Chapter 11

Stormwater Treatment Practice Design Guidance

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Volume II: Design

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This chapter provides guidance on the design, construction, and maintenance of the stormwater treatment practices contained in this Manual. **Table 11-1** lists the individual primary and secondary stormwater treatment practices that were introduced in Chapter Six and are described further in subsequent sections of this chapter.

Table 11-1
Summary of Stormwater Treatment Practices

Primary (P) Treatment Practice	Secondary (S) Treatment Practice
Stormwater Ponds (P1) ○ Micropool Extended Detention Pond ○ Wet Pond ○ Wet Extended Detention Pond ○ Multiple Pond System ○ Pocket Pond Stormwater Wetlands (P2) ○ Shallow Wetland ○ Extended Detention Wetland ○ Pond/Wetland System Infiltration Practices (P3) ○ Infiltration Trench ○ Infiltration Basin Filtering Practices (P4) ○ Surface Sand Filter ○ Underground Sand Filter ○ Perimeter Sand Filter ○ Organic Filter ○ Bioretention Water Quality Swales (P5) ○ Dry Swale ○ Wet Swale	Conventional Practices ○ Dry Detention Pond (S1) ○ Underground Detention Facilities (S2) ○ Deep Sump Catch Basins (S3) ○ Oil/Particle Separators (S4) ○ Dry Wells (S5) ○ Permeable Pavement (S6) ○ Vegetated Filter Strips/Level Spreaders (S7) ○ Grass Drainage Channels (S8) Innovative/Emerging Technologies ○ Catch Basin Inserts (S9) ○ Hydrodynamic Separators (S10) ○ Media Filters (S11) ○ Underground Infiltration Systems (S12) ○ Alum Injection (S13)

Primary Treatment Practices

This chapter provides the following information for each primary treatment practice:

Description: A brief description of the treatment practice. The stormwater management benefits of the treatment practice (i.e., runoff volume reduction, pollutant reduction, stream channel/conveyance protection, and flood control) and effectiveness for removal of specific categories of pollutants are summarized at the beginning of each description for quick reference and screening.

Design Variations: Descriptions of common design variations for those treatment practices for which multiple designs have been developed.

Advantages: The major beneficial factors or considerations (e.g., environmental, economic, safety) for selecting a specific stormwater treatment practice.

Limitations: The major limitations or drawbacks of a stormwater treatment practice that may preclude its use for a given site.

Siting Considerations: The site conditions required for implementation of a stormwater treatment practice, such as minimum contributing drainage area, subsurface conditions, and minimum setbacks.

Design Criteria: Specific technical requirements and recommendations for designing the major elements of a stormwater treatment practice, including criteria for design variants within each treatment practice category.

Construction: Recommended construction procedures and methods to ensure that a stormwater treatment practice functions as designed.

Inspection and Maintenance: Routine and non-routine operation and maintenance required for the stormwater treatment practice to function properly over time.

Cost Considerations: Approximate capital costs to design, construct, and implement the stormwater treatment practice, as well as approximate annual operation and maintenance costs, where available.

Secondary Treatment Practices

Secondary treatment practices are described in less detail due to their limited applicability for water quality control. The following guidance is provided for these treatment practices:

Description: A brief description and associated stormwater management benefits of the treatment practice.

Reasons for Limited Use: Rationale for why the practice generally does not meet the performance standards required for classification as a primary treatment practice.

Suitable Applications: The conditions or applications for which the practice is typically suitable (i.e., pretreatment, ultra-urban environments, etc.)

Design Considerations: Key factors for siting, designing, and implementing the treatment practice.

Stormwater Ponds

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Primary Treatment Practice	●
Secondary Treatment Practice	

Stormwater Management Benefits

Pollutant Reduction	
Sediment	■
Phosphorus	■
Nitrogen	■
Metals	■
Pathogens	▣
Floatables*	■
Oil and Grease*	■
Dissolved Pollutants	▣
Runoff Volume Reduction	
Runoff Capture	■
Groundwater Recharge	□
Stream Channel Protection	■
Peak Flow Control	■

Key: ■ Significant Benefit
▣ Partial Benefit
□ Low or Unknown Benefit

*Only if a skimmer is incorporated

Implementation Requirements

Cost ....Moderate
Maintenance.......................Moderate

Description

Stormwater ponds are vegetated ponds that retain a permanent pool of water and are constructed to provide both treatment and attenuation of stormwater flows. This section addresses four types of stormwater ponds:

- *Wet Pond*
- *Micropool Extended Detention Pond*
- *Wet Extended Detention Pond*
- *Multiple Pond System*

Through careful design, stormwater ponds can be effective at removing urban pollutants. Treatment is primarily achieved by the sedimentation process where suspended particles and pollutants settle to the bottom of the pond. Stormwater ponds can also potentially reduce soluble pollutants in stormwater discharges by adsorption to sediment, bacterial decomposition, and the biological processes of aquatic and fringe wetland vegetation.

The key to maximizing the pollutant removal effectiveness of stormwater ponds is maintaining a permanent pool. To achieve this, wet ponds typically require a large contributing watershed with either an impermeable liner or an elevated water table without a liner. The pool typically operates on the instantaneously mixed reservoir principle where incoming water mixes with the existing pool and undergoes treatment through sedimentation and the other processes. When the existing pool is at or near the pond outlet or when the primary flow path through the pond is highly linear, the pond may act as a plug flow system in which incoming water displaces the permanent pool, which is then discharged from the pond. The value provided by this process is that a portion of the "new," polluted runoff is retained as the "old," treated water is discharged from the pond, thereby allowing extended treatment of the water quality volume (WQV). For example, when sized to store the WQV, a pond system will retain all of the water from storms that generate runoff less than or equal to the WQV and result in a significantly increased period of time available for treatment. For storms that generate runoff greater than the WQV, wet ponds still provide a reduced level of treatment through conventional settling and filtration for the additional runoff volume that is conveyed through the pond. The pond volume should be greater than or equal to the WQV to ensure at least one-day retention time within the pond.

When properly designed, the permanent pool reduces the velocity of incoming water to prevent resuspension of particles and promote settling of newly introduced suspended solids. The energy dissipating and treatment properties of the permanent pool are enhanced by aquatic vegetation, which is an essential part of the stormwater pond design. In contrast, dry detention ponds, or dry extended detention ponds that have no permanent pool, are not considered an acceptable option for treating the WQV due to the potential for resuspension of accumulated sediment by incoming storm flows during the early portion of a storm event when the pond is empty.

Several design variations of stormwater ponds exist that can fit a wide range of design conditions. Descriptions of these design variations are provided in the following section.

Design Variations

Wet Ponds: Wet ponds typically consist of two general components - a forebay and a permanent wet pool. The forebay provides pretreatment by capturing coarse sediment particles in order to minimize the need to remove the sediments from the primary wet pool. The wet pool serves as the primary treatment mechanism and where much of the retention capacity exists. Wet ponds can be sized for a wide range of watershed sizes, if adequate space exists. For example, a variation on the conventional wet pond, sometimes referred to as a "pocket pond", is intended to serve relatively small drainage areas (between one and five acres). Because of these smaller drainage areas and the resulting lower hydraulic loads of pocket ponds, outlet structures can be simplified and often do not have safety features such as emergency spillways and low level drains. **Figure 11-P1-1** depicts a typical schematic design of a conventional wet pond, while **Figure 11-P1-2** shows a typical schematic design of a modified wet pond or "pocket pond".

Several adaptations of this basic design have been developed to achieve the specific treatment goals of various watershed or site conditions. These wet pond design variations are described below.

Micropool Extended Detention Pond: Micropool extended detention basins are primarily used for peak runoff control and utilize a smaller permanent pool than conventional wet ponds. While micropool extended detention ponds are not as efficient as wet ponds for the removal of pollutants, they should be considered when a large open pool might be undesirable or unacceptable. Undesirable conditions could include thermal impacts to receiving streams from a large open pool, safety concerns in residential areas, or where maintaining a large open pool of water would be difficult due to a limited drainage area or deep groundwater.

Micropool extended detention ponds are also efficient as a stormwater retrofit to improve the treatment performance of existing detention basins. **Figure 11-P1-3** depicts a typical schematic design of a micropool extended detention pond.

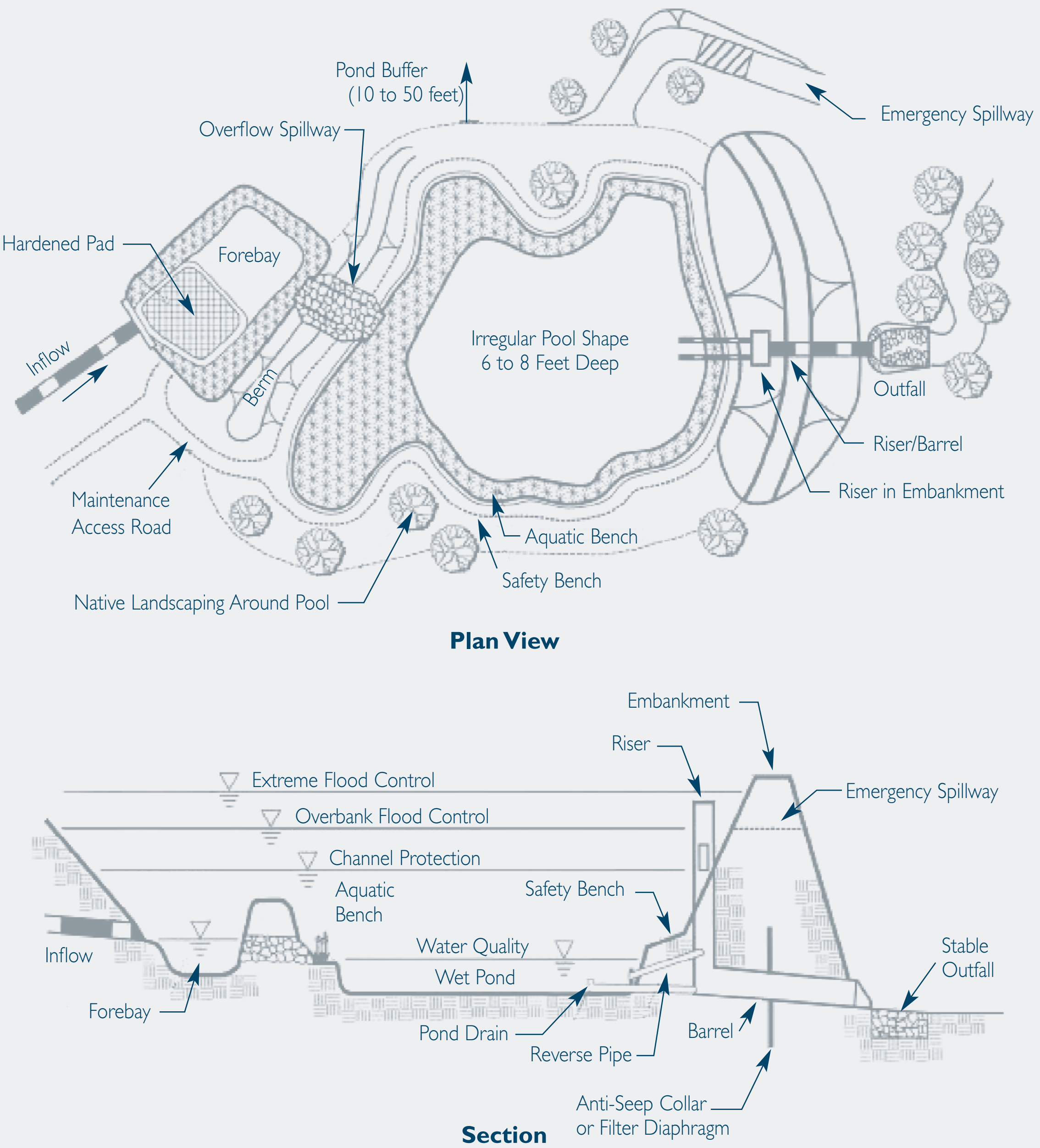
Wet Extended Detention Ponds: These ponds are very similar to wet ponds with the exception that their design is more focused on attenuating peak runoff flows. As a result, more storage volume is committed to managing peak flows as opposed to maximizing the wet pool depth. The configuration of the outfall structure may also differ from typical wet pond designs to provide additional storage volume above the level of the permanent pool. **Figure 11-P1-4** depicts a typical schematic design of a wet extended detention pond.

Multiple Pond System: Multiple pond systems consist of several wet pools that are constructed in a series following a forebay. The advantage of these systems is that they can improve treatment efficiency by better simulating plug flow conditions as compared to a single large wet pool. Also, these systems can reduce overall maintenance needs since more frequent maintenance would be performed within the first pool cells as opposed to the large, primary pool. The disadvantage of these systems is that they typically require more land area to treat the same water quality volume. **Figure 11-P1-5** depicts a typical schematic design of a multiple pond system.

Advantages

- *Can capture/treat both particulate and soluble pollutants. Stormwater ponds are one of the most effective stormwater treatment practices for treating soluble pollutants.*
- *Can provide an aesthetic benefit if open water is desired as part of an overall landscaping plan.*
- *May provide wildlife habitat with appropriate design elements.*
- *Can be adapted to fit a wide range of sites. Design variations allow this control to be utilized for both small and large drainage areas. Pollutant removal mechanisms make stormwater ponds efficient in treatment of pollutants-of-concern from a wide range of land uses.*

Figure 11-P1-1 Wet Pond



Source: Adapted from NYDEC, 2001.

Limitations

- *Unlined ponds that intercept groundwater have potential to impact groundwater quality if dissolved pollutants are present in the runoff.*
- *Lined ponds typically require a minimum drainage area in order to maintain a permanent pool, which may become difficult during extended dry periods.*
- *Require a relatively large land area that is directly proportional to the size of the area draining to it.*
- *May cause thermal impacts to receiving waters and thereby are not recommended to discharge directly to cold water fish habitats.*
- *Require more storage volume (i.e., above permanent pool) to attenuate peak flows.*
- *Potential breeding habitat for mosquitoes, particularly for smaller ponds with stagnant water or isolated pockets of standing water (rather than large open water bodies). Circulating water in the permanent pool may minimize this problem. This may be a more significant problem for lined basins.*
- *Pollutant removal efficiency can be affected in cold climates due to ice formation on the permanent pool and longer particle settling times associated with higher density water during winter months. However, modifications to a pond's design can help maintain the primary pollutant removal mechanism of sedimentation.*
- *Ponds with steep side slopes and/or deep wet pools may present a safety issue to nearby pedestrians.*
- *Stormwater ponds can serve as decoy wetlands, intercepting breeding amphibians moving toward vernal pools. If amphibians deposit their eggs in these artificial ponds/wetlands, they rarely survive due to the sediment and pollutant loads, as well as fluctuations in water quality, quantity, and temperature.*

Siting Considerations

Drainage Area: Stormwater ponds that utilize a liner system should have a contributing drainage area that is adequate to maintain minimum water levels. Typically, minimum contributing watersheds for unlined ponds are twenty-five acres for wet ponds, wet extended detention ponds, and multiple pond systems; ten acres for micropool extended detention ponds; and one to five acres for pocket ponds.

Groundwater: Unlined basins must intersect the groundwater table in order to maintain the desired permanent pool. In this case, the elevations of the basin should be established such that the groundwater elevation is equal to the desired permanent pool elevation. Seasonal variations of groundwater elevations should be considered, which can be very pronounced in low permeability soils.

Land Uses: Land uses will dictate potential pollutants-of-concern and potential safety risks. For those land uses where there is significant potential for soluble pollutants, especially those that are highly susceptible to groundwater transport, the use of a liner is recommended. An impermeable liner may not be required depending on risk of downstream contamination, but a low permeability liner constructed in till soils may be acceptable. With regard to potential safety issues, adjacent residential land uses pose the greatest risks where mosquito breeding and water hazards must be considered.

Baseflow: A small amount of baseflow is desirable to maintain circulation and reduce the potential for low dissolved oxygen levels during late summer. This baseflow can be provided by groundwater infiltrating into either the basin or the collection system above the pond.

Site Slopes: Steep on-site slopes may result in the need for a large embankment to be constructed to provide the desired storage volume, which could require a dam construction permit from the Connecticut DEP. Steep slopes may also present design and construction challenges, and significantly increase the cost of earthwork.

Receiving Waters: The sensitivity of receiving waters should be evaluated to determine whether the effects of the warmer stormwater discharges from the wet pond could be detrimental to cold water fish or other sensitive aquatic species.

Flood Zones: Ponds should not be located in floodways, floodplains, or tidal lands, especially those that require construction of an embankment. Floodwaters could flush out stored pollutants or damage pond embankments.

Natural Wetlands/Vernal Pools: Natural wetlands and vernal pool depressions should not be used, either temporarily or permanently, as a stormwater pond or wetland. Stormwater ponds should be located at least 750 feet from a vernal pool. They should not be sited between vernal pools, or in areas that are known primary amphibian overland migration routes.

Table 11-P1-1 Design Criteria for Stormwater Ponds

Parameter	Design Criteria
Setback requirements[1]	❍ 50 feet from on-site sewage disposal systems ❍ 50 feet from private wells ❍ 10 feet from a property line ❍ 20 feet from any structure ❍ 50 feet from any steep slope (greater than 15%) ❍ 750 feet from a vernal pool
Preferred Shape	Curvilinear
Side Slopes	3:1 maximum or flatter preferred
Length to Width Ratio	3:1 minimum along the flow path between the inlet and outlet; flow length is the length at mid-depth (avg. top width+avg. bottom width)/2
Pretreatment Volume	Forebays are highly recommended for wet ponds and sized to contain 10% of the WQV. For sites with potential for higher pollutant loads (see Chapter Seven), 100% of the WQV must receive pretreatment.
Pond Volume	Minimum pond volume, including pretreatment volume, should be equal to or exceed the WQV.
Drainage Area	Minimum contributing drainage area is 25 acres for wet ponds, 10 acres for extended detention basins, and 1-5 acres for pocket ponds.
Underlying Soils	Low permeability soils are best (NRCS Hydrologic Soil Group A and B soils require modifications to maintain a permanent pool unless groundwater is intercepted).
Capacity	The minimum ratio of pool volume to runoff volume must be greater than 2:1 and preferably 4:1. A 4:1 ratio provides 85-90% sediment removal based on a residence time of two weeks.
Depth	❍ An average pool depth of 3 to 6 feet is recommended and varying depths in the pond are preferred. ❍ The aquatic bench should be 12-18 inches deep. ❍ Ponds should not be greater than 8 feet deep.

1 Minimum requirements. State and local requirements supercede.

Design Criteria

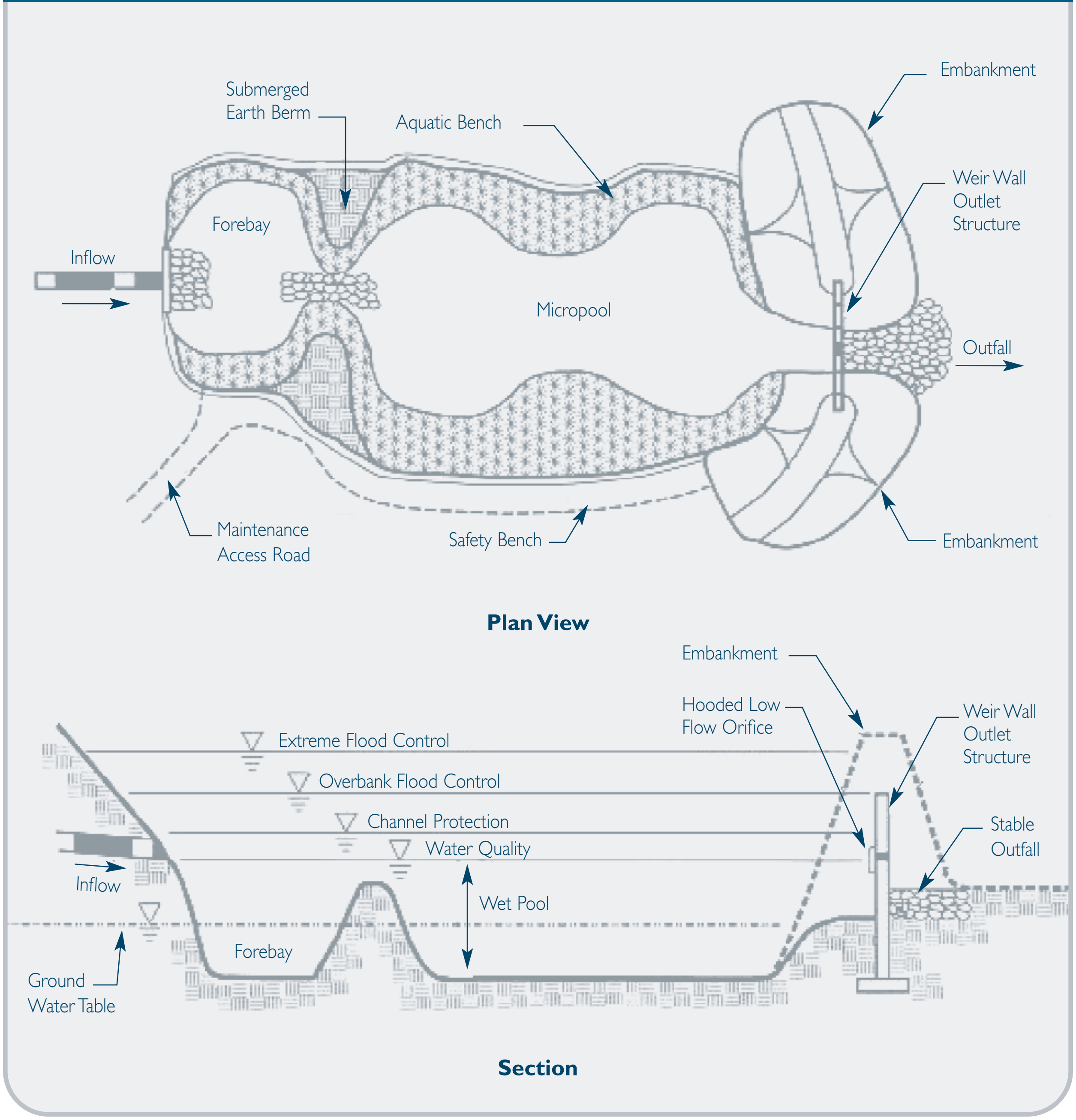
Pond designs may vary considerably due to site constraints, local requirements, or the designer's preferences. Design considerations for stormwater ponds are presented below and summarized in **Table 11-P1-1.**

Forebay

A sediment forebay is recommended for all wet pond systems. The purpose of the forebay is to provide pretreatment by settling out coarse sediment particles, which will enhance treatment performance, reduce maintenance, and increase the longevity of a stormwater pond. A forebay is a separate cell within the pond formed by a barrier such as an earthen berm, concrete weir, or gabion baskets.

- *The forebay should be sized to contain at least 10 percent of the WQV and be of an adequate depth to prevent resuspension of collected sediments during the design storm, often being four to six feet deep. The goal of the forebay is to at least remove particles consistent with the size of medium sand. The forebay storage volume may be used to fulfill the total WQV requirement of this system. The forebay must also include additional sediment storage volume that may not be used for WQV calculations.*
- *The outlet from the forebay should be designed in a manner that prevents erosion of the embankment and primary pool. This outlet can be configured in a number of ways including a culvert, weir, or spillway channel. The outlet should be designed to convey the same design flow proposed to enter the basin. The outlet invert must be elevated in a manner such that 10 percent of the WQV can be stored below it in addition to the required sediment volume.*
- *The forebay should have a minimum length to width ratio of 2:1 and a preferred length to width ratio of 3:1.*

Figure 11-P1-2 Pocket Pond



Source: Adapted from NYDEC, 2001.

Design Variation	Percent of Water Quality Volume (WQV) Permanent Pool	Extended Detention
Wet Pond	100%	0%
Micropool Extended Detention Pond	20% min.	80% max.
Wet Extended Detention Pond	50% min.	50% max.
Multiple Pond System	50% min.	50% max.
Pocket Pond	50% min.	50% max.

Table 11-P1-2 Water Quality Volume Distribution in Pond Designs

Source: NYDEC, 2001.

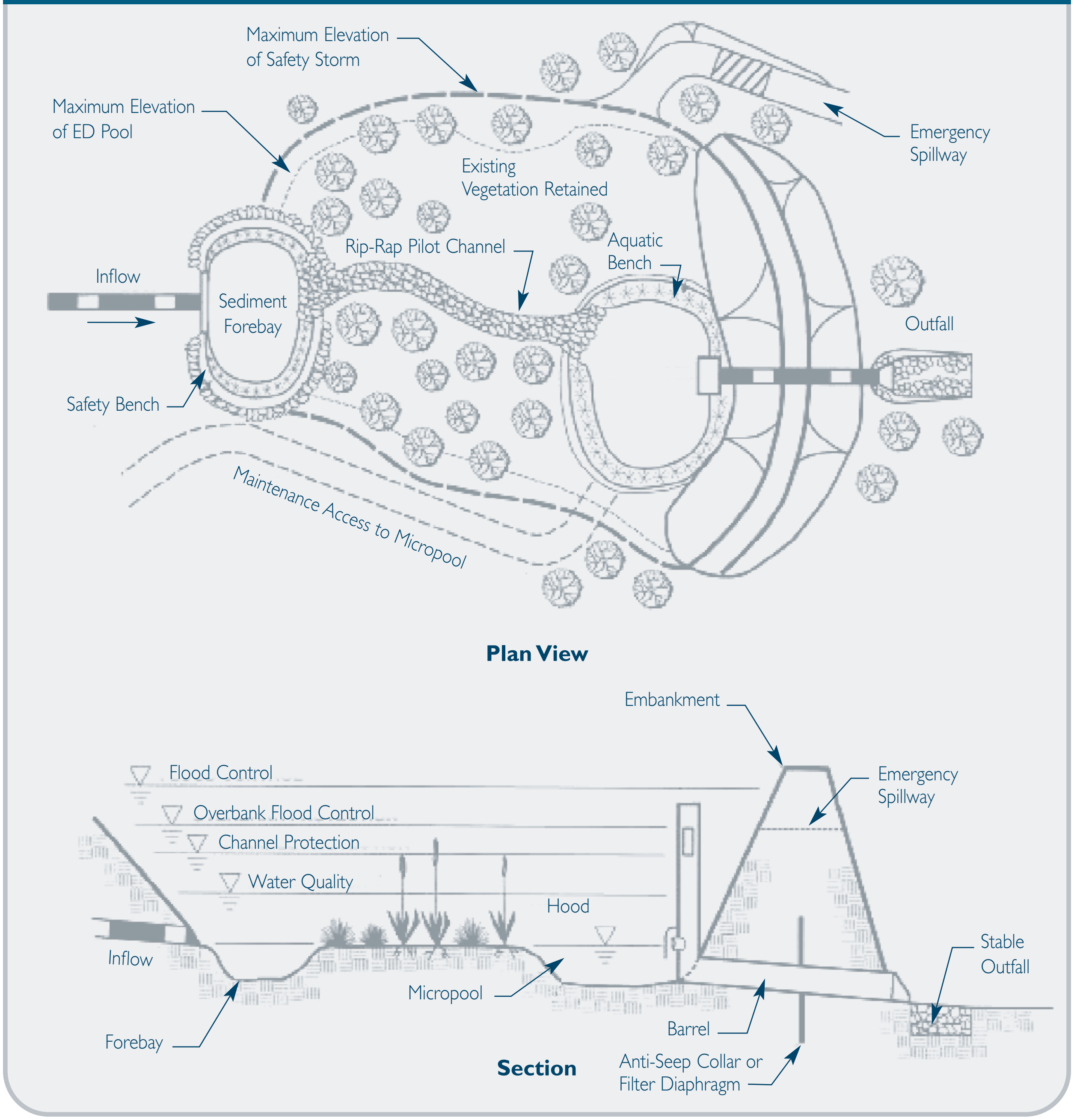
- *Direct access for appropriate maintenance equipment should be provided to the forebay and may include a ramp to the bottom if equipment cannot reach all points within the forebay from the top. The forebay can be lined with a concrete pad to allow easy removal of sediment and to minimize the possibility of excavating subsurface soils or undercutting embankments during routine maintenance.*
- *A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition.*
- *A barrier, such as an earthen berm, gabions, or a concrete weir may be used to separate the forebay from the permanent pool. This barrier should be armored as necessary to prevent erosion of the embankment if it overtops. This armoring could consist of materials such as riprap, pavers, or geosynthetics designed to resist slope erosion. If a channel is used to convey flows from the forebay to the pond, the side slopes of the channel must be armored as well.*
- *Additional pretreatment can be provided in the forebay by raising the embankment to provide some detention of incoming flows.*

Wet Pool

Stormwater pond design features primarily enhance the removal of pollutants by increasing the residence time of stormwater in the pond and providing habitat for aquatic plants.

