conveyance system to provide pretreatment – Can provide sufficient runoff control to replace curb and gutter in single-family residential subdivisions and on highway medians – Economical	– Low pollutant removal rates – Leaching from culverts and fertilized lawns may actually increase the presence of trace metals and nutrients	Low compared to curb and gutter
Structural management practices that do not consistently remove 80% TSS			
Vegetated filter strip	– Low maintenance requirements – Can be used as part of the runoff conveyance system to provide pretreatment – Can effectively reduce particulate pollutant levels in areas where runoff velocity is low to moderate – Provides excellent urban wildlife habitat – Economical	– Often concentrates water, which significantly reduces effectiveness – Ability to remove soluble pollutants highly variable – Limited feasibility in highly urbanized areas where runoff velocities are high and flow is concentrated – Requires periodic repair, regrading, and sediment removal to prevent channelization	Low

Table 5.6 (continued).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Water quality inlet Catch basins with sand filter	– Provide high removal efficiencies of particulates – Require minimal land area – Flexibility to retrofit existing small drainage areas – Higher removal of nutrient as compared to catch basins and oil/grit separator	– Not feasible for drainage areas greater than 5 acres – Only feasible for areas that are stabilized and highly impervious – Not effective as water quality control for intense storms	Information not available
Water quality inlet Oil/grit separator	– Captures coarse-grained sediments and some hydrocarbons – Requires minimal land area – Flexibility to retrofit existing small drainage areas and applicable to most urban areas – Shows some capacity to trap trash, debris, and other floatables – Can be adapted to all regions of the country	– Not feasible for drainage area greater than 1 acre – Minimal nutrient and organic matter removal – Not effective as water quality control for intense storms – Concern exists for the pollutant toxicity of trapped residuals – Require high maintenance	High, compared to trenches and sand filters
Extended detention dry pond with micropool	– Can provide peak flow control – Possible to provide good particulate removal – Can serve large development – Requires less capital cost and land area when compared to wet pond – Does not generally release water or anoxic water downstream – Provides excellent protection for downstream channel erosion – Can create valuable wetland and meadow habitat when properly landscaped	– Removal rates for soluble pollutants are quite low – Not economical for drainage area less than 10 acres – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors	Lowest cost alternative in size range

[a]Comparative cost information from Schueler, 1992

Table 5.7: Regional, site-specific, and maintenance considerations for management practices (USEPA, 1993; Caraco and Claytor, 1997; Schueler, in press).

Management Practice and Specifications	Cold Climate Restrictions (Caraco and Claytor, 1997)	Arid and Semi-Arid Regional Restrictions (Schueler, in press)
Infiltration basins *Size of drainage area*: Moderate to large *Site requirements:* Deep, permeable soils *Maintenance burdens*: High *Longevity:* Low	– Avoid areas with permafrost – Monitor ground water for chlorides – Do not infiltrate road/parking lot snowmelt if chlorides are a concern – Increase percolation requirements – Use 20 foot minimum setback between road subgrade and practice	– No recharge in hot-spot areas – Do not treat pervious areas – Use multiple pretreatment – Soil limitations exist in arid areas
Infiltration trenches *Size of drainage area*: Moderate *Site requirements:* Deep, permeable soils *Maintenance burdens*: High *Longevity:* Low	– Avoid areas with permafrost – Monitor ground water for chlorides – Do not infiltrate road/parking lot snowmelt if chlorides are a concern – Increase percolation requirements – Use 20-foot minimum setback between road subgrade and practice	– No recharge in hot-spot areas – Do not treat pervious areas – Use multiple pretreatment – Soil limitations exist in arid areas
Vegetated filter strips *Size of drainage area*: Small *Site requirements:* Low-density areas with low slopes *Maintenance burdens*: Low *Longevity:* Low if poorly maintained	– Small setback may be required between filter strips and roads when frost heave is a concern – Avoid areas with permafrost – Use cold- and salt-tolerant vegetation – Plowed snow can be stored in-practice	– Use drought-tolerant vegetation
Grassed swales *Size of drainage area*: Small *Site requirements*: Low-density areas with <15% slope *Maintenance burdens*: Low *Longevity:* High if maintained	– Avoid areas with permafrost – Use cold- and salt-tolerant vegetation – Plowed snow can be stored in the practice – Increase underdrain pipe diameter and size of gravel bed – Provide ice-free culverts – Ensure soil bed is highly permeable	– Not recommended for pollutant removal in arid areas – Of limited use in semi-arid areas – Ensure adequate erosion protection of channels
Porous pavement *Size of drainage area*: Small *Site requirements*: Deep permeable soils, low slopes, and restricted traffic *Maintenance burdens*: Moderate to high *Longevity:* Low	– Only use on non-sanded surfaces – Pavement may be damaged by snow plows – Maintenance is essential	
Filtration basins and sand filters *Size of drainage area*: Widely applicable *Site requirements*: Widely applicable *Maintenance burdens*: Moderate *Longevity:* Low to moderate	– Reduced treatment effectiveness during cold season – Underground filters only effective if placed below the frost line – Peat/compost media ineffective during winter and may become impervious if frozen	– Preferred in both arid and semi-arid areas. Arid area filters require greater pretreatment
Bioretention	– Reduced treatment effectiveness during cold season – Pretreatment should be used to prevent "choking" of vegetation	

