Current Water Quality Best Management Practices Design Guidance

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The objective is to document current Best Management Practices (BMP) design guidance. A BMP mitigates adverse stormwater impacts (quantity or quality, or both) associated with land development activities. The water quality benefits of BMPs in treating urban stormwater runoff are the focus. Several BMPs are described in terms of their applicability, pollutant removal efficiency, and general design parameters. These include extended detention ponds, wet ponds, infiltration trenches and basins, sand filters, porous pavement, and vegetative practices (including constructed wetlands).

Urban best management practices (BMP) are used to mitigate the adverse stormwater impacts associated with development activities. BMPs can be used for stormwater (quantity) control benefits or pollutant removal capabilities (quality control), or both. Several BMP options are available and should be carefully considered based on site-specific conditions, economy, and the overall management objectives of the watershed.

The discussion of BMPs in this paper focuses on the water quality benefits of various mitigation measures, including the following:

- Extended detention ponds,
- Wet ponds,
- Infiltration trenches,
- Infiltration basins,
- Porous pavement,
- Sand filters, and
- Vegetative practices.

In addition to the pollutant removal capability of each measure, limited design guidance is also provided. Several factors are involved in determining the suitability of a particular BMP, including physical conditions at the site, the watershed area served, and stormwater and water quality objectives. In terms of water quality benefit, Table 1 provides a comparative analysis of pollutant removal for various BMP designs (*1*). Generally, BMPs provide high pollutant removal for nonsoluble particulate pollutants, such as suspended sediment and trace metals. Lower rates are achieved for soluble pollutants such as phosphorus and nitrogen.

GENERAL BMP SELECTION GUIDANCE

State and local governments generally adopt stormwater management water quality criteria as they relate to the selection of BMP (*2*). The criteria can involve requirements that compel a developer to design a facility that meets either a performance-based standard or a technology-based standard.

Virginia's Department of Conservation and Recreation recently adopted such criteria. The performance criteria are based on required phosphorus removal efficiency depending on the size of the contributing drainage area. Those criteria follow:

- Drainage areas less than 2 ha (5 acres) must remove at least 15 percent of the total phosphorus pollutant load after development,
- Drainage areas 2 ha (5 acres) or greater must remove at least 40 percent of the total phosphorus pollutant load after development, and
- The predevelopment load shall be based on an equivalent average cover of 16 percent imperviousness or 0.5 kg/ha/year (0.45 lb/acre/year).

The technology-based criteria involve selection of a particular BMP based on a project's percent impervious area and the size of the contributing drainage area. Table 2 summarizes these criteria.

EXTENDED DETENTION PONDS

Dry ponds, or extended detention ponds, are depressed basins that store a portion of stormwater runoff following a storm event. Water is typically stored for up to 48 hr following a storm by means of a hydraulic control structure that restricts outlet discharge. Detention of the stormwater provides an opportunity for urban pollutants carried by the flow to settle out. The water quality benefits of a detention pond can be increased by extending the detention time. Removal of as much as 90 percent of particulates is possible if stormwater is retained for 24 hr or more. Extended detention ponds are normally dry between storm events. They do not retain a permanent water pool. Figure 1 shows the plan and profile views of a typical extended detention facility and its components.

Pollutant Removal Capabilities

Up to 90 percent of particulate settling can be achieved in an extended detention pond; however, removal effectiveness for soluble particulates, such as nitrogen, is limited. Addition of a wetlands to act as a biological filter at the lower stage of the pond introduces biological processes that can significantly increase the removal of soluble compounds. Table 1 shows the pollutant removal capability of two different extended detention pond designs.

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TABLE 1 Pollutant Removal Comparison for Various Urban BMP Designs

BMP/design	Pollutant removal efficiency (%)						
	Suspended Sediment	Total Phosphorus	Total Nitrogen	Oxygen Demand	Trace Metals	Bacteria	Overall Removal Capability
Extended detention pond							
Design 1	60 - 80	20 - 40	20 - 40	20 - 40	40 - 60	Unknown	Moderate
Design 2	80 - 100	60 - 80	40 - 60	40 - 60	60 - 80	Unknown	High
Wet pond							
Design 3	60 - 80	40 - 60	20 - 40	20 - 40	20 - 40	Unknown	Moderate
Design 4	80 - 100	60 - 80	40 - 60	40 - 60	60 - 80	Unknown	High
Infiltration trench							
Design 5	60 - 80	40 - 60	40 - 60	60 - 80	60 - 80	60 - 80	Moderate
Design 6	80 - 100	60 - 80	60 - 80	80 - 100	80 - 100	80 - 100	High
Infiltration basin							
Design 5	60 - 80	40 - 60	40 - 60	60 - 80	40 - 60	60 - 80	Moderate
Design 6	80 - 100	60 - 80	60 - 80	80 - 100	80 - 100	80 - 100	High
Porous pavement							
Design 5	40 - 60	60 - 80	40 - 60	60 - 80	40 - 60	60 - 80	Moderate
Design 6	80 - 100	60 - 80	60 - 80	80 - 100	80 - 100	80 - 100	High
Filter strip							
Design 8	20 - 40	0 - 20	0 - 20	0 - 20	20 - 40	Unknown	Low
Design 9	80 - 100	40 - 60	40 - 60	40 - 60	80 - 100	Unknown	Moderate
Grassed swale							
Design 10	0 - 20	0 - 20	0 - 20	0 - 20	0 - 20	Unknown	Low
Design 11	20 - 40	20 - 40	20 - 40	20 - 40	0 - 20	Unknown	Low
Sand Filter							
Design 12	85	40	35	Unknown	50 - 70	40	Moderate
Design 13	90	70	50	90	80	90	High
Biofiltration Swale	83	29	Unknown	Unknown	46 - 72	--	Moderate

