CHAPTER

3

STORMWATER CONTROLS

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3.1.1 Stormwater Management Controls - Categories and Applicability

3.1.1.1 Introduction

Stormwater management structural controls are engineered facilities intended to treat stormwater runoff and/or mitigate the effects of increased stormwater runoff peak rate, volume, and velocity due to development. This section provides an overview of structural stormwater controls (also called stormwater management facilities) that can be used to address local stormwater management standards. Many of the structural stormwater controls can be used in an Integrated Site Design (ISD) approach, where a control (or set of controls) are designed and constructed to achieve multiple objectives: 1) water quality control; 2) channel protection; and 3) flood control. More information on the ISD Approach is provided in Volume 2, Chapter 1.

3.1.1.2 Control Categories

The stormwater management controls recommended in this Manual vary in their applicability and ability to meet stormwater management goals. These stormwater controls fall into three categories, depending upon their applicability to remove the pollutant of concern for both the City of Wichita and Sedgwick County which is total suspended solids (TSS). The three categories are: primary TSS treatment facilities, secondary TSS treatment facilities, and other stormwater management facilities.

Primary TSS Treatment Facilities

Primary TSS treatment facilities are structural controls that have the ability to effectively treat the Water Quality Volume (WQ_v) and have been shown to be able to remove up to 90% of the annual average total suspended solids (TSS) load in typical post-development urban runoff when designed, constructed, and maintained in accordance with recommended specifications. These controls are recommended for use with a wide variety of land uses and development types. Several of these controls can also be designed to achieve other ISD approach objectives, that is, downstream channel protection and/or flood control. Primary TSS treatment facilities are recommended for a site wherever feasible and practical.

Secondary TSS Treatment Facilities

Secondary TSS treatment facilities are recommended only for limited use or for special site or design conditions. Generally, these practices are: (1) intended to address “hotspot” or specific land use constraints or conditions; and/or, (2) have high or special maintenance requirements that may discourage their use. These types of structural controls are typically used for water quality treatment only. Some of these controls can be used as a pretreatment measure or in series with other structural controls to meet pollutant removal goals.

Other Stormwater Management Facilities

Other stormwater management facilities are controls that do not provide TSS treatment and therefore may be used for runoff quantity control only (i.e., peak discharge or volume control). These controls should be used in coordination with primary or secondary TSS treatment facilities. This category also includes the green (or vegetated) roof which is a special control that addresses both water quality and quantity, because it reduces the amount of stormwater runoff.

Table 3-1 lists the all of the structural stormwater control practices included in this Manual. A summary of the suitability, performance, and other considerations applicable to these controls is presented in Appendix E Table E-1 and Table E-2. A detailed discussion of each of the controls, as well as design criteria and other information, is provided in sections 3.2, 3.3 and 3.4. Operations and maintenance checklists are provided in section **Error! Reference source not found.**.

Table 3-1 Structural Controls

Structural Control	Description
Stormwater (Wet) Ponds (primary)	**Stormwater ponds** are stormwater retention basins that have a permanent pool (or micropool) of water. All or a portion of runoff from each rain event is detained and treated in the pool. A stormwater pond may incorporate a portion of the WQ_v in extended detention above the permanent pool level.
Conventional Dry Detention Pond (other) Dry Extended Detention Pond (primary) Underground Dry Detention (other)	**Conventional dry detention** ponds are surface facilities intended to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts. **Dry extended detention (ED)** ponds are surface facilities intended to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts as well as provide water quality treatment. **Underground detention** tanks and vaults are an alternative to conventional surface dry detention for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area.
Enhanced Dry Swale (primary) Grass Channel (primary)	**Enhanced swales** are vegetated open channels with underdrain provisions that are designed and constructed to capture and treat stormwater runoff within dry cells formed by check dams or other means. **Grass swales or channels** provide “biofiltering” of stormwater runoff as it flows across the grass surface of the conveyance channel.

Structural Control	Description
Infiltration Trench (primary) Soakage Trench (primary)	An **infiltration trench** is an excavated trench filled with stone aggregate used to capture and allow infiltration of stormwater runoff into the surrounding soils from the bottom and sides of the trench. **Soakage trenches** are a variation of infiltration trenches. Soakage trenches drain through a perforated pipe buried in gravel. They are used in highly impervious areas where conditions do not allow surface infiltration and where pollutant concentrations in runoff are minimal (i.e. non-industrial rooftops). They may be used in conjunction with other stormwater devices, such as downspouts.
Filter Strip (primary) Surface Sand Filter (primary) Underground Sand Filter (secondary) Organic Filter (secondary)	**Filter strips** provide "biofiltering" of stormwater runoff as it flows across and through the grassed surface. **Surface sand filters** are structures designed to treat stormwater runoff through filtration, using a sand bed as its primary filter media. Filtered runoff may be returned to the conveyance system, or allowed to partially exfiltrate into the soil. **Underground sand filters** are a design variation of the surface sand filter, where the sand filter chambers and media are located in an underground vault. **Organic filters** are surface sand filters where organic materials such as a leaf compost or peat/sand mixture are used as the filter media. These media may be able to provide enhanced removal of some contaminants, such as heavy metals. Given their potentially high maintenance requirements, they should only be used in environments that warrant their use.
Bioretention Area (primary)	**Bioretention areas** are shallow stormwater basins or landscaped areas which utilize engineered soils and vegetation to capture and treat stormwater runoff. Runoff may be returned to the conveyance system, or allowed to partially infiltrate into the soil or evaporate.
Stormwater Wetland (primary)	**Stormwater wetlands** are constructed wetland systems used for stormwater management. Stormwater wetlands consist of a combination of shallow marsh areas, open water, and semi-wet areas above the permanent water surface.
Proprietary Treatment Systems (secondary)	**Proprietary treatment systems** are manufactured structural control systems available from commercial vendors designed to treat stormwater runoff and/or provide water quantity control. Proprietary systems often can be used on small sites and in space-limited areas, as well as in pretreatment applications. However, proprietary systems are often more costly than other alternatives, may have high maintenance requirements, and often lack adequate independent performance data.
Gravity Separator (secondary)	**Gravity separator** controls use the movement of stormwater runoff through a specially designed structure to remove target pollutants (such as oil from water). They are typically used on smaller impervious commercial sites and urban hotspots. These controls are typically used as a pretreatment measure and as part of a treatment train approach.

Structural Control	Description
Alum Treatment (secondary)	**Alum treatment** provides for the removal of suspended solids from stormwater runoff entering a wet pond by injecting liquid alum into storm sewer lines on a flow-weighted basis during rain events. Alum treatment should only be considered for large-scale projects where high water quality is desired.
Green Roof (other) Modular Porous Paver System (other) Porous Pavement (other)	A **green roof** uses a small amount of substrate over an impermeable membrane to support a covering of plants. The green roof both detains and consumes (through evapotranspiration) runoff from the otherwise impervious roof surface as well as moderates rooftop temperatures. A green roof can also provide aesthetic or habitat benefits. **Modular porous paver systems** consist of open void paver units laid on a gravel subgrade. **Porous pavement** is a permeable surface with an underlying stone reservoir to temporarily store surface runoff before it infiltrates into the subsoil. (Porous concrete is the term for a mixture of course aggregate, Portland cement, and water that allows for rapid movement of water through the concrete.) Both porous concrete and porous paver systems have high workmanship and maintenance requirements.

3.1.2 Suitability of Stormwater Controls to Meet the IDS Approach Objectives

3.1.2.1 Water Quality

All of the primary and secondary stormwater controls provide some degree of pollutant removal. Pollutant removal capabilities for a given structural stormwater control practice are based on a number of factors including the physical, chemical, and/or biological processes that take place in the structural control and the design and sizing of the facility. In addition, pollutant removal efficiencies for the same structural control type and facility design can vary widely depending on the tributary land use and area, incoming pollutant concentration, flow rate, volume, pollutant loads, rainfall pattern, time of year, maintenance frequency, and numerous other factors.

Table 3-2 provides nominal design removal efficiencies for each of the control practices. It should be noted that these values are average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. A structural control design may be capable of exceeding these performances; however the values in the table are minimum reasonable values that can be assumed to be achieved when the structural control is sized, designed, constructed, and maintained in accordance with recommended specifications in this Manual. For some listed controls, pollutant removal rates are not indicated because there is insufficient data for setting those rates, or the removal efficiency is dependent on the design of the specific device or installation. Where the pollutant removal capabilities of an individual structural stormwater control are not sufficient for a given site application, additional controls may be used in series and/or in parallel ("treatment train" approach).

For additional information and data on the range of pollutant removal capabilities for various structural stormwater controls, the reader is referred to the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the International Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

Table 3-2 Design Pollutant Removal Efficiencies for Stormwater Controls (Percentage)

Structural Control	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Metals	Fecal Coliform[g]
Stormwater Pond	80	55	30	50	70
Conventional Dry Detention Pond	a	a	a	a	a
Dry Extended Detention Pond	60	35	25	25	b
Underground Dry Detention Basin	a	a	a	a	a
Enhanced Swale	90	50	50	40	b
Grass Channel	50	25	20	30	b
Infiltration Trench	90	60	60	90	90
Soakage Trench	90	60	60	90	90
Vegetative Filter Strip	50	20	20	40	b
Surface Sand Filter	80	50	30	50	40
Underground Sand Filter	80	50	30	50	40
Organic Filter	80	60	40	75	50
Bioretention Area	85	60	50	80	b
Stormwater Wetland	75	45	30	50	70 g
Proprietary Treatment	c	c	c	c	d
Gravity Separator	c	c	c	d	d
Alum Treatment	90	80	60	75	90
Green Roof	e	e	e	e	e
Modular Porous Paver System	f	80	80	90	f
Porous Pavement	f	80	80	90	f

a for peak flow control only, does not provide appreciable water quality benefit
b insufficient data to assign a pollutant removal value
c removal efficiency depends on specific device
d usually not applicable or determinable
e removal efficiency depends on specific installation
f must not be used to remove TSS due to clogging; use for quantity control only
g Assumes no animal population present to deposit waste in or near the facility

3.1.2.2 Channel Protection

Some of the stormwater management controls presented in this Manual have the ability to detain and regulate the discharge of the 1-year, 24-hour storm event and therefore can provide long-term channel protection volume (CP_v) control. These include stormwater ponds, detention ponds, stormwater wetlands, porous surface systems, and, to some extent, other runoff-detaining or infiltrating facilities.

3.1.2.3 Flood Control

On-Site**:** Selected stormwater management controls (grassed swales, detention ponds, stormwater ponds, and stormwater wetlands) may be used in conjunction with other drainage controls (storm sewers, channels, curbs and gutters, etc.) to safely convey stormwater through a development in accordance with the stormwater drainage design criteria.

Downstream**:** Selected stormwater management controls (grassed swales, infiltration systems, detention ponds, stormwater ponds, and stormwater wetlands) may be used to retain, detain and otherwise regulate the volume and rates of stormwater discharge from flood events, as determined by the downstream assessment, in accordance with flood control criteria.

3.1.3 Selecting Stormwater Management Controls

3.1.3.1 Screening Process

Outlined below is a screening process intended to assist the site designer and design engineer in the selection of the most appropriate structural controls for a development site, and to provide guidance on factors to consider in their physical location.

In general, the following four criteria should be evaluated in order to select the appropriate structural control(s) or group of controls for a development, as summarized in Appendix E, Table E-1:

- Stormwater Management Suitability;
- Relative Water Quality Treatment Performance;
- Site Applicability; and,
- Implementation Considerations.

In addition, for a given site, the following factors should be considered and any specific design criteria or restrictions need to be evaluated, as summarized in Appendix E, Table E-2:

- Physiographic Factors;
- Soils; and,
- Special Considerations.

Finally, environmental and other local, State and federal regulations must be considered as they may influence the location of a structural control on the site, or may require a permit.

The following describes a selection process for comparing and evaluating various structural stormwater controls using a screening matrix and a list of location and permitting factors. These tools are provided to assist the design engineer in selecting the subset of structural controls that will meet the stormwater management and design objectives for a development site or project.

Step 1 - Overall Applicability

Through the use of the four screening categories in the matrix shown in Appendix E, Table E-1, the site designer evaluates and screens the overall applicability of the full set of structural controls as well as the constraints of the site in question. The following are the details of the various screening categories and individual characteristics used to evaluate the structural controls.

Stormwater Management Suitability

The first category in the matrix examines the capability of each structural control option to provide all or part of water quality treatment, downstream channel protection, and flood control requirements. A blank entry means that the structural control cannot or is not typically used to meet the indicated requirement.

Ability to treat the WQ_v: This indicates whether a structural control can be used to treat all or part of the WQ_v. The presence of a “P” or an “S” indicates whether the control is a Primary or Secondary control (see Section 3.1.1.2) for meeting the TSS reduction goal.

Ability to provide the CP_v: This indicates whether the structural control can be used to provide all or part of the extended detention required for the CP_v. The presence of a “P” indicates that the structural control is commonly used. An “S” indicates that the structural control may be used, but the volume provided is usually limited.

Ability to provide Flood Control: This indicates whether a structural control can be used to meet the flood control criteria. The presence of a “P” indicates that the structural control is typically used to provide peak flow reduction of the flood events, including the 100-year storm event. An “S” indicates that the control can be used to reduce the volume and rate of onsite runoff, but is usually not sufficient to provide the majority of flood control.

Relative Water Quality Treatment Performance

The second category of the matrix provides an overview of the pollutant removal performance of each structural control option, when designed, constructed, and maintained according to the criteria and specifications in this Manual.

Ability to provide TSS and Sediment Removal: This column indicates the capability of a structural control to remove sediment in runoff. The Primary (“P”) structural controls remove 30% to 90% of the average annual TSS load in typical urban post-development runoff (and a proportional removal of other pollutants).

<u>Ability to provide Nutrient Treatment:</u> This column indicates the capability of a structural control to remove nutrients (nitrogen and phosphorus) in runoff.

<u>Ability to provide Bacteria Removal:</u> This column indicates the capability of a structural control to remove bacteria in runoff.

<u>Ability to accept Hotspot Runoff:</u> The last column indicates the capability of a structural control to treat runoff from designated hotspots. Hotspots are land uses or activities which produce higher concentrations of trace metals, hydrocarbons, or other priority pollutants. Examples of hotspots might include: gas stations, convenience stores, marinas, public works storage areas, garbage transfer facilities, material storage sites, vehicle service and maintenance areas, commercial nurseries, vehicle washing/steam cleaning, industrial sites, industrial rooftops, and auto salvage or recycling facilities. A check mark indicates that the structural control may be used for a hotspot site; however, it may have specific design restrictions. Please see the specific design criteria for the structural control for more details. Please note that hotspot treatment must be tailored to the characteristics of the hotspot runoff pollutants to be removed. Designation of a control as suitable for accepting hotspot runoff does not necessarily mean it is the appropriate treatment facility for that particular hotspot condition. Such a designation simply indicates that the facility is commonly used for treatment of some types of hotspot runoff. For example, and oil-water separator is appropriate for runoff containing some types of floatable greases or oils, whereas a surface sand filter would not be suitable.

Site Applicability

The third category of the matrix provides an overview of the specific site conditions or criteria that must be met for a particular structural control to be suitable. In some cases, these values are recommended values or limits and can be exceeded or reduced with proper design or depending on specific circumstances. Please see the specific criteria section of the structural control for more details.

<u>Drainage Area:</u> This column indicates the approximate minimum or maximum drainage area considered suitable for the structural control practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, a variance would be required. Likewise, the minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (baseflow or groundwater), the mechanisms employed to prevent outlet clogging, or design variations used to maintain a permanent pool (e.g., liners).

<u>Slope:</u> This column identifies general slope restrictions for the specific structural control practice.

<u>Minimum Head:</u> This column provides an estimate of the minimum site elevation difference needed from the inflow to the outflow to allow for gravity operation within the structural control.

<u>Water Table:</u> This column indicates water table or groundwater separation requirements for certain controls.

Implementation Considerations

The fourth category in the matrix provides additional considerations for the applicability of each structural control option.

Residential Subdivision Use: This column identifies whether or not a structural control is suitable for typical residential subdivision development (not including high-density or ultra-urban areas).

Ultra-Urban: This column identifies those structural controls appropriate for use in very high-density (ultra-urban) areas, or areas where space is a premium.

Relative Capital Cost: The structural controls are ranked according to their relative construction cost per impervious acre treated, as determined from cost surveys.

Maintenance Burden: This column assesses the relative maintenance effort needed for a structural stormwater control, in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging), and reported failure rates. It should be noted that all structural controls require routine inspection and maintenance.

Step 2 - Specific Criteria

The last three categories in the screening matrix, shown in Appendix E, Table E-2, provide an overview of various specific design criteria and specifications, or exclusions for a structural control that may be present due to a site's general physiographic character, soils, or location in a watershed with special water resources considerations.

Physiographic Factors

Three key factors to consider are low-relief, high-relief, and karst terrain. Low relief (very flat) areas are common throughout Sedgwick County. High relief (steep and hilly) areas are rare but do exist in limited lot-scale areas. Karst areas (due to dissolution of salt beds) are limited to the northwest part of Sedgwick County. Special geotechnical testing requirements may be needed in karst areas.

- Low relief areas need special consideration because structural controls require a hydraulic head to move stormwater runoff through the facility.
- High relief may limit the use of some structural controls that need flat or gently sloping areas to settle out sediment or to reduce velocities. In other cases, high relief may impact dam heights to the point that a structural control becomes infeasible.
- Karst terrain can limit the use of some structural controls as the infiltration of polluted waters directly into underground streams found in karst areas may be prohibited. In addition, ponding areas may not reliably hold water in karst areas.

Soils

The key evaluation factors are based on an initial investigation of the NRCS hydrologic soils groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors.

Special Considerations

The design of structural stormwater controls is fundamentally influenced by the nature of the downstream water body that will be receiving the stormwater discharge. In addition, the designer should consult with the appropriate approval authority to determine if the development project is subject to additional or overriding stormwater structural control criteria as a result of an adopted local watershed plan or special provision.

In some cases, higher pollutant removal or environmental performance is needed to fully protect aquatic resources and/or human health and safety within a particular watershed or receiving water. Therefore, special design criteria for a particular structural control or the exclusion of one or more controls may need to be considered within these watersheds or areas. Examples of important watershed factors to consider include:

<u>High Quality (or Potential High Quality) Streams (streams with a watershed impervious cover less than approximately 15%):</u> These streams may also possess high quality cool water or warm water aquatic resources or endangered species. These streams may also be specially designated by local authorities.

<u>Wellhead and Aquifer Protection:</u> Areas that recharge existing water supply wells and aquifers present a unique management challenge. The key design constraint is to prevent possible groundwater contamination by preventing infiltration of untreated hotspot runoff. At the same time, recharge of unpolluted stormwater is encouraged to help maintain flow in streams and wells during dry weather.

<u>Reservoir Protection:</u> Watersheds that deliver surface runoff to water supply reservoirs or impoundments are a special concern. Depending on the treatment available, it may be necessary to achieve a greater level of pollutant removal for the pollutants of concern, such as bacteria pathogens, nutrients, sediment, or metals. One particular management concern for reservoirs is ensuring stormwater hotspots are adequately treated so they do not contaminate water supplies.

Step 3 - Location and Permitting Considerations

In the last step, a site designer assesses the physical and environmental features at the site to determine the optimal location for the selected structural control or group of controls. The checklist below (Table 3-3) provides a condensed summary of current restrictions as they relate to common site features that may be regulated under local, State, or federal laws and regulations. These restrictions fall into one of three general categories:

- Locating a structural control within an area when expressly prohibited by law.

- Locating a structural control within an area that is strongly discouraged, and is only allowed on a case by case basis. Local, State, and/or federal permits shall be obtained, and the applicant will need to supply additional documentation to justify locating the stormwater control within the regulated area.
- Structural stormwater controls located in accordance with local setback requirements.

This checklist is only intended as a general guide to location and permitting requirements as they relate to siting of stormwater structural controls. Consultation with the appropriate regulatory agency or authority is the best strategy.

Table 3-3 Location and Permitting Checklist

Site Feature	Location and Permitting Guidance
Jurisdictional Wetland (Waters of the U.S) U.S. Army Corps of Engineers Regulatory Permit	✓ Jurisdictional wetlands should be delineated prior to siting structural control. ✓ Use of natural wetlands for stormwater quality treatment is contrary to the goals of the Clean Water Act and should be avoided. ✓ Stormwater should be treated prior to discharge into a natural wetland. ✓ Structural controls may also be restricted in local buffer zones. Buffer zones may be utilized as a non-structural filter strip (i.e., accept sheet flow). ✓ Should justify that no practical upland preventive treatment alternatives exist. ✓ Where practical, excess stormwater flows should be conveyed away from jurisdictional wetlands.
Stream Channel (Waters of the U.S) U.S. Army Corps of Engineers Section 404 Permit	✓ All Waters of the U.S. (streams, ponds, lakes, etc.) should be delineated prior to design. ✓ Use of any Waters of the U.S. for stormwater quality treatment is contrary to the goals of the Clean Water Act and should be avoided. ✓ Stormwater should be treated prior to discharge into Waters of the U.S. ✓ In-stream ponds for stormwater quality treatment are highly discouraged. ✓ Must justify that no practical upland preventive treatment alternatives exist. ✓ Temporary runoff storage preferred over permanent pools. ✓ Implement measures that reduce downstream warming.
Stream and Floodplain Permits Kansas Department of Agriculture	✓ Kansas Department of Agriculture - Division of Water Resources permits for stream obstruction, channel change, flood plain fill, levee, water appropriations and buffers.

Site Feature	Location and Permitting Guidance
100 Year Floodplain Local Stormwater review Authority	✓ Grading and fill for structural control construction is generally discouraged within the 100 year floodplain, as delineated by FEMA flood insurance rate maps, FEMA flood boundary and floodway maps, or more stringent local floodplain maps. ✓ Floodplain fill cannot raise the floodplain water surface elevation by more than limits set by the appropriate jurisdiction.
Utilities Local Review Authority	✓ Call appropriate agency to locate existing utilities prior to design. ✓ Note the location of proposed utilities to serve development. ✓ Structural controls are discouraged within utility easements or rights of way for public or private utilities.
Roads	✓ Consult KDOT for setback requirements from State maintained roads. ✓ Consult Wichita or Sedgwick County authority for setback requirements for City or County streets and roads.
Structures	✓ Consult Wichita or Sedgwick County authority for required structural control setbacks from structures.
Water Wells	✓ Consult Wichita or Sedgwick County authority for required minimum setbacks for stormwater infiltration and other structural controls.

3.1.3.2 Example Application

A 15-acre institutional area (e.g., church and associated buildings) is being constructed in a dense urban area. The impervious coverage of the site is 40%. The site drains to an urban stream that is highly impacted from hydrologic alterations (accelerated channel erosion). The stream channel is deeply incised and hydraulically disconnected from the original floodplain; consequently, flooding is not an issue. The channel drains to a larger sediment-laden stream. Low permeability soils limit infiltration practices.

Objective: Avoid additional accelerated erosion to receiving channel and reduce TSS loads to the sediment-laden stream.

Target Removal: Provide stormwater management to mitigate for accelerated channel incision and reduce TSS loadings by 80%.

Activity/Runoff Characteristics: The proposed site is to have large areas of impervious surface in the form of parking and structures. However, there will be a large contiguous portion of turf grass proposed for the front of the parcel that will have a relatively steep slope (approximately 10%) and will drain to the storm drain system associated with the entrance drive. Stormwater runoff from the site is expected to exhibit fairly high sediment.

Table 3-4 lists the results of the selection analysis using the screening matrix described previously. The highlighted rows indicate the controls selected for this example. The X's indicate inadequacies in the control for this site. The ✓'s indicate adequate control capabilities for this site. The process involves moving left to right across the matrix for each control. Note that after a control is excluded, no further evaluation is performed for that control.

While there is a downstream sediment-laden stream to consider, there are no special watershed factors or physiographic factors to preclude the use of any of the practices from the structural control list. Due to the size of the drainage area, most stormwater ponds and wetlands (permanent pools) are removed from consideration. However, an extended detention micropool would be acceptable. In addition, the site's impermeable soils remove infiltration controls from being considered. Other controls are ruled out on the basis of aesthetics, cost and other subjective factors. The micropool can probably be used to achieve channel protection and flood control. If not, a dry extended detention pond (with forebay) may be used.

Table 3-4 Sample Structural Control Selection Matrix

Structural Control Alternative	TSS Removal Suitability	Site Applicability	Implementation Considerations	Physiographic Factors/Soils	Special Considerations	Other Issues OK
Stormwater Pond	✓	✓ ED micropool	✓	✓	✓	✓
Conventional Dry Detention Pond	X					
Dry Extended Detention Pond	✓	✓	✓	✓	✓	✓
Underground Dry Detention Basin	X					
Enhanced Dry Swale	✓	✓	X turf too steep			
Grass Channel	✓	✓	X turf too steep			
Infiltration Trench	✓	✓	✓	X		
Soakage Trench	✓	✓	✓	X		
Filter Strip	✓	✓	X turf too steep			
Surface Sand Filter	✓	✓	✓	✓	✓	Aesthetics and High Cost
Underground Sand Filter	✓	✓	✓	✓	✓	2 acres max drainage area
Organic Filter	✓	✓	✓	✓	✓	High Cost

Structural Control Alternative	TSS Removal Suitability	Site Applicability	Implementation Considerations	Physiographic Factors/Soils	Special Considerations	Other Issues OK
Bioretention Area	✓	✓	✓	✓	✓	✓
Stormwater Wetland	✓	X				
Proprietary Treatment	✓	✓	✓	✓	✓	High Cost
Gravity Separator	✓	✓	✓	✓	✓	High Cost
Alum Treatment	✓	✓	✓	✓	✓	High Cost
Green Roof	✓	X				
Modular Porous Paver System	✓	✓	✓	✓	✓	✓
Porous Pavement	X					

To provide additional pollutant removal capabilities in an attempt to better meet the target removal, bioretention could be used to treat the parking lot and driveway runoff. The bioretention will provide some TSS removal while improving the aesthetics of the site.

The site drainage system could be designed so the bioretention drains to the extended detention micropool pond for additional treatment. If milder sloped turf areas are provided, such as along the sides of the parking lots, vegetated swales and filters could be added to the list of acceptable controls for additional treatment if not restricted by soil permeability.

Finally, modular porous pavers would be a good choice for the occasional overflow parking that a church typically receives during weekly services. The low infiltration rate of site soils could be overcome by adding an underdrain to the pavers.

3.1.4 On-Line Versus Off-Line Structural Controls

3.1.4.1 Introduction

Structural stormwater controls are designed to be either "on-line" or "off-line." Figure 3-1 shows an example of an off-line sand filter and an on-line enhanced swale.

On-line facilities may provide treatment of all or part of the WQ_v and may provide control of all or part of the CP_v. They may be designed to control flood flows; if not, they are designed to receive and safely pass the entire range of storm flows up to the 100-year discharge.

Off-line facilities are designed to receive only a specified flow rate or volume through the use of a flow regulator (i.e. diversion structure, flow splitter, etc). Flow regulators are typically used to divert all or a portion of the WQ_v to an off-line structural control sized and designed to treat and control that portion of the WQ_v. After the design runoff flow has been treated and/or controlled, it is returned to the conveyance system. Flow Regulators

Flow regulation to off-line structural stormwater controls can be achieved by either:

- Diverting the WQ_V or other specific maximum flow rate to an off-line structural stormwater control, or
- Bypassing flows in excess of the design flow rate. The peak water quality flow rate (Q_{wq}) is used as a design parameter to calculate the peak flow rate of the WQ_v and is calculated using the procedure found in Chapter 4.

Flow regulators can be flow splitter devices, diversion structures, or overflow structures. Examples are shown in Figures 3-2, 3-3 and 3-4.

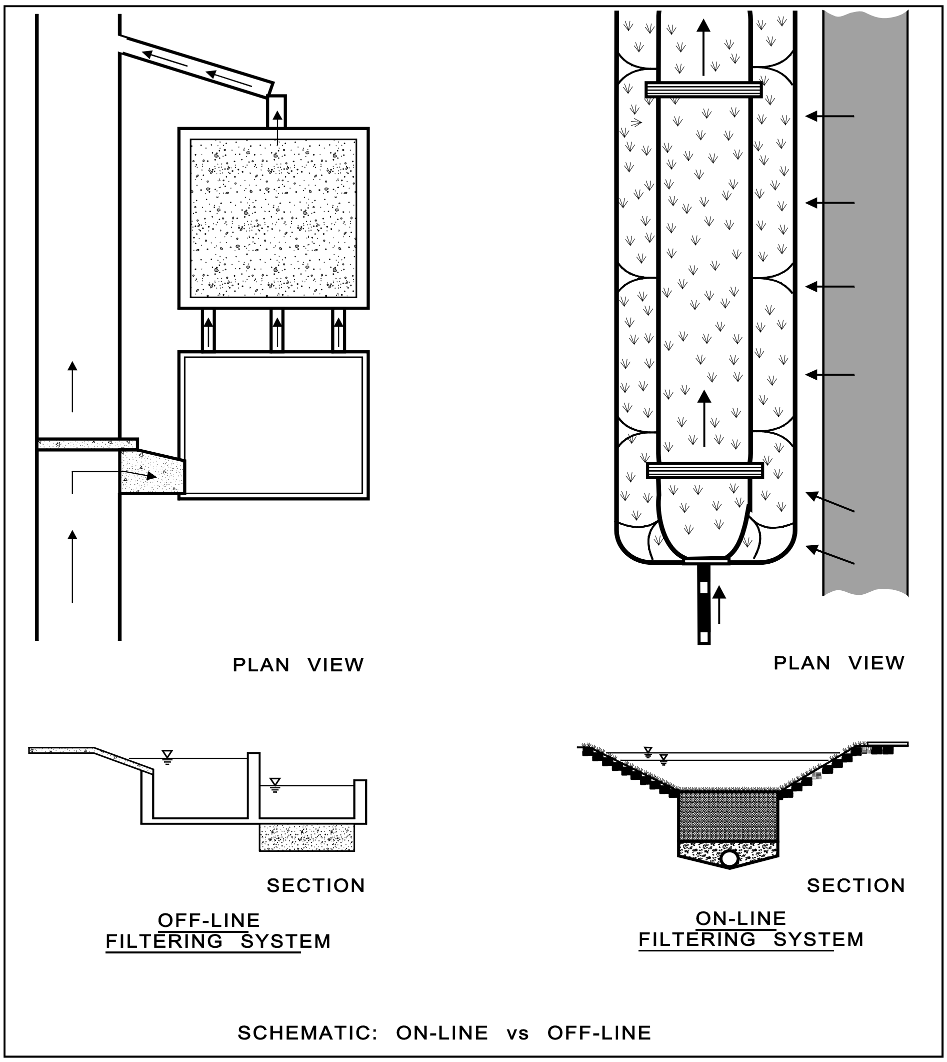

Figure 3-1 Example of On-Line vs Off-Line Structural Controls

(Claytor & Schueler, 1996)

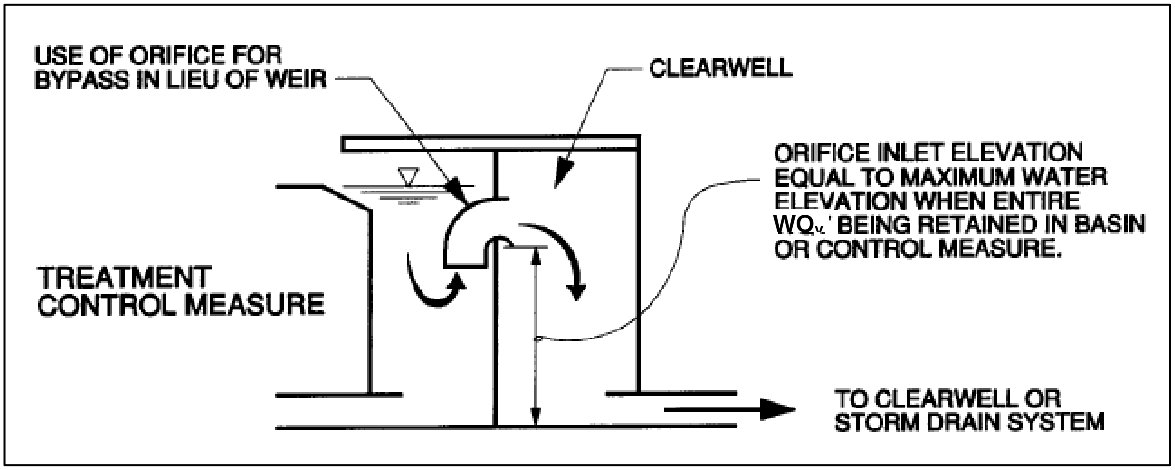

Figure 3-2 Outlet Flow Regulator
(Source: City of Sacramento, 2000)

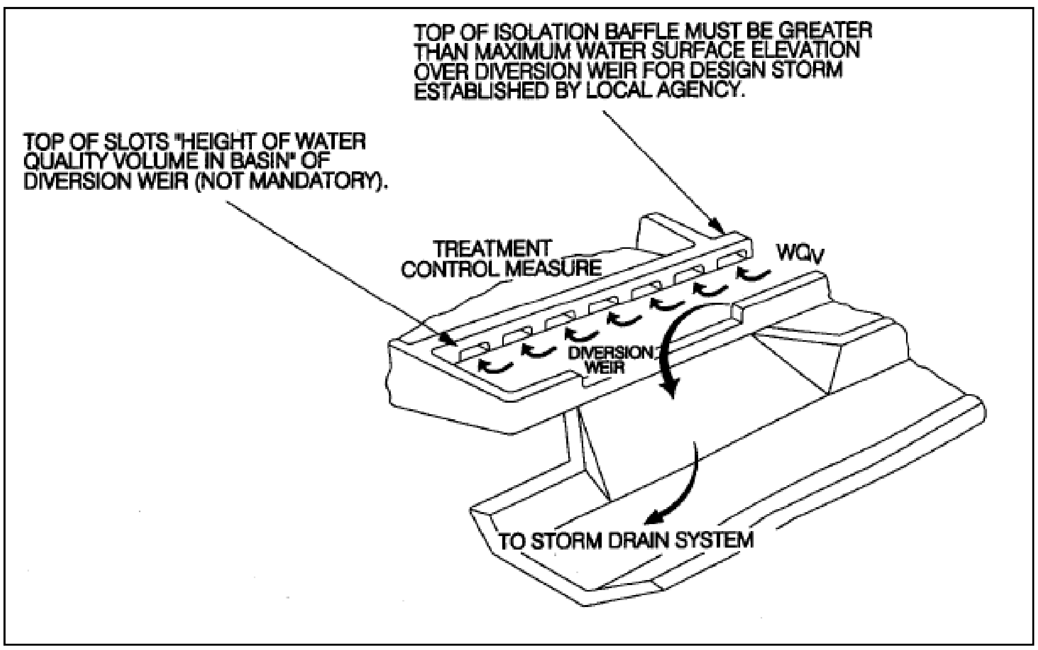

Figure 3-3 Surface Channel Diversion Structure
(Source: City of Sacramento, 2000)

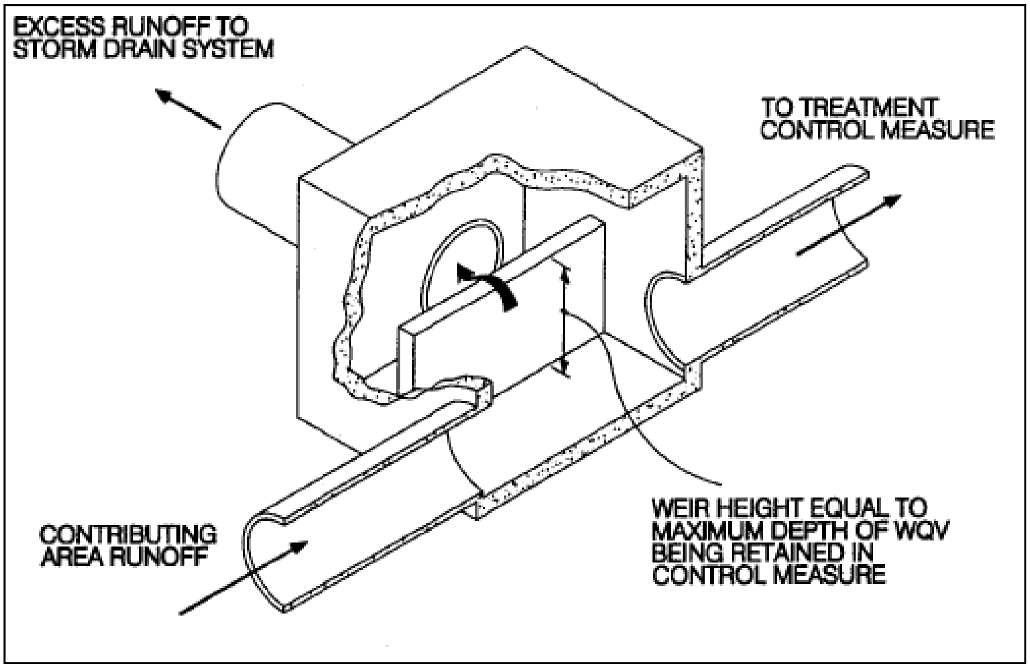

Figure 3-4 Pipe Interceptor Diversion Structure
(Source: City of Sacramento, 2000)

3.1.5 Regional versus On-Site Stormwater Management

3.1.5.1 Introduction

Using individual, on-site structural stormwater controls for each development is the typical approach for controlling stormwater quality and quantity.

A potential alternative approach is for a community to install strategically located regional stormwater controls in a subwatershed rather than require on-site controls (see Figure 3-5). For this Manual, regional stormwater controls are defined as facilities designed to manage stormwater runoff from multiple projects through a local jurisdiction program, where the individual projects may assist in the financing of the facility, and the requirement for on-site controls is either eliminated or reduced. Regional controls are allowed in the City of Wichita and Sedgwick County, provided that such controls can achieve the water quality channel protection and peak discharge standards defined in the local jurisdictions stormwater ordinance and the policies in Volume 1, Chapter 3 of this manual.

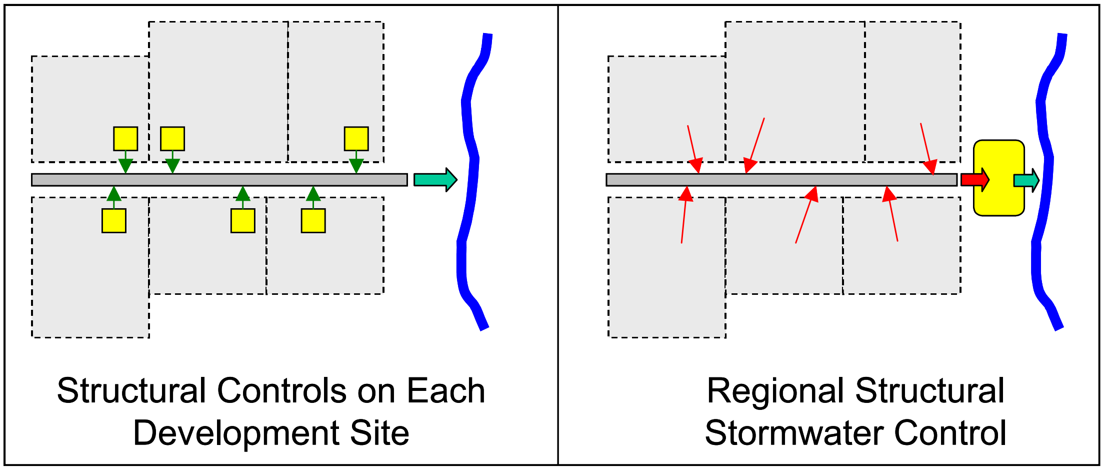

Figure 3-5 On-Site vs Regional Stormwater Management

3.1.5.2 Advantages and Disadvantages of Regional Stormwater Controls

The use of a regional stormwater facility is not always the best solution and the following "pros" and "cons" should be considered during the decision process.

Advantages of Regional Stormwater Controls

Reduced Construction Costs: Design and construction of a single regional stormwater control facility can be more cost-effective than numerous individual on-site structural controls.

Reduced Operation and Maintenance Costs: Rather than multiple owners and associations being responsible for the maintenance of several stormwater facilities on their developments, it is simpler and more cost effective to establish scheduled maintenance of a single regional facility.

Higher Assurance of Maintenance: Regional stormwater facilities are far more likely to be adequately maintained as they are large and have a higher visibility.

Maximum Utilization of Developable Land: Developers would be able to maximize the utilization of the proposed development for the purpose intended by minimizing the land normally set aside for the construction of stormwater structural controls.

Other Benefits: Well-sited regional stormwater facilities often can serve as a community recreational and aesthetic amenity.

Disadvantages of Regional Stormwater Controls

Location and Siting: Regional stormwater facilities may be difficult to site, particularly for large facilities or in areas with existing development.

Maintenance: The local government is typically responsible for the operation and maintenance of a regional stormwater facility.

Need for Planning: The implementation of regional stormwater controls requires substantial planning, financing, and permitting. Land acquisition must be in place ahead of future projected growth.

Water Quality and Channel Protection: Without on-site water quality and channel protection, regional controls do not protect smaller streams upstream of the facility from degradation and channel erosion.

Ponding Impacts: Upstream inundation from a regional facility impoundment can eliminate floodplains, wetlands, and other habitat.

3.1.5.3 Important Considerations for the Use of Regional Stormwater Controls

If a regional stormwater control is planned, then it must be ensured that the conveyances between the individual upstream developments and the regional facility can handle the design peak flows and volumes without causing adverse impact or property damage. Siting and designing regional facilities may be done by city of Wichita and/or Sedgwick County as part of watershed master planning efforts. Development and redevelopments will be required to compensate the local jurisdiction for construction of these regional facilities through any equitable and legal system proposed in the watershed master plan. At a minimum, future watershed master plans must provide:

- Protection against water quality impacts to meet the 80% TSS removal standard;
- protection against channel erosion to meet the channel protection requirement; and,
- protection against downstream flooding to meet the peak flow control standard and 10% rule.

Furthermore, unless the system consists of completely man-made conveyances (i.e. storm drains, pipes, constructed channels, etc) on-site structural controls for water quality and downstream channel protection will likely be required for all developments within the regional facility's drainage area. Federal water quality provisions do not allow the degradation of water bodies from untreated stormwater discharges, and it is U.S. EPA policy to not allow regional stormwater controls that would degrade stream quality between the upstream development and the regional facility. Further, without adequate channel protection, aquatic habitats and water quality in the channel network upstream of a regional facility may be degraded by channel erosion if they are not protected from bankfull flows and high velocities.

Based on these concerns, both the EPA and the U.S. Army Corps of Engineers have expressed opposition to in-stream regional stormwater control facilities. In-stream facilities should be avoided if possible and will likely need to be permitted on a case-by-case basis.

3.1.6 Using Structural Stormwater Controls in Series

3.1.6.1 Stormwater Treatment Trains

The minimum stormwater management standards are an integrated planning and design approach whose components work together to limit the adverse impacts of development on downstream waters and riparian areas. This approach is sometimes called a stormwater "treatment train." When considered comprehensively, a treatment train consists of all the design concepts and nonstructural and structural controls that work to attain water quality and quantity goals. This is illustrated in Figure 3-6.

Figure 3-6 Generalized Stormwater Treatment Train

Runoff and Load Generation: The initial part of the "train" is located at the source of runoff and pollutant load generation, and consists of pollution prevention practices and optional "Preferred Site Design" practices that reduce runoff and stormwater pollutants.

Pretreatment: The next step in the treatment train consists of pretreatment measures. These measures typically do not provide sufficient pollutant removal to meet the overall TSS target reduction goal, but do provide calculable water quality benefits that may be applied towards meeting the WQ_v treatment requirement. In addition, pre-treatment may reduce maintenance and/or improve the performance of downstream facilities. These measures include:

- Structural controls that achieve less than the overall TSS target removal rate, but provide pretreatment for sources such as hotspots.
- Pretreatment facilities such as sediment forebays.

Standard Treatment and/or Quantity Control: The last step is standard water quality treatment and/or quantity (channel protection and flood) control. This is achieved through the use of structural controls to achieve overall water quality and quantity goals.

3.1.6.2 Use of Multiple Structural Controls in Series

Many combinations of structural controls may be used for a site. The following are descriptions of some examples of how controls and other practices may be combined to achieve the goals of the integrated design approach.

- Stormwater ponds are often used to achieve overall target TSS removal as well as channel protection and flood control, thus meeting all of the requirements of the integrated site design approach in a single facility.

- The other structural controls achieving overall TSS target removal each (bioretention, sand or organic filters, infiltration or soakage trenches, and enhanced swales) are typically used in combination with other water quality controls and with detention flood controls to meet the integrated site design goals. The detention facilities are located downstream from the water quality controls either on-site or combined into a regional or neighborhood facility.
- Where a structural control does not meet the overall TSS target removal criteria, one or more additional downstream controls must be used. For example, urban hotspot land may be fit with devices adjacent to parking or service areas designed to remove petroleum hydrocarbons. These devices may also serve as pretreatment devices removing the coarser fraction of sediment. One or more downstream structural controls are then used to meet the full TSS removal goal, as well as water quantity control.
- An environmentally sensitive large lot subdivision may be designed and developed so as to waive the water quality treatment requirement altogether. However, detention controls may still be required for downstream channel protection and flood control.

WQ_V reductions (See Volume 2, Chapter 2) may be employed to reduce the WQ_V requirement. In this case, for a smaller site, a well designed structural control may provide TSS removal while a dry detention pond provides flood control. Direct discharge to a large stream and local downstream floodplain management practices may eliminate the need for channel protection and flood control storage altogether. (See Volume 2, Chapter 4)

The combinations of structural stormwater controls are limited only by the need to employ measures of proven effectiveness while meeting regulatory and physical site requirements. Figure 3-7 through Figure 3-9 illustrate applications of the treatment train concept to a moderate density residential neighbourhood, a small commercial site, and a large shopping mall site.

In Figure 3-7, runoff from yards and driveways reaches roadside grass channels. Then, all stormwater flows to an extended detention micropool stormwater pond.

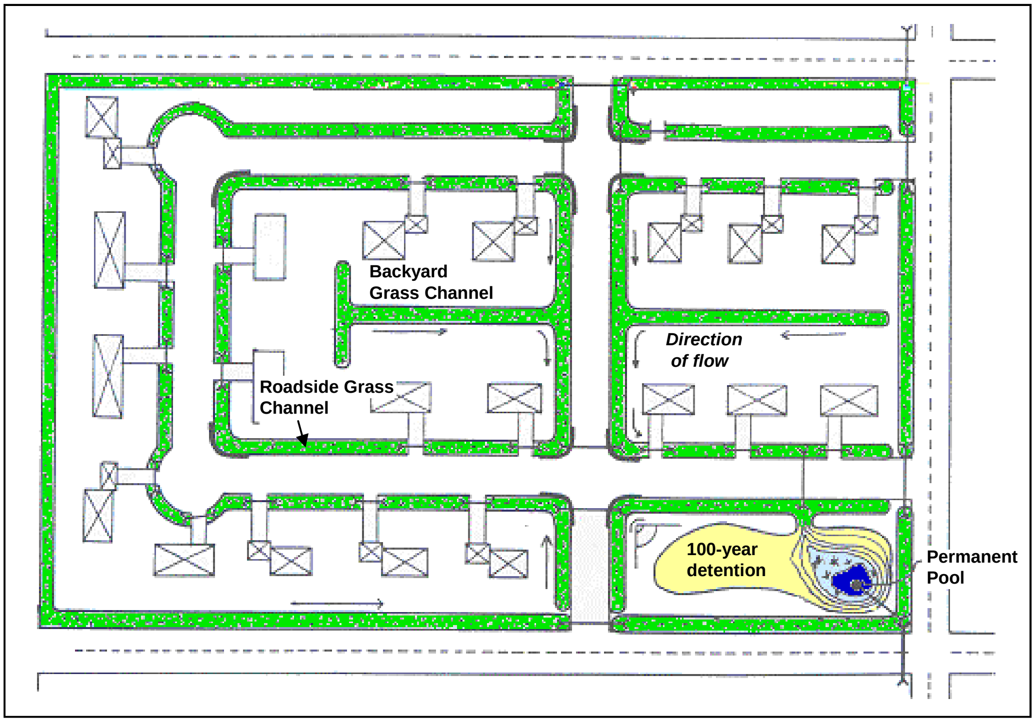

Figure 3-7 Example Treatment Train – Rural Residential Subdivision
(Adapted from: NIPC, 2000)

A gas station and convenience store is depicted in Figure 3-8. In this case, the decision was made to intercept hydrocarbons and oils using a commercial gravity (oil-water) separator located on the site prior to draining to a sand filter for removal of finer particles and TSS. No stormwater control for channel protection is required as the system drains to the municipal storm drain pipe system. Flood control is provided by a regional stormwater control downstream.

Figure 3-9 shows an example treatment train for a commercial shopping center. In this case, runoff from rooftops and parking lots drains to depressed parking lot islands, perimeter grass channels, and bioretention areas. Slotted curbs are used at the entrances to these swales to better distribute the flow and to settle out the very coarse particles at the parking lot edge for sweepers to remove. Runoff is then conveyed to an extended detention wet pond for additional pollutant removal and channel protection. Flood control is provided through parking lot detention. (The acceptability of parking lot detention will be determined by the local reviewing authority on a case-by-case basis.)