- *Provide water quality treatment storage to capture the computed WQV from the contributing drainage area in the proposed forebay, permanent pool, extended detention area, and marsh. The division of storage between the permanent pool and extended detention is outlined in* ***Table 11-P1-2.***
- *Water quality storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, extended detention, and marsh).*
- *The minimum pool size should be equal to the WQV. A larger volume should be used to achieve greater pollutant removal when it is necessary to meet specific water quality standards.*
- *Underwater or marsh berms may be incorporated in the design to lengthen the flow path through the pond.*
- *Shade should be provided, at a minimum, at least at the pond outlet in an effort to mitigate warming of discharge water.*
- *The minimum length:width ratio for the pond is 3:1.*
- *Upper stages of the pond should provide temporary storage of large storms (10, 25, or 100-year events) to control peak discharge rates.*
- *Provide variable pond depths of 4 to 6 feet but not exceeding depths of 8 feet. Maintaining pond water depths in excess of 4 feet precludes invasive emergent vegetation such as cattails. Emergent vegetation provides mosquito larvae with refuge from predators and increases nutrient availability.*
- *Chemicals (e.g., aluminum sulfate or alum) can be injected into pond stormwater discharges or added directly to the permanent pool or*

Figure 11-P1-3 Micropool Extended Dentention Pond



Source: Adapted from NYDEC, 2001.

sediment forebay to enhance removal of fine particulates and dissolved pollutants within the pond.

- *Maintain pond water quality sufficient to support mosquito-feeding fish. Stormwater ponds often develop mini-ecosystems where birds, frogs, and other insects feed, many of which are natural predators of mosquitoes and nuisance insects. Ponds can also be stocked with predatory fish native to Connecticut that feed on mosquito larvae such as banded sunfish, flathead minnows, Eastern mud minnows, and several species of killfish. The DEP Fisheries Division should be consulted regarding species selection. Other natural predators of mosquitoes such as dragonfly nymphs can also be used.*

Conveyance

Stormwater should be conveyed to and from all stormwater management practices safely and to minimize erosion potential.

Inlet Protection

- *The number of inlets should be minimized and one inlet is preferable. The inlet should be located at the most hydraulically remote point from the outlet to minimize the potential for short-circuiting, and should be located in a manner that meets or exceeds desired length to width ratios.*
- *Inlet areas should be stabilized to ensure that non-erosive conditions exist for the design storm event.*
- *The ideal inlet configuration is above the permanent pool to prevent potential hydraulic constrictions due to freezing.*

Outlet Protection

- *The channel immediately below a pond outfall should be modified to prevent erosion and conform to natural topography by use of a plunge pool or a riprap pad and sized for peak discharge velocities.*
- *Outlet protection should be used to reduce flow to non-erosive velocities from the principal spillway based on actual cover and soil conditions.*
- *If a pond outlet discharges to a perennial stream or channel with dry weather base flow, tree clearing should be minimized and a forested riparian zone re-established.*
- *To convey potential flood flows from the basin, an armored emergency spillway should be provided.*

Pond Liners

- *When a pond is located such that the permanent pool does not intercept groundwater, a liner may be needed to maintain minimum water levels. Pond liners are also necessary for ponds that may present a risk to groundwater quality.* ***Table 11-P1-3*** *lists recommended specifications for clay and geomembrane liners.*

Pond Benches

- *For pond side slopes steeper than 4:1, provide a flat safety bench that extends 10 feet outward from the normal water edge to the toe of the pond side slope.*
- *Incorporate a flat aquatic bench that extends 10 feet inward from the normal shoreline at a depth of 12-18 inches below the normal pool water surface elevation.*

Table 11-P1-3 Linear Specifications

Linear Material	Property	Recommended Specifications
Clay	Minimum Thickness	6 to 12 inches
	Permeability	1x10-5 cm/sec[1]
	Particle Size	Minimum 15% passing #200 sieve[1]
Geomembrane	Minimum Thickness	30 mils (0.03 inches)
	Material	Ultraviolet resistant, impermeable poly-liner

Source: [1]NYDEC, 2001; all other listed specifications from City of Austin in Washington, 2000 (in Metropolitan Council, 2001).

Maintenance Reduction Features

In addition to regular maintenance activities needed to maintain the function of stormwater practices, some design features can be incorporated to ease the maintenance burden of each practice. In wet ponds, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

- *Ponds should be designed with non-clogging outlets, such as a weir, or by incorporating trash racks for culverts and orifice openings.*
- *To prevent clogging from ice or floatables, a reverse slope outlet pipe can be used to draw water from below the permanent pool up to the outlet structure. The invert of the pipe drawing from the pool should be at least 18 inches from the bottom to prevent sediment discharge.*
- *No orifice should be less than 6 inches in diameter with a trash rack to prevent clogging.*
- *Ponds should have a manually operated drain to draw down the pond for infrequent maintenance or dredging of the main cell of the pond.*
- *Metal components of outlet structures should be corrosion resistant, but not galvanized due to the contribution of zinc to water.*
- *Outlet structures should be resistant to frost heave and ice action in the pond.*

Landscaping

Constructing landscaped wet ponds can enhance their aesthetic value. Aquatic plantings around the edge of the pond can provide pollutant uptake, stabilize the soil at the edge of the pond, and improve habitat. Maintaining high vegetation along the edge of the pond (not mowing to the edge) can also deter waterfowl access and filter pollutants.

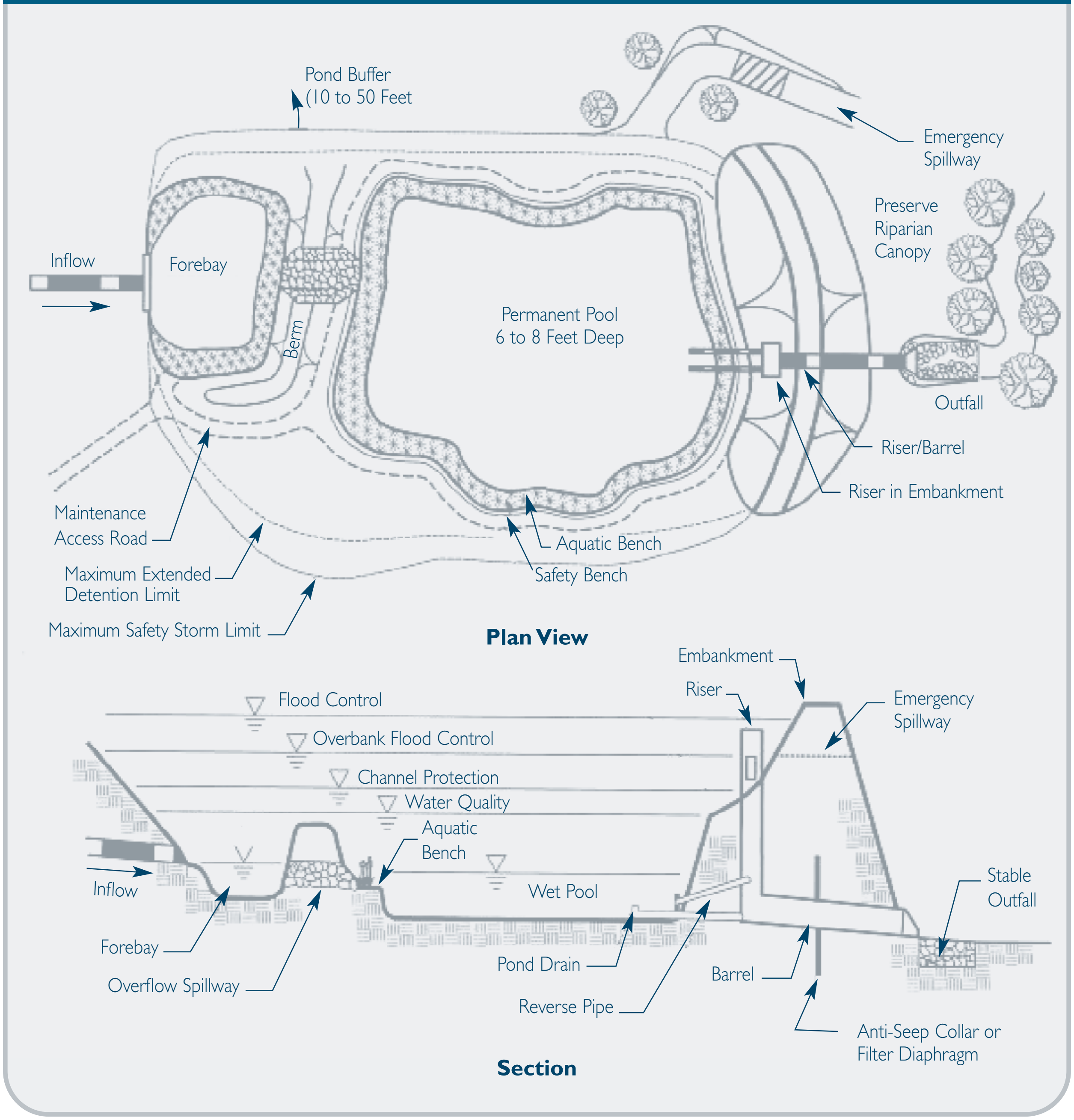
- *Wetland plantings should be encouraged in a pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes, or within shallow areas of the pool.*
- *The best depth for establishing wetland plants, either through transplantation or volunteer colonization, is within approximately six inches of the normal pool elevation.*
- *Soils should be modified (e.g., scarified or tilled) to mitigate compaction that occurs during construction around the proposed planting sites.*
- *Avoid species that require full shade, are susceptible to winterkill, or are prone to wind damage.*
- *Woody vegetation may not be planted or allowed to grow within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure.*
- *Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To help discourage resident geese populations, the buffer can be planted with trees, shrubs, and native ground covers.*
- *Annual mowing of the pond buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.*
- *Plant the pond with salt-tolerant vegetation if the stormwater pond receives road runoff.*

Cold Climate Pond Design Considerations

The following design elements should be considered to minimize potential performance impacts caused by cold weather:

- *Inlet pipes should not be submerged, since this can result in freezing and upstream damage or flooding.*
- *Bury all pipes below the frost line to prevent frost heave and pipe freezing. Bury pipes at the point furthest from the pond deeper than the frost line to minimize the length of pipe exposed.*
- *Increase the slope of inlet pipes to a minimum of 1 percent, if site conditions allow, to prevent standing water in the pipe and reduce the potential for ice formation.*
- *If perforated riser pipes are used, the minimum orifice diameter should be 0.5 inches. In addition, the pipe should have a diameter of at least 6 inches.*
- *When a standard weir is used, the minimum slot width should be 3 inches, especially when the slot is tall.*
- *Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of base flow through the system.*
- *In cold climates, riser hoods and reverse slope pipes should draw from at least 6 inches below the typical ice layer. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet. Reverse slope pipes should not be used for off-line ponds.*

Figure 11-P1-4 Wet Extended Detention Pond



Source: Adapted from NYDEC, 2001.

Table 11-P1-4 Typical Maintenance Activities for Stormwater Ponds	
Activity	**Schedule**
❍ If wetland components are included, inspect for invasive vegetation.	Semi-annual inspection
❍ Inspect for damage. ❍ Note signs of hydrocarbon build-up, and remove if detected. ❍ Monitor for sediment accumulation in the facility and forebay. ❍ Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual inspection
❍ Repair undercut or eroded areas.	As needed maintenance
❍ Clean and remove debris from inlet and outlet structures. ❍ Mow side slopes. High grass along pond edge will discourage waterfowl from taking up residence and serve to filter pollutants.	Monthly maintenance
❍ Wetland plant management and harvesting. ❍ Drain pond in fall and let frost kill plants, then dredge in spring.	Annual maintenance (if needed)
❍ Removal of sediment from the forebay.	5 year maintenance
❍ Remove sediment when the pool volume has become reduced significantly, or when significant algal growth is observed.	10 year maintenance; more frequent dredging in developing watersheds with significant sediment loads

Source: Adapted from WMI, 1997.

- *Trash racks should be installed at a shallow angle to prevent ice formation.*
- *Additional storage should be provided to account for storage lost to ice buildup. Ice thickness may be estimated by consulting with local authorities (e.g. the fire department) with knowledge of the typical ice thickness in the area.*

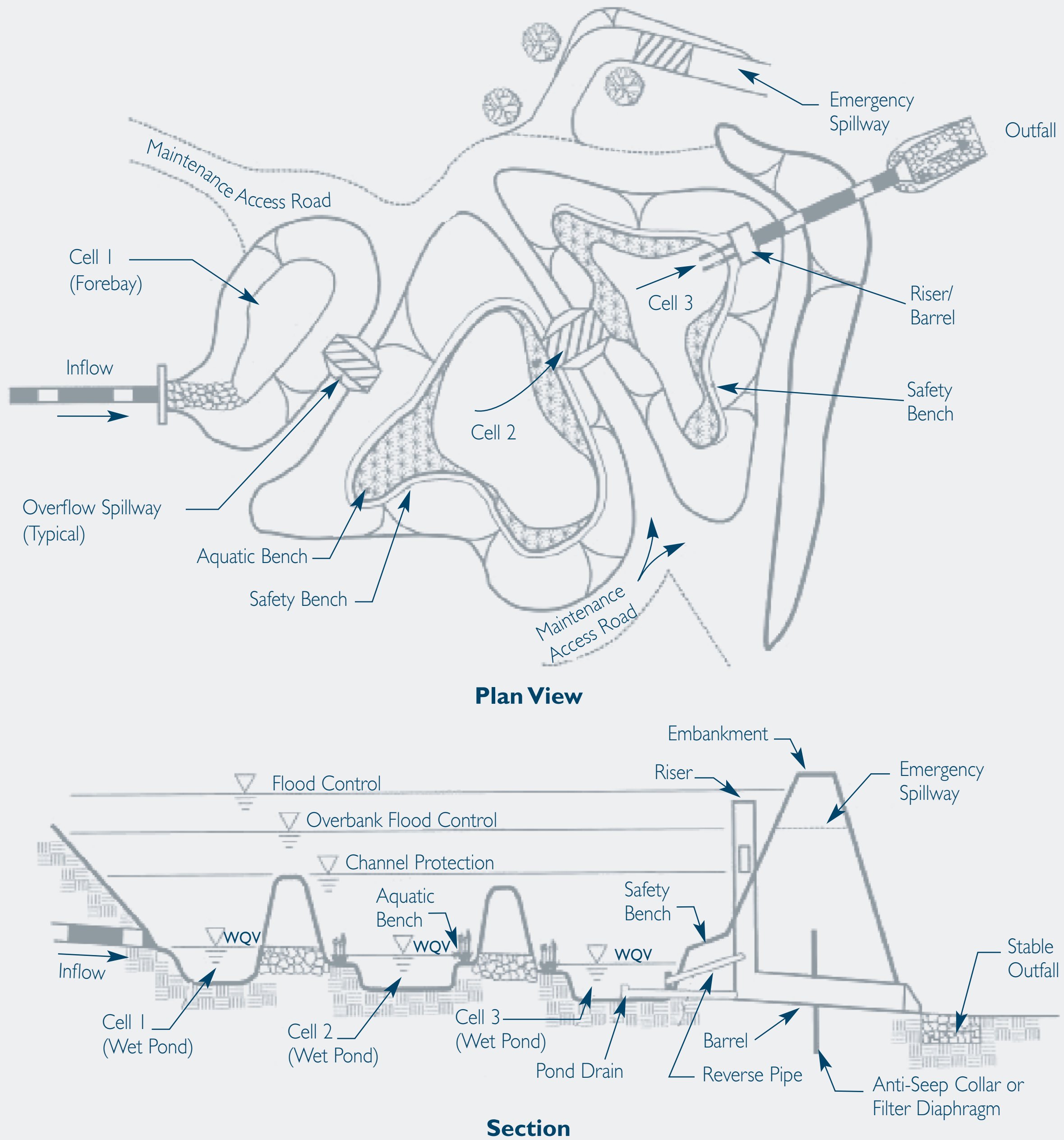
Construction

- *Any stormwater treatment practices that create an embankment, including stormwater ponds, are under the jurisdiction of the Dam Safety Section of the Connecticut DEP Inland Water Resources Division (IWRD) and should be constructed, inspected, and maintained in accordance with Connecticut General Statutes §§22a-401 through 22a-411, inclusive, and applicable DEP guidance.*
- *Avoid soil compaction to promote growth of vegetation.*
- *Temporary erosion and sediment controls should be used during construction and sediment deposited in the stormwater pond should be removed after construction.*
- *Appropriate soil stabilization methods should be used before permanent vegetation is established. Seeding, sodding, and other temporary soil stabilization controls should be implemented in accordance with the* Connecticut Guidelines for Soil Erosion and Sediment Control.
- *Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.*

Inspection and Maintenance

- *Plans for stormwater ponds should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.*
- *The principal spillway should be equipped with a removable trash rack, and generally accessible from dry land.*
- *Sediment removal in the forebay should occur at a minimum of every five years or after the sediment storage capacity in the forebay capacity has been filled.*

Figure 11-P1-5 Multiple Pond System



Source: Adapted from NYDEC, 2001.

- *Sediment removed from stormwater ponds should be disposed of according to an approved comprehensive operation and maintenance plan.*
- *Recommended maintenance activities for stormwater ponds are summarized in* ***Table 11-P1-4.***

Maintenance Access

- *A maintenance right-of-way or easement should extend to the pond from a public road.*
- *Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15 percent, and be appropriately stabilized to withstand maintenance equipment and vehicles.*
- *The maintenance access should extend to the forebay, safety bench, riser, and outlet and be designed to allow vehicles to turn around.*

Non-clogging Low Flow Orifice

- *A low flow orifice shall be provided, with the size of the orifice sufficient to ensure that no clogging will occur.*
- *The low flow orifice should be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 6 inches) or by internal orifice protection that may allow for smaller diameters (minimum of 1 inch).*
- *The preferred method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point one foot below the normal pool elevation.*
- *Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round pipe that extends at least 12 inches below the normal pool level.*
- *The use of horizontally extended perforated pipe protected by geotextile fabric and gravel is not recommended. Vertical pipes may be used as an alternative if a permanent pool is present.*

Riser in Embankment

- *The riser must be located within the embankment for maintenance access, safety and aesthetics.*
- *Lockable manhole covers and manhole steps within easy reach of valves and other controls should provide access to the riser. The principal spillway opening should be "fenced" with pipe at 8-inch intervals for safety purposes.*

Pond Drain

- *Except where local slopes prohibit this design, each pond should have a drain pipe that can completely or partially drain the pond. The drain pipe shall have an elbow or protected intake within the pond to prevent sediment deposition in the pipe, and a diameter capable of draining the pond within 24 hours.*
- *Pond retention times can be increased to enhance water quality control during storm events by maintaining ponds at low levels before storms and increasing the available pond volume during storms.*
- *Care should be exercised during pond draining to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The approving jurisdiction should be notified before draining a pond.*

Adjustable Gate Valve

- *Both the WQV extended detention pipe and the pond drain may be equipped with an adjustable gate valve, typically a handwheel activated knife gate valve.*
- *Valves should be located inside of the riser at a point where they will not normally be inundated and can be operated in a safe manner.*
- *Both the WQV extended detention pipe and the pond drain should be sized one pipe size greater than the calculated design diameter.*
- *To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step, or other fixed object.*

Safety Features

- *Side slopes to the pond should not exceed 3:1 and should terminate at a safety bench.*
- *The principal spillway opening must not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.*
- *Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool.*
- *Warning signs prohibiting swimming and skating should be posted.*
- *Pond fencing is generally not encouraged, but may be required by some municipalities. The preferred method is to grade the pond to eliminate dropoffs or other safety hazards.*

Cost Considerations

Wet ponds are relatively inexpensive stormwater practices, but costs vary widely depending on the complexity of the design or difficulty of site constraints. The costs of stormwater ponds may be estimated using the following equation (Brown and Schueler, 1997):

$$C = 24.5V^{0.705}$$

where: C = Construction, design, and permitting cost.
V = Volume in the pond to include the 10-year storm (ft^3).

Costs should be adjusted for inflation to reflect current costs. The annual cost of routine maintenance is typically estimated at about 3 to 5 percent of the construction cost (EPA Wet Pond Fact Sheet, http://www.epa.gov/npdes/menuofbmps/menu.htm). Ponds typically have a design life longer than twenty years.

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Stormwater Wetlands

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Primary Treatment Practice ●
Secondary Treatment Practice

Stormwater Management Benefits

Pollutant Reduction	
Sediment	■
Phosphorus	■
Nitrogen	■
Metals	■
Pathogens	▣
Floatables*	■
Oil and Grease*	■
Dissolved Pollutants	▣
Runoff Volume Reduction	
Runoff Capture	■
Groundwater Recharge	□
Stream Channel Protection	■
Peak Flow Control	■

Key: ■ Significant Benefit
▣ Partial Benefit
□ Low or Unknown Benefit

*Only if a skimmer is incorporated

Implementation Requirements

Cost ....Moderate
Maintenance........................Moderate

Description

Stormwater wetlands are constructed wetlands that incorporate marsh areas and permanent pools to provide enhanced treatment and attenuation of stormwater flows. Stormwater wetlands differ from stormwater ponds in that wetland vegetation is a major element of the overall treatment mechanism as opposed to a supplementary component. This section includes three types of stormwater wetlands:

- *Shallow Wetland*
- *Extended Detention Shallow Wetland*
- *Pond/Wetland System*

While stormwater wetlands can provide some of the ecological benefits associated with natural wetlands, these benefits are secondary to the function of the system to treat stormwater. Stormwater wetlands can be very effective at removing pollutants and reducing peak flows of runoff from developed areas. Removal of particulate pollutants in stormwater wetlands can occur through a number of mechanisms similar to stormwater ponds including sedimentation and filtration by wetland vegetation. Soluble pollutants can also be removed by adsorption to sediments and vegetation, absorption, precipitation, microbial decomposition, and biological processes of aquatic and fringe wetland vegetation. Stormwater wetlands are particularly advantageous when nitrogen and/or dissolved pollutants are a concern.

The key to maximizing pollutant removal effectiveness in stormwater wetlands is maintaining wet conditions adequate to support wetland vegetation. To achieve this, the constructed wetlands must either intercept the groundwater table or must be lined with an impermeable liner and have a watershed large enough to supply storm flows that will maintain wetness even during dry periods.

Stormwater wetland systems should be designed to operate on the plug flow principle where incoming water displaces the water retained in the system from the previous storm event. This is accomplished by maximizing length versus width ratios and/or by creating distinct cells along the treatment path. Ideally, the wetland system would be designed to retain the water quality volume (WQV) between storm events. As a result, storms that generate runoff less than the WQV would be entirely retained while only a percentage of the runoff from storms that generate more than the WQV would be retained. The value provided by this process is that a portion of the "new" polluted runoff is retained, and the "old" treated water is discharged from the wetland, thereby allowing extended treatment of the WQV.

Stormwater wetlands should be equipped with a sediment forebay or similar form of pretreatment to minimize the discharge of sediment to the primary treatment wetland. High solids loadings to the system will degrade system performance and result in more frequent cleaning, which could result in additional disturbance to the wetland vegetation. A micropool or permanent pool is often included just prior to the discharge for additional solids removal.

Design Variations

There are several common stormwater wetland design variations. The various designs are characterized by the volume of the wetland in the deep pool, high marsh, and low marsh zones, and whether the design allows for detention of small storms above the permanent pool.

Shallow Wetland: Most shallow wetland systems, also referred to as shallow marsh wetlands, consist of aquatic vegetation with a permanent pool ranging from 6 to 18 inches during normal conditions. Shallow wetlands are designed such that flow through the wetlands is conveyed uniformly across the treatment area. While pathways, streams or other varied water depths could enhance the aesthetic or ecosystem value of the wetland, they could also cause short-circuiting through the wetland thereby reducing the overall treatment effectiveness. As a result, to maximize treatment performance, providing a uniformly sloped system is recommended. In order to enhance plug flow conditions across the wetland, individual wetland cells can be constructed and separated by weirs. **Figure 11-P2-1** depicts a typical schematic design of a shallow wetland.

Extended Detention Shallow Wetland: Extended detention shallow wetlands provide a greater degree of downstream channel protection as they are designed with more vertical storage capacity. The additional vertical storage volume also provides extra runoff detention above the normal pool elevations. Water levels in the extended detention shallow wetland may increase by as much as three feet after a storm event and return gradually to pre-storm elevations within 24 hours of the storm event. The growing area in extended detention shallow wetlands extends from the normal pool elevation to the maximum water surface elevation. Wetland plants that tolerate intermittent flooding and dry periods should be selected for the extended detention area above the shallow marsh elevations. **Figure 11-P2-2** depicts a typical schematic design of an extended detention shallow wetland.

Pond/Wetland Systems: Multiple cell systems, such as pond/wetland systems, utilize at least one pond component in conjunction with a shallow marsh component. The first cell is typically a wet pond, which provides pretreatment of the runoff by removing particulate pollutants. The wet pond is also used to reduce the velocity of the runoff entering the system. The shallow marsh then polishes the runoff, particularly for soluble pollutants, prior to discharge. These systems require less space than the shallow marsh systems since more of the water volume is stored in the deep pool which can be designed to reduce peak flows. Because of this system's ability to significantly reduce the velocity and volume of incoming peak flows (i.e., flow equalization or dampening), it can often achieve higher pollutant removal rates than other similarly sized stormwater wetland systems. **Figure 11-P2-3** depicts a typical schematic design of a pond/wetland system.

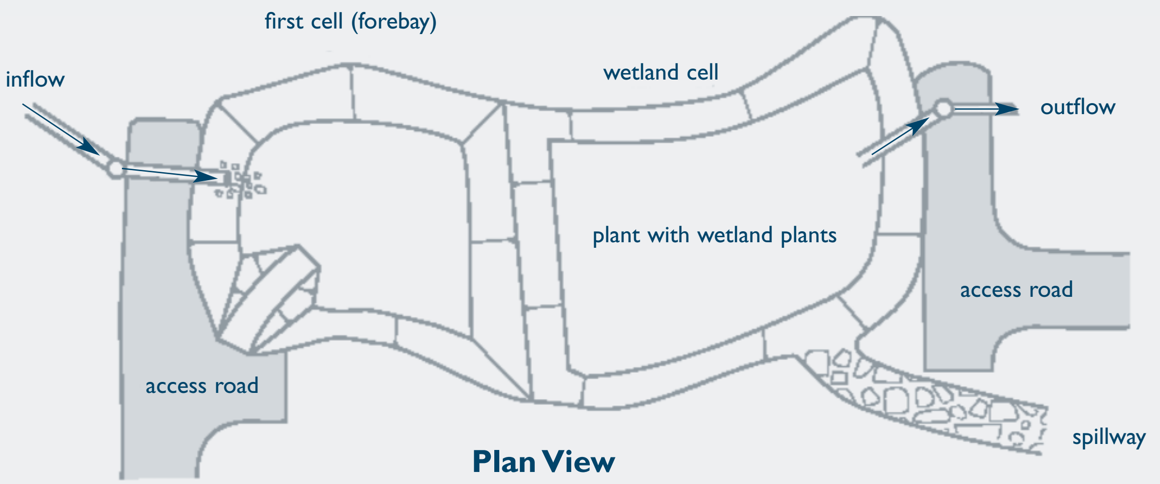
Advantages

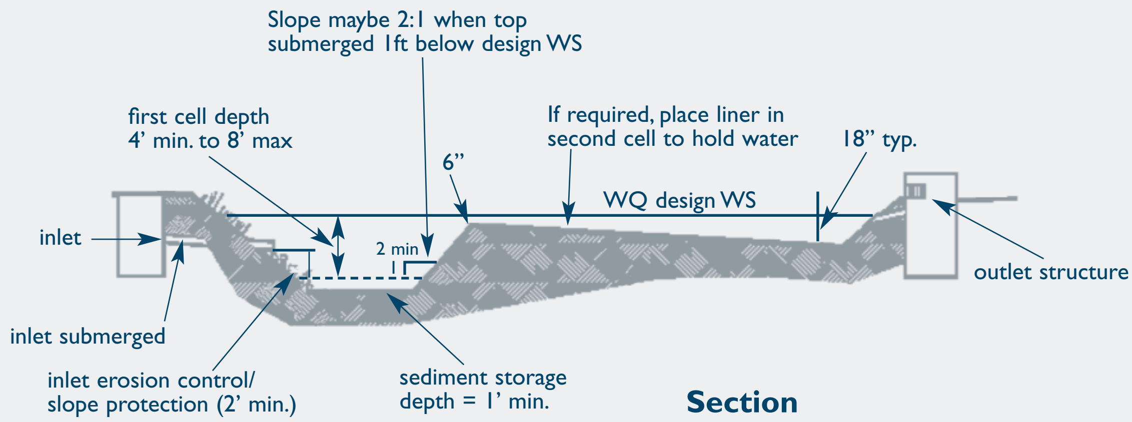
- *Efficient at removing both particulate and soluble pollutants.*
- *Capable of providing aesthetic benefits.*
- *Capable of providing wildlife habitat with appropriate design elements.*
- *Provide ability to attenuate peak runoff flows.*

Limitations

- *More costly than extended detention basins.*
- *Require a relatively large land area that is directly proportional to the size of the contributing drainage area.*
- *Very sensitive to the ability to maintain wet conditions especially during extended dry weather when there may be significant evaporative losses.*

Figure 11-P2-1 Shallow Wetland





Source: Adapted from King County Department of Natural Resources, 1998.