Table 5.7 (continued).

Management Practice and Specifications	Cold Climate Restrictions (Caraco and Claytor, 1997)	Arid and Semi-Arid Regional Restrictions (Schueler, in press)
Water quality inlets *Size of drainage area*: Small *Site requirements:* Impervious catchments *Maintenance burdens*: Cleaned twice a year *Longevity:* High	– Few restrictions	
Extended detention dry ponds *Size of drainage area*: Moderate to large *Site requirements:* Deep soils *Maintenance burdens*: Dry ponds have relatively high burdens *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Preferred in arid climates and acceptable in semi-arid climates
Wet ponds *Size of drainage area*: Moderate to large *Site requirements*: Deep soils *Maintenance burdens*: Low *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Not recommended in arid areas and of limited use in semi-arid areas
Wetlands *Size of drainage area*: Moderate to large *Site requirements:* Poorly drained soils, space may be limiting *Maintenance burdens*: Annual harvesting of vegetation *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Not recommended in arid areas and of limited use in semi-arid areas

Table 5.8 presents pollutant removal efficiency statistics for the management practices discussed in this section. These values originate from the *National Pollutant Removal Performance Database for Stormwater BMPs* (Caraco and Winer, 2000). The database was compiled through a comprehensive literature search focusing on runoff treatment practice monitoring sites from 1990 to present. In addition, approximately 60 previously collected monitoring studies from 1977 and 1989 were included in the database. All 139 studies meet the two following criteria: (1) the researchers used automated equipment that enabled flow or time-based composite samples; and (2) they documented the method used to compute removal efficiency. With respect to the number of storms sampled, more than three-quarters of the studies were based on five or more storm samples. The sample size was not reported in the remaining studies.

Table 5.8: Effectiveness of management practices for runoff control (adapted from Caraco and Winer, 2000).

Runoff Treatment or Control Practice Category or Type	Median Pollutant Removal (Percent)							
	No. of studies	TSS	TP	OP	TN	NOx	Cu	Zn
Quality Control Pond	3	3	19	N/A	5	9	10	5
Dry Extended Detention Pond	6	61	20	N/A	31	-2	29	29
Dry Ponds	9	47	19	N/A	25	3.5	26	26
Wet Extended Detention Pond	14	80	55	69	35	63	44	69
Multiple-Pond System	1	91	76	N/A	N/A	87	N/A	N/A
Wet Pond	28	79	49	39	32	36	58	65
Wet Ponds	43	80	51	65	33	43	57	66
Shallow Marsh	20	83	43	66	26	73	33	42
Extended Detention Wetland	4	69	39	59	56	35	N/A	-74
Pond/Wetland System	10	71	56	37	19	40	58	56
Submerged Gravel Wetland	2	83	64	14	19	81	21	55
Wetlands	36	76	49	48	30	67	40	44
Organic Filter	7	88	61	30	41	-15	66	89
Perimeter Sand Filter	3	79	41	68	47	-53	25	69
Surface Sand Filter	7	87	59	N/A	31.5	-13	49	80
Vertical Sand Filter	2	58	45	21	15	-87	32	56
Bioretention	1	N/A	65	N/A	49	16	97	95
Filtering Practices[a]	18	86	59	*57*	38	-14	49	88
Infiltration Trench	3	100	42	100	42	82	N/A	N/A
Porous Pavement	3	95	65	10	83	N/A	N/A	99
Ditches[b]	9	31	-16	N/A	-9	24	14	0
Grass Channel	3	68	29	32	N/A	-25	42	45
Dry Swale	4	93	83	70	92	90	70	86
Wet Swale	2	74	28	-31	40	31	11	33
Open Channel Practices	9	81	34	*1.0*	*84*	31	51	71
Oil-Grit Separator	1	-8	-41	40	N/A	47	-11	17

Shaded rows show data for groups of practices (i.e., dry ponds include quality control ponds and dry extended detention ponds).
Numbers in italics are based on fewer than five data points.
[a] Excludes vertical sand filters
[b] Refers to open channel practices not designed for water quality.
TSS=total suspended solids, TP=total phosphorus, OP=ortho-phosphorus, TN=total nitrogen, NOx=nitrate and nitrite nitrogen, Cu=copper, Zn=zinc.