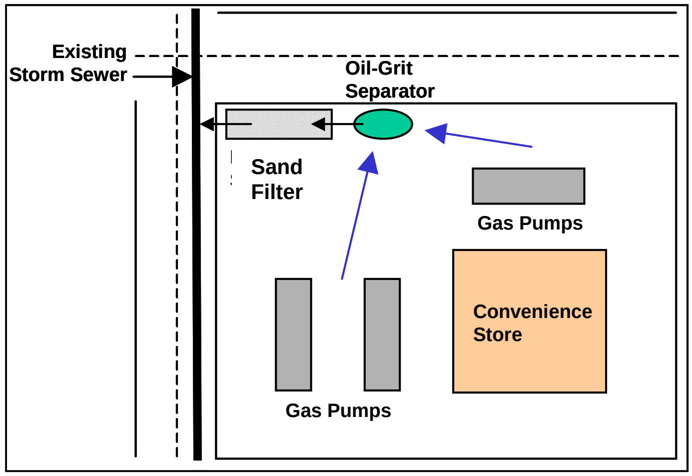

Figure 3-8 Example Treatment Train – Small Commercial Site

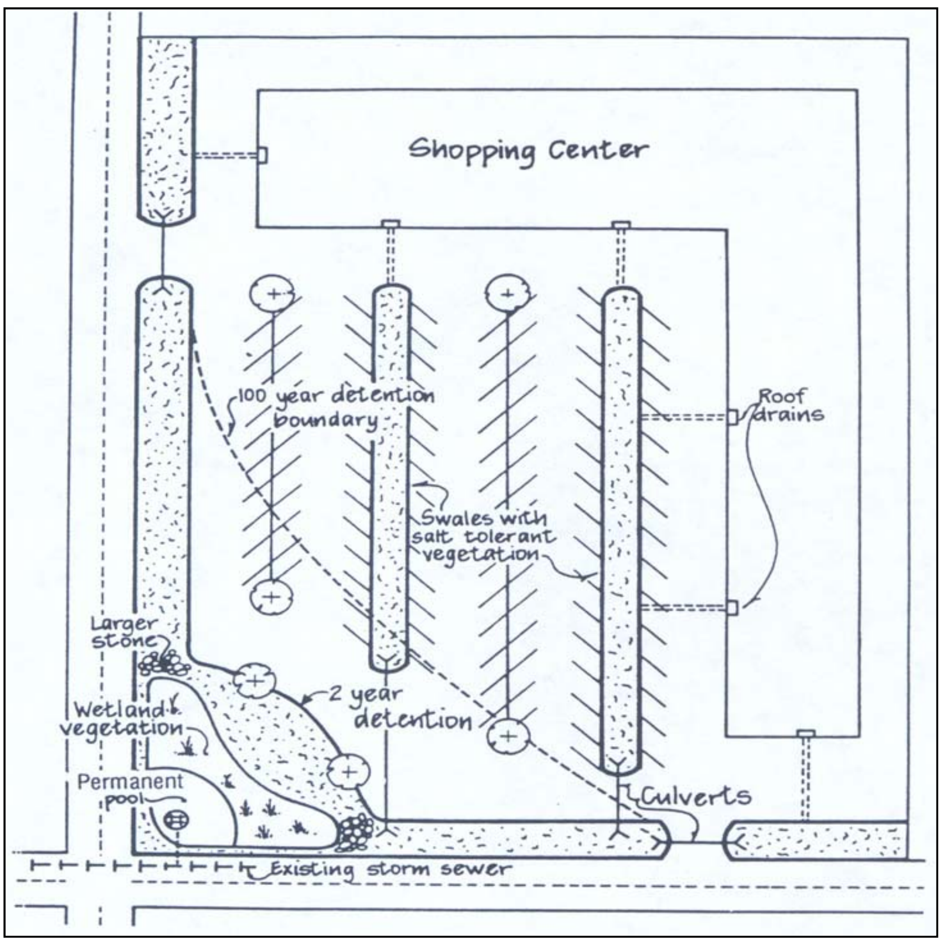

Figure 3-9 Example Treatment Train – Large Commercial Development
(Source: NIPC, 2000)

3.2 Primary TSS Treatment Facilities

This section contains design guidelines for the following TSS treatment facilities:

- Stormwater pond
- Extended dry detention pond
- Vegetative filter strip
- Grassed channel
- Enhanced swale
- Infiltration trench
- Soakage trench
- Surface sand filter
- Bioretention areas
- Stormwater wetland

3.2.1 Stormwater Pond

Primary Water Quality Facility

Description: Constructed stormwater retention basin that has a permanent water quality pool (or micropool). Runoff from each water quality rain event displaces all or part of the permanent pool, and is treated in the pool primarily through settling and biological uptake mechanisms.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Minimum contributing drainage area of 25 acres; 10 acres for extended detention micropool pond
- A sediment forebay or equivalent upstream pretreatment must be provided
- Minimum length to width ratio for the pond is 1.5:1
- Pond slopes shall adhere to those found in Figure 3-12

ADVANTAGES / BENEFITS:

- Moderate to high removal rate of urban pollutants
- High community acceptance
- Opportunity for wildlife habitat

DISADVANTAGES / LIMITATIONS:

- Potential for thermal impacts/downstream warming
- Dam height restrictions for high relief areas
- Pond drainage can be problematic for low relief terrain

MAINTENANCE REQUIREMENTS:

- Remove debris from inlet and outlet structures
- Maintain side slopes / remove invasive vegetation
- Monitor sediment accumulation and remove periodically
- Dam inspection and maintenance

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total Nitrogen
M	**Metals –** Cadmium, Copper, Lead & Zinc
H	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Quality Protection**
✓	**Channel Protection**
✓	**On-Site Flood Control**
✓	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirements**
L	**Capital Costs**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *10-25 acres min*

Soils: *Hydrologic group 'A' and 'B' soils may require pond liners*

Other Considerations:

- *Outlet Clogging*
- *Safety Bench*
- *Landscaping*

L=Low **M**=Moderate **H**=High

3.2.1.1 General Description

Stormwater ponds (also referred to as retention ponds, wet ponds, or wet extended detention ponds) are constructed stormwater retention basins that have a permanent (dead storage) pool of water throughout the year. They can be created by excavation and/or by construction of embankments at an already existing natural depression.

In a stormwater pond, all or a portion of the runoff from each rain event is retained and treated in the pool through gravitational settling and biological uptake until it is displaced by runoff from the next storm. The permanent pool also serves to protect deposited sediments from resuspension. Additional temporary storage (live storage) is provided for extended detention of the 1-year storm for downstream CP_v, as well as conventional detention of larger storm events to meet peak flow control requirements. A portion of the WQ_v may also be temporarily stored (detained) above the permanent pool for water quality treatment.

Stormwater ponds are among the most cost-effective and widely used stormwater practices. A well-designed and landscaped pond can be an aesthetic feature on a development site when planned and located properly.

There are several different variations of stormwater pond design, the most common of which include the wet pond, the wet extended detention pond, and the micropool extended detention pond. In addition, multiple stormwater ponds can be placed in series or parallel to increase performance or meet site design constraints. Below are descriptions of each design variation:

Wet Pond: Wet ponds are stormwater basins constructed with a permanent (dead storage) pool of water equal to the WQ_V. Stormwater runoff displaces the water already present in the pool. Temporary storage (live storage) can be provided above the permanent pool elevation for CP_V and peak flow control.

Wet Extended Detention (ED) Pond: A wet extended detention pond is a wet pond where the WQ_V is split between the permanent pool and extended detention (ED) storage provided above the permanent pool. During water quality storm events, water is detained above the permanent pool for 24 hours. This design has similar pollutant removal to a traditional wet pond, but consumes less space. Additional temporary storage can be provided above the ED pool for CP_V and peak flow control.

Micropool Extended Detention (ED) Pond: The micropool extended detention pond is a variation of the extended detention wet pond where only a small “micropool” is maintained at the outlet to the pond. The outlet structure is sized to detain the WQ_V for 24 hours. The micropool helps to inhibit resuspension of previously settled sediments and also helps to prevent clogging of the low flow orifice.

Multiple Pond Systems: Multiple pond systems consist of constructed facilities that provide water quality and quantity control volume storage in two or more cells. The additional cells can create longer pollutant removal pathways and improved downstream protection.

Figure 3-10 shows a number of examples of stormwater pond variants. Section 3.2.1.8 provides plan view and profile schematics for the design of a wet pond, a wet extended detention pond, a micropool extended detention pond, and a multiple pond system.

Wet Pond

Wet ED Pond

Micropool ED Pond

Figure 3-10 Stormwater Pond Examples

Conventional dry detention basins do not provide a permanent pool and are not acceptable for general use to meet water quality criteria, as they fail to demonstrate an ability to meet the majority of the water quality goals. In addition, dry detention basins are prone to clogging and resuspension of previously settled solids and require a higher frequency of maintenance than most wet ponds if used for untreated stormwater flows. However, these facilities can be used in combination with appropriate water quality controls to provide channel protection and peak flow control. For further discussion please see Section 3.4.1.

3.2.1.2 Stormwater Management Suitability

Stormwater ponds may be designed to control both stormwater quantity and quality. Thus, a stormwater pond can be used to address all of the integrated stormwater sizing criteria for a given drainage area.

Water Quality

Ponds treat incoming stormwater runoff by physical, biological, and chemical processes. The primary removal mechanism is gravitational settling of particulates, organic matter, metals, bacteria, and organics as stormwater runoff resides in the pond. Another mechanism for pollutant removal is uptake by algae and wetland plants in the permanent pool – particularly of nutrients. Volatilization and chemical activity also work to break down and eliminate a number of other stormwater contaminants such as hydrocarbons.

Channel Protection

A portion of the storage volume above the permanent pool in a stormwater pond, or above the water quality ED pool in an extended detention pond, can be used to provide control of the CP_v. This is accomplished by detaining the 1-year, 24-hour storm runoff volume for 24 hours.

On-Site Flood Control

A stormwater pond located within the development (i.e., not at the project boundary) can provide detention storage for on-site peak flow control, if required.

Downstream Flood Control

A stormwater pond can be used to provide detention to control the peak flows at the project boundary and downstream of the project for the 2 through 100-year floods, in accordance with the peak flow control requirements for new developments. In all cases, the pond structure is designed to safely pass extreme storm flows (i.e., the 100-year event).

3.2.1.3 Pollutant Removal Capabilities

All of the stormwater pond design variations are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when designed, constructed, and maintained in accordance with the specifications discussed herein. Undersized or poorly designed ponds can drastically reduce TSS removal performance.

The following design pollutant removal rates are typical percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach.

- Total Suspended Solids – 80%
- Total Phosphorus – 55%
- Total Nitrogen – 30%
- Heavy Metals – 50%
- Fecal Coliform – 70% (if no resident waterfowl population present)

For additional information and data on pollutant removal capabilities, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.1.4 Application and Site Feasibility Criteria

Stormwater ponds are generally applicable to most types of development and can be used in both residential and nonresidential areas. The following criteria should be evaluated to ensure the suitability of a stormwater pond for meeting stormwater management objectives on a development site.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra-Urban Areas – Land requirements may preclude use
- Regional Stormwater Control – YES

Physical Feasibility - Physical Constraints at Project Site

<u>Drainage Area:</u> As a guideline, a minimum of 25 acres is needed for a wet pond and an extended detention wet pond to maintain a permanent pool. Ten acres minimum is required for an extended detention micropool pond. Drainage area requirements must be checked with a water balance analysis (See Volume 2, Chapter 4) or other approved method for determining the drainage area necessary to sustain a permanent pool. A smaller drainage area may be acceptable if supported by an approved water balance analysis.

<u>Space Required:</u> Approximately 2 to 5% of the tributary drainage area.

<u>Site Slope:</u> Typically slopes are not more than 15% across the pond.

<u>Minimum Head</u>: Elevation difference needed at a site from the inflow to the outflow: 6 to 8 feet.

<u>Minimum Depth to Water Table:</u> A minimum separation distance of 5 feet is required between the bottom of the pond and the elevation of the historical high water table for unlined ponds, 2 feet for lined ponds.

<u>Soils:</u> Underlying soils of hydrologic group “C” or “D” should be adequate to maintain a permanent pool. Most group “A” soils and some group “B” soils will require a pond liner. Evaluation of soils should be based on an actual subsurface analysis and permeability tests.

Other Constraints / Considerations

<u>Local Aquatic Habitat:</u> Consideration should be given to the thermal influence of stormwater pond outflows on downstream local aquatic habitats.

3.2.1.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of a stormwater pond facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

A. LOCATION AND SITING

- Stormwater ponds should have a minimum contributing drainage area of 25 acres or more for wet pond or extended detention wet pond to maintain a permanent pool. (See previous discussion.) For an extended detention micropool pond, the minimum drainage area is 10 acres. A smaller drainage area can be considered when water availability can be confirmed (such as from a upstream groundwater spring source). In any case, a water balance must be performed to verify a sustainable source of water (See Volume 2, Chapter 4). Ensure that an appropriate anti-clogging device is provided for the pond outlet.
- A stormwater pond should be sited such that the topography allows for maximum runoff storage at minimum excavation or construction costs. Pond siting should also take into account the location and use of other site features such as buffers and undisturbed natural areas and should attempt to aesthetically "fit" the facility into the landscape.
- Stormwater ponds should not be located on steep (>15%) or unstable slopes.
- Ponds cannot be located within a stream or any other navigable waters of the U.S., including wetlands, without obtaining applicable local, state and federal permits.
- No utilities should be located within the reserve boundary for the pond/basin site, if a reserve is required.

B. GENERAL DESIGN

- A well-designed stormwater pond consists of:
- Permanent pool of water for water quality treatment,
- Overlying temporary storage zone in which runoff control volumes are detained for quantity control, and
- Shallow littoral zone (aquatic bench) along the edge of the permanent pool that acts as a biological filter and wave-action diffuser.
- To the maximum extent practicable, the long axis of a pond shall be oriented east-west to minimize erosion from wind waves.
- In addition, all stormwater pond designs must include a sediment forebay or equivalent pretreatment at all major inflows to the basin to allow heavier sediments to drop out of suspension before the runoff enters the permanent pool.
- Additional pond design features include a principal spillway, an emergency spillway, maintenance access, safety bench, pond buffer, and appropriate native landscaping.

- Stormwater ponds located in floodplains or backwater areas must perform as specified for peak flow control for any tailwater condition, up to the Base Flood Elevation (BFE). Thepotential for back flow into the pond must be addressed with flap gates or by providing sufficient volume to receive backflow up to the BFE, and still provide peak flow control surcharge volume in the pond (above the BFE).

Figure 3-14 through Figure 3-17 provide plan view and profile schematics for the design of a wet pond, extended detention wet pond, extended detention micropool pond and a multiple pond system.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

In general, pond designs are unique for each site and application. However, there are number of geometric ratios and limiting depths for pond design that must be observed for adequate pollutant removal, ease of maintenance, and improved safety.

- Permanent pool volume is typically sized as follows:
  - Standard wet ponds: 100% of the water quality treatment volume (1.0 WQ_v);
  - Extended detention wet ponds: 50% of the water quality treatment volume (0.5 WQ_v) with the remaining 50% in the extended detention above the permanent pool;
  - Extended detention micropool ponds: Approximately 0.1 acre-inch per impervious acre, with the balance of WQ_v in the extended detention.
- Proper geometric design is essential to prevent hydraulic short-circuiting (unequal distribution of inflow), which results in the failure of the pond to achieve adequate levels of pollutant removal. The minimum length-to-width ratio for the permanent pool shape is 1.5:1, and should ideally be greater than 3:1 to avoid short-circuiting. In addition, ponds should be wedge-shaped when possible so that flow enters the pond and gradually spreads out, improving the sedimentation process. Baffles, pond shaping or islands can be added within the permanent pool to increase the flow path.

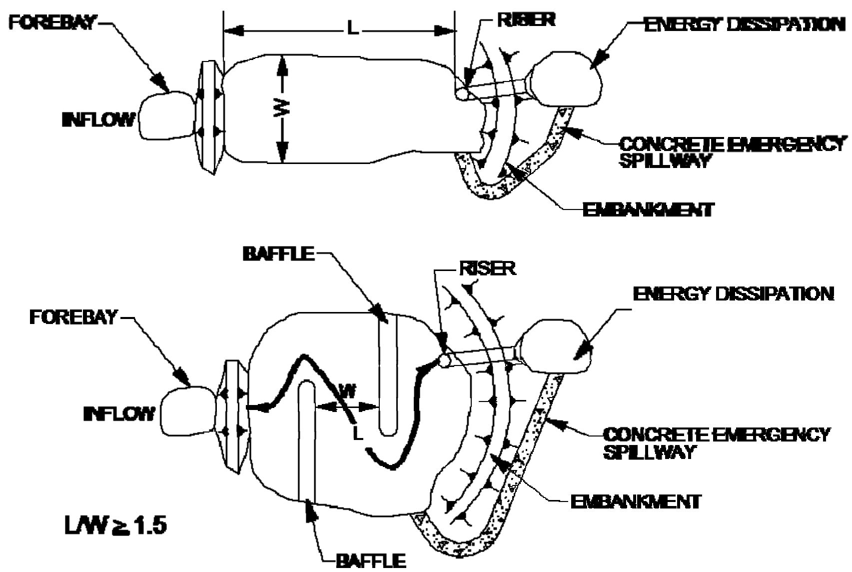

Figure 3-11 Permanent Pool Length to Width Ratio

- Minimum depth for the pond bottom shall be 3 to 4 feet, though a minimum depth of 10 feet is recommended for ponds where fish habitat is desired. Deeper areas near the outlet will yield cooler bottom water discharges that may mitigate potential downstream thermal effects.
- Side slopes to the pond may not exceed 5:1 (h:v) unless a safety bench is provided, and in no case shall exceed 3:1 (see Figure 3-12). All side slopes should be verified with a geotechnical evaluation to ensure slope stability.
- Safety benches shall have a maximum slope of 10:1, and a minimum width of 10'.
- The perimeter of all deep pool areas (3 feet or greater in depth) shall be surrounded by an aquatic bench. The aquatic bench shall extend inward from the normal pool edge 10-15 feet on average and have a maximum depth of 18 inches below the normal pool water surface elevation (see Figure 3-12).
- The pond edge shall have turf reinforcing mesh or riprap covering the area from 2 feet above the normal pool to 2 feet below the normal pool to protect areas of the pond that will be exposed to wave action. Appendix D provides wind roses for Wichita during each month of the year to aid in locating areas that will require reinforcement. Local winds are most pronounced coming from the north and south directions.
- The contours and shape of the permanent pool should be irregular to provide a natural landscape effect.

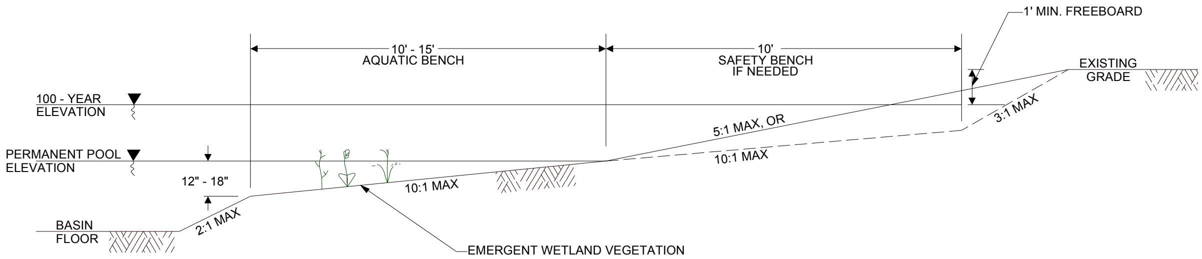

Figure 3-12 Typical Stormwater Pond Geometry Criteria

D. PRETREATMENT / INLETS

- Each pond shall have a sediment forebay or equivalent upstream pre-treatment at each inlet. A sediment forebay is designed to remove incoming larger sediment from the stormwater flow prior to dispersal in the larger permanent pool. Pretreatment consists of a separate cell, formed by an acceptable barrier between the forebay and pond. A forebay is to be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. In some design configurations, the pretreatment volume may be located within the permanent pool.
- A forebay must be sized to contain 0.1 acre-inch per impervious acre of contributing drainage and should be 4 to 6 feet deep. The pretreatment storage volume is part of the total WQ_v requirement and may be subtracted from WQ_v for permanent pool sizing.
- A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment deposition over time. The bottom of the forebay may be hardened (e.g., using concrete, paver blocks, etc.) to make sediment removal easier.
- Pond inflow channels are to be stabilized with flared riprap aprons, or the equivalent. Inlet pipes to the pond can be partially submerged. Inflow pipe, channel velocities, and exit velocities from the forebay must be nonerosive.

E. OUTLET STRUCTURES

- Flow control from a stormwater pond is accomplished with the use of a principal spillway consisting of a concrete riser and barrel. The riser is a vertical pipe, typically with several weirs and/or orifices at various levels. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment (see Figure 3-13). Where practicable, the riser should be located within the embankment for maintenance access, safety and aesthetics.

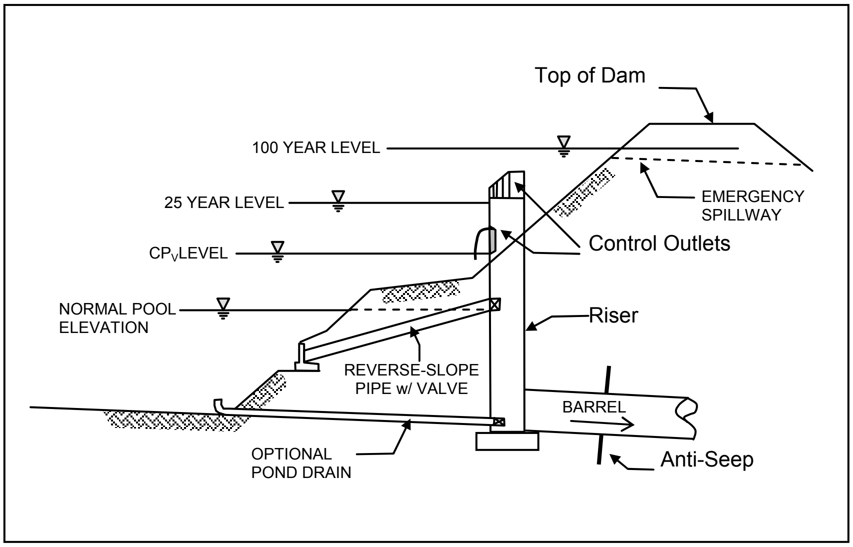

Figure 3-13 Typical Pond Outlet Structure

- A number of outlets at varying depths in the riser provide flow control for routing of the water quality (for extended wet detention), channel protection, and flood control runoff volumes. The number and configuration of the outlets (orifices and weirs) vary, depending on the specific pond design conditions.
- Ponds must be designed per Kansas dam safety guidelines, when applicable.
- As an example, a wet pond riser configuration is typically comprised of a channel protection outlet (usually an orifice) and flood control outlet (often a slot or weir). The channel protection orifice is sized to detain the channel protection storage volume for 24-hours. Since the WQ_V is fully contained in the permanent pool in this example, no orifice sizing is necessary for this volume. As runoff from a water quality event enters the wet pond, it simply displaces that same volume through the channel protection orifice. Thus an off-line wet pond providing only water quality treatment can use a simple overflow weir as the outlet structure.
- In the case of an extended detention wet pond or extended detention micropool pond, there is a need for an additional outlet (usually an orifice) that is sized to pass the extended detention WQ_V that is surcharged on top of the permanent pool. Flow will first pass through this orifice, which is sized to detain the water quality extended detention volume for 24 hours. All extended detention orifices shall be protected from clogging using treatments such as those described in Section 5.6.4. The preferred design is a reverse slope pipe attached to the riser, with its inlet submerged one foot or more below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond. The next outlet is usually sized for the release of the channel protection storage volume. The outlet (often an orifice) invert is located at the maximum elevation associated with the extended detention WQ_V and is sized in conjunction with the extended detention orifice to detain the channel protection storage volume for 24-hours.

- Other than orifices, alternative hydraulic control methods include broad-crested, sharp-crested, V-notch, and proportional weirs, or outlet pipes (discharging to the riser) protected by a hood that extends at least 12 inches below the normal pool.
- Higher flows (on-site and downstream flood control) pass through openings or slots protected by trash racks further up on the riser.
- After entering the riser, flow is conveyed through the outlet barrel and is discharged downstream. Anti-seep collars should be installed on the outlet barrel to reduce the potential for pipe failure.
- Riprap, plunge pools, pads, or other energy dissipators are to be placed at the outlet of the barrel to prevent scoure and erosion. If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a vegetated riparian zone in the shortest possible distance.
- Each pond may have a bottom drain pipe with an adjustable valve that can drain the pond within 24 hours (from the crest of the riser to within 1 foot above the bottom of the pond). The bottom drain is optional. It is recommended to check with the local jurisdiction to see if a bottom drain is required.
- The pond drain should be sized one pipe size greater than the calculated design diameter. The drain valve is typically a handwheel activated knife or gate valve. Valve controls shall be located inside of the riser, if practicable, at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner.

See the design procedures in Volume 2, Chapters 4 and 5 for additional information and specifications on pond routing and outlet works.

F. EMERGENCY SPILLWAY

- A concrete emergency spillway is to be included in the stormwater pond design to safely pass the 100-year flood event. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges. All local and state dam safety requirements must be met, where applicable.
- A minimum of one foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme (100-year, 24-hour) flood to the lowest point of the dam embankment, not counting the emergency spillway. The water surface elevation must be based on routing the 100-year inflow hydrograph through the pond while assuming no discharge from the pond except through the emergency spillway.

G. MAINTENANCE ACCESS

- The local jurisdiction may require that the pond be placed in a reserve and/or establishment of a drainage easement to the pond, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no

more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

- When required, reserves and/or drainage easements must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.
- Access to the riser is to be provided by lockable manhole covers, and manhole steps should be within easy reach of valves and other controls.

H. SAFETY FEATURES

- All embankments and spillways must be designed to State of Kansas guidelines for dam safety, where applicable.
- Fencing of ponds may be required in some cases by the local review authority. In lieu of fencing, one method is to manage the contours of the pond through the inclusion of a safety bench (see above) to eliminate dropoffs and reduce the potential for accidental drowning. In addition, the safety bench can be landscaped to deter access to the pool.
- The spillway openings (riser and outlet barrel) should be protected to prevent entry by children. Endwalls above pipe outfalls greater than 36 inches in diameter should be fenced to prevent access and subsequent fall hazards.

I. LANDSCAPING

- Aquatic vegetation can play an important role in pollutant removal in a stormwater pond. In addition, vegetation can enhance the appearance of the pond, stabilize side slopes, serve as wildlife habitat, and can temporarily conceal unsightly trash and debris. Therefore, wetland plants should be encouraged in a pond design, along the aquatic bench (fringe wetlands), the safety bench and side slopes (ED ponds), and within shallow areas of the pool itself. The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within 6 inches (plus or minus) of the normal pool elevation.
- Woody vegetation may not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure (tree exclusion zone).
- Where practicable, a pond buffer should be provided that extends 25 feet outward from the maximum water surface elevation of the pond. The pond buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers) or that are part of the overall stormwater management concept plan. No structures should be located within the buffer.
- Existing trees should be preserved in the buffer area during construction in areas where the minimum distance requirements of the previous paragraph (tree exclusion zone) can be satisfied. It is desirable to locate conservation areas adjacent to ponds. The buffer can be planted with trees, shrubs and native ground covers.
- Selected fish species can be stocked in a pond to aid in mosquito prevention.

- A fountain or solar-powered aerator may be used for oxygenation of water in the permanent pool if required to sustain fish.
- Compatible multi-objective use of stormwater pond locations is encouraged.

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

Low Relief: Maximum normal pool depth is limited; providing pond drain can be problematic;

High Relief: Embankment heights may be restrictive;

Karst: Requires poly or clay liner to sustain a permanent pool of water and protect aquifers; limits on ponding depth; geotechnical tests may be required.

Soils

- Hydrologic group “A” soils, and some “B” soils, require pond liner.

Special Downstream Watershed Considerations

Local Sensitive Downstream Aquatic Habitat: Extended detention micropool pond is the best alternative to minimize or eliminate impacts due to warm water discharges when sensitive aquatic habitat is located downstream of the pond. For wet ponds and extended detention wet ponds, consider providing off-line WQ_V treatment to reduce the size of pond or if possible, design a smaller, but deeper pond, with vegetation surrounding the pond to provide solar shading and minimize thermal impacts.

Aquifer Protection: Reduce potential groundwater contamination by pretreating hotspot runoff prior to hotspot runoff entering pond. May require liner for type “A” and “B” soils.

Dams

The most commonly used material for small dam construction is earth fill, but structural concrete can also be used. For on-site stormwater controls in high density areas of development or where land values are very costly, the use of a structural concrete dam can save a significant amount of land and in some cases make a more aesthetically appealing outfall structure than the typical riser and barrel assembly.

The following are general guidelines for the construction of detention pond dams. Where applicable, the construction specifications should be provided by a Professional Engineer of Record for the dam design.

- **General**
  - The dam area shall be cleared, grubbed and stripped of all vegetative material and topsoil prior to dam construction.

- **Earth Dams**
  - The dam construction plans shall indicate allowable soil materials to be used, compaction required, locations of core trenches if used, any sub-drainage facilities to be installed to control seepage, plus horizontal and vertical dimensions of the earthen structure.
  - The sub-grade of the dam shall be scarified prior to the placement and compaction of the first lift of soil backfill to ensure a good bond between the existing soil and the earthen dam.
  - Placement of earth fill shall be in controlled lifts with proper compaction.
  - Placement of spillway or outflow pipes through the dam shall be per the plan details, with proper backfill and compaction of any excavated trenches. Hydraulic flooding or other compaction methods of saturated soil shall not be allowed.
  - Topsoil and soil additives necessary for the establishment of permanent ground cover above the normal water surface elevation and on the downstream side of the dam shall be installed and seeded as soon as practical to avoid rilling and erosion of the dam's earthen embankment.
  - Do not plant trees or shrubs on the earth dam. Their root systems cause seepage and damage to the structure.

- **Concrete Dams**
  - Concrete dams shall be designed and built in accordance with the American Concrete Institute's (ACI) latest guidelines for Environmental Engineering Concrete Structures. Particular attention shall be paid to water tightness, crack control, concrete materials and construction practices.
  - The construction plans shall indicate materials, plus horizontal and vertical dimensions necessary for the construction of the dam. Details and information shall be provided on joint types and spacing to be used.
  - At least half of the water surface perimeter of the pond at normal pool elevation shall be constructed with a vegetated earthen embankment or graded slope.
  - Principal and emergency spillways can be incorporated into a weir overflow over the weir if splash pads or another type of control structure is provided to protect the downstream toe of the concrete structure.
  - Placement of drain valves, overflow controls and other penetrations of the concrete wall shall not be located on the same vertical line to prevent creating a weakened plane where uncontrolled cracks can form. Locations should also anticipate operation during storm events when overflow weirs will be operating.

3.2.1.6 Design Procedures for Stormwater Ponds

Step 1 Compute runoff control volumes using the Integrated Design Approach: Calculate the WQv, CPv or channel protection inflow hydrograph, and the peak flow control inflow hydrographs using methods discussed in Volume 2, Chapter 4.

Step 2 Confirm local design criteria and applicability:

Consider any special site-specific design conditions/criteria.

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3 Determine pretreatment volume:

A sediment forebay is provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4 to 6 feet deep. The forebay storage volume counts toward the total WQ_v requirement and may be subtracted from the WQ_v for subsequent calculations.

Step 4 Determine permanent pool volume and water quality extended detention volume:

<u>Wet Pond:</u> Size permanent pool volume to 1.0 WQ_v

<u>Extended Detention Wet Pond:</u> Size permanent pool volume to 0.5 WQ_v. Size extended detention volume to 0.5 WQ_v.

<u>Extended Detention Micropool Pond:</u> Size permanent pool volume to 0.1 acre-inch per impervious acre. Size extended detention volume to remainder of WQ_v.

Step 5 Layout pond grading and determine storage available for permanent pool and extended detention water quality pool, as applicable:

This step involves designing the grading for the pond (establishing contours) and determining the elevation-storage relationship for the pond. This typically requires a trial and revision approach as the design is refined.

Include safety and aquatic benches.

Set WQ_V permanent pool elevation based on calculated permanent pool volume and the elevation-storage curve for the pond (see above).

Step 6 Determine elevation and orifice size for extended detention portion of WQ_V (for extended wet detention ponds and micropool ponds):

Set orifice elevation at top of permanent pool.

Set top of extended detention pool based on extended detention volume and pond elevation-storage curve.

By trial and revision, select an orifice size that will drain 90% of the WQ_V in 24 hours. The 90% criteria is intended to address the tendency of the drawdown method (see Chapter 4 of Volume 2) to oversize the orifice.

Step 7 Determine elevation and orifice size for channel protection extended detention:

Wet Pond: The CP_V orifice is placed at the top of the permanent WQ_V pool. The preferred method is to route the 1-year, 24-hour inflow hydrograph through the pond, and select an orifice size that provides 24 hours of detention between the centroid of the inflow hydrograph and the centroid of the outflow hydrograph.

In lieu of the routing method, a "simplified method" is available for determining the CP_V and for configuring the CP_V orifice. This method is described in detail in Chapter 4. In summary, the method consists of estimating the peak inflow and outflow to and from the pond for a 24-hour detention time, the CP_V, and the corresponding maximum head on the orifice. This information is then used to size the orifice.

Wet Extended Detention Pond and Wet Extended Detention Micropool Pond: For wet extended detention ponds, the CP_V orifice is typically located at the top of the permanent part of the WQ_V pool. As with the wet pond, the preferred method is to route the 1-year, 24-hour inflow hydrograph through the pond, and select the orifice size that provides 24 hours of detention between the centroids of the inflow and outflow hydrographs. However, in some cases, the simplified method discussed above may be used. The simplified method is strictly applicable to the situation where the active pool (in this case the CP_V pool and the extended detention portion of the WQ_V pool) is controlled by one or more orifices at the same elevation. However, it is rare that the WQ_V orifice alone can serve to regulate both the WQ_V and CP_V. In most cases, a CP_V orifice is also required. If the elevations of the centers of the WQ_V and CP_V orifices are "approximately" the same, then the simplified method is applicable. Until further information is available, the elevations of the centers of the orifices will be considered "approximately" the same if the difference between the center elevations does not exceed 20% of the CP_V depth.

Step 8 Prepare hydrology analysis for floods and design embankment(s) and spillway(s):

Size additional control structure orifices, weirs and emergency spillway as required for flood control and freeboard.

Provide safe passage for the 100-year event.

Step 9 Investigate potential pond hazard classification:

The design and construction of stormwater management ponds are required to follow the latest version of the Kansas dam safety guidelines, where applicable.

Step 10 Design inlets, sediment pre-treatment facilities, outlet structures, maintenance access, and safety features:

See Volume 2, Chapter 5 for more details.

Step 11 Prepare Vegetation and Landscaping Plan:

A landscaping plan for a stormwater pond and its buffer should be prepared to indicate how aquatic and terrestrial areas will be stabilized and established with vegetation.

3.2.1.7 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants").
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the pond, and also clearly identify drainage and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.1.8 Example Schematics

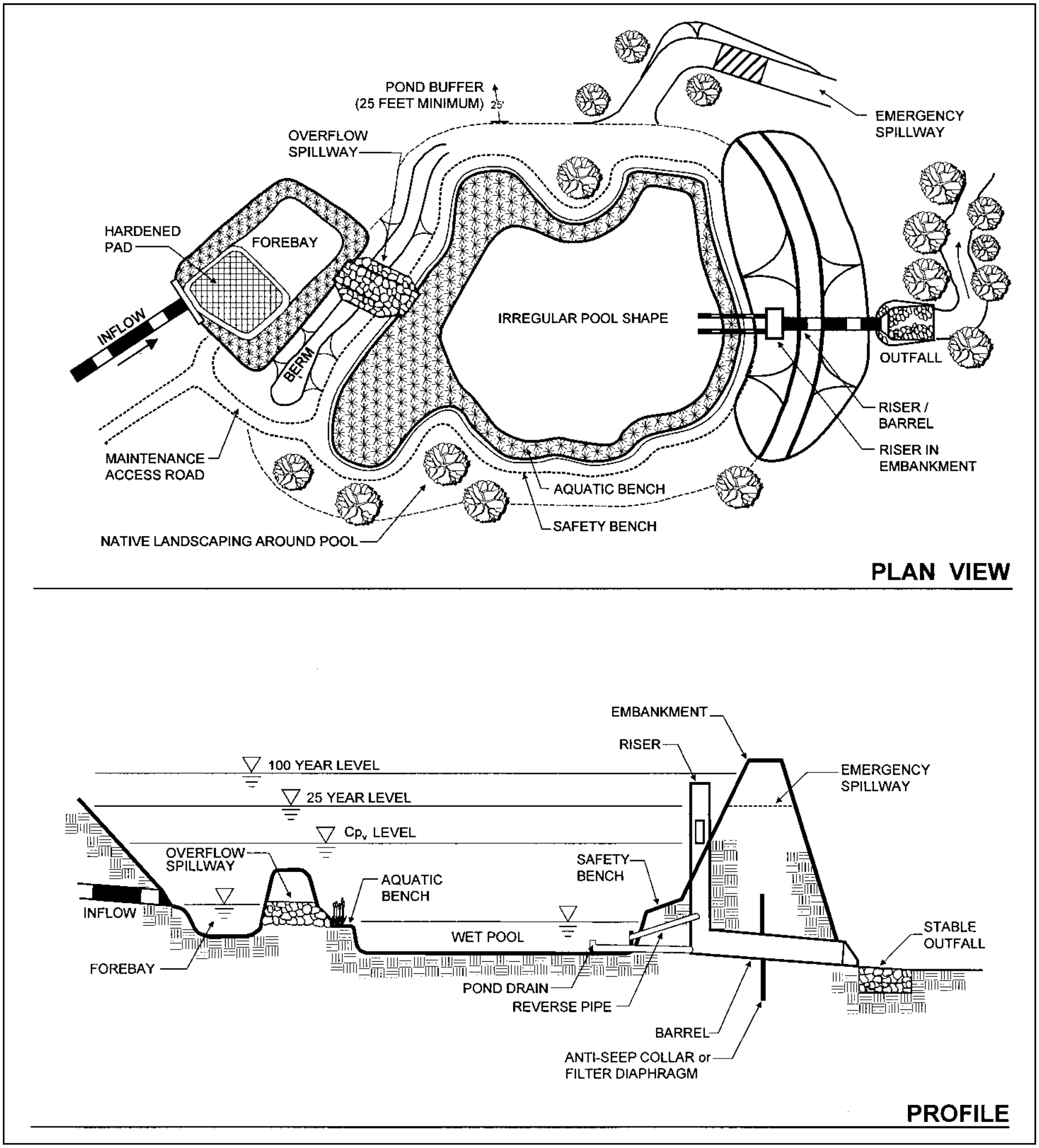

Figure 3-14 Schematic of Wet Pond
(MSDM, 2000)

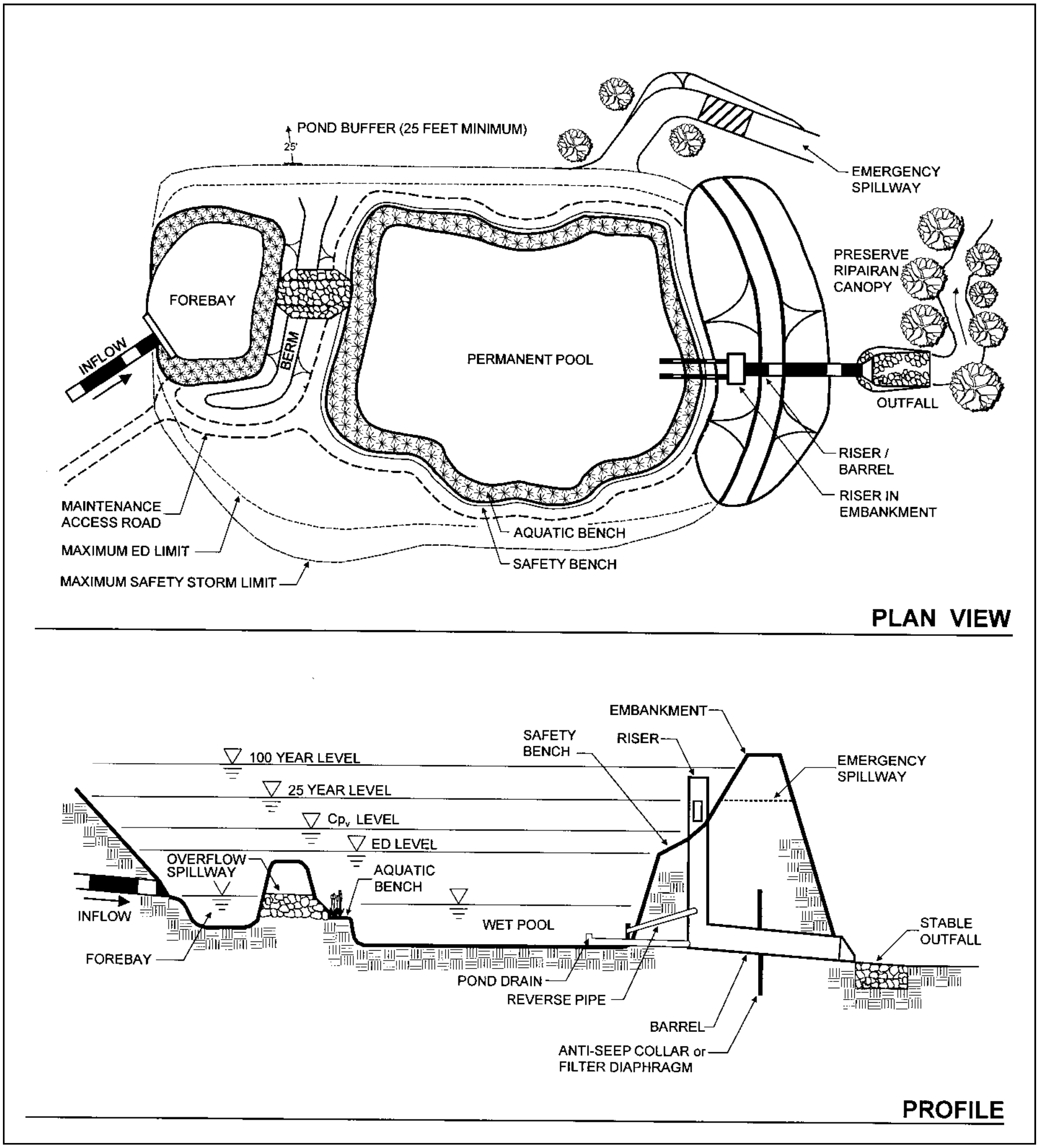

Figure 3-15 Schematic of Wet Extended Detention Pond
(MSDM, 2000)

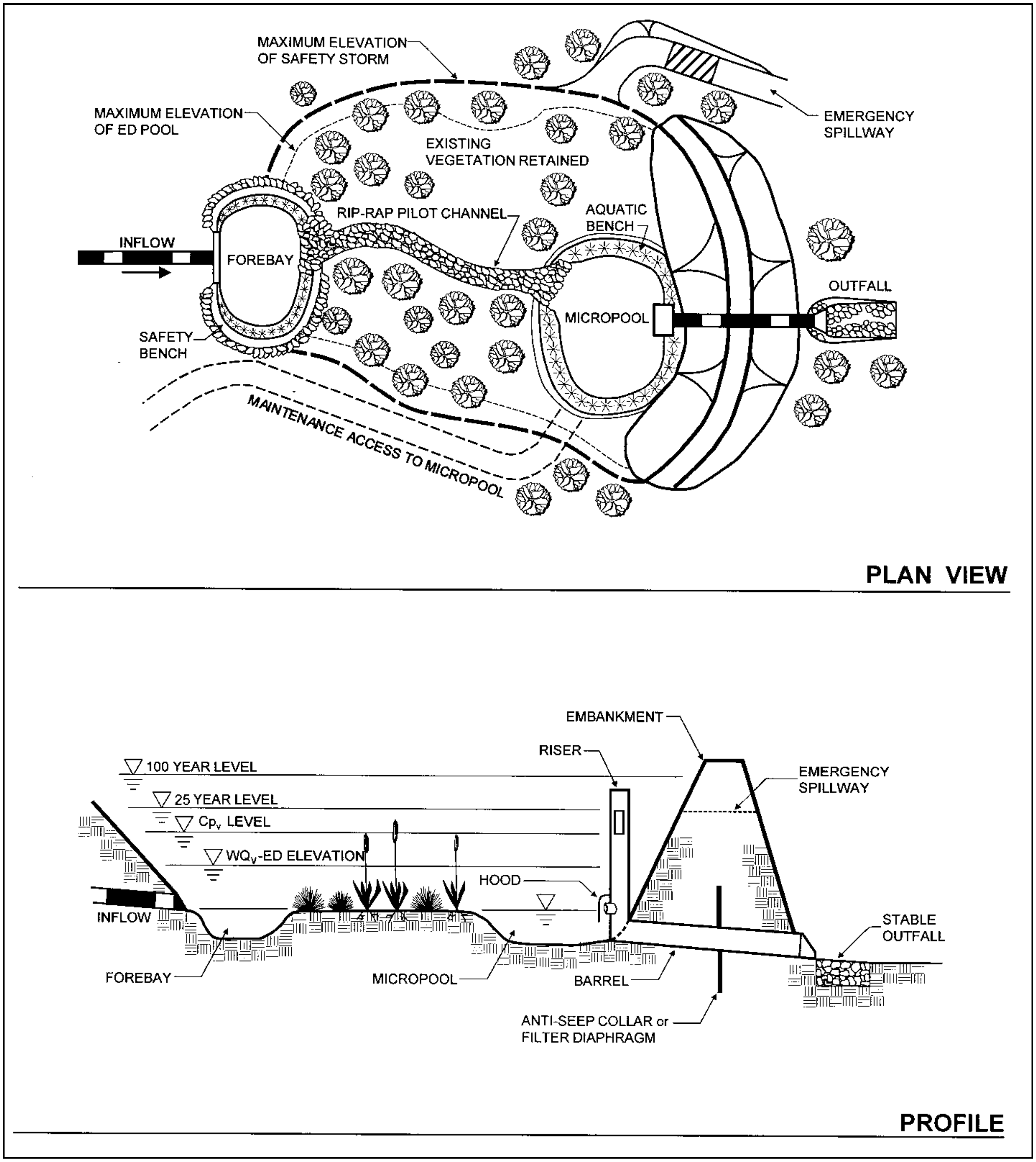

Figure 3-16 Schematic of Micropool Extended Detention Pond
(MSDM, 2000)

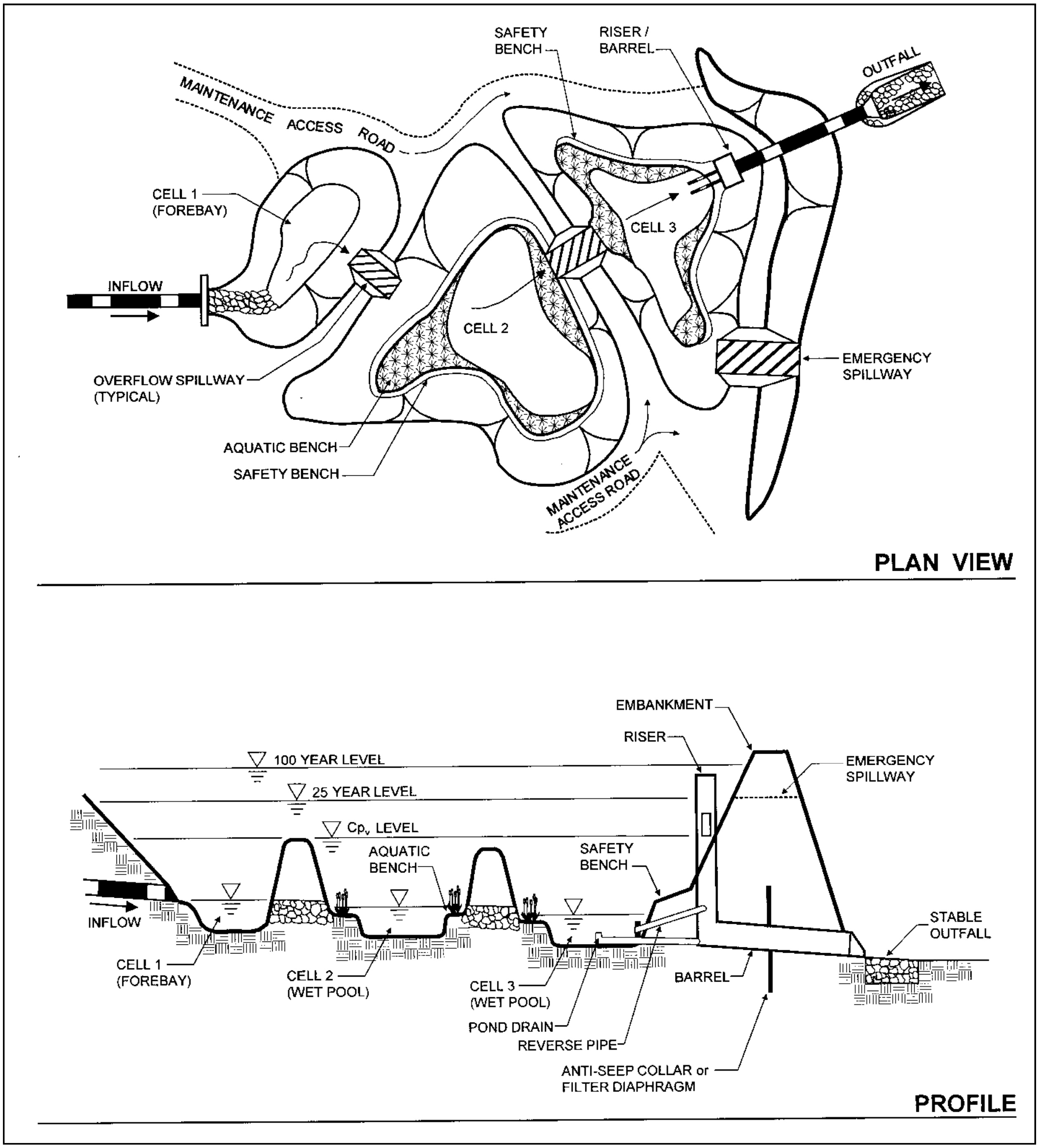

Figure 3-17 Schematic of Multiple Pond System
(MSDM, 2000)

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3.2.2 Extended Dry Detention Pond

Primary Water Quality Facility

Description: A surface storage basin or facility designed to provide water quantity and quality control through detention and/or extended detention of stormwater runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Designed for the control of peak flood flows and the removal of stormwater pollutants

ADVANTAGES / BENEFITS:

- Useful alternative to “wet pond” when drainage area is not large enough to maintain a permanent pool
- May or may not be used in conjunction with water quality structural control
- Recreational and other open space opportunities between storm runoff events

DISADVANTAGES / LIMITATIONS:

- Pollutant removal efficiency less than wet pond

MAINTENANCE REQUIREMENTS:

- Remove debris from inlet and outlet structures
- Maintain side slopes/remove invasive vegetation
- Monitor sediment accumulation and remove periodically
- Dam inspection and maintenance

POLLUTANT REMOVAL

M	**Total Suspended Solids**
L	**Nutrients –** Total Phosphorus & Total Nitrogen
L	**Metals –** Cadmium, Copper, Lead & Zinc
No Data	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Q ality Protection**
✓	**Channel Protection**
✓	**On-Site lood Control**
✓	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirements**
M	**Capital Costs**
M	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *No restrictions*

Soils: *Hydrologic group ‘A’ and ‘B’ soils may require pond liner*

Other Considerations:

- *Recreational and open space uses for dry detention*

L=Low **M**=Moderate **H**=High

3.2.2.1 General Description

Dry extended detention (ED) ponds are surface facilities intended to provide extended periods of detention for water quality and channel protection control, and may also serve to control peak flood flows.