Design 1: First-flush runoff volume detained for 6-12 h. **Design 2**: Runoff volume produced by 25 mm (1.0 in), detained 24 h, but with shallow marsh in bottom stage. **Design 3**: Permanent pool equal to 13 mm (0.5 in) storage per impervious acre. **Design 4**: Permanent pool equal to 4.0 (Vr); approx. 2 weeks retention. **Design 5**: Facility exfiltrates first-flush; 13 mm (0.5 in) runoff/imper. acre. **Design 6**: Facility exfiltrates all runoff, up to the 2-yr design storm. **Design 7**: 11 m^3 (400 ft^3) wet storage per impervious acre. **Design 8**: 6-m (20-ft) wide turf strip. **Design 9**: 30-m (100-ft) wide forested strip, with level spreader. **Design 10**: High-slope swales with no check dams. **Design 11**: Low-gradient swales with check dams. **Design 12**: Non-peat (Austin, Texas) sand filter. **Design 13**: Peat-sand filters.

Design Guidance

Extended detention ponds are typically used for drainage areas of 4 ha (10 acres) or more. To achieve the desired water quality benefits, the dry pond must have the appropriate storage volume and detention time. The basic dimensions of the pond are dependent on the required BMP volume and other site-limiting factors such as topography, existing and proposed utilities, depth to bedrock, and so forth. Guidance related to the design of a dry pond follows (*3*):

- *Storage:* Structure should store a minimum of 13 mm ($^1/_2$ in.) of runoff in the extended detention pool and should store and attenuate the 2- and 10-year storm events in the standard detention pool, and safely pass the 100-year storm.
- *Detention time:* Detention time should be a minimum of 24 hr; 48-hr detention time would achieve maximum pollutant removal.
- *Hydraulic devices:* An outflow hydraulic device can be used to detain stormwater flow for a specific time to allow for settling of pollutants. Orifice-type designs are typically used to release the stormwater over a 24- to 48-hr period.

TABLE 2 Technology-Based Criteria Matrix for BMP Selection

% Impervious of property to control point	Drainage Area	
	< 5 ac	≥ 5 ac
0-21	TYPE I BMP vegetated filter strip grass swale	TYPE V BMP extended detention retention
22-37	TYPE II BMP modified grass swale extended detention	TYPE VI BMP extended detention retention
38-66	TYPE III BMP biofiltration swale modified extended detention constructed wetlands infiltration	TYPE VII BMP modified extended detention constructed wetlands infiltration modified retention
67-100	TYPE IV BMP any combination of II & III	TYPE VIII BMP any combination of VI & VII

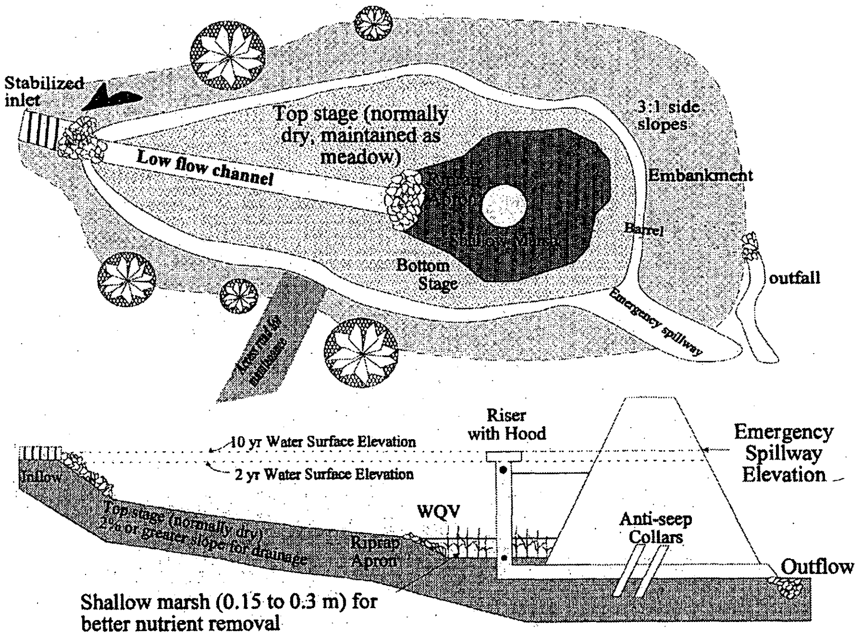

FIGURE 1 Extended detention pond.