Strecker et al. (2000) identified problems with comparing different management practice effectiveness studies. They suggested that inconsistent study methods, lack of associated design information, and multiple reporting protocols make wide-scale assessments of management practices difficult. Also, differences in monitoring strategies and data evaluation methods contribute significantly to the wide range of reported management practice effectiveness.

EPA recognizes that 80 percent TSS removal efficiency cannot be achieved for each storm event and understands that TSS removal efficiency will fluctuate above and below 80 percent for individual storms. Researchers have noted that efficiency estimation is often based on pollutant loads into and out of the management practice on a storm-by-storm basis. Therefore, a multiple-study analysis or summary is based on the assumption that all storms are equal when computing average pollutant removal. Storm-by-storm comparisons are probably not effective because many storms are not large enough to displace the permanent pool volume. They recommend that effectiveness be evaluated using statistical characterizations of the inflow and outflow concentrations because if enough samples are collected, total loads into and out of the management practice can be used reliably.

Strecker et al. (2000) also analyzed the use of effluent data to measure the influence of certain design criteria on management practice efficiency. Some studies suggest that management practices can only treat runoff to a specified pollutant concentration. However, if relatively clean water enters a practice, performance data based on removal efficiency might not fully characterize whether the practice is well designed and effective. Therefore, pollutant removal efficiency, when it is expressed as percent removal, might not be an accurate representation of

Verifying the Performance of Environmental Technologies

EPA's Environmental Technology Verification (ETV) Program, which began in October 1995, was instituted to verify the performance of innovative technical solutions to problems that threaten human health and the environment. ETV was created to significantly accelerate the entrance of new environmental technologies into the domestic and international marketplaces. The program operates through public and private testing partnerships to evaluate the performance of environmental technology in all media, including air, water, soil, ecosystems, waste, pollution prevention, and monitoring. More information about the ETV Program is available at http://www.epa.gov/etv (USEPA, 2001b).

Another method for evaluating technology is the Environmental Technology Evaluation Center (EvTEC), which was established by the Civil Engineering Research Foundation (CERF) through EPA's ETV Program. EvTEC is an independent, market-based approach to technology verification and was established to accelerate the adoption of environmental technologies into practice. More information about EvTEC is available at http://www.cerf.org/evtec (CERF, 2001).

EPA and NSF International, an independent, nonprofit testing organization, have developed a testing protocol to determine the viability of runoff treatment technologies and other wet weather flow controls, including runoff, combined sewer overflow (CSO), and sanitary sewer overflow (SSO). NSF International will also test and verify high-rate separation/clarification and high-rate disinfection technologies, flow monitoring equipment, and wet weather models.

Participants in the study include vendors who want to demonstrate the effectiveness of their technologies. Results of the pilot will be useful to a variety of stakeholders including municipalities, businesses, vendors, consulting engineers, and regulatory agencies. Once verification reports have been completed, vendors may use the results in their marketing efforts. Results will be made publicly available through EPA's and NSF's Web sites at http://www.epa.gov/etv and http://www.nsf.org/business/ETV_EPA_NSF/index.asp?program=ETVEPANSF, respectively. More information about the program is available at http://www.wateronline.com/content/news/article.asp?docid={17DDF263-29B8-11D5-A770-00D0B7694F32} (Water-Online, 2001).

International Stormwater Best Management Practices Database

The American Society of Civil Engineers, in cooperation with EPA, has compiled the *International Stormwater Best Management Practices Database*, which contains performance data from more than 200 management practice studies. Information provided for the management practices includes test site location, researcher contact data, watershed characteristics, regional climate statistics, management practice design parameters, monitoring equipment types, and monitoring data such as precipitation, flow, and water quality. More information on the database's purpose, design, and documentation can be found at http://www.bmpdatabase.org/.

how well a management practice is performing. Although more research is necessary to accurately determine the effectiveness of management practices, Strecker et al. recommend that standard methods and detailed guidance on data collection be used to improve data transferability.

Table 5.9 presents information concerning the costs associated with selected structural practices. The sources of these data are publicly available articles (some are a compilation of numerous studies).

Table 5.9: Costs of selected management practices (Claytor and Schueler, 1996; Brown and Schueler, 1997).