- *May cause thermal impacts to receiving waters and thereby should not discharge directly to cold water fish habitats.*
- *Potential breeding habitat for mosquitoes, particularly for systems with isolated pockets of standing water (standing longer than 5 days). Circulating water in the permanent pool may minimize this problem. This may be a more significant problem for lined systems.*
- *Wetland systems with steep side slopes and/or deep wet pools may present a safety issue to nearby pedestrians.*
- *Stormwater wetlands can serve as decoy wetlands, intercepting breeding amphibians moving toward vernal pools. If amphibians deposit their eggs in these artificial wetlands, they rarely survive due to the sediment and pollutant loads, as well as fluctuations in water quality, quantity, and temperature.*

Siting Considerations

Drainage Area: Stormwater wetlands that utilize a liner system to maintain the desired permanent pool should have a contributing drainage area that is adequate to maintain minimum water levels. Typically, minimum contributing drainage areas are twenty-five acres, especially for shallow systems. A water budget for the wetlands should be calculated to ensure that evaporation losses do not exceed inflows during warm weather months.

Groundwater: Unlined basins must intersect the groundwater table in order to maintain the desired permanent pool. In this case, the elevations of the basin should be established such that the groundwater elevation is equal to the desired permanent pool elevation. Seasonal variations of groundwater elevations should be considered, which can be very pronounced in low permeability soils.

Land Uses: Land uses will dictate potential pollutants-of-concern and potential safety risks. For those land uses where there is significant potential for soluble pollutants, especially those that are highly susceptible to groundwater transport, the use of a liner is recommended. An impermeable liner may not be required, depending on the risk of downgradient contamination, but a low permeable liner constructed in till soils may be acceptable. Adjacent residential land uses pose the greatest public safety risks where mosquito breeding and water hazards must be considered.

Baseflow: A small amount of baseflow is desirable to maintain circulation and reduce the potential for low dissolved oxygen levels during late summer, and to reduce mosquito breeding. This baseflow can be provided by groundwater infiltrating into either the wetland or the collection system above the pond.

Site Slopes: Steep on-site slopes may result in the need for a large embankment to be constructed to provide the desired storage volume and could require a dam construction permit from the Connecticut DEP. Steep slopes may also present design and construction challenges, and significantly increase the cost of earthwork.

Receiving Waters: The sensitivity of receiving waters should be evaluated to determine whether the effects of the warmer stormwater discharges from the wetland could be detrimental to cold-water fish or other sensitive aquatic species.

Flood Zones: Constructed wetlands should not be located in floodways, floodplains, or tidal lands, especially those that require construction of an embankment. Floodwaters could flush out stored pollutants or damage pond embankments.

Natural Wetlands/Vernal Pools: Natural wetlands and vernal pool depressions should not be used, either temporarily or permanently, as a stormwater pond or wetland. Stormwater wetlands should be located at least 750 feet from a vernal pool. They should not be sited between vernal pools or in areas that are known primary amphibian overland migration routes.

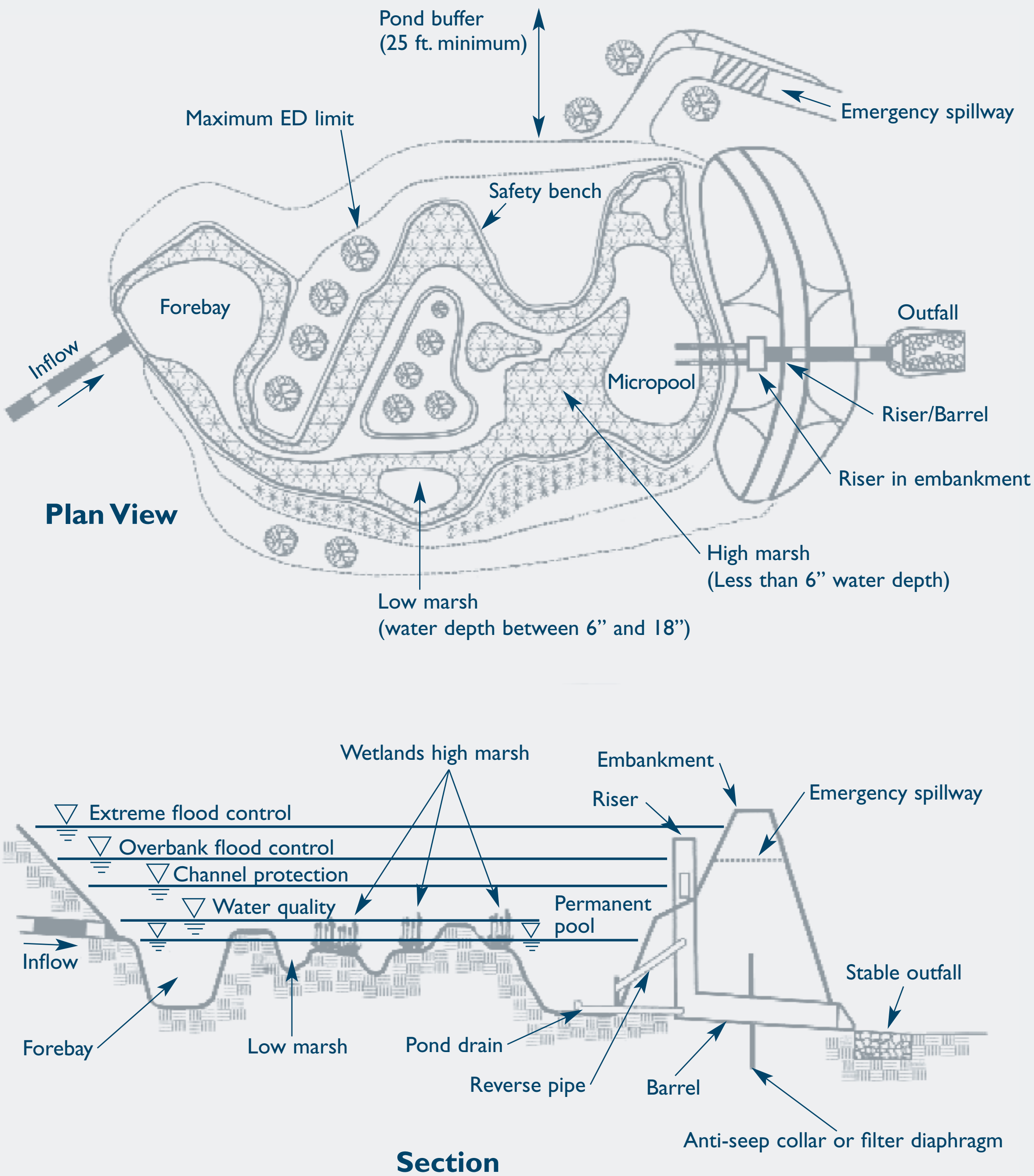
Design Criteria

Wetland designs may vary considerably due to site constraints, local requirements, or the designer's preferences. The five common design elements that should be considered for all stormwater wetlands are:

- *Pretreatment*
- *Treatment*
- *Conveyance*
- *Maintenance reduction*
- *Landscaping*

Design considerations for stormwater wetlands are presented below and summarized in **Table 11-P2-1**.

Figure 11-P2-2 Extended Detention Shallow Wetland



Source: Adapted from NYDEC, 2001.

Table 11-P2-1 Design Criteria for Stormwater Wetlands

Parameter	Design Criteria
Setback requirements[1]	❍ 50 feet from on-site sewage disposal system ❍ 50 feet from private well ❍ 10 feet from property line ❍ 20 feet from any structure ❍ 50 feet from any steep slope (greater than 15%) ❍ 750 feet from a vernal pool
Preferred Shape	Curvilinear
Side Slopes	3:1 maximum or flatter preferred
Length to Width Ratio	3:1 minimum along the flow path between the inlet and outlet; flow length is the length at mid-depth. Mid-depth is (avg. top width+avg. bottom width)/2
Pretreatment Volume	Forebays are highly recommended for stormwater wetlands and sized to contain at least 10% of the WQV. Outlet micropools should also be sized to contain 10% of the WQV. For sites with potential for higher pollutant loads, 100% of the WQV must receive pretreatment.
Drainage Area	Minimum contributing drainage area is typically 25 acres. Stormwater wetland should have a surface area at least 1 to 1.5% of the contributing watershed area.
Underlying Soils	Low permeability soils are best (NRCS Hydrologic Soil Group A and B soils require modifications to maintain a permanent pool unless groundwater is intercepted).
Size	The size of the wetland area will be based on desired pollutant removal efficiencies and the depth of water available to store the WQV. Suggested guidelines for the ratio of wetland to watershed areas is 0.2 for shallow marshes and 0.01 for extended detention shallow wetland systems and pond/wetlands.
Depth	Average water levels in the marsh/wetland areas can vary between 0.5 and 1.5 feet. Maximum water depths will depend on the site topography and the design of the system. Forebays and micropools should typically have a permanent pool depth of between 4 and 6 feet.

[1]Minimum requirements. State and local requirements supercede.

Source: Adapted from MADEP, 1997 and Schueler, 1992.

Forebay

A sediment forebay is recommended for all stormwater wetland systems. Sediment forebays provide pretreatment by settling out coarse solids, which enhances treatment performance, reduces maintenance, and increases the longevity of the system. This is especially critical in wetland systems where removal of solids would disturb existing wetland vegetation and temporarily affect treatment performance.

- *The forebay should be sized to contain at least 10 percent of the WQV and have an adequate depth to prevent resuspension of collected sediments during the design storm, often being 4 to 6 feet deep. Maintaining water depths in excess of 4 feet precludes invasive emergent vegetation such as cattails. Emergent vegetation provides mosquito larvae with refuge from predators and increases nutrient availability.*
- *In larger open water areas of the wetland system (forebay and micropool), maintain water quality sufficient to support mosquito-feeding fish. Stormwater ponds and wetlands often develop mini-ecosystems where birds, frogs, and other insects feed, many of which are natural predators of mosquitoes and nuisance insects. Ponds can also be stocked with predatory fish native to Connecticut that feed on mosquito larvae such as banded sunfish, flathead minnows, Eastern mud minnows, and several species of killfish. The DEP Fisheries Division should be consulted regarding species selection. Other natural predators of mosquitoes such as dragonfly nymphs can also be used.*
- *The forebay must also include additional sediment storage volume that may not be used for WQV calculations.*

- *The outlet from the forebay should be designed in a manner to evenly distribute flow across the wetland/marsh area and prevent erosion of the embankment. This outlet can be configured in a number of ways, including a culvert with a distribution header or spillway channel. The outlet should be designed to safely convey the same design flow that is proposed to enter the basin. The outlet invert must be elevated in a manner such that 10 percent of the WQV can be stored below it in addition to the required sediment volume.*
- *The forebay should have a minimum length to width ratio of 2:1 and a preferred length to width ratio of 3:1.*
- *Direct access for appropriate maintenance equipment should be provided to the forebay and may include a ramp to the bottom if equipment cannot reach all points within the forebay from the top. The forebay can be lined with a concrete pad to allow easier removal of sediment and to minimize the possibility of excavating subsurface soils or undercutting embankments during routine maintenance.*
- *A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition.*
- *A barrier, such as an earthen berm, gabions, or a concrete weir may be used to separate the forebay from the permanent pool. This barrier should be armored as necessary to prevent erosion of the embankment if it overtops. This armoring could consist of materials such as riprap, pavers, or geosynthetics designed to resist slope erosion.*
- *Additional pretreatment can be provided in the forebay by raising the embankment to provide some detention of incoming flows.*

Wetland/Marsh Area

The size of the wetland/marsh area should be based on pollutant influent concentrations, base flow, peak design flow, and desired effluent concentrations. Kadlec and Knight (1996) have developed area-based, first-order wetland design models to predict treatment area requirements. The use of these models is recommended to size the wetland areas. This model is as follows:

General Model:

$J = k\,(C - C^*)$; *where* $\quad k = k_{20}\,\theta_k^{(T-20)}$

$\qquad\qquad\qquad\qquad\quad C^* = C^*_{20}\,\theta_c^{(T-20)}$

Where: J = Removal rate (g/m2/yr)
k = First-order, area-based rate constant (m/yr)
k_{20} = Rate constant at 20°C (m/yr)
C = Pollutant concentration (mg/L)
C^* = Irreducible background concentration (mg/L)
C^*_{20} = Irreducible background concentration at 20°C (mg/L)
T = Temperature, °C
θc = Temperature coefficient for background concentration
θk = Temperature coefficient for rate constant

Wetland Area (based on modified plug-flow hydraulics):

$$A = Q / HLR = -\frac{Q}{k} \left\langle \ln \left(\frac{C2 - C^*}{C1 - C^*} \right) \right\rangle$$

Where: HLR = Hydraulic loading rate (m/yr)
A = Wetland area at normal pool elevation (m2), excluding habitat islands
Q = Design inflow rate (m3/yr)
$C1$ = Inflow concentration (mg/L)
$C2$ = Outflow concentration (mg/L)

Model Parameter Values (at 20°C):

	BOD	TSS	NH3-N	NO3+NO2-N	TN	TP
K_{20}, *m/yr*	35	1,000	18	35	22	12
θk	1.00	1.00	1.04	1.09	1.05	1.00
C_{20}, *mg/L*	6	5.1+0.16C1	0.0	0.0	1.5	0.02
θc	–	1.065	–	–	–	1.00

BOD = biochemical oxygen demand
TSS = total suspended solids
NH3-N = ammonia nitrogen
NO_3+NO_2-N = nitrate and nitrite nitrogen
TN = total nitrogen
TP = total phosphorus

In order to better simulate plug flow conditions and minimize short-circuiting, individual wetland cells can be constructed along the flow path. Weirs, berms, or shallow marsh areas can be used to form these cells. However, the cells should be designed such that flow is redistributed along the edge of each cell. To reduce the potential for mosquito breeding, incorporate contiguous marsh areas rather than isolated pockets, and slope the marsh areas to the deepest pool.

Infiltration Design and Water Balance

The rate of infiltration through the bottom of the wetland can be estimated by using Darcy's law. For most wetlands, the rate of infiltration is relatively constant. Wetlands act as storage reservoirs, retaining water during precipitation events and releasing it slowly as outlet flow and infiltration. During summer months when evapotranspiration losses are large, pool levels commonly drop episodically below the design operating level and outflow ceases.

Ideally, wetlands should not completely dewater under conditions of normal precipitation. To identify potential problems, a monthly water balance should be analyzed for the proposed wetland. The pool level at the end of each month can be estimated as follows:

$$PL = PL_0 + [BF + (PR \times AW) + (PR \times AD \times RO) - (ET \times AW) - (I \times A)] / A$$

Where:
- PL = Pool depth at the end of month (feet)
- PL_0 = Pool depth from the previous month (feet)
- BF = Total monthly flow into the wetland (acre-feet)
- PR = Total monthly precipitation (feet)
- AW = Area of wetland (acres)
- AD = Area of tributary drainage (acres)
- RO = Weighted Volumetric Runoff Coefficient
- ET = Monthly potential evapotranspiration (feet)
- A = Area inundated at depth PL0 (acres)
- I = Monthly infiltration (feet)

If the calculated pool depth at the end of the month is greater than the normal pool depth established at the outlet, then outflow will occur during that month. The quantity is not important. In months with a net outflow, the beginning pool depth for the next month will equal the normal pool depth.

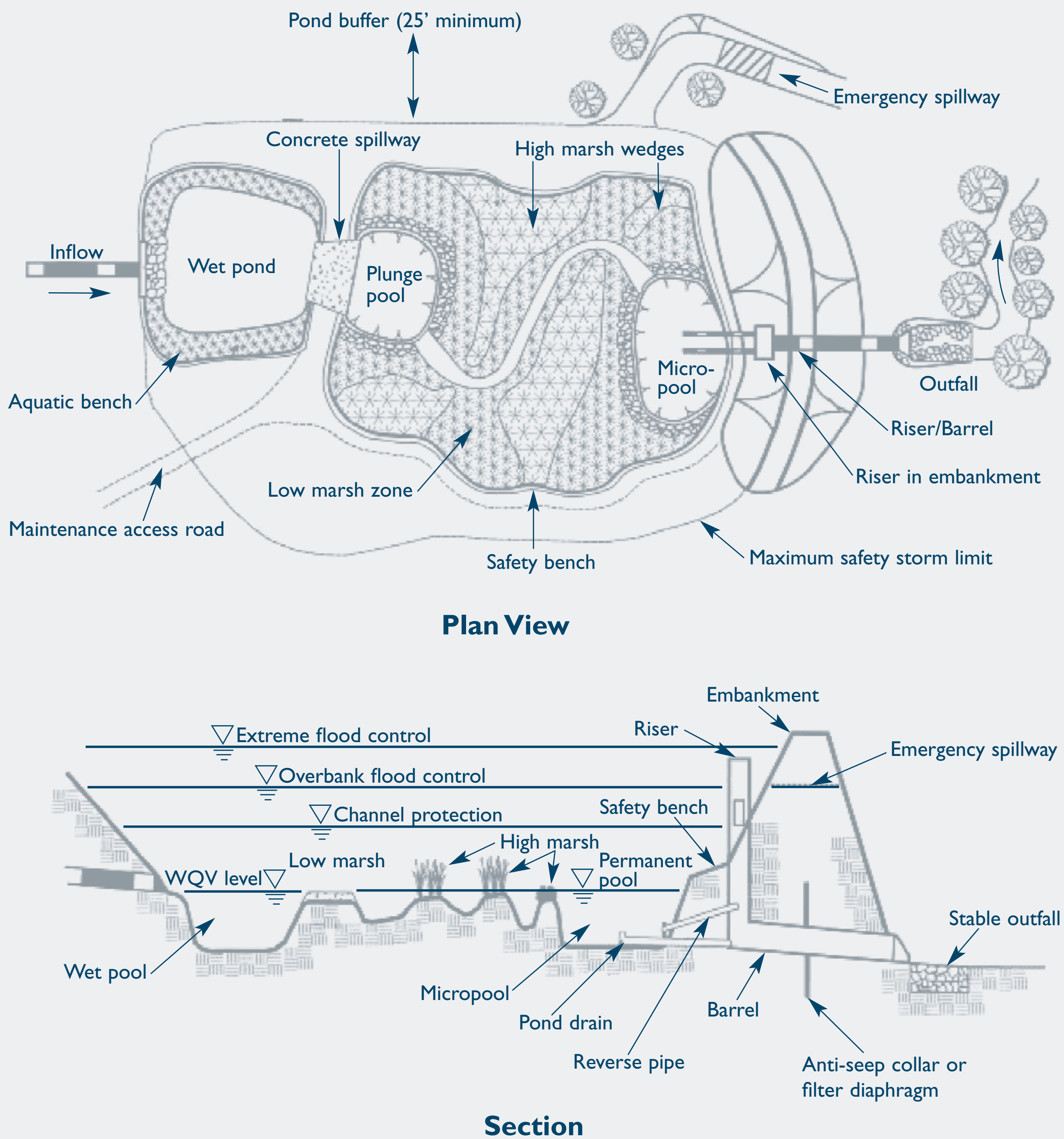
Tables or equations for estimating potential evapotranspiration are available from many sources, including Kadlec and Knight (1996). However, for conceptual design purposes, wetland evapotranspiration can be estimated as 80 percent of the pan evaporation rate.

In most wetlands, the area that is inundated varies with depth. The normal operating pool depth also may be adjusted seasonally to accommodate changes in the water budget. These factors should be accounted for in the calculation. If the water balance predicts that the wetland will dewater, design modifications can be considered, including:

- *Reducing the infiltration rate by adding a clay layer or synthetic liner*
- *Relocating the proposed wetland to increase the contributing drainage area*
- *Increasing the normal operating pool level*

Limitations on increasing the normal pool level will be imposed by the need for shallow water habitat to support emergent plant vegetation. Short periods during which the wetland becomes dry may be tolerated in some instances. However, the selection of plants must be tailored to accommodate these adverse conditions and special considerations will be required for the maintenance of the wetland during dry periods.

Figure 11-P2-3 Pond/Wetland System



Source: Adapted from NYDEC, 2001.

Conveyance

Stormwater should be conveyed to and from all stormwater management practices safely and to minimize erosion potential.

Inlet Protection

- *The number of inlets should be minimized, and one inlet is preferable. The inlet should be located at the most hydraulically remote point from the outlet, but in any case should be located in a manner that meets or exceeds desired length to width ratios.*
- *Inlet areas should be stabilized to ensure that non-erosive conditions exist for the design storm event.*
- *The ideal inlet discharge configuration is above the permanent pool to prevent potential hydraulic impacts from freezing.*

Oulet Protection

- *The channel immediately below an outfall should be modified to prevent erosion and conform to natural topography by use of a plunge pool or a riprap pad and sized for peak discharge velocities.*
- *Outlet protection should be used to reduce flow to non-erosive velocities from the principal spillway based on actual cover and soil conditions (3.5 to 5.0 ft/s).*
- *If a pond outlet discharges to a perennial stream or channel with dry weather base flow, tree clearing should be minimized and a forested riparian zone re-established.*
- *To convey potential flood flows from the basin, an armored emergency spillway should be provided.*

Wetland Liners

When the permanent pool does not intercept groundwater, a liner may be needed to maintain minimum water levels. Liners are also necessary for wetland systems that may present a risk to groundwater quality. **Table 11-P2-2** lists recommended specifications for clay and geomembrane liners.

Pool Benches

These specifications apply to permanent pools at the sediment forebay and micropool.

- *For side slopes steeper than 4:1, provide a 10-foot wide flat safety bench above the permanent pool level.*

Vegetation

High pollutant removal efficiencies are dependent on a dense cover of emergent plant vegetation. Actual plant species do not appear to be as important as plant growth habitat. In particular, use plants that have high colonization and growth rates, can establish large surface areas that continue through the winter dormant season, have high potential for treating pollutants, and are very robust in flooded environments. **Appendix A** contains planting guidance for stormwater wetlands. Other landscaping criteria include the following:

- *Soils should be modified to mitigate compaction that occurs during construction around the proposed planting sites.*
- *Woody vegetation may not be planted or allowed to grow within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure.*
- *Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds and wetlands. To help discourage resident geese populations, the buffer can be planted with trees, shrubs, and native ground covers.*
- *Annual mowing of the pond/wetland buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.*

Maintenance Reduction Features

In addition to regular maintenance activities needed to maintain the function of stormwater practices, some design features can be incorporated to ease the maintenance burden of each practice. In constructed wetlands, maintenance reduction features include techniques to reduce the amount of required maintenance, as well as techniques to make regular maintenance activities easier.

- *Outlets should be designed with non-clogging features, such as a weir, or by incorporating trash racks for culverts and orifice openings.*
- *To prevent clogging from ice or floatables, a reverse slope outlet pipe can be used to draw water from below the permanent pool up to the outlet structure. The invert of the pipe drawing from the pool should be at least 18 inches from the bottom to prevent sediment discharge.*
- *Orifices should be no smaller than 6 inches in diameter, and have a trash rack to prevent clogging.*

Table 11-P2-2 Stormwater Wetland Liner Specifications		
Linear Material	**Property**	**Recommended Specifications**
Clay	Minimum Thickness	6 to 12 inches
	Permeability	1×10^{-5} cm/sec[1]
	Particle Size	Minimum 15% passing #200 sieve[1]
Geomembrane	Minimum Thickness	30 mils (0.03 inches)
	Material	Ultraviolet resistant, impermeable poly-liner

Source: [1]NYDEC, 2001; all other listed specifications from City of Austin in Washington, 2000 (in Metropolitan Council, 2001).

- *Pools should have a manually operated drain to draw down the pond for infrequent maintenance or dredging of the main cell of the pond.*
- *Metal components of outlet structures should be corrosion resistant, but not galvanized due to the contribution of zinc to water (Washington, 2000).*
- *Outlet structures should be resistant to frost heave and ice action in the pond.*

Cold Climate Design Considerations

The following design elements should be considered to minimize potential performance impacts caused by cold weather:

- *Inlet pipes should not be submerged, since this can result in freezing and upstream damage or flooding.*
- *Bury pipes below the frost line to prevent frost heave and pipe freezing.*
- *To prevent standing water in the pipe and to reduce the potential for ice formation, increase the slope of inlet pipes to a minimum of 1 percent, if site conditions allow.*
- *If perforated riser pipes are used, the minimum orifice diameter should be 0.5 inches. In addition, the pipe should have a diameter of at least 6 inches.*
- *When a standard weir is used, the minimum slot width should be 3 inches, especially when the slot is tall.*
- *Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of base flow through the system.*
- *Riser hoods and reverse slope pipes should draw from at least 6 inches below the typical ice layer. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet. Reverse slope pipes should not be used for off-line ponds.*
- *Trash racks should be installed at a shallow angle to prevent ice formation.*
- *Additional storage should be provided to account for storage lost to ice buildup, especially in shallow wetlands where much of the pool becomes frozen. Ice thickness may be estimated by consulting with local authorities (the fire department, for example) with knowledge of the typical ice thickness in the area.*

Construction

- *Any stormwater treatment practices that create an embankment, including stormwater wetlands, are under the jurisdiction of the Dam Safety Section of the Connecticut DEP Inland Water Resources Division (IWRD) and should be constructed, inspected, and maintained in accordance with CGS §§22a-401 through 22a-411, inclusive, and applicable DEP guidance.*
- *Avoid soil compaction to promote growth of vegetation.*
- *Temporary erosion and sediment controls should be used during construction, and sediment deposited in the wetlands should be removed after construction, but preferably before wetland vegetation is planted.*
- *Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.*

- *Establishment of wetland plantings is critical. As a result, installation should be as directed by a biologist or landscape architect.*

Inspection and Maintenance

- *Plans for stormwater wetlands should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.*
- *The principal spillway should be equipped with a removable trash rack, and generally accessible from dry land.*
- *Sediment removal in the forebay and micropool should occur at a minimum of every five years or before the sediment storage capacity has been filled.*
- *Sediment removed should be disposed of according to an approved comprehensive operation and maintenance plan.*
- *Inspect twice per year for the first three years to evaluate plant sustainability, water levels, slope stability, and the outlet structure.*
- *Perform maintenance outside of vegetative growing and wildlife seasons.*
- *Harvesting of dead plant material is not required except in cases where high pollutant removal efficiencies, especially for nutrients, are required.*

Maintenance Access

- *A maintenance right of way or easement should extend to the wetland from a public road.*
- *Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15 percent, and be appropriately stabilized to withstand maintenance equipment and vehicles.*
- *The maintenance access should extend to the forebay, safety bench, riser, and outlet and be designed to allow vehicles to turn around.*

Non-clogging Low Flow Orifice

- *A low flow orifice shall be provided, with the size of the orifice sufficient to ensure that no clogging will occur.*
- *The low flow orifice should be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 6 inches) or by internal orifice protection that may allow for smaller diameters (minimum of 1 inch).*
- *The preferred method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point one foot below the normal pool elevation.*
- *Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round pipe that extends at least 12 inches below the normal pool level.*
- *The use of horizontally extended perforated pipe protected by geotextile fabric and gravel is not recommended. Vertical pipes may be used as an alternative if a permanent pool is present.*

Riser in Embankment

- *The riser must be located within the embankment for maintenance access, safety, and aesthetics.*
- *Lockable manhole covers, and manhole steps within easy reach of valves and other controls should provide access to the riser. The principal spillway opening should be "fenced" with pipe at 8-inch intervals for safety purposes.*

Drain

- *Except where local slopes prohibit this design, each wetland should have a drain pipe that can completely or partially drain the wetland. The drain pipe shall have an elbow or protected intake within the pond to prevent sediment deposition, and a diameter capable of draining the pond within 24 hours.*
- *Care should be exercised during pond draining to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The approving jurisdiction must be notified before draining a pond.*

Table 11-P2-3 Typical Maintenance Activities for Stormwater Wetlands

Activity	Schedule
❍ If necessary, re-plant wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season.	One-time
❍ Inspect for invasive vegetation and remove where possible.	Semi-annual inspection
❍ Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. ❍ Note signs of hydrocarbon build-up, and deal with appropriately. ❍ Monitor for sediment accumulation in the facility and forebay. ❍ Examine to ensure that inlet and outlet devices are free of debris and are operational.	Annual inspection
❍ Repair undercut or eroded areas.	As needed maintenance
❍ Clean and remove debris from inlet and outlet structures. ❍ Mow side slopes.	Frequent (3-4 times/year) maintenance
❍ Harvest wetland plants that have been "choked out" by sediment build-up. ❍ Supplement wetland plants if significant portions have not established (at least 50% of the surface area) or have been choked out.	Annual maintenance (if needed)
❍ Remove sediment from the forebay.	5 to 7 year maintenance
❍ Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.	20 to 50 year maintenance

Source: WMI, 1997.

Cost Considerations

Stormwater wetlands are relatively inexpensive stormwater treatment practices, but vary widely depending on the complexity of the design or site constraints. The costs of stormwater wetlands are generally 25 percent more expensive than stormwater ponds of an equivalent volume and may be estimated using the following equation (Brown and Schueler, 1997):

$$C = 30.6V^{0.705}$$

where: C = Construction, design, and permitting cost.
V = Wetland volume needed to control the 10-year storm (ft^3).

Results should be modified for inflation to reflect current costs. The annual cost of routine maintenance is typically estimated at approximately 3 to 5 percent of the construction cost (EPA Storm Water Wetland Fact Sheet, http://www.epa.gov/npdes/menuofbmps/menu.htm). Stormwater wetlands typically have a design life longer than twenty years.