- *Channels:* Riprap stabilization should be provided within the low flow channel in the basin and at the outflow channel to resist erodible velocities, spread the flow, and prevent scour.
- *Pond slopes:* Upper stage should contain a minimum 50 to 1 (h:v) grade, lower stage is essentially flat, side slopes should be no steeper than 3 to 1 (h:v) and no flatter than 20 to 1 (h:v).
- *Embankment:* Freeboard of 0.3 m (1 ft) should be provided above the design high-water elevation.
- *Buffers:* A minimum 7.5-m (25-ft) wide buffer strip between the pond and private residences should be provided and landscaped with low-maintenance vegetation.

WET PONDS

A wet pond, or retention pond, serves the dual purpose of controlling the volume of stormwater runoff and removing pollutants from the runoff. Wet ponds are designed to retain a permanent pool during dry weather. Wet ponds are an attractive BMP alternative because the permanent pool can be used for recreation and as an emergency source of water. Volumes of water above the permanent pool are released by hydraulic outlet devices designed to discharge flows at various elevations and peak flow rates.

Pollutant Removal Capabilities

Research indicates that wet ponds are more effective at removing pollutants than extended detention dry ponds (*4*). Pollutant removal in wet ponds is accomplished through gravity settling, biological stabilization of solubles, and infiltration. Reliable pollutant removal can be achieved if the permanent pool is sized to store between 13 to 26 mm (0.5 to 1.0 in.) of runoff per contributing watershed area.

Nutrient removal efficiencies of wet ponds have been shown to vary directly with the ratio of the volume of the permanent pool to the volume of runoff produced from the mean storm (0.45 * in. * watershed acres). Table 1 shows the pollutant removal capabilities of three different wet pond designs.

Design Guidance

Wet ponds are typically used for drainage areas of 4 ha (10 acres) or more. To achieve the desired water quality benefits, the permanent pool in the wet pond must be at least three times the water quality volume. The basic dimensions of the pond are dependent on the required storage volume and other site-limiting factors such as topography, existing and proposed utilities, depth to bedrock, and so forth. Other factors, such as a sediment forebay and a vegetated perimeter, increase the pollutant removal effectiveness of the pond. Guidance related to several factors involved in the design of a wet pond are provided below (*3*).

- *Volume:* Permanent pool volume should be at least three times the water quality volume (*5*) (using 13 mm (0.5 in) of runoff over the catchment determines water quality volume). Wet pond should attenuate 2- and 10-year runoff events to predevelopment flood peaks, and safely pass the 100-year storm.
- *Shape:* Pool shape should take advantage of the natural site topography. Typically, wet ponds are wedge shaped, with a length-to-width ratio of 3 to 1.
- *Benches and ledges:* Benches are shallow shelves along the permanent pool perimeter, usually less than 0.9 m (3 ft) deep. The ledge width is at least 3 m (10 ft). The shelf area design provides a platform for aquatic plants or a safety zone. The shelf for aquatic plants should be shallow, approximately 0.3 to 0.6 m (1 to 2 ft),

depending on the aquatic species selected. The slope leading to the edge should be 1 to 3 or flatter.

- *Depth:* The pool must be deep enough to satisfy volume requirements. [Typical average pond depths are 0.9 to 2.4 m (3 to 8 ft).]
- *Sediment forebay:* Forebay design should include a method to either reduce velocities at the inlet (such as a flat bench) or an entrance stilling basin to allow sediment to drop out before entering the main pool.
- *Hydraulic devices:* An outlet device, typically a riser-pipe barrel system, should be designed to release runoff in excess of the BMP volume and to control storm peaks.
- *Buffers:* A landscaped buffer strip at least 7.5-m (25-ft) wide should be provided around the perimeter of the pond.

INFILTRATION TRENCHES

Infiltration trenches are shallow excavations that have been backfilled with a coarse stone media. The trench forms an underground reservoir that collects runoff (infiltration) and either exfiltrates it to the subsoil or diverts it to an outflow facility. Infiltration trenches are suitable for drainage areas of less than 2 ha (5 acres). The trenches primarily provide moderate to high removal of fine particulates and soluble pollutants, but also are used to restore peak flows to predevelopment levels. Use of an infiltration trench is feasible only when soils are permeable and the groundwater table is below the bottom of the trench. Figure 2 is a schematic of a typical infiltration trench (*6*).

Pollutant Removal Capabilities

Pollutant removal mechanisms in a trench system include adsorption, straining, and microbial decomposition below the trench. Pretreatment areas, such as grassed swales leading to the trench, are typically used to remove coarse particulate contaminants to avoid clogging the trench.