Management Practice	Construction Costs[a]	Useful Life (years)	Total Annual Costs
Infiltration basin[b]			
Average	$0.55/ft^3$ storage	25[c]	–
Report range	$0.22–$1.31/ft^3$	–	$0.03–$0.05/ft^3$
Probable range	$0.44–$0.76/ft^3$	–	–
Infiltration trench[b]			
Average	$4.36/ft^3$ storage	10[c]	–
Report range	$0.98–$10.04/ft^3$	–	$0.03–$0.10/ft^3$
Probable range	$2.73–$8.18/ft^3$	–	–
Infiltration practices[d]			
Average	$2.99/ft^3$ storage	–	–
Report range	$2.13-4.27/ft^3$ storage	–	–
Vegetated swales[b]			
Established from seed			
Average	$7.09/linear ft	50[e]	$1.09/linear ft
Report range	$4.91–$9.27/linear ft	–	–
Established from sod			
Average	$21.82/linear ft	50[e]	$2.18/linear ft
Report range	$8.73–$54.56/linear ft	–	–
Porous pavement[b]			
Average	$1.64/ft^2$	10[f]	$0.16/ft^2$
Report range	$1.09-$2.18/ft^2$	–	–
Concrete grid pavement[b]			
Average	$1.09/ft^2$	20	$0.05/ft^2$
Report range	$1.09–$2.18/ft^2$	–	–
Filtration basins[b]			
Average (probable)	$5.46/ft^3$ storage	25[g]	–
Report range	$1.09–12.00/ft^3$	–	$0.11–$0.87/ft^3$
Probable range	$2.18–9.82/ft^3$	–	–
Bioretention practices[d]			
Average	$6.83/ft^3$ storage	–	–
Filtration practices[d]			
Average	$2.63/ft^3$ storage	–	–
Range	$2.13-6.40/ft^3$ storage	–	–
Water quality inlet[b,h]			
Average	$2,182 each	50	$164 each
Report range	$1,200–3,273 each	–	–
Probable range	–	–	–
Water quality inlet with sand filter[b,h] Average (probable)	$10,900/drainage acre	50	$764/drainage acre

Table 5.9 (continued).

Management Practice	Construction Costs[a]	Useful Life (years)	Total Annual Costs
Oil/grit separator[b,h]			
Average	\$19,640/drainage acre	50	\$1,091/drainage acre
Report range	\$16,370–\$21,820/drainage acre	–	–
Stabilization with ground cover[b,h]			
From existing vegetation			
Average	\$0	50	Natural: \$109/acre
Report range	–	–	Managed: \$873/acre
From seed			
Average	\$436/acre	50	Natural: \$131/acre
Report range	\$218–\$1,091/acre	–	Managed: \$900/acre
From seed and mulch			
Average	\$1,637/acre	50	Natural: \$218/acre
Report range	\$872–\$3,819/acre	–	Managed: \$982/acre
From sod			
Average	\$12,330/acre	50	Natural: \$764/acre
Report range	\$4,910–\$52,375/acre	–	Managed: \$1,528/acre
Ext. Detention Dry Pond[b,h]			
Average	\$0.55/ft^3 storage	50	–
Report range	\$0.05–\$3.49/ft^3	–	\$0.008–\$0.33/ft^3
Probable range	\$0.10–\$5.46/ft^3	–	–
Wet Pond and Extended Detention Wet Pond[b]	\$0.55/ft^3 storage	50	\$0.009–\$0.08/ft^3
Storage vol. < 1 million ft^3	\$0.05–\$1.09/ft^3	–	–
Average	\$0.55–\$1.09/ft^3	–	–
Report range	\$0.27/ft^3 storage	50	–
Probable range	\$0.05–\$0.55/ft^3	–	\$0.009–\$0.08/ft^3
Storage vol. > 1 million ft^3	\$0.11–\$0.55/ft^3	–	–
Average (probable)			
Report range (probable)			
Probable range			

[a]Costs updated using the Bureau of Labor Statistics Inflation Calculator.
[b]Claytor and Schueler, 1996.
[c]References indicate the useful life for infiltration basins and infiltration trenches at 25-50 and 10-15 years, respectively. Because of the high failure rate, infiltration basins are assumed to have a useful life span of 25 years and infiltration trenches are assumed to have a useful life span of 10 years.
[d]Brown and Schueler, 1997.
[e]Useful life is assumed to equal the life of the project, assumed to be 50 years.
[f]No information was available for porous pavement. It is assumed to be similar to infiltration trenches.
[g]No information was available for filtration basins. It was assumed to be similar to infiltration basins.
[h] These practices do not meet the 80 percent TSS removal, thus it is recommended that they be used with other management practices in a treatment train.