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Infiltration Practices

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Primary Treatment Practice	●
Secondary Treatment Practice	

Stormwater Management Benefits

Pollutant Reduction	
Sediment	■ Significant Benefit
Phosphorus	■ Significant Benefit
Nitrogen	■ Significant Benefit
Metals	■ Significant Benefit
Pathogens	■ Partial Benefit
Floatables*	■ Partial Benefit
Oil and Grease*	■ Partial Benefit
Dissolved Pollutants	■ Partial Benefit
Runoff Volume Reduction	
Runoff Capture	■ Significant Benefit
Groundwater Recharge	■ Significant Benefit
Stream Channel Protection	■ Partial Benefit
Peak Flow Control	■ Partial Benefit

Key: ■ Significant Benefit
■ Partial Benefit
□ Low or Unknown Benefit

*Only if a skimmer is incorporated

Implementation Requirements

Cost ....Moderate
Maintenance...................................High

Description

Stormwater infiltration practices are designed to capture stormwater runoff and infiltrate it into the ground over a period of days. This section includes two types of infiltration practices:

- *Infiltration Trench*
- *Infiltration Basin*

Infiltration practices reduce runoff volume, remove fine sediment and associated pollutants, recharge groundwater, and provide partial attenuation of peak flows for storm events equal to or less than the design storm. Infiltration practices are appropriate for small drainage areas, but can also be used for larger multiple lot applications, in contrast to rain gardens and dry wells, which are primarily intended for single lots.

Infiltration trenches are shallow, excavated, stone-filled trenches in which stormwater is collected and infiltrated into the ground. Infiltration trenches can be constructed at a ground surface depression to intercept overland flow or can receive piped runoff discharged directly into the trench. Runoff gradually percolates through the bottom and sides of the trench, removing pollutants through sorption, trapping, straining, and bacterial degradation or transformation.

Infiltration basins are stormwater impoundments designed to capture and infiltrate the water quality volume over several days, but do not retain a permanent pool. Infiltration basins can be designed as off-line devices to infiltrate the water quality volume and bypass larger flows to downstream flood control facilities or as combined infiltration/flood control facilities by providing detention above the infiltration zone. This section describes off-line basins designed for groundwater recharge and stormwater quality control, rather than for flood control. The bottom of an infiltration basin typically contains vegetation to increase the infiltration capacity of the basin, allow for vegetative uptake, and reduce soil erosion and scouring of the basin.

A number of underground infiltration structures, including premanufactured pipes, vaults, and modular structures, have been developed in recent years as alternatives to infiltration trenches and basins for space-limited sites and stormwater retrofit applications. Performance of these systems varies by manufacturer and system design. These systems are currently considered secondary treatment practices due to limited field performance data, although pollutant removal efficiency is anticipated to be similar to that of infiltration trenches and basins.

Infiltration practices are susceptible to clogging by suspended solids in stormwater runoff. Therefore, infiltration trenches and basins require pretreatment to remove a portion of the solids load before entering the infiltration practice. Infiltration trenches and basins are often preceded by other primary or secondary treatment practices that are effective in removing coarse solids, as well as oil, grease, and floatable organic and inorganic material. Infiltration practices are not appropriate in areas that contribute high concentrations of sediment, hydrocarbons, or other floatables without adequate pretreatment.

Because infiltration practices recharge stormwater directly to groundwater, they can potentially contaminate groundwater supplies with dissolved pollutants contained in stormwater runoff or mobilized from subsurface contamination. Runoff sources that cause particular problems for infiltration structures include sites with high pesticide levels; manufacturing and industrial sites, due to potentially high concentrations of soluble toxicants and heavy metals; and snowmelt runoff because of salts. Infiltration practices should be carefully sited and designed to minimize the risk of groundwater contamination. Runoff from residential areas (rooftops and lawns) is generally considered the least polluted and, therefore, the safest runoff for discharge to infiltration structures (Wisconsin DNR, 2000).

Advantages

- *Promote groundwater recharge and baseflow in nearby streams.*
- *Reduce the volume of runoff, thereby reducing the size and cost of downstream drainage and stormwater control facilities.*
- *Provide partial attenuation of peak flows, thereby reducing local flooding and maintaining streambank integrity.*
- *Appropriate for small or space-limited sites.*

Limitations

- *Potential failure due to improper siting, design (including inadequate pretreatment), construction, and maintenance. Infiltration basins usually fail for one or more of the following reasons (Wisconsin DNR, 2000):*
  - *Premature clogging*
  - *A design infiltration rate greater than the actual infiltration rate*
  - *Because the basin was first used for site construction erosion control*
  - *Soil was compacted during construction*
  - *The upland soils or basin walls were not stabilized with vegetation, and sediment was delivered to the basin*
- *Potential for mosquito breeding due to standing water in the event of system failure.*
- *Risk of groundwater contamination depending on subsurface conditions, land use, and aquifer susceptibility.*
- *Require frequent inspection and maintenance.*
- *Not suitable for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads without pretreatment sized to treat the entire water quality volume.*
- *Low removal of dissolved pollutants in very coarse soils.*
- *Use generally restricted to small drainage areas.*
- *Significantly reduced performance in the winter due to frozen soils.*
- *Failure is not readily apparent until the system is severely compromised.*
- *Visual inspection alone may not detect problems.*

Siting Considerations

Drainage Area: The maximum contributing drainage area for infiltration trenches should not exceed 5 acres (2 acres is recommended). The maximum contributing drainage area for infiltration basins should not exceed 25 acres (10 acres is recommended). While theoretically feasible, provided soils are sufficiently permeable, infiltration from larger contributing drainage areas can lead to problems such as groundwater mounding, clogging, and compaction.

Soils: Underlying soils should have a minimum infiltration rate of 0.3 inches per hour, as initially determined from NRCS soil textural classifications.

Table 11-P3-1 Minimum Infiltration Rates of NRCS Hydrologic Soil Groups		
Group	**Soil Texture**	**Minimum Infiltration Rate (in/hr)**
A	Sand, loamy sand, or sandy loam	0.30 – 0.45
B	Silt loam or loam	0.15 – 0.30
C	Sandy clay loam	0.05 – 0.15
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	0 – 0.05

Note: Tabulated infiltration rates are approximately equal to saturated hydraulic conductivities.
Source: U.S. Soil Conservation Service, 1986.

(**Table 11-P3-1**), and subsequently confirmed by a field investigation acceptable to the review authority. Soils should generally have a clay content of less than 30 percent and a silt/clay content of less than 40 percent. Suitable soils generally include sand, loamy sand, sandy loam, loam, and silt loam. Recommended soil investigation procedures include:

- *Infiltration rates can be determined through an appropriate field permeability test.*
- *Infiltration rates should be reduced by a safety factor to account for clogging over time. The recommended design infiltration rate is equal to one-half the field-measured infiltration rate (i.e., safety factor of 2).*
- *Test pits or soil borings should be used to determine depth to groundwater, depth to bedrock (if within 4 feet of proposed bottom of infiltration structure), and soil type.*
- *Test pits or soil borings should be excavated or dug to a depth of 4 feet below the proposed bottom of the facility.*
- *Infiltration tests, soil borings, or test pits should be located at the proposed infiltration facility to identify localized soil conditions.*
- *Testing should be performed by a qualified professional registered in the State of Connecticut. (licensed Professional Engineer, Professional Geologist, or Certified Soil Scientist).*
- *For infiltration trenches, one field test and one test pit or soil boring should be performed per 50 linear feet of trench. A minimum of two field tests and test pits or soil borings should be taken at each trench. The design should be based on the slowest rate obtained from the infiltration tests performed at the site.*
- *For infiltration basins, one field test and one test pit or soil boring should be performed per 5,000 square feet of basin area. A minimum of three field tests and test pits or soil borings should be performed at each basin. The design of the basin should be based on the slowest rate obtained from the field tests performed at the site.*

Land Use: Infiltration practices should not be used to infiltrate runoff containing significant concentrations of soluble pollutants that could contaminate groundwater, without adequate pretreatment. Land uses or activities that typically generate stormwater with higher pollutant loads are identified in Chapter Seven. Infiltration practices should not be used in areas of existing subsurface contamination, and may be prohibited or restricted within aquifer protection areas or wellhead protection areas at the discretion of the review authority.

Slopes: Infiltration basins are not recommended in areas with natural slopes greater than 15 percent, and should be located at least 50 feet from slopes greater than 15 percent, since steep slopes can cause water leakage in the lower portions of the basin and may reduce infiltration rates due to lateral water movement.

Water Table: The bottom of the infiltration facility should be located at least 3 feet above the seasonally high water table or bedrock, as documented by on-site soil testing.

Miscellaneous: Infiltration practices should not be placed over fill materials and, except where recommended by local or state health departments or by the Department of Environmental Protection, should be located at least 75 feet away from:

- *Drinking water supply wells*
- *Septic systems (any components)*
- *Surface water bodies*
- *Building foundations (at least 100 feet upgradient and at least 25 feet downgradient from building foundations)*

Design Criteria

Design considerations for infiltration trenches and basins are presented below and summarized in **Table 11-P3-2.**

Infiltration Trench

Figure 11-P3-1 depicts a typical schematic design of an infiltration trench. Two infiltration trench designs commonly used for parking lots are shown in **Figure 11-P3-2.**

Design Volume

- *Infiltration trenches should be designed to infiltrate the entire water quality volume through the bottom of the trench (sides are not considered in sizing).*
- *Infiltration trenches should be designed as off-line practices.*

Pretreatment

- *Pretreatment should be provided to accommodate 25 percent of the water quality volume. Pretreatment generally consists of a sediment forebay or other device designed to capture coarse particulate pollutants, floatables, and oil and grease (if necessary). Pretreatment is required for soils with infiltration rates over 3.0 inches per hour.*
- *A vegetative buffer around the trench is recommended to intercept surface runoff and prolong the life of the structure.*

Draining Time

- *Infiltration trenches should be designed to completely drain the water quality volume into the soil within 48 to 72 hours after the storm event. Infiltration trenches should completely dewater between storms.*
- *A minimum draining time of 12 hours is recommended to ensure adequate pollutant removal.*

Infiltration Rate

- *A minimum field-measured soil infiltration rate of 0.3 inches per hour is recommended as a practical lower limit for the feasibility of infiltration practices. Lower infiltration rates may be acceptable provided that the water quality volume and drain time criteria can be met. Field-measured soil infiltration rates should not exceed 5.0 inches per hour.*

Trench Surface Area and Depth

- *The bottom area of the trench should be sized to allow for infiltration of the entire water quality volume within 48 hours. The trench bottom area can be calculated using the following equation (Metropolitan Council, 2001):*

$$A = \frac{12WQV}{Pnt}$$

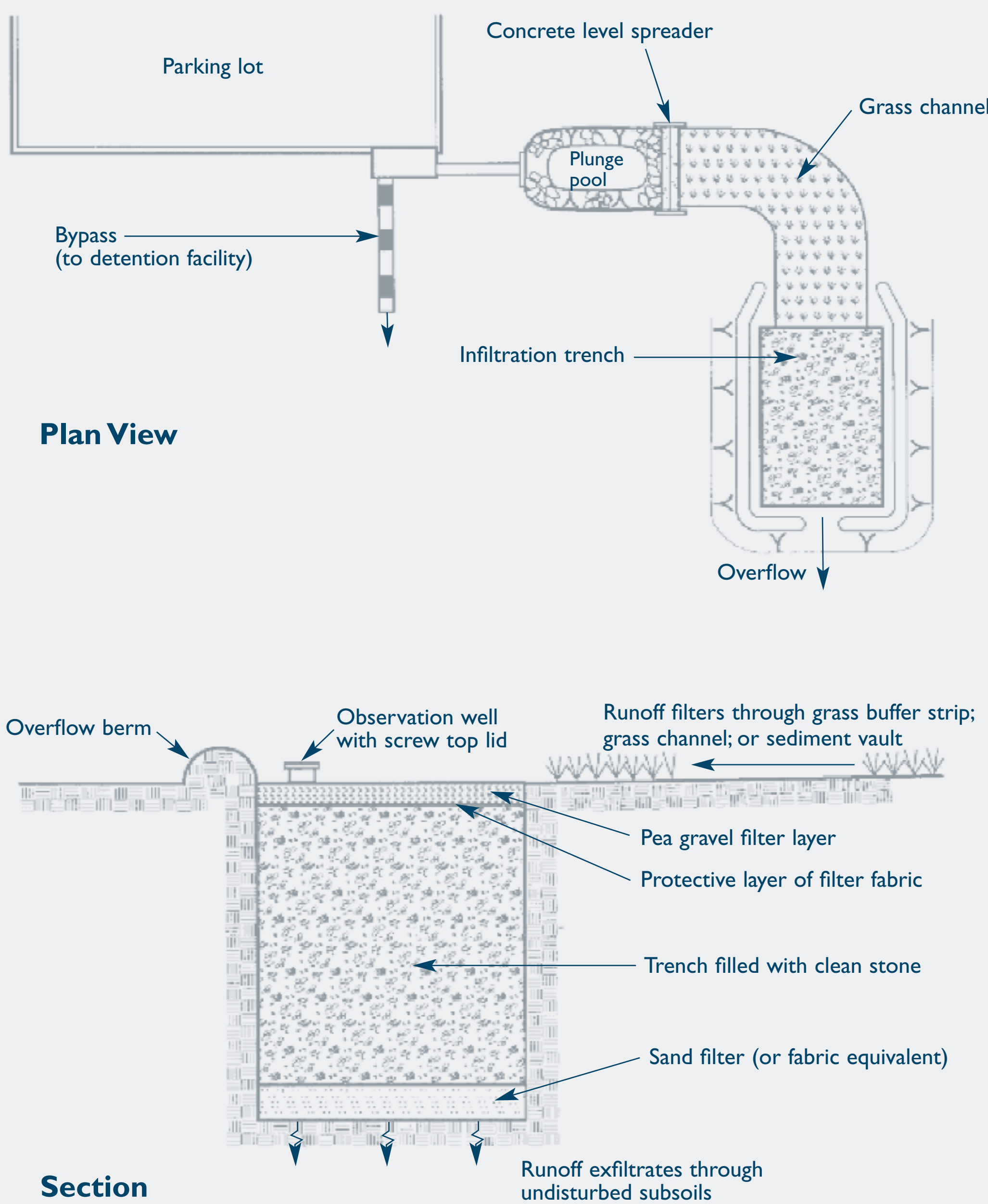
where: A = effective bottom area of trench (ft^2)
WQV = water quality volume (ft^3)
P = design infiltration rate of soil (in/hr) (one-half the minimum field measured infiltration rate)
n = porosity of storage media (0.4 for 1.5- to 3-inch diameter clean washed stone)
t = maximum drain time (48 hours)

- *The trench should be sized to hold the entire water quality volume. Therefore, the length of the trench should be determined based on the water quality volume and the calculated effective bottom area.*

Storage Media

- *The trench should be filled with clean, washed aggregate with a diameter of 1.5 to 3 inches (porosity of 40 percent). The surface of the trench should be lined with permeable filter fabric and additional washed pea gravel or similar aggregate to improve sediment filtering in the top of the trench.*
- *The sides of the trench should be lined with filter fabric. The filter fabric should be compatible with the soil textures and application. The bottom of the trench can be lined with filter fabric or 6 to 12 inches of clean sand. Clean sand is preferred over filter fabric since clogging can occur at the*

Figure 11-P3-1 Infiltration Trench



Source: Adapted from Center for Watershed Protection, 2000.

Table 11-P3-2 Design Criteria for Infiltration Practices

Parameter	Design Criteria
Design Volume	Entire water quality volume (WQV)
Pretreatment Volume	25% of WQV
Maximum Draining Time	48 to 72 hours after storm event (entire WQV)
Minimum Draining Time	12 hours (for adequate pollutant removal)
Maximum Contributing Drainage Area	Trench: 5 acres (2 recommended) Basin: 25 acres (10 recommended)
Minimum Infiltration Rate	0.3 in/hr (as measured in the field), lower infiltration rates may be acceptable provided sufficient basin floor area is provided to meet the required WQV and drain time
Maximum Infiltration Rate	5.0 in/hr (as measured in the field); pretreatment required for infiltration rates over 3.0 in/hr
Depth	Trench: 2 to 10 feet (trench depth) Basin: 3 feet (ponding depth) recommended, unless used as combined infiltration and flood control facilities

Source: Adapted from Wisconsin Department of Natural Resources, 2000; NYDEC, 2001; Metropolitan Council, 2001; MADEP, 1997; Lee et al., 1998.

filter fabric layer, and sand restricts downward flow less than fabric. Sand also encourages drainage and prevents compaction of the native soil while the stone aggregate is added.

- *An observation well should be installed along the trench centerline to monitor the water drainage in the system. The well should consist of a well-anchored, vertical perforated PVC pipe with a lockable aboveground cap (**Figure 11-P3-3**).*

Conveyance

- *Surface runoff exceeding the capacity of the trench should be conveyed in a stabilized channel if runoff velocities exceed erosive velocities (3.5 to 5.0 feet per second). If velocities do not exceed the non-erosive threshold, overflow may be accommodated by natural topography.*
- *Stormwater outfalls should be designed to convey the overflow associated with the 10-year design storm.*

Winter Operation

- *Infiltration trenches can be operated in the winter if the bottom of the trench is below the frost line.*
- *Freezing is less likely if a subsurface pipe carries runoff directly into the stone aggregate.*
- *Trenches covered with topsoil may not operate efficiently during the winter months because frozen soils tend to reduce infiltration.*

Infiltration Basin

Figure 11-P3-4 depicts a typical schematic design of an infiltration basin.

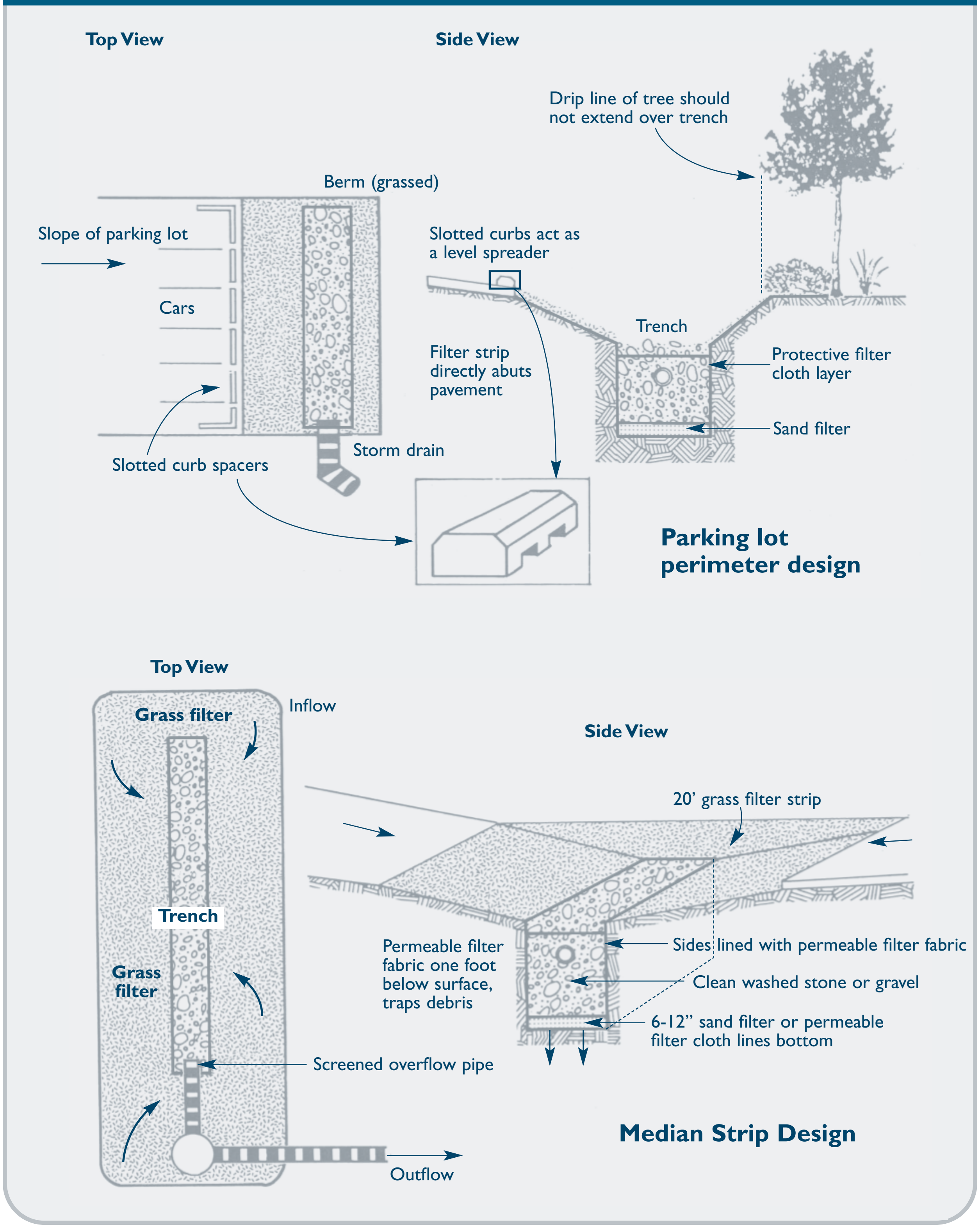
Design Volume

- *Infiltration basins should be designed to infiltrate the entire water quality volume through the bottom of the basin.*
- *Infiltration basins should generally be designed as off-line practices, unless used as combined infiltration and flood control facilities or where retention of runoff from storms larger than the water quality design storm is required (e.g., discharges within 500 feet of tidal wetlands to meet runoff capture criterion).*

Pretreatment

- *Pretreatment should be provided to accommodate 25 percent of the water quality volume. Pretreatment generally consists of a sediment forebay or other device designed to capture coarse particulate pollutants, floatables, and oil and grease (if necessary). Pretreatment is required for soils with infiltration rates over 3.0 inches per hour.*

Figure 11-P3-2 Infiltration Trench Designs for Parking Lots



Source: Adapted from Schueler, 1987.

Draining Time

- *Infiltration basins should be designed to completely drain the water quality volume into the soil within 48 to 72 hours after the storm event. Infiltration basins should completely dewater between storms.*
- *A minimum draining time of 12 hours is recommended to ensure adequate pollutant removal.*

Infiltration Rate

- *A minimum field-measured soil infiltration rate of 0.3 inches per hour is recommended as a practical lower limit for the feasibility of infiltration practices. Lower infiltration rates may be acceptable provided that the water quality volume and drain time criteria can be met. Field-measured soil infiltration rates should not exceed 5.0 inches per hour.*

Basin Dimensions and Configuration

- *The basin dimensions can be determined from the required storage volume and maximum depth of the basin. The required storage volume is equal to the water quality volume plus precipitation that falls within the basin during the water quality design storm:*

$$V = WQV + (P)(A_b)$$

where:
D = required basin storage volume
P = design water quality volume
t = design precipitation = 1 inch
A_b = basin surface area

This equation conservatively assumes no infiltration during the water quality design storm. The depth of water in off-line infiltration basins should not exceed 3 feet for safety considerations. Larger depths may be required for combined infiltration/flood control basins. The maximum basin depth can be calculated from the following equation:

$$D = Pt$$

where:
D = maximum basin depth (in)
P = design infiltration rate of soil (in/hr) (one-half the minimum field measured infiltration rate)
t = maximum drain or ponding time (48 hours)

- *The length and width of the basin can be calculated from the water depth and required basin storage volume, as shown above.*
- *The basin shape can be any configuration that blends with the surrounding landscape.*
- *The floor of the basin should be graded as flat as possible for uniform ponding and infiltration.*
- *The basin side slopes should be no steeper than 3:1 (horizontal:vertical). Flatter side slopes are preferred for vegetative stabilization, easier mowing and maintenance access, and safety.*
- *Infiltration basins may be equipped with an underdrain system for dewatering when the systems become clogged.*

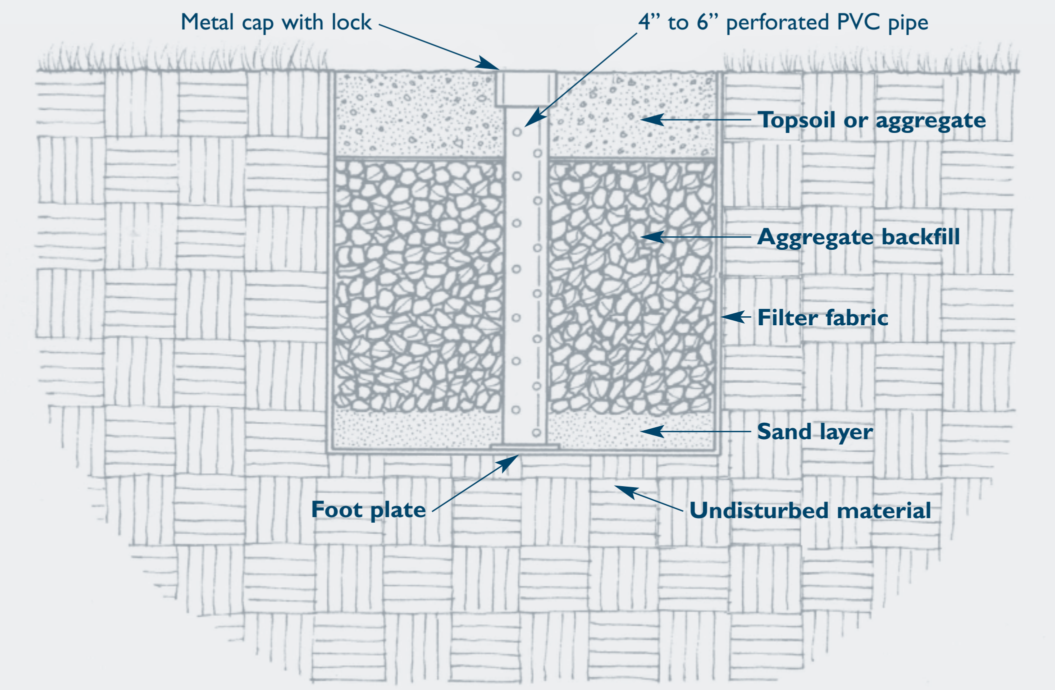
Conveyance

- *Inlet channels to the basin should be stabilized to mitigate against erosive velocities. Riprap used for this purpose should be designed to spread flow uniformly over the basin floor.*
- *A bypass flow path or pipe should be incorporated into the design of the basin to convey high flows around the basin via an upstream flow splitter.*
- *Stormwater bypass conveyances should be designed to convey the overflow associated with the 10-year design storm.*
- *Infiltration basins should be equipped with an emergency spillway capable of passing runoff from large storms without damage to the impoundment. The overflow should be conveyed in a stabilized channel if runoff velocities exceed erosive velocities (3.5 to 5.0 feet per second). If velocities do not exceed the non-erosive threshold, overflow may be accommodated by natural topography.*

Vegetation

- *Vegetative buffers are recommended around the perimeter of the basin for erosion control and additional sediment filtering.*
- *The bottom and side slopes of the basin should be planted with a dense stand of water-tolerant grass. Plant roots enhance the pore space and infiltration in the underlying soil. Use of low-maintenance, rapidly germinating grasses is recommended. Plants should be able to withstand prolonged periods of wet and dry*

Figure 11-P3-3 Observation Well Detail



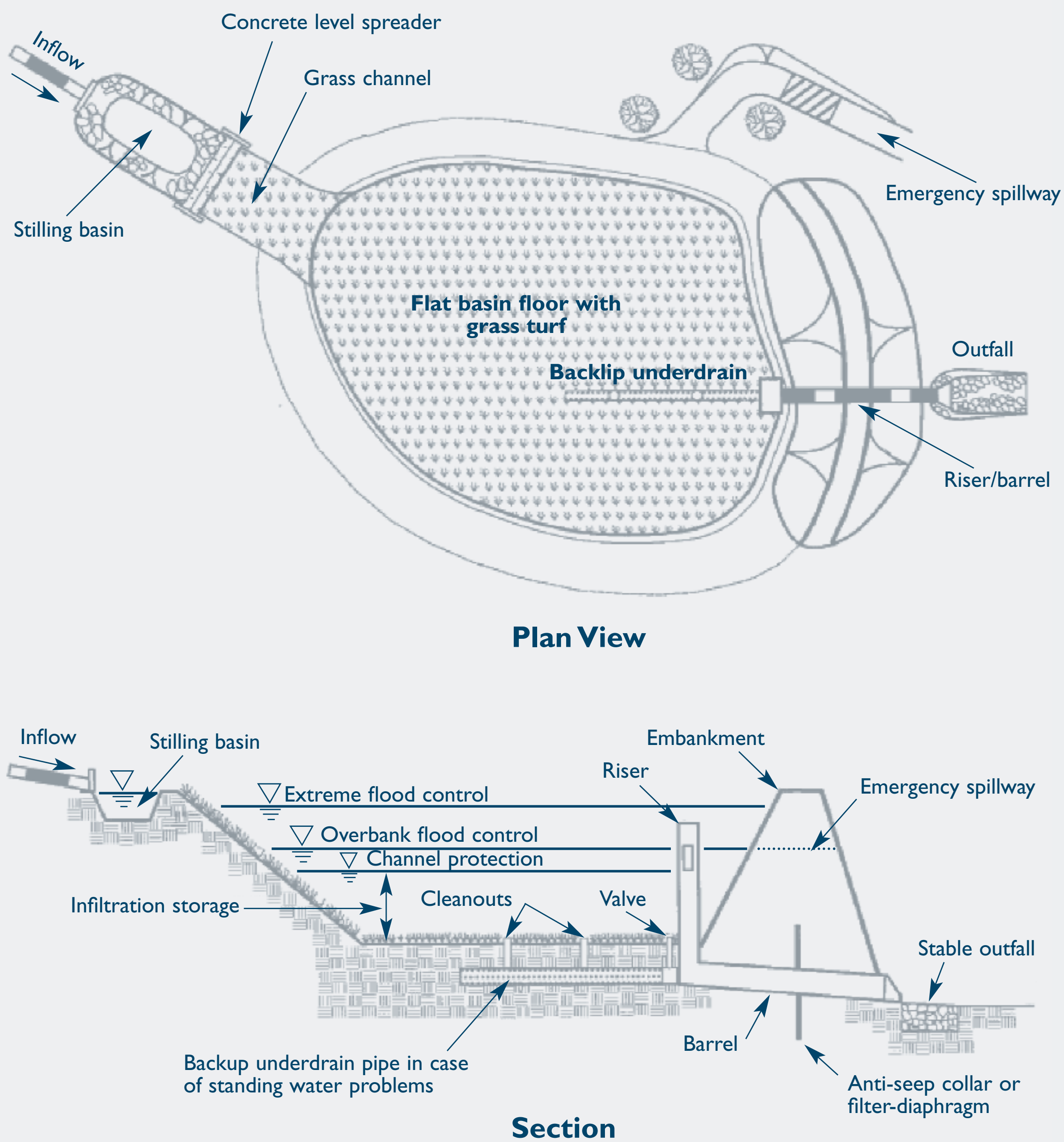
Source: Wisconsin DNR, 2000.

conditions. Highly invasive plants are not recommended. Recommended plant species generally include those species appropriate for hydrologic zones 3 and 4 in ***Table A-1 of Appendix A.*** *Loose stone, riprap, or other materials requiring hand removal of debris should not be used on the basin floor.*

Construction

- *Any stormwater treatment practices that create an embankment, including stormwater infiltration basins, are under the jurisdiction of the Dam Safety Section of the Connecticut DEP Inland Water Resources Division (IWRD) and should be constructed, inspected, and maintained in accordance with CGS §§ 22a-401 through 22a-411, inclusive, and applicable DEP guidance.*
- *Proper construction of infiltration practices is critical to minimize the risk of premature failure.*
- *Infiltration practices should not be used as temporary sediment basins during construction.*
- *Infiltration practices should be constructed at or near the end of the development construction. The development plan sheets should list the proper construction sequence so that the infiltration structure is protected during construction.*
- *Before the development site is graded, the area of the infiltration practices should be roped off and flagged to prevent soil compaction by heavy equipment.*
- *Light earth-moving equipment (backhoes or wheel and ladder type trenchers) should be used to excavate infiltration practices. Heavy equipment can cause soil compaction and reduce infiltration capacity. Compaction of the infiltration area and surrounding soils during construction should be avoided.*
- *Smearing of soil at the interface of the basin or trench floor and sides should be avoided.*
- *The sides and bottom of an infiltration trench should be raked or scarified after the trench is excavated to restore infiltration rates.*
- *The floor of an infiltration basin should be raked or deep tilled after final grading to restore infiltration rates.*

Figure 11-P3-4 Infiltration Basin



Source: Wisconsin DNR, 2000.