Research on rapid infiltration land wastewater treatment systems provides a basis for estimating the performance of infiltration trenches. Table 1 summarizes pollutant removal rates for two different infiltration trench designs.

Design Guidance

There are three basic types of infiltration designs: complete exfiltration, partial exfiltration, and water quality systems. Complete exfiltration trenches have a stone reservoir large enough to store the entire design storm runoff volume and exfiltrate all runoff to underlying soils. Partial exfiltration trenches provide short-term underground detention, which is most effective during smaller storms. Current designs use a perforated underdrain at the bottom of the trench to collect runoff and direct it to a central outlet. Water quality trenches only accommodate first-flush volumes. The first flush is defined as the first 13 mm (0.5 in.) of runoff per contributing impervious acre.

The facility should infiltrate the water quality volume within 48 hr. Infiltration trenches generally serve small drainage areas

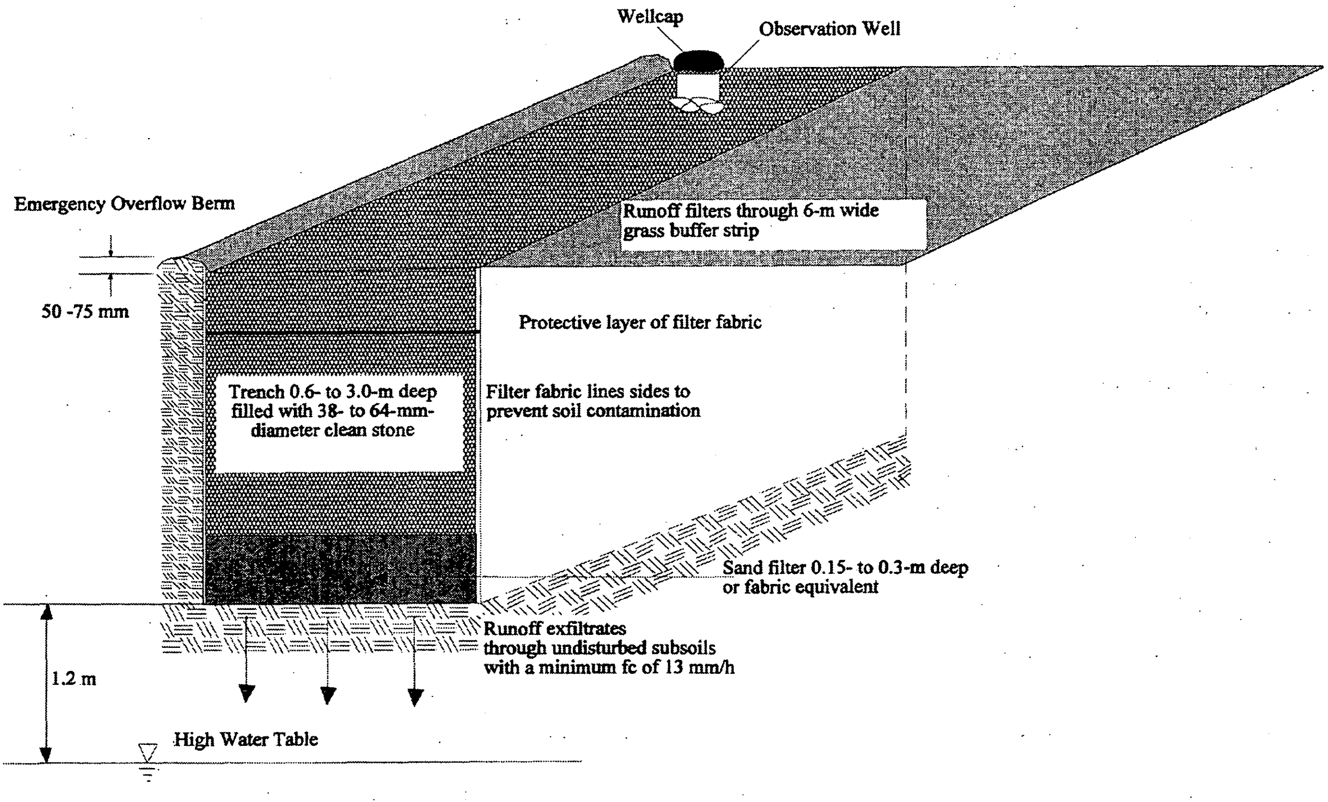

FIGURE 2 Schematic of an infiltration trench.

(such as parking lots) and are usually not designed to control peak storm flows. Once the storage volume has been determined, the dimensions of the facility can be estimated.

Design Considerations

- Filter cloth should surround all sides of the trench and should have at least a 0.3-m (1-ft) overlap on the top of the trench to prevent soil contamination and to protect the groundwater.
- Observation well is a perforated 100- to 150-mm (4- to 6-in.) polyvinyl chloride pipe located at the center of the infiltration trench. (The well is used to inspect the facility, monitor sediment accumulation, and determine when trench dewatering is necessary.)
- A 50- to 75-mm (2- to 3-in.) emergency overflow berm should be located on the downstream side of the trench.
- A vegetated buffer strip that conveys surface flow to the trench should be located on all sides of the trench.