5.5 Managing Structural Controls to Reduce Mosquito-Breeding Habitat

In recent years, concern has been raised that storm water management facilities have been breeding grounds for mosquitoes (Conlon, 2002). This is a public health concern because mosquitoes are known vectors for disease-causing arboviruses such as malaria, yellow fever, dengue fever, St. Louis encephalitis, and West Nile virus, to name a few. The relationship between storm water management and mosquito breeding exists because the presence of standing and sometimes stagnant water facilitates the two aquatic stages of a mosquito's life cycle—the egg and larval stages.

Not all mosquito species are vectors for disease, but control is still warranted because, even if not a health risk, mosquitoes are considered a nuisance. Mosquito species have different habitat preferences, and two basic groups can breed in the urban environment: permanent water species and floodwater species (Metzger et al., 2002). Permanent water species would be likely to propagate in storm water management facilities that always contain water, such as wet detention ponds and constructed wetlands. Floodwater species would likely inhabit "dry" systems such as extended detention dry ponds that have fluctuating water levels.

This issue has caused a fair amount of controversy because mosquito-breeding habitats are prevalent in urban and suburban environments. Metzger et al. (2002) identified a few of the numerous manmade mosquito-breeding habitats in urban and suburban environments:

> Urban environments provide mosquitoes with a vast array of new habitats: humid and arid, above and below ground, small water-holding containers and large ponds, polluted and clean water. Aquatic habitats are found around people's homes (birdbaths, jars, flower pots, neglected pools and Jacuzzis and clogged rain gutters), in unregulated waste dumps (used tires, barrels, bottles, and cans), in parks (ponds, lakes, and streams), and in the city's own infrastructure (storm drains, sewer systems, catch basins, and culverts). Many of these sources are replenished frequently by stormwater and urban runoff (e.g., irrigation, washing cars). Adding to this, increasingly stringent urban stormwater runoff regulations have recently mandated the construction of structural practices for both volume reduction and pollution management, many of which have created additional sources of standing water. This abundance of habitats has favored mosquitoes and allowed many species to greatly expand their range and increase in number.

Although storm water management facilities are not the sole source of standing water, public concern has raised the question of how these facilities can be managed, redesigned, or otherwise modified to reduce the creation of disease vectors close to urban population centers.

The California Department of Health Services' Vector-Borne Disease Section (2002), in cooperation with the California Department of Transportation (Caltrans), undertook a study to evaluate retrofit opportunities for storm water management. Part of this study investigated the mosquito production of 37 structural management practices in southern California. Eight categories of practices were constructed and examined as part of the study: (1) biofiltration strips and swales; (2) filtration devices (Austin-type and Delaware-type sand media filters, multi-chambered treatment train sand media filters, and a proprietary canister filter); (3) extended detention basins; (4) infiltration devices (basins and trenches); (5) continuous deflective separators (CDSs); (6) an oil/water separator; (7) drain-inlet inserts; and (8) a constructed wetland (retention pond). The study consisted of comprehensive surveillance and monitoring of each practice for mosquito production, as well as follow-up monitoring after modifications had been made to reduce the potential to produce mosquitoes. Of the eight different technologies implemented by Caltrans, those that maintained permanent sources of standing water in sumps or basins (MCTT, CDS, and the retention pond) provided excellent habitat for immature mosquitoes and frequently supported large populations relative to other structural designs. In contrast, practices designed to drain rapidly (i.e., biofiltration swales and strips, Austin-type sand media filters, infiltration basins and trenches, and extended detention basins) provided less-suitable habitats and rarely harbored mosquitoes.

The project was expanded to a nationwide investigation using phone and mail surveys and site visits to 150 agencies in 28 states. Of the 72 agencies that completed a questionnaire, 86 percent reported mosquito production associated with storm water management facilities. The survey found that inadequate maintenance resulted in accumulation of trash and other constituents (e.g., sediment, vegetation, organic debris).

The Southwest Florida Water Management District conducted a study to determine the extent to which storm water management facilities were breeding mosquitoes and offer recommendations for minimizing mosquito production (Livingston, no date). After examining more than 200 management practices with both permanent pools and intermittent pools, they found that 76 percent of all practices were mosquito productive, and that 66 percent of the permanently flooded practices and 69 percent of the intermittently flooded practices bred mosquitoes. Larval density was smaller and more dispersed in wet detention systems than in intermittently flooded systems. The wet detention systems that did not breed mosquitoes shared a paucity of vegetation, abundant fish, and good aeration. The intermittently flooded dry detention pond systems that did not produce mosquitoes were those that drained or dried within 72 hours.