3.2.2.2 Pollutant Removal Capabilities

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- Total Suspended Solids – 60%
- Total Phosphorus – 35%
- Total Nitrogen – 25%
- Heavy Metals – 25%
- Fecal Coliform – Insufficient data to provide pollutant removal rate

For additional information and data on pollutant removal capabilities, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.2.3 Design Criteria and Specifications

Location

- Extended dry detention ponds must combine with other structural stormwater controls to provide treatment of the full WQ_v. They may be part of a treatment train which treats the WQ_v.

General Design

- Extended dry detention ponds are sized to provide 24 hours of extended detention of the WQ_V.
- Extended dry detention ponds are sized to provide 24 hours of extended detention of the CP_V.
- Extended dry detention ponds can also provide additional storage volume for conventional detention (peak flow reduction) of the 2 through 100-year storm event.
- Routing calculations must be used to demonstrate that the flood storage volume and outlet structure configuration are adequate. See Volume 2, Chapters 4 and 5 for procedures on the design of detention storage.

- Design may be subject to the requirements of the Kansas dam safety program based on the volume, dam height, and level of hazard.
- Earthen embankments shall have side slopes no steeper than 3:1 (horizontal to vertical).
- Vegetated slopes shall be less than 20 feet in height and shall have side slopes no steeper than 4:1 (horizontal to vertical). Riprap-protected slopes shall be no steeper than 3:1. Geotechnical slope stability analysis is recommended for slopes greater than 10 feet in height.
- Areas above the normal high water elevations of the detention facility should be sloped toward the basin to allow drainage and to prevent standing water. Careful grading is required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions. A low flow or pilot channel across the facility bottom from the inlet to the outlet (often constructed with riprap or a concrete flume) is recommended to convey low flows and prevent standing water conditions.
- Ponds cannot be located within a stream or any other navigable waters of the U.S., including wetlands, without obtaining applicable local, Kansas and federal permits.
- Dry extended detention ponds located in floodplains or backwater areas must perform as specified for peak flow control for any tailwater condition, up to the Base Flood Elevation (BFE). The potential for back flow into the pond must be addressed with flap gates or by providing sufficient volume to receive backflow up to the BFE, and still provide peak flow control surcharge volume in the pond (above the BFE).

Inlet and Outlet Structures

- Discharge into the pond from inflow channels or pipes are to be stabilized with flared riprap aprons, or the equivalent. A sediment forebay or equivalent upstream pretreatment with a volume of 0.1 inches per impervious acre of contributing drainage shall be provided upstream of the pond. The pre-treatment storage volume is part of the total WQ_v required.
- An orifice capable of detaining the WQ_v for 24 hours must be provided. The orifice shall be adequately protected from clogging using designs found in chapter 5.
- Likewise, the outlet structure must have an orifice capable of detaining the CP_v for 24 hours. Orifice protection requirements are the same as for the WQ_v.
- For peak flow control, discharge is controlled by a principal spillway, typically consisting of a riser and outlet pipe. The WQ_v and CP_v orifices are usually incorporated into the riser. Additional orifices and weirs are incorporated into the riser to control the 2 through 100-year design storms.
- Small outlets that will be subject to clogging or are difficult to maintain are not acceptable.
- See Volume 2, Chapters 4 and 5 for more information on the design of outlet works.
- Seepage control or anti-seep collars should be provided for all outlet pipes.

- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the principal spillway outlet to prevent scouring and erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a vegetated riparian zone in the shortest possible distance.
- A concrete emergency spillway is to be included in the stormwater pond design to safely pass the extreme flood flow. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the 100 year flood event, to the lowest point of the dam embankment not counting the emergency spillway. The 100-year flood elevation for emergency spillway design is based on the elevation required to pass the 100-year flow with no discharge through the principal spillway.
- Please refer to "Stormwater Pond", Section 3.2.1, for additional requirements applicable to all surface detention ponds.
- The use of the simplified method (Chapter 4) for configuring the CP_v orifice is the same as for wet extended detention ponds (Section 3.2.1.).

Maintenance Access

- The local jurisdiction may require that the pond be placed in a reserve and/or establishment of a drainage easement to the pond, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- When required, reserves and/or drainage easements must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.
- Access to the riser is to be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls.

3.2.2.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants").
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be

found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.

3. As-built drawings must accurately identify the location and layout of the pond, and also clearly identify drainage and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.2.5 Example Schematics

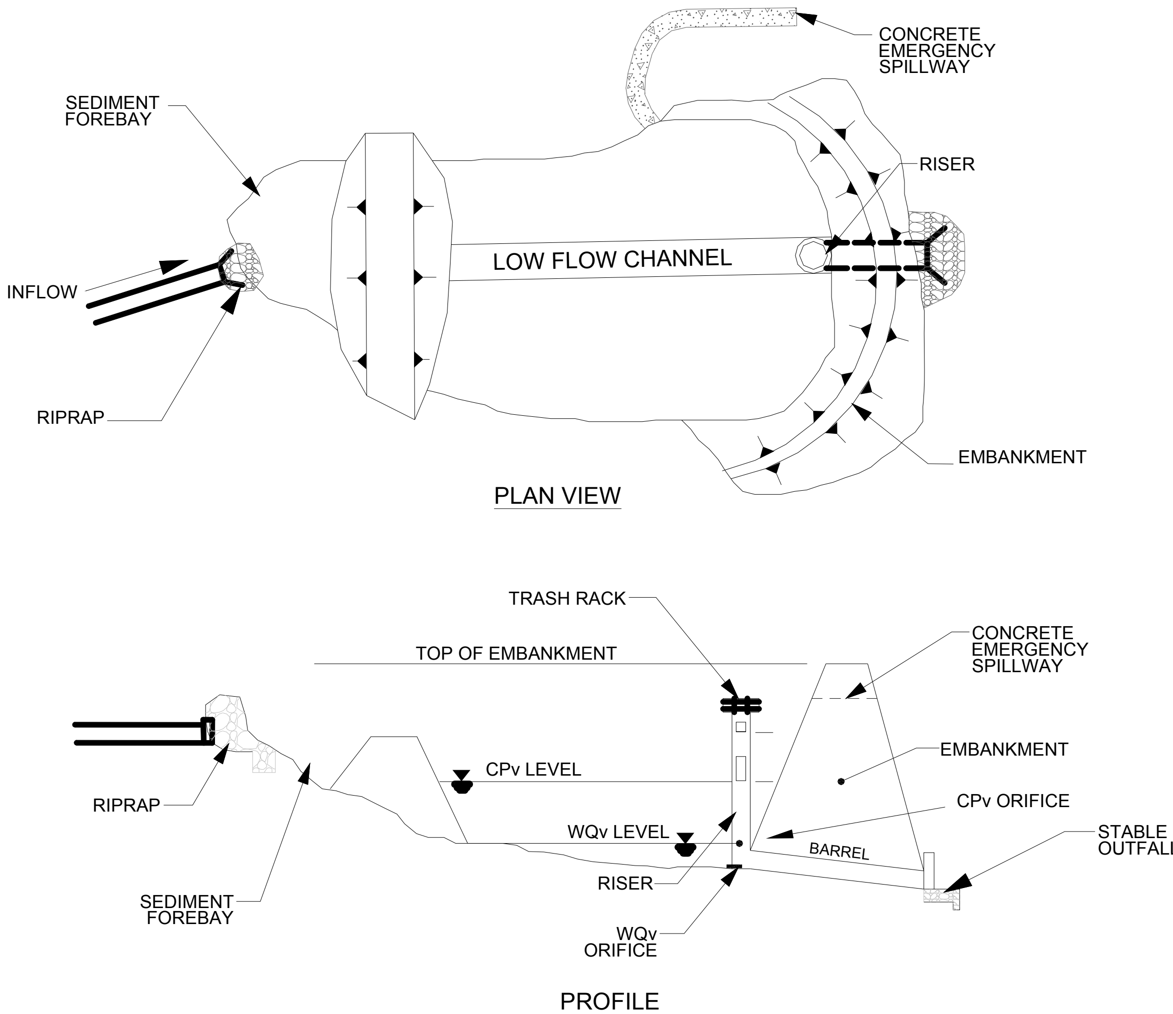

Figure 3-18 Schematic of Dry Extended Detention Basin

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3.2.3 Vegetative Filter Strip

Primary Water Quality Facility

Description: Filter strips are uniformly graded and well vegetated sections of land engineered and designed to treat runoff and remove pollutants through vegetative filtering and infiltration.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Runoff from an adjacent impervious area must be evenly distributed across the filter strip as sheet flow
- Sheet flow must be ensured via a combination of vegetation, slope and length criteria

ADVANTAGES / BENEFITS:

- Can be used as part of the runoff conveyance system to provide pretreatment
- Can provide groundwater recharge
- Reasonably low construction cost

DISADVANTAGES / LIMITATIONS:

- Cannot alone achieve the 80% TSS removal target
- Large land requirement

MAINTENANCE REQUIREMENTS:

- Requires periodic repair, regrading, and sediment removal to prevent channelization

POLLUTANT REMOVAL

M	**Total Suspended Solids**
L	**Nutrients –** Total Phosphorus & Total Nitrogen
M	**Metals –** Cadmium, Copper, Lead & Zinc
No Data	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Water Quality Protection**
- ☐ **Channel Protection**
- ☐ **On-Site Flood Control**
- ☐ **Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

H	**Land Requirements**
L	**Relative Capital Costs**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *2 acres max*

Soils: *No restrictions*

Other Considerations:

- *Use in buffer system*

L=Low **M**=Moderate **H**=High

3.2.3.1 General Description

Filter strips are uniformly graded and densely vegetated sections of land engineered to treat runoff and remove pollutants through vegetative filtering and infiltration. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, small parking lots, and other pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer, or as pretreatment for another structural stormwater control. Filter strips can serve as a buffer between incompatible land uses, be landscaped to be aesthetically pleasing, and provide groundwater recharge in areas with pervious soils.

Filter strips rely on the use of vegetation to slow runoff velocities and filter out sediment and other pollutants from urban stormwater. There can also be a reduction in runoff volume for smaller flows that infiltrate pervious soils while contained within the filter strip. To be effective, however, sheet flow must be maintained across the entire filter strip. Once runoff flow concentrates, it effectively short-circuits the filter strip and reduces any water quality benefits. Therefore, a flow spreader is often included at the top of the filter strip design.

There are two different filter strip designs: a simple filter strip and a design that includes a permeable berm at the bottom. The presence of the berm increases the contact time with the runoff, thus reducing the overall width of the filter strip required to treat stormwater runoff. Filter strips are typically an on-line practice, so they must be designed to withstand the full range of storm events without eroding.

3.2.3.2 Pollutant Removal Capabilities

Pollutant removal from filter strips is highly variable and depends primarily on density of vegetation and contact time for filtration and infiltration. These, in turn, depend on soil and vegetation type, slope, and presence of sheet flow.

The following pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach.

- Total Suspended Solids – 50%
- Total Phosphorus – 20%
- Total Nitrogen – 20%
- Heavy Metals – 40%
- Fecal Coliform – insufficient data

For additional information and data on pollutant removal capabilities, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.3.3 Design Criteria and Specifications

General Criteria

- Filter strips may be used to treat small drainage areas. Flow must enter the filter strip as overland flow spread out over the width (long dimension; perpendicular to flow) of the strip. Flow usually concentrates within a maximum of 75 feet for impervious surfaces, and 150 feet for pervious surfaces (Claytor & Schueler, 1996). These are the maximum allowable contributing flow paths for filter strips unless special provisions are made to ensure design flows spread evenly across the filter strip, instead of becoming concentrated.
- Filter strips should be integrated within site designs.
- Filter strips should be constructed outside any natural stream buffer area whenever possible to maintain a more natural buffer along the channel.
- Filter strips should be designed for slopes between 2% and 6%. Greater slopes than this would encourage the formation of concentrated flow. Flatter slopes would encourage standing water.
- The depth of sheet flow along filter strips should normally be limited to approximately 1 inch to discourage flow concentrations. A depth of 0.5 inches is ideal, where practicable.
- Filter strips should not be used on soils that cannot sustain a dense grass cover with high retardance. Designers should choose a grass that can withstand relatively high velocity flows at the entrances, and both wet and dry periods.
- The flow path should be at least 15 feet across the strip to provide filtration and contact time for water quality treatment. A minimum of 25 feet is preferred (where available).
- Both the top and toe regions of the slope should be as flat and even as possible to encourage sheet flow and prevent erosion.
- An effective flow spreader is a gravel diaphragm at the top of the slope (ASTM D 448 size 6, 1/8” to 3/8”). The 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. Other types of flow spreaders include a concrete sill, curb stops, or curb and gutter with “sawteeth” cut into it.
- Ensure that flows in excess of design flow move through the strip without damaging it. A bypass channel or overflow spillway with protected channel section may be required to handle flows above the allowable as defined below.
- Pedestrian and vehicular traffic across the filter strip should be limited.
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement to the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

- When a berm is used at the downstream end of the filter strip, outlets must be provided to drain the WQ_V over a 24 hour period.
- Maximum discharge loading per foot of filter strip width (perpendicular to flow path) is found using the Manning's equation:

Equation 3-1

$$q = \frac{0.00237}{n} Y^{\frac{5}{3}} S^{\frac{1}{2}}$$

where:

q	=	discharge per foot of width of filter strip (cfs/ft)
Y	=	allowable depth of flow (inches)
S	=	slope of filter strip (percent)
n	=	Manning's "n" roughness coefficient

(use n = 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

- The minimum width of a filter strip is:

Equation 3-2

$$W_{fMIN} = \frac{Q_{wv}}{q}$$

where:

W_{fMIN}	=	minimum filter strip width perpendicular to flow (feet)
Q	=	peak flow for the water quality (1.2") storm (cfs)
q	=	flow per unit width of filter strip (cfs/ft)

Filter without Berm

- Size filter strip (parallel to flow path) for a contact time of 5 minutes minimum
- Equation for filter length is based on the SCS TR55 sheet flow travel time (equation 4-5):

Equation 3-3

$$L_f = \frac{(T_t)^{1.25} (P_{2-24})^{0.625} (S)^{0.5}}{3.34n}$$

where:

L_f	=	length of filter strip parallel to flow path (ft)
T_t	=	travel time through filter strip (5 minute minimum)
P_{2-24}	=	2-year, 24-hour rainfall depth = 3.5 inches (see Chapter 4)
S	=	slope of filter strip (percent)
n	=	Manning's "n" roughness coefficient

(use n = 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

Filter Strips with Berm

- Size outlet pipes to ensure that the bermed area drains within 24 hours.
- Specify grasses resistant to frequent inundation within the shallow ponding limit.

- Berm material should be of sand, gravel and sandy loam to encourage grass cover (Sand: ASTM C-33 fine aggregate concrete sand 0.02"-0.04", Gravel: AASHTO M-43 ½" to 1").
- Size filter strip to contain at least the WQ_v within the wedge of water backed up behind the berm.
- Maximum berm height is 12 inches.

Filter Strips for Pretreatment

- A number of other structural controls, including bioretention areas and infiltration trenches, may utilize a filter strip as a pretreatment measure. The required length of the filter strip flow path depends on the drainage area, imperviousness, and the filter strip slope. Table 3-5 provides sizing guidance for using filter strips for pretreatment.

Table 3-5 Filter Strip Sizing Guidance When Using for Pretreatment

Parameter	Impervious Areas				Pervious Areas (Lawns, etc)			
Maximum inflow approach length (feet)	35		75		75		100	
Filter strip slope (max = 6%)	2%	> 2%	2%	> 2%	2%	> 2%	2%	> 2%
Filter strip minimum length (feet)	10	15	20	25	10	15	15	20

(Source: Claytor and Schueler, 1996)

3.2.3.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operations and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the facility, and clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.3.5 Example Schematic

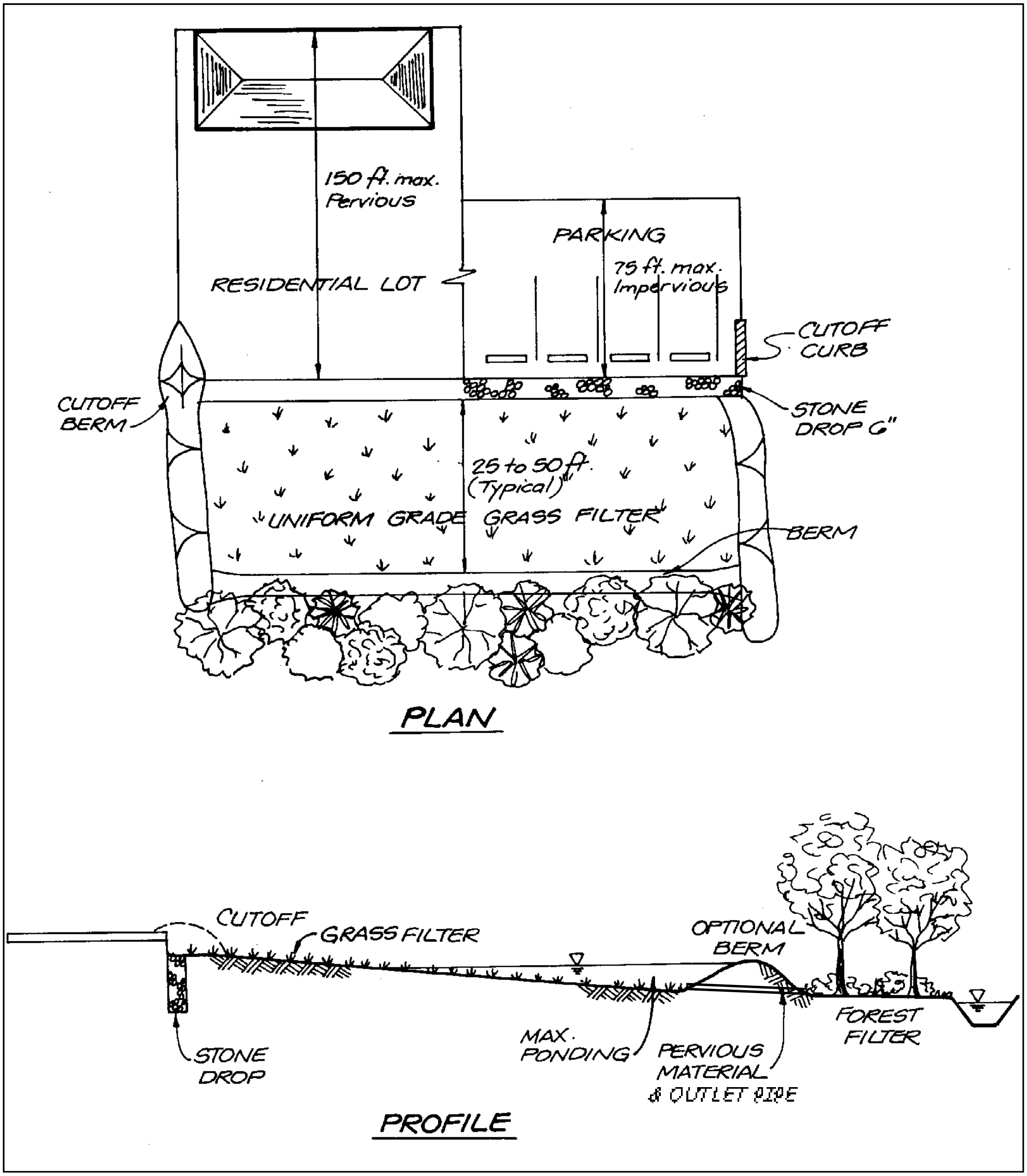


Figure 3-19 Schematic of Filter Strip (with optional Berm)
(Claytor & Schueler, 1996)

3.2.3.6 Design Example

Basic Data

Small commercial lot 150 feet length x 100 feet wide located

- Drainage area treated by filter (A) = 0.2 acres
- Runoff coefficient (R_v) = 0.70
- Slope (S) = 4%
- Depth (Y) = 0.5 inches
- Manning's n = 0.25
- Time of Concentration (t_c) = 8 minutes

Calculate Maximum Discharge Loading Per Foot of Filter Strip Width

Using Manning's equation again:

$$q = \frac{0.00237}{0.25} * (0.5)^{5/3} * (4)^{1/2} = 0.006\ cfs/ft$$

Calculate the Water Quality Peak Flow

Compute the WQ_V in inches over the drainage area (thus expressed as Q_{wv}) using equation 4-25:

$$Q_{wv} = P * R_v = 1.2 * 0.7 = 0.84 inches$$

Compute modified CN for 1.2-inch rainfall (P=1.2); using Q_{wv} (in inches) for Q:

$$CN = \frac{1000}{\left[10 + 5P + 10Q - 10\left(Q^2 + 1.25QP\right)^{1/2}\right]}$$

$$CN = \frac{1000}{\left[10 + (5 * 1.2) + (10 * 0.84) - 10 * \left(0.84^2 + 1.25 * 0.84 * 1.2\right)^{1/2}\right]} = 96.3 \quad \text{(Use CN = 96)}$$

For CN = 96 and an estimated time of concentration (T_c) of 8 minutes (0.13 hours), compute the Q_{wq} for a 1.2-inch storm.

From Table 4-9, I_a = 0.083, therefore $\frac{I_a}{P} = \frac{0.083}{1.2} = 0.07$

From Figure 4-6 for a Type II storm (using the limiting values) $q_u = 940\,csm/in$. Therefore, the peak discharge for the WQ_v (expressed as Q_{wq}) can be calculated using equation 4-18:

$$Q_{wq} = q_u * A * WQ_v = 940\,csm/in * \frac{0.20ac}{640\,ac/mi^2} * 0.84in = 0.25cfs$$

Minimum Filter Width

Using Equation 3-2:

$$W_{fMIN} = \frac{Q_{wq}}{q} = \frac{0.25}{0.006} = 42\ feet$$

Filter without Berm

- 2-year, 24-hour storm = 3.5 inches (see Chapter 4)
- Use 5 minute travel (minimum contact) time

Using Equation 3-3:

$$L_f = \frac{(5)^{1.25} * (3.5)^{0.625} * (4)^{0.5}}{3.34 * 0.25} = 39feet$$

Note: Reducing the filter strip slope to 2% and planting a denser grass (raising the Manning n to 0.35) would reduce the filter strip length to 20 feet.

Filter with Berm

Compute the required WQ_V in cubic feet:

$$WQ_v = \frac{P * R_v * A}{12} = \frac{1.2 * 0.7 * 0.2}{12} = 0.014 \text{ ac-ft or } 610 \text{ ft}^3$$

The volume of the "wedge" of water captured by the filter strip is:

$$Volume = W_f * depth * L_f$$

Where "depth" is average depth of water captured in the wedge.

For an average captured depth of 4.5 inches or 0.38 feet (a berm height of 9 inches):

$Volume = 42ft * 0.375ft * 40ft = 630ft^3$ is > 610 ft^3, therefore OK

Size outlet(s) to drain the stored volume of water over a 24 hour period.

3.2.4 Grassed Channel

Primary Water Quality Facility

Description: Vegetated open channels designed to filter stormwater runoff and meet velocity targets for the water quality design storm event.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Longitudinal slopes must be less than 4%
- Flow velocities in the channel must be less than 1 ft/s for the WQ storm

ADVANTAGES / BENEFITS:

- Can be used as part of the runoff conveyance system to provide pretreatment
- Grass channels can act to partially infiltrate runoff from small storm events if underlying soils are pervious
- Often less expensive to construct than curb and gutter systems

DISADVANTAGES / LIMITATIONS:

- May require more maintenance than curb and gutter system
- Cannot alone achieve the 80% TSS removal target
- Potential for bottom erosion and re-suspension
- Standing water may not be acceptable in some areas
- Cannot be used on steep slopes

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Quality Protection**
	Channel Protection
✓	**On-Site Flood Control**
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

H	**Land Requirements**
L	**Relative Capital Costs**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *5 acres max*

Soils: *No restrictions*

Other Considerations:

- *Curb and gutter replacement*

L=Low **M**=Moderate **H**=High

POLLUTANT REMOVAL

L	**Total Suspended Solids**
L	**Nutrients –** Total Phosphorus & Total Nitrogen
L	**Metals –** Cadmium, Copper, Lead & Zinc
No Data	**Pathogens –** Coliform, Streptococci & E. Coli

3.2.4.1 General Description

Grass channels are typically designed to provide nominal treatment of runoff as well as reduce runoff velocities for treatment in other stormwater management facilities. Grass channels are well suited to a number of applications and land uses, including treating runoff from roads and parking lots, as well as from pervious surfaces.

Grass channels differ from the enhanced swale design in that they do not have an engineered filter media to enhance pollutant removal capabilities and, therefore, have a lower pollutant removal rate than for an enhanced swale. Grass channels can partially infiltrate runoff from small storm events in areas with pervious soils. When properly incorporated into an overall site design, grass channels can reduce impervious cover, slow runoff, accent the natural landscape, and provide aesthetic benefits.

When designing a grass channel, the two primary considerations are channel capacity and minimization of erosion. Runoff velocity should not exceed 1.0 foot per second during the peak discharge associated with the water quality design rainfall event, water depth must be less than 4 inches (height of the grass), and the total length of a grass channel should provide at least 5 minutes of residence time. (Depth and velocity may be greater for flood flows exceeding the water quality design event.) To enhance water quality treatment, grass channels must have broader bottoms, lower slopes, and denser vegetation than most drainage channels.

3.2.4.2 Pollutant Removal Capabilities

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach.

- Total Suspended Solids – 50%
- Total Phosphorus – 25%
- Total Nitrogen – 20%
- Heavy Metals – 30%
- Fecal Coliform – insufficient data

Fecal coliform removal is uncertain. In fact, grass channels are often a source of fecal coliforms from local residents walking their dogs.

For additional information and data on pollutant removal capabilities, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.4.3 Design Criteria and Specifications

- Grass channels should generally be used to treat small drainage areas of less than 5 acres. If the practices are used on larger drainage areas, the flows and volumes through the channel become too large to allow for filtering and infiltration of runoff.
- Grass channels shall be designed on slopes of less than 4%; channel slopes between 1% and 2% are recommended. However, for small slopes some longterm standing water may occur.
- Grass channels can be used on most soils with some restrictions on the most impermeable soils. Grass channels should not be used on hydrologic soil group D soils.
- A grass channel should accommodate the peak flow for the water quality design storm Q_{wq}.
- Grass channels shall have a trapezoidal or parabolic cross section with side slopes 3:1 or flatter.
- The bottom of the channel should be between 2 and 8 feet wide. The minimum width ensures an adequate filtering surface for water quality treatment, and the maximum width resists braiding, which is the formation of small channels within the swale bottom. The bottom width is a dependent variable in the calculation of velocity based on Manning's equation. If a larger channel is needed, the use of a compound cross section is recommended.
- Runoff velocities must be nonerosive. The full-channel design velocity will typically govern. See allowable velocities in Chapter 5. A mechanism for safely passing or bypassing flood flows larger than the water quality event must be provided.
- A 5 minute residence time is required for the water quality peak flow. Residence time may be increased by reducing the slope of the channel, increasing the wetted perimeter, or planting a denser grass (raising the Manning's n).
- The depth from the bottom of the channel to the historically high groundwater elevation should be at least 5 feet.
- Incorporation of permeable check dams within the channel will aid in obtaining the required minimum detention time.
- Designers should choose a grass that can withstand relatively high velocity flows at the downstream end of the channel where it discharges into other conveyances or ponds.
- A forebay is recommended in order to settle out the larger particles before they are introduced to the main channel.
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement to the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

Grass Channels for Pretreatment

A number of other structural controls, including bioretention areas and infiltration trenches, may utilize a grass channel as a pretreatment measure. The length of the grass channel depends on the drainage area, land use, and channel slope. Table 3-6 provides sizing guidance for grass channels for a 1 acre drainage area. The minimum grassed channel length should be 20 feet.

Table 3-6 Bioretention Grass Channel Sizing Guidance When Used as Pretreatment

Parameter	≤ 33% Impervious		Between 34% and 66% Impervious		≥ 67% Impervious	
Slope (max = 4%)	≤ 2%	> 2%	≤ 2%	> 2%	≤ 2%	> 2%
Grass channel minimum length (feet) assumes 2-foot wide bottom width	25	40	30	45	35	50

(Source: Claytor and Schueler, 1996)

3.2.4.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the facility, and clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.4.5 Example Schematics

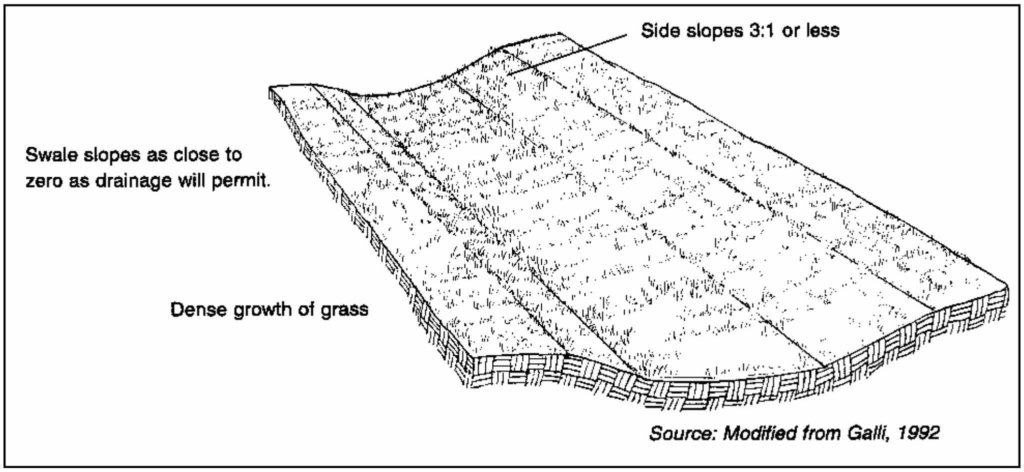


Figure 3-20 Typical Grass Channel

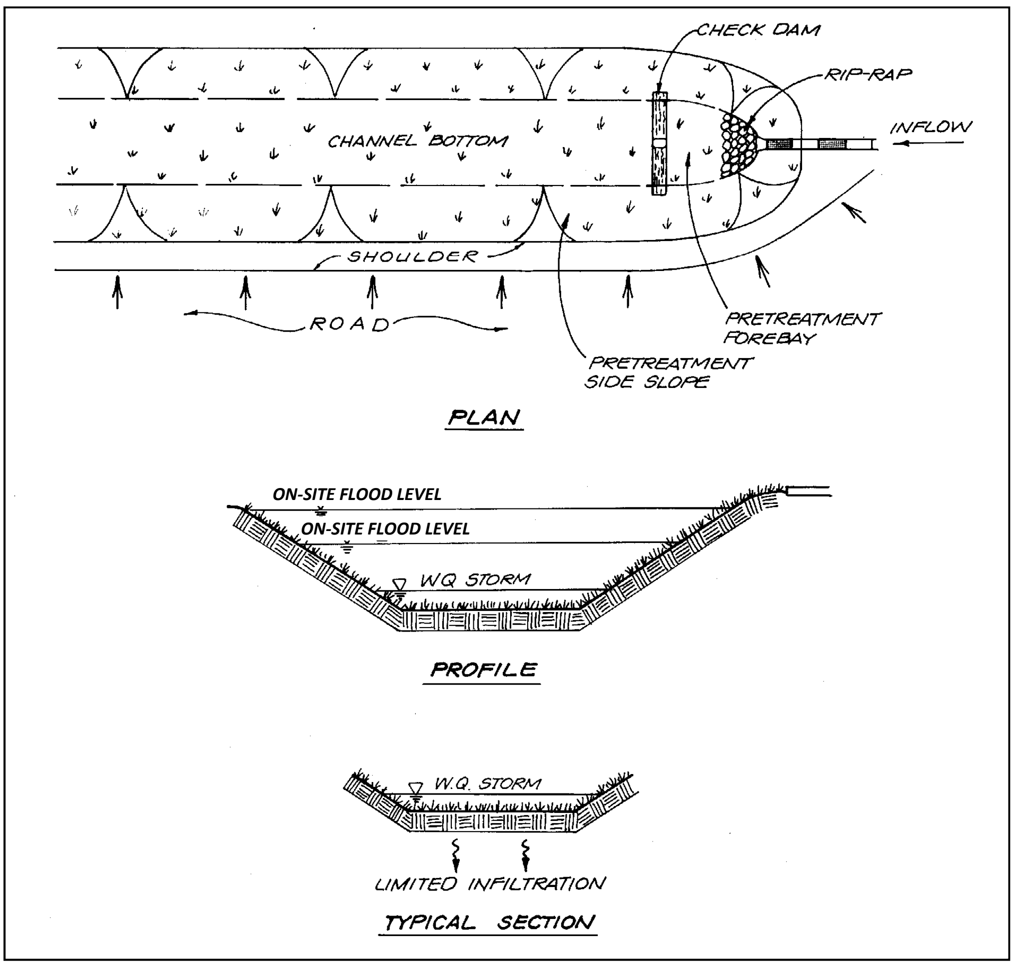


Figure 3-21 Schematic of a Typical Grass Channel
(Claytor & Schueler, 1996)

3.2.4.6 Design Example

Basic Data

Small commercial lot 300 feet deep x 145 feet wide

- Drainage area (A) = 1.0 acres
- Rainfall (P) = 1.2 inches (water quality event)
- Runoff coefficient (R_v) = 0.70

Water Quality Peak Flow

Compute the Water Quality Protection Volume in inches over the drainage area:

$$WQ_v = P * R_v = 1.2 * 0.70 = 0.84 inches$$

Compute modified CN for P = 1.2-inches and WQ_v in inches for Q:

$$CN = \frac{1000}{\left[10 + 5P + 10Q - 10\left(Q^2 + 1.25QP\right)^{1/2}\right]}$$

$$CN = \frac{1000}{\left[10 + (5*1.2) + (10*0.84) - 10*\left(0.84^2 + 1.25*0.84*1.2\right)^{1/2}\right]} = 96.3 \text{ (Use CN=96)}$$

For CN = 96 and an estimated time of concentration (T_c) of 8 minutes (0.13 hours), compute the Q_{wq} for a 1.2-inch storm.

From Table 4-9, I_a = 0.083, therefore $\frac{I_a}{P} = \frac{0.083}{1.2} = 0.07$

From Figure 4-6 for a Type II storm (using the limiting values) $q_u = 940 \, csm/in$ and therefore:

$$Q_{wq} = 940 \, csm/in * \frac{1.0ac}{640 \, ac/mi^2} * 0.84in = 1.23cfs$$

Utilize Q_{wq} to Size the Channel

The maximum flow depth for water quality treatment should be approximately the same height of the grass. A maximum flow depth of 4 inches is allowed for water quality design. A maximum flow velocity of 1.0 foot per second for water quality treatment is required. For Manning's n use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass. Site slope is 2% or 0.02 ft/ft for the example.

Input variables:

n	=	0.15
S	=	0.02 ft/ft
D	=	4/12 = 0.33 ft

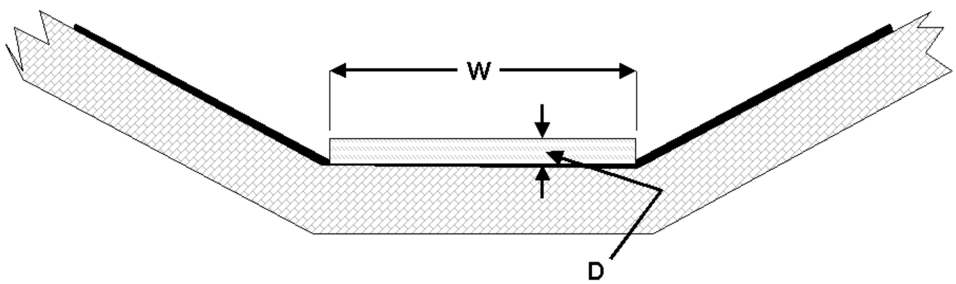
Then:

$$Q_{wq} = Q = VA = \frac{1.49}{n} D^{2/3} S^{1/2} DW$$

where:

Q	=	peak flow (cfs)
V	=	velocity (ft/sec)
A	=	flow area (ft^2) = WD
W	=	channel bottom width (ft)
D	=	flow depth (ft)
S	=	slope (ft/ft)

(Note: D approximates hydraulic radius and WD approximates flow area for shallow flows)



Then for a known n, Q, D and S, a minimum width can be calculated.

$$W = \frac{nQ}{1.49 D^{5/3} S^{1/2}} = \frac{0.15 * 1.23}{1.49 * 0.33^{5/3} * 0.02^{1/2}} = 5.56\, ft \text{ minimum}$$

$$V = \frac{Q}{WD} = \frac{1.23}{5.56 * 4/12} = 0.66\, fps \text{ (OK)}$$

(Note: WD approximates flow area for shallow flows.)

Minimum length for 5-minute residence time:

$$L = V * T = 0.66 * 5 * 60 = 198\, ft$$

where:

L	=	Length (ft)
T	=	time (sec)

Depending on the site geometry, the width or slope or density of grass (Manning's n value) might be adjusted to slow the velocity and shorten the channel in the next design iteration, if required.

3.2.5 Enhanced Swale

Primary Water Quality Facility

Description: Vegetated open channels that are explicitly designed and constructed to capture and treat stormwater runoff within dry cells formed by check dams or other means.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Longitudinal slopes must be less than 4%
- Bottom width of 2 to 8 feet
- Side slopes of 3:1 or flatter required
- Convey the on-site design storm event with 1 foot minimum freeboard

ADVANTAGES / BENEFITS:

- Combines stormwater treatment with runoff conveyance system
- Often less expensive than curb and gutter
- Reduces runoff velocity
- Aesthetic improvement

DISADVANTAGES / LIMITATIONS:

- Higher maintenance than curb and gutter systems
- Cannot be used on steep slopes
- Possible resuspension of sediment
- Concerns with aesthetics of 4"-6" high grass in residential areas

MAINTENANCE REQUIREMENTS:

- Maintain grass heights of approximately 4 to 6 inches
- Remove sediment from forebay and channel

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total Nitrogen
M	**Metals –** Cadmium, Copper, Lead & Zinc
No Data	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Quality Protection**
	Channel Protection
✓	**On-Site Flood Control**
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

H	**Land Requirements**
M	**Relative Capital Costs**
M	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *5 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Permeable soil layer (dry swale)*

L=Low **M**=Moderate **H**=High

3.2.5.1 General Description

Enhanced swales (also referred to as water quality swales) are conveyance channels engineered to capture and treat all or a portion of the WQ_v for a drainage area. They differ from a normal drainage channel or swale through the incorporation of specific features that enhance stormwater pollutant removal effectiveness.

Enhanced swales are designed with limited longitudinal slopes to force the flow to be slow and shallow, thus allowing for particulates to settle and prevent erosion. Berms and/or check dams installed perpendicular to the flow path promote settling and infiltration.

The enhanced swale is designed to include a filter bed of prepared soil that overlays an underdrain system. The swales are sized to allow the WQ_v to be filtered or infiltrated through the bottom of the swale. They are dry most of the time and are often a preferred option in residential settings.

Figure 3-22 Enhanced Swale Example

Enhanced swales are not to be confused with a filter strip or grass channel. Ordinary grass channels are not engineered to provide the same treatment capability as a well-designed enhanced swale with filter media. Filter strips are designed to accommodate overland flow rather than channelized flow. Both of these practices may be used for pretreatment or included in a “treatment train” approach where redundant treatment is provided.

3.2.5.2 Stormwater Management Suitability

Enhanced swale systems are designed primarily for stormwater quality and have only a limited ability to provide channel protection or peak flow reduction.

Water Quality

Enhanced swale systems rely primarily on filtration through an engineered media to provide removal of stormwater contaminants.

Channel Protection

Generally, only the WQ_v is treated by an enhanced swale, and another structural control must be used to provide CP_v extended detention. However, for some smaller sites, a swale may be designed to capture and detain the full CP_v.

On-Site Flood Control

Enhanced swales must provide flow diversion and/or be designed to safely pass on-site flood flows. Another structural control must be used in conjunction with an enhanced swale system to reduce the post-development peak flow.

3.2.5.3 Pollutant Removal Capabilities

The enhanced swale is presumed to be able to remove 90% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed swales can reduce TSS removal performance.

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- Total Suspended Solids – 90%
- Total Phosphorus – 50%
- Total Nitrogen – 50%
- Heavy Metals – 40%
- Fecal Coliform – insufficient data

For additional information and data on pollutant removal capabilities for enhanced swales, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.5.4 Application and Feasibility Criteria

Enhanced swales can be used in a variety of development types; however, they are primarily applicable to residential and institutional areas of low to moderate density where the impervious cover in the contributing drainage area is relatively small and along roads and highways. Because of their relatively large land requirement, enhanced swales are generally not used in higher density areas.

The topography and soils of a site will determine the applicability of the use of enhanced swales. Overall, the topography should allow for the design of a swale with sufficient slope and cross-sectional area to maintain nonerosive velocities. The following criteria should be evaluated to ensure the suitability of an enhanced swale for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – NO
- Regional Stormwater Control – NO

Physical Feasibility - Physical Constraints at Project Site

Drainage Area: 5 acres maximum

Space Required: Approximately 10% to 20% of the tributary impervious area.

Site Slope: Typically no more than 4% channel slope

Minimum Head: Elevation difference needed at a site from the inflow to the outflow: typically 1 to 5 feet.

Soils: Engineered media for swale underdrainage.

Other Constraints / Considerations

Aquifer Protection: 5 feet minimum separation between bottom of facility and historically high groundwater.

3.2.5.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of an enhanced swale system. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

A. LOCATION AND SITING

- An enhanced swale should be sited such that the topography allows for the design of a channel with sufficiently mild slope (unless small drop structures are used) and a minimized cross-sectional area to maintain nonerosive velocities.
- Enhanced swale systems should have a contributing drainage area of 5 acres or less.
- Swale siting should also take into account the location and use of other site features, such as buffers and undisturbed natural areas, and should attempt to aesthetically “fit” the facility into the landscape.

B. GENERAL DESIGN

- Enhanced swales are designed to treat the WQ_v through a volume-based design, and to safely pass larger storm flows.
- An enhanced swale system consists of an open conveyance channel with a filter bed of permeable soils that overlay an underdrain system. Flow passes into and is detained in the main portion of the channel where it is filtered through the soil bed. Runoff is collected and conveyed by a perforated pipe and gravel underdrain system to the outlet. Figure 3-23 provides a plan view and cross-section schematic for the design of a dry swale system.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

- Channel slopes between 1% and 2% are recommended unless topography necessitates a steeper slope, in which case 6 to 12 inch drop structures can be placed to limit the energy slope to within the recommended 1 to 2% range. Energy dissipation will be required below the drops. Spacing between the drops should not be spaced less than 50 feet.
- Enhanced swales should have a bottom width of 2 to 8 feet to ensure adequate filtration. Wider channels can be designed, but should contain a multi-level cross section to prevent channel braiding or uncontrolled sub-channel formation.
- Enhanced swales are parabolic or trapezoidal in cross section and shall be designed with moderate side slopes not greater than 3:1 for ease of maintenance and side inflow by sheet flow.
- Enhanced swales shall have a maximum WQ_v ponding depth of 18 inches at the end point of the channel, with an average depth of less than12 inches, under peak WQ_v conditions.
- The peak velocity for the design events must be nonerosive for the soil and vegetative cover provided. See Volume 2, Chapter 5 for allowable velocities.
- If the system is on-line, swales should be sized to convey or bypass runoff from the design flood event safely with 1 feet minimum freeboard.
- Enhanced swales are sized to store and infiltrate the WQ_v with not more than 18 inches of ponding and allow for full filtering through the permeable soil layer. The maximum ponding time is 48 hours, though a 24-hour ponding time is more desirable.
- The bed of the enhanced swale consists of a permeable soil layer of at least 30 inches in depth, above a 4 inch diameter perforated PVC pipe (AASHTO M 252) longitudinal underdrain in a 6 inch gravel layer. The soil media should have an infiltration rate of 1.0 to 1.5 foot per day and contain a high level of organic material to facilitate pollutant removal. A permeable filter fabric is placed between the gravel layer and the overlying soil.
- The channel and underdrain excavation should be limited to the width and depth specified in the design. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and shall be scarified prior to placement of gravel and permeable soil. The sides of the channel shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling.

D. PRETREATMENT / INLETS

- Inlets to enhanced swales must be provided with energy dissipaters such as riprap.
- A forebay or equivalent upstream pretreatment (sized at 0.1 acre-inch of volume per impervious acre of contributing drainage area) shall be provided at the upstream end of the facility to capture the larger particles. The forebay volume may be counted as part of the WQ_v.
- Enhanced swale systems that receive direct concentrated runoff may have a 6-inch drop to a gravel diaphragm flow spreader at the upstream end of the control to help spread the inflow.
- A gravel diaphragm and gentle side slopes may be provided along the top of channels to provide pretreatment for lateral sheet flows.

E. OUTLET STRUCTURES

- The underdrain system should discharge to the storm drainage infrastructure or a stable outfall.

F. EMERGENCY SPILLWAY

- Enhanced swales must be adequately designed to safely pass flows that exceed the design storm flows.

G. MAINTENANCE ACCESS

- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement to the entire length of the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

H. SAFETY FEATURES

- Ponding depths should be limited to a maximum of 18 inches.

I. LANDSCAPING

- Landscape design should specify proper grass species based on specific site and soils conditions present along the channel.

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

<u>Low Relief:</u> Reduced need for use of check dams.

High Relief: Often infeasible if slopes are greater than 4%.

Karst: No infiltration of hotspot runoff from dry swales; use impermeable liner.

Soils

- No additional criteria.

Special Downstream Watershed Considerations

Aquifer Protection: 5 feet minimum distance above historical groundwater for unlined swale, 2 feet for lined swale.

3.2.5.6 Design Procedures

Step 1 Compute runoff control volumes.

Calculate the WQ_v.

Step 2 Confirm local design criteria and applicability.

Consider any special site-specific design conditions/criteria.

Step 3 Determine pre-treatment volume.

Step 4 Determine swale dimensions.

Size bottom width, depth, length, and slope necessary to store WQ_v with not more than 18 inches of ponding at the downstream end.

- Slope cannot exceed 4% (1 to 2% recommended);
- Bottom width should range from 2 to 8 feet;
- Ensure that side slopes are not steeper than 3:1;
- Ensure swale can pass design storm with minimum 1' freeboard.

Step 5 Compute number of check dams (or similar structures) required to detain $WQ_{v.}$

The size and spacing of check dams should be designed such that the WQ_v will be detained within the length of the swale, and energy slope is less than 2%.

Step 6 Calculate draw-down time.

Planting soil should pass (infiltrate) at least 1.0 feet in 24 hours and must completely filter WQ_v within 48 hours.

Step 7 Check water quality and design flood event velocity erosion potential and freeboard.

Check for erosive velocities and freeboard, and modify design as appropriate per guidance found in Chapter 5.

Step 8 Design inlets, sediment forebay, and underdrain system.

See Chapter 4 and Chapter 5 for more details.

Step 9 Prepare Vegetation and Landscaping Plan.

A landscaping plan for an enhanced swale should be prepared to indicate how the enhanced swale system will be stabilized and established with vegetation.

3.2.5.7 Design Example

Basic Data

Small commercial lot 300 feet deep x 145 feet wide.

- Drainage area (A) = 1.0 acres
- Rainfall (P) = 1.2 inches (water quality event)
- Runoff coefficient (R_v) = 0.70

Water Quality Peak Flow

Compute the Water Quality Protection Volume in inches over the drainage area:

$$WQ_v = P * R_v = 1.2 * 0.70 = 0.84 \text{ inches}$$

Compute the Water Quality Peak Flow (see the grassed swale example for detailed calculations).

$$Q_{wq} = 940 \, {}^{csm}\!/_{in} * \frac{1.0ac}{640 \, {}^{ac}\!/_{mi^2}} * 0.84in = 1.23 \text{ cfs}$$

Pre-treatment Volume (Forebay)

Compute the size of the sediment forebay (assume 80% of site is impervious)

$$V_{pre} = (0.80)(0.1'')(1'/12'') = 1.2 * 0.70 = 0.0067 \text{acre-ft}$$

Enhanced Swale Design

Determine the swale dimensions (assume trapezoidal channel with max depth of 18 inches). The Q_{wq} will be utilized to size the channel. The maximum flow depth of 4 inches is allowed for water quality design. A maximum flow velocity of 1.0 foot per second for water quality treatment is required. For Manning's n use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass.

Input variables:

n	=	0.15
D	=	1'

Side Slopes	=	2:1
Channel Slope	=	0.015 ft/ft

Then:

$$Q_{wq} = Q = VA = \frac{1.49}{n} D^{2/3} S^{1/2} DW$$

where:

Q	=	peak flow (cfs)
V	=	velocity (ft/sec)
A	=	flow area (ft^2) = WD
W	=	channel bottom width (ft)
D	=	flow depth (ft)
S	=	slope (ft/ft)

A minimum width can be calculated.

$$W = \frac{nQ}{1.49 D^{5/3} S^{1/2}} = \frac{0.15 * 1.23}{1.49 * 1^{5/3} * 0.015^{1/2}} = 1\,\text{ft}$$

$$V = \frac{Q}{WD} = \frac{1.23}{(1')(1')} = 1.23\,fps\,(>1\text{fps})$$

Increase width to 4'.

$$V = \frac{Q}{WD} = \frac{1.23}{(4')(1')} = 0.31\,fps\,(\text{OK})$$

Check Dams

Compute the number of check dams required to detain the WQ_v. With where:

- Dam height = 1.5 feet
- Spacing of check dams will be 60 feet (based on top of downstream dam same elevation as upstream dam's toe).