Trench Location

- The trench should be between 0.6- and 3.0-m (2- and 10-ft) deep. Underlying soils must provide infiltration rates greater than 13 mm (0.5 in.)/hr.
- The trench bottom should be situated a minimum of 1.2 m (4 ft) above the seasonal high water table.
- A 0.15- to 0.3-m (6- to 12-in.) deep filter of clean washed sand may be substituted for the filter fabric on the bottom of the trench.
- For trenches located below the ground surface, a minimum of 0.3 m (1 ft) of soil cover should be provided for the establishment of vegetation.
- Trenches should be located at least 30 m (100 ft) away from a drinking water well (*1*). If the bottom of the basin is too close to a potable water supply, an impermeable liner should be used so runoff does not infiltrate into the groundwater system.

Backfill Material

- Backfill material in the trench should have a D_{50} of between 38 and 76 mm (1.5 and 3 in.).
- Porosity of the material should be between 0.3 and 0.4.
- Minimum thickness of the backfill layer should be 0.3 m (1.0 ft).

INFILTRATION BASINS

An infiltration basin is an excavated area that impounds stormwater flow and gradually exfiltrates it through the basin floor. They are similar in appearance and construction to conventional dry ponds. The detained runoff is exfiltrated through permeable soils beneath the basin, removing both fine and soluble pollutants. Basins can be adapted to provide stormwater management functions by attenuating peak discharges from large design storms, and can serve drainage areas up to 20 ha (50 acres).

Pollutant Removal Capabilities

Infiltration basins remove fine and soluble particulate pollutants from runoff by slowly exfiltrating stored flow through the underlying soil layer. Removal mechanisms include adsorption, straining, and microbial decomposition in the basin subsoils. Trapping of large particulate matter is accomplished within pretreatment areas to minimize clogging. Table 1 summarizes pollutant removal rates for two different infiltration basin designs.

Design Guidance

Infiltration basins typically serve small watersheds, 2 to 20 ha (5 to 50 acres). For the basin to function properly, soils at the basin site should have a minimum exfiltration rate of 13 mm/hr (0.5 in./hr). Basins should be located a minimum of 1.2 m (4 ft) above bedrock and the seasonally high groundwater table. The following equation can be used to determine the depth of the basin:

$$d = \frac{f \cdot T_s}{1000} \tag{1}$$

where:

d = basin depth (m),
f = soil infiltration rate (mm/hr), and
T_s = basin detention time (hr).

Guidance related to several factors involved in the design of infiltration basins follows.

- *Degree of exfiltration:* To achieve high pollutant removal rates, the basin should provide for the exfiltration of the first half in. of runoff per contributing impervious acre.
- *Quantity:* Quantity in an infiltration basin is controlled in a manner similar to that in detention ponds. The basin should be designed to attenuate the peak flows from the 2- and 10-year flows, and pass the 100-year storm safely.
- *Basin shape:* The floor of the basin should be graded as flat as possible to permit uniform ponding and exfiltration; embankment side slopes should have a maximum slope of 3:1 for ease of mowing and bank stabilization.
- *Vegetation:* The floor of the infiltration basin should be stabilized by a dense turf of water-tolerant reed canary grass or tall fescue (*6*). (The dense turf promotes pollutant filtering and prevents erosion of the basin floor.)
- *Buffer:* A minimum 7.6-m (25-ft) buffer should be maintained between the infiltration basin and adjacent properties.
- *Access:* A 3.7-m (12-ft) wide access road to the basin floor should be provided for use by light equipment.

POROUS PAVEMENT

Porous pavement allows surface runoff to permeate through the road and into an underlying gravel or stone reservoir. Runoff stored in the reservoir is then exfiltrated to the subsoil. A typical porous pavement system is illustrated in Figure 3. Porous pavement is an effective means of removing both soluble and fine particulates in urban runoff, provided that it is properly designed and maintained. Use is limited to low volume parking areas and restricted traffic roadways. As a BMP, porous pavement is feasible only on sites having deep permeable soils and low water table and bedrock levels.