The Florida researchers also investigated several pesticides and found them to be between 91 and 100 percent effective at controlling existing larval infestations in intermittently flooded systems within 24 hours of treatment, although one treatment in a system with high organic content was found to be ineffective against dense larval populations. The researchers also found that sustained-release materials such as pellets were effective for up to five weeks after application, whereas short-term controls required regular application.

Regular monitoring for mosquito adults and larvae, retrofitting and maintenance of practices to reduce the likelihood for breeding, and pesticide application where needed are the three key actions for eliminating mosquito breeding in storm water facilities. The Centers for Disease Control and Prevention discussed the role of pesticides that kill adult mosquitoes (adulticides) in mosquito management and recommended that their use be incorporated into an integrated pest management program that includes surveillance, source reduction, chemical control (larvicide and adulticide), biological control, and public relations and education (Rose, 2001).

Surveillance programs track diseases in bird populations, vector-borne pathogens in mosquitoes, mosquito populations, larval habitats, mosquito traps, biting counts, and reports by the public (Rose, 2001). Control activities are initiated when threshold populations are exceeded, and predictions are made from seasonal records and weather data.

Source reduction entails eliminating or altering larval habitats. This can be achieved through public education campaigns, with outreach to both children and adults. Additionally, state and local mosquito control agencies can alter the hydrology of open water and marshy areas to reduce or prevent the proliferation of mosquito larvae. Rose (2001) suggests techniques in which mosquito-producing areas in marshes are connected by shallow ditches to deep-water habitats to allow drainage or fish access, and minimally flooding the marsh during the summer but flap-gating impounded areas to reintegrate them to the estuary for the rest of the year.

Biological control can be achieved using various predators such as dragonfly nymphs and predacious mosquitoes (Rose, 2001). Mosquito fish are the most commonly used agents for biological control because they are easily reared, although they also feed on non-target species. Other types of organisms that might be used for mosquito control include several fish types other than *Gambusia*, as well as fungi, protozoans, nematodes, and predacious copepods.

It is essential that storm water managers and public works crews who maintain storm water management facilities be educated in integrated pest management. They should be trained to identify design flaws or maintenance needs that might create mosquito-breeding habitat, and they should know the procedures for reporting and remedying the problem. Pesticide handlers should have the required training under the Federal Insecticide, Fungicide, and Rodenticide Act and all chemicals should be applied at rates recommended on the packaging. Treated areas should be monitored after application to determine the efficacy of the applications and identify where pesticide resistance might be occurring.

There are steps that a storm water manager can take to reduce the likelihood that mosquitoes will breed in storm water management facilities. From a design standpoint, most management practices other than wet retention ponds are intended to drain within 72 hours. This is a safe drainage time because mosquitoes need at least that long for their aquatic life stages. Additionally, Metzger et al. (2002) found that several design features of storm water management practices contributed to vector production, including the use of sumps, catch basins, or spreader troughs that did not drain completely; the use of loose riprap that could hold small amounts of water; pumps or motors designed to “automatically” drain water from structures; and effluent pipes with discharge orifices prone to clogging because of their small diameter.

Livingston (no date) recommends the following design considerations to minimize mosquitoes:

- Designs must be based on site characteristics to ensure that the most appropriate type of storm water management facility is selected. Vegetated dry retention systems should be designed as off-line systems. They should be used only where the soil and water table conditions will assure that the system drains or dries within 24 to 36 hours, and where the seasonal high water table is at least two feet below the bottom of the system. If on-line retention areas are used, they should be designed to be dry within three days of a 25-year, 24-hour storm.

- Dry retention systems need to be carefully constructed to avoid compacting the soil and reducing its infiltration rate. They also should have flat bottoms to avoid having areas of standing water.

- To minimize decaying organic matter, the grass or other vegetation in dry retention areas should be regularly mowed and the clippings removed and composted.

- The littoral zone of wet detention areas should be planted with aquatic macrophytes such as *Sagittaria latifolia* (duck potato), *Sagittaria lancifolia* (lance-leaf arrowhead), *Juncus effusus* (soft rush), *Pontedaria lancifolia* (pickerelweed), *Juncus roemerianus* (needle rush), *Scirpus californicus* (giant bulrush), and *Scirpus validus* (soft stem bulrush). Cattails (*Typha* spp.) should never be planted in or allowed to remain in storm water systems as they grow very profusely, creating a large quantity of decaying matter.

- Wet detention systems should be stocked with native *Gambusia* spp. minnows (mosquito fish) to foster biological predation of mosquito larvae. If needed because of site conditions, a "minnow sump" should be excavated in the deepest part of the pond to assure permanent habitat and survival during droughts.