The total volume need to be storage behind dams equals:

$$WQ_v = (0.84\,\text{inches})(1\,\text{acre}) = 3050\,\text{ft}^3$$

Each dam stores: Volume = (length behind dam)(width of dam)(water depth behind dam) = (60')(1.5')(4') = 360 ft^3

A total of (3050)/(360) = 8 check dams will be needed to capture the water quality volume.

3.2.5.8 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the facility, and clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.5.9 Example Schematics

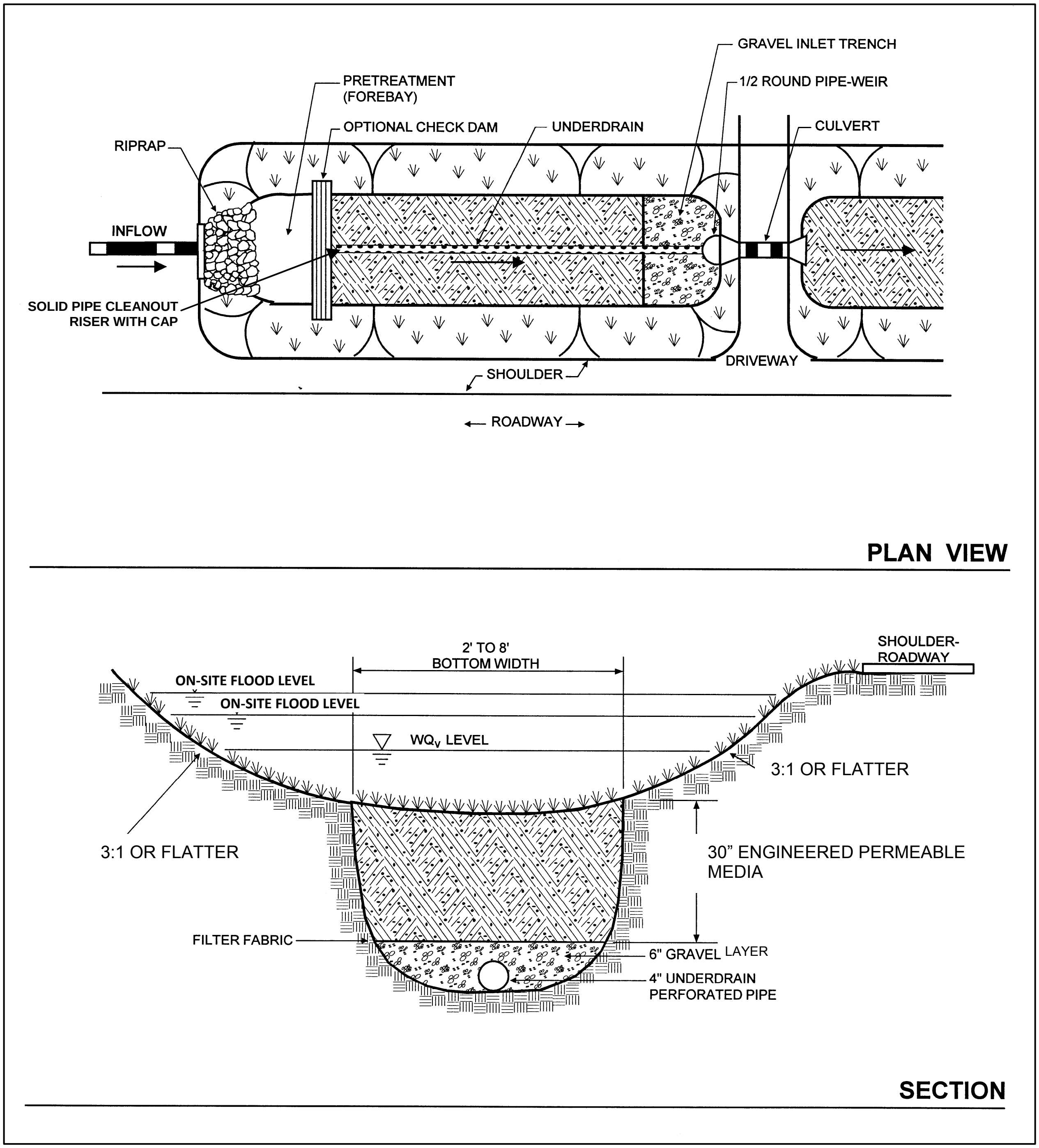


Figure 3-23 Schematic of Dry Swale
(MSDM, 2000)

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3.2.6 Infiltration Trench

Primary Water Quality Facility

Description: Excavated trench filled with stone aggregate used to capture and infiltrate stormwater runoff into the surrounding soils from the bottom and sides of the trench.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Soil infiltration rate of 0.5 in/hr or greater required
- Excavated trench (3 to 8 foot depth) filled with stone media (1.5 to 2.5-inch diameter), gravel, and sand layers
- A sediment forebay and grass channel, or equivalent upstream pretreatment, must be provided

ADVANTAGES / BENEFITS:

- Excellent water quality treatment
- Flexible configuration
- Can contribute to channel protection and peak flow control
- Provides for groundwater recharge
- Good for small sites with porous soils

DISADVANTAGES / LIMITATIONS:

- Potential for groundwater contamination
- High clogging potential; should not be used on sites with fine-particle soils (clays or silts) in drainage area
- Significant setback requirements
- Restrictions in karst areas
- Geotechnical testing required, two borings per facility

MAINTENANCE REQUIREMENTS:

- Inspect for clogging
- Remove sediment from forebay
- Replace gravel layer as needed

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total Nitrogen
H	**Metals –** Cadmium, Copper, Lead & Zinc
H	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Quality Protection**
✓	**Channel Protection**
✓	**On-Site Flood Control**
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max.*

Soils: *Pervious soils required (0.5 in/hr or greater)*

Other Considerations:

- *Must not be placed under pavement or concrete*

L=Low **M**=Moderate **H**=High

3.2.6.1 General Description

Infiltration trenches are excavations typically filled with stone to create a temporary underground reservoir for stormwater runoff (see Figure 3-24). This runoff volume gradually filtrates through the bottom and sides of the trench into the subsoil and eventually reaches the water table. By diverting runoff into the soil, an infiltration trench not only treats the WQ_V, but also helps to preserve the natural water balance on a site and can recharge groundwater and preserve baseflow. Due to this fact, infiltration systems are limited to areas with highly porous soils (infiltration rate of > 0.5 in/hr) where the water table and/or bedrock are located well below the bottom of the trench (5' or more below). In addition, infiltration trenches must be carefully sited to avoid the potential of groundwater contamination.

Infiltration trenches are not intended to trap coarse sediment and must always be designed with a sediment forebay and grass channel or filter strip, or other appropriate pretreatment measures to prevent clogging and failure. Due to their potential for failure, these facilities must only be considered for sites where upstream sediment control can be ensured.

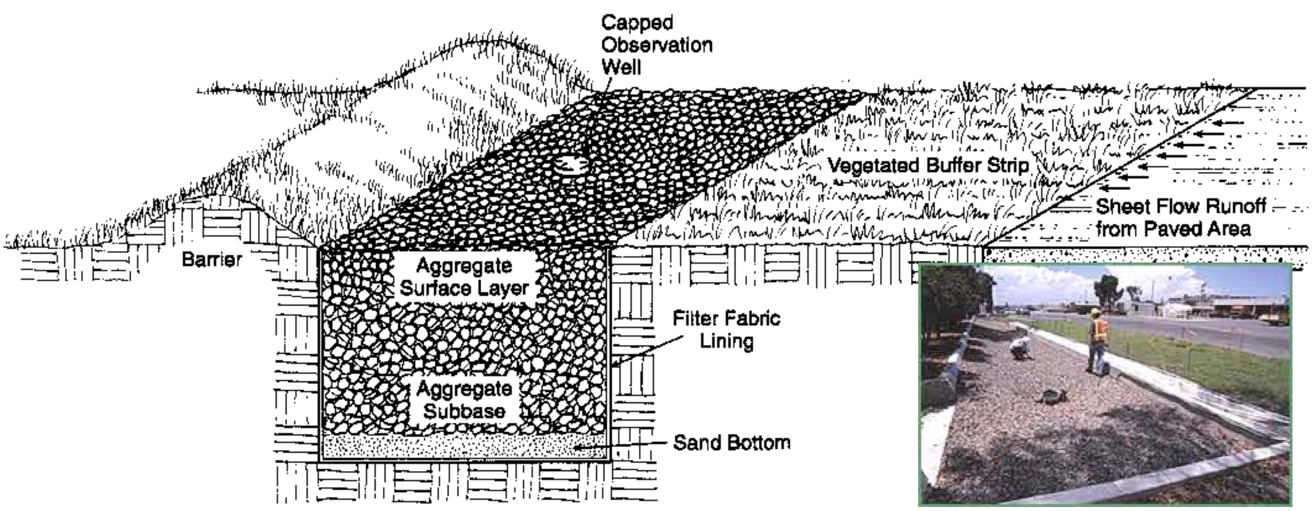


Figure 3-24 Infiltration Trench Example
(Knox Co., TN, 2008)

3.2.6.2 Stormwater Management Suitability

Infiltration trenches are designed primarily for stormwater quality, i.e. the removal of stormwater pollutants. However, they can provide limited runoff quantity control, particularly for smaller storm events. For some smaller sites, trenches can be designed to capture and infiltrate the CP_v in addition to WQ_v. An infiltration trench will need to be used in conjunction with another structural control to provide flood control, if required.

Water Quality Protection

Using the natural filtering properties of soil, infiltration trenches can remove a wide variety of pollutants from stormwater through sorption, precipitation, filtering, and bacterial and chemical degradation. Sediment load and other suspended solids are removed from runoff by pretreatment measures in the facility that treats flows before they reach the trench surface.

Section 3.2.6.3 provides pollutant removal efficiencies that can be used for planning and design purposes.

Channel Protection

For smaller sites, an infiltration trench may be designed to capture and infiltrate the entire CP_v in either an off- or on-line configuration. For larger sites, or where only the WQ_v is diverted to the trench, another structural control must be used to provide CP_v extended detention.

Flood Control

Infiltration trench facilities must provide flow diversion and/or be designed to safely pass design flood events and protect the filter bed and facility.

The volume of runoff removed and treated by the infiltration trench may be included in the on-site and/or downstream flood control calculations (see Chapter 3).

3.2.6.3 Pollutant Removal Capabilities

An infiltration trench is presumed to be able to remove 90% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed infiltration trenches can reduce TSS removal performance.

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach.

- Total Suspended Solids – 90%
- Total Phosphorus – 60%
- Total Nitrogen – 60%
- Heavy Metals – 90%
- Fecal Coliform – 90%

For additional information and data on pollutant removal capabilities for infiltration trenches, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.6.4 Application and Site Feasibility Criteria

Infiltration trenches are generally suited for medium-to-high density residential, commercial, and institutional developments where the subsoil is sufficiently permeable to provide an infiltration rate of 0.5 inches/hour or greater and the water table is 5 feet or more below the bottom of the trench, to prevent groundwater contamination. They are applicable primarily to impervious areas without high levels of fine particulates (clay/silt soils) in the runoff and should only be considered for sites where the sediment load is relatively low.

Infiltration trenches can either be used to capture sheet flow from a drainage area or function as an off-line device. Due to the relatively narrow shape, infiltration trenches can be adapted to many different types of sites. Unlike some other structural stormwater controls, they can easily fit into the margin, perimeter, or other unused areas of developed sites.

To protect groundwater from potential contamination, runoff from designated hotspot land uses or activities must not be infiltrated. Infiltration trenches should not be used for manufacturing and industrial sites, where there is a potential for high concentrations of soluble pollutants and heavy metals. In addition, infiltration should not be considered for areas with a high pesticide concentration. Infiltration trenches are also not suitable in areas with karst geology without adequate geotechnical testing by qualified individuals and in accordance with local requirements.

The following criteria should be evaluated to ensure the suitability of an infiltration trench for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – YES (if no hotspots)
- Regional Stormwater Control – NO

Physical Feasibility - Physical Constraints at Project Site

<u>Drainage Area:</u> 5 acres maximum

<u>Space Required:</u> Will vary depending on the depth of the facility.

<u>Site Slope:</u> No more than 6% slope to limit excavation (trench bottom must be on zero grade).

<u>Minimum Head:</u> Elevation difference needed at a site from the inflow to the outflow: 1 foot

<u>Minimum Depth to Water Table:</u> 5 feet required between the bottom of the infiltration trench and the elevation of the historic high water table.

<u>Soils:</u> Infiltration rate greater than 0.5 inches per hour required (typically hydrologic group “A”, some group “B” soils).

Other Constraints / Considerations

Aquifer Protection: No hotspot runoff allowed. Bottom of trench to be five foot minimum above historic high groundwater table.

3.2.6.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of an infiltration trench facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

A. LOCATION AND SITING

- To be suitable for infiltration, underlying soils should have an infiltration rate (f_c) of 0.5 inches per hour or greater, as initially determined from NRCS soil textural classification and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5,000 square feet, with a minimum of two borings per facility (taken within the proposed limits of the facility). Infiltration trenches cannot be used in fill soils.
- Infiltration trenches should have a contributing drainage area of 5 acres or less.
- Soils on the drainage area tributary to an infiltration trench should have a clay content of less than 20% and a silt/clay content of less than 40% to prevent clogging and failure.
- There should be at least 5 feet between the bottom of the infiltration trench and the elevation of the historic high water table.
- Clay lenses, bedrock or other restrictive layers below the bottom of the trench will reduce infiltration rates unless excavated.
- Minimum setback requirements for infiltration trench facilities per local regulations.
- When used in an off-line configuration, the WQv is diverted to the infiltration trench through the use of a flow splitter. Stormwater flows greater than the WQv are diverted to other controls or downstream using a diversion structure or flow splitter.
- To reduce the potential for costly maintenance and/or system reconstruction, it is recommended that the trench be located in an open or lawn area, with the top of the structure as close to the ground surface as possible.
- Infiltration trenches are designed for intermittent flow and must be allowed to drain and allow re-aeration of the surrounding soil between rainfall events. They must not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

B. GENERAL DESIGN

- A well-designed infiltration trench consists of:
  - Excavated shallow trench backfilled with sand, coarse stone, and gravel, and lined with a filter fabric;

  - Appropriate pretreatment measures; and,
  - One or more observation wells to show how quickly the trench dewaters or to determine if the device is clogged.

- An example of an on-line infiltration trench is shown in Figure 3-24. Figure 3-25 provides a plan view and profile schematic for the design of an off-line infiltration trench facility.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

- The required trench storage volume is equal to the WQ_v. For smaller sites, an infiltration trench can be designed with a larger storage volume to include the CP_v.
- A trench must be designed to fully dewater the entire WQ_v within 24 to 48 hours after the WQ_v rainfall event. The slowest infiltration rate obtained from tests performed at the site should be used in the design calculations.
- Trench depths should be between 3 and 8 feet, to provide for easier maintenance. The width of a trench must be less than 25 feet.
- Broad, shallow trenches reduce the risk of clogging by spreading the flow over a larger area for infiltration.
- The surface area required is calculated based on the trench depth; soil infiltration rate, aggregate void space, and fill time (assume a fill time of 2 hours).
- The bottom slope of a trench should be flat across its length and width to evenly distribute flows, encourage uniform infiltration through the bottom, and reduce the risk of clogging.
- The stone aggregate used in the trench should be washed gravel 1.5 to 2.5 inches in diameter with a void space of about 40%. Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 (this includes a factor of safety) should be used in calculations, unless aggregate specific data exist.
- A 6-inch layer of clean, washed sand is placed on the bottom of the trench to encourage drainage and prevent compaction of the native soil while the stone aggregate is added.
- The infiltration trench is lined on the bottom, sides and top by an appropriate geotextile filter fabric that prevents soil piping but has greater permeability than the parent soil. The top layer of filter fabric is located 2 to 6 inches from the top of the trench and serves to prevent sediment from passing into the stone aggregate. Since this top layer serves as a sediment barrier, it will need to be replaced more frequently and must be readily separated from the side sections.
- The top surface of the infiltration trench above the filter fabric is typically covered with gravel. The gravel layer improves sediment filtering and maximizes the pollutant removal in the top of the trench. In addition, it can easily be removed and replaced should the device begin to clog. Alternatively, the trench can be covered with permeable topsoil and planted with grass in a landscaped area.
- An observation well must be installed in every infiltration trench and should consist of a perforated PVC pipe, 4 to 6 inches in diameter, extending to the bottom of the trench (see

Figure 3-26 for an observation well detail). The observation well will show the rate of dewatering after a storm, as well as provide a means of determining sediment levels at the bottom and when the filter fabric at the top is clogged and maintenance is needed. It should be installed along the centerline of the structure, flush with the ground elevation of the trench. A visible floating marker should be provided to indicate the water level. The top of the well should be capped and locked to discourage vandalism and tampering.

- The trench excavation should be limited to the width and depth specified in the design. Excavated material should be placed away from the open trench so as not to jeopardize the stability of the trench sidewalls. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and should be scarified prior to placement of sand. The sides of the trench shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling. All infiltration trench facilities should be protected during site construction and should be constructed after upstream areas have been stabilized.

D. PRETREATMENT / INLETS

- Pretreatment facilities must always be used in conjunction with an infiltration trench to prevent clogging and failure.
- For a trench receiving sheet flow from an adjacent drainage area, the pretreatment system should consist of a vegetated filter strip with a minimum 20-foot length. A vegetated buffer strip around the entire trench is required if the facility is receiving runoff from both directions.
- For an off-line configuration, pretreatment should consist of a sediment forebay, vault, plunge pool, or similar sedimentation chamber (with energy dissipaters) sized to 25% of the WQ_v. Exit velocities from the pretreatment chamber must be nonerosive.

E. OUTLET STRUCTURES

- Outlet structures are required for flood flows that cannot be infiltrated.

F. EMERGENCY SPILLWAY

- Typically, for off-line designs, there is no need for an emergency spillway. However, a nonerosive overflow channel should be provided to pass safely flows that exceed the storage capacity of the trench to a stabilized downstream area or watercourse.

G. MAINTENANCE ACCESS

- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement to the entire length of the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

H. SAFETY FEATURES

- In general, infiltration trenches are not likely to pose a physical threat to the public and do not need to be fenced.

I. LANDSCAPING

- Vegetated filter strips and buffers should fit into and blend with surrounding area. Native grasses are preferable, if compatible. The trench may be covered with permeable topsoil and planted with grass in a landscaped area.

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

Low Relief: No additional criteria.

High Relief: Maximum site slope of 6%.

Karst: Not suitable without adequate geotechnical testing.

Special Downstream Watershed Considerations

- No additional criteria.

3.2.6.6 Design Procedures

Step 1 Compute runoff control volumes from the integrated design approach.

Calculate the WQ_v using equation 1-1.

Step 2 Confirm local design criteria and applicability.

Consider any special site-specific design conditions/criteria.

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3 Compute WQ_v peak discharge (Q_{wq}) using equation 4-18.

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion (see Chapter 4).

- Using WQ_v (or total volume to be infiltrated), compute CN using equation 4-3.
- Compute time of concentration.
- Determine appropriate unit peak discharge from time of concentration.
- Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

Step 4 Size flow diversion structure, if needed.

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the infiltration trench.

Size low flow orifice, weir, or other device to pass Q_{wq}.

Step 5 Size infiltration trench

The area of the trench can be determined from the following equation: (MSDM, 2000).

$$A = \frac{WQ_v}{(nd + kT / 12)}$$

where:

A	=	Surface Area (ft^2)
WQ_v	=	Water Quality Protection Volume (or total volume to be infiltrated)
n	=	porosity of aggregate
d	=	trench depth (feet)
k	=	soil percolation (inches/hour)
T	=	Fill Time (time for the practice to fill with water), in hours

A porosity value n = 0.32 (includes a factor of safety) should be used for gravel having a void space of 40%.

All infiltration systems should be designed to fully dewater the entire WQ_v within 24 to 48 hours after the rainfall event.

A fill time T = 2 hours may be used, which is a conservative estimate for T. A fill time of 2 hours is recommended since this would give the site adequate time to infiltrate and evaporate the water quality storm of 1.2 inches. Larger values, if used, will reduce the treatment of the water quality storm event and therefore would need to be validated by the site design engineer.

Step 6 Determine pretreatment volume and design pretreatment measures.

Size pretreatment facility to treat 25% of the WQ_v for off-line configurations.

Step 7 Design spillway(s)

Adequate stormwater outfalls should be provided for the overflow exceeding the capacity of the trench, ensuring nonerosive velocities on the down-slope.

3.2.6.7 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.

2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the facility, and must clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.6.8 Example Schematics

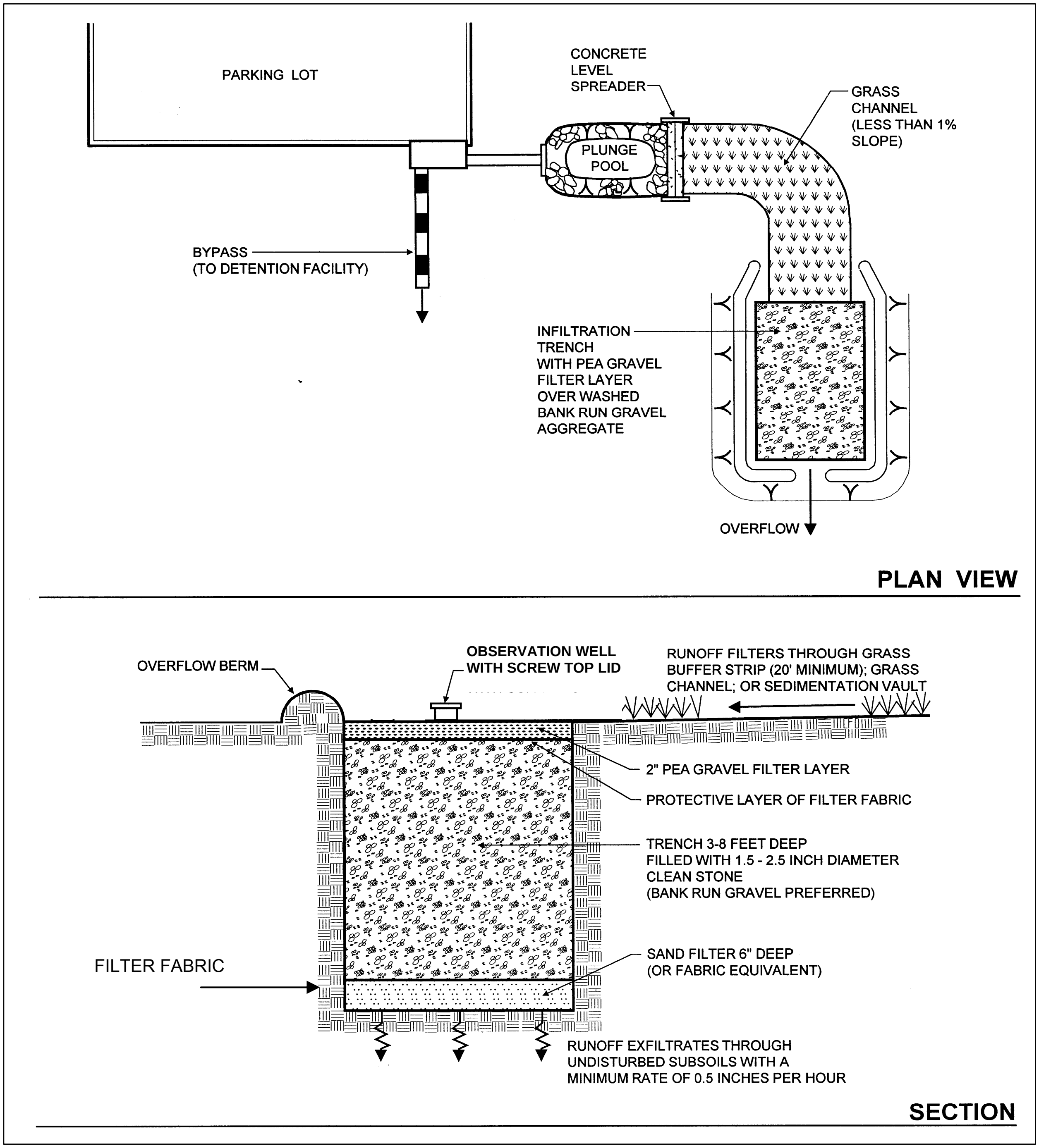


Figure 3-25 Schematic of a Typical Infiltration Trench
(MSDM, 2000)

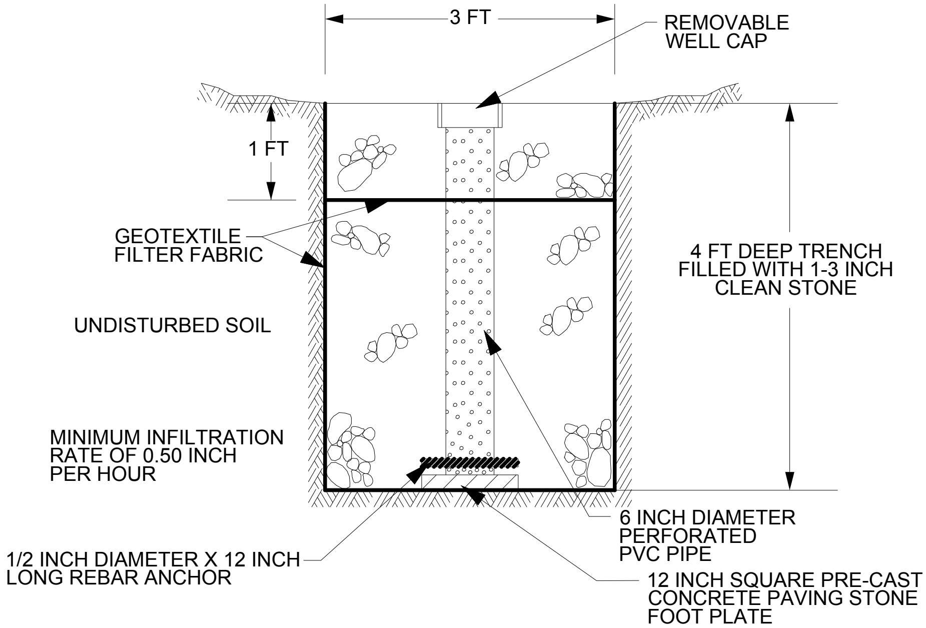
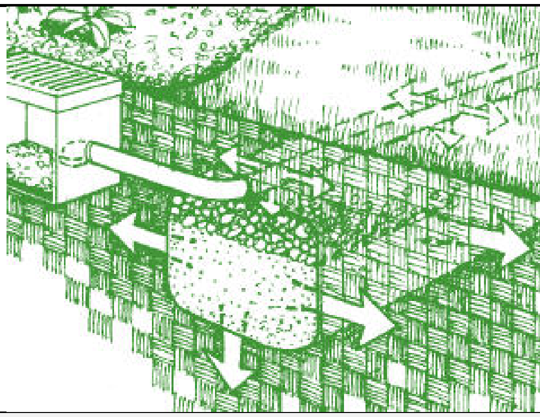


Figure 3-26 Observation Well Detail

- The aggregate material for the trench should consist of a clean aggregate with a maximum diameter of 3 inches and a minimum diameter of 1.5 inches.
- The aggregate should be graded such that there will be few aggregates smaller than the selected size. For design purposes, void space for these aggregates may be assumed to be 40%.
- A 6-inch layer of clean, washed sand is placed on the bottom of the trench to encourage drainage and prevent compaction of the native soil, while the stone aggregate is added.
- The aggregate should be completely surrounded with an engineering filter fabric. If the trench has an aggregate surface, filter fabric should surround all of the aggregate fill material except for the top 1 foot.
- The observation well should consist of perforated PVC pipe, 4 to 6 inches diameter, located in the center of the trench, and be constructed flush with the ground elevation of the trench.
- The screw top lid should be cast iron and clearly labelled as an observation well.

3.2.7 Soakage Trench

Primary Water Quality Facility



Description: Soakage trenches are a variation of infiltration trenches. Soakage trenches drain through a perforated pipe buried in gravel. They are used in highly impervious areas where conditions do not allow surface infiltration and where pollutant concentrations in runoff are minimal (i.e. non-industrial rooftops). They may also be used in conjunction with local unregulated stormwater devices, such as residential roof downspouts.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for space-limited applications
- Like other infiltration devices, soakage trenches should not be used for stormwater containing high sediment loads to minimize clogging

ADVANTAGES / BENEFITS:

- Filtration provides pollutant removal capability
- Reservoir decreases peak flow rates

DISADVANTAGES / LIMITATIONS:

- Subsurface pipe considered an injection well and may require special permit

MAINTENANCE REQUIREMENTS:

- Remove sediment and oil/grease from pre-treatment devices, as well as overflow structures
- Mow grass filter strips as necessary

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total Nitrogen
H	**Metals –** Cadmium, Copper, Lead & Zinc
H	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Quality Protection**
	Channel Protection
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max.*

Soils: *Pervious soils required (0.5 in/hr or greater)*

L=Low **M**=Moderate **H**=High

3.2.7.1 General Description

Soakage trenches represent a variation of the infiltration trench. Regular infiltration trenches receive drainage from the surface, but in highly urbanized areas there is often not a suitable area available for this type of setup. Soakage trenches utilize a perforated pipe embedded within the trench to introduce inflow, thereby minimizing the surface area required for the device. They can be located under pavement, although this is not recommended because of the expense of maintaining if the trench ultimately clogs. A sediment sump may be used to decrease this problem.

Soakage trenches used for stormwater disposal are considered Class V injection devices by the EPA and fall under the Kansas UIC program.

3.2.7.2 Pollutant Removal Capabilities

Pollutant removal is similar to infiltration trenches, but care should be taken to avoid clogging with sediments.

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- Total Suspended Solids – 90%
- Total Phosphorus – 60%
- Total Nitrogen – 60%
- Heavy Metals – 90%
- Fecal Coliform – 90%

For additional information and data on pollutant removal capabilities, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.7.3 Design Criteria and Specifications

- The trench shall be excavated in native soil, uncompacted by heavy equipment.
- The trench should be at least 3 feet deep and 2.5 feet wide as shown in Figure 3-27. The exact dimensions will depend on the drainage characteristics of the surrounding soils.
- A minimum separation distance of 5 feet is required between the bottom of the trench and the elevation of the historical high water table for soakage trenches without underdrains, 2 feet for soakage trenches with underdrains. Soakage trenches shall not be used to infiltrate untreated hotspot runoff.

- A sediment trap may be installed upstream of the perforated pipe if pretreatment is needed prior to discharge.
- The bottom of the trench should be filled with at least 18 inches of medium sand meeting ASTM C-33 and enveloped in filter fabric.
- A minimum of six inches of ¾ inch – 2 ½ inch round or crushed rock shall be placed on top of the fabric covered sand base. The crushed rock shall also be enclosed in filter fabric.
- The inflow pipe should be sized based on delivery of the water quality flow to the trench, and should be a minimum of 3 inches in diameter.
- The perforated distribution pipe shall be an approved leach field pipe with holes oriented downward. It shall be covered with filter fabric, with at least 12 inches of backfill above the pipe.
- The trench should be sized in the same manner as a conventional infiltration trench (see Section 3.2.6.) and the pipe perforations over-sized to ensure that the sand is the limitation to flow and not the pipe perforations.
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- A pipe inspection and cleanout port shall be employed to allow inspection and maintenance.

3.2.7.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. “Covenants for Permanent Maintenance of Stormwater Management Facilities” (also called the “Maintenance Covenants”). An example covenants document can be found in Volume 3.
2. “Inspection Checklist and Maintenance Guidance” for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the facility, and also clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.7.5 Example Schematics

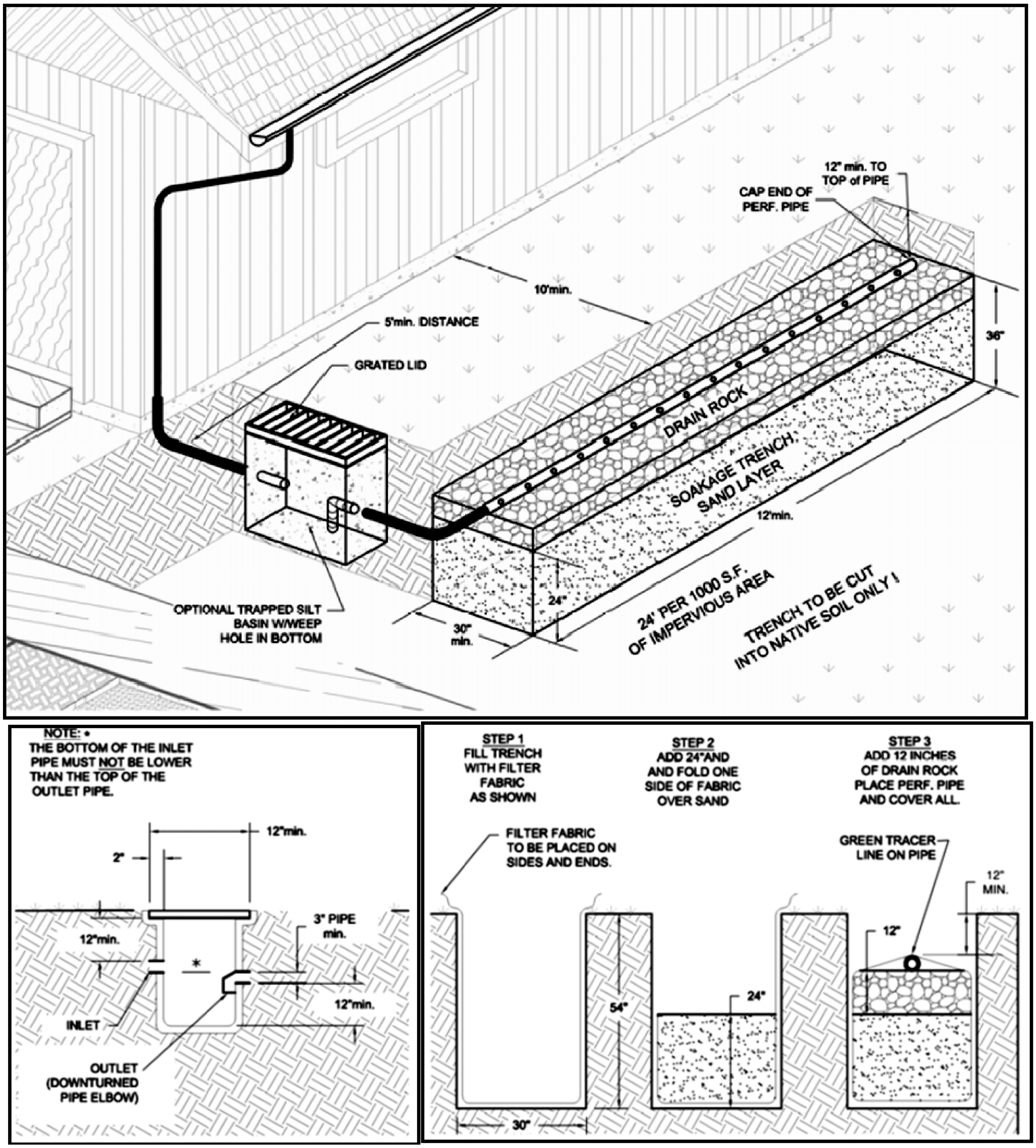


Figure 3-27 Schematic of an Example Soakage Trench Installation
(Source: City of Eugene, Oregon)

3.2.8 Surface Sand Filter

Primary Water Quality Facility

Description: Multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay, a sand bed as its primary filter media, and an underdrain collection system.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Typically requires 2 to 6 feet of head
- Maximum contributing drainage area of 10 acres for surface sand filter
- Sand filter media with underdrain system

ADVANTAGES / BENEFITS:

- Applicable to small drainage areas
- Good for highly impervious areas
- Good retrofit capability

DISADVANTAGES / LIMITATIONS:

- High maintenance burden
- Not recommended for areas with high sediment content in stormwater or clay/silt runoff areas
- Relatively expensive
- Possible odor problems

MAINTENANCE REQUIREMENTS:

- Inspect for clogging – rake first inch of sand
- Remove sediment from forebay/chamber
- Replace sand filter media as needed

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total Nitrogen
M	**Metals –** Cadmium, Copper, Lead & Zinc
M	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Quality Protection**
✓	**Channel Protection**
	On-Site Flood Control
	Downstream Flood Control

Accepts Hotspot Runoff: *Yes*

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *2-10 acres max*

Soils: *Clay or silty soils may require pretreatment*

Other Considerations:

- *Typically needs to be combined with other controls to provide water quantity control*
- *Hotspot treatment*

L=Low **M**=Moderate **H**=High

3.2.8.1 General Description

Sand filters (also referred to as filtration basins) are structural stormwater controls that capture and temporarily store stormwater runoff and pass it through a filter bed of sand. Most sand filter systems consist of two-chamber structures. The first chamber is a sediment forebay or sedimentation chamber, which removes floatables and heavy sediments. The second is the filtration chamber, which removes additional pollutants by filtering the runoff through a sand bed. The filtered runoff is typically collected and returned to the conveyance system, though it can also be partially or fully infiltrated into the surrounding soil in areas with porous soils if not used for hotspot treatment, and if the infiltration face is at least 5 feet above the historically high groundwater elevation.

Because they have few site constraints beside head requirements, sand filters can be used on development sites where the use of other structural controls may be precluded. However, sand filter systems can be relatively expensive to construct, install, and maintain.

Surface Sand Filter: The surface sand filter is a ground-level open air structure that consists of a pretreatment sediment forebay and a filter bed chamber. This system can treat drainage areas up to 10 acres in size and is typically located off-line. Surface sand filters can be designed as an excavation with earthen embankments or as a concrete or block structure.

Figure 3-28 Sand Filter Example

3.2.8.2 Stormwater Management Suitability

Sand filter systems are designed primarily as off-line systems for stormwater quality (i.e., the removal of stormwater pollutants) and will typically need to be used in conjunction with another structural control to provide downstream channel protection, on-site flood control, and downstream flood control, if required. However, under certain circumstances, filters can provide limited runoff quantity control, particularly for smaller storm events.

Water Quality

In sand filter systems, stormwater pollutants are removed through a combination of gravitational settling, filtration, and adsorption. The filtration process effectively reduces suspended solids and particulates, biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants. Surface sand filters with a grass cover have additional opportunities for vegetation uptake of pollutants, particularly nutrients.

Channel Protection

For smaller sites, a sand filter may be designed to capture the entire CPv in either an off- or on-line configuration. Given that a sand filter system is typically designed to completely drain over 40 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites or where only the WQv is diverted to the sand filter facility, another structural control must be used to provide CPv extended detention.

On-Site Flood Control

Another structural control must be used in conjunction with a sand filter system to reduce the post-development peak flow to pre-development levels (detention) if needed.

Downstream Flood Control

Sand filter facilities must provide flow diversion and/or be designed to safely pass design flood events and protect the filter bed and facility.

The volume of runoff removed and treated by the sand filter may be included in the on-site flood control and downstream flood control calculations. (See Chapter 3.)

3.2.8.3 Pollutant Removal Capabilities

The surface sand filter is presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed sand filters can reduce TSS removal performance.

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach.

- Total Suspended Solids – 80%
- Total Phosphorus – 50%
- Total Nitrogen – 30%
- Heavy Metals – 50%

- Fecal Coliform – 40%

For additional information and data on pollutant removal capabilities for sand filters, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.8.4 Application and Site Feasibility Criteria

Sand filter systems are well suited for highly impervious areas where land available for structural controls is limited. Sand filters should primarily be considered for commercial, industrial, and institutional areas where the sediment load is relatively low, such as: parking lots, driveways, loading docks, gas stations, garages, and storage yards. Sand filters may also be feasible and appropriate in some multi-family or higher density residential developments.

To avoid rapid clogging and failure of the filter media, the use of sand filters should be avoided in areas with less than 50% impervious cover, or high sediment yield sites with clay/silt soils.

The following basic criteria should be evaluated to ensure the suitability of a sand filter facility for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – NO
- Suitable for High Density/Ultra Urban Areas – YES
- Regional Stormwater Control – NO

Physical Feasibility - Physical Constraints at Project Site

Drainage Area: 10 acres maximum for surface sand filter.

Space Required: Function of available head at site.

Site Slope: No more than 6% slope across filter location.

Minimum Head: Elevation difference needed at a site from the inflow to the outflow: 5 feet

Minimum Depth to Water Table: For a surface sand filter with infiltration, 5 feet is required between the bottom of the sand filter and the elevation of the historic high water table, and must not treat hotspot runoff.

Soils: No restrictions; Group "A" soils generally required if the filtered water is released into surrounding soils.

Downstream Water Surface: Downstream flood conditions need to be verified to avoid surcharging and back washing of the filter material.

Other Constraints / Considerations

Aquifer Protection: Do not allow infiltration of untreated hotspot runoff into groundwater. A minimum separation distance of 5 feet is required between the bottom of the filter and the elevation of the historical high water table.

3.2.8.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of a sand filter facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

A. LOCATION AND SITING

- Surface sand filters should have a contributing drainage area of 10 acres or less.
- Sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with less than 50% imperviousness or high clay/silt sediment loads must not use a sand filter without adequate pretreatment due to potential clogging and failure of the filter bed. Any disturbed areas within the sand filter facility drainage area should be identified and stabilized. Filtration controls should only be constructed after the construction site is stabilized.
- Surface sand filters are generally used in an off-line configuration where the WQ_v is diverted to the filter facility through the use of a flow diversion structure and flow splitter. Stormwater flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
- Sand filter systems are designed for intermittent flow and must be allowed to drain and reaerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

B. GENERAL DESIGN

- A surface sand filter facility consists of a two-chamber open-air structure, which is located at ground-level. The first chamber is the sediment forebay (sedimentation chamber) while the second chamber houses the sand filter bed. Flow enters the sedimentation chamber where settling of larger sediment particles occurs. Runoff is then discharged from the sedimentation chamber through a perforated standpipe into the filtration chamber. After passing though the filter bed, runoff is collected by a perforated pipe and gravel underdrain system. Figure 3-32 provides plan and profile schematics of a surface sand filter.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

- The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQ_v prior to filtration. Figure 3-29 illustrates the distribution of the treatment volume (0.75 WQ_v) among the various components of the surface sand filter, including:

- V_s – volume within the sedimentation basin;
- V_f – volume within the voids in the filter bed;
- $V_{f\text{-}temp}$ – temporary volume stored above the filter bed;
- A_s – the surface area of the sedimentation basin;
- A_f – surface area of the filter media;
- h_s – height of water in the sedimentation basin;
- h_{temp} – depth of temporary volume;
- h_f – average height of water above the filter media (1/2 h_{temp});
- d_f – depth of filter media.

- The sedimentation chamber must be sized to at least 25% of the computed WQ_v and have a length-to-width ratio of at least 2:1. Inlet and outlet structures should be located at opposite ends of the chamber.

The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in 40 hours or less.

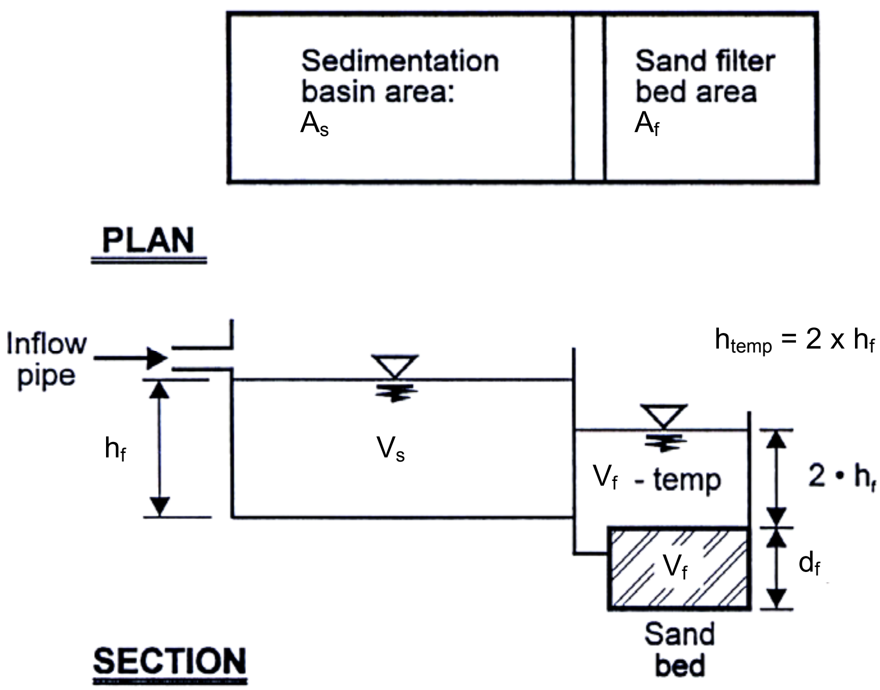


Figure 3-29 Surface Sand Filter Volumes
Source: Claytor and Schueler, 1996

- The filter media consists of an 18 inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand) on top of the underdrain system. Three inches of topsoil are placed over the sand bed. Permeable filter fabric is placed both above and below the sand bed to prevent clogging of the sand filter and the underdrain system. A proper fabric selection is critical. Choose a filter fabric with equivalent pore openings to prevent clogging by sandy filler material. Figure 3-30 illustrates a typical media cross section.
- The filter bed is equipped with a 6 inch perforated PVC pipe (AASHTO M 252) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8-inch per foot (1% slope). Holes should be 3/8 inch diameter and spaced approximately 6 inches on center. Gravel should be clean washed aggregate with a maximum diameter of 2.5 inches and a minimum diameter of 0.5 inches with a void space of about 40% meeting the gradation listed below. Aggregate contaminated with soil shall not be used.

Table 3-7 Percent Passing per Sieve Size for Aggregate Gradation

Gradation	
Sieve Size	% Passing
2.5”	100
2”	90-100
1.5”	35-70
1”	0-15
0.5”	0-5

- The structure containing the surface sand filter may be constructed of impermeable media such as concrete, or through the use of excavations and earthen embankments. When constructed with earthen walls/embankments, filter fabric should be used to line the bottom and side slopes of the structures before installation of the underdrain system and filter media.

D. PRETREATMENT / INLETS

- Pretreatment of runoff in a sand filter system is provided by the sedimentation chamber.
- Inlets to surface sand filters are to be provided with energy dissipaters. Exit velocities from the sedimentation chamber must be nonerosive.
- Figure 3-31 shows a typical inlet pipe from the sedimentation basin to the filter media basin for the surface sand filter.

E. OUTLET STRUCTURES

- Outlet pipe is to be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for emergency overflows and spillways).

F. EMERGENCY SPILLWAY

- An emergency or bypass spillway must be included in the surface sand filter to safely pass flows that exceed the water quality design flows. The spillway prevents filter water levels from overtopping the embankment and causing structural damage.

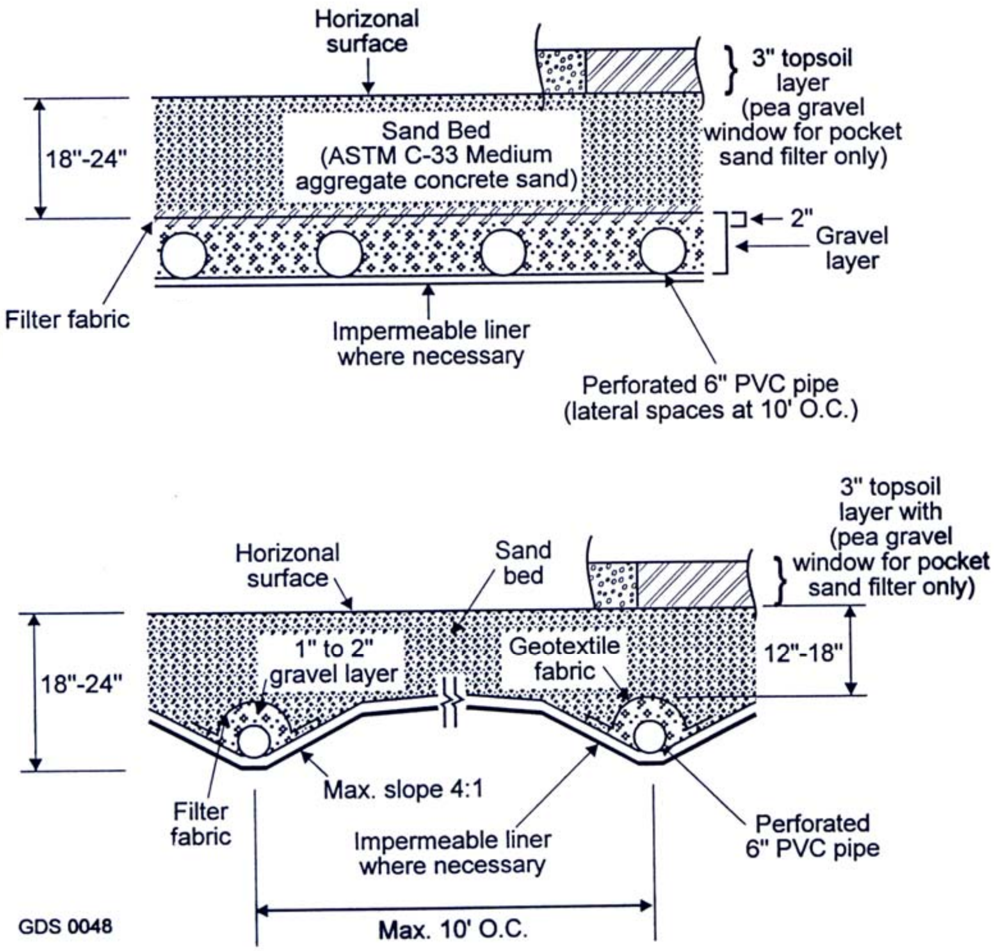


Figure 3-30 Typical Sand Filter Media Cross Sections
(Source: Claytor and Schueler, 1996)

G. MAINTENANCE ACCESS

- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

H. SAFETY FEATURES

- Surface sand filter facilities can be fenced to prevent access.