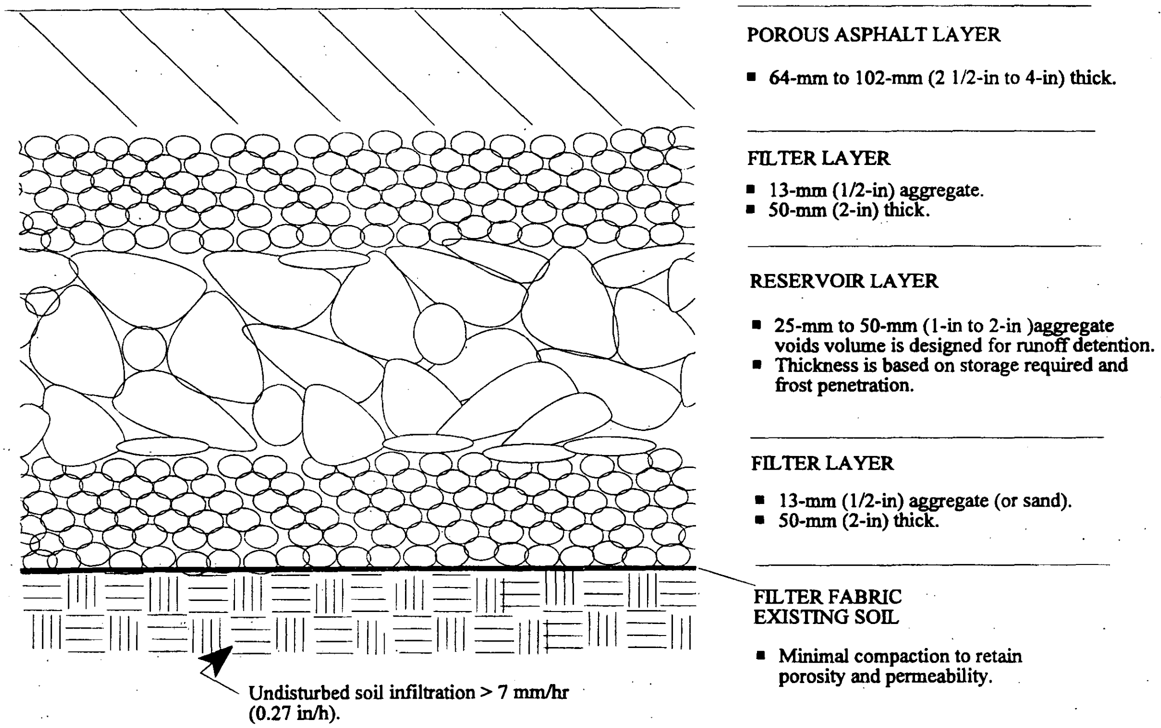

FIGURE 3 Porous asphalt paving typical section.

Pollutant Removal Capabilities

Porous pavement is designed primarily to remove fine-grained and soluble pollutants from runoff. Coarse pollutants should not be introduced to the pavement system because they can clog the asphalt and filter cloth pores, reducing the efficiency of the system. Pollutant removal mechanisms in a porous pavement system include adsorption, trapping and straining of fine-grained particles, and microbial decomposition below the pavement. Table 1 summarizes the pollutant removal capabilities of two different porous pavement designs.

Design Guidance

The critical design consideration in a porous pavement system is the depth of the large aggregate layer, which is a function of detention time, porosity of the aggregate, and the soil infiltration rate. The bottom of the facility should be located below the frost line and approximately 1.2 m (4 ft) above bedrock and the seasonal high water table. The following are design considerations for the proper design of an effective porous pavement system:

- *Applicability:* Parking areas and low traffic volume roads are the most suitable areas for porous pavements. Drainage areas for porous paving sites are generally between 0.1 and 4.0 ha (1/4 and 10 acres).
- *Practicality:* Porous pavement can be a cost-effective BMP in commercial areas. Costs have been shown to be comparable to conventional pavement systems (*4*). As a storage facility, porous pavement can recreate predevelopment hydrology, provide increased groundwater recharge, and is an excellent pollutant remover. To maintain an effective porous pavement system, care must be taken to prevent clogging of the voids.
- *Soils:* For a porous pavement system to be feasible, the infiltration rate of soils should be at least 7 mm/hr (0.27 in./hr). Clay content within the soil should be less than 30 percent.
- *Slope:* Grades at porous pavement sites should be as flat as possible, preferably less than 5 percent.
- *Sediment inputs:* Sediment should be kept completely away from a porous pavement system before, during, and after construction. Post-construction sediment control is extremely important to prevent pavement failure from clogging. The proper sediment and erosion control practices must be instituted to ensure that sediment is not tracked onto the pavement by construction vehicles.

SAND FILTERS

Sand filters provide stormwater treatment in which first-flush runoff is strained through a sand bed before being returned to a stream or channel. Sand filters are generally used in small parking lots and urban areas and are particularly useful for groundwater protection where infiltration into soils is not feasible. Alternative designs of sand filters use a top layer of peat or some form of grass cover through which runoff is passed before being strained through the sand layer. This combination of layers increases pollutant removal.

Pollutant Removal Capabilities

The main pollutant removal mechanism in a sand filter is straining through the sand or peat. Limited nutrient removal is accomplished through biological uptake at the grass cover crop.

Performance monitoring studies have been performed for three sand filter systems in Austin, Texas (*6*). Pollutant removal efficiencies for enhanced systems using peat and sand layers has been estimated empirically (7). Table 1 presents the removal percentages for various pollutants for both the sand filters studied in Austin, Texas, and the estimated sand-peat system.