- Sustained-release larvicides should be used whenever necessary with systems known to be mosquito productive treated before the onset of the mosquito life cycle.

- Regular inspection and maintenance of storm water systems is essential to ensure that the facility drains as designed. Such maintenance involves removing submerged vegetation and clearing sediments away from inlets, outlets, and the bottom of the pool or holding area.

5.6 Information Resources

The *Technology Review: Ultra-Urban Stormwater Treatment Technologies* (Brueske, 2000) was compiled to provide a review of "ultra-urban" storm water treatment technologies. These types of technologies are designed to remove pollutants from runoff in highly developed areas where land values are high and available space is limited. Ultra-urban technologies differ from traditional runoff treatment controls in that they are very compact and can be retrofitted into existing runoff collection systems. The document specifically analyzes four types of treatment technologies: gravity separation, swirl concentration, screening, and filtration. Technology review findings were then used to develop a design protocol for selecting and installing ultra-urban treatment technologies. This document can be downloaded in PDF format from http://depts.washington.edu/cuwrm/research/ultraurbn.pdf.

The California Department of Transportation (Caltrans) prepared two handbooks on storm water quality as an updated version of the *Construction Contractor's Guide and Specifications*. These new manuals are the *Construction Site Best Management Practices (BMPs) Manual* and the *Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Control Program (WPCP) Preparation Manual*. The two manuals provide background information on Caltrans' program to control water pollution, offer instructions for selecting and implementing construction site best management practices, and help to standardize the process for preparing and implementing the SWPPP and the WPCP. Caltrans requires contractors to prepare and implement a program to control water pollution during the construction of all projects. The manuals are available for download at http://www.dot.ca.gov/hq/construc/stormwater/manuals.htm.

The Milwaukee Metropolitan Sewerage District developed a manual entitled "Surface Water and Storm Water Rules Guidance Manual" in 2002 that is available on their Web site at http://www.mmsd.com/stormwaterweb/Startpg.htm. The document includes an extensive discussion of the principles of storm water management, descriptions of both structural and nonstructural measures to control storm water, and sizing procedures for detention basins, among other topics.

In August 1998 the Center for Watershed Protection published *Better Site Design: A Handbook for Changing Development Rules in Your Community*. The publication covers everything from basic engineering principles to "actual versus perceived" barriers to implementing better site designs. The handbook outlines 22 guidelines for better developments and provides a detailed rationale for each principle. *Better Site Design* also examines current practices in local communities, details the economic and environmental benefits of better site designs, and presents case studies from across the country. The document is available for purchase from the Center for Watershed Protection at http://www.cwp.org/.

In 2000 the Maryland Department of the Environment published the *Maryland Stormwater Design Manual*. The manual was designed to protect Maryland waters from the adverse impacts of urban runoff, to provide design guidance on the most effective structural and nonstructural management practices for development sites, and to improve the quality of management practices that are recommended by the state of Maryland. The first volume of the manual contains information on management practice siting and design on new development sites to comply with Maryland's 14 storm water performance standards. A unique feature is the use of storm water credits for rewarding innovative storm water management designs. The second volume contains detailed technical information on runoff control practices, including step-by-step design examples. Both volumes are available for download at http://www.mde.state.md.us/environment/wma/stormwatermanual.

In 1995 the Metropolitan Washington Council of Governments (MWCOG) published *Site Planning for Urban Stream Protection*, which presents a watershed approach to site planning and examines new ways to reduce pollutant loads and protect aquatic resources through nonstructural practices and improved construction site planning. The book also provides insight into the importance of imperviousness, watershed-based zoning, concentration of development, headwater streets, stream buffers, green parking lots, and other land planning topics. The document is available for purchase from MWCOG at http://www.mwcog.org/ic/95708.html.

The *Texas Nonpoint SourceBOOK* is an interactive Web tool that was designed to provide runoff management information to public works professionals and other interested parties in Texas and elsewhere. This site, which can be accessed at http://www.txnpsbook.org/, includes a beginner's guide to urban nonpoint source management issues, a discussion of water quality issues in Texas, elements of a storm water management program, information on storm water utilities, tips for assessing and selecting management practices, a comprehensive listing of links to other sites, frequently asked questions, and nonpoint source news.

In 1999 the Denver Urban Drainage and Flood Control District published the *Urban Storm Drainage Criteria Manual*. The manual was designed to provide guidance for local jurisdictions, developers, contractors, and industrial and commercial operators in selecting, designing, implementing, and maintaining management practices to improve runoff quality. The third volume of this manual is primarily targeted at developing and redeveloping residential and commercial areas. The manual is available for purchase at http://www.udfcd.org/.