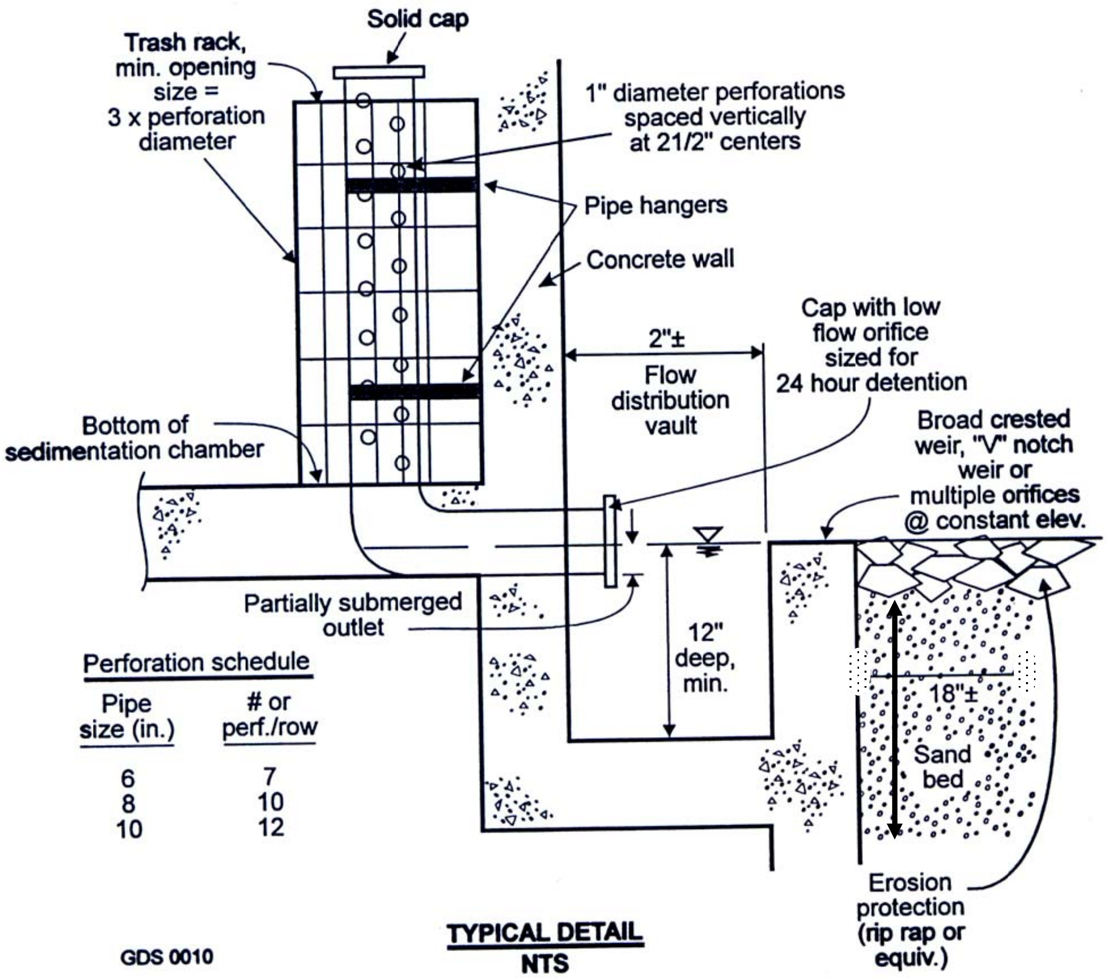


Figure 3-31 Example Surface Sand Filter Perforated Stand-Pipe
(Source: Claytor and Schueler, 1996)

I. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

Low Relief: Use of surface sand filter may be limited by low head.

High Relief: Filter bed surface must be level.

Karst: Use polyliner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure.

Soils

- No restrictions.

Special Downstream Watershed Considerations

<u>Aquifer Protection:</u> Use polyliner or impermeable membrane to seal bottom of sand filter if historically high water table is within 5 feet of surface or use watertight structure.

3.2.8.6 Design Procedures

Step 1 Compute runoff control volume.

Calculate the WQ_v using equation 1-1.

Step 2 Confirm local design criteria and applicability.

Consider any special site-specific design conditions/criteria.

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3 Compute peak discharge for the WQ_v, called Q_{wq}, using equation 4-18.

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion structures.

a. Using WQ_v, compute CN using equation 4-3.

b. Compute time of concentration (Chapter 4, Section 4).

c. Determine appropriate unit peak discharge from time of concentration (Chapter 4, Section 8).

d. Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v using equation 4-18.

Step 4 Size flow diversion structure if needed.

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the sand filter facility.

Size low flow orifice, weir, or other device to pass Q_{wq}.

Step 5 Size filtration basin chamber.

The filter area is sized using the following equation (based on Darcy's Law):

Equation 3-4

$$A_f = \frac{WQ_v * d_f}{k * \left(h_f + d_f\right) * t_f}$$

where:

A_f	=	surface area of filter bed (ft2)
d_f	=	filter bed depth (ft) (typically 1.5 ft, no more than 2 ft)
k	=	coefficient of permeability of filter media (ft/day) (use 3.5 ft/day for sand)
h_f	=	average height of water above filter bed (ft) (1/2 h_{temp}, which varies based on site but h_{temp} is typically ≤ 6 feet)
t_f	=	design filter bed drain time (days) (1.67 days or 40 hours is recommended maximum)

Set preliminary dimensions of filtration basin chamber.

Step 6 Size sedimentation chamber

The sedimentation chamber should be sized to at least 25% of the computed WQ_v and have a length-to-width ratio of 2:1. The Camp-Hazen equation is used to compute the required surface area: (Claytor & Schueler, 1996)

Equation 3-5 $$A_s = -\frac{Q_o}{w} * Ln(1 - E)$$

where:

As	=	sedimentation basin surface area (ft^2)
Q_o	=	rate of outflow = the WQ_v over a 24-hour period
w	=	particle settling velocity (ft/sec)
E	=	trap efficiency

Assuming:

- 90% sediment trap efficiency (0.9);
- particle settling velocity (ft/sec) = 0.0033 ft/sec for imperviousness ≥ 75%;
- particle settling velocity (ft/sec) = 0.0004 ft/sec for imperviousness < 75%;
- average of 24 hour holding period.

Then:

As	=	(0.0081) (WQ_v) ft^2 for Imperviousness ≥ 75%
As	=	(0.066) (WQ_v) ft^2 for Imperviousness < 75%

Set preliminary dimensions of sedimentation chamber.

Step 7 Compute V_{min} for 75% of the WQ_v, as required by the design specifications.

Equation 3-6 $$V_{min} = 0.75 * WQ_v$$

Step 8 Compute storage volumes within facility and sedimentation chamber orifice size (Claytor & Schueler, 1996).

$$V_{min} = 0.75 * WQ_v = V_s + V_f + V_{f-temp}$$

- Compute V_f = water volume within filter bed/gravel/pipe = $A_f * d_f * n$

Where: n = porosity = 0.4 for most applications

- Compute $V_{f\text{-temp}}$ = temporary storage volume above the filter bed = $2 * h_f * A_f$
- Compute V_s = volume within sediment chamber = $V_{min} - V_f - V_{f\text{-temp}}$
- Compute h_s = height in sedimentation chamber = V_s/A_s
- Ensure h_s and h_f fit available head and other dimensions still fit; change as necessary in design iterations until all site dimensions fit.
- Size orifice from sediment chamber to filter chamber to release V_s within 24-hours at average release rate with 0.5 h_s as average head.

Step 9 Design inlets, pretreatment facilities, underdrain system, and outlet structures

See Chapter 5 for more details.

Step 10 Compute overflow weir sizes

- Size overflow weir at elevation h_s in sedimentation chamber (above perforated stand pipe) to handle surcharge of flow through filter system from storms producing more than WQ_v design event.
- Plan inlet protection for overflow from sedimentation chamber and size overflow weir at elevation h_f in filtration chamber (above perforated stand pipe) to handle surcharge of flow through filter system from storms producing more than WQ_v design event.

3.2.8.7 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the layout and location of the facility, and also clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.8.8 Example Schematics

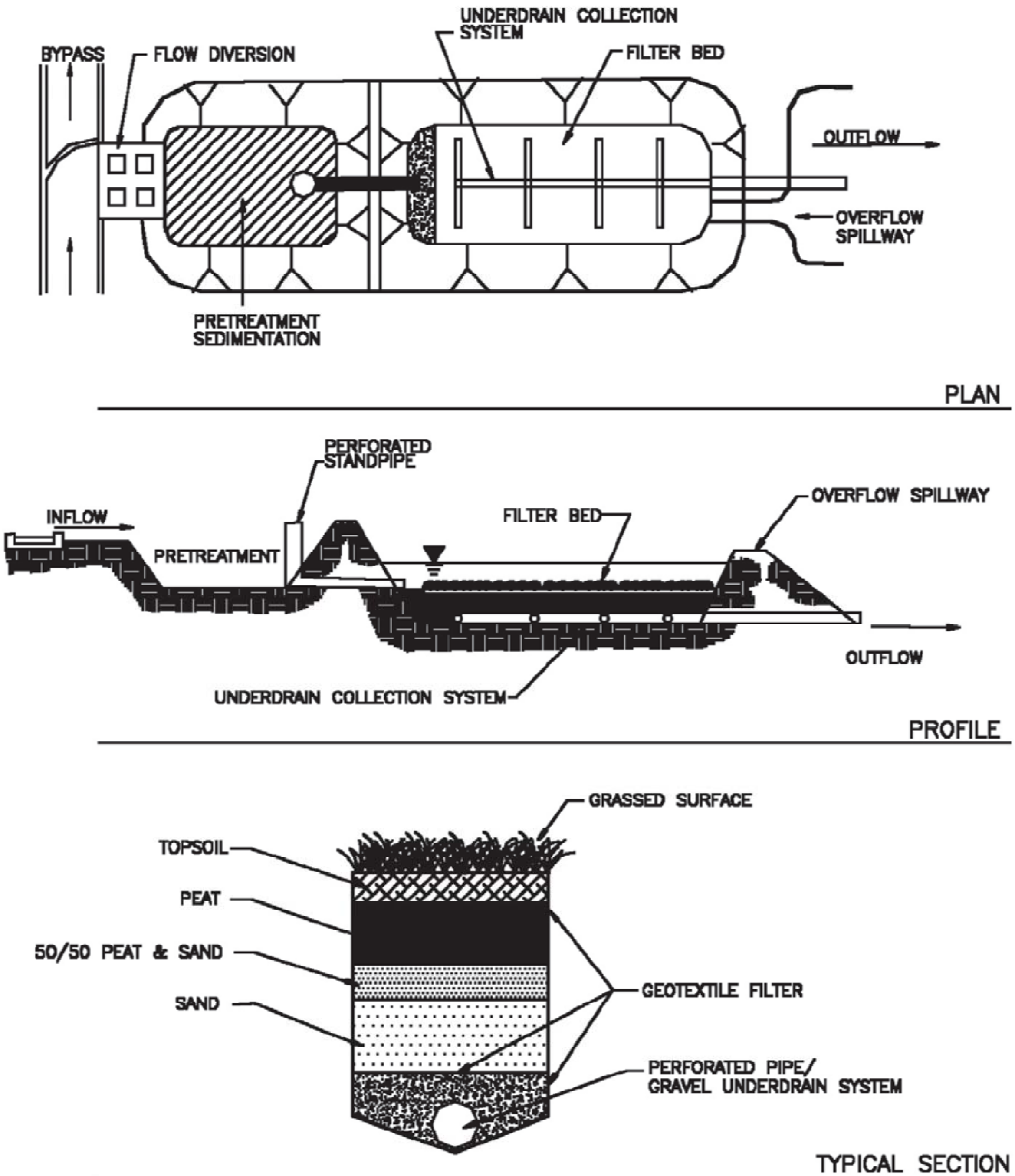


Figure 3-32 Schematic of Surface Sand Filter
(adapted from Claytor & Schueler, 1996).

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3.2.9 Bioretention Areas

Primary Water Quality Facility

Description: Shallow stormwater basin or landscaped area that utilizes engineered soils and vegetation to capture and treat runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Maximum contributing drainage area of 5 acres (< 2 acres recommended)
- Treatment area consists of grass filter, sand bed, ponding area, organic/mulch layer, planting soil, and vegetation
- Typically requires 5 feet of head

ADVANTAGES / BENEFITS:

- Applicable to small drainage areas
- Good for highly impervious areas, flexible siting
- Relatively low maintenance requirements
- Can be planned as an aesthetic feature

DISADVANTAGES / LIMITATIONS:

- Requires extensive landscaping
- Not recommended for areas with steep slopes

MAINTENANCE REQUIREMENTS:

- Inspect and repair/replace treatment area components
- Prune and weed vegetation
- Remove sediment from forebay and retention chamber
- May require irrigation during establishment phase

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total Nitrogen
H	**Metals –** Cadmium, Copper, Lead & Zinc
No Data	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Water Quality Protection**
- ✓ **Channel Protectio**
- ✓ **On-Site Flood Control**
- ✓ **Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirements**
M	**Relative Capital Costs**
L	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max (<2 acres recommended)*

Soils: *Planting soils must meet specified criteria; No restrictions on surrounding soils.*

Other Considerations:

- *Use of native plants is recommended.*

L=Low **M**=Moderate **H**=High

3.2.9.1 General Description

Bioretention areas (also referred to as bioretention filters or rain gardens) are structural stormwater controls that capture and temporarily store the WQ_v using soils and vegetation in shallow basins or landscaped areas to remove pollutants from stormwater runoff.

Bioretention areas are engineered facilities in which runoff is conveyed as sheet flow to the “treatment area” which consists of a grass buffer strip, ponding area, organic or mulch layer, planting soil, and vegetation. An optional sand or aggregate bed can also be included in the design to provide aeration and drainage of the planting soil. The filtered runoff is typically collected and returned to the conveyance system after detention, though it may infiltrate. Because bioretention areas remove pollutants using filtration, they are applicable primarly to impervious areas without high levels of fine particulates (clay/silt soils) in the runoff and should only be considered for sites where the sediment load is relatively low.

There are numerous design applications, both on- and off-line, for bioretention areas. These include use on single-family residential lots (rain gardens), as off-line facilities adjacent to parking lots, along highway and road drainage swales, within larger landscaped pervious areas, and as landscaped islands in impervious or high-density environments. Figure 3-33 and Figure 3-34 illustrate examples of bioretention facilities.

Residential Rain Garden

Landscaped Island

Newly Constructed Bioretention Area

Newly Planted Bioretention Area

Figure 3-33 Bioretention Area Examples

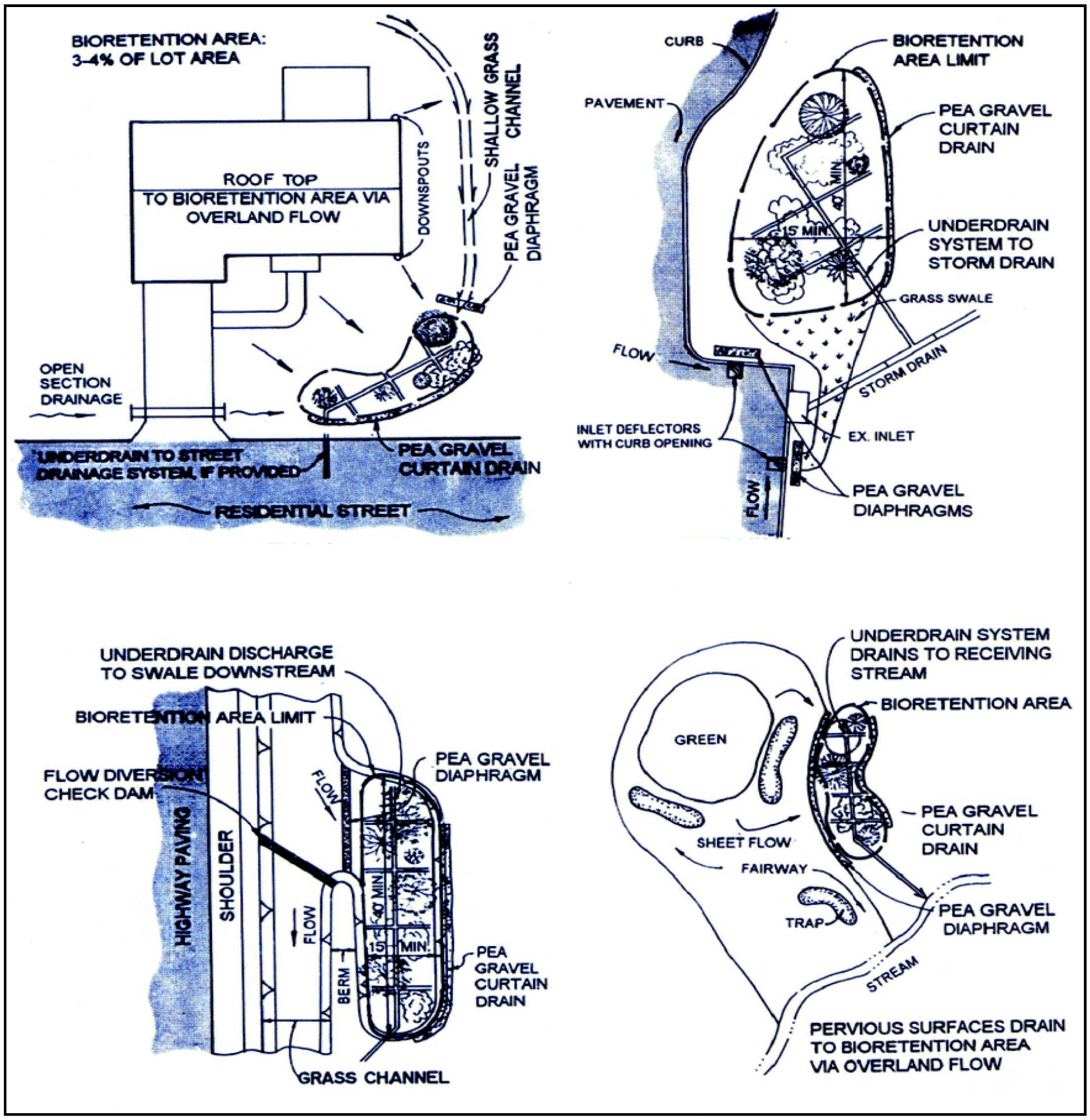

Figure 3-34 Bioretention area examples
(Claytor & Schueler, 1996)

3.2.9.2 Stormwater Management Suitability

Bioretention areas are designed primarily for stormwater quality, i.e. the removal of stormwater pollutants. Bioretention can provide limited runoff quantity control, particularly for smaller storm events. These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, bioretention areas will typically need to be used in conjunction with another structural control to provide channel protection as well as flood control. It is important to ensure that a bioretention area safely bypasses higher flows.

Water Quality Protection

Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the bioretention area is designed to perform a specific function (see Figure 3-35). The grass filter strip (or grass channel) reduces incoming runoff velocity and filters particulates from the runoff. The ponding area provides for temporary storage of stormwater runoff prior to its infiltration or vegetation uptake, and provides additional settling capacity. The organic or mulch layer provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. The planting soil in the bioretention facility acts as a filtration system, and clay in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients, and other pollutants. Both woody and herbaceous plants in the ponding area provide vegetative uptake of runoff and pollutants and also serve to stabilize the surrounding soils. Finally, a sand or aggregate bed provides for positive drainage and aerobic conditions in the planting soil and provides a final polishing treatment media.

Section 3.2.9.3 gives data on pollutant removal efficiencies that can be used for planning and design purposes.

Channel Protection

For smaller sites, a bioretention area may be designed to capture the entire CP_v in either an off- or on-line configuration. Given that a bioretention facility is typically designed to completely drain over 48 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will usually be met. For larger sites where only the WQ_v is diverted to the bioretention facility, another structural control usually must be used to provide CP_v extended detention.

Flood Control

Bioretention areas must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the ponding area, mulch layer, and vegetation.

The volume of runoff removed and treated in the bioretention area may be included in flood control calculations (see Chapter 3).

3.2.9.3 Pollutant Removal Capabilities

Bioretention areas are presumed to be able to remove 85% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed bioretention areas can reduce TSS removal performance.

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach.

- Total Suspended Solids – 85%
- Total Phosphorus – 60%
- Total Nitrogen – 50%
- Heavy Metals – 80%
- Fecal Coliform – insufficient data

For additional information and data on pollutant removal capabilities, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.9.4 Application and Site Feasibility Criteria

Bioretention areas are suitable for many types of development, from single-family residential to high-density commercial projects. Bioretention is also well suited for small lots, including those of one acre or less. Because of its ability to be incorporated in landscaped areas, the use of bioretention is extremely flexible. Bioretention areas are an ideal structural stormwater control for use as roadway median strips and parking lot islands and are also good candidates for the treatment of runoff from pervious areas, such as a golf course.

The following criteria should be evaluated to ensure the suitability of a bioretention area for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – YES
- Regional Stormwater Control – NO

Physical Feasibility - Physical Constraints at Project Site

Drainage Area: 5 acres maximum; 0.5 to 2 acres are preferred.

Space Required: Approximately 5-7% of the tributary impervious area is normally required.

Site Slope: No more than 6% slope

Minimum Head: Elevation difference needed at a site from the inflow to the outflow: 3 to 5 feet.

Minimum Depth to Water Table: A minimum separation distance of 5 feet is required between the bottom of the cell and the elevation of the historical high water table for bioretention areas without underdrains, 2 feet for cells with underdrains.

Soils: No restrictions; engineered media required.

3.2.9.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of a bioretention facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

A. LOCATION AND SITING

- Bioretention areas should have a maximum contributing drainage area of 5 acres or less; 0.5 to 2 acres are preferred. Multiple bioretention areas can be used for larger areas.
- Bioretention areas can either be used to capture sheet flow from a drainage area or function as an off-line device. On-line designs should be limited to a maximum drainage area of 0.5 acres unless special precautions are taken to protect from erosion during high flows.
- When used in an off-line configuration, the WQ_v is diverted to the bioretention area through the use of a flow splitter. Stormwater flows greater than the WQ_v are diverted to other controls or downstream.
- Bioretention systems are designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.
- Bioretention area locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design.

B. GENERAL DESIGN

- A well-designed bioretention area consists of:
  - Grass filter strip (or grass channel) between the contributing drainage area and the ponding area, except where site conditions preclude its use;
  - Ponding area containing vegetation with a planting soil bed;
  - Organic/mulch layer;
  - Sand or gravel layer between the planting soil and the gravel underneath to provide filtering of the particles prior to entering gravel layer; and,
  - Gravel and perforated pipe underdrain system to collect runoff that has filtered through the soil layers (bioretention areas can optionally be designed to infiltrate into the soil – see description of infiltration trenches for infiltration criteria).
- A bioretention area design will also include some of the following:
  - Optional sand filter layer to spread flow, filter runoff, and aid in aeration and drainage of the planting soil;

- Stone diaphragm at the beginning of the grass filter strip to reduce runoff velocities and spread flow into the grass filter;
- Inflow diversion or an overflow structure consisting of one of five main methods:
  - Use a flow diversion structure;
  - For curbed pavements use an inlet deflector (see Figure 3-38);
  - Use a slotted curb and design the parking lot grades to divert the WQ_v into the facility; bypass additional runoff to a downstream catch basin inlet; requires temporary ponding in the parking lot;
  - The use of a short deflector weir (maximum height 6 inches) designed to divert the maximum water quality peak flow into the bioretention area;
  - An in-system overflow consisting of an overflow catch basin inlet and/or a gravel curtain drain overflow.

See Figure 3-35 for an overview of the various components of a bioretention area. Figure 3-36 provides a plan view and profile schematic of an on-line bioretention area. An example of an off-line facility is shown in Figure 3-37.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

- Recommended minimum dimensions of a bioretention area are 10 feet wide by 40 feet long. All designs except small residential applications should maintain a length to width ratio of at least 2:1.
- The planting soil filter bed is sized using a Darcy's Law equation with a filter bed drain time of less than 48 hours (less than 6 hours residential neighborhoods and 24 hours non-residential preferred) and a coefficient of soil permeability (k) of greater than 0.5 ft/day.
- The maximum recommended ponding depth of the bioretention areas is 6 inches with a drain time normally of 3 to 4 hours in residential settings.
- The planting soil bed must be at least 2.5 feet in depth and up to 4 feet if shrubs or trees are to be planted. (Shallow-rooted shrubs or trees must be selected to avoid fouling of the drainage system by roots.) Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 5 to 8%. The soil must have an infiltration rate of at least 0.5 inches per hour (1.0 in/hr preferred) and a pH between 5.5 and 6.5. In addition, the planting soil should have a 1.5 to 3% organic content and a maximum 500 ppm concentration of soluble salts.
- For on-line configurations, a grass filter strip with a gravel diaphragm is typically utilized (see Figure 3-36) as the pretreatment measure. The required length of the filter strip depends on the drainage area, imperviousness, and the filter strip slope. Design guidance on filter strips for pretreatment can be found in Section 3.2.3.
- For off-line applications, a grass channel with a gravel diaphragm flow spreader is used for pretreatment. The length of the grass channel depends on the drainage area, land use,

and channel slope. The minimum grassed channel length should be 20 feet. Design guidance on grass channels for pretreatment can be found in Section 3.2.4.

- The mulch layer should consist of 2 to 4 inches of commercially available fine shredded hardwood mulch or shredded hardwood chips.
- The sand bed (optional) should be 12 to 18 inches thick. Sand should be clean and have less than 15% silt or clay content.
- Gravel for the 4" to 9" thick layer above the gravel bedding (and diaphragm and curtain, where used), should be ASTM D 448 size No. 6 (1/8 inch to ¼ inch).
- The underdrain collection system is equipped with a 6-inch perforated PVC pipe (AASHTO M 252) in an 8-inch gravel layer. The pipe should have 3/8-inch perforations, spaced at 6-inch centers, with a minimum of 4 holes per row. The pipe is spaced at a maximum of 10 feet on center and a minimum grade of 0.5% must be maintained.
- A narrow 24 inch wide permeable filter fabric is placed on the gravel layer directly above the perforated pipes to limit piping of soil directly into the pipe. Filter fabric is also placed along the vertical or sloping outer walls of the bioretention system to limit vertical infiltration prior to filtration through the soil.

D. PRETREATMENT / INLETS

- Adequate pretreatment and inlet protection for bioretention systems is provided when all of the following are provided: (a) grass filter strip below a level spreader, or grass channel, (b) gravel diaphragm and (c) an organic or mulch layer.

E. OUTLET STRUCTURES

- Outlet pipe is to be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary.

F. EMERGENCY SPILLWAY

- An overflow structure and nonerosive overflow channel must be provided to safely pass flows from the bioretention area that exceeds the storage capacity to a stabilized downstream area or watercourse. If the system is located off-line, the overflow should be set above the shallow ponding limit.
- The high flow overflow system within the structure typically consists of an area drain catchbasin, though any number of conventional systems could be used. The throat of the catch basin inlet is normally placed 6 inches above the mulch layer. It should be designed as a domed grate or a covered weir structure to avoid clogging with floating mulch and debris, and should be located at a distance from inlets to avoid short circuiting of flow. It may also be placed into the side slope of the structure maintaining a neat contoured appearance.

G. MAINTENANCE ACCESS

- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

H. SAFETY FEATURES

- Bioretention areas generally do not require any special safety features. Fencing of bioretention facilities is not generally desirable.

I. LANDSCAPING

- Landscaping is critical to the performance and function of bioretention areas. Native species are encouraged.
- A dense and vigorous vegetative cover should be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Side slopes should be sodded to limit erosion of fine particles onto the bioretention surface.
- The bioretention area should be vegetated to resemble a terrestrial ecosystem,
  - With a mature tree canopy, subcanopy of understory trees, scrub layer, and herbaceous ground cover. Three species each of both trees and scrubs are recommended to be planted.
  - With native prairie grasses.
- For bioretention areas with trees, the tree-to-shrub ratio should be 2:1 to 3:1. On average, the trees should be spaced 8 feet apart. Plants should be placed to replicate a natural forest. Woody vegetation should not be specified at inflow locations.
- For bioretention areas with prairie grasses, native grasses should be well established, with a mixture of species. Wildflowers may be incorporated into the design to add color and visual interest.
- After the trees and shrubs or grasses are established, the ground cover and mulch should be established.
- Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost, aesthetics, shallow or deep rooted, maintenance, etc. Planting recommendations for bioretention facilities are as follows:
  - Native plant species should be specified over non-native species.
  - Vegetation should be selected based on a specified zone of hydric tolerance.
  - A selection of trees with an understory of shrubs and herbaceous materials or a mixture of prairie grasses should be provided.

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

Low Relief: Use of bioretention areas may be limited by low head.

High Relief: Ponding area surface must be relatively level.

Karst: Use poly-liner or impermeable membrane to seal bottom if infiltration is deemed appropriate by a geotechnical engineer.

Soils

- No restrictions

Special Downstream Watershed Considerations

Aquifer Protection: A minimum separation distance of 5 feet is required between the bottom of the cell and the elevation of the historical high water table for bioretention areas without underdrains, 2 feet for cells with underdrains.

3.2.9.6 Design Procedures

Step 1 Compute runoff control volumes from the integrated design approach.

Calculate the WQ_v using equation 1-1

Step 2 Confirm local design criteria and applicability.

Consider any special site-specific design conditions/criteria.

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3 Compute WQ_v peak discharge (Q_{wq}).

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion structures (see Chapter 4).

- Using WQ_v (or total volume to be captured), compute CN using equation 4.3.
- Compute time of concentration (Chapter 4, Section 4).
- Determine appropriate unit peak discharge from time of concentration (Chapter 4, Section 8).
- Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v using equation 4.18.

Step 4 Size flow diversion structure, if needed.

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the bioretention area.

Size low flow orifice, weir, or other device to pass Q_{wq} (Chapter 5, Section 6).

Step 5 Determine size of bioretention ponding/filter area.

The required planting soil filter bed area is computed using the following equation (based on Darcy's Law): (Claytor & Schueler, 1996).

Equation 3-7

$$A_f = \frac{WQ_v * d_f}{k * (h_f + d_f) * t_f}$$

where:
A_f = surface area of ponding area (ft^2)
WQ_v = water quality protection volume (or total volume to be captured)
d_f = filter bed depth (2.5 feet minimum)
k = coefficient of permeability of filter media (ft/day) (use 0.5 ft/day for silt-loam)
h_f = average height of water above filter bed (ft) (typically 3 in, half of the 6 in ponding depth)
t_f = design filter bed drain time (days) (2.0 days or 48 hours is recommended maximum)

Step 6 Set design elevations and dimensions of facility.

Step 7 Design conveyances to facility (off-line systems) (Chapter 3, Section 1).

See the example Figure 3-37 to determine the type of conveyances needed for the site.

Step 8 Design pretreatment (Chapter 2, Section 3).

Pretreat with a grass filter strip (on-line configuration) or grass channel (off-line), and stone diaphragm.

Step 9 Size underdrain system

See Section 3.2.9.5.

Step 10 Design emergency overflow

See Section 3.2.10.5.

An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Nonerosive velocities need to be ensured at the outlet point.

Step 11 Prepare vegetation and landscaping plan.

A landscaping plan for the bioretention area should be prepared to indicate how it will be established with vegetation.

3.2.9.7 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the facility, and also clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.9.8 Example Schematics

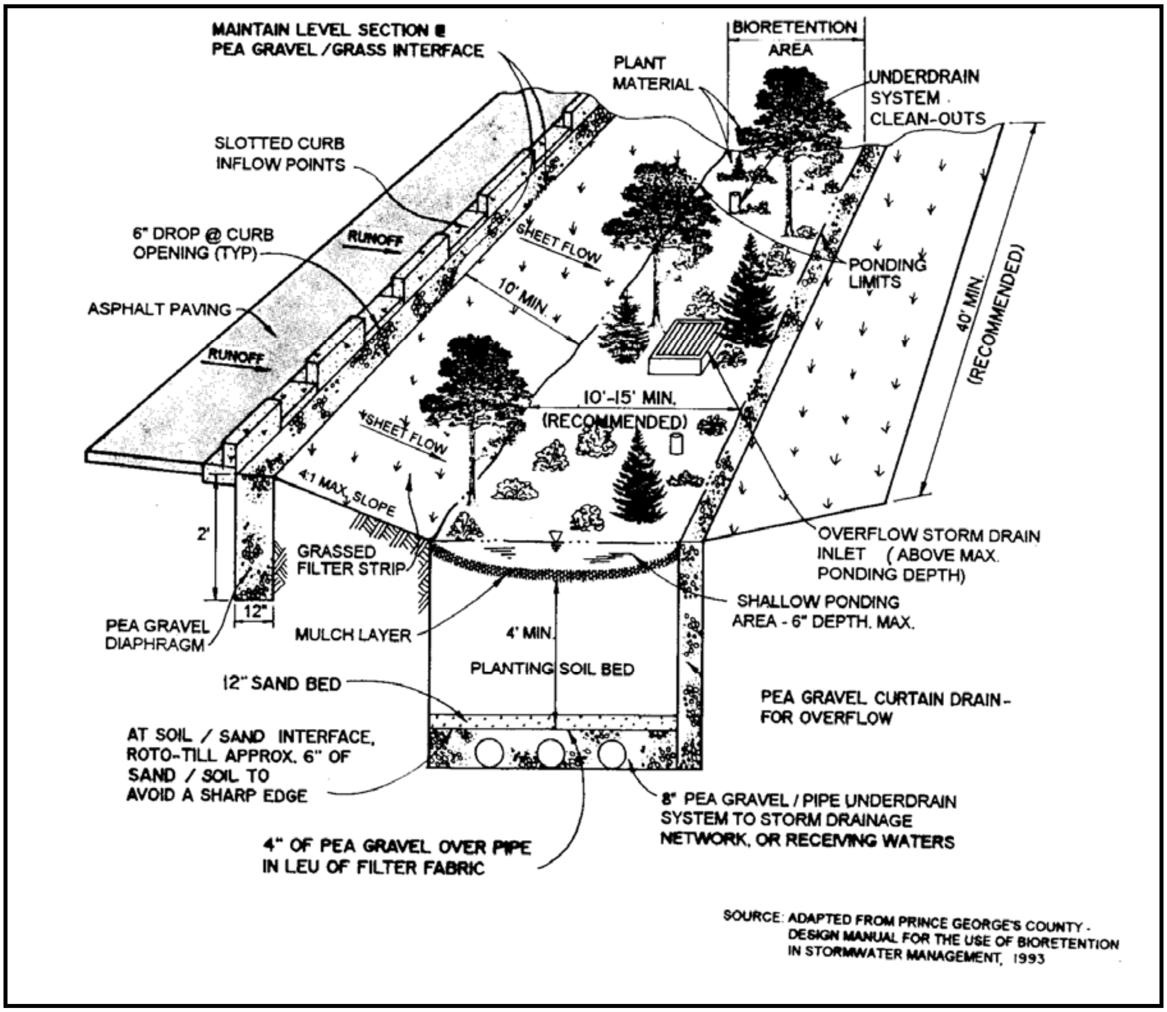

Figure 3-35 Schematic of a Typical Bioretention Area
(Source: Claytor and Schueler, 1996)

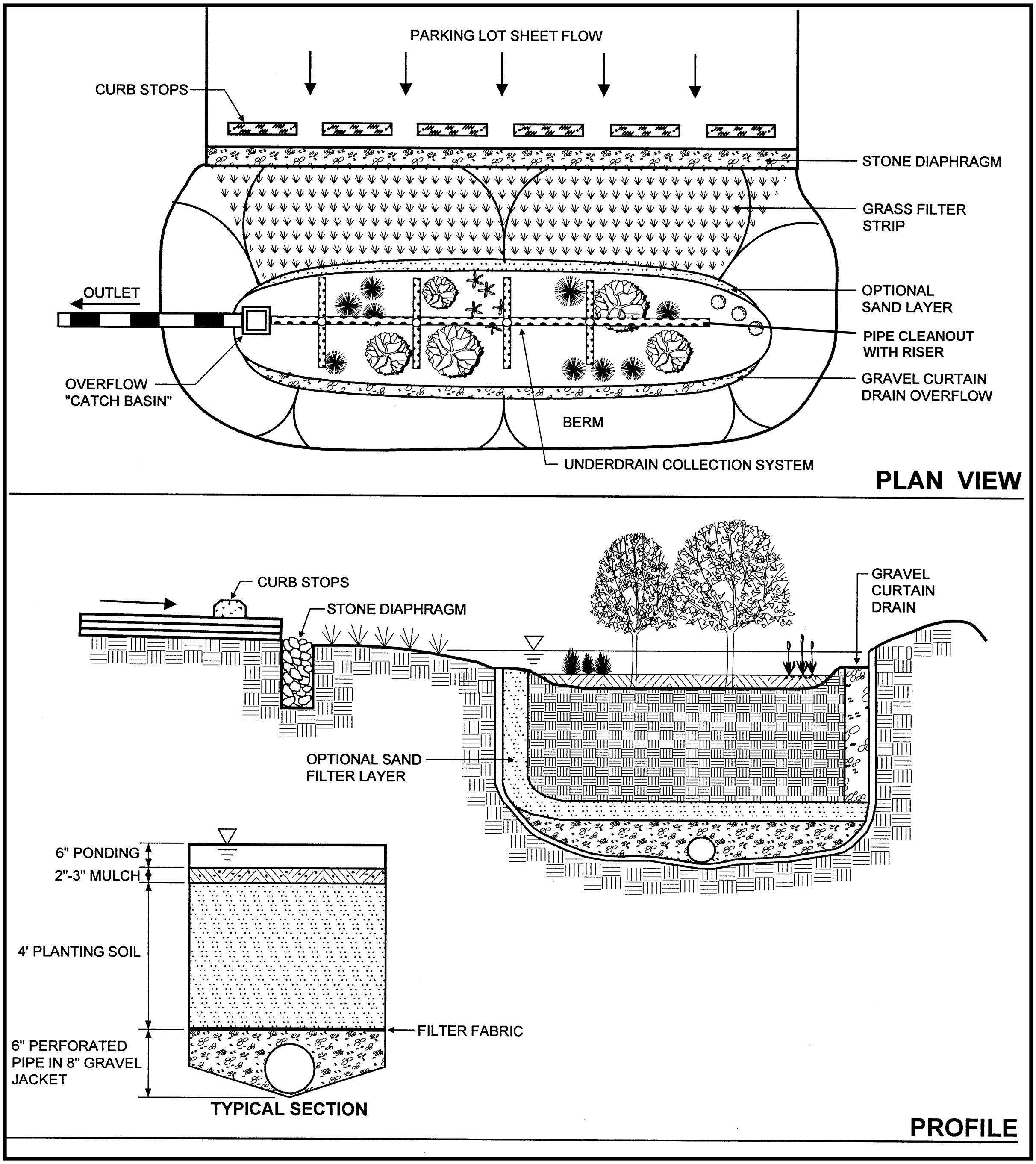

Figure 3-36 Schematic of a Typical On-Line Bioretention Area
(Source: Claytor and Schueler, 1996)

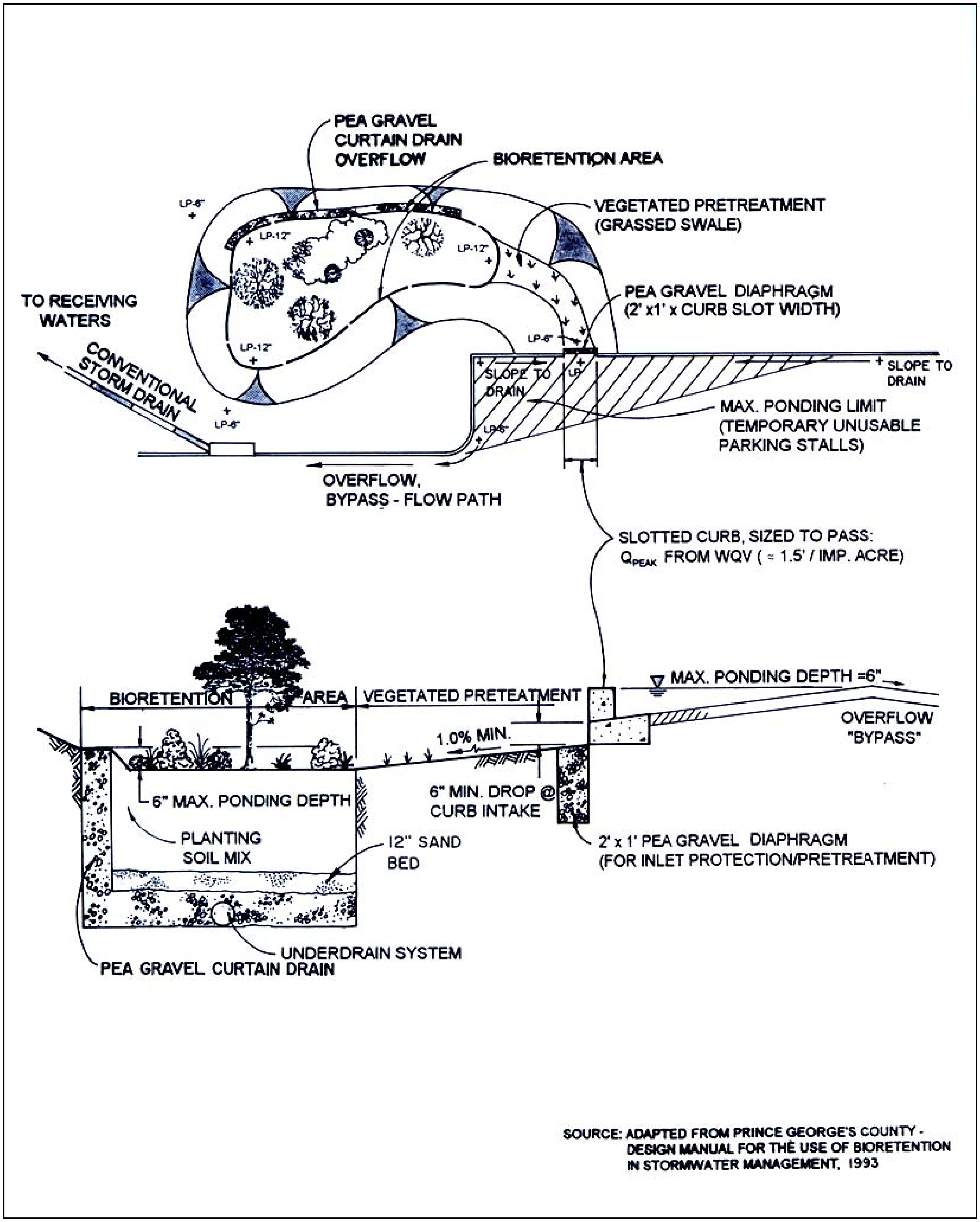

Figure 3-37 Schematic of a Typical Off-Line Bioretention Area
(Source: Claytor and Schueler, 1996)

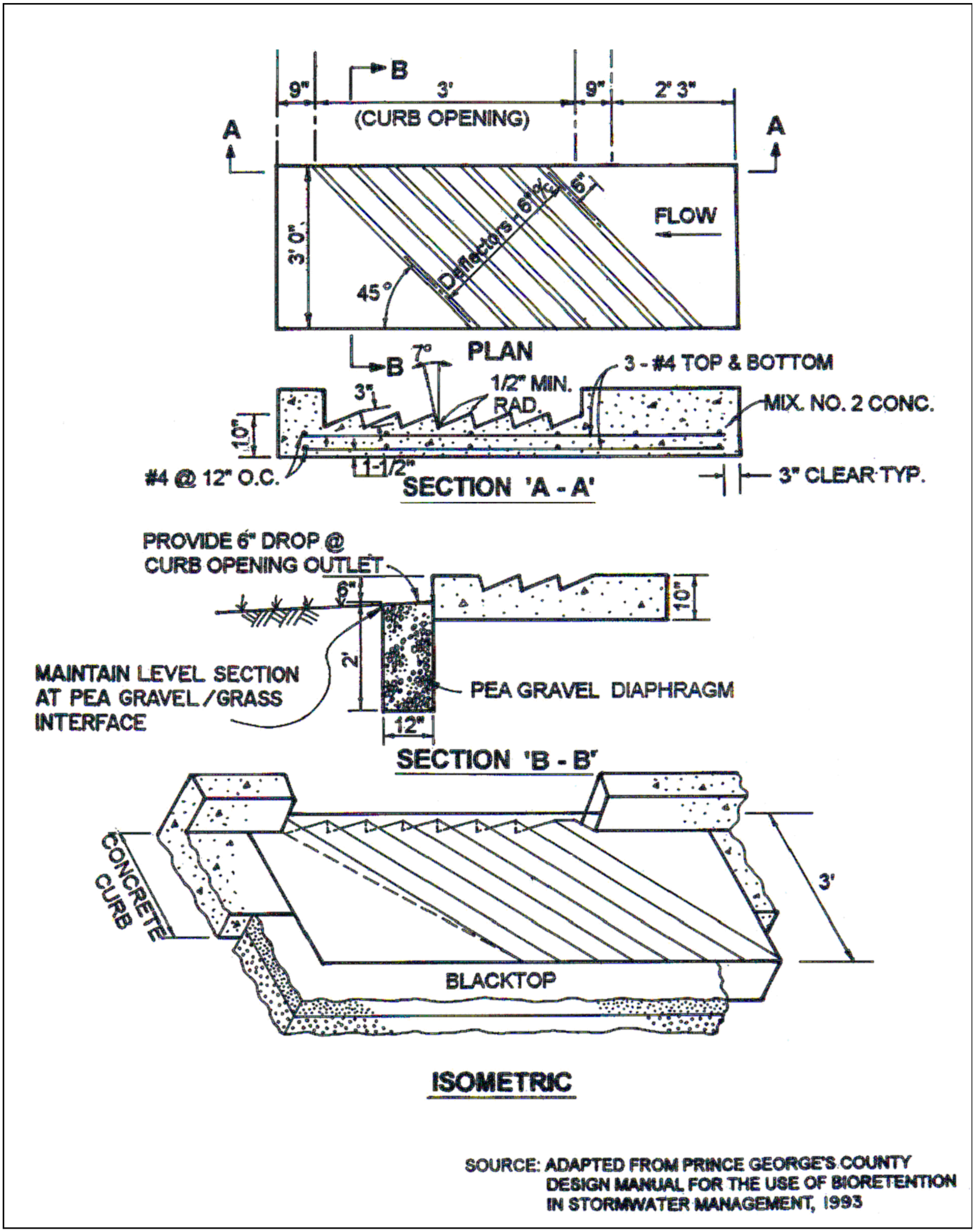

Figure 3-38 Schematic of a Typical Inlet Deflector
(Source: Claytor and Schueler, 1996).

3.2.10 Stormwater Wetland

Primary Water Quality Facility

Description: Constructed wetland used for stormwater management. Runoff is both stored and treated in the wetland facility.

KEY CONSIDERATIONS

DESIGN CRITERIA:
- Minimum contributing drainage area of 25 acres
- Minimum dry weather flow path of 2:1 (length: width) should be provided from inflow to outflow
- Minimum of 35% of total surface area should have a depth of 6 inches or less; 10% to 20% of surface area should be deep pool (1.5 to 6 foot depth)

ADVANTAGES / BENEFITS:
- Good nutrient removal
- Provides natural wildlife habitat
- Relatively low maintenance costs

DISADVANTAGES / LIMITATIONS:
- Requires large land area
- Needs continuous baseflow for viable wetland
- Sediment regulation is critical to sustain wetlands
- Large commitment to establish vegetation in the first 3 years

MAINTENANCE REQUIREMENTS:
- Replace wetland vegetation to maintain at least 50% surface area coverage
- Remove invasive vegetation
- Monitor sediment accumulation and remove periodically

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total Nitrogen
M	**Metals –** Cadmium, Copper, Lead & Zinc
H	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Water Quality Protection**
- ✓ **Channel Protection**
- ✓ **On-Site Flood Control**
- ✓ **Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

H	**Land Requirements**
M	**Capital Costs**

Maintenance Burden

M	**Shallow Wetland**
M	**ED Shallow Wetland**
M	**Pond/Wetland**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *25 acres min*

Soils: *Hydrologic group 'A' and 'B' soils may require liner*

L=Low **M**=Moderate **H**=High

3.2.10.1 General Description

Stormwater wetlands (also referred to as constructed wetlands) are constructed shallow marsh systems that are designed to both treat urban stormwater and control runoff volumes. As stormwater runoff flows through the wetland facility, pollutant removal is achieved through settling and uptake by marsh vegetation.

Wetlands are among the most effective stormwater practices in terms of pollutant removal and also offer aesthetic value and wildlife habitat. Constructed stormwater wetlands differ from natural wetland systems in that they are engineered facilities designed specifically for the purpose of treating stormwater runoff and typically have less biodiversity than natural wetlands both in terms of plant and animal life.

There are several design variations of the stormwater wetland, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland. These include the shallow wetland, the extended detention shallow wetland, and the pond/wetland system. Figure 3-39 contains photos of various wetlands. Below are descriptions of each design variant:

Shallow Wetland: In the shallow wetland design, most of the water quality treatment volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay at the inlet to the wetland, and the micropool at the outlet. One disadvantage of this design is that, since the pool is very shallow, a relatively large amount of land is typically needed to store the WQ_V.

Extended Detention (ED) Shallow Wetland: The extended detention (ED) shallow wetland design is the same as the shallow wetland; however, part of the water quality treatment volume is provided as extended detention above the surface of the marsh and released over a period of 24 hours. This design can treat a greater volume of stormwater in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate both wet and dry periods need to be specified in the extended detention zone.

Pond/Wetland Systems: The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland where stormwater flows receive additional treatment. Less land is required for a pond/wetland system than for the shallow wetland or the extended detention shallow wetland systems.

Shallow Wetland

Shallow ED Wetland

Figure 3-39 Stormwater Wetland Examples

3.2.10.2 Stormwater Management Suitability

Similar to stormwater ponds, stormwater wetlands are designed to control both stormwater quantity and quality.