Design Guidance

Sand filters generally provide water quality treatment of runoff from watershed areas between 0.2 to 4.0 ha ($^1/_2$ to 10 acres). They are mainly used to treat small parking lots and ultra-urban areas. It is feasible to apply a sand filter system in areas that preclude the use of infiltration devices, such as areas where soils are thin, evaporation rates are high, and soil infiltration rates are low. The use of sand filters is also ideal as a retrofit BMP for established urban watershed areas, specifically those areas developed before the passage of stormwater management regulations.

VEGETATIVE PRACTICES

Several types of vegetative BMPs can be applied to convey and filter runoff. They are discussed in this paper under grassed swales, filter strips, and wetlands.

Vegetative practices are nonstructural BMPs and are significantly less costly than structural controls. Typically, vegetative practices are used with structural BMPs, particularly as a means of pretreating runoff before it is transferred to a location for retention, detention, storage, or discharge. Level spreaders are excavated depressions that run across the swale perpendicular to the flow. Level spreaders and check dams may be incorporated into a swale design to reduce overland runoff velocities. Figure 4 is a schematic of a grassed-swale, level spreader, and check dam.

Grassed Swales

Swales are generally used as roadside channels or as alternatives to curbs and gutters in residential areas. Grassed conveyances are designed to store, filter, and infiltrate runoff and to reduce runoff velocities to control peak discharges.

Pollutant Removal Capability

Pollutant removal mechanisms of a grassed swale include the filtering action of the grass, which removes particulate pollutants, and infiltration into the subsoil, which removes soluble pollutants. A recent study on biofiltration swales indicates the following removal rates shown in Table 1 (8). These results are based on 9.3 min of residence time for a 61-m (200-ft) swale. Pollutant removal rates can be expected to be less with a shorter residence time and shorter swale length. Residence time refers to the time period that runoff comes into contact with the vegetation and soils. The actual rate of removal for a swale depends on the length, slope, soil permeability, hydraulic residence time, flow depth, runoff velocity, and the characteristics of the vegetation. The expected removal efficiency of a well-designed, well-maintained conventional swale is summarized in Table 1 for two different designs.

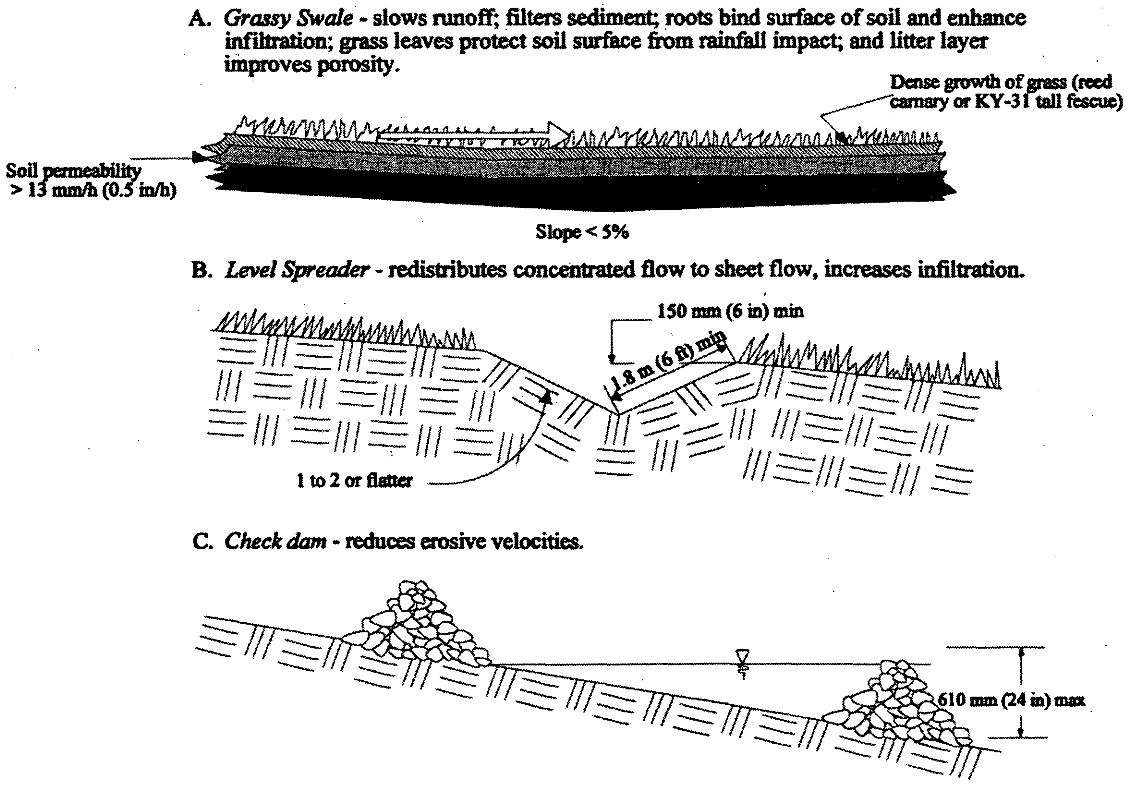

FIGURE 4 Schematic of grassed-swale level spreader and check dam.