- *Appropriate erosion and sediment controls should be utilized during construction, as well as immediately following construction, to stabilize the soils in and around the basin.*

Inspection and Maintenance

- *Plans for infiltration practices should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.*
- *Pretreatment devices should be inspected and cleaned at least twice a year.*
- *For the first few months after construction, infiltration trenches and basins should be inspected after every major storm. Inspections should focus on the duration of standing water in a basin or in the observation well of a trench after a storm. Ponding water after 48 hours indicates that the bottom of the infiltration structure may be clogged. If the bottom of the trench becomes clogged, all of the stone aggregate and filter fabric must be removed and replaced with new material. The bottom of the trench may need to be tilled to enhance infiltration. Water ponded at the surface of a trench may indicate only surface clogging.*
- *After the first few months of operation, maintenance schedules for infiltration practices should be based on field observations, although inspections should be performed at least twice per year. For infiltration trenches, observations should include checking for accumulated sediment, leaves and debris in the pretreatment device, clogging of inlet and outlet pipes, and ponded water inside and on the surface of the trench. For infiltration basins, observations should include measurement of differential accumulation of sediment, erosion of the basin floor, health of the basin vegetation, and condition of riprap.*
- *Grass clippings, leaves, and accumulated sediment should be removed routinely from the surface of infiltration trenches. The upper layer of stone and filter fabric may need to be replaced to repair surface clogging.*
- *Sediment should be removed from infiltration basins when the sediment is dry (visible cracks) and readily separates from the floor of the basin to minimize smearing the basin floor. The remaining soil should be tilled and revegetated.*
- *The grass in the basin, side slopes, and buffer areas should be mowed, and grass clippings and accumulated trash removed at least twice during the growing season. Mowing should not be performed when the ground is soft to avoid the creation of ruts and compaction, which can reduce infiltration.*

Cost Considerations

Costs for implementation of infiltration practices are highly variable from site to site depending on soil conditions and the required pretreatment. Typical installation costs for infiltration trenches and basins are approximately \$5.00 and \$2.00 per cubic foot (adjusted for inflation) of stormwater treated (SWRPC, 1999), respectively. The cost per impervious acre treated varies by region and design variant. Infiltration basins are relatively cost-effective practices because little infrastructure is needed. Infiltration basins typically consume about 2 to 3 percent of the site draining to them. Maintenance costs for infiltration basins are estimated at 5 to 10 percent of construction costs, while maintenance costs for infiltration trenches are estimated at 20 percent of construction costs (EPA, 2002). Infiltration trenches are more expensive to construct than some other treatment practices in terms of cost per volume of stormwater treated. Because infiltration practices have high failure rates if improperly designed, constructed, and maintained, these practices may require frequent replacement, which would reduce their overall cost effectiveness.

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Filtering Practices

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Primary Treatment Practice	●
Secondary Treatment Practice	

Stormwater Management Benefits

Pollutant Reduction	
Sediment	Significant Benefit
Phosphorus	Significant Benefit
Nitrogen	Significant Benefit
Metals	Significant Benefit
Pathogens	Significant Benefit
Floatables*	Partial Benefit
Oil and Grease*	Significant Benefit
Dissolved Pollutants	Partial Benefit
Runoff Volume Reduction	
Runoff Capture	Low or Unknown Benefit
Groundwater Recharge	Partial Benefit
Stream Channel Protection	Low or Unknown Benefit
Peak Flow Control	Low or Unknown Benefit

Key: ■ Significant Benefit
■ Partial Benefit
□ Low or Unknown Benefit

*Only if a skimmer is incorporated

Implementation Requirements

Capital Cost....................................High

Maintenance Burden...................High

Description

Stormwater filtering practices capture and store stormwater runoff and pass it through a filtering media such as sand, organic material, or soil for pollutant removal. Stormwater filtering practices generally fall into two categories, which are described in this section:

- *Surface filters (including bioretention)*
- *Underground filters*

Stormwater filters are primarily water quality control devices designed to remove particulate pollutants and, to a lesser degree, bacteria and nutrients. A separate facility would typically be required to provide channel protection and peak flow control. Most filtering systems consist of four design components:

- *Inflow regulation to divert the water quality volume into the structure*
- *Pretreatment to capture coarse sediments*
- *Filter surface and media*
- *Outflow mechanism to return treated flows back to the conveyance system or into the soil*

Stormwater filtering practices are typically applied to small drainage areas (5 to 10 acres) and designed as off-line systems to treat the water quality volume and bypass larger flows. The water quality volume is diverted into a pretreatment settling chamber or forebay where coarse solids are allowed to settle, thereby reducing the amount of sediment that reaches the filter. Water flows to the filter surface in a controlled manner, where finer sediment and attached pollutants are trapped or strained out and microbial breakdown of pollutants (i.e., nitrification) can occur. Filtered stormwater is then collected below the filter bed or media and either returned to the conveyance system via an underdrain or allowed to infiltrate into the soil (i.e., exfiltration). Due to their similarity to infiltration basins, which were discussed in the previous section, exfiltration systems are not addressed in this section.

Stormwater filtering practices are commonly used to treat runoff from small sites such as parking lots and small developments; areas with high pollution potential such as industrial sites; or in highly urbanized areas where space is limited. A number of surface and underground stormwater filter design variations have been developed for these types of applications. Underground filters can be placed under parking lots and are well suited to highly urbanized areas or space-limited sites since they consume no surface space. As such, stormwater filters are often suitable for retrofit applications where space is typically limited. Stormwater filtration systems that do not discharge to the soil (i.e., are contained in a structure or equipped with an impermeable liner) are also suitable options for treating runoff from industrial areas and other land uses with high pollutant potential since the water is not allowed to infiltrate into the soil and potentially contaminate groundwater.

Design Variations

Surface Filters

Surface Sand Filter: The surface sand filter is the original sand filter design, in which both the filter bed and sedimentation chamber are aboveground. Surface sand filters can consist of excavated, earthen basins or aboveground concrete chambers (i.e., Austin Sand Filter). **Figure 11-P4-1** and **Figure 11-P4-2** depict schematics of two common surface sand filter designs.

Organic Filters: Organic filters are similar to surface sand filters, with the sand medium replaced with or supplemented by material having a higher organic content such as peat or compost. Organic filters are generally ineffective during the winter in cold climates because they retain water and consequently freeze solid and become completely impervious. Organic filters are not recommended for use in Connecticut and, therefore, are not addressed in this Manual.

Bioretention: Bioretention systems are shallow landscaped depressions designed to manage and treat stormwater runoff. Bioretention systems are a variation of a surface sand filter, where the sand filtration media is replaced with a planted soil bed designed to remove pollutants through physical and biological processes (EPA, 2002). Stormwater flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Treated water is allowed to infiltrate into the surrounding soils or is collected by an underdrain system and discharged to the storm sewer system or receiving waters. Small-scale bioretention applications (i.e., residential yards, median strips, parking lot islands), commonly referred to as rain gardens, are also described in Chapter Four of this Manual as a Low Impact Development design practice. **Figure 11-P4-3** depicts schematic designs of several common types of bioretention facilities.

Underground Filters

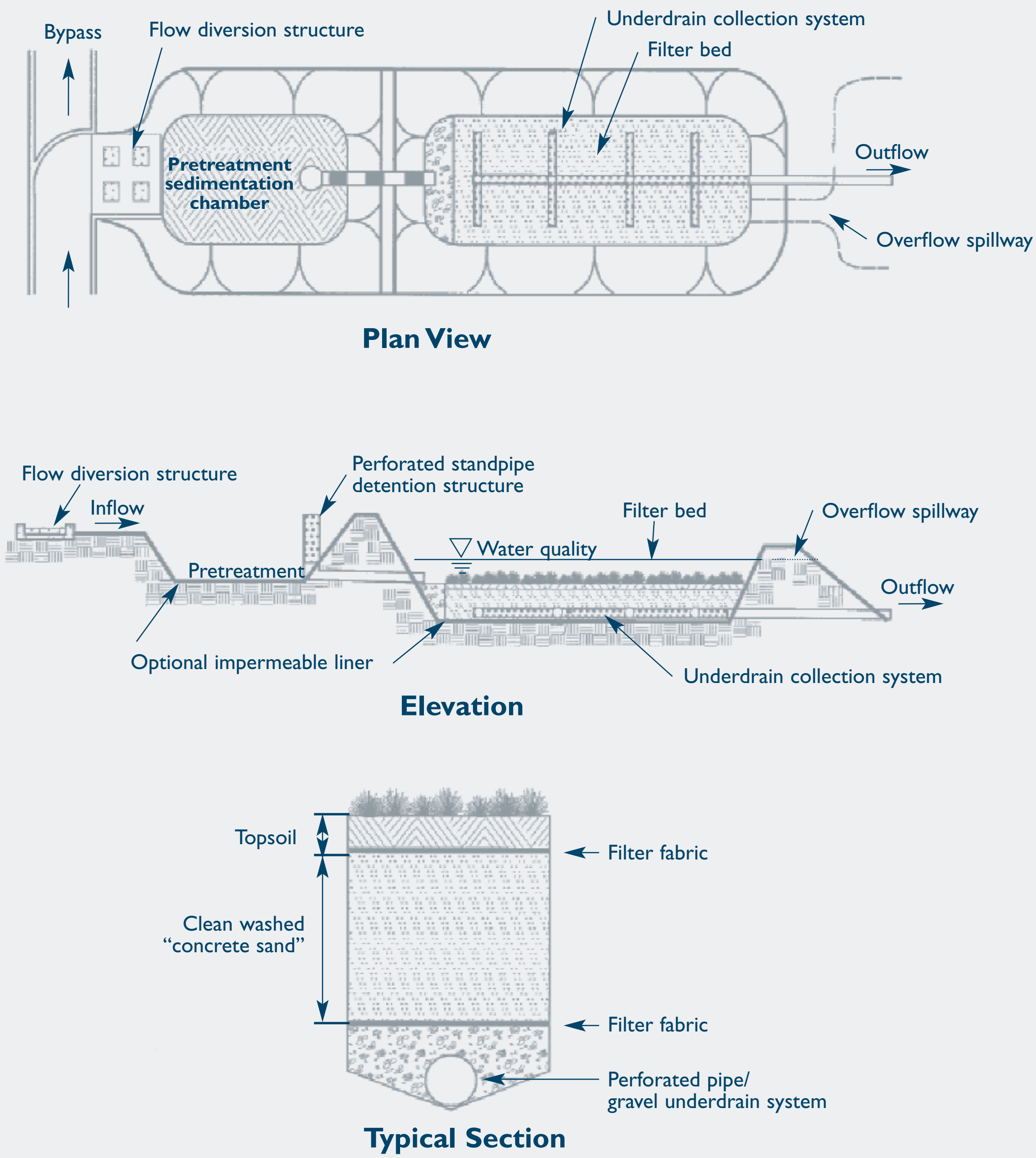
D.C. Sand Filter: This underground vaulted filter design was developed by the District of Columbia in the late 1980s. The D.C. Sand Filter includes three chambers. The first chamber and a portion of the second chamber contain a permanent pool of water, which provides sedimentation and removal of floatables and oil and grease. Water flows through a submerged opening near the dividing wall that connects the two chambers, into the second chamber and onto the filter bed. Filtered water is collected by an underdrain system and flows into the third chamber, which acts like a clearwell and overflow chamber (EPA, 2002). A schematic of the D.C. Sand Filter is shown in **Figure 11-P4-4.**

Perimeter Sand Filter: The perimeter sand filter is an underground vault sand filter that was originally developed in Delaware (also known as the "Delaware Sand Filter") for use around the perimeter of parking lots. The system contains two parallel chambers and a clearwell. Overland flow enters the first chamber through slotted grates, which acts as a sedimentation chamber. Water then flows over weirs into the second chamber, which contains the filter media. Filtered water is collected by an underdrain system and flows into a clearwell before discharging to the storm drain system. A schematic of a perimeter sand filter is shown in **Figure 11-P4-5.**

Alexandria Sand Filter: The Alexandria Sand Filter, developed in Alexandria, Virginia, is similar to the D.C. Sand Filter in that it consists of three distinct chambers: a sediment chamber, a filtering chamber, and a clearwell. However, the Alexandria design replaces the permanent pool oil/water separator with a gabion barrier that filters and dissipates energy. This variation is a dry system designed to drain between storms. **Figure 11-P4-6** shows a schematic of an Alexandria Sand Filter.

Proprietary Designs: A number of proprietary underground media filter designs have been developed in recent years. These systems consist of the

Figure 11-P4-1 Earthen Surface Sand Filter



Source: Adapted from Center for Watershed Protection, 2000.

same general configuration, with specialized filter media targeted at removal of various particulate and soluble pollutants. Most of these pre-manufactured systems consist of a sedimentation chamber and a filtration chamber that holds a series of canisters with replaceable/recyclable media cartridges. These systems currently are not considered primary treatment practices due to limited peer-reviewed data on their performance under field conditions. Proprietary filtering designs are discussed further as secondary treatment practices later in this chapter.

Advantages

- *Applicable to small drainage areas.*
- *Can be applied to most sites due to relatively few constraints and many design variations (i.e., highly versatile).*
- *May require less space than other treatment practices. Underground filters can be used where space limitations preclude surface filters.*
- *Ideal for stormwater retrofits and highly developed sites.*
- *High solids, metals, and bacteria removal efficiency.*
- *High longevity for sand filters.*
- *Bioretention can provide groundwater recharge.*

Limitations

- *Pretreatment required to prevent filter media from clogging.*
- *Limited to smaller drainage areas.*
- *Frequent maintenance required.*
- *Relatively expensive to construct.*
- *Typically require a minimum head difference of approximately 5 feet between the inlet and outlet of the filter.*
- *Surface sand filters not feasible in areas of high water tables.*
- *Should not be used in areas of heavy sediment loads (i.e., unstabilized construction sites).*
- *Provide little or no quantity control.*
- *Surface and perimeter filters may be susceptible to freezing.*
- *Surface filters can be unattractive without grass or vegetative cover. Bioretention may be a more aesthetically pleasing alternative due to incorporation of plants.*
- *May have odor and mosquito-breeding problems if not designed properly.*

Siting Considerations

Drainage Area: The maximum contributing drainage area for most surface and underground filtering practices is between 5 and 10 acres. Filtering practices can be used to treat runoff from larger drainage areas if properly designed, although the potential for clogging increases for drainage areas larger than 10 acres. Bioretention should be restricted to drainage areas of 5 acres or less.

Slopes and Head Requirements: Filtering systems can be used on sites with slopes of approximately 6 percent or less. Most stormwater filter designs require between 5 and 7 feet of head difference between the filter inlet and outlet to allow sufficient gravity flow through the system. Perimeter sand filters and bioretention areas require as little as 2 feet of head.

Soils: Stormwater filtering systems that return filtered runoff to the conveyance system and do not infiltrate into the ground can be used in almost any soil type. Bioretention designs that rely on infiltration can be used only when the soil infiltration characteristics are appropriate (see the Infiltration Practices section of this chapter).

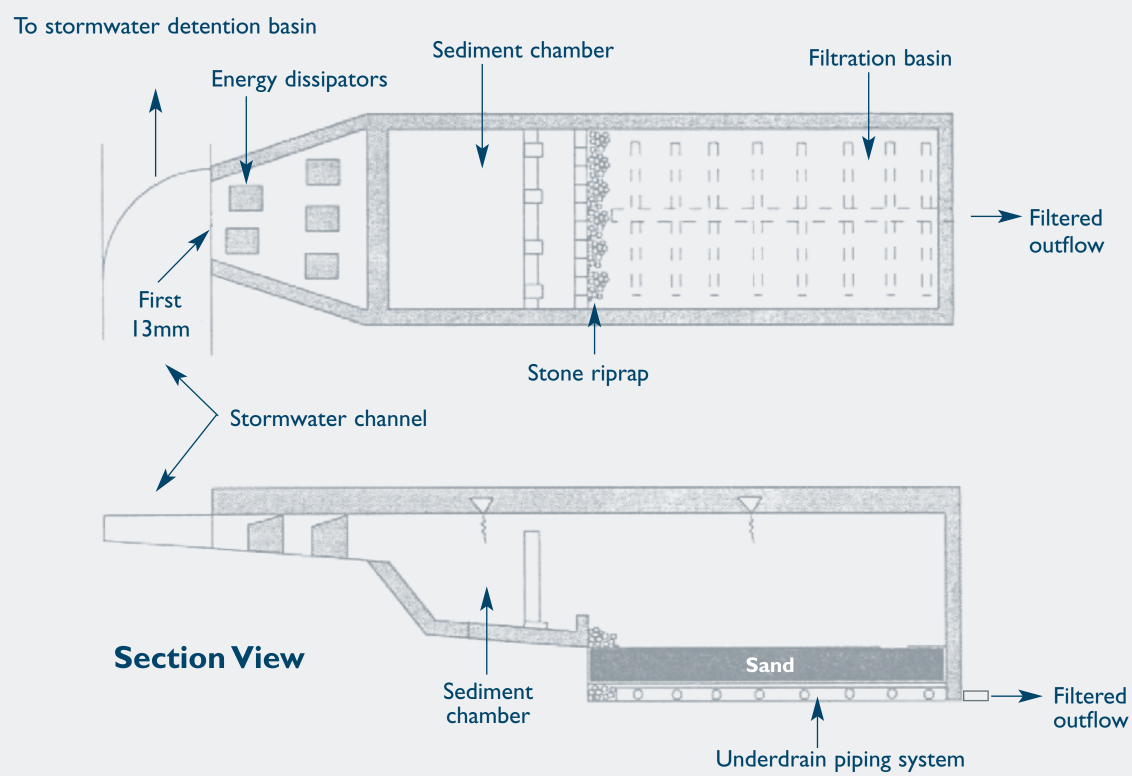
Land Use: Filtering systems are generally applicable to highly impervious sites.

Water Table: At least 3 feet of separation is recommended between the bottom of the filter and the seasonally high groundwater table to maintain adequate drainage, prevent structural damage to the filter, and minimize the potential for interaction with groundwater.

Design Criteria

The design criteria presented in this section are applicable to surface sand filters, bioretention systems, and underground filters. Considerations for specific design variations are also included.

Figure 11-P4-2 Austin Sand Filter



Source: Adapted from FHWA, 1996.

Pretreatment

- *Pretreatment should be provided to store at least 25 percent of the water quality volume and release it to the filter media over a 24-hour period. Storage and pretreatment of the entire water quality volume (also known as "full sedimentation" design) may be required for sites with less than 75 percent imperviousness or sites with unusually high sediment loads.*
- *Pretreatment generally consists of a dry or wet sedimentation chamber or sediment forebay. A length-to-width ratio of between 1.5:1 and 3:1 is recommended for the pretreatment area.*
- *The required surface area of the sedimentation chamber or forebay for full sedimentation design can be determined using the following equation (Camp-Hazen):*

$$A_s = -\frac{Q}{W} \ln (1-E)$$

where: A_s = sedimentation surface area (ft_2)
Q = discharge rate from drainage area (ft^3/s) = $WQV/24hr$*
W = particle settling velocity (0.0004 ft/s recommended for silt)
E = sediment removal efficiency (assume 0.9 or 90%)

*(between 25 and 100 percent of the water quality volume can be used for partial sedimentation design)

Design Volume

- *Surface sand filters should provide at least 75 percent of the water quality volume in the practice (including above the filter, in the filter media voids, and in the pretreatment chamber) and be designed to completely drain in 24 hours or less.*

Filter Bed

- *The filter media for a surface sand filter should consist of medium sand (ASTM C-33 concrete sand). Grain size analysis provided by the supplier is recommended to confirm the sand specification. However, if other media are desired to address specific pollutants, pilot testing is recommended to determine actual hydraulic conductivity.*
- *The required filter bed area should be calculated using the principles of Darcy's Law, which relates the velocity of porous media flow to the hydraulic head and hydraulic conductivity of the filter medium:*

$$A_f = \frac{(WQV)(d)}{[(k)(t)(h+d)]}$$

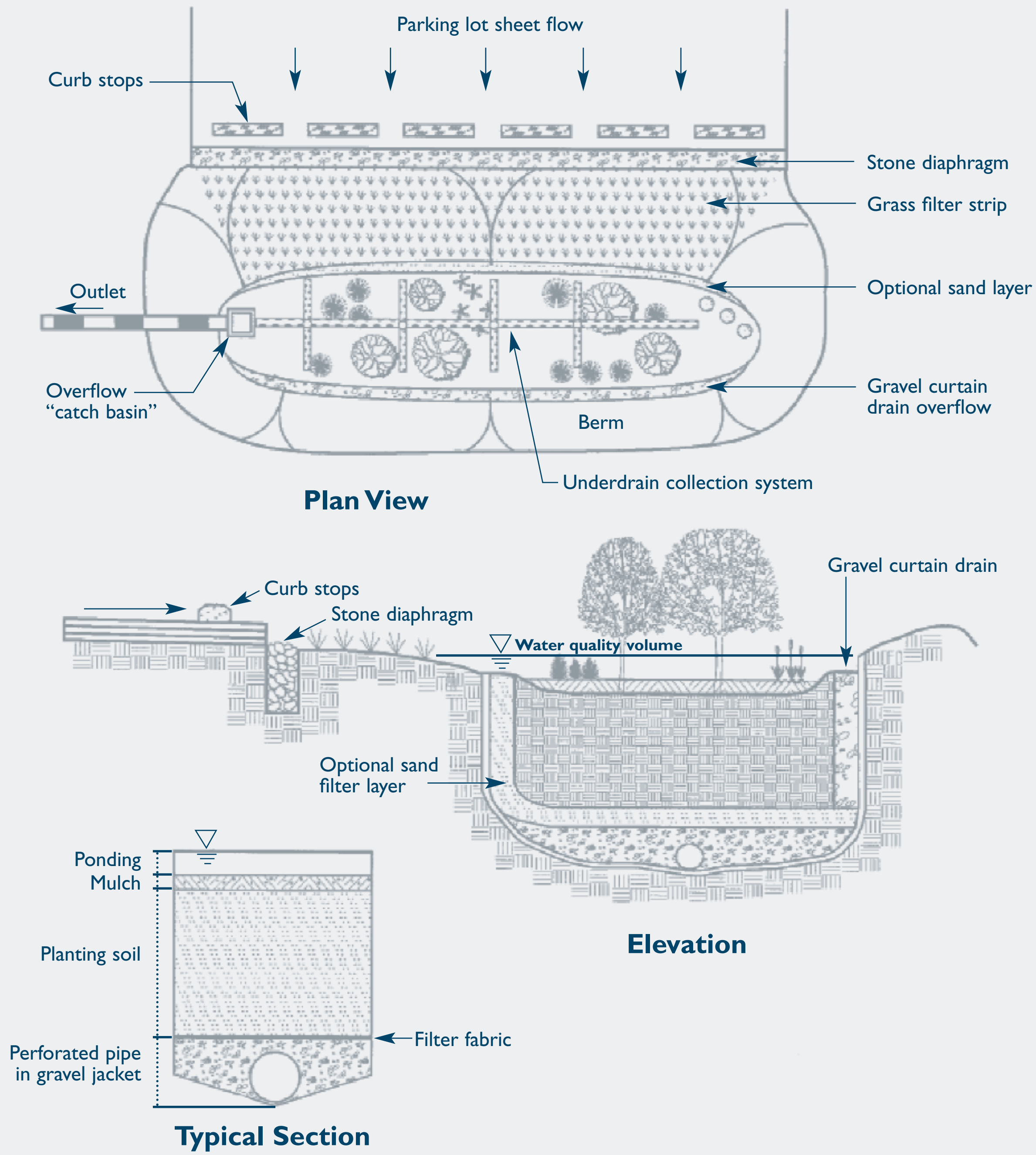
where: A_f = filter bed surface area (ft2)
WQV = water quality volume (ft3)
d = filter bed depth (ft)
k = hydraulic conductivity of filter media (ft/day)
t = time for the water quality volume to drain from the system (24 hours)
h = average height of water above filter bed during water quality design storm

- *A typical hydraulic conductivity value for medium sand is 20 feet per day. Laboratory analysis is recommended to determine the hydraulic conductivity of the actual filter media.*
- *The recommended minimum filter bed depth is 18 inches. Consolidation of the filter media should be taken into account when measuring final bed depth. The surface of the filter bed should be level to ensure equal distribution of flow in the bed.*
- *Mosquito entry points to underground filter systems should be sealed (adult female mosquitoes can use openings as small as 1/16 inch to access water for egg laying).*

Underdrain System

- *The underdrain system should consist of 6-inch diameter or larger PVC perforated pipes reinforced to withstand the weight of the overburden (schedule 40 PVC or greater). A central collector pipe with lateral feeders is a common underdrain piping configuration. The main collector underdrain pipe should have a minimum slope of one percent. The maximum distance between two adjacent lateral feeder pipes is 10 feet.*
- *Perforations in the underdrain piping should be half-inch holes spaced 6 inches apart longitudinally, with rows 120 degrees apart (Metropolitan Council, 2001).*
- *The underdrain piping should be set in 1 to 2-inch diameter stone or gravel washed free of fines and organic material. The stone or gravel layer should provide at least 2 inches of coverage over the tops of the drainage pipes. The stone or gravel layer should be separated from the filter media by a permeable geotextile fabric. Geotextile fabric (and an impermeable liner if*

Figure 11-P4-3 Bioretention



Source: Adapted from Center for Watershed Protection, 2000.