Water Quality

Pollutants are removed from stormwater runoff in a wetland through uptake by wetland vegetation and algae, vegetative filtering, and through gravitational settling in the slow moving marsh flows. Other pollutant removal mechanisms are also at work in a stormwater wetland including chemical and biological decomposition and volatilization. Section 3.2.10.3 provides pollutant removal efficiencies that can be used for planning and design purposes.

Channel Protection

The storage volume above the permanent pool/water surface level in a stormwater wetland is used to provide control of the channel protection volume (CP_v). This is accomplished by detaining the 1-year, 24-hour storm runoff for 24 hours (extended detention). It is best to do this with minimum vertical water level fluctuation, as extreme fluctuation may stress vegetation.

Flood Control

In situations where it is required, stormwater wetlands can also be used to provide detention to control peak flows. However, care must be exercised to provide a design that does not cause excessive velocities or other conditions that would disturb or damage the wetland system. When peak flow control is not incorporated into the design, a stormwater wetland must be designed to safely pass or bypass flood flows.

3.2.10.3 Pollutant Removal Capabilities

All of the stormwater wetland design variants are presumed to be able to remove 75% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed wetland facilities can reduce TSS removal performance.

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach.

- Total Suspended Solids – 75%
- Total Phosphorus – 45%
- Total Nitrogen – 30%
- Heavy Metals – 50%
- Fecal Coliform – 70% (if no resident waterfowl population present)

For additional information and data on pollutant removal capabilities, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.2.10.4 Application and Site Feasibility Criteria

Stormwater wetlands are generally applicable to most types of development, and can be utilized in both residential and nonresidential areas. However, due to the large land requirements, wetlands may not be practical in higher density areas. The following criteria should be evaluated to ensure the suitability of a stormwater wetland for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – Land requirements may preclude use
- Regional Stormwater Control – YES
- Hotspot Runoff – NO

Physical Feasibility - Physical Constraints at Project Site

Drainage Area: A minimum of 25 acres and a positive water balance is needed to maintain wetland conditions.

Space Required: Approximately 3 to 5% of the tributary drainage area.

Site Slope: There should not be a slope greater than 8% across the wetland site.

Minimum Head: Elevation difference needed at a site from the inflow to the outflow: 3 to 5 feet.

Minimum Depth to Water Table: The bottom of constructed wetlands must be at least 5 feet above the historical high groundwater elevation if unlined, or 2 feet if lined.

Soils: Permeable soils are not well suited for a constructed stormwater wetland. Underlying soils of hydrologic group 'C' or 'D' should be adequate to maintain wetland conditions. Most group 'A' soils and some group 'B' soils will require a liner. Evaluation of soils should be based on an actual subsurface analysis and permeability tests.

3.2.10.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of a stormwater wetland facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

A. LOCATION AND SITING

- Stormwater wetlands should normally have a minimum contributing drainage area of 25 acres or more.
- A continuous base flow is required to support wetland vegetation. A water balance must be performed to demonstrate that a stormwater wetland can withstand a 30 day drought at summer evaporation rates without completely drawing down (see Chapter 4).
- Wetland siting should also take into account the location and use of other site features such as natural depressions, buffers, and undisturbed natural areas, and should attempt to aesthetically "fit" the facility into the landscape. Bedrock close to the surface may prevent excavation.
- Stormwater wetlands cannot be located within navigable waters of the U.S., including natural wetlands, without obtaining a Section 404 permit under the Clean Water Act, and other applicable federal and State permits. In some isolated cases, a wetlands permit may be granted to convert an existing degraded wetland in the context of local watershed restoration efforts.
- If a wetland facility is not used for flood control, it should be designed as an off-line system to bypass higher flows rather than passing them through the wetland system.
- Minimum setback requirements for stormwater wetland facilities shall be a specified by local regulations.
- All utilities should be located outside of the wetland site.

B. GENERAL DESIGN

- A well-designed stormwater wetland consists of:
  - Shallow marsh areas of varying depths with wetland vegetation;

- Permanent micropool; and,
- Overlying zone in which runoff control volumes are stored.

- Pond/wetland systems also include a stormwater pond facility (see Section 3.2.1 for pond design information).
- In addition, all wetland designs must include a sediment forebay or equivalent upstream pre-treatment (providing a volume of 0.1 inch over the contributing impervious area) at the inflow to the facility to allow heavier sediments to drop out of suspension before the runoff enters the wetland marsh. The pre-treatment storage volume is part of the total WQ_v.
- Wetlands functioning as flood control facilities located in floodplains or backwater areas must perform as specified for peak flow control for any tailwater condition, up to the Base Flood Elevation (BFE). The potential for back flow into the pond must be addressed with flap gates or by providing sufficient volume to receive backflow up to the BFE, and still provide peak flow control surcharge volume in the pond (above the BFE).
- Additional wetland design features include an emergency spillway, maintenance access, safety bench, wetland buffer, and appropriate wetland vegetation and native landscaping.

Figure 3-41 through Figure 3-43 provide plan and profile schematics for the design of a shallow wetland, extended detention shallow wetland and pond/wetland system, respectively.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

In general, wetland designs are unique for each site and application. However, there are a number of geometric ratios and limiting depths for the design of a stormwater wetland that must be observed for adequate pollutant removal, ease of maintenance, and improved safety. Table 3-8 provides the recommended physical specifications and geometry for the various stormwater wetland design variants, (Schueler, 1992).

Table 3-8 Recommended Design Criteria for Stormwater Wetlands

Design Criteria	Shallow Wetland	ED Shallow Wetland	Pond/Wetland
Length to Width Ratio (minimum)	2:1	2:1	2:1
Extended Detention (ED)	No	Yes	Optional
Allocation of WQv Volume (pool/marsh/ED) in %	25/75/0	25/25/50	70/30/0 (includes pond volume)
Allocation of Surface Area (deepwater/low marsh/high marsh/semi-wet) in %	20/35/40/5	10/35/45/10	45/25/25/5 (includes pond surface area)
Forebay/Upstream Pretreatment	Required	Required	Required

Design Criteria	Shallow Wetland	ED Shallow Wetland	Pond/Wetland
Micropool	Required	Required	Required
Outlet Configuration	Reverse-slope pipe or hooded broad-crested weir	Reverse-slope pipe or hooded broad-crested weir	Reverse-slope pipe or hooded broad-crested weir

- The stormwater wetland should be designed with the recommended proportion of “depth zones.” Each of the three wetland design variants has depth zone allocations which are given as a percentage of the stormwater wetland surface area. Target allocations are found in Table 3-8. The four basic depth zones are:

Deepwater zone

From 1.5 to 6 feet deep. Includes the outlet micropool and deepwater channels through the wetland facility. This zone supports little emergent wetland vegetation, but may support submerged or floating vegetation.

Low marsh zone

From 6 to 18 inches below the normal permanent pool or water surface elevation. This zone is suitable for the growth of several emergent wetland plant species.

High marsh zone

From 6 inches below the pool to the normal pool elevation. This zone will support a greater density and diversity of wetland species than the low marsh zone. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone.

Semi-wet zone

Those areas above the permanent pool that are inundated during larger storm events. This zone supports a number of species that can survive flooding.

- A minimum dry weather flow path of 2:1 (length to width) is required from inflow to outlet across the stormwater wetland and should ideally be greater than 3:1. This path may be achieved by constructing internal dikes or berms, using marsh plantings, and by using multiple cells. Finger channels are commonly used in surface flow systems to create serpentine configurations and prevent short-circuiting. Microtopography (contours along the bottom of a wetland or marsh that provide a variety of conditions for different species needs and increases the surface area to volume ratio) is encouraged to enhance wetland diversity.
- A 4 to 6 foot deep micropool must be included in the design at the outlet to prevent the outlet from clogging and resuspension of sediments, and to mitigate thermal effects.

- Maximum depth of any permanent pool areas should generally not exceed 6 feet.
- The volume of the extended detention must not comprise more than 50% of the total WQ_v, and its maximum water surface elevation must not extend more than 3 feet above the normal pool. Q_p and/or CP_v storage can be provided above the maximum WQ_v elevation within the wetland.
- The perimeter of all deep pool areas (4 feet or greater in depth) should be surrounded by safety and aquatic benches similar to those for stormwater ponds (see Section 3.2.1).
- The contours of the wetland should be irregular to provide a more natural landscaping effect.

D. PRETREATMENT / INLETS

- Sediment regulation is critical to sustain stormwater wetlands. A wetland facility should have a sediment forebay or equivalent upstream pretreatment. A sediment forebay is designed to remove incoming sediment from the stormwater flow prior to dispersal into the wetland. The forebay should consist of a separate cell, formed by an acceptable barrier. A forebay is to be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the wetland facility.
- The forebay is sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4 to 6 feet deep. The pretreatment storage volume is part of the total WQ_v requirement and may be subtracted from WQ_v for wetland storage sizing.
- A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment deposition over time. The bottom of the forebay may be hardened (e.g., using concrete, paver blocks, etc.) to make sediment removal easier.
- Pipes or channels discharging into the wetland are to be stabilized with flared riprap aprons, or the equivalent. Inlet pipes to the pond can be partially submerged. Inflow pipe discharge, channel velocities and exit velocities from the forebay must be nonerosive.

E. OUTLET STRUCTURES

- Flow control from a stormwater wetland is typically accomplished with the use of a riser and barrel principal spillway. The riser is a vertical pipe or inlet structure that is attached to the base of the micropool with a watertight connection. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment (see Figure 3-40). The riser should be located within the embankment for maintenance access, safety, and aesthetics.
- A number of outlets at varying depths in the riser provide internal flow control for routing of the water quality protection, channel protection, and flood control runoff volumes. The number of orifices can vary and is a function of the pond design requirements.
- For shallow wetlands, the riser configuration is typically comprised of a channel protection outlet (usually an orifice) and flood control outlet (often a slot or weir). The channel protection orifice is sized to detain the channel protection storage volume for 24 hours. Since the WQ_V is fully contained in the permanent pool, no orifice sizing is necessary for

this volume. As runoff from a water quality event enters the wet pond, it simply displaces that same volume through the channel protection orifice. Thus an off-line shallow wetland providing only water quality treatment can use a simple overflow weir as the outlet structure.

- In the case of an extended detention (ED) shallow wetland, there is generally a need for an additional outlet (usually an orifice) that is sized to pass the extended detention WQ_V that is surcharged on top of the permanent pool. Flow will first pass through this orifice, which is sized to detain the water quality extended detention volume for 24 hours. The preferred design is a reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond. The next outlet is sized for the release of the channel protection storage volume. The outlet (often an orifice) invert is located at the maximum elevation associated with the extended detention WQ_V and is sized to detain the channel protection storage volume for 24 hours.
- Alternative hydraulic control methods to an orifice can be used and include the use of a broad-crested rectangular, V-notch, proportional weir, or an outlet pipe protected by a hood that extends at least 12 inches below the normal pool.

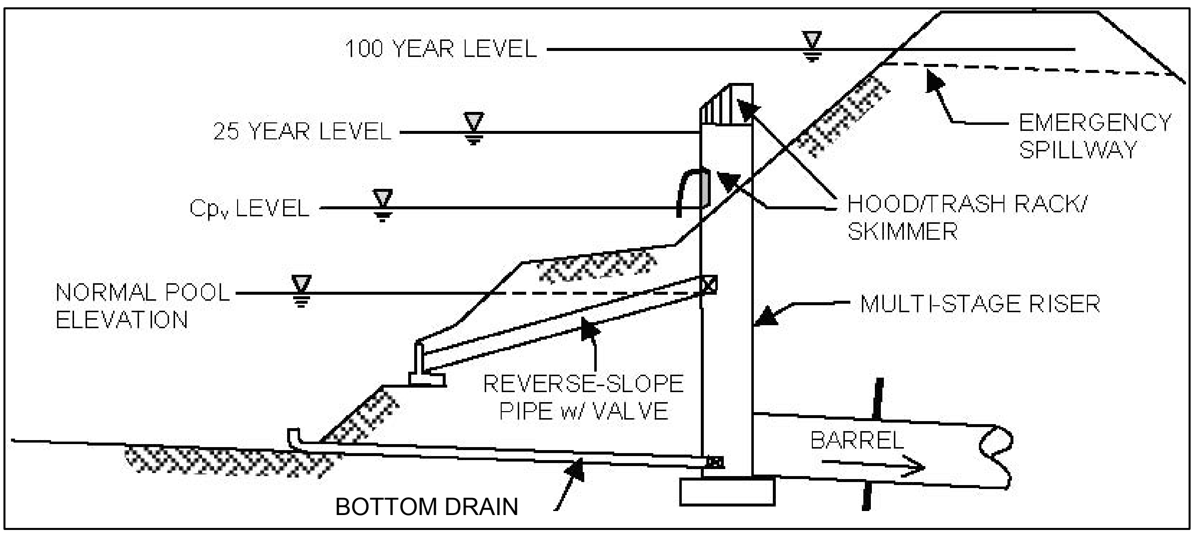

Figure 3-40 Typical Wetland Facility Outlet Structure

- The water quality outlet (if design is for an extended detention shallow wetland) and channel protection outlet may be fitted with adjustable gate valves or other mechanism that can be used to adjust detention time.
- Higher flows pass through openings or slots protected by trash racks further up on the riser.
- After entering the riser, flow is conveyed through the barrel and is discharged downstream. Anti-seep collars should be installed on the outlet barrel to reduce the potential for pipe failure.

- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the outlet of the barrel to prevent scouring and erosion. If a wetland facility daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance.
- The wetland facility may have a bottom drain pipe located in the micropool with an adjustable valve that can dewater the wetland within 24 hours. The bottom drain is optional. It is recommended to check with the local jurisdiction to see if a bottom drain is required.
- The bottom drain should be sized one pipe size greater than the calculated design diameter. The drain valve is typically a handwheel activated knife or gate valve. Valve controls shall be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner.

See the design procedures in Volume 2, Chapters 4 and 5 for additional information on pond routing and outlet works.

F. EMERGENCY SPILLWAY

- An emergency spillway is to be included in the stormwater wetland design to safely pass flows that exceed the design storm flows. The spillway prevents the wetland's water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the 100-year flood to the lowest point on top of the dam, not counting the emergency spillway. The 100-year flood elevation for emergency spillway design is based on the elevation required to pass the 100-year flow with no discharge through the principal spillway.

G. MAINTENANCE ACCESS

- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- When required, the maintenance access must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.
- Access to the riser is to be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

H. SAFETY FEATURES

- All embankments and spillways must be designed to Kansas dam safety regulations, when applicable.
- Fencing may be required for safety. A preferred method is to manage the contours of deep pool areas through the inclusion of a safety bench (see above) to eliminate dropoffs and reduce the potential for accidental drowning.
- The principal spillway opening should not permit access by small children, and endwalls above pipe outfalls greater than 36 inches in diameter should be fenced to prevent a fall hazard.

I. LANDSCAPING

- A landscaping plan should be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of landscaping zones, selection of corresponding plant species, planting plan, sequence for preparing wetland bed (including soil amendments, if needed), and sources of plant material.
- Landscaping zones include low marsh, high marsh, and semi-wet zones. The low marsh zone ranges from 6 to 18 inches below the normal pool. This zone is suitable for the growth of several emergent plant species. The high marsh zone ranges from 6 inches below the pool up to the normal pool. This zone will support greater density and diversity of emergent wetland plant species. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone. The semi-wet zone refers to those areas above the permanent pool that are inundated on an irregular basis and can be expected to support wetland plants.
- The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers.
- Woody vegetation may not be planted on a dam embankment or allowed to grow within 15 feet of the toe of the dam and 25 feet from the principal spillway structure (tree exclusion area).
- A wetland buffer shall extend 25 feet outward from the maximum water surface elevation, with an additional 15 foot setback to structures. The wetland buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers) or that are part of the overall stormwater management concept plan.
- Existing trees should be preserved in the buffer area during construction unless they would infringe on the tree exclusion area. It is desirable to locate vegetated conservation areas adjacent to ponds. To discourage resident water fowl populations, the buffer can be planted with trees, shrubs and native ground covers if not in the tree exclusion area.
- The soils of a wetland buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration and therefore may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed

planting sites and backfill these with uncompacted topsoil. However, these features must not be located within the tree exclusion area, and must not violate the groundwater clearance requirements.

J. ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

Low Relief: Providing wetland drain can be problematic.

High Relief: Embankment heights restricted

Karst: Requires poly or clay liner to sustain a permanent pool of water and protect aquifers; limits on ponding depth; geotechnical tests may be required.

Soils

- Hydrologic group ‘A’ soils and some group ‘B’ soils may require liner.

Special Downstream Watershed Considerations

Aquifer Protection: Inflow of untreated hotspot runoff not permitted. May require liner for type “A” and some “B” soils. Five foot minimum clearance above historical high groundwater for unlined wetlands, 2 feet for lined.

3.2.10.6 Design Procedures

Step 1 Compute runoff control volumes from the integrated design approach.

Calculate the WQ_v. See Chapter 1 and Chapter 4.

Step 2 Confirm local design criteria and applicability.

Consider any special site-specific design conditions/criteria.

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3 Determine pretreatment volume

A sediment forebay is provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. The forebay should be sized to contain 0.1 acre-inch per impervious acre of contributing drainage and should be 4 to 6 feet deep. The forebay storage volume counts toward the total WQ_v requirement and may be subtracted from the WQ_v for subsequent calculations.

Step 4 Allocate the WQv volume among marsh, micropool, and extended detention volumes.

Use recommended criteria from Table 3-8.

Step 5 Determine wetland location and preliminary geometry, including distribution of wetland depth zones.

This step involves initially laying out the wetland design and determining the distribution of wetland surface area among the various depth zones (high marsh, low marsh, and deepwater). Set WQ_v permanent pool elevation (and WQ_v-ED elevation for extended detention shallow wetland) based on volumes calculated earlier.

Step 6 Compute extended detention orifice release rate(s) and size(s), and establish CP_v elevation.

Shallow Wetland: The CP_v elevation is determined from the stage-storage relationship and the orifice is then sized to release the channel protection storage volume over a 24 hour period. The channel protection orifice shall be adequately protected from clogging by an acceptable treatment as shown in Chapter 5, or a similar treatment at the discretion of the site engineer. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool is a recommended design.

ED Shallow Wetland: Based on the elevations established in Step 5 for the extended detention portion of the WQ_V, the water quality orifice is sized to release this extended detention volume in 24 hours. The water quality orifice shall be adequately protected from clogging by an acceptable treatment as shown in Chapter 5, or a similar treatment at the discretion of the site engineer. A reverse slope pipe attached to the riser, with its inlet submerged one foot below the elevation of the permanent pool, is a recommended design. The CP_v elevation is then determined from the stage-storage relationship. The invert of the channel protection orifice is located at the water quality extended detention elevation, and the orifice is sized to release the channel protection storage volume over a 24 hour period.

Step 7 Calculate the flood control release rates and water surface elevations.

Set up a stage-storage-discharge relationship for the control structure for the extended detention orifice(s) and the flood control storms. Route floods through facility and adjust accordingly to achieve peak flow control.

Step 8 Design embankment(s) and spillway(s).

Size the emergency spillway by routing 100-year flood through the spillway in accordance with the previously discussed criteria. Set the top of dam elevation based on a minimum of 1 foot of freeboard.

At final design, provide safe passage for the 100-year event.

Step 9 Investigate potential pond/wetland hazard classification.

The design and construction of stormwater management ponds and wetlands are required to follow the latest version of the State of Kansas dam safety regulations, where applicable.

Step 10 Design inlets, sediment forebay(s), outlet structures, maintenance access, and safety features.

Step 11 Prepare Vegetation and Landscaping Plan

A landscaping plan for the wetland facility and its buffer should be prepared to indicate how aquatic and terrestrial areas will be stabilized and established with vegetation.

3.2.10.7 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the wetland and also clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.2.10.8 Example Schematics

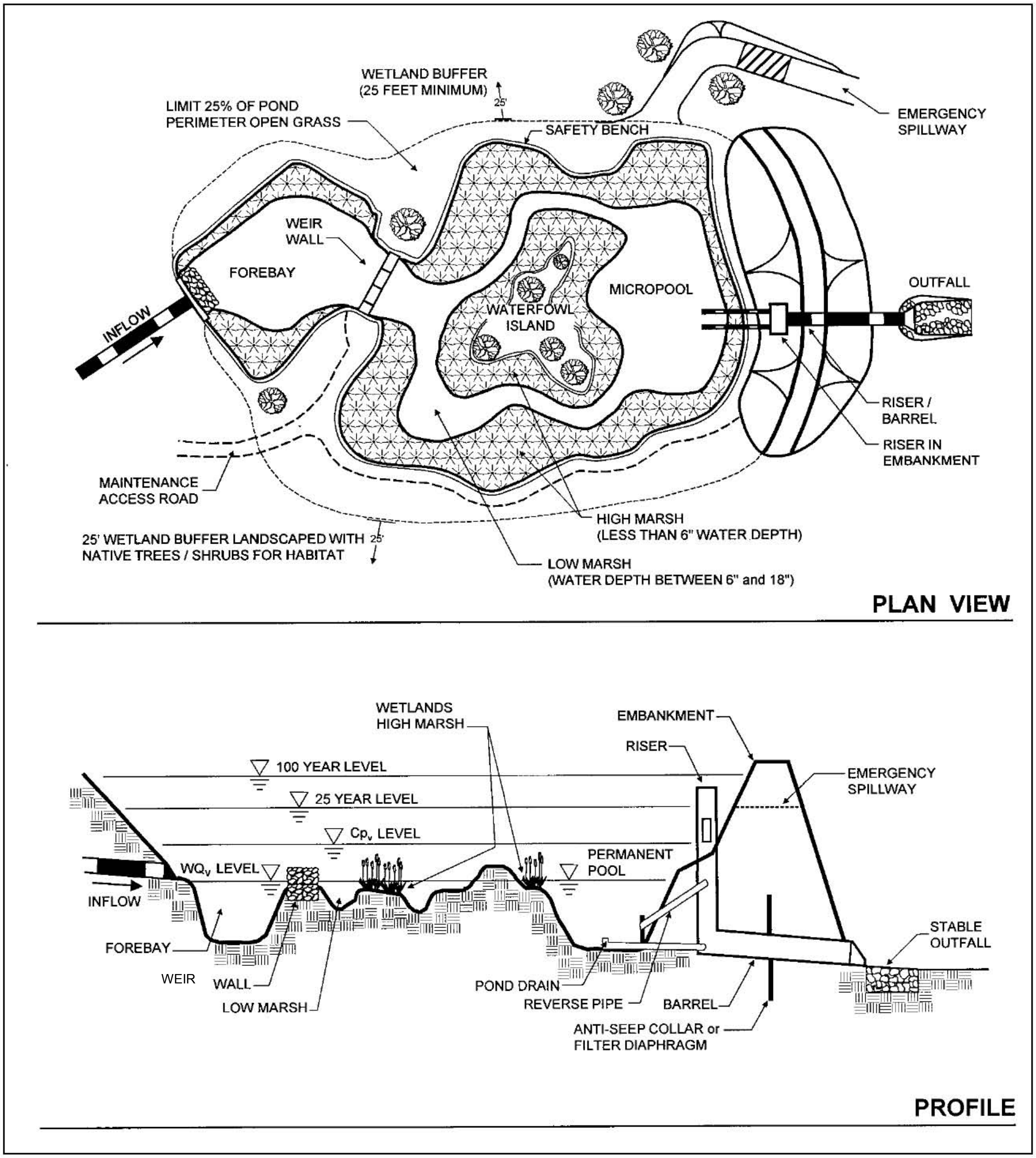

Figure 3-41 Schematic of Shallow Wetland
(MSDM, 2000)

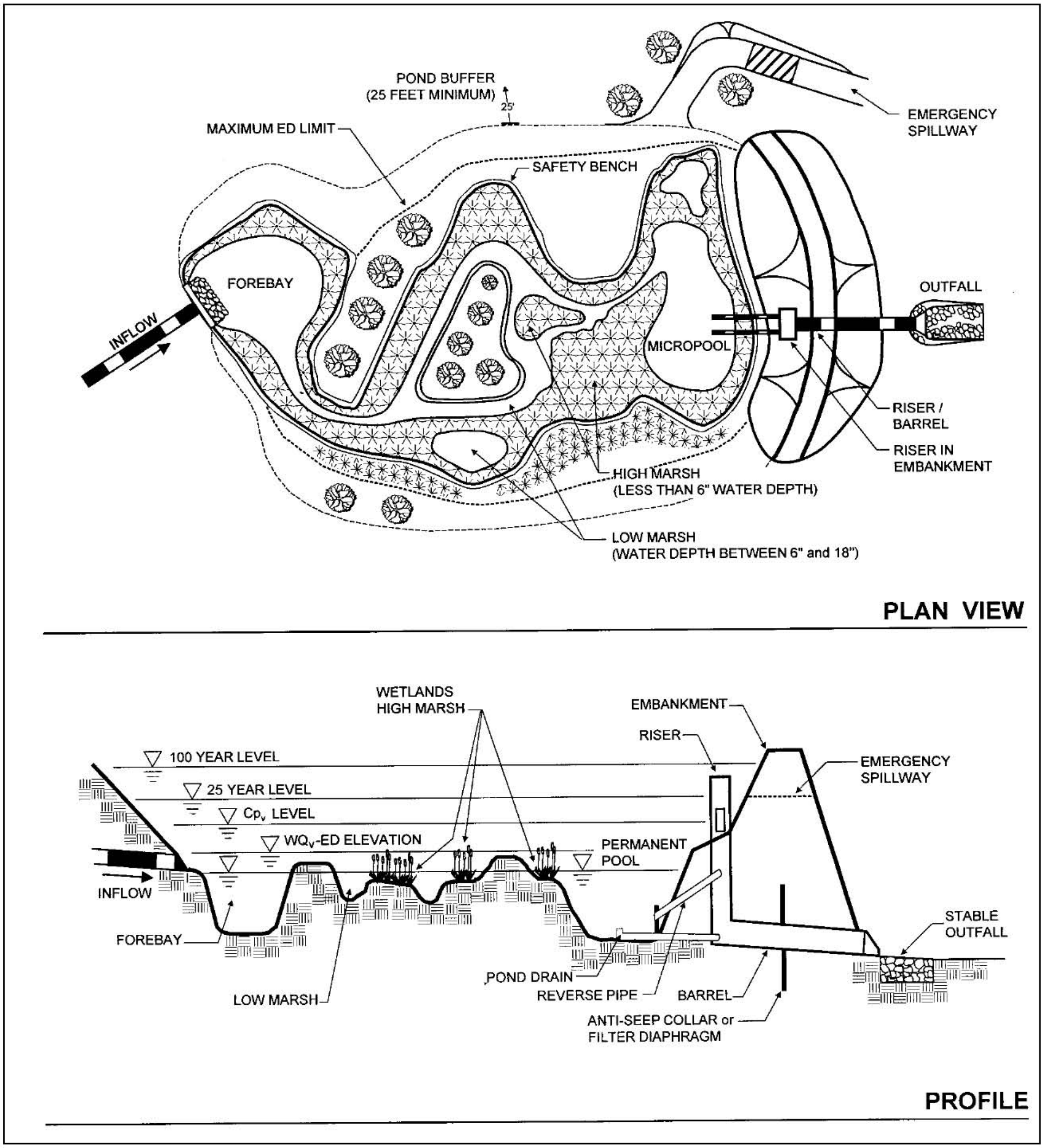

Figure 3-42 Schematic of Extended Detention Shallow Wetland
(MSDM, 2000)

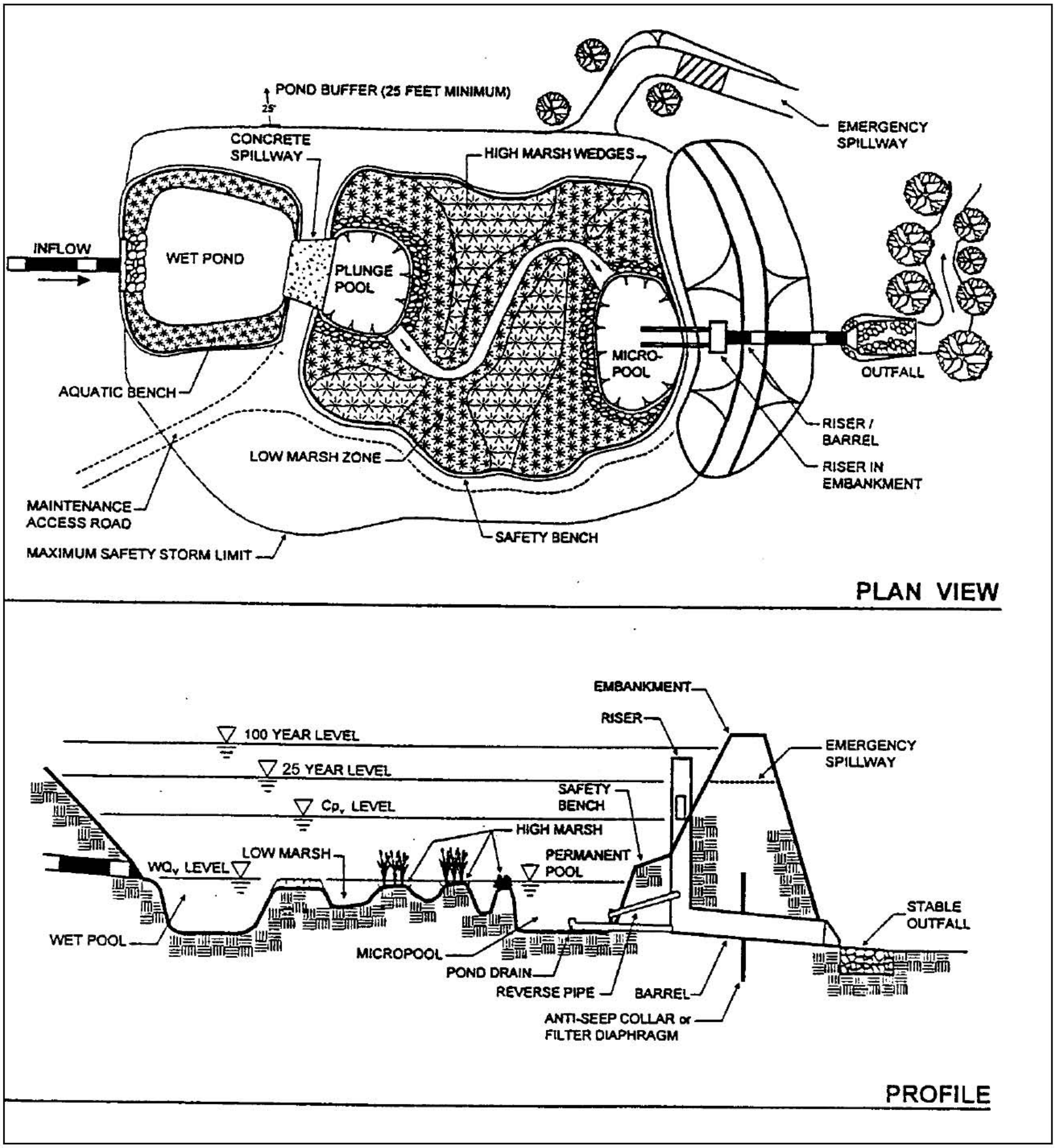

Figure 3-43 Schematic of Pond/Wetland System
(MSDM, 2000)

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3.3 Secondary TSS Treatment Facilities

This section contains design guidelines for the following TSS treatment facilities:

- Proprietary Treatment Systems
- Gravity (Oil-Water) Separator
- Alum Treatment
- Underground Sand Filter
- Organic Filter

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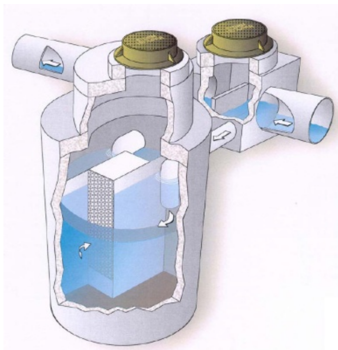
3.3.1 Proprietary Treatment Systems

Secondary Water Quality Facility



Description: Manufactured structural control systems available from commercial vendors designed to treat stormwater runoff.

Example of a manhole media filtration system (Park Environmental Equipment)

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Independent performance data must be available to prove a demonstrated capability of meeting claimed TSS removal performance
- System or device must be appropriate for use in Sedgwick County, Kansas conditions

ADVANTAGES / BENEFITS:

- Typically small space requirement
- Can often remove coarse sediments well

DISADVANTAGES / LIMITATIONS:

- Depending on the proprietary system, there may be:
  - Limited performance data;
  - Application constraints such as poor removal of fine sediment;
  - High maintenance requirements;
  - Higher costs than other structural control alternatives.
- Installation and operations/maintenance requirements must be understood by all parties approving, owning, using and maintaining the system or device in question

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Water Quality Protection**
- ☐ **Channel Protection**
- ☐ **On-Site Flood Control**
- ☐ **Downstream**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *Depends on the specific proprietary structural control*

High Density/Ultra-Urban: *Yes*

Drainage Area: *Depends on the specific proprietary structural control*

Soils: *No restrictions*

L=Low **M**=Moderate **H**=High

Note: *It is the policy of this Manual not to recommend any specific commercial vendors for proprietary systems. However, this section is being included in order to provide a base rationale for approving the use of a proprietary system or practice.*

3.3.1.1 General Description

There are many types of commercially-available proprietary stormwater structural controls available for water quality treatment. These systems include:

- Hydrodynamic systems such as gravity and vortex separators;
- Filtration systems;
- Catch basin media inserts;
- Chemical treatment systems; and,
- Package treatment plants.

Many proprietary systems are useful on small sites and space-limited areas where there is not enough land or room for other structural control alternatives. Proprietary systems can often be used in pretreatment applications in a treatment train. However, proprietary systems are often more costly than other alternatives and may have high maintenance requirements. Perhaps the most common difficulty in using a proprietary system is the lack of adequate independent performance data, particularly for use in south-central Kansas. Below are general guidelines that should be followed before considering the use of a proprietary commercial system.

3.3.1.2 Guidelines for Using Proprietary Systems

In order for use as a control, a proprietary system must have a demonstrated capability of meeting the stormwater management goals for which it is being intended. This means that the system must provide:

- Independent third-party scientific verification of the ability of the proprietary system to meet claimed water quality treatment performance;
- Proven record of longevity in the field;
- Proven ability to function in Sedgwick County, Kansas conditions (e.g., climate, rainfall patterns, soil types, etc.) or in satisfactorily similar conditions; and,
- Maintainability - Documented procedures for required maintenance including collection and removal of pollutants or debris, and no reliance on specially manufactured or proprietary materials/devices for long-term maintenance of the facility.

For a proprietary system to meet the above, the following monitoring criteria must be met for supporting studies:

- At least 15 storm events must be sampled;
- The study must be independent or independently verified (i.e., may not be conducted by the vendor or designer);

- The study must be conducted in the field, as opposed to laboratory testing;
- Field monitoring must be conducted using standard protocols which require proportional sampling both upstream and downstream of the device;
- Concentrations reported in the study must be flow-weighted; and,
- The propriety system or device must have been in place for at least one year at the time of monitoring.

Although local data is preferred, data from other regions can be accepted as long as the design accounts for the local conditions.

3.3.1.3 Other Requirements

- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

3.3.1.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. “Covenants for Permanent Maintenance of Stormwater Management Facilities” (also called the “Maintenance Covenants”). An example covenants document can be found in Volume 3.
2. “Inspection Checklist and Maintenance Guidance” for each type of stormwater facility that is located on the property. Detailed inspection and maintenance guidance must be prepared by the manufacturer or design engineer.
3. As-built drawings must accurately show the location of the facility, and clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

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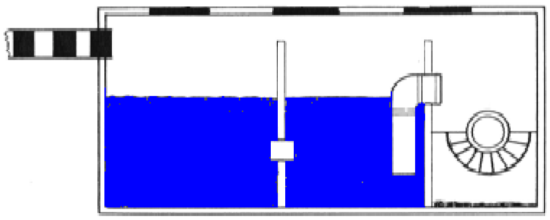
3.3.2 Gravity (Oil-Water) Separator

Secondary Water Quality Facility



Description: Hydrodynamic separation device designed to remove settleable solids, oil and grease, debris, and floatables from stormwater runoff through gravitational settling and trapping of pollutants.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for hotspot, space-limited, or pretreatment applications
- Intended for the removal of settleable solids (grit and sediment) and floatable matter, including oil and grease
- Performance dependent on design and frequency of inspection and cleanout of unit

DISADVANTAGES / LIMITATIONS:

- Usually cannot alone achieve the 80% TSS removal target
- Limited performance data
- Dissolved pollutants are not effectively removed

MAINTENANCE REQUIREMENTS:

- Frequent maintenance required

POLLUTANT REMOVAL

Varies	**Total Suspended Solids**
Varies	**Nutrients –** Total Phosphorus & Total Nitrogen
No Data	**Metals –** Cadmium, Copper, Lead & Zinc
No Data	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

- [✓] **Water Quality Protection**
- [ ] **Channel Protection**
- [ ] **On-Site Flood Control**
- [ ] **Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *1 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Hotspot areas*
- *Pretreatment*

L=Low **M**=Moderate **H**=High

3.3.2.1 General Description

Gravity separators (also known as oil-water separators) are hydrodynamic separation devices that are designed to remove grit and heavy sediments, oil and grease, debris, and floatable matter from stormwater runoff through gravitational settling and trapping. Gravity separator units contain a permanent pool of water and typically consist of an inlet chamber, separation/storage chamber, a bypass chamber, and an access port for maintenance purposes. Runoff enters the inlet chamber where heavy sediments and solids drop out. The flow moves into the main gravity separation chamber, where further settling of suspended solids takes place. Oil and grease are skimmed and stored in a waste oil storage compartment for future removal. After moving into the outlet chamber, the clarified runoff is then discharged.

The performance of these systems is based primarily on the relatively low solubility of petroleum products in water and the difference between the specific gravity of water and the specific gravities of petroleum compounds. Gravity separators are not designed to separate other products such as solvents, detergents, or dissolved pollutants. The typical gravity separator unit may be enhanced with a pretreatment swirl concentrator chamber, oil draw-off devices that continuously remove the accumulated light liquids, and flow control valves regulating the flow rate into the unit.

Gravity separators are best used in commercial, industrial, and transportation landuse areas and are intended primarily as a pretreatment measure for high-density or ultra urban sites, or for use in hydrocarbon hotspots, such as gas stations and areas with high vehicular traffic. However, gravity separators cannot be used for the removal of dissolved or emulsified oils and pollutants such as coolants, soluble lubricants, glycols, and alcohols.

Since re-suspension of accumulated sediments is possible during heavy storm events, gravity separator units are typically installed off-line. Gravity separators are available as prefabricated proprietary systems from a number of different commercial vendors.

3.3.2.2 Pollutant Removal Capabilities

Testing of gravity separators has shown that they can remove between 40 and 50% of the TSS loading when used in an off-line configuration (Curran, 1996 and Henry, 1999). Gravity separators also provide removal of debris, hydrocarbons, trash and other floatables. They provide only minimal removal of nutrients and organic matter.

The following design pollutant removal rates are achievable pollutant reduction percentages for planning purposes derived from sampling data, modeling and professional judgment. Actual design values will depend on the specific facility design. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach.

- Total Suspended Solids – 40% (varies by device)
- Total Phosphorus – 5% (varies by device)

- Total Nitrogen – 5% (varies by device)
- Heavy Metals – insufficient data
- Fecal Coliform – insufficient data

Actual field testing data and pollutant removal rates from an independent source should be obtained before using a proprietary gravity separator system.

3.3.2.3 Design Criteria and Specifications

- The use of gravity (oil-water) separators should be limited to the following applications:
  - Pretreatment for other structural stormwater controls;
  - High-density, ultra urban or other space-limited development sites;
  - Hotspot areas where the control of grit, floatables, and/or oil and grease are required.
- Gravity separators are typically used for areas less than 5 acres. It is recommended that the contributing area to any individual gravity separator be limited to 1 acre or less of impervious cover.
- Gravity separator systems can be installed in almost any soil or terrain. Since these devices are underground, appearance is not an issue and public safety risks are low.
- Gravity separators are flow rate based devices. This contrasts with most other stormwater structural controls, which are sized based on capturing and treating a specific volume.
- Gravity separator units are typically designed to bypass runoff flows in excess of the design flow rate. Some designs have built-in high flow bypass mechanisms. Other designs require a diversion structure or flow splitter ahead of the device in the drainage system. An adequate outfall must be provided.
- The separation chamber should provide for three separate storage volumes:
  - A volume for separated oil storage at the top of the chamber;
  - A volume for settleable solids accumulation at the bottom of the chamber;
  - A volume required to give adequate flow-through detention time for separation of oil and sediment from the stormwater flow.
- The total wet storage of the gravity separator unit should be at least 400 cubic feet per contributing impervious acre.
- The minimum depth of the permanent pools should be 4 feet.
- Horizontal velocity through the separation chamber should be 1 to 3 ft/min or less. No velocities in the device should exceed the entrance velocity.
- A trash rack should be included in the design to capture floating debris, preferably near the inlet chamber to prevent debris from becoming oil impregnated.

- Ideally, a gravity separator design will provide an oil draw-off mechanism to a separate chamber or storage area.
- Adequate maintenance access to each chamber must be provided for inspection and cleanout of a gravity separator unit.
- Gravity separator units should be watertight to prevent possible groundwater contamination.
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The design criteria and specifications of a proprietary gravity separator unit should be obtained from the manufacturer.

3.3.2.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately show the location of the facility, and clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.3.2.5 Example Schematic

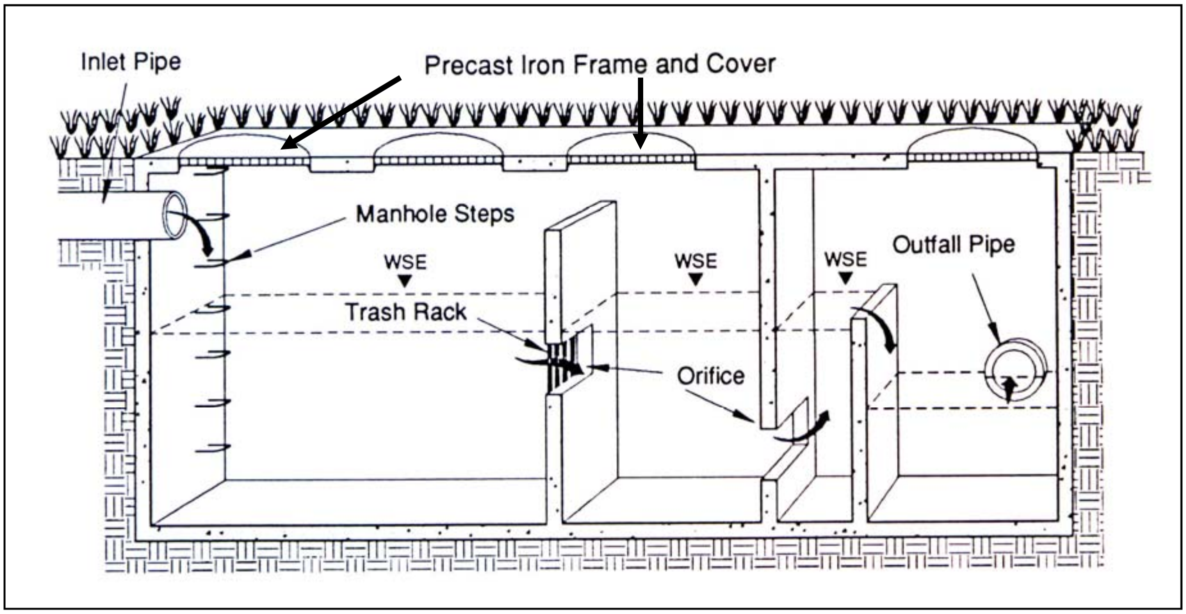


Figure 3-44 Schematic of an Example Gravity (Oil-Water) Separator
(NVRC, 1992)

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3.3.3 Alum Treatment

Secondary Water Quality Facility

Description: Chemical treatment of stormwater runoff entering a wet pond by injecting liquid alum into storm sewer lines on a flow-weighted basis during rain events.

KEY CONSIDERATIONS

ADVANTAGES / BENEFITS:

- Reduces concentrations of total suspended sediments, phosphorus, and heavy metals

DISADVANTAGES / LIMITATIONS:

- Dependent on pH level ranging from 6.0 to 7.5 during treatment process
- Intended for areas requiring large-scale stormwater treatment from a piped stormwater drainage system
- High maintenance requirements
- Alum application will lower pH of receiving waters
- High capital and operations and maintenance costs

MAINTENANCE REQUIREMENTS:

- Adjust dosage to ensure proper dosage and delivery of runoff to the settling pond
- Dredge settling pond and properly dispose of accumulated floc

POTENTIAL* POLLUTANT REMOVAL

H	**Total Suspended Solids**
H/M	**Nutrients –** Total Phosphorus & Total Nitrogen
H	**Metals –** Cadmium, Copper, Lead & Zinc
H	**Pathogens –** Coliform, Streptococci & E. Coli

*Depends On Specific Installation

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Water Quality Protection**
- ☐ **Channel Protection**
- ☐ **On-Site Flood Control**
- ☐ **Downstream Flood Control**

Accepts Hotspot Runoff: *Yes, For Lined Off-line Ponds*

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *25 acres min.*

Soils: *No restrictions*

Other Considerations:

- *Regional Treatment*

L=Low **M**=Moderate **H**=High

3.3.3.1 General Description

The process of alum (aluminum sulfate) treatment provides treatment of stormwater runoff from a piped stormwater drainage system entering a wet pond or basin by injecting liquid alum into storm sewer lines on a flow-weighted basis during rain events. When added to runoff, liquid alum forms nontoxic precipitates of aluminum hydroxide [$Al(OH)_3$] and aluminum phosphate [$AlPO_4$]. However, alum will lower the pH of receiving waters and must be closely monitored to avoid adverse impacts on aquatic life.

The alum precipitate or "floc" formed during coagulation of stormwater combines with phosphorus, suspended solids, and heavy metals and removes them from the water column. Once settled, the floc is stable in sediments and will not re-dissolve due to changes in redox potential or pH under conditions normally found in surface water bodies. Laboratory or field testing may be necessary to verify feasibility and to establish design, maintenance, and operational parameters, such as the optimum coagulant dose required to achieve the desired water quality goals, chemical pumping rates, and pump sizes.

The capital construction costs of alum stormwater treatment systems is less independent of watershed size and more dependent on the number of outfall locations treated.

Estimated annual operations and maintenance (O&M) costs include chemical, power, manpower for routine inspections, equipment renewal, and replacement costs.

Ferric chloride has also been used for flow-proportional injection for removing phosphorus and other pollutants. Although ferric chloride is less toxic to aquatic life than alum, it has a number of significant disadvantages. Ferric chloride dosage rates are dependent on the pollutant concentrations in the stormwater runoff, unlike alum. Ferric chloride does not form a floc that settles out suspended pollutants. And, once settled, ferric chloride may be released from sediments under anaerobic conditions.

3.3.3.2 Pollutant Removal Capabilities

Alum treatment has consistently achieved a 85 to 95% reduction in total phosphorus, 90 to 95% reduction in orthophosphorus, 60 to 70% reduction in total nitrogen, 50 to 90% reduction in heavy metals, 95 to 99% reduction in turbidity and TSS, 60% reduction in BOD, and >99% reduction in fecal coliform bacteria compared with raw stormwater characteristics.

The following design pollutant removal rates are achievable reduction percentages for planning purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach. Actual removal rates will depend on the specific installation design.

- Total Suspended Solids – 90%
- Total Phosphorus – 80%

- Total Nitrogen – 60%
- Heavy Metals – 75%
- Fecal Coliform – 90%

3.3.3.3 Design Criteria and Specifications

Alum treatment systems are fairly complex, and design details are beyond the scope of this manual. However, further information can be obtained by contacting local municipalities and engineers who have designed and implemented successful systems. The following are general guidelines for alum treatment systems:

- Injection points should be 100 feet upstream of discharge points;
- Alum concentration is typically 10 μg/l;
- Alum treatment systems may need to control pH;
- For pond design, the required size is approximately 1% of the drainage basin size, as opposed to 2-5% of the drainage basin area for a standard detention pond;
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

3.3.3.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

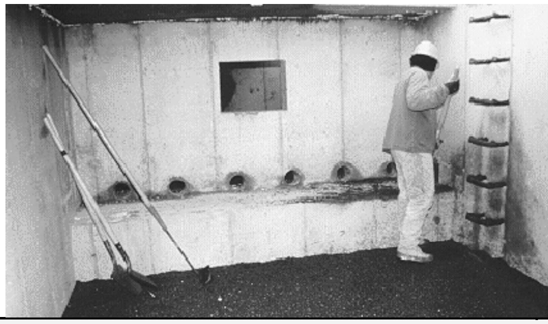
1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the facility, and also clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

Figure 3-45 Alum Treatment System and Injection Equipment

3.3.4 Underground Sand Filter

Secondary Water Quality Facility



Description: The underground sand filter is a design variation of the surface sand filter, where the sand filter chambers and media are located in an underground vault.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Maximum contributing drainage area of 2 acres
- Typically requires 2 to 6 feet of head
- Precast concrete shells available, which decrease construction costs
- Underdrain required

ADVANTAGES / BENEFITS:

- High pollutant removal
- Applicable to small drainage areas
- Good for highly impervious areas
- Good retrofit capability

DISADVANTAGES / LIMITATIONS:

- High maintenance burden
- Not recommended for areas with high sediment content in stormwater or clay/silt runoff areas
- Cannot be installed until site construction is complete
- Possible odor problems

MAINTENANCE REQUIREMENTS:

- Inspect for clogging – rake first inch of sand
- Remove sediment from forebay/chamber
- Replace sand filter media as needed

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total
M	**Metals –** Cadmium, Copper, Lead & Zinc
M	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

- [x] **Water Quality Protection**
- [x] **Channel Protection**
- [ ] **On-Site Flood Control**
- [ ] **Downstream Flood**

Accepts Hotspot Runoff: *Yes*

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *2 acres maximum*

Soils: *Not recommended for clay/silt drainage areas that are not stabilized*

Other Considerations:

- *Typically needs to be combined with other controls to provide water quantity control*

L=Low **M**=Moderate **H**=High

3.3.4.1 General Description

The underground sand filter is a design variant of the surface sand filter. The underground sand filter is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area such as a parking lot. The system consists of a sedimentation chamber and a sand bed filter. Runoff flows into the structure through a series of inlet grates located along the top of the control. Underground sand filters are best used for high-density land uses or ultra-urban applications where space for surface stormwater controls is limited. Figure 33 presents an example of an underground sand filter.