In 1995 EPA published *Economic Benefits of Runoff Controls* (EPA-841-S-95-002), which contains a description of studies that document increases in property values and rental prices when properly designed runoff controls are used as visual amenities. The document is available for download from EPA's National Environmental Publications Internet Site (NEPIS) at http://www.epa.gov/ncepihom/nepishom.

EPA published the *Preliminary Data Summary of Urban Storm Water Best Management Practices* in 1999. The document summarizes existing information and data on the effectiveness of management practices to control and reduce pollutants in storm water. The report also provides a synopsis of what is currently known about the expected costs and environmental benefits of management practices, and identifies information gaps. The document is available for download in PDF format at http://www.epa.gov/ost/stormwater/usw_a.pdf.

In 1992 the Washington State Department of Ecology published its *Stormwater Management Manual for the Puget Sound Basin*. The manual is divided into five documents: Volume I: Minimum Technical Requirements; Volume II: Construction Stormwater Pollution Prevention; Volume III: Hydrologic Analysis and Flow Control Design; Volume IV: Source Control BMPs;

and Volume V: Runoff Treatment BMPs. All five volumes are available for download at http://www.ecy.wa.gov/biblio/9911.html.

The Washington State Department of Ecology's Water Quality Program has developed a Nonpoint Source Pollution home page. This Web site, accessible at http://www.ecy.wa.gov/programs/wq/nonpoint, contains nonpoint source program information, posters, resources, and references. The Department of Ecology has also made available a copy of the draft of *Instream Flows in Washington State: Past, Present, and Future*. The document is available at http://www.olympus.net/community/dungenesswc/InstreamFlowversion12.PDF.

The Metropolitan Council of St. Paul/Minneapolis developed the *Urban Small Sites Best Management Practices (BMP) Manual* to provide assistance to communities in planning for storm water management for sites of less than 5 acres located in cold climates. The document focuses on low-impact development practices that promote the restoration and preservation of natural hydrology. The manual includes information on the selection of BMPs and model storm water ordinances and contains a regulatory analysis for watershed programs. The document is available at http://www.metrocouncil.org/environment/Watershed/bmp/manual.htm.

An excellent discussion of the design of infiltration techniques in limestone/carbonate bedrock areas can be found in a new design manual developed for the Lehigh Valley Planning Commission (LVPC) by Cahill Associates. The manual, *Technical Best Management Practice Manual and Infiltration Feasibility Report: Infiltration of Stormwater in Areas Underlain by Bedrock in the Little Lehigh Creek Watershed,* is available from the LVPC at 961 Marcon Boulevard, Suite 310, Allentown, Pennsylvania, 18109, 1-888-627-2626 (toll free), lvpc@lvpc.org.

The Virginia Municipal League published an article titled "Stafford County helps pioneer low impact design movement" describing the process by which Stafford County, Virginia, incorporated low-impact design into its development codes. The article includes links to Builders for the Bay, an organization that provides assistance to local communities wishing to update their codes, as well as several other helpful resources for communities. The article can be downloaded at http://www.vml.org/VTC/VTC3908-2.html.

The American Mosquito Control Association's Web site, located at http://www.mosquito.org/, offers information about mosquitoes and their control along with links, frequently asked questions, and West Nile virus information.

American Rivers developed a report on low impact development techniques for the Great Lakes region called *Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management.* The report includes an overview of many runoff control techniques, including pros and cons of each practice. The report can be downloaded in PDF format from the American Rivers Web site at www.americanrivers.org (visit the "Resources" link and choose to view a complete list of publications).

The Villanova University Stormwater Partnership conducts research on management practices to control urban runoff. The organization has established a "Stormwater BMP Park" with a constructed wetland, a biofiltration traffic island, and a porous concrete site. Research results and outreach materials can be found at http://www3.villanova.edu/VUSP/.

The EPA "Final Action for Effluent Guidelines and Standards for the Construction and Development Category" can be found at http://www.epa.gov/fedrgstr/. The Technical Development Document (EPA-821-B-04-001), which contains information on costs and technologies, is available from US EPA/NSCEP. P.O. Box 42419, Cincinnati, Ohio 45242-2419, (800) 490-9198 or http://www.epa.gov/waterscience/guide/construction.

EPA's *The Use of Best Managment Practices (BMPs) in Urban Watersheds* evaluates design, effectiveness, and cost considerations for storm water management practices. The document canbe downloaded in PDF format from http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184.pdf (cover and table of contents) and http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184chap1.pdf (Chapters 1–6).

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