Liner Material	Property	Recommended Specifications
Clay	Minimum Thickness	6 to 12 inches
	Permeability	1×10^{-5} cm/sec[1]
	Particle Size	Minimum 15% passing #200 sieve[1]
Geomembrane	Minimum Thickness	30 mils (0.03 inches)
	Material	Ultraviolet resistant, impermeable poly-liner

Table 11-P4-1 Liner Specifications

Source: [1]NYDEC, 2001; other listed specifications from City of Austin in Washington, 2000 (in Metropolitan Council, 2001).

necessary, see below) should also be placed below the stone or gravel layer.

- *Cleanouts should be provided at both ends of the main collector pipe and extend to the surface of the filter.*

Impermeable Liner

- *An impermeable liner (clay, geomembrane, or concrete) should be used for excavated surface sand filters when infiltration below the filter or pretreatment area could result in groundwater contamination, such as in aquifer protection areas or in areas with the potential for high pollutant loads (e.g. soluble metals and organics).* ***Table 11-P4-1*** *lists recommended specifications for clay and geomembrane liners.*

Conveyance

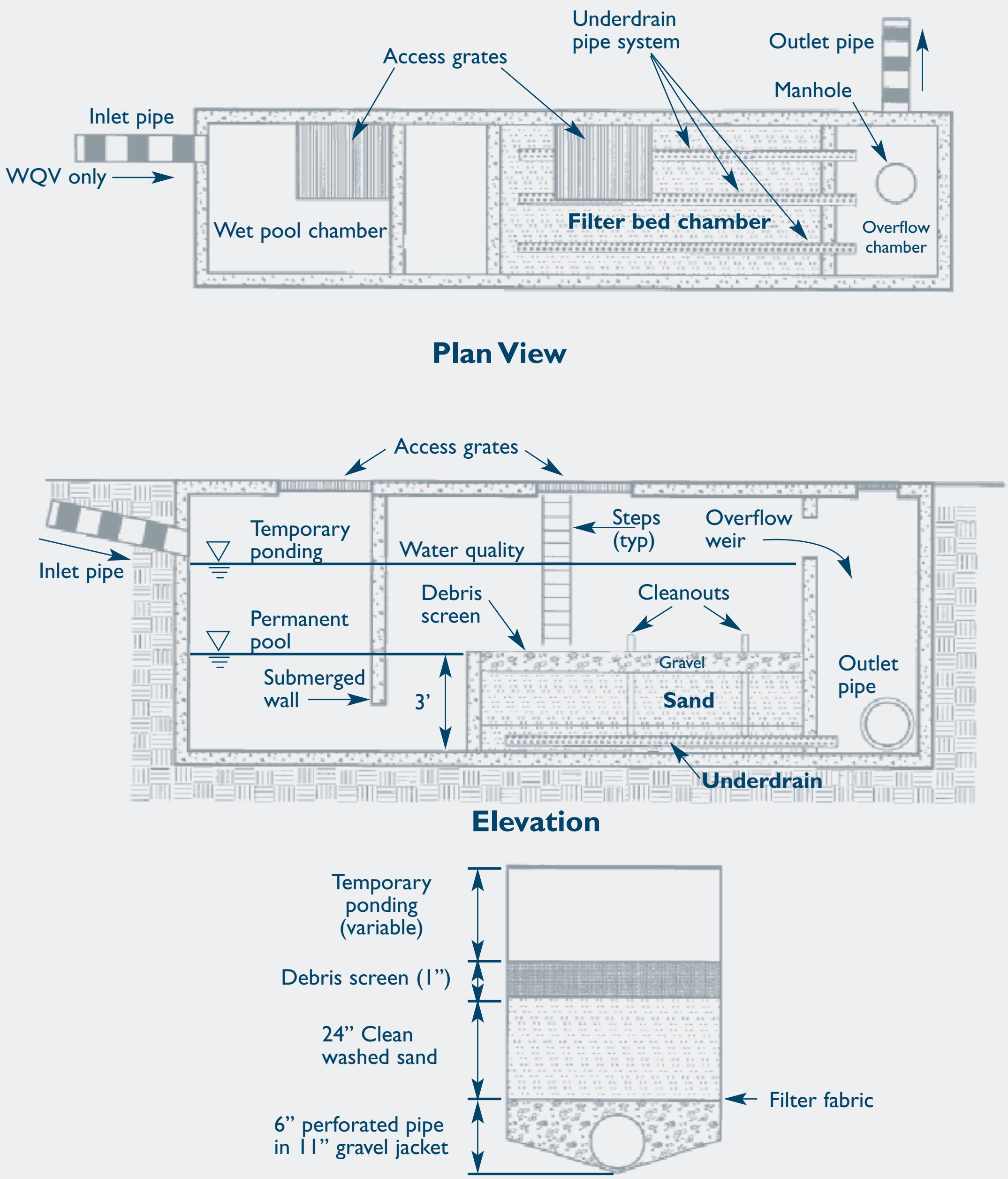
- *A flow diversion structure should be provided to divert the water quality volume to the filtering practice and allow larger flows to bypass the system.*
- *An overflow should be provided within the filtering practice to pass the 10-year design storm to the storm drainage system or stabilized channel.*
- *Inlet structures should be designed to minimize turbulence and spread flow uniformly across the surface of the filter.*
- *Stone riprap or other velocity dissipation methods should be used at the inlet to the filter bed to prevent scour of the filter media.*

Landscaping/Vegetation

- *Planting of surface filters with a grass cover is not recommended since grass clippings can result in reduced permeability or clogging of the filter surface. Grass cover can also conceal the treatment structure or cause it to blend in with surrounding vegetation, thereby potentially resulting in decreased maintenance (i.e., out-of-sight, out-of-mind).*
- *Bioretention facilities generally consist of the following hydric zones:*
  - ***Lowest Zone:*** *The lowest zone supports plant species adapted to standing and fluctuating water levels and corresponds to hydrologic zones 2 and 3 in Table A-1 of Appendix A.*
  - ***Middle Zone:*** *The middle zone supports a slightly drier group of plants, but still tolerates fluctuating water levels. This zone corresponds to hydrologic zones 3 and 4 in* ***Table A-1 of Appendix A****.*
  - ***Outer Zone:*** *The outer or highest zone generally supports plants adapted to drier conditions. This zone corresponds to hydrologic zones 5 and 6 in* ***Table A-1 of Appendix A****.*

(Claytor and Schueler, 1996). Plants should be selected to simulate a terrestrial forested community of native species. The following planting plan design considerations should be followed for bioretention areas:

Figure 11-P4-4 D.C. Underground Sand Filter



Source: Adapted from Center for Watershed Protection, 2000.

- *Use native plant species*
- *Select vegetation based on hydric zones*
- *Plant layout should be random and natural*
- *Establish canopy with an understory of shrubs and herbaceous plants*
- *Do not use woody vegetation near inflow locations*
- *Plant trees along the perimeter of the bioretention area*
- *Do not specify noxious weeds*
- *Wind, sun, exposure, insects, disease, aesthetics, existing utilities, traffic, and safety issues should be considered for plant selection and location.*

(Claytor and Schueler, 1996).

Winter Operation

- *Surface sand filters and perimeter filters can be ineffective during the winter months due to freezing of the filter bed.*
- *Where possible, the filter bed should be below the frost line.*
- *A larger underdrain system (i.e., larger diameter and more frequently spaced underdrain pipes and stone or gravel) may encourage faster draining and reduce the potential for freezing during winter months.*
- *Filters that receive significant road sand should be equipped with a larger pretreatment sediment chamber or forebay.*

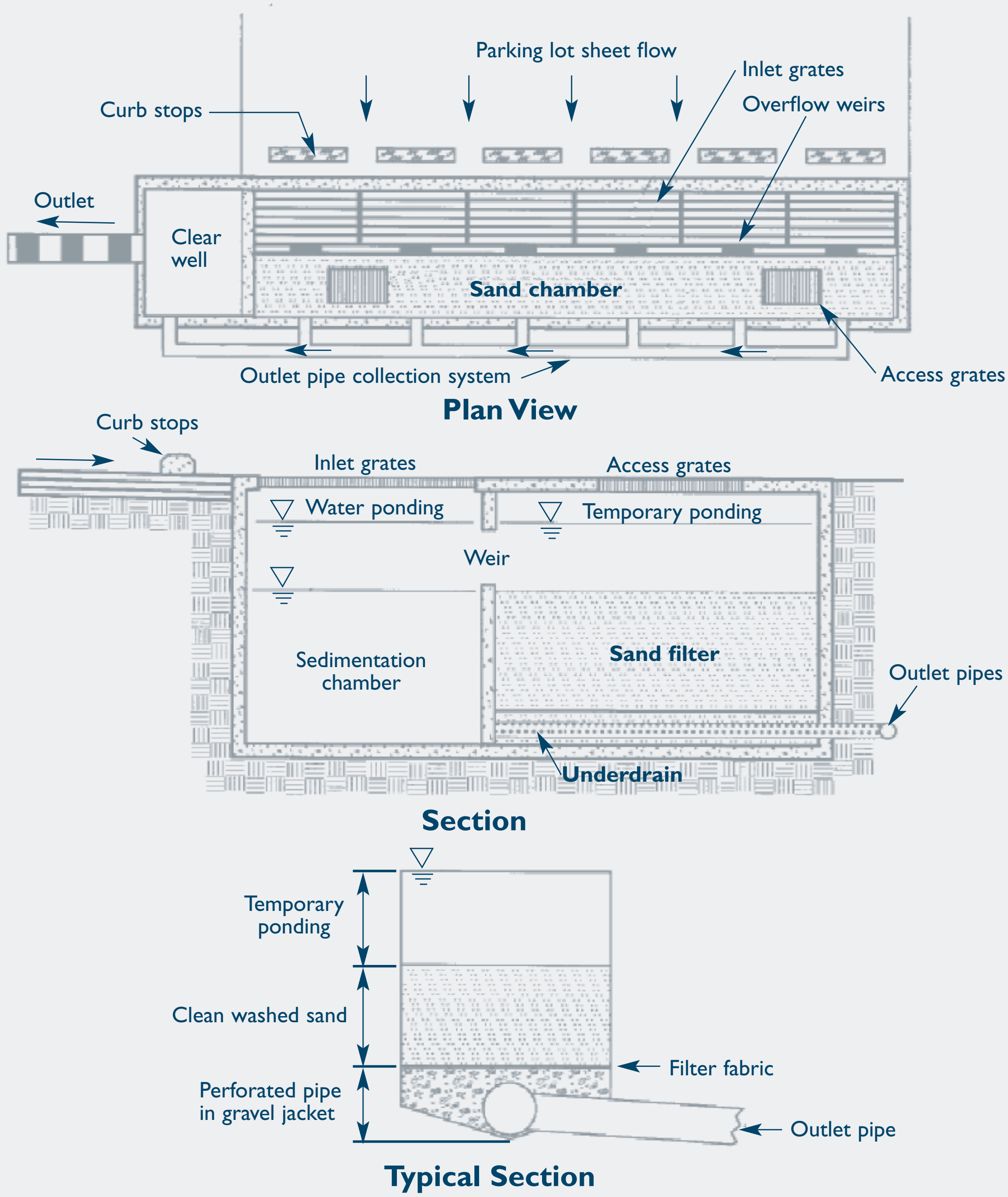
Construction

- *Any stormwater treatment practices that create an embankment, including surface sand filters or similar stormwater filtration systems, are under the jurisdiction of the Dam Safety Section of the Connecticut DEP Inland Water Resources Division (IWRD) and should be constructed, inspected, and maintained in accordance with Connecticut General Statutes §§22a-401 through 22a-411, inclusive, and applicable DEP guidance.*
- *The contributing drainage area should be stabilized to the maximum extent practicable and erosion and sediment controls should be in place during construction.*
- *Filtering systems should not be used as temporary sediment traps for construction erosion and sediment control.*
- *The filter media should be wetted periodically during construction to allow for consolidation of the filter media and proper filter media depth. Sand and other filter media should be carefully placed to avoid formation of voids and short-circuiting.*
- *Over-compaction of the filter media should be avoided to preserve filtration capacity. Mechanical compaction of the filter media should be avoided. Excavation should be performed with backhoes or lightweight equipment rather than loaders.*
- *The underdrain piping should be reinforced to withstand the weight of the overburden.*

Inspection and Maintenance

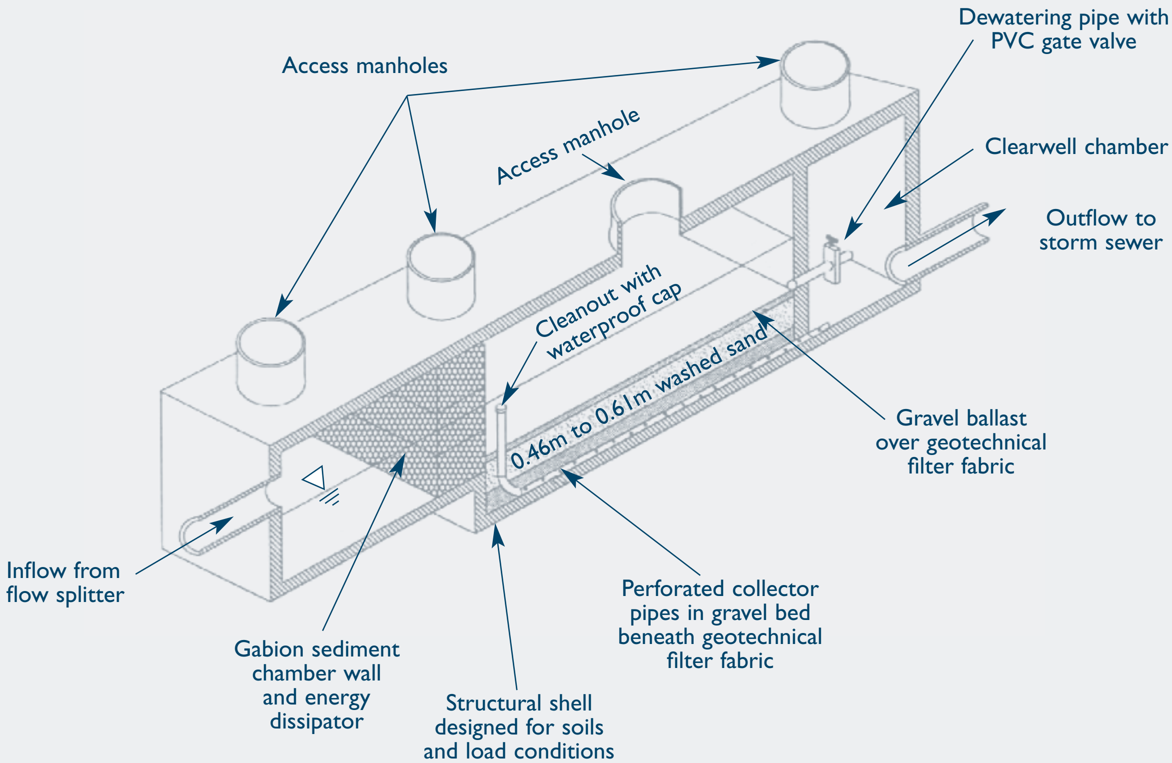
- *Maintenance is critical for the proper operation of filtering systems.*
- *Plans for filtering practices should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.*
- *Filtering practices should be inspected after every major storm in the first few months following construction. The filter should be inspected at least every 6 months thereafter. Inspections should focus on:*
  - *Checking the filter surface for standing water or other evidence of clogging, such as discolored or accumulated sediments.*
  - *Checking the sedimentation chamber or forebay for sediment accumulation, trash, and debris.*
  - *Checking inlets, outlets, and overflow spillway for blockage, structural integrity, and evidence of erosion.*
- *Sediment should be removed from the sedimentation chamber or forebay when it accumulates to a depth of more than 12 inches or 10 percent of the pretreatment volume. The sedimentation chamber or forebay outlet devices should be cleaned when drawdown times exceed 36 hours.*
- *Sediment should be removed from the filter bed when the accumulation exceeds one inch or when there is evidence that the infiltration*

Figure 11-P4-5 Perimeter (Delaware) Sand Filter



Source: Adapted from Center for Watershed Protection, 2000.

Figure 11-P4-6 Alexandria Underground Sand Filter



Source: Adapted from FHWA, 1996.

capacity of the filter bed has been significantly reduced (i.e., observed water level above the filter exceeds the design level or drawdown time exceeds 36 to 48 hours). As a rule-of-thumb, the top several inches of the filter bed (typically discolored material) should be removed and replaced annually, or more frequently if necessary. The material should be removed with rakes where possible rather than heavy construction equipment to avoid compaction of the filter bed. Heavy equipment could be used if the system is designed with dimensions that allow equipment to be located outside the filter, while a backhoe shovel reaches inside the filter to remove sediment. Removed sediments should be dewatered (if necessary) and disposed of in an acceptable manner.

- *Bioretention areas require seasonal landscaping maintenance, including:*
  - *Watering plants as necessary during first growing season*
  - *Watering as necessary during dry periods*
  - *Re-mulching void areas as necessary*
  - *Treating diseased trees and shrubs as necessary*
  - *Monthly inspection of soil and repairing eroded areas*
  - *Monthly removal of litter and debris*
  - *Adding mulch annually*

(Center for Watershed Protection, 2001).

Cost Considerations

Costs for implementation of stormwater filtering practices are generally higher than other stormwater treatment practices, but vary widely due to many different filter designs. A study by Brown and Schueler (1997) found typical installation costs between $3.00 and $6.00 per cubic foot of stormwater treated. These costs should be adjusted for inflation to reflect current costs. The cost per impervious acre treated varies by region and design variant. While underground filters are generally more expensive to construct than surface filters, they consume no surface space, which makes them relatively cost-effective in ultra-urban areas where land is at a premium (EPA, 1999).

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Water Quality Swales

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Primary Treatment Practice	●
Secondary Treatment Practice	

Stormwater Management Benefits

Pollutant Reduction	
Sediment	Significant Benefit
Phosphorus	Partial Benefit
Nitrogen	Partial Benefit
Metals	Partial Benefit
Pathogens	Low or Unknown Benefit
Floatables	Low or Unknown Benefit
Oil and Grease	Low or Unknown Benefit
Dissolved Pollutants	Partial Benefit
Runoff Volume Reduction	
Runoff Capture	Low or Unknown Benefit
Groundwater Recharge*	Partial Benefit
Stream Channel Protection	Partial Benefit
Peak Flow Control	Low or Unknown Benefit

Key: ■ Significant Benefit
■ Partial Benefit
□ Low or Unknown Benefit

*Dry swale design only

Implementation Requirements

Cost ....Low
Maintenance ....Low

Description

Water quality swales are vegetated open channels designed to treat and attenuate the water quality volume and convey excess stormwater runoff. This section includes two types of water quality swales:

- *Dry Swale*
- *Wet Swale*

Water quality swales provide significantly higher pollutant removal than traditional grass drainage channels (see secondary treatment practices), which are designed for conveyance rather than water quality treatment.

Dry swales are designed to temporarily hold the water quality volume of a storm in a pool or series of pools created by permanent check dams at culverts or driveway crossings. The soil bed consists of native soils or highly permeable fill material, underlain by an underdrain system. Pollutants are removed through sedimentation, adsorption, nutrient uptake, and infiltration.

Wet swales also temporarily store and treat the entire water quality volume. However, unlike dry swales, wet swales are constructed directly within existing soils and are not underlain by a soil filter bed or underdrain system. Wet swales store the water quality volume within a series of cells within the channel, which may be formed by berms or check dams and may contain wetland vegetation (Metropolitan Council, 2001). The pollutant removal mechanisms in wet swales are similar to those of stormwater wetlands, which rely on sedimentation, adsorption, and microbial breakdown. Water quality swales can be used in place of curbs, gutters, and storm drain systems on residential and commercial sites to enhance pollutant removal and provide limited groundwater recharge, flood control, and channel protection benefits.

Advantages

- *Provide pretreatment for other stormwater treatment practices by trapping, filtering, and infiltrating pollutants.*
- *Generally lower capital cost than traditional curb and gutter drainage systems.*
- *Reduce the runoff volume through some infiltration and groundwater recharge (particularly for dry swales).*
- *Can be used to divert water around potential pollutant sources.*
- *Provide limited peak runoff attenuation and stream channel protection by reducing runoff velocity and providing temporary storage.*
- *Provide runoff conveyance.*
- *Linear nature makes swales ideal for highway and residential road runoff.*

Limitations

- *Require more maintenance than traditional curb and gutter drainage systems.*
- *Individual dry swales treat a relatively small area.*
- *May be impractical in areas with very flat grades, steep topography, or poorly drained soils (Metropolitan Council, 2001).*
- *Subject to erosion during large storms.*
- *Large area requirements for highly impervious sites.*
- *May not be practical in areas with many driveway culverts or extensive sidewalk systems (MADEP, 1997).*
- *Can produce mosquito-breeding habitat if flat slope, poor drainage, or microtopography created during construction or mowing allows pooling of water for more than 5 days.*

Siting Considerations

Drainage Area: The maximum contributing drainage area for water quality swales should be limited to 5 acres. Conventional grass drainage channels designed primarily for conveyance rather than water quality are appropriate for drainage areas up to 50 acres in size (see Secondary Treatment Practices).

Land Use: Vegetated swales can be readily incorporated into a site drainage plan. Swales are most applicable to low to moderate density land uses such as residential development, small commercial parking lots, and other institutional land uses.

- *Dry swales are primarily designed to receive drainage from small impervious areas, such as small parking lots and rooftops, and rural roads (Claytor and Schueler, 1996).*
- *Wet swales are primarily used for highway runoff, small parking lots, rooftops, and pervious areas (Claytor and Schueler, 1996). Wet swales may not be appropriate in some residential areas because of the potential for stagnant water and nuisance ponding.*

For high density residential, commercial, and industrial land uses, the water quality volume will likely be too large to be accommodated with most swale designs. Swales may be appropriate for pretreatment in conjunction with other practices for these higher density land uses or for stormwater retrofit applications.

Slopes: Site topography should allow for the design of a swale with sufficient slope and cross-sectional area to maintain non-erosive velocities. In areas of steep slopes, swales should run parallel to contours.

Soils and Water Table: Dry swales can be sited on most moderately or well-drained soils. The bottom of the swale should be two to four feet above the seasonal high water table. Wet swales should only be used where the water table is at or near the soil surface or where soil types are poorly drained. When the channel is excavated, the swale bed soils should be saturated most of the time.

Design Criteria

Design considerations for dry and wet swales are presented below and summarized in **Table 11-P5-1.**

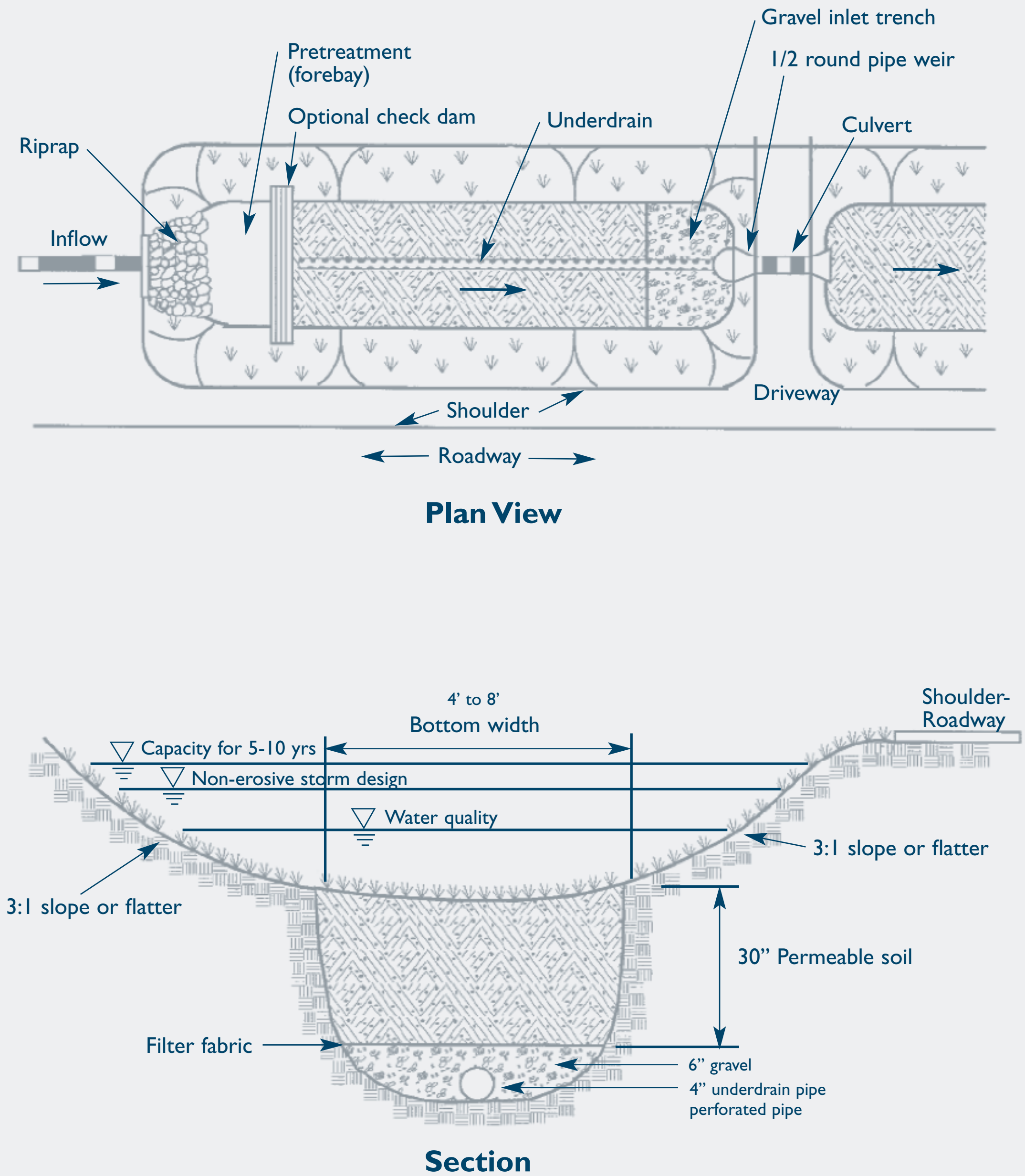
Dry Swale

Figure 11-P5-1 and **Figure 11-P5-2** depict typical schematic designs of dry swales.

Channel Shape and Slope

- *Dry swales should have a trapezoidal or parabolic cross-section with relatively flat side slopes (3:1 horizontal:vertical maximum, 4:1 or flatter recommended for maintenance).*
- *The channel bottom width should be between two and eight feet for construction considera tions, water quality treatment, and to minimize the potential for re-channelization of flow.*

Figure 11-P5-1 Dry Swale – Parabolic Cross Section



Source: Center for Watershed Protection, 2000.

Table 11-P5-1 Design Criteria for Dry and Wet Swales

Parameter	Design Criteria
Pretreatment Volume	25% of the water quality volume (WQV)
Preferred Shape	Trapezoidal or parabolic
Bottom Width	4 feet minimum recommended for maintenance, 8 feet maximum, widths up to 16 feet are allowable if a dividing berm or structure is used
Side Slopes	3(h):1(v) maximum, 4:1 or flatter recommended for maintenance (where space permits)
Longitudinal Slope	1% to 2% without check dams, up to 5% with check dams
Sizing Criteria	Length, width, depth, and slope needed to provide surface storage for the WQV. ❍ **Dry Swale:** maximum ponding time of 24 hours ❍ **Wet Swale:** retain the WQV for 24 hours; ponding may continue longer (5 days recommended maximum duration to avoid potential for mosquito-breeding)
Underlying Soil Bed	Equal to swale width. ❍ **Dry Swale:** moderately permeable soils (USCS ML, SM, or SC), 30 inches deep with gravel/pipe underdrain system ❍ **Wet Swale:** undisturbed soils, no underdrain system
Depth and Capacity	❍ Surface storage of WQV with a maximum ponding depth of 18 inches for water quality treatment ❍ Safely convey 2-year storm with non-erosive velocity ❍ Adequate capacity for 10-year storm with 6 inches of freeboard

Source: Adapted from Claytor and Schueler, 1996.