Design Guidance

Grassed swales are designed to provide erosion protection, remove pollutants, and provide a transition to channels, inlets, and receiving waters. Designers of swales should consider site topography, slope, and soil infiltration rates. Swale shapes are typically trapezoidal or parabolic, with side slopes 3:1 or flatter. The infiltration rate of underlying soil should be greater than 13 mm/hr (0.5 in./hr), although this is not necessary. Grassed swales clean water primarily through particle fallout resulting from reduced velocities, instead of infiltration into the subsoil.

Filter Strips

Filter strips are similar to grassed swales but differ in that they are designed to convey only overland sheet flow. Filter strips are used to filter runoff before its entrance to a channel, infiltration facility, or receiving water.

Pollutant Removal Capability

The pollutant removal efficiencies of filter strips are similar to that of grassed swales. Moderate to high removal of particulate pollutants (sediment, organic material, trace metal) can be expected. Filter strips are less efficient at removing soluble pollutants because of the small portion of runoff that is infiltrated into the soil.

Design Guidance

Filter strips should be constructed with dense, deep-rooted, water-resistant grass. Forested filter strips can also be used and are often preferred because of their higher pollutant removal capabilities (*1*). Appropriate sizing of a filter strip is important to achieving adequate pollutant removal. It is suggested that strips be a minimum of 6 m (20 ft) in length, with a recommended length of 24 to 30 m (80 to 100 ft) (*9*). Other sources indicate that the length be at least as long as the contributing runoff area to achieve optimal removal (*1*). Slopes of filter strips should be no greater than 5 percent.

To evenly distribute flow over the filter strip, a level spreader should be used. The spreader prevents the formation of eroded channels in the strip, which causes "short circuiting" of the strip.

Wetlands

Wetlands can be a highly efficient means of removing pollutants from urban runoff. Often, wetlands or shallow marshes are used with other BMPs (such as at the lower stage of an extended detention pond) to achieve maximum pollutant removal. A recent study concluded that detention basins and wetlands appear to function equally well at removing monitored pollutant parameters (*10*). An ideal design of a wetland as a quality measure would include the creation of a detention basin upstream of the wetland, which pretreats stormwater. The detention basin provides an area where heavy particulate matter can settle out, minimizing disturbance of the wetland soils and vegetation.

Pollutant Removal Capability

Pollutant removal mechanisms at work in a wetland system include sedimentation, adsorption, filtration, infiltration, and biological uptake. The removal processes within a wetland are not fully understood, and actual removal efficiencies are difficult to gauge. A wide variation of removal efficiency is generally observed because of the wide range of wetland characteristics (vegetation, hydrology).

Recent case studies have investigated the pollutant removal efficiencies of wetlands (*10*). These studies monitored total suspended solids (TSS), nutrients, and metals. There is a wide variability in the reported efficiencies of the wetlands, but some general conclusions can be drawn.

- Median removal efficiency for TSS was 76 percent, indicating good pollutant removal potential for fine particulate pollutants;
- Removal efficiencies are higher and more consistent in constructed wetlands than in natural systems; and
- Nutrient removal is variable and is a function of the season, vegetation type, and other wetland characteristics.

Design Guidance

Careful design of a wetland system is necessary to achieve good pollutant removal capabilities, specifically as it relates to establishment of vegetation. As mentioned earlier, wetlands are often used with ponds: either at the perimeter of a wet pond, at the lower stage of an extended detention pond, or in a sediment forebay. The following design guidance describes methods for the successful establishment of a wetlands (*1*):

- *Site Selection:* A potential wetland site must have sufficient inflow (baseflow and runoff) to maintain a constant water pool. Outflow by infiltration must be less than the inflow to the basin. Soils in the area should support this balance; otherwise, a clay or plastic liner must be used.
- *Water depth:* Many types of wetlands vegetation require specific water depths in order to flourish. Grading of the basin should be done carefully to achieve appropriate depths throughout the wetlands. Approximately 75 percent of the wetland pond area should have water depths less than 300 mm (12 in.) (*4*). This provides the optimal growth depth for most wetland plant species.
- *Aquatic bench:* A perimeter area of approximately 3 to 6 m (10 to 20 ft) beyond the constant pool of the wetlands, which is periodically flooded during runoff events, should be established for aquatic emergents.
- *Outlet structure:* Wetland basins should use an extended detention time of 24 hr for a 1-year storm (*4*). Outlet structures should be designed to dam up the water necessary for the wetland, detain the volume required for extended detention, and permit water to flow from the wetland without blockage. If extended detention is not possible, the surface area of the marsh should constitute approximately three percent of the contributing watershed (*1*).
- *Vegetation:* At least five different wetland species should be established in the marsh. Two primary species should be planted throughout 30 percent of the total shallow water area, 0.6 to 0.9 m (2 to 3 ft) apart. Up to three secondary species should be established, approximately 125 plants per ha (50 plants per acre), around the perimeter of the wetland.

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