Figure 3-46 Example of an Underground Sand Filter

Multiple configurations have been developed for underground filters including the DC filter and the Delaware filter. The DC filter is intended to treat stormwater that is conveyed by a storm drain system. The Delaware filter (also known as the perimeter sand filter) is designed to collect flow directly from impervious surfaces and is well suited for installation along parking areas. Both systems operate in the same manner.

The underground sand filter is a three-chamber system. The initial chamber is a sedimentation (pretreatment) chamber that temporarily stores runoff and utilizes a wet pool to capture sediment. The sedimentation chamber is connected to the sand filter chamber by a submerged wall that protects the filter bed from oil and trash. The filter bed is 18 to 24 inches deep and may have a protective screen of gravel or permeable geotextile to limit clogging. The sand filter chamber also includes an underdrain system with inspection and clean out wells. Perforated drain pipes under the sand filter bed extend into a third chamber that collects filtered runoff. Flows beyond the filter capacity are diverted through an overflow weir.

Due to its location below the surface, underground sand filters have a high maintenance burden and should only be used where adequate inspection and maintenance can be ensured.

3.3.4.2 Stormwater Management Suitability

Underground sand filter systems are designed primarily as off-line systems for treatment of the water quality volume and will typically need to be used in conjunction with another structural BMP that can provide downstream channel protection, overbank flood protection, and extreme flood protection. However, under certain circumstances, underground sand filters can provide limited runoff quantity control, particularly for smaller storm events.

Water Quality (WQv)
In underground sand filter systems, stormwater pollutants are removed through a combination of gravitational settling, filtration and adsorption. The filtration process effectively removes suspended solids and particulates, biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants.

Channel Protection (CPv)
For smaller sites, an underground sand filter may be designed to capture the entire channel protection volume (CPv) in either an off- or on-line configuration. Given that an underground sand filter system is typically designed to completely drain over 40 hours, the channel protection design requirement for extended detention of the 1-year, 24-hour storm runoff volume can be met. For larger sites or where only the WQv is diverted to the underground sand filter facility, another structural control must be used to provide extended detention of the CPv.

Overbank Flood Protection (up to Qp25) and Extreme Flood Protection (Qp100)
Underground sand filters are not useful for flood protection. Another structural control, such as a conventional detention pond, must be used in conjunction with an underground sand filter system to control stormwater peak discharges. Further, underground sand filter facilities utilized on-line must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the filter bed and facility.

3.3.4.3 Pollutant Removal Capabilities

Underground sand filters are presumed to be able to remove 80% of the total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed underground sand filters can reduce TSS removal performance.

Additionally, research has shown that use of underground sand filters will have benefits beyond the removal of TSS, such as the removal of other pollutants (i.e. phosphorous, nitrogen, fecal coliform and heavy metals), as well, which is useful information should the pollutant removal criteria change in the future. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data.

- Total Suspended Solids – 80%
- Total Phosphorus – 50%
- Total Nitrogen – 30%
- Heavy Metals – 50%
- Pathogens – 40%

For additional information and data on pollutant removal capabilities for underground sand filters, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the International Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.3.4.4 Application and Site Feasibility Criteria

Underground sand filter systems are well-suited for highly impervious areas where land available for structural BMPs is limited. Underground sand filters should primarily be considered for new construction or retrofit opportunities for commercial, industrial, and institutional areas where the sediment load is relatively low, such as: parking lots, driveways, loading docks, gas stations, garages, airport runways/taxiways, and storage yards.

To avoid rapid clogging and failure of the filter media, the use of underground sand filters should be avoided in areas with less than 50% impervious cover, or high sediment yield sites with clay/silt soils.

The following basic criteria should be evaluated to ensure the suitability of an underground sand filter facility for meeting stormwater management objectives on a site or development.

General Feasibility

- Not suitable for use in a residential subdivision.
- Suitable for use in high density/ultra-urban areas.
- Not suitable for use as a regional stormwater control. On-site applications are typically most feasible.

Physical Feasibility - Physical Constraints at Project Site

- <u>Drainage Area</u> – 2 acres maximum for an underground sand filter.
- <u>Space Required</u> – Function of available head at site.
- <u>Minimum Head</u> – The surface slope across the filter location should be no greater than 6%. The elevation difference needed at a site from the inflow to the outflow is 2 to 6 feet.

- Minimum Depth to Water Table – If used on a site with an underlying water supply aquifer, a separation distance of 2 feet is required between the bottom of the sand filter and the elevation of the seasonally high water table to prevent groundwater contamination.
- Soils – Not recommended for clay/silt drainage areas that are not stabilized.

Other Constraints / Considerations

- Aquifer Protection – Do not allow infiltration of filtered hotspot runoff into groundwater.

3.3.4.5 Planning and Design Standards

The following standards shall be considered minimum design standards for the design of underground sand filters. Underground sand filters that are not designed to these standards will not be approved. The local jurisdiction shall have the authority to require additional design conditions if deemed necessary.

A. Construction Sequencing

- Care shall be taken during construction to minimize the risk of premature failure of the underground sand filter due to deposition of sediments from disturbed, unstabilized areas. This can be minimized or avoided by proper construction sequencing.
- Ideally, the construction of an underground filter shall take place after the construction site has been stabilized. In the event that the underground sand filter is not constructed after site stabilization, diversion of site runoff around the sand filter and installation and maintenance of appropriate erosion prevention and sediment controls prior to site stabilization is required.
- Diversion berms shall be maintained around an underground sand filter during all phases of construction. No runoff shall enter the sand filter area prior to completion of construction and the complete stabilization of construction areas. Erosion prevention and sediment controls shall be maintained around the filter to prevent runoff and sediment from entering the sand filter during construction.
- Underground sand filters shall not be used as a temporary sediment trap for construction activities.
- During and after excavation of the underground sand filter area, all excavated materials shall be placed downstream, away from the sand filter, to prevent redeposit of the material during runoff events.

B. Location and Siting

- Underground sand filters shall have a contributing drainage area of 2 acres or less.
- Underground sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sand filters shall not be utilized for sites that have less than 50% impervious cover. Any disturbed or denuded areas located within the area draining to and

treated by the underground sand filter shall be stabilized prior to construction and use of the sand filter.

- Delaware underground sand filters are typically sited along the edge, or perimeter, of an impervious area such as a parking lot.
- DC underground sand filters are installed within the storm drain system.
- Underground sand filter systems shall be designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They shall not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

C. Physical Specifications / Geometry

- The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQv prior to filtration. Figures 4-60 and 4-61 illustrate the distribution of the treatment volume (0.75 WQv) among the various components of the underground sand filters, including:
    - Vw – wet pool volume within the sedimentation basin
    - Vf – volume within the voids in the filter bed
    - Vtemp – temporary volume stored above the filter bed
    - As – the surface area of the sedimentation basin
    - Af – surface area of the filter media
    - hf – average height of water above the filter media (1/2 htemp)
    - df – depth of filter media
- The sedimentation chamber shall be sized to at least 50% of the computed WQv.
- The filter area shall be sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand shall be used. The filter bed shall be designed to completely drain in 40 hours or less.
- The filter media shall consist of an 18 inch to 24 inch layer of clean washed medium aggregate concrete sand (ASTM C-33) on top of the underdrain system. Figure 4-62 illustrates a typical media cross section.
- The filter bed shall be equipped with a 6 inch perforated pipe underdrain (PVC AASHTO M 252, HDPE, or other suitable pipe material) in a gravel layer. The underdrain shall have a minimum grade of 1/8 inch per foot (1% slope). Holes shall be 3/8 inch diameter and spaced approximately 6 inches on center. Gravel shall be clean-washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches with a void space of about 40%. Aggregate contaminated with soil shall not be used.

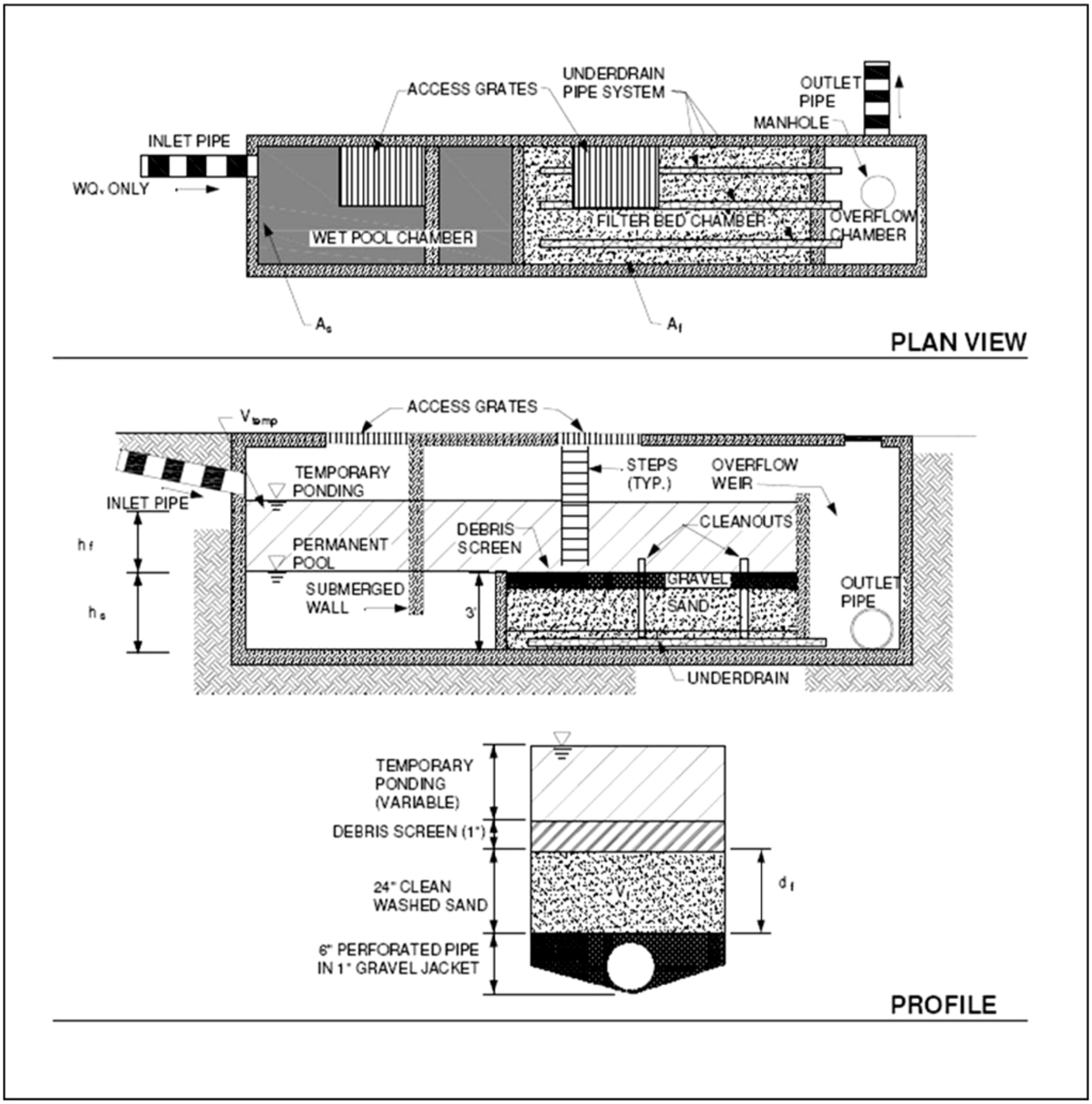


Figure 3-47 Underground (DC) Sand Filter Volumes
(Source: Center for Watershed Protection)

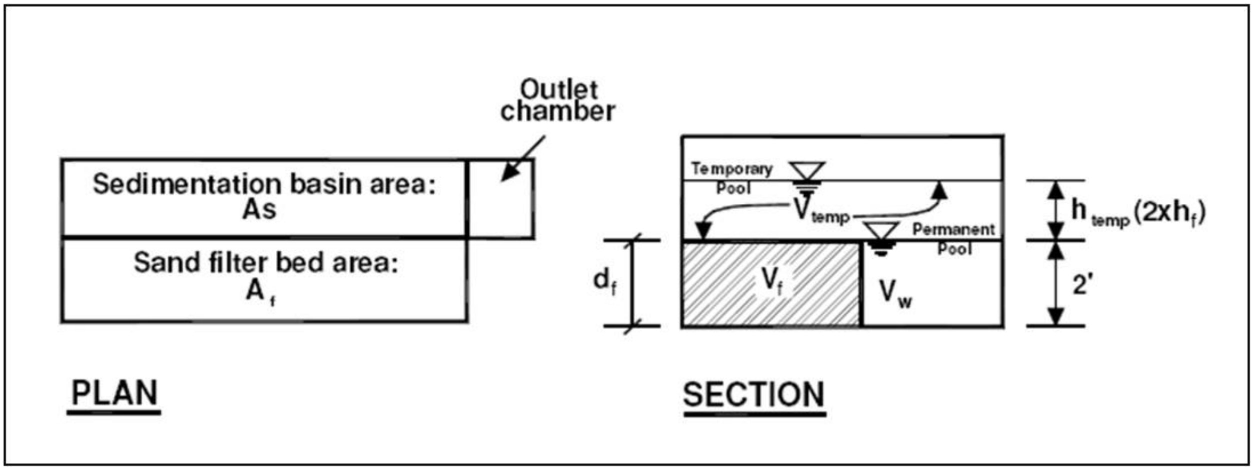


Figure 3-48 Perimeter Sand Filter Volumes
(Source: Claytor and Schueler, 1996)

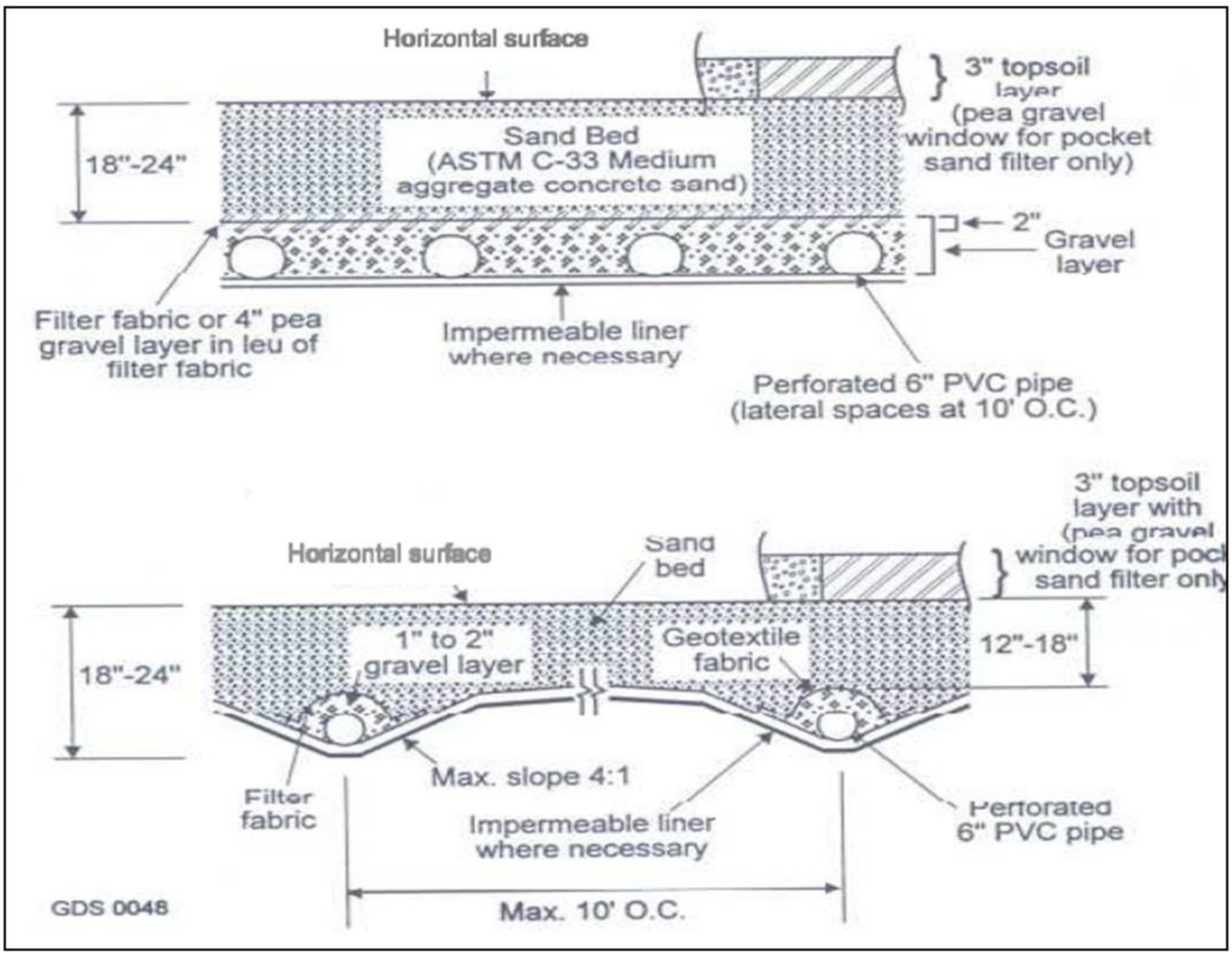


Figure 3-49 Typical Sand Filter Media Cross Sections
(Source: Claytor and Schueler, 1996)

D. Outlet Structures

- An outlet pipe shall be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for emergency overflows and spillways). However, the design shall ensure that the discharges from the underdrain system occur in a non-erosive manner.

E. Emergency Spillway

- An emergency bypass spillway or weir must be included in the underground sand filter design to safely pass flows that exceed the WQv (and CPv if the filter is utilized for channel protection purposes).

F. Maintenance Access

- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles. Adequate access must be provided to the grates of the filter bed. Facility designs must enable maintenance personnel to easily remove and replace upper layers of the filter media.

G. Safety Features

- Inlets, access grates and outlets shall be designed and maintained so as not to permit access by children. Inlet and access grates to the underground sand filters may be locked.

3.3.4.6 Design Procedures

Step 1 Compute runoff control volumes

Calculate the WQ_v using equation 1-1.

Step 2 Determine if the development site and conditions are appropriate for the use of an underground sand filter.

Consider the Application and Site Feasibility Criteria Check with local agencies as appropriate to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3 Compute the peak discharge for the WQ_v, called Q_{wq}, using equation 4-18.

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion structures.

(a) Using WQ_v, compute CN using equation 4-3.

(b) Compute time of concentration (Chapter 4, Section 4).

(c) Determine appropriate unit peak discharge from time of concentration (Chapter 4, Section 8).

(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQv using equation 4-18.

Step 4 Size flow diversion structure, (if needed)

If a diversion structure is utilized, a flow regulator should be supplied to divert the WQ_v to the underground sand filter facility.

Size low flow orifice, weir, or other device to pass Q_{wq}.

Step 5 Size filtration basin chamber

The filter area is sized using the following equation (based on Darcy's Law):

Equation 3-8
$$A_f = \frac{WQ_v * d_f}{k * (h_f + d_f) * t_f}$$

where:

A_f	=	surface area of filter bed (ft2)
d_f	=	filter bed depth (ft) (typically 1.5 ft, no more than 2 ft)
k	=	coefficient of permeability of filter media (ft/day) (use 3.5 ft/day for sand)
h_f	=	average height of water above filter bed (ft) (1/2 h_{temp}, which varies based on site but h_{temp} is typically ≤ 6 feet)
t_f	=	design filter bed drain time (days) (1.67 days or 40 hours is recommended maximum)

Set preliminary dimensions of filtration basin chamber.

Step 6 Size sedimentation chamber

Depending on the type of underground sand filter system utilized, the sedimentation chamber shall be sized to at least 50% of the computed WQ_v and have a length-to-width ratio of 2:1. The Camp-Hazen equation is used to compute the required surface area: (Claytor & Schueler, 1996)

Equation 3-9
$$A_s = -\frac{Q_o}{w} * Ln(1 - E)$$

where:

As	=	sedimentation basin surface area (ft^2)
Q_o	=	rate of outflow = the WQ_v over a 24-hour period
w	=	particle settling velocity (ft/sec)
E	=	trap efficiency

Assuming:

- 90% sediment trap efficiency (0.9);

- particle settling velocity (ft/sec) = 0.0033 ft/sec for imperviousness ≥ 75%;
- particle settling velocity (ft/sec) = 0.0004 ft/sec for imperviousness < 75%;
- average of 24 hour holding period.

Then:

As = (0.0081) (WQ_v) ft^2 for Imperviousness ≥ 75%

As = (0.066) (WQ_v) ft^2 for Imperviousness < 75%

Set preliminary dimensions of sedimentation chamber.

Step 7 Compute V_{min} for 75% of the WQ_v, as required by the design specifications.

Equation 3-10 $$V_{\min} = 0.75 * WQ_v$$

Step 8 Compute storage volumes within entire facility and sedimentation chamber orifice size (Claytor & Schueler, 1996).

Underground (D.C.) sand filter:

Vmin = 0.75 WQv = Vs + Vf + Vf-temp

1. Compute Vf = water volume within filter bed/gravel/pipe = Af * df * n

   Where: n = porosity = 0.4 for most applications
2. Compute Vf-temp = temporary storage volume above the filter bed = 2 * hf * Af
3. Compute Vs = volume within sediment chamber = Vmin - Vf - Vf-temp
4. Compute hs = height in sedimentation chamber = Vs/As
5. Ensure hs and hf fit available head and other dimensions still fit – change as necessary in design iterations until all site dimensions fit.
6. Size orifice from sediment chamber to filter chamber to release Vs within 24-hours at average release rate with 0.5 hs as average head.
7. Design outlet structure with perforations allowing for a safety factor of safety times the orifice capacity.
8. Size distribution chamber to spread flow over filtration media – level spreader weir or orifices.

Underground perimeter (Delaware) sand filter:

1. Compute Vf = water volume within filter bed/gravel/pipe = Af * df * n

   where: Af = surface area of filter bed (ft2)

   df = filter bed depth (1.5 ft)

   (at least 18 inches, no more than 24 inches)

   n = porosity = 0.4 for most applications
2. Compute Vw = wet pool storage volume As * 2 feet minimum

3. Compute Vtemp = temporary storage volume = Vmin – (Vf + Vw)
4. Compute htemp = temporary storage height = Vtemp / (Af + As)
5. Ensure htemp ³ 2 * hf, otherwise decrease hf and re-compute. Ensure dimensions fit available head and area – change as necessary in design iterations until all site dimensions fit.
6. Size distribution slots from sediment chamber to filter chamber.

Step 9 Design inlets, underdrain system, and outlet structures.

See Chapter 5 for more details.

Step 10 Compute overflow weir sizes.

Underground (D.C.) sand filter:

Vmin = 0.75 WQv = Vs + Vf + Vf-temp

1. Compute Vf = water volume within filter bed/gravel/pipe = Af * df * n
   where: n = porosity = 0.4 for most applications
2. Compute Vf-temp = temporary storage volume above the filter bed = 2 * hf * Af
3. Compute Vs = volume within sediment chamber = Vmin - Vf - Vf-temp
4. Compute hs = height in sedimentation chamber = Vs/As
5. Ensure hs and hf fit available head and other dimensions still fit – change as necessary in design iterations until all site dimensions fit.
6. Size orifice from sediment chamber to filter chamber to release Vs within 24-hours at average release rate with 0.5 hs as average head.
7. Design outlet structure with perforations allowing for a safety factor of times the orifice capacity.
8. Size distribution chamber to spread flow over filtration media – level spreader weir or orifices.

Underground perimeter (Delaware) sand filter: Size overflow weir at end of sedimentation chamber to handle excess inflow, set at WQv elevation.

3.3.4.7 Example Schematics

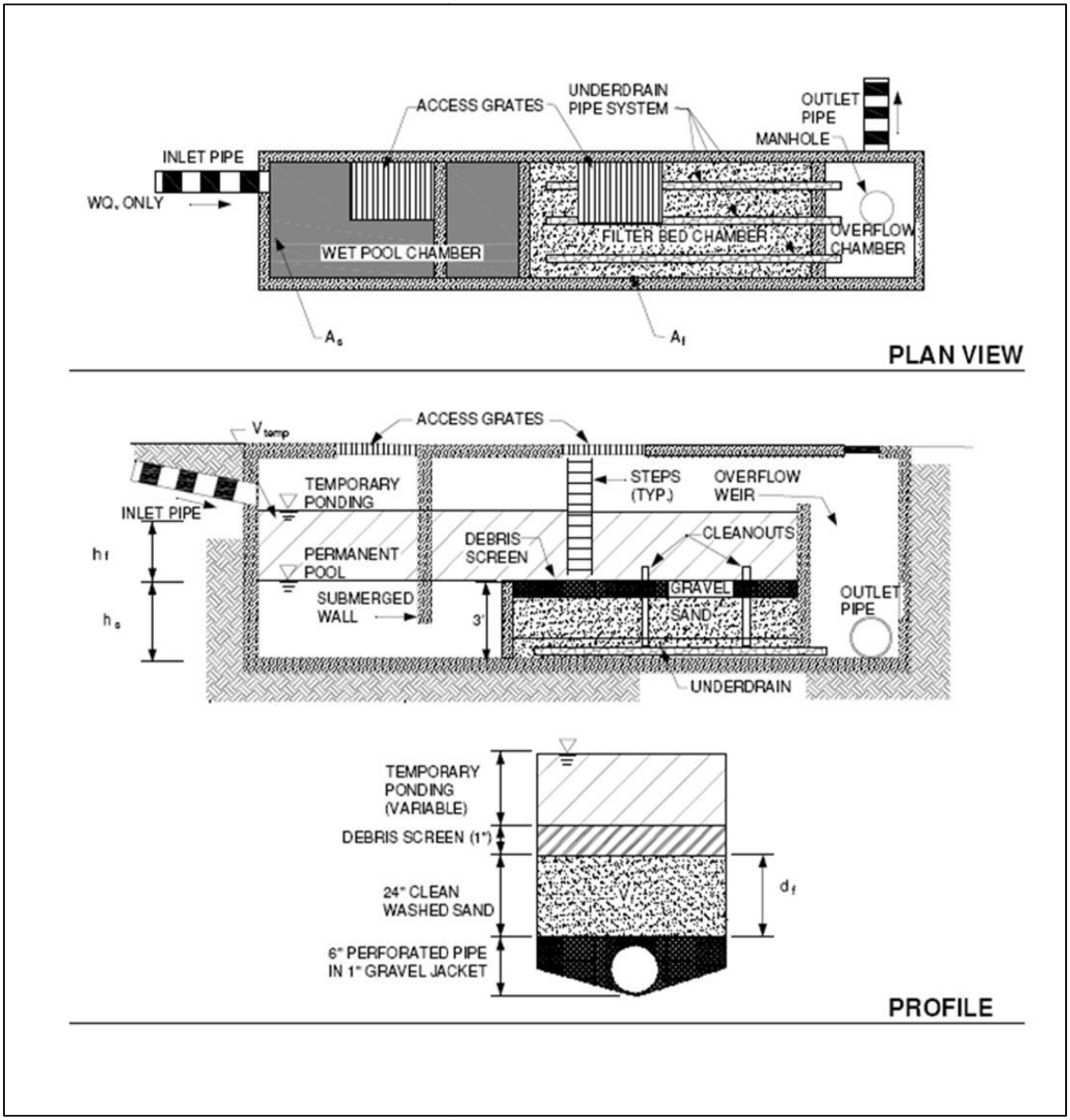


Figure 3-50 Schematic of an Underground (D.C.) Sand Filter
(Source: Center for Watershed Protection)

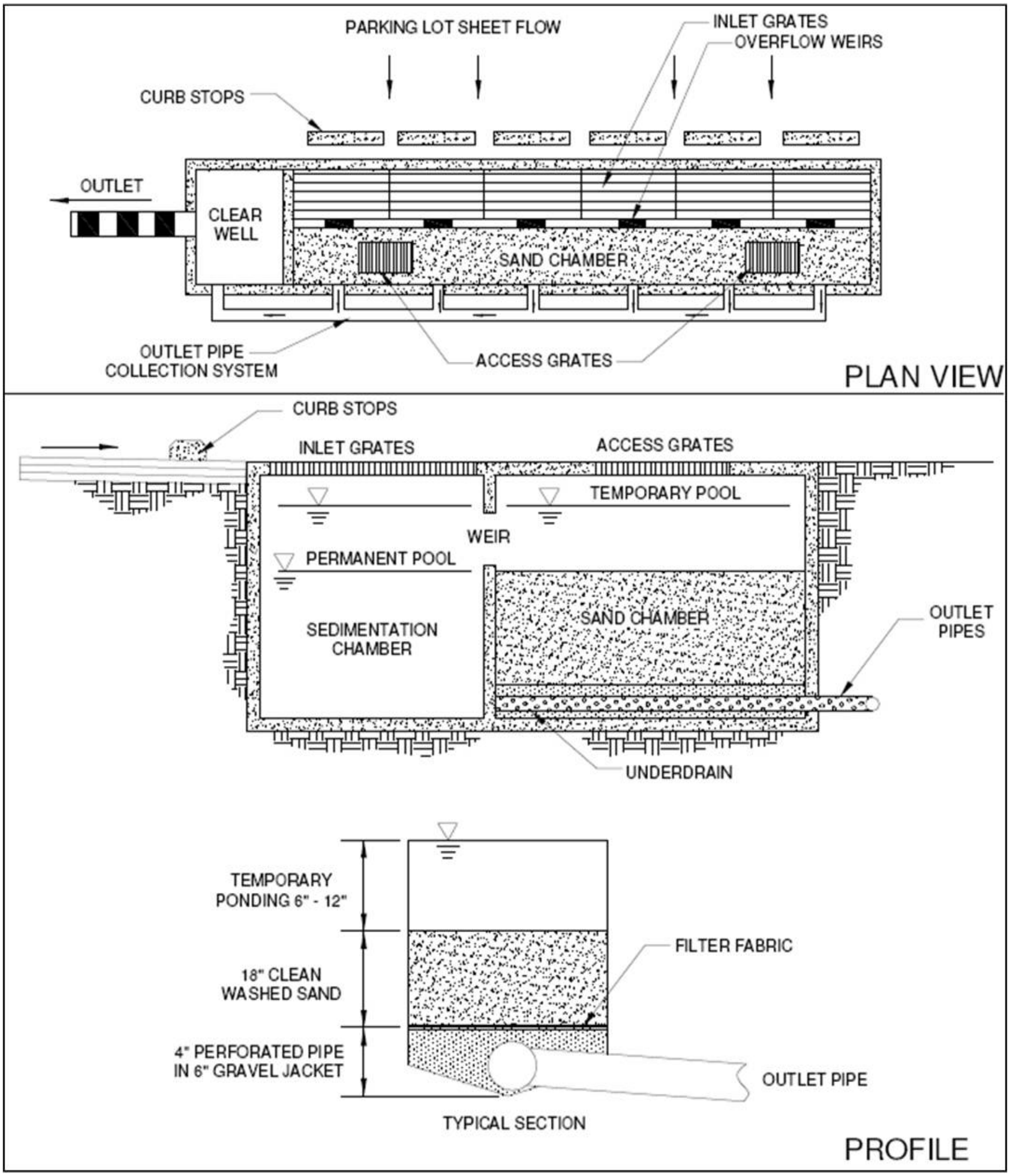


Figure 3-51 Schematic of Perimeter (Delaware) Sand Filter
(Source: Center for Watershed Protection)

3.3.5 Organic Filter

Secondary Water Quality Facility

Description: Design variation of the surface sand filter using organic materials in the filter media.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Minimum head requirement of 5 to 8 feet

ADVANTAGES / BENEFITS:

- High pollutant removal capability
- Removal of dissolved pollutants is greater than sand filters due to cation exchange capacity

DISADVANTAGES / LIMITATIONS:

- Severe clogging potential if exposed soil surfaces exist upstream
- Intended for hotspot or space-limited applications, or for areas requiring enhanced pollutant removal capability
- High maintenance requirements
- Filter may require more frequent maintenance than most of the other stormwater controls

MAINTENANCE REQUIREMENTS:

- Mow and stabilize the area draining to the organic filter
- Remove sediment from filter bed

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients –** Total Phosphorus & Total Nitrogen
H	**Metals –** Cadmium, Copper, Lead & Zinc
M	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Water Quality Protection**
- ☐ **Channel Protection**
- ☐ **On-Site Flood Control**
- ☐ **Downstream Flood Control**

Accepts Hotspot Runoff: *Yes*

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *10 acres max.*

Soils: *No restrictions*

Other Considerations:

- *Hotspot areas*

L=Low **M**=Moderate **H**=High

3.3.5.1 General Description

The organic filter is a design variant of the surface sand filter, which uses organic materials such as leaf compost or a peat/sand mixture as the filter media. The organic material enhances pollutant removal by providing adsorption of contaminants such as soluble metals, hydrocarbons, and other organic chemicals.

As with the surface sand filter, an organic filter consists of a pretreatment chamber, and one or more filter cells. Each filter bed contains a layer of leaf compost or the peat/sand mixture, followed by filter fabric and a gravel/perforated pipe underdrain system. The filter bed and subsoils can be separated by an impermeable polyliner or concrete structure to prevent movement into groundwater.

Organic filters are typically used in high-density applications, or for areas requiring enhanced pollutant removal ability. Maintenance is typically higher than the surface sand filter facility due to the potential for clogging and breakdown of the filter media. In addition, organic filter systems have a higher head requirement than sand filters.

3.3.5.2 Pollutant Removal Capabilities

The following design pollutant removal rates are average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach. (Note: In some cases, organic materials may be a source of soluble phosphorus and nitrates.)

- Total Suspended Solids – 80%
- Total Phosphorus – 60%
- Total Nitrogen – 40%
- Heavy Metals – 75%
- Fecal Coliform – 50%

For additional information and data on pollutant removal capabilities, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

3.3.5.3 Design Criteria and Specifications

- Organic filters are typically used on relatively small sites (up to 10 acres), to minimize potential clogging.
- The typical minimum head requirement (elevation difference needed at a site from the inflow to the outflow) for an organic filter is 5 to 8 feet.

- Organic filters can utilize a variety of organic materials as the filtering media. Two typical media bed configurations are the peat/sand filter and compost filter (see Figure 3-52). The peat filter includes an 18-inch 50/50 peat/sand mix over a 6-inch sand layer and can be optionally by 3 inches of topsoil and vegetation for aesthetic purposes. The compost filter has an 18-inch compost layer. Both variants utilize a gravel underdrain system.
- The type of peat used in a peat/sand filter is critically important. Fibric peat in which undecomposed fibrous organic material is readily identifiable is the preferred type. Hemic peat containing more decomposed material may also be used. Sapric peat made up of largely decomposed matter should not be used in an organic filter.
- Typically, organic filters are designed as "off-line" systems, meaning that the WQ_v is diverted to the filter facility through the use of a flow diversion structure and flow splitter. Stormwater flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
- Consult the design criteria for the surface sand filter (see Section 3.2.8) for the organic filter siting requirements, and sizing/design steps. The following permeability values may be used: sand = 3.5 ft/day, peat = 2.0 ft/day, and leaf compost = 8.5 ft/day. A porosity of 0.4 may be assumed.
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- A minimum separation distance of 5 feet is required between the bottom of the filter and the elevation of the historical high water table for filter without underdrains, 2 feet for filters with underdrains.

3.3.5.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. “Covenants for Permanent Maintenance of Stormwater Management Facilities” (also called the “Maintenance Covenants”). An example covenants document can be found in Volume 3.
2. “Inspection Checklist and Maintenance Guidance” for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location of the facility, and also clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.3.5.5 Example Schematic

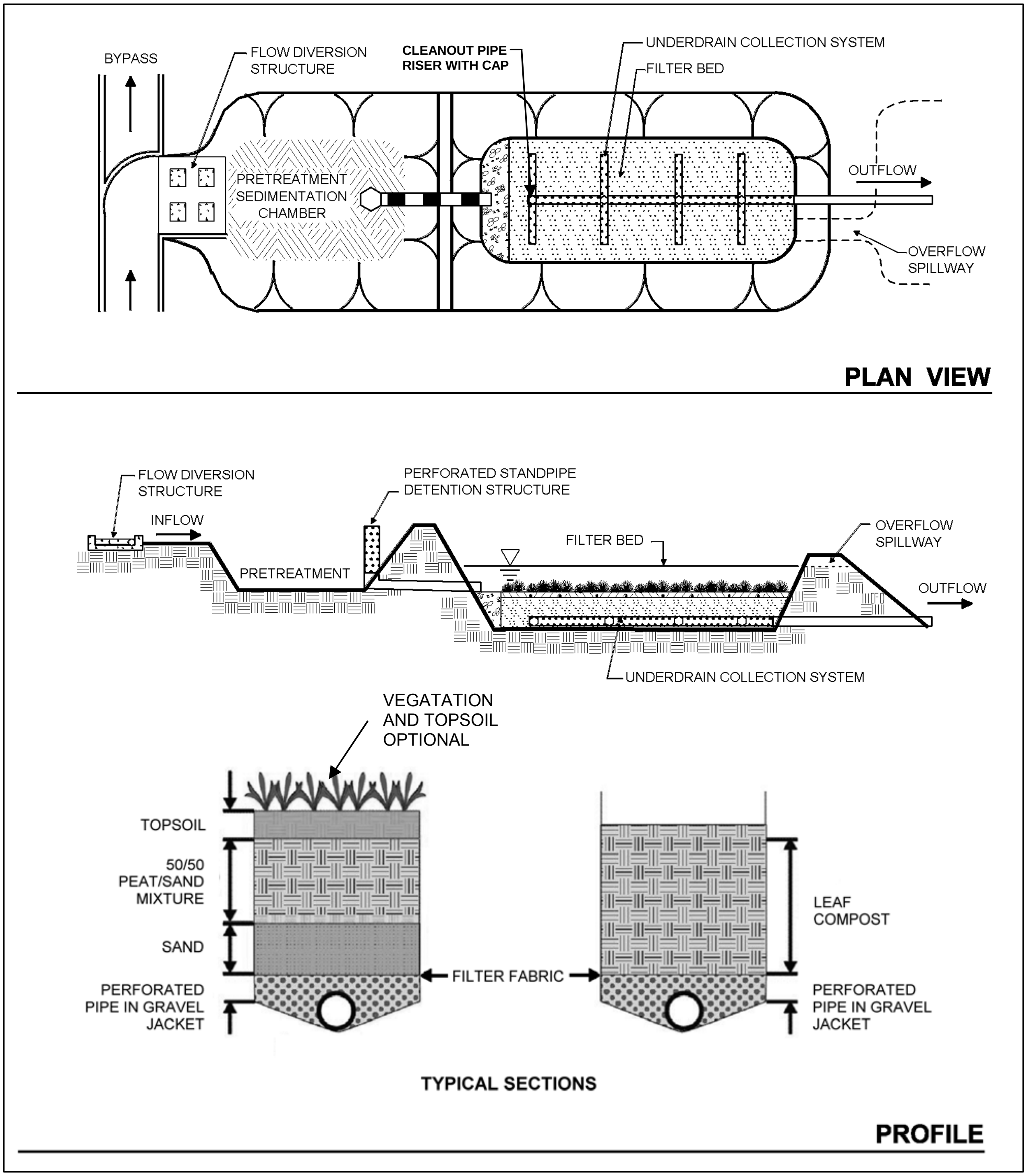


Figure 3-52 Schematic of Organic Filter
(adapted from Claytor & Schueler, 1996)

3.4 Other Stormwater Management Facilities

This section contains design guidelines for the following stormwater management facilities:

- Conventional Dry Detention
- Underground Dry Detention
- Porous Pavement
- Modular Porous Paver Systems
- Green Roof

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3.4.1 Conventional Dry Detention Pond

Other Water Quantity Facility

Description: A surface storage basin or facility designed to provide water quantity control through detention of stormwater runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Designed for runoff quantity (peak flow) control

ADVANTAGES / BENEFITS:

- Typically less costly than stormwater (wet) ponds for equivalent flood storage
- Used in conjunction with water quality structural control
- Recreational and other open space opportunities between storm runoff events

DISADVANTAGES / LIMITATIONS:

- Controls for stormwater quantity only

MAINTENANCE REQUIREMENTS:

- Remove debris from inlet and outlet structures
- Maintain side slopes/remove invasive vegetation
- Monitor sediment accumulation and remove periodically
- Dam inspection and maintenance

POLLUTANT REMOVAL

--	**Total Suspended Solids**
--	**Nutrients –** Total Phosphorus & Total Nitrogen
--	**Metals –** Cadmium, Copper, Lead & Zinc
--	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

	Water Quality Protection
	Channel Protection
✓	**On-Site Flood Control**
✓	**Downstream**

IMPLEMENTATION CONSIDERATIONS

M	**Land Requirements**
L	**Relative Capital Costs**
M	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *No restrictions*

Soils: *Hydrologic group 'A' and 'B' soils may require pond liner if groundwater mounding is not desirable*

Other Considerations:

- *Recreational and open space uses for dry detention*

L=Low **M**=Moderate **H**=High

3.4.1.1 General Description

Conventional dry detention ponds are surface facilities intended to provide for the temporary storage of stormwater runoff to control peak flood flows. These facilities temporarily detain stormwater runoff, releasing the flow over a period of time. They are designed to completely drain following a storm event and are normally dry between rain events.

Conventional dry detention ponds may be used to control peak flows on-site, at the project boundary, and downstream of the project. They can be designed to control the full range of flood flows, from the 2-year event up to the 100-year event. They provide limited pollutant removal benefits due to the typically short detention time and resuspension sediments in the pond. Conventional detention facilities must be used in a treatment train approach with other controls that provide treatment of the WQ_v.

3.4.1.2 Design Criteria and Specifications

Location

- Conventional dry detention ponds are to be located downstream of other structural stormwater controls providing treatment of the WQ_v and control of the CP_v.

General Design

- Conventional dry detention ponds are sized to temporarily store the volume of runoff required to provide flood protection up to the 100-year storm.
- Routing calculations must be used to demonstrate that the storage volume and outlet structure configuration are adequate. See Chapter 4 for procedures on the design of detention storage.
- Conventional dry detention ponds located in floodplains or backwater areas must perform as specified for peak flow control for any tailwater condition, up to the Base Flood Elevation (BFE). The potential for back flow into the pond must be addressed with flap gates or by providing sufficient volume to receive backflow up to the BFE, and still provide peak flow control surcharge volume in the pond (above the BFE).
- The design may be subject to the requirements of the Kansas dam safety program based on the volume, dam height, and level of hazard.
- Earthen embankments shall have side slopes no steeper than 4:1 (horizontal to vertical) maximum.
- Vegetated slopes shall be less than 20 feet in height and shall have side slopes no steeper than 4:1 (horizontal to vertical). Riprap-protected slopes shall be no steeper than 3:1. Geotechnical slope stability analysis is required for slopes greater than 10 feet in height.
- Areas above the normal high water elevations of the detention facility should be sloped toward the basin to allow drainage and to prevent standing water. Careful finish grading is

required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions. A low flow or pilot channel across the facility bottom from the inlet to the outlet (often constructed with riprap or a concrete flume) is recommended to convey low flows and prevent standing water conditions.

- To the extent practicable, the long axis of ponds should be oriented east-west to minimize wind wave bank erosion.
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

Inlet and Outlet Structures

- The discharge from inflow channels or pipes is to be stabilized with flared riprap aprons, or the equivalent. A sediment forebay or equivalent upstream pretreatment sized to 0.1 acre-inch per impervious acre of contributing drainage should be provided for in-line dry detention basins that are located downstream of off-line water quality treatment controls.
- For a dry detention basin, the principal spillway or outlet structure (usually a concrete riser with orifices and an outlet pipe, or just an outlet pipe) is sized for its flood control functions (based on hydrologic routing calculations). Small outlet openings that will be subject to clogging or are difficult to maintain are not acceptable. Trash racks, hoods, or other protection against debris blockage of principal spillway outlets are required. See Section 3.2.1 and Chapter 5.
- See Chapter 4 and Chapter 5 for more information on the design of outlet works.
- Seepage control or anti-seep collars should be provided for all outlet pipes through earth dams.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the pond outlet pipe to prevent scouring and erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a vegetated riparian zone in the shortest possible distance.
- A concrete emergency spillway is to be included in the stormwater pond design to safely pass the 100-year, 24-hour rainfall flood event. The spillway prevents pond water levels from overtopping the embankment. When applicable, the emergency spillway must be designed to State of Kansas requirements for dam safety and must be located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the 100-year flood, to the lowest point of the dam embankment not counting the emergency spillway. The 100-year flood elevation for emergency spillway

design is based on the elevation required to pass the 100-year flow with no discharge through the principal spillway.

- Please refer to “Stormwater Pond”, Section 3.2.1, for additional requirements applicable to all surface detention ponds.

3.4.1.3 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. “Covenants for Permanent Maintenance of Stormwater Management Facilities” (also called the “Maintenance Covenants”). An example covenants document can be found in Volume 3.
2. “Inspection Checklist and Maintenance Guidance” for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location and layout of the pond, and also clearly identify drainage and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.4.1.4 Example Schematics

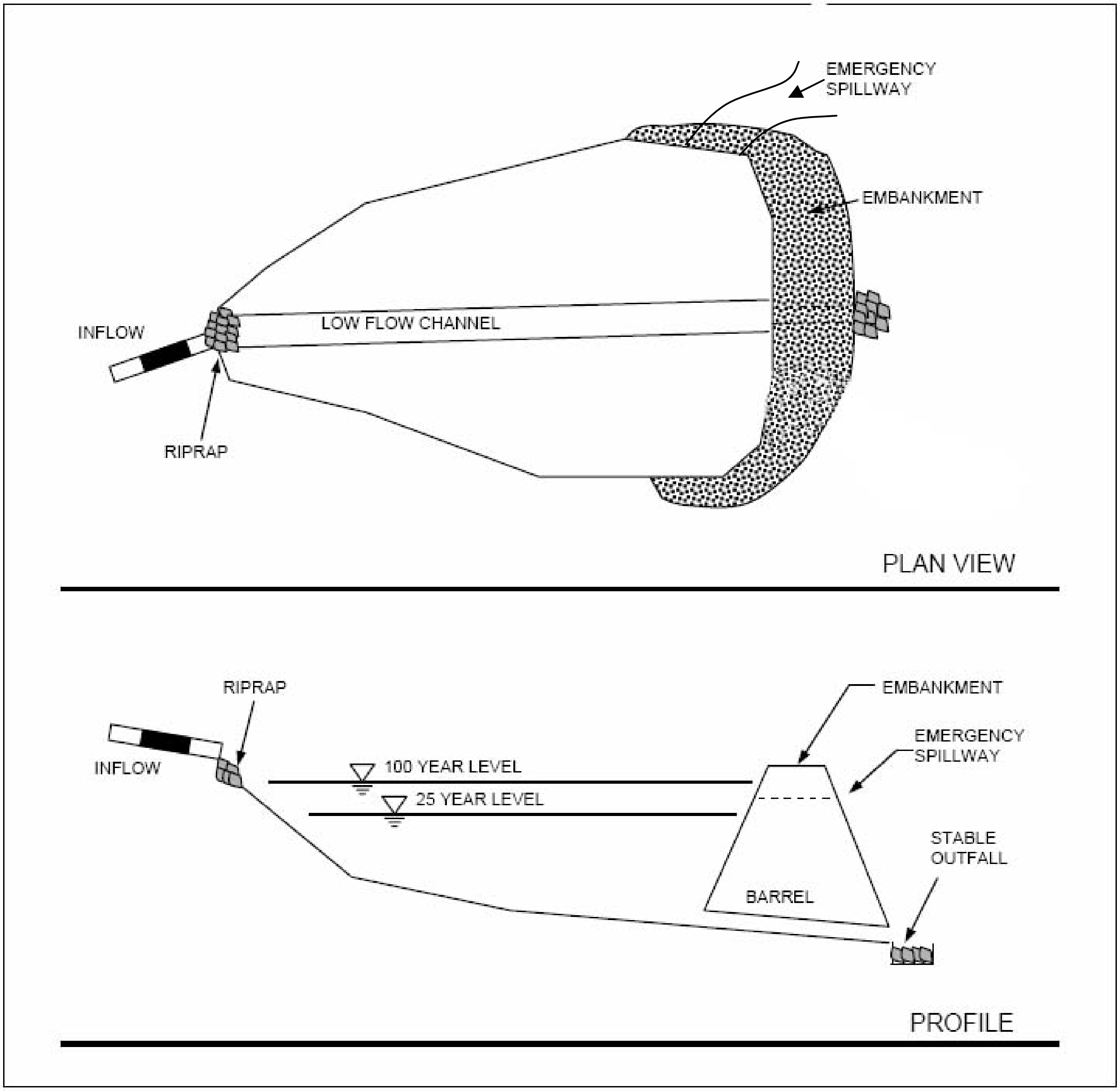

Figure 3-53 Schematic of a Basic Conventional Dry Detention Pond

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3.4.2 Underground Dry Detention Pond

Other Water Quantity Facility

Description: Detention storage located in underground pipe/tank systems or vaults designed to provide water quantity control through detention of stormwater runoff.

KEY CONSIDERATIONS

ADVANTAGES / BENEFITS:

- Does not take up surface space
- Used in conjunction with water quality controls
- Concrete vaults or pipe/tank systems can be used

DISADVANTAGES / LIMITATIONS:

- Controls for stormwater quantity only – not intended to provide water quality treatment
- Intended for space-limited applications
- High initial construction cost as well as replacement cost

MAINTENANCE REQUIREMENTS:

- Clean and remove debris from inlet and outlet structures
- Perform structural repairs to inlet and outlets

POLLUTANT REMOVAL

--	**Total Suspended Solids**
--	**Nutrients –** Total Phosphorus & Total Nitrogen
--	**Metals –** Cadmium, Copper, Lead & Zinc
--	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

	Water Quality Protection
✓	**Channel Protection**
✓	**On-Site Flood Control**
✓	**Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Soils: *No restrictions*

L=Low **M**=Moderate **H**=High

3.4.2.1 General Description

Detention vaults are box-shaped underground stormwater storage facilities typically constructed with reinforced concrete. Detention pipe/tank systems are underground storage facilities typically constructed with large diameter pipe or pre-cast concrete culvert sections. They serve as an alternative to surface dry detention for stormwater quantity control, particularly for space-limited areas where there is not adequate land for a detention basin.