- *Check dams may be used to increase in-channel detention, provided that adequate capacity is available to handle peak design flows.*
- *The longitudinal slope of the dry swale should be between one and two percent. Steeper slopes (up to five percent) may be used in conjunction with check dams (vertical drop of 6 to 12 inches). Check dams require additional energy dissipation measures and should be placed no closer than at 50 to 100 foot intervals.*
- *Pretreatment should be provided to accommodate 25 percent of the water quality volume. Pretreatment generally consists of a sediment forebay behind a check dam between the inlet and the main body of the swale. The check dam and area immediately downstream of the check dam should be underlain by a stone base to prevent scour. The check dam may be constructed of timber, concrete, or similar material. Earth and stone check dams are not recommended since they require more maintenance.*
- *Outlet protection is required at the discharge point from a dry swale to prevent scour.*

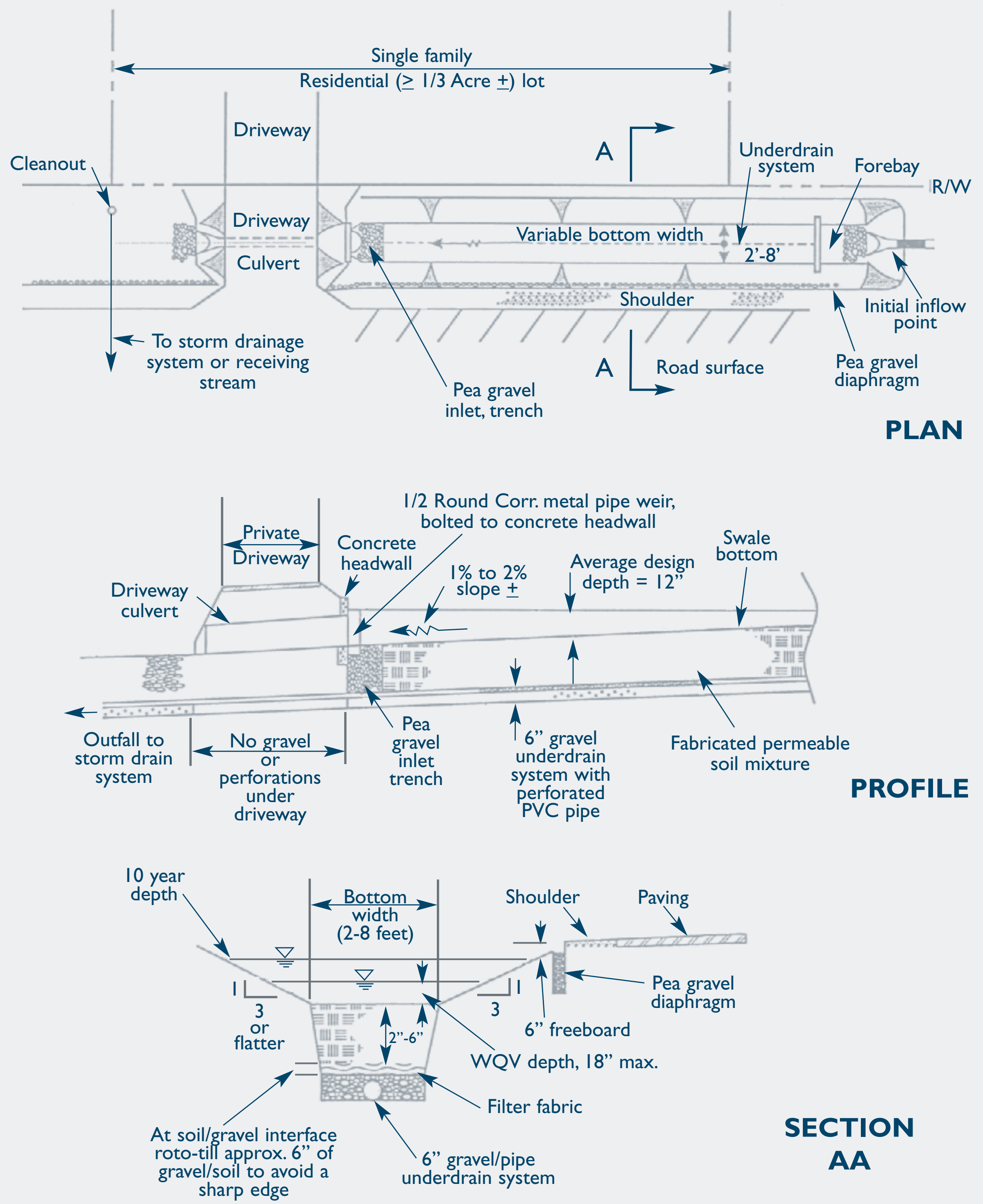
Channel Size

- *Dry swales should be designed to temporarily accommodate the water quality volume through surface ponding (a maximum depth of 18 inches is recommended). Surface ponding should dissipate within 24 hours.*
- *Dry swales should be sized to convey the 10-year storm with a minimum of 6 inches of freeboard, and channel slopes and backs should be designed to prevent erosive channel velocities.*

Underlying Soils

- *Dry swales should have a 30-inch deep soil bed consisting of a sand/loam mixture (approximately 50/50 mix) having an infiltration capacity of at least 1 foot per day.*
- *Where soils do not permit full infiltration, an underdrain system should be installed beneath the soil layer, consisting of a gravel layer surrounding a longitudinally perforated pipe (minimum 6-inch diameter recommended).*

Figure 11-P5-2 Dry Swale – Trapezoidal Cross Section



Source: Claytor and Schueler, 1996.

Vegetation

- *Vegetation should be designed for regular mowing, like a typical lawn, or less frequently (annually or semi-annually).*
- *Native grasses are preferred for enhanced biodiversity, wildlife habitat, and drought tolerance. Grass species should be sod-forming, resistant to frequent inundation, rigid and upright in high flows, and salt tolerant if located along a roadway. Wetland species may be used for the bottom of a wet swale. The maximum velocity should not exceed erosive velocities for the soil type and vegetation condition of the channel (see **Connecticut Guidelines for Soil Erosion and Sediment Control** for maximum permissible velocities). The following grasses perform well in an open channel environment:*
  - *Red Fescue* (Festuca rubra)
  - *Tall Fescue* (Festuca arundinacea)
  - *Redtop* (Agrostis alba)
  - *Smooth Bromegrass* (Bromus inermis)
  - *Reed Canarygrass* (Phalaris arundinacea L.)

Wet Swale

Figure 11-P5-3 depicts a typical schematic design of a wet swale.

Channel Shape and Slope

- *Wet swales should have a trapezoidal or parabolic cross-section with relatively flat side slopes (3:1 horizontal:vertical maximum, 4:1 or flatter recommended for maintenance).*
- *The channel bottom width should be between four and eight feet.*
- *Check dams may be used to increase in-channel detention, provided that adequate capacity is available to handle peak design flows.*
- *The longitudinal slope of the dry swale should be between one and two percent. Steeper slopes may be used in conjunction with check dams (vertical drop of 6 to 12 inches). Check dams require additional energy dissipation measures and should be placed no closer than at 50 to 100 foot intervals.*
- *Pretreatment should be provided to accommodate 25 percent of the water quality volume. Pretreatment generally consists of a sediment forebay behind a check dam between the inlet and the main body of the swale. The check dam and area immediately downstream of the check dam should be underlain by a stone base to prevent scour. The check dam may be constructed of timber or concrete, and may incorporate v-notch weirs to direct low flow volumes. Earth and stone check dams are not recommended since they require more maintenance.*
- *Outlet protection is required at any discharge point from a wet swale to prevent scour at the outlet.*

Channel Size

- *Wet swales should be designed to temporarily retain the water quality volume for 24 hours, but ponding may continue for longer periods depending on the depth and elevation to the water table (5 days recommended maximum duration to reduce the potential for mosquito breeding). A maximum ponding depth of 18 inches (at the end point of the channel) is recommended for storage of the water quality volume.*
- *Wet swales should be sized to convey the 10-year storm with a minimum of 6 inches of freeboard, and channel slopes and backs should be designed to prevent erosive velocities.*

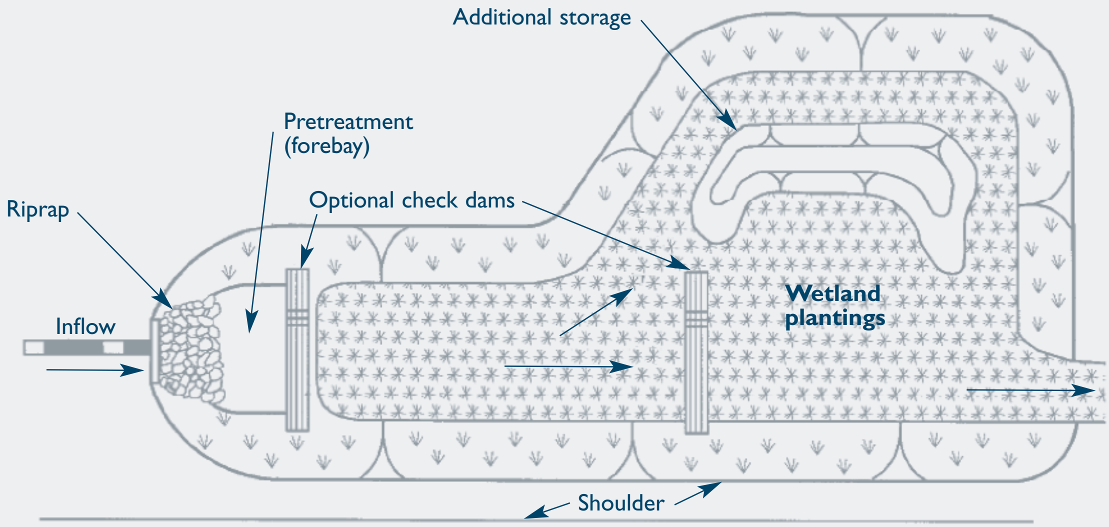
Underlying Soils

- *The soil bed below wet swales should consist of undisturbed soils. This area may be periodically inundated and remain wet for extended periods.*
- *Wet swales should not be constructed in gravelly and coarse sandy soils that cannot easily support dense vegetation.*

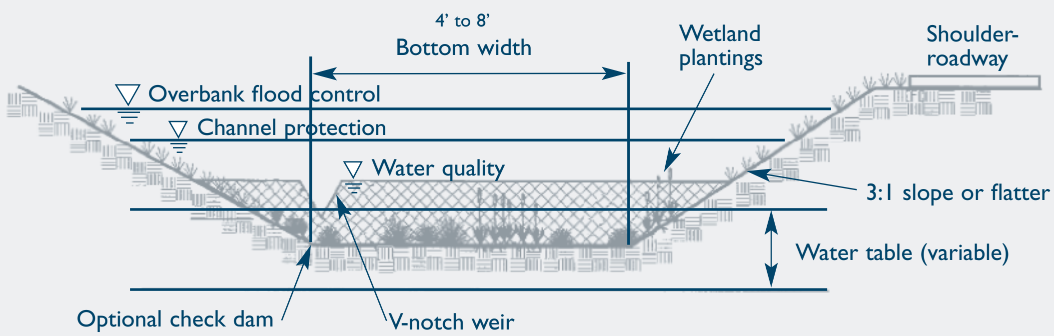
Vegetation

- *The permanent channel vegetation should be suitable for the site and soil conditions.*
- *Native grasses are preferred for enhanced biodiversity and wildlife habitat. Grass species should be resistant to sustained inundation and/or a high water table and salt tolerant if located along a roadway. Wetland species are appropriate for the bottom of a wet swale. The maximum velocity should not exceed erosive velocities for the soil type and vegetation condition of the channel (see **Connecticut Guidelines for Soil Erosion and Sediment Control** for maximum permissible velocities). The following grasses perform well in an open channel environment:*
  - *Red Fescue* (Festuca rubra)
  - *Tall Fescue* (Festuca arundinacea)
  - *Redtop* (Agrostis alba)

Figure 11-P5-3 Wet Swale



Plan View



Section

Source: Adapted from Center for Watershed Protection, 2000.

- *Smooth Bromegrass* (Bromus inermis)
- *Reed Canarygrass* (Phalaris arundinacea L.)

Construction

- *Avoid soil compaction and the creation of micro-topography that could result in pooling of water for more than 5 days.*
- *Accurate grading is critical to the proper functioning of the swale and will affect the treatment performance.*
- *Temporary erosion and sediment controls should be used during construction.*
- *Appropriate soil stabilization methods should be used before permanent vegetation is established. Seeding, sodding, and other temporary soil stabilization controls should be implemented in accordance with the* ***Connecticut Guidelines for Soil Erosion and Sediment Control.***

Inspection and Maintenance

- *Plans for water quality swales should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.*
- *Inspect swales several times during the first few months to ensure that grass cover is established. Inspect swales semi-annually for the remainder of the first year and after major storm events. Annual inspections are sufficient after the first year.*
- *The initial sediment forebay should be inspected annually for clogging and sediment buildup. Sediment buildup should be removed when approximately 25 percent of the water quality volume or channel capacity has been exceeded. Excessive trash and debris should be removed and disposed of in an appropriate location.*
- *The vegetation along the swale bottom and side slopes should be inspected for erosion and repaired (seeded or sodded), as necessary.*
- *Grass should be mowed on a regular basis, but at least once per year. Dry swales should be mowed as required to maintain grass heights of 4 to 6 inches during the growing season. Wet swales, which typically incorporate wetland vegetation, require less frequent mowing. To avoid the creation of ruts and compaction, which can reduce infiltration and lead to poor drainage, mowing should not be performed when the ground is soft..*

Cost Considerations

Limited data exist on the cost to implement water quality swales, although they are relatively inexpensive to construct compared to other stormwater treatment practices. The cost to design and construct most water quality swales can be estimated as $0.50 per square foot of swale surface area, based on 1997 prices (EPA, 1999). These costs should be adjusted for inflation to reflect current costs.

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Center for Watershed Protection (CWP). 2000. *The Vermont Stormwater Management Handbook Technical Support Document – Public Review Draft.* Prepared For Vermont Agency of Natural Resources.

Claytor, R.A. and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Silver Spring, Maryland.

Massachusetts Department of Environmental Protection (MADEP) and the Massachusetts Office of Coastal Zone Management. 1997. *Stormwater Management, Volume Two: Stormwater Technical Handbook*. Boston, Massachusetts.

Metropolitan Council. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates*. Prepared by Barr Engineering Company. St. Paul, Minnesota.

United States Environmental Protection Agency (EPA). 1999. *Preliminary Data Summary of Urban Storm Water Best Management Practices*. EPA 821-R-99-012, Office of Water. Washington, D.C.

Dry Detention Ponds

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Practice	
Primary Treatment Practice	
Secondary Treatment Practice	●

Stormwater Management Benefits

Benefit	
Pollutant Reduction	
Sediment	Partial Benefit
Phosphorus	Low or Unknown Benefit
Nitrogen	Low or Unknown Benefit
Metals	Low or Unknown Benefit
Pathogens	Low or Unknown Benefit
Floatables*	Partial Benefit
Oil and Grease*	Partial Benefit
Dissolved Pollutants	Low or Unknown Benefit
Runoff Volume Reduction	
Runoff Capture	Low or Unknown Benefit
Groundwater Recharge	Partial Benefit
Stream Channel Protection	Significant Benefit
Peak Flow Control	Significant Benefit

Key: ■ Significant Benefit
■ Partial Benefit
□ Low or Unknown Benefit

*Only if a skimmer is used

Suitable Applications

Application	
Pretreatment	Low or Unknown Benefit
Treatment Train	Significant Benefit
Ultra-Urban	Low or Unknown Benefit
Stormwater Retrofits	Low or Unknown Benefit
Other	Low or Unknown Benefit

Description

Dry detention ponds, also known as "dry ponds" or "detention basins", are stormwater basins designed to capture, temporarily hold, and gradually release a volume of stormwater runoff to attenuate and delay stormwater runoff peaks. Dry detention ponds provide water quantity control (peak flow control and stream channel protection) as opposed to water quality control. The outlet structure of a dry detention pond is located at the bottom of the pond and sized to limit the maximum flow rate. Dry ponds are designed to completely empty out, typically in less than 24 hours, resulting in limited settling of particulate matter and the potential for re-suspension of sediment by subsequent runoff events. Conventional dry detention ponds differ from extended detention ponds, which provide a minimum 24-hour detention time and enhanced pollutant removal (*see* Stormwater Ponds section of this chapter). Dry detention ponds are not suitable as infiltration or groundwater recharge measures, and therefore do not reduce runoff volumes. **Figure 11-S1-1** shows a schematic of a typical dry detention pond.

Reasons for Limited Use

- *Not intended for water quality treatment. Most dry detention ponds have detention times of less than 24 hours and lack a permanent pool, providing insufficient settling of particles, and minimal stormwater treatment.*
- *Susceptible to re-suspension of settled material by subsequent storms.*
- *Generally require a drainage area of 10 acres or greater to avoid an excessively small outlet structure susceptible to clogging.*

Suitable Applications

- *Primarily for water quantity control to attenuate peak flows, limit downstream flooding, and provide some degree of channel protection.*

- *Low-density residential, industrial, and commercial developments with adequate space and low visibility.*
- *As part of a stormwater treatment train, particularly in combination with other primary or secondary treatment practices that provide pollutant reduction, runoff volume reduction, or groundwater recharge. The size of dry ponds can be reduced substantially by placing them at the end of the treatment train to take advantage of reduced runoff volume resulting from upstream practices that employ infiltration.*
- *Less frequently used portions of larger or regional dry detention basins can offer recreational, aesthetic, or open space opportunities (e.g., athletic fields, jogging and walking trails, picnic areas).*

Design Considerations

The design of detention ponds is dictated by local stormwater quantity control requirements. Local ordinances typically require that post-development peak flows be controlled to pre-development levels for storms ranging from 2-year through 100-year return periods. Control of more frequent events may also be required. The reader should consult the local authority for specific quantity control requirements, as well as the following references for guidance on the design and implementation of conventional dry detention ponds for stormwater quantity control:

- Connecticut Department of Transportation (ConnDOT), *Connecticut Department of Transportation Drainage Manual,* October 2000.
- Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE), *Design and Construction of Urban Stormwater Management Systems (Urban Runoff Quality Management (WEF Manual of Practice FD-20 and ASCE Manual and Report on Engineering Practice No. 77), 1992.*

Whenever possible, detention ponds should be designed as extended detention ponds or wet ponds, or used in conjunction with other stormwater treatment practices to provide water quality benefits. Extended detention ponds, which are considered primary stormwater treatment practices (see the Stormwater Ponds section of this chapter), are modified dry detention ponds that incorporate a number of enhancements for improved water quality function. Older, existing dry ponds are also good candidates for stormwater retrofits by incorporating these recommended enhancements (see Chapter Ten), which are summarized below.

Sediment Forebay: A sediment forebay is an additional storage area near the inlet of the pond that facilitates maintenance and improves pollutant removal by capturing large particles. Sediment forebays can be created by berms or baffles constructed of stone, riprap, gabions or similar materials. The forebay should include a deep permanent pool to minimize the potential for scour and re-suspension (Metropolitan Council, 2001).

Extended Detention Storage: Extended detention requires sufficient storage capacity to hold stormwater for at least 24 hours to allow solids to settle out. The additional storage volume is usually provided in the lower stages of the pond for treatment of smaller storms associated with the water quality volume, while the upper stages provide storage capacity for large, infrequent storms. To reduce the potential for mosquito breeding, detention ponds should not be designed to hold water for longer than 5 days.

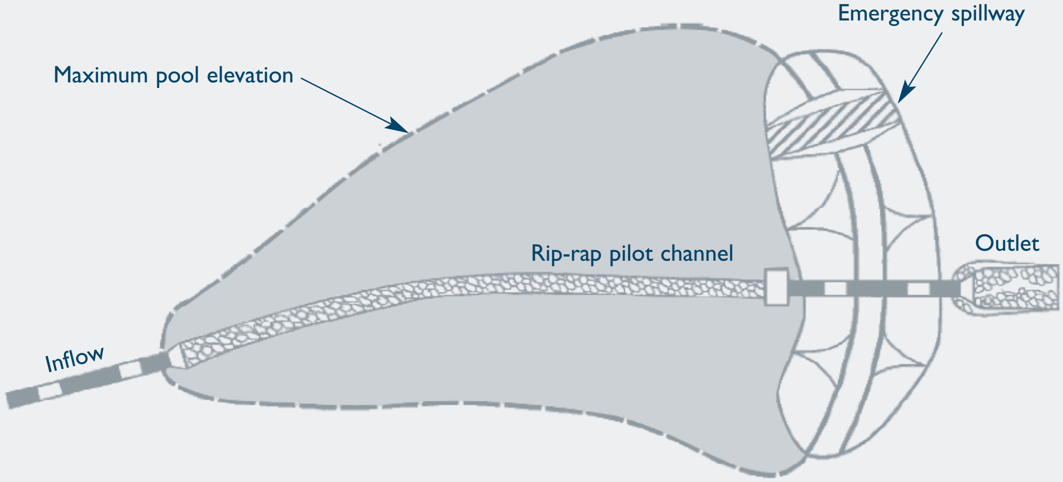
Any stormwater treatment practices that create an embankment, including stormwater detention ponds, are under the jurisdiction of the Dam Safety Section of the Connecticut DEP Inland Water Resources Division (IWRD) and should be constructed, inspected, and maintained in accordance with Connecticut General Statutes §§22a-401 through 22a-411, inclusive, and applicable DEP guidance.

Outlet Wet Pool: A relatively shallow, permanent pool of water at the pond outlet can provide additional pollutant removal by settling finer sediment and reducing re-suspension. The wet pool or micropool can also be planted with wetland species to enhance pollutant removal.

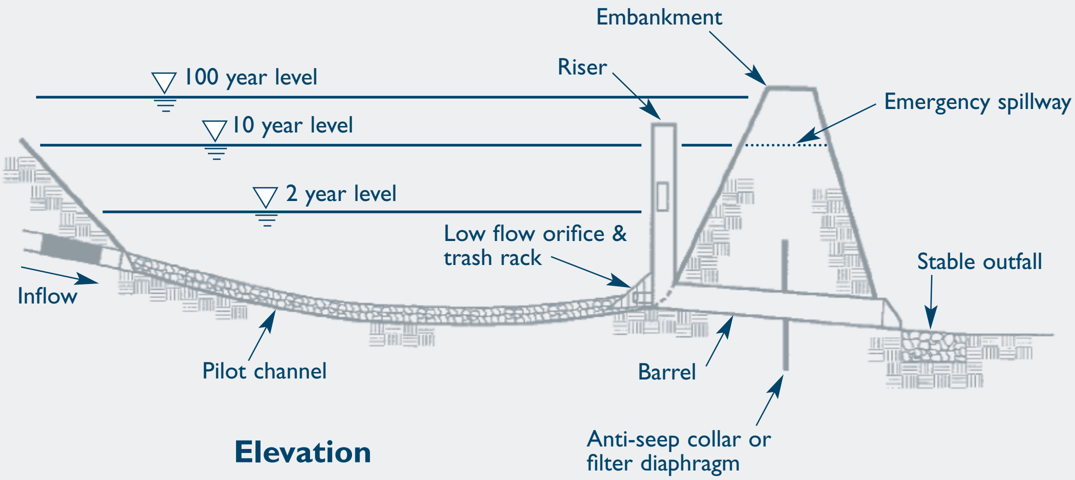
Pond Configuration: The inlet and outlet of the pond should be positioned to minimize short-circuiting. Baffles and internal grading can be used to lengthen the flow path within the pond. A minimum length-to-width ratio of 2:1 is recommended, and irregularly shaped ponds are desirable due to their more natural and less engineered appearance.

Low Flow Channels: Low flow channels prevent erosion as runoff first enters a dry pond during the initial period of a storm event, and after a storm, route the final portion to the pond outlet.

Figure 11-S1-1 Dry Detention Pond



Plan View



Elevation

Source: Adapted from Center for Watershed Protection, 2000.

References

Center for Watershed Protection (CWP). 2000. *The Vermont Stormwater Management Handbook Technical Support Document – Public Review Draft*. Prepared For Vermont Agency of Natural Resources.

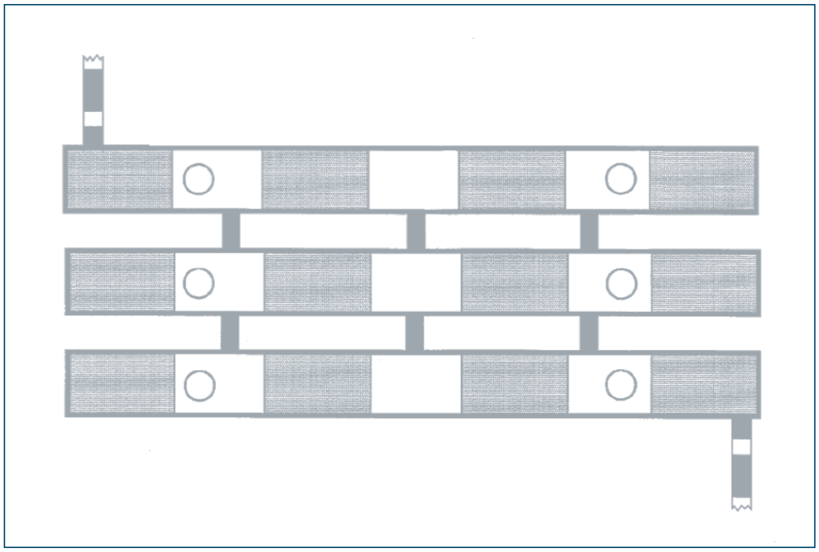
Connecticut Department of Transportation (DOT). 2000. *Connecticut Department of Transportation Drainage Manual*.

Metropolitan Council. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates*. Prepared by Barr Engineering Company. St. Paul, Minnesota.

United States Environmental Protection Agency (EPA). 2002. *National Menu of Best Management Practices for Stormwater Phase II*. URL: http://www.epa.gov/npdes/menuofbmps/menu.htm, Last Modified January 24, 2002.

Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE). 1992. Design and Construction of Urban Stormwater Management Systems. WEF Manual of Practice FD-20 and ASCE Manual and Report on Engineering Practice No. 77.

Underground Detention Facilities



Source: Adapted from Center for Watershed Protection, 2000.

Treatment Practice Type

Treatment Practice Type	
Primary Treatment Practice	
Secondary Treatment Practice	●

Stormwater Management Benefits

Benefit	
Pollutant Reduction	
Sediment	□
Phosphorus	□
Nitrogen	□
Metals	□
Pathogens	□
Floatables	□
Oil and Grease	□
Dissolved Pollutants	□
Runoff Volume Reduction	
Runoff Capture	□
Groundwater Recharge	□
Stream Channel Protection	■
Peak Flow Control	■

Key: ■ Significant Benefit
▪ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Application	
Pretreatment	□
Treatment Train	■
Ultra-Urban	■
Stormwater Retrofits	■
Other	□

Description

Underground detention facilities such as vaults, pipes, tanks, and other subsurface structures are designed to temporarily store stormwater runoff for water quantity control. Like aboveground detention ponds, underground detention facilities are designed to drain completely between runoff events, thereby providing storage capacity for subsequent events. Underground detention facilities are intended to control peak flows, limit downstream flooding, and provide some channel protection. However, they provide little, if any, pollutant removal (i.e., settling of coarse sediment) and are susceptible to re-suspension of sediment during subsequent storms. **Figure 11-S2-1** depicts a typical underground detention pipe system. Other modular lattice or pipe systems such as those described in the "Underground Infiltration Facilities" section of this chapter can be used as detention facilities rather than for exfiltration.

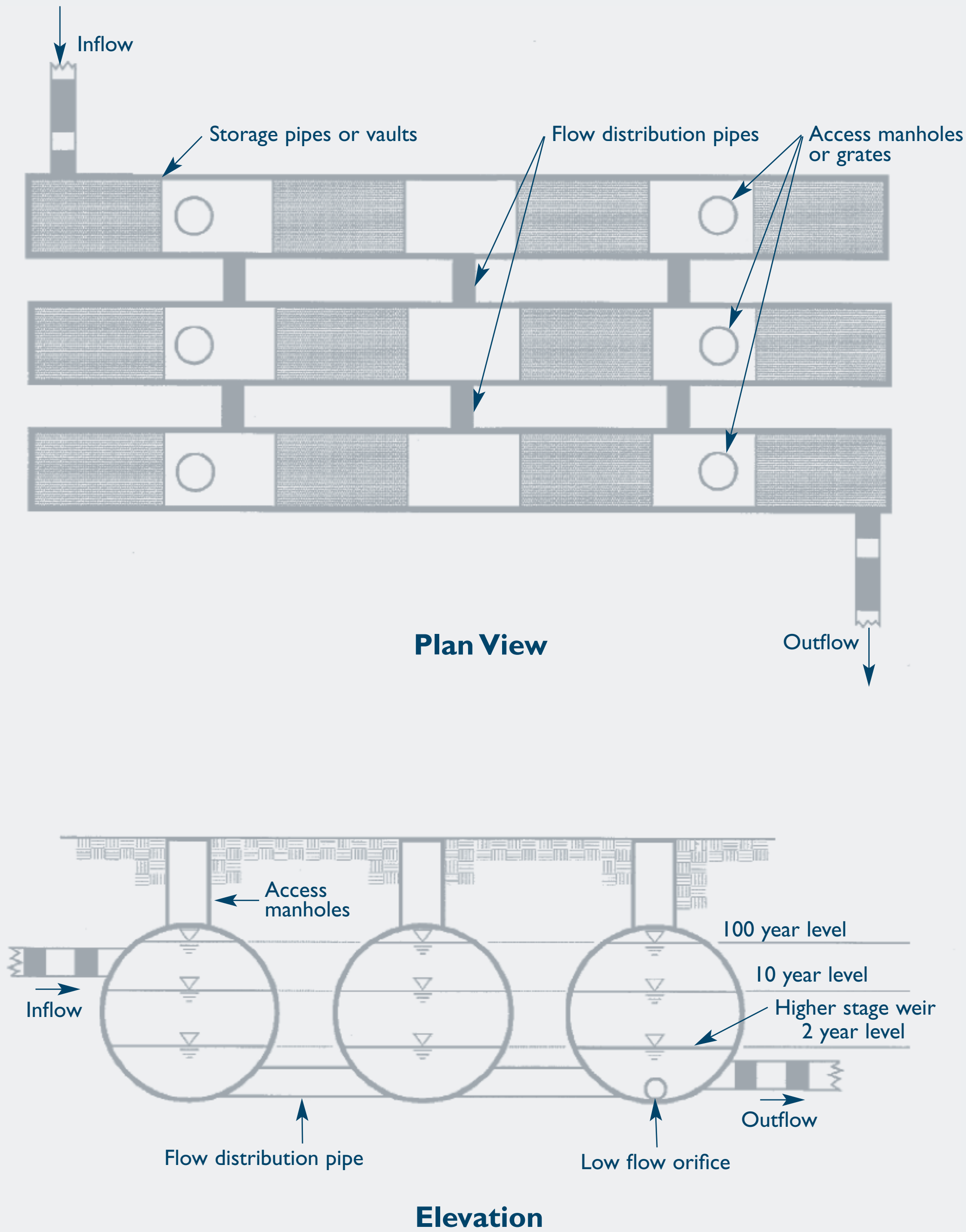
Reasons for Limited Use

- *Not intended for water quality treatment. Typically provide less than 24 hours of detention time.*
- *Susceptible to re-suspension of settled material by subsequent storms.*
- *Do not reduce runoff volume or promote groundwater recharge.*

Suitable Applications

- *Primarily for water quantity control to attenuate peak flows, limit downstream flooding, and provide some degree of channel protection.*
- *Suitable for stormwater quantity control at space-limited sites where traditional aboveground detention facilities are impractical due to excessive space requirements. These systems can be installed under parking lots and other developed areas, provided that the system can be accessed for maintenance purposes.*

Figure 11-S2-1 Underground Detention Pipe System



Source: Adapted from Center for Watershed Protection, 2000.

- *Useful in stormwater retrofit applications to provide additional temporary storage volume and attenuate peak flows.*
- *As part of a stormwater treatment train, particularly in combination with other primary or secondary treatment practices that provide pollutant reduction, runoff volume reduction, or groundwater recharge.*

Design Considerations

Siting: Underground detention systems are generally applicable to small development sites and should be installed in locations that are easily accessible for routine and non-routine maintenance. These systems should not be located in areas or below structures that cannot be excavated in the event that the system needs to be replaced. Access manholes should be located at upstream, downstream, and intermediate locations, as appropriate

Pretreatment: Appropriate pretreatment (e.g., oil/particle separator, hydrodynamic device, catch basin inserts, or other secondary or primary treatment practices) should be provided to minimize the quantity of sediment that reaches the detention system.

Inlets, Outlets, and Overflows: Underground systems are typically designed as on-line systems that capture frequent runoff events from paved areas. Outlets are sized to restrict maximum flow rates in accordance with local peak flow control requirements, such as controlling post-development peak flows to pre-development levels for storms ranging from 2-year through 100-year return periods. Emergency surface overflows should be designed to convey the 100-year runoff in case the outlet becomes clogged. Potential mosquito entry points should be sealed (adult female mosquitoes can use openings as small as 1/16 inch to access water for egg laying).

References

Center for Watershed Protection (CWP). 2000. *The Vermont Stormwater Management Handbook Technical Support Document – Public Review Draft*. Prepared For Vermont Agency of Natural Resources.

United States Environmental Protection Agency (EPA). 1999. *Storm Water Technology Fact Sheet: Infiltration Drainfields*. EPA 832-F-99-018. Office of Water. Washington, D.C.

United States Environmental Protection Agency (EPA). 2002. *National Menu of Best Management Practices for Stormwater Phase II*. URL: http://www.epa.gov/npdes/menuofbmps/menu.htm,

Deep Sump Catch Basins

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Primary Treatment Practice
Secondary Treatment Practice ●

Stormwater Management Benefits

Pollutant Reduction	
Sediment	▣
Phosphorus	□
Nitrogen	□
Metals	□
Pathogens	□
Floatables	▣
Oil and Grease	▣
Dissolved Pollutants	□
Runoff Volume Reduction	
Runoff Capture	□
Groundwater Recharge	□
Stream Channel Protection	□
Peak Flow Control	□

Key: ■ Significant Benefit
▣ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Pretreatment	■
Treatment Train	■
Ultra-Urban	■
Stormwater Retrofits	■
Other	□

Description

Deep sump catch basins, also known as oil and grease catch basins, are storm drain inlets that typically include a grate or curb inlet and a sump to capture trash, debris, and some sediment and oil and grease. Stormwater runoff enters the catch basin via an inlet pipe located at the top of the basin. The basin outlet pipe is located below the inlet and can be equipped with a hood (i.e., an inverted pipe). Floatables such as trash and oil and grease are trapped on the permanent pool of water, while coarse sediment settles to the bottom of the basin sump. **Figure 11-S3-1** shows a schematic of a typical deep sump catch basin.

Catch basins are commonly used in drainage systems and can be used as pretreatment for other stormwater treatment practices. However, most catch basins are not ideally designed for sediment and pollutant removal. The performance of deep sump catch basins at removing sediment and associated pollutants depends on several factors including the size of the sump, the presence of a hooded outlet, and maintenance frequency.

Reasons for Limited Use

Catch basins have several major limitations, including:

- *Even ideally designed catch basins (those with deep sumps, hooded outlets, and adequate sump capacity) are far less effective at removing pollutants than primary stormwater management practices such as stormwater ponds, wetlands, filters, and infiltration practices.*
- *Can become a source of pollutants unless maintained frequently.*
- *Sediments can be re-suspended and floatables may be passed downstream during large storms.*
- *Cannot effectively remove soluble pollutants or fine particles.*
- *May become mosquito breeding habitat between rainfall events.*

(EPA, 2002).

Suitable Applications

- *For limited removal of trash, debris, oil and grease, and sediment from stormwater runoff from relatively small impervious areas (parking lots, gas stations, and other commercial development).*
- *To provide pretreatment for other stormwater treatment practices.*
- *For retrofit of existing stormwater drainage systems to provide floatables and limited sediment control. See Chapter Ten for examples of catch basin stormwater retrofits.*

Design Considerations

Drainage Area: The contributing drainage area to any deep sump catch basin generally should not exceed 1/4 acre of impervious cover.

Design: Catch basin performance is related to the volume of the sump below the outlet. A recommended catch basin sizing criterion relates the catch basin sump depth to the diameter of the outlet pipe (D), as follows:

- *The sump depth (distance from the bottom of the outlet pipe to the bottom of the basin) should be at least 4D and increased if cleaning is infrequent or if the contributing drainage area has high sediment loads.*
- *The diameter of the catch basin should be at least 4 feet.*
- *The bottom of the outlet pipe should be at least 4 feet from the bottom of the catch basin inlet grate.*

(Lager et al., 1997). Where high sediment loads are anticipated, the catch basin can be sized to accommodate the volume of sediment that enters the system, with a factor of safety (Pitt et al., 2000).

Where feasible, deep sump catch basins should be designed as off-line systems (i.e., collectors or preceded by a flow diversion structure) to minimize re-suspension of sediment during large storms. The basic design should also incorporate a hooded outlet consisting of an inverted elbow pipe to prevent floatable materials and trash from entering the storm drainage system. Hooded outlets may be impractical for outlet pipes larger than 24 inches in diameter. Catch basin hoods that reduce or eliminate siphoning should be used. Catch basins should be watertight to maintain a permanent pool of water and provide higher floatable capture efficiency. Catch basin inserts, which are described elsewhere in this chapter, can be used to filter runoff entering the catch basin, although their effectiveness is unproven and they require frequent sediment removal.

Maintenance: Typical maintenance of catch basins includes trash removal from the grate (and screen or other debris-capturing device if one is used) and removal of sediment using a vacuum truck. Studies have shown that catch basins can capture sediments up to approximately 50 percent of the sump volume. Above this volume, catch basins reach steady state due to re-suspension of sediment (Pitt, 1984). Frequent cleanout maintains available sump volume for treatment purposes.

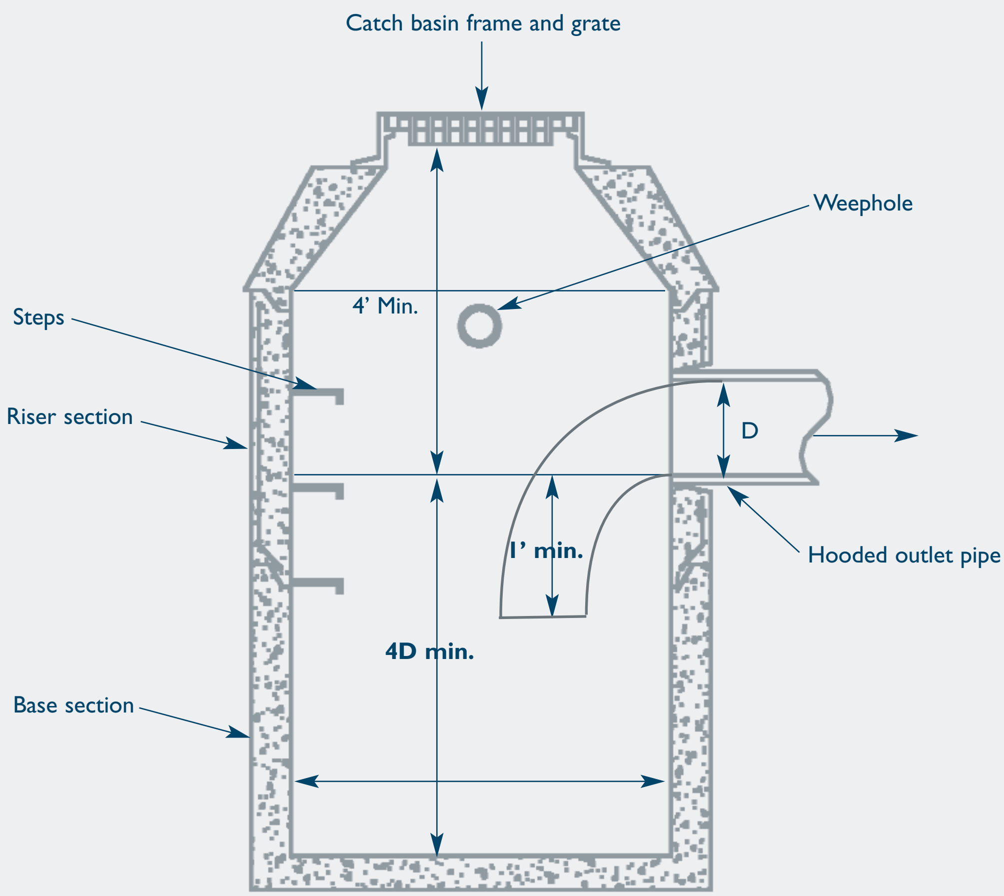
Catch basins should be cleaned at least annually, after the snow and ice removal season is over and as soon as possible before spring rainfall events. In general, a catch basin should be cleaned if the depth of deposits is greater than or equal to one-half the depth from the bottom of the basin to the invert of the lowest pipe in the basin (EPA, 1999). If a catch basin significantly exceeds this one-half depth standard during the annual inspection, then it should be cleaned more frequently.

In addition, areas with higher pollutant loadings or discharging to sensitive water bodies should also be cleaned more frequently (WEF and ASCE, 1998). More frequent cleaning of drainage systems may also be needed in areas with relatively flat grades or low flows since they may rarely achieve sufficiently high flows for self-flushing (Fergusen et al., 1997).

Plans for catch basins should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

Sediment Disposal: Polluted water or sediment removed from catch basins should be properly handled and disposed in accordance with local, state, and federal regulations. Before disposal, an appropriate chemical analysis of the material should be performed to determine proper methods for storage and disposal (EPA, 1999).

Figure 11-S3-1 Typical Deep Sump Catch Basin



Source: Adapted from Urban Stormwater Management and Technology: Update and Users' Guide, 1977.

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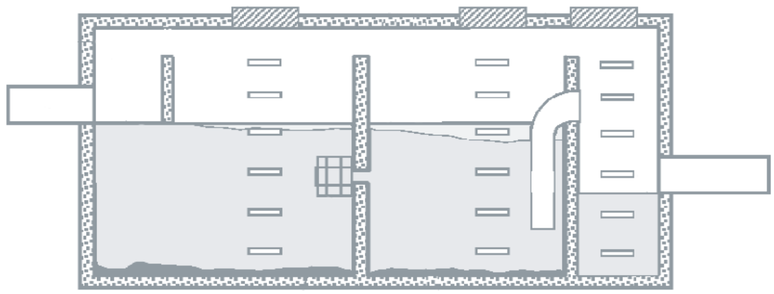
Oil/Particle Separators



Source: City of Knoxville, 2001.

Treatment Practice Type

Primary Treatment Practice
Secondary Treatment Practice ●

Stormwater Management Benefits

Pollutant Reduction	
Sediment	▨
Phosphorus	□
Nitrogen	□
Metals	□
Pathogens	□
Floatables	■
Oil and Grease	■
Dissolved Pollutants	□
Runoff Volume Reduction	
Runoff Capture	□
Groundwater Recharge	□
Stream Channel Protection	□
Peak Flow Control	□

Key: ■ Significant Benefit
▨ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Pretreatment	■
Treatment Train	■
Ultra-Urban	■
Stormwater Retrofits	■
Other	■

Description

Oil/particle separators, also called oil/grit separators, water quality inlets, and oil/water separators, consist of one or more chambers designed to remove trash and debris and to promote sedimentation of coarse materials and separation of free oil (as opposed to emulsified or dissolved oil) from stormwater runoff. Oil/particle separators are typically designed as off-line systems for pretreatment of runoff from small impervious areas, and therefore provide minimal attenuation of flow. Due to their limited storage capacity and volume, these systems have only limited water quality treatment capabilities. While oil/particle separators can effectively trap floatables and oil and grease, they are ineffective at removing nutrients and metals and only capture coarse sediment.

Several conventional oil/particle separator design variations exist, including:

- *Conventional gravity separators (water quality inlets)*
- *Coalescing plate (oil/water) separators*

Conventional gravity separators (also called American Petroleum Institute or API separators) typically consist of three baffled chambers and rely on gravity and the physical characteristics of oil and sediments to achieve pollutant removal. The first chamber is a sedimentation chamber where floatable debris is trapped and gravity settling of sediments occurs. The second chamber is designed primarily for oil separation, and the third chamber provides additional settling prior to discharging to the storm drain system or downstream treatment practice. Many design modifications exist to enhance system performance including the addition of orifices, inverted elbow pipes and diffusion structures. **Figures 11-S4-1** and **11-S4-2** illustrate several examples of conventional gravity separator designs.

Conventional gravity separators used for stormwater treatment are similar to wastewater oil/water separators, but have several important differences. **Figure 11-S4-3** shows a typical oil/water separator designed to treat wastewater discharges from vehicle washing and floor drains. As shown in the figure, wastewater separators commonly employ a single chamber with tee or elbow inlet and outlet pipes. The magnitude and duration of stormwater flows are typically much more variable than wastewater flows and, therefore, the single-chamber design does not provide sufficient protection against re-suspension of sediment during runoff events. Single-chamber wastewater oil/water separators should not be used for stormwater applications.

The basic gravity separator design can be modified by adding coalescing plates to increase the effectiveness of oil/water separation and reduce the size of the required unit. A series of coalescing plates, constructed of oil-attracting materials such as polypropylene and typically spaced an inch apart, attract small oil droplets which begin to concentrate until they are large enough to float to the water surface and separate from the stormwater (EPA, 1999). **Figure 11-S4-4** shows a typical coalescing plate separator design.

A number of recently developed proprietary separator designs also exist. These are addressed in the Hydrodynamic Separators section of this chapter.

Reasons for Limited Use

- *Limited pollutant removal. Cannot effectively remove soluble pollutants or fine particles.*
- *Can become a source of pollutants due to re-suspension of sediment unless maintained frequently. Maintenance often neglected ("out of sight and out of mind").*
- *Limited to relatively small contributing drainage areas.*

Suitable Applications

- *For limited removal of trash, debris, oil and grease, and sediment from stormwater runoff from relatively small impervious areas with high traffic volumes or high potential for spills such as:*
  - *Parking lots*
  - *Streets*
  - *Truck loading areas*
  - *Gas stations*
  - *Refueling areas*
  - *Automotive repair facilities*
  - *Fleet maintenance yards*
  - *Commercial vehicle washing facilities*
  - *Industrial facilities.*
- *To provide pretreatment for other stormwater treatment practices.*
- *For retrofit of existing stormwater drainage systems, particularly in highly developed (ultra-urban) areas.*

Design Considerations

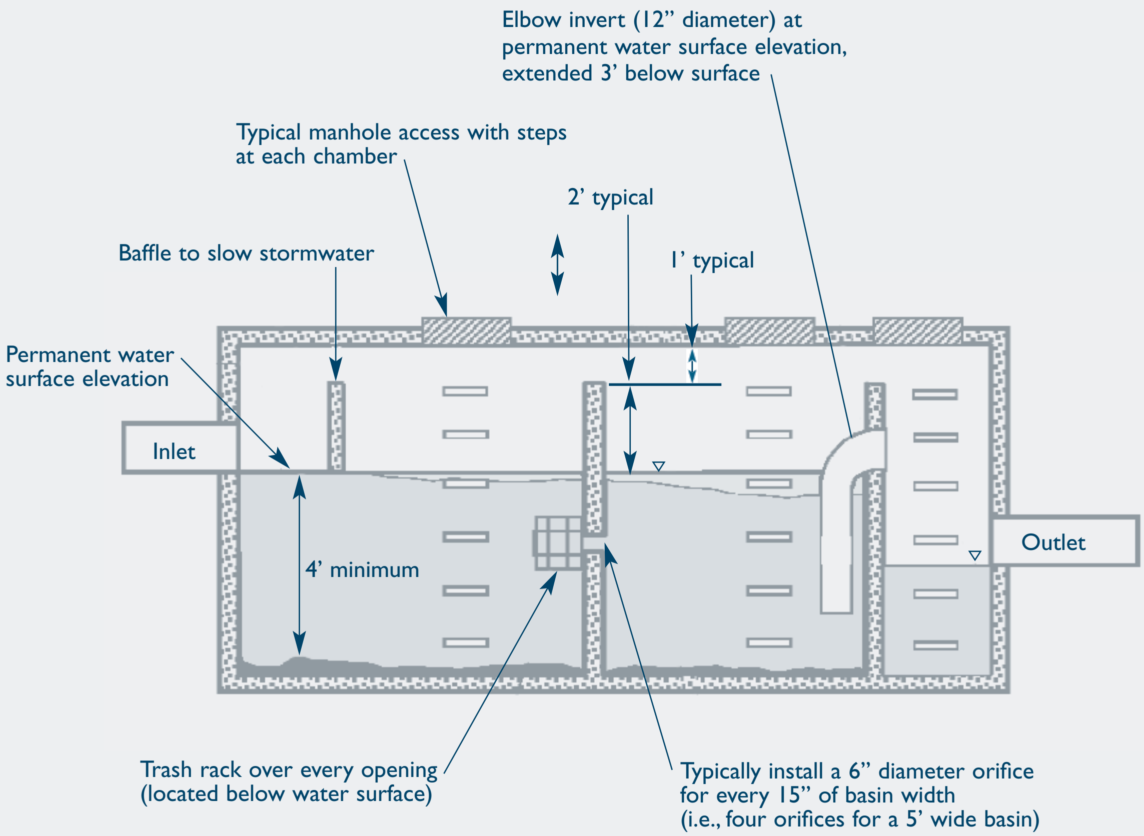
Drainage Area: The contributing drainage area to conventional oil/particle separators generally should be limited to one acre or less of impervious cover. Separators should only be used in an off-line configuration to treat the design water quality flow (peak flow associated with the design water quality volume). Upstream diversion structures can be used to divert higher flows around the separator. On-line units receive higher flows that cause increased turbulence and re-suspension of settled material (EPA, 1999).

Sizing/Design: The combined volume of the permanent pools in the chambers should be 400 cubic feet per acre of contributing impervious area. The pools should be at least 4 feet deep, and the third chamber should also be used as a permanent pool.

A trash rack or screen should be used to cover the discharge outlet and orifices between chambers. An inverted elbow pipe should be located between the second and third chambers, and the bottom of the elbow pipe should be at least 3 feet below the second chamber permanent pool. Each chamber should be equipped with manholes and access steps/ladders for maintenance and cleaning. Potential mosquito entry points should be sealed (adult female mosquitoes can use openings as small as 1/16 inch to access water for egg laying).

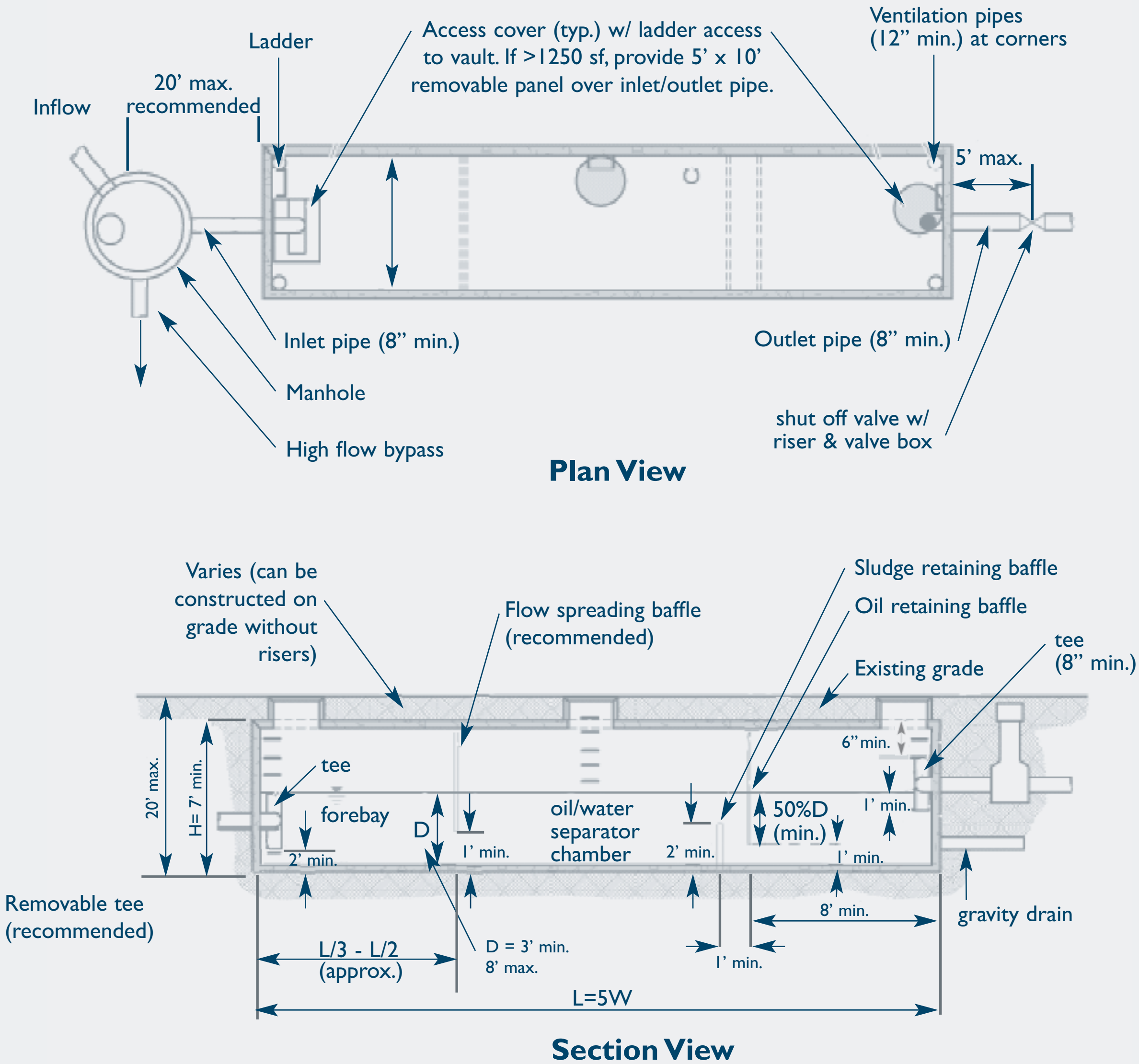
Maintenance: Maintenance is critical for proper operation of oil/particle separators. Separators that are not maintained can be significant sources of pollution. Separators should be inspected at least

Figure 11-S4-1 Example of Conventional Gravity Separator Design (Design Alternate 1)



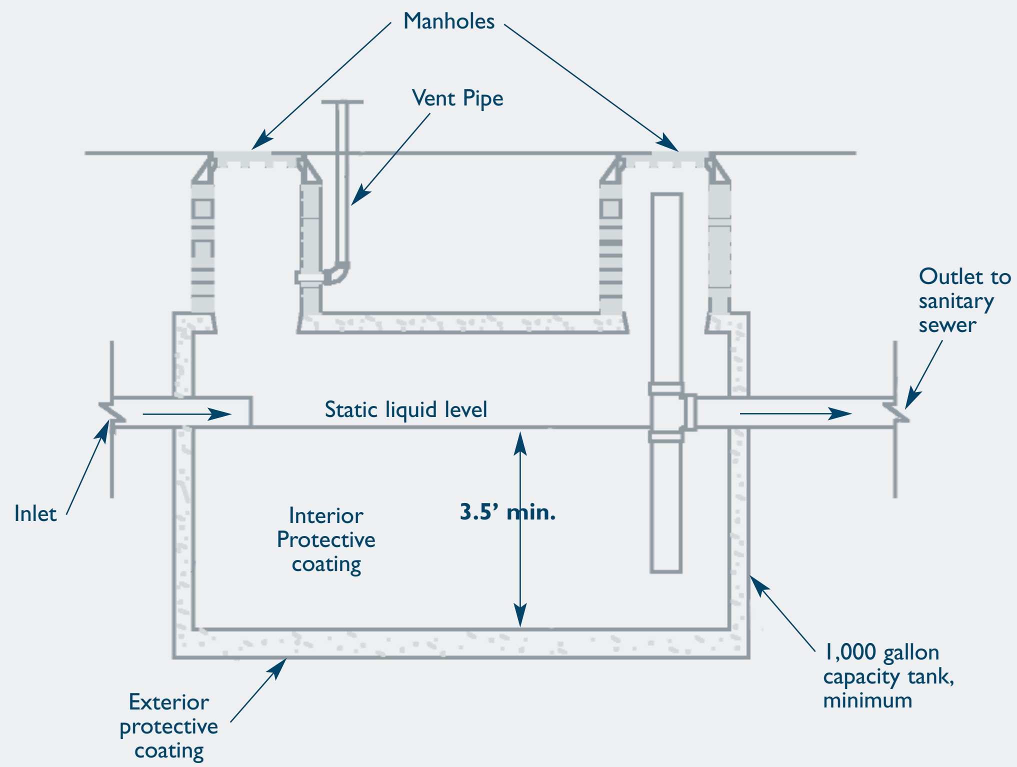
Source: City of Knoxville, 2001.

Figure 11-S4-2 Example of Conventional Gravity Separator Design (Design Alternate 2)



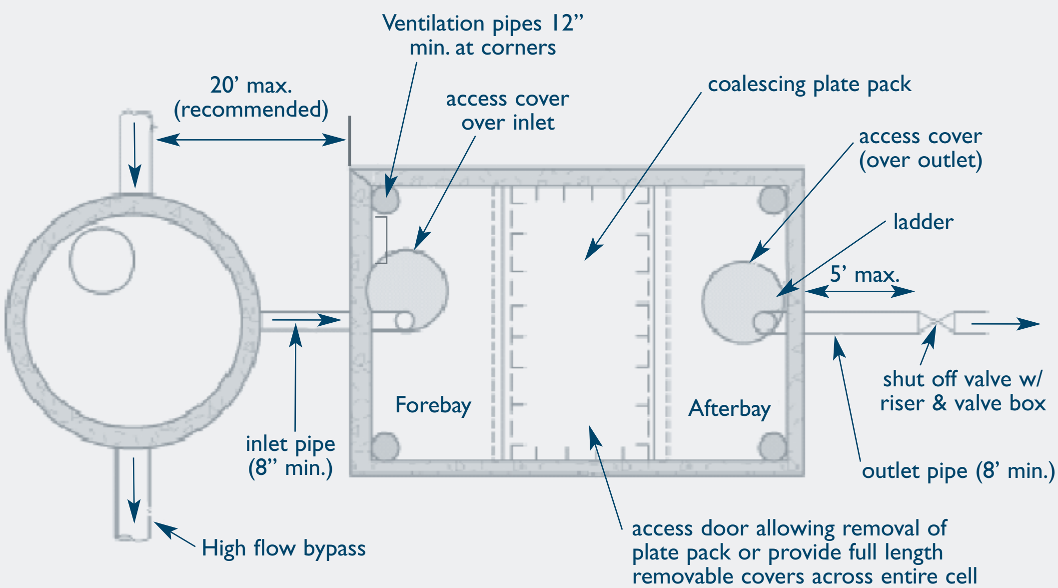
Source: Washington, 2000.

Figure 11-S4-3 Example of a Typical Wastewater Oil/Water Separator