Underground detention systems can provide channel protection through extended detention of the CP_v, and flood control through aboveground detention. Basic storage design and routing methods are the same as for detention basins except that a bypass for high flows may be included.

Underground detention systems are not intended for water quality treatment and must be used in a treatment train approach with other structural controls that provide treatment of the WQ_v. This will help prevent the underground vault or tank from becoming clogged with trash or sediment and significantly reduces the maintenance requirements for an underground detention system.

Underground detention systems located in floodplains or backwater areas must perform as specified for peak flow control for any tailwater condition, up to the Base Flood Elevation (BFE). The potential for back flow into the pond must be addressed with flap gates or by providing sufficient volume to receive backflow up to the BFE, and still provide peak flow control surcharge volume in the pond (above the BFE).

Prefabricated vaults are available from commercial vendors. In addition, several pipe manufacturers have developed packaged detention systems.

3.4.2.2 Design Criteria and Specifications

Location

- Underground detention systems are to be located downstream of other structural stormwater controls providing treatment of the WQ_v.
- The contributing drainage area to be served by a single underground detention vault or tank is typically less than 200 acres.

General Design

- Underground detention systems may be sized to provide extended detention of the CP_V for 24 hours, and/or to temporarily store the volume of runoff required to provide the desired flood protection.
- Routing calculations must be used to demonstrate that the storage volume is adequate. See Chapter 4 for procedures on the design of detention storage.
- Detention Vaults: All construction joints must be provided with embedded waterstops.

- Detention Pipe/Tank Systems: The minimum pipe diameter for underground detention tanks is 36 inches.
- Underground detention vaults and pipe/tank systems must meet structural requirements for external and internal loads, as applicable.
- Adequate air venting above the maximum water surface is essential for proper operation of the detention system.
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles. Access must be provided over the inlet pipe and outflow structure. Access openings can consist of a standard frame, grate and solid cover, or a removable panel. Vaults with widths of 10 feet or less should have removable lids.

Inlet and Outlet Structures

- A separate sediment sump or vault chamber with a volume of 0.1 inches per impervious acre of contributing drainage shall be provided at the inlet for on-line underground detention systems that are located downstream of an off-line water quality treatment control.
- For CP_v control, a low flow orifice capable of detaining the CP_V for 24 hours must be provided. The channel protection orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (i.e., an overperforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter.
- For on-site flood control, an additional outlet is sized for control of the chosen return period (based on hydrologic routing calculations) and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure.
- See Chapter 5 for more information on the design of outlet works.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion. See Chapter 5 for more guidance.
- An emergency spillway shall be included in the underground detention system design to safely pass the 100-year flood flow.

3.4.2.3 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the layout and location of the facility, and also clearly identify reserves and access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.4.2.4 Example Schematics

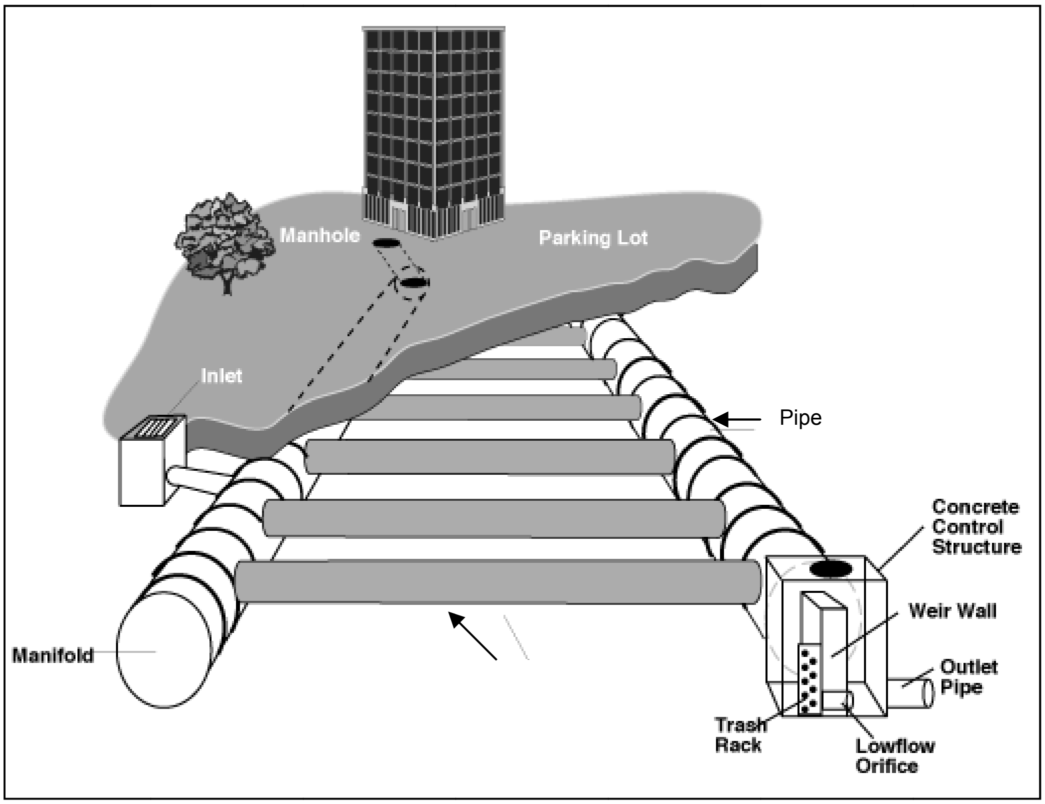

Figure 3-54 Example Underground Detention Tank System

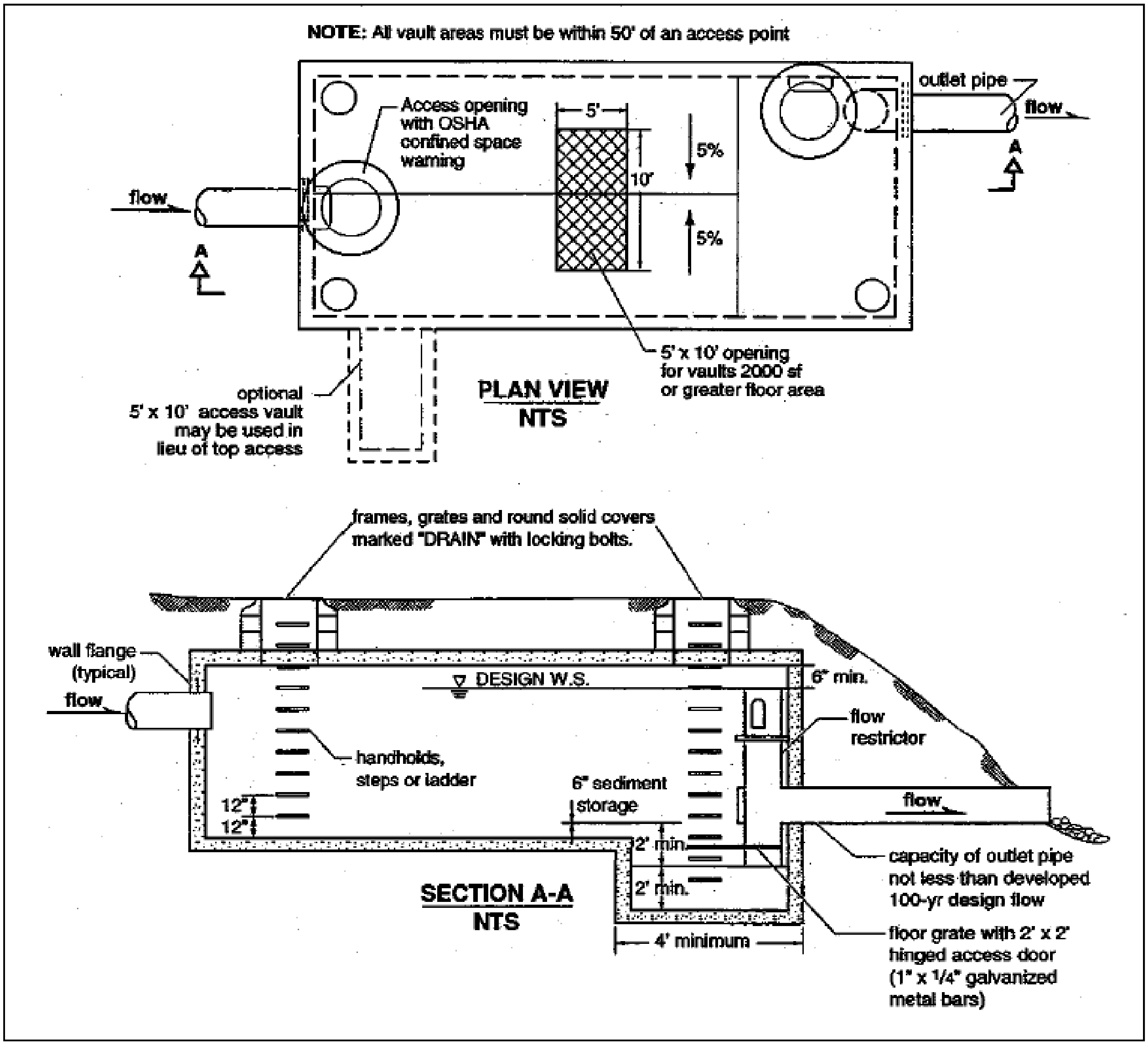

Figure 3-55 Schematic of Typical Underground Detention Vault
(Source: WDE, 2000)

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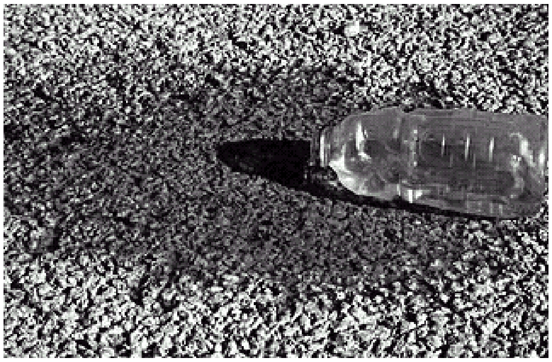
3.4.3 Porous Pavement

Other Water Quantity Facility



Description: Porous concrete is the term for a mixture of coarse aggregate, portland cement and water that allows for rapid infiltration of water through the material. The pavement overlays a stone aggregate base lined with geotextile. This aggregate reservoir provides temporary storage as runoff infiltrates into underlying permeable soils.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Should not be used in areas of soils with low permeability, wellhead protection zones, or areas of water supply aquifer recharge
- Soil infiltration rate of 0.5 in/hr or greater required
- Excavated area filled with stone media, gravel and sand filter layers with observation well

ADVANTAGES / BENEFITS:

- Provides reduction in runoff volume
- Less need for inlets and piping

DISADVANTAGES / LIMITATIONS:

- Restrictions on use by heavy vehicles
- High maintenance requirements
- Special attention to design and construction needed
- Potential for high failure rate if poorly designed, poorly constructed, not adequately maintained, or used in unstabilized (eroding soil) areas
- Snow and ice removal limited
- Potential for groundwater contamination
- Not allowed for TSS removal

POLLUTANT REMOVAL

--	**Total Suspended Solids**
H	**Nutrients –** Total Phosphorus & Total Nitrogen
H	**Metals –** Cadmium, Copper, Lead & Zinc
--	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Quality Protection**
✓	**Channel Protection**
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
M	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max*

Soils: *Soil infiltration rate of 0.5 in/hr or greater required, unless an underdrain is provided*

L=Low **M**=Moderate **H**=High

3.4.3.1 General Description

Porous pavement (also referred to as enhanced porosity concrete, porous concrete, portland cement pervious pavement, and pervious pavement) is a subset of a broader family of pervious pavements including porous asphalt, and various kinds of grids and paver systems. Porous concrete is thought to have a greater ability than porous asphalt to maintain its porosity in hot weather and thus is provided as a limited application control in this manual. Although, porous concrete has seen growing use, there is still limited practical experience with this measure. According to the U.S. EPA, porous pavement sites have had a high failure rate – approximately 75 percent. Failure has been attributed to poor design, inadequate construction techniques, soils with low permeability, heavy vehicular traffic, and poor maintenance. This measure, if used, should be carefully monitored.

Porous concrete consists of a specially formulated mixture of portland cement, uniform open graded coarse aggregate, and water. The concrete layer has a high permeability that is often many times that of the underlying permeable soil layer which allows rapid percolation of rainwater through the surface and into the layers beneath. The void space in porous concrete is in the 15% to 22% range compared to three to five percent for conventional pavements. The permeable surface is placed over a layer of open-graded gravel and crushed stone. The void spaces in the stone act as a storage reservoir for runoff.

For some sites, porous pavement can be designed to capture and infiltrate part or all of the CP_v when the option of infiltrating the difference between the pre- and post-development 1-year, 24-hour runoff is used. Porous concrete will need to be used in conjunction with another structural control to provide downstream flood control, as required.

The infiltration rate of the soils in the subgrade should be adequate to support drawdown of the entire runoff capture volume within 24 to 48 hours. Special care must be taken during construction to avoid undue compaction of the underlying soils which could affect the soil infiltration capability.

Porous concrete systems are typically used in low-traffic areas such as the following types of applications:

- Parking pads in parking lots;
- Overflow parking areas;
- Residential street parking lanes;
- Recreational trails;
- Golf cart and pedestrian paths;
- Plazas and public squares;
- Emergency vehicle and fire access lanes.

Slopes should be flat or gentle to facilitate infiltration versus runoff.

The historically high groundwater water table should be a minimum of five feet below the bottom of the gravel layer; 2 feet for pavements with under drains.

Porous concrete has the positive characteristics of volume reduction due to infiltration, groundwater recharge, and an ability to blend into the urban landscape relatively unnoticed.

A drawback is the complexity of porous concrete systems compared to conventional pavements. Porous concrete systems require a very high level of construction workmanship to ensure that they function as designed. They experience a high failure rate if they are not designed, constructed, and maintained properly.

Like other infiltration controls, porous concrete should not be used in areas that experience high rates of particle deposition by wind, and or in traffic areas where sanding or salting is used during winter weather.

3.4.3.2 Pollutant Removal Capabilities

The following deisgn pollutant removal rates are average polluntant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment.

- Total Suspnded Solids – must not be used to remove this pollutant
- Total Phosphorus – 80%
- Total Nitrogen – 80%
- Metals – 90%
- Fecal Coliform – must not be used to remove this pollutant

3.4.3.3 Design Criteria and Specifications

- Porous concrete systems can be used where the underlying in-situ subsoils have an infiltration rate greater than 0.5 inches per hour or the use of an underdrain. Therefore, porous concrete systems are not suitable on sites with hydrologic group D or most group C soils, or soils with a high (>30%) clay content. During construction and preparation of the subgrade, special care must be taken to avoid compaction of the underlying soils. If used on poorly drained soils, an underdrain may be provided beneath the base stone to dewater the pavement.
- Porous pavement may be used to achieve part or all of the channel protection requirements (i.e., infiltrating all or part of the difference between the pre- and post-development 1-year, 24-hour runoff) by sizing the pavement and infiltration bed to accommodate all or part of the CP_V runoff.
- If it is a load bearing surface, then the pavement and underlying bed system should be able to support the maximum design load.

- Porous concrete systems shall not be used on slopes greater than 5% with slopes of no greater than 2% recommended. For slopes greater than 1% barriers perpendicular to the direction of drainage should be installed in sub-grade material to keep it from washing away. Filter fabric shall be placed at the bottom and sides of the aggregate to keep soil from migrating into the aggregate and reducing porosity.
- A minimum of two feet of clearance is recommended between the bottom of the gravel base course and underlying bedrock or five feet above the historic high groundwater table; 2 feet for systems with under drains.
- Porous concrete systems should be sited at least 10 feet down-gradient from buildings and a safe distance away from drinking water wells.
- To protect groundwater from potential contamination, runoff from untreated designated hotspot landuses or activities must not be infiltrated. Porous concrete should not be used for manufacturing and industrial sites, where there is a potential for high concentrations of soluble pollutants and heavy metals. In addition, porous concrete should not be considered for areas with a high pesticide concentration. Porous concrete is also not suitable in areas with karst geology without adequate geotechnical testing by qualified individuals and in accordance with local requirements.
- The design must use methods to convey runoff from rainfall larger than the design event to the conveyance system.
- A maintenance right of way or easement must be provided to the facility from a public road or easement. The maintenance access easement shall be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The cross-section typically consists of four layers, as shown in Figure 3-56. Descriptions of each of the layers is presented below:

  Porous Concrete Layer: The porous concrete layer consists of an open-graded concrete mixture usually ranging from depths of 6 to 8 inches depending on required bearing strength and pavement design requirements. Porous concrete can be assumed to contain 18 percent voids (porosity = 0.18) for design purposes. Thus, for example, a 4 inch thick porous concrete layer would hold 0.72 inches of rainfall. The omission of the fine aggregate provides the porosity of the porous pavement. To provide a smooth riding surface and to enhance handling and placement a coarse aggregate of 3/8 inch maximum size is normally used. Use coarse aggregate (3/8 to No. 16) per ASTM C 33 or No. 89 coarse aggregate (3/8 to No. 50) per ASTM D 448.

  Top Filter Layer: Consists of a 1/2 inch diameter crushed stone to a depth of 1 to 2 inches. This layer serves to stabilize the porous concrete layer.

  Reservoir Layer: The reservoir gravel base course consists of washed, bank-run gravel, 0.5 to 2.5 inches in diameter with a void space of about 40% meeting the gradation listed below. The depth of this layer depends on the desired storage volume, which is a function of the soil infiltration rate and void spaces, but typically ranges from two to four feet. The layer must have a minimum depth of ten inches. The layer should be designed to drain completely in 48 hours. Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 (this includes a factor of safety) should be used in calculations unless aggregate specific data exist.

Table 3-9 Percent Passing per Sieve Size for Aggregate Gradation

Gradation	
Sieve Size	% Passing
2 ½”	100
2”	90 – 100
1 ½”	35 – 70
1”	0 – 15
½”	0 - 5

Bottom Filter Layer: The surface of the subgrade should be an 6 inch layer of sand (ASTM C-33 concrete sand) and be completely flat to promote infiltration across the entire surface. This layer serves to stabilize the reservoir layer, to protect the underlying soil from compaction, and act as the interface between the reservoir layer and the filter fabric covering the underlying soil.

Filter Fabric: It is very important to line the entire trench area, including the sides, with filter fabric prior to placement of the aggregate. The filter fabric serves a very important function by inhibiting soil from migrating into the reservoir layer and reducing storage capacity. Fabric should be MIRIFI # 140N or equivalent.

Underlying Soil: The underlying soil should have an infiltration capacity of at least 0.5 in/hr, but preferably greater than 0.5 in/hr as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test per 5000 square feet, with a minimum of two borings per facility (taken within the proposed limits of the facility). Test borings are recommended to determine the soil classification, seasonal high ground water table elevation, and impervious substrata, and an initial estimate of permeability. Often a double-ring infiltrometer test is done at subgrade elevation to determine the infiltration rate of the least permeable layer, and, for safety, one-half that measured value is taken for infiltration calculations. Porous pavement cannot be used on fill soils.

- Details of construction of the concrete layer are beyond the scope of this manual. However, construction of porous concrete requires precision and requires special handling, timing, and placement to perform adequately (LACDPW, 2000, Paine, 1992, Maryland, 1984). Installers shall be certified in the placement of porous concrete.

- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no

more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

3.4.3.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Templates for each stormwater management facility can be found in Volume 3 of this manual. These templates can be amended slightly for use in more customized O&M plans.
3. As-built drawings must accurately identify the location of porous pavement and maintenance access easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

3.4.3.5 Example Schematics

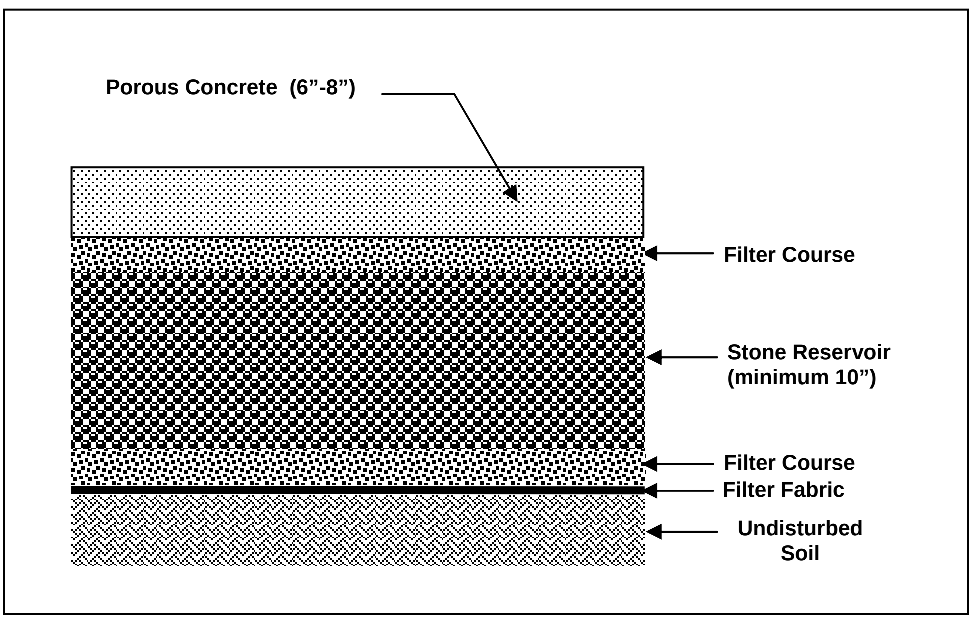


Figure 3-56 Porous Concrete System Section
(Modified From: LAC 2000)

Figure 3-57 Porous Concrete System Installation

Figure 3-58 Typical Porous Concrete System Applications
(Knox Co., TN, 2008)

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3.4.4 Modular Porous Paver Systems

Other Water Quantity Facility

Description: A pavement surface composed of structural units with void areas that are filled with pervious materials such as sand, gravel or grass turf. Porous pavers are installed over a gravel base course that provides storage as runoff infiltrates through the porous paver system into underlying permeable soils.

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Intended for low volume traffic areas, or for residential or overflow parking applications
- Should not be used in areas of soils with low permeability, wellhead protection zones, or recharge areas of water supply aquifer recharge
- Soil infiltration rate of 0.5 in/hr or greater required, unless an underdrain is provided

ADVANTAGES / BENEFITS:

- Provides reduction in runoff volume
- Available from commercial vendors

DISADVANTAGES / LIMITATIONS:

- Restrictions on use by heavy vehicles
- High maintenance requirements
- Potential for high failure rate if not adequately maintained or used in unstabilized areas
- Potential for groundwater contamination
- Not allowed for TSS removal

POLLUTANT REMOVAL

--	**Total Suspended Solids**
H	**Nutrients –** Total Phosphorus & Total Nitrogen
H	**Metals –** Cadmium, Copper, Lead & Zinc
--	**Pathogens –** Coliform, Streptococci & E. Coli

STORMWATER MANAGEMENT SUITABILITY

✓	**Water Quality Protection**
✓	**Channel Protection**
	On-Site Flood Control
	Downstream Flood Control

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
M	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max*

Soils: *Soil infiltration rate of 0.5 in/hr or greater required, unless an underdrain is provided*

L=Low **M**=Moderate **H**=High

3.4.4.1 General Description

Modular porous pavers are structural units, such as concrete blocks, bricks, or reinforced plastic mats, with regularly interspersed void areas used to create a load-bearing pavement surface. The void areas are filled with pervious materials (gravel, sand, or grass turf) to create a system that allows for the infiltration of stormwater runoff. The use of porous paver systems results in a reduction of the effective impervious area on a site (see Section 3.4.4.3), and the additional infiltration may be used to infiltrate all or part of the difference between the pre- and post-development 1-year, 24-hour CP_V.

There are many different types of modular porous pavers available from different manufacturers, including both pre-cast and mold in-place concrete blocks, concrete grids, interlocking bricks, and plastic mats with hollow rings or hexagonal cells (see Figure 3-59).

Modular porous pavers are typically placed on a gravel (stone aggregate) base course. Runoff infiltrates through the porous paver surface into the gravel base course, which acts as a storage reservoir as it infiltrates to the underlying soil. The infiltration rate of the soils in the subgrade must be adequate to support drawdown of the entire runoff capture volume within 24 to 48 hours. Special care must be taken during construction to avoid undue compaction of the underlying soils, which could affect the soils' infiltration capability.

Modular porous paver systems are typically used in low-traffic areas such as the following types of applications:

- Parking pads in parking lots;
- Overflow parking areas;
- Residential driveways;
- Residential street parking lanes;
- Recreational trails;
- Golf cart and pedestrian paths;
- Emergency vehicle and fire access lanes.

Slopes should be flat or gentle to facilitate infiltration versus runoff. Bedrock should be a minimum of two feet below the bottom of the gravel layer, and historically high groundwater must be at least 5 feet below the bottom of the gravel bed.

Porous paver systems have the positive characteristics of volume reduction due to infiltration, groundwater recharge, and an ability to blend into the normal urban landscape relatively unnoticed. It also may result in a reduction in the need for (and cost of) other stormwater infrastructure which may somewhat offset the placement cost.

A major drawback is the cost and complexity of modular porous paver systems compared to conventional pavements. Porous paver systems require a very high level of construction workmanship to ensure that they function as designed and do not settle unevenly. In addition, there is the difficulty and cost of rehabilitating the surfaces should they become clogged. Therefore, consideration of porous paver systems should include the construction and maintenance requirements and costs.

Like other infiltration controls, porous paver systems should not be used in areas that experience high rates of wind deposited particulates, or receive inflow from areas with highly erosive (unstable) soils. Also it cannot be used in traffic areas where sanding or salting is used during winter weather.

3.4.4.2 Pollutant Removal Capabilities

The following deisgn pollutant removal rates are average polluntant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment.

- Total Suspnded Solids – must not be used to remove this pollutant
- Total Phosphorus – 80%
- Total Nitrogen – 80%
- Metals – 90%
- Fecal Coliform – must not be used to remove this pollutant

3.4.4.3 Design Criteria and Specifications

- Porous paver systems can be used where the underlying in-situ subsoils have an infiltration rate of between 0.5 and 3.0 inches per hour. Therefore, porous paver systems are not suitable on sites with hydrologic group D or most group C soils, or soils with a high (>30%) clay content without an under drain system. During construction and preparation of the subgrade, special care must be taken to avoid compaction of the soils.
- Porous paver systems should ideally be used in applications where the pavement receives tributary runoff only from impervious areas. The ratio of the contributing impervious area to the porous paver surface area should be no greater than 3:1.
- If runoff is coming from adjacent pervious areas, it is important that those areas be fully stabilized to prevent sediment loads and clogging of the porous paver surface. Pretreatment using filter strips or vegetated swales for coarse sediment removal is recommended.
- Porous paver systems are not recommended on sites with a slope greater than 2%.
- A minimum of 2 feet of clearance is required between the bottom of the gravel base course and underlying bedrock, or 5 feet above the historically high groundwater table. Inflow from untreated hotspots is not permitted.
- Porous paver systems should be sited at least 10 feet down gradient from buildings and a safe distance from drinking water wells.

- An appropriate modular porous paver should be selected for the intended application. A minimum of 40% of the surface area should consist of open void space. If it is a load bearing surface, then the pavers should be able to support the maximum load.
- For flood control calculations, the area may be assumed to be 60% impervious, and 40% disturbed “B” soil.
- The porous paver infill is selected based on the volume to be infiltrated and the infiltration rate. Masonry sand (such as ASTM C-33 concrete sand) has a high infiltration rate and should be used in applications where no vegetation is desired. A sandy loam soil has a substantially lower infiltration rate, but will provide for growth of a grass ground cover.
- A 1-inch top course (filter layer) of sand (ASTM C-33 concrete sand) underlain by filter fabric is placed under the porous pavers and above the gravel base course.
- The gravel base course consists of washed, bank-run gravel, 0.5 to 2.5 inches in diameter with a void space of about 40% meeting the gradation listed below. The depth of this layer depends on the desired storage volume, which is a function of the soil infiltration rate and void spaces, but typically ranges from two to four feet. The layer must have a minimum depth of nine inches. The layer should be designed to drain completely in 24-48 hours. Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 (this includes a factor of safety) should be used in calculations unless aggregate specific data exist.

Table 3-10 Percent Passing per Sieve Size for Aggregate Gradation

Gradation	
Sieve Size	% Passing
2 ½”	100
2”	90 – 100
1 ½”	35 – 70
1”	0 – 15
½”	0 - 5

- The surface of the subgrade should be lined with filter fabric and an 8-inch layer of sand (ASTM C-33 concrete sand) and be flat to promote infiltration across the entire surface.
- The porous paver system must be designed to convey larger storm event flows to the conveyance system.
- For the purpose of sizing downstream flood conveyance and controls, porous paver surface areas can be assumed to be 40% disturbed ”B” soil and 60% impervious rather than 100% impervious.
- The local jurisdiction may require that the facility be placed in a reserve and/or establishment of a drainage easement the facility, which is accessible from a public road or other accessible easement. When required, the drainage easement should be at least 20 feet wide, provide a minimum traversable width of 15 feet, have a maximum slope of no

more than 10%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

3.4.4.4 Inspection and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of stormwater management facilities. An operation and maintenance plan is required and shall include:

1. "Covenants for Permanent Maintenance of Stormwater Management Facilities" (also called the "Maintenance Covenants"). An example covenants document can be found in Volume 3.
2. "Inspection Checklist and Maintenance Guidance" for each type of stormwater facility that is located on the property. Detailed inspection and maintenance guidance shall be provided by the manufacturer and/or design engineer.
3. As-built drawings must accurately identify the location of the paver area, and also clearly identify the reserves and maintenance easements.

All stormwater management facilities must be maintained in accordance with the O&M Plan.

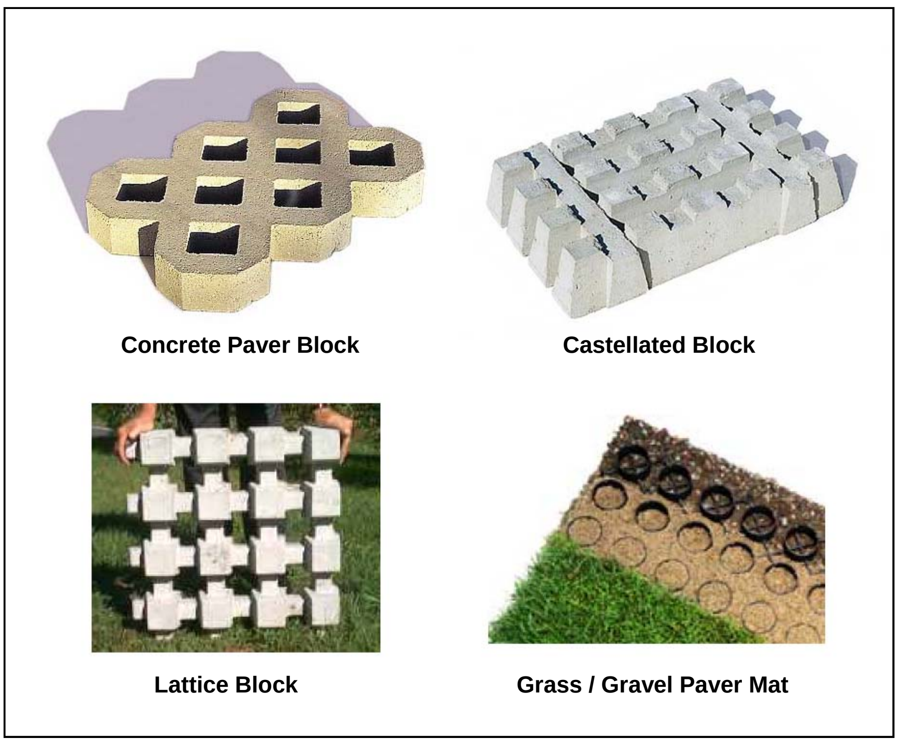

Figure 3-59 Examples of Modular Porous Pavers

3.4.4.5 Example Schematics

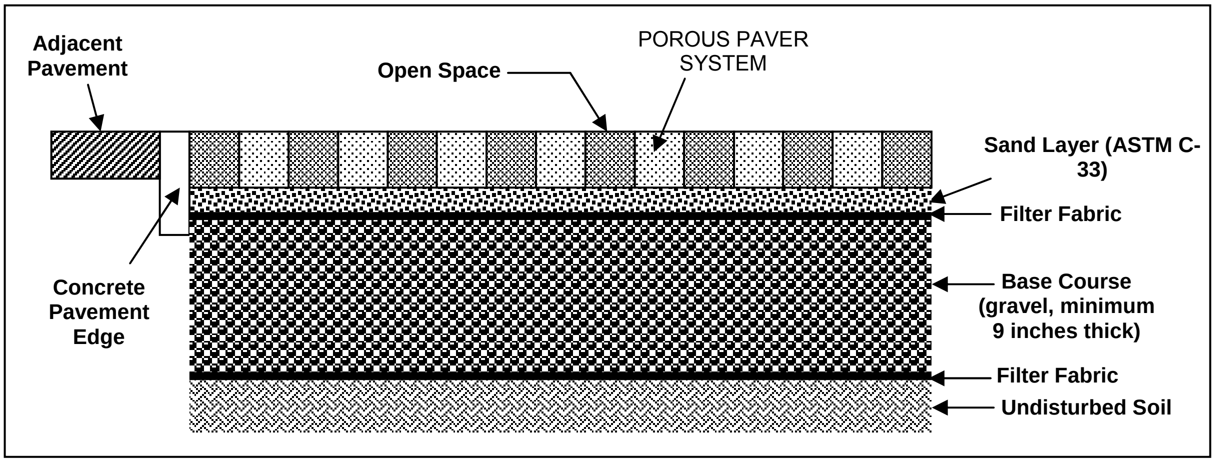

Figure 3-60 Modular Porous Paver System Section

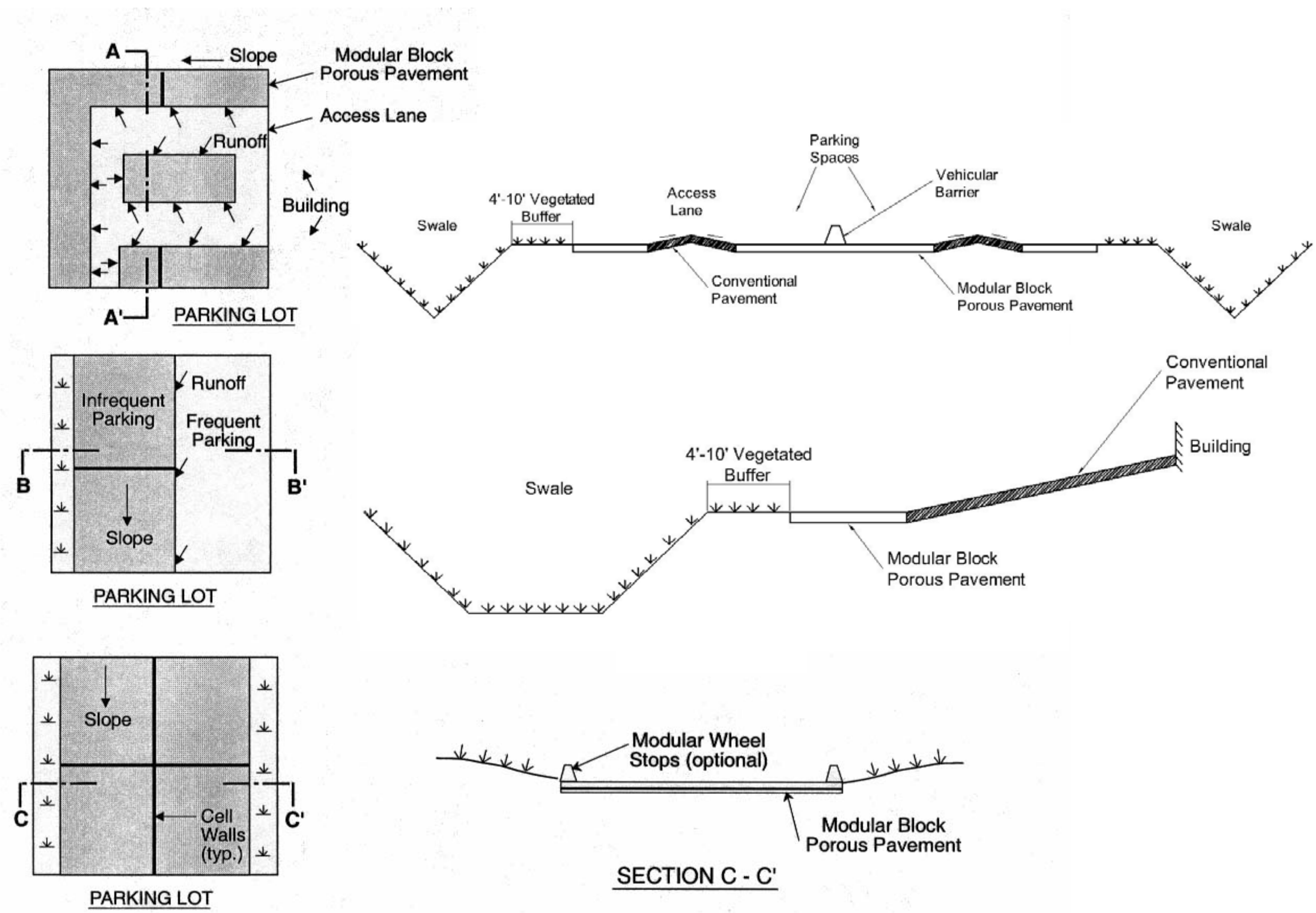

Figure 3-61 Typical Modular Porous Paver System Applications
(Source: UDFCD, 1999)

3.4.5 Green Roof

Other Water Quality Facility

Description: A green roof uses a small amount of substrate over an impermeable membrane to support a covering of plants. The green roof detains/retains runoff from the otherwise impervious roof surface as well as moderate rooftop temperatures. With the right plants, a green roof will also provide aesthetic or habitat benefits. Green roofs have been used in Europe for decades.

(Hamilton Building, Portland OR)

KEY CONSIDERATIONS

DESIGN CRITERIA:

- Relatively new in North America
- Potential for high failure rate if poorly designed, poorly constructed, not adequately maintained

ADVANTAGES / BENEFITS:

- Provides reduction in runoff volume
- Energy savings, aesthetics, allows dual use, noise reduction, reduces urban heat island effect

DISADVANTAGES / LIMITATIONS:

- High cost
- Requires additional roof support
- Requires more maintenance than regular roofs
- Special attention to design and construction needed
- Requires close coordination with plant specialists
- Potential for leakage due to plant roots penetrating membrane

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Water Quality Prot ctio**
- ✓ **Channel Protection**
- ☐ **On Site Flood Control**
- ☐ **Downstream Flood Control**

IMPLEMENTATION CONSIDERATIONS

L	**Land Requirements**
H	**Relative Capital Costs**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No restrictions.*

Soils: *No restrictions*

L=Low **M**=Moderate **H**=High

POLLUTANT REMOVAL

--	**Total Suspended Solids**
--	**Nutrients –** Total Phosphorus & Total Nitrogen
--	**Metals –** Cadmium, Copper, Lead & Zinc
--	**Pathogens –** Coliform, Streptococci & E. Coli

3.4.5.1 General Description

Green roofs (also referred to as vegetated roofs, ecoroofs, roof gardens, or roof meadows) are vegetated roofs used in place of conventional roofing, such as gravel-ballasted roofs. They are used as part of sustainable development initiatives, along with narrow streets, permeable pavement, and various infiltration devices. There are two main types of green roofs. The first is what is called roof gardens or intensive green roofs. They may be thought of as a garden on the roof. They have a greater diversity of plants, including trees and shrubs, but require deeper soil, increased load bearing capacity, and require more maintenance. The second has been referred to as roof meadows or extensive green roofs. The vegetation is limited and similar to an alpine meadow, requiring less soil depth and minimal maintenance. Due to the considerably greater costs and structural design requirements of intensive green roofs, only the second type of green roof, the roof meadow or extensive type is discussed in this manual.

The green roof is designed to control smaller storms by intercepting and retaining or storing water until the peak storm event has passed. The plants intercept and delay runoff by capturing and holding precipitation in the foliage, absorbing water in the root zone, and slowing the velocity of direct runoff by increasing retardance to flow and extending the flowpath through the vegetation. Water is also stored and evaporated from the growing media. Green roofs can capture and evaporate up to 100 percent of the incident precipitation, depending on the roof design and the storm characteristics.

Monitoring in Pennsylvania, for instance, showed reductions of approximately 2/3 in runoff from a green roof (15.5 inches runoff from 44 inches of rainfall). Furthermore, runoff was negligible for storm events of less than 0.6 inches. A study done for Portland, Oregon, indicated a reduction in stormwater discharges from the downtown area of between 11 and 15% annually if half of the roofs in the downtown area were retrofitted as green roofs.

Green roofs also:

- reduce the temperature of runoff;
- reduce the “heat island” effect of urban buildings;
- help insulate the building;
- improve visual aesthetics;
- protect roofs from weather;
- improve building insulation;
- reduce noise; and,
- provide habitat for wildlife.

As with a conventional roof, a green roof must safely drain runoff from the roof. It may be desirable to drain the runoff to a rainwater harvesting system such as rain barrels or other stormwater facilities such as rain gardens and swales.

Significant removals of heavy metals by green roofs have been reported, but there is not enough evidence to include removal rates at this time.

3.4.5.2 Design Criteria and Specifications

- An architect or structural engineer must be involved to ensure that the building will provide the structural support needed for a green roof.
- Generally, the building structure must be adequate to hold an additional 10 to 25 pounds per square foot (psf) saturated weight, depending on the vegetation and growth medium that will be used. (This is in addition to snow load requirements.) <u>These loads are for preliminary planning only and may vary significantly from design loads</u>.
- Green roofs can be used on flat or pitched roofs up to 40 percent. Although, on a roof slope greater than 10 degrees, the green roof installer needs to ensure that the plant layer does not slip or slump through its own weight, especially when it becomes wet. Horizontal strapping, wood, plastic, or metal, may be necessary. Some commercial support grid systems are also available for this purpose.
- A green roof typically consists of several layers, as shown in Figure 3-62. A waterproof membrane is placed over the roof's structure. A root barrier is placed on top of the membrane to prevent roots from penetrating the membrane and causing leaks. A layer for drainage is installed above this, followed by the growth media. The vegetation is then planted to form the top layer. Details of the various layers are given below.
- Waterproof membranes are made of various materials, such as synthetic rubber (EPDM), hypolan (CPSE), reinforced PVC, or modified asphalts (bitumens). The membranes are available in various forms, liquid, sheets, or rolls. Check with the manufacturer to determine their strength and functional characteristics of the membrane under consideration.
- Root barriers are made of dense materials or are treated with copper or other materials that inhibit root penetration, protecting the waterproof membrane from being breached. A root barrier may not be necessary for synthetic rubber or reinforced PVC membranes, but will likely be needed for asphalt mixtures. Check with the manufacturer to determine if a root barrier is required for a particular product.
- The drainage layer of a green roof is usually constructed of various forms of plastic sheeting, a layer of gravel, or in some cases, the growth medium.
- The growth medium is generally 2 to 6 inches thick and made of a material that drains relatively quickly. Commercial mixtures containing coir (coconut fiber), pumice, or expanded clay are available. Sand, gravel, crushed brick, and peat are also commonly used. Suppliers recommend limiting organic material to less than 33% to reduce fire hazards and prevent long-term degradation. The City of Portland, Oregon has found a mix of 1/3 topsoil, 1/3 compost, and 1/3 perlite may be sufficient for many applications. Growth media can weigh from 16 to 35 psf when saturated depending on the type (intensive/extensive), with the most typical range being from 10-25 psf.

- When dry, all of the growth media are light-weight and prone to wind erosion. It is important to keep media covered before planting and ensure good coverage after vegetation is established.
- Selecting the right vegetation is critical to minimize maintenance requirements. Due to the shallowness of the growing medium and the extreme desert-like microclimate on many roofs, plants are typically alpine, dryland, or indigenous. Ideally, the vegetation should be:
  - Drought-tolerant, requiring little or no irrigation after establishment;
  - Self-sustaining, without fertilizers, pesticides, or herbicides;
  - Able to withstand heat, cold, and high winds;
  - Shallow root structure;
  - Low growing, needing little or no mowing or trimming; and,
  - Perennial or self propagating, able to spread and cover blank spots by itself.
- A mix of sedum/succulent plant communities is recommended because they possess many of these attributes. Certain wildflowers, herbs, forbs, grasses, mosses, and other low groundcovers can also be used to provide additional habitat benefits or aesthetics; however, these plants need more watering and maintenance to survive and keep their appearance.
- Green roof vegetation is usually established by one or more of the following methods: seeding, cuttings, vegetation mats, and plugs/potted plants.
  - Seeds can be either hand sown or broadcast in a slurry (hydroseeded). Seeding takes longer to establish and requires more weeding, erosion control, and watering than the other methods.
  - Cuttings or sprigs are small plant sections. They are hand sown and require more weeding, erosion control, and watering than mats.
  - Vegetation mats are sod-like mats that achieve full plant coverage very quickly. They provide immediate erosion control, do not need mulch, and minimize weed intrusion. They generally require less ongoing maintenance than the other methods but are more expensive.
  - Plugs or potted plants may provide more design flexibility than mats. However, they take longer to achieve full coverage, are more prone to erosion, need more watering during establishment, require mulching, and more weeding.
- Irrigation is necessary during the establishment period and possibly during drought conditions, regardless of the planting method used. The goal is to minimize the need for irrigation by paying close attention to plant selection, soil, and various roof characteristics.
- It is necessary to provide controlled overflow point(s) to prevent overloading of roof.

3.4.5.3 Inspection and Maintenance Requirements

Table 3-11 Typical Maintenance Activities for Green Roofs

Activity	Schedule
Watering to help establish vegetation	As needed
Replant to cover bare spots or dead plants	Monthly
Weeding (as needed, based on inspection)	Two or three times yearly
Water and trimming to prevent fire hazards (if grasses or similar plants are used)	As needed
Inspect drains for clogging	Twice per year
Inspect the roof for leakage	Annually, or as needed
If leaks occur, remove and stockpile vegetation, growth media, and drainage layer. Replace membrane and root barrier, followed by stockpiled material.	Upon failure

3.4.5.4 Example Schematic

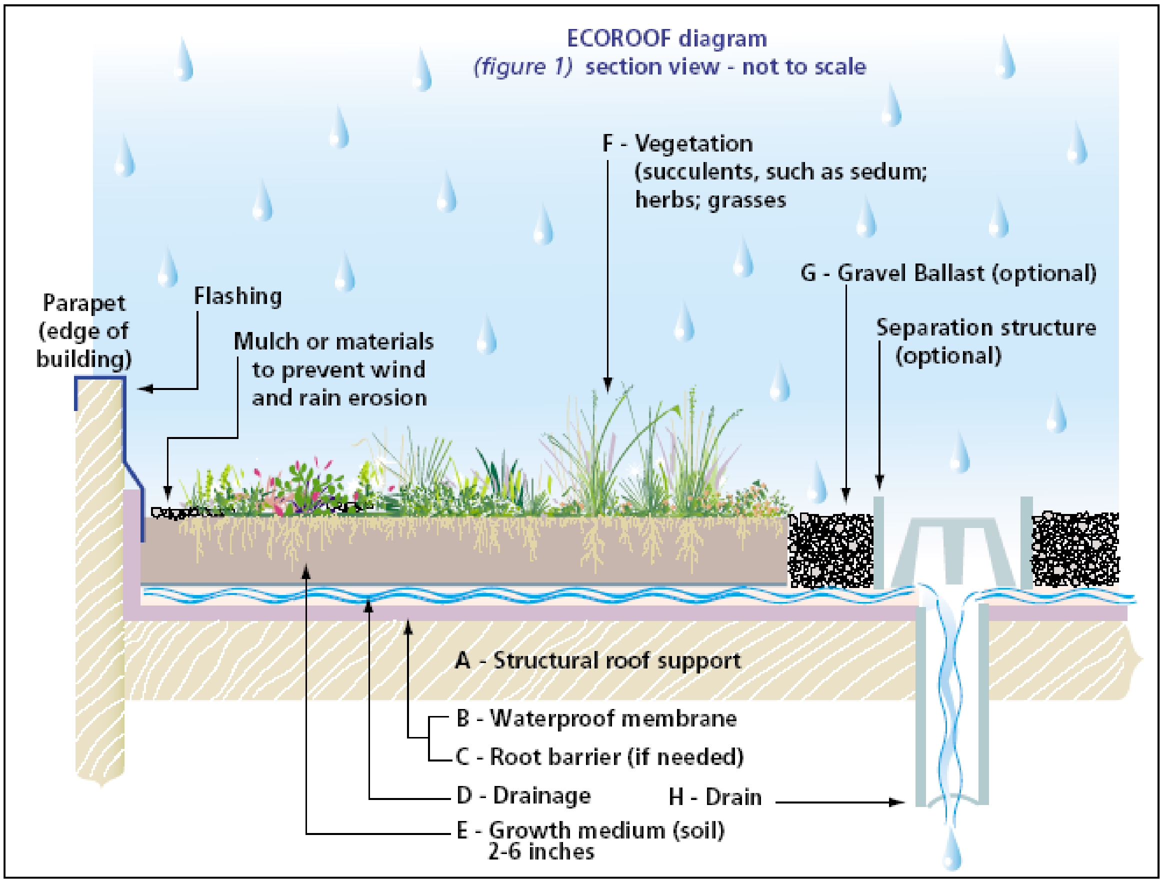

Figure 3-62 Typical Green Roof Cross Section
(from City of Portland, Oregon)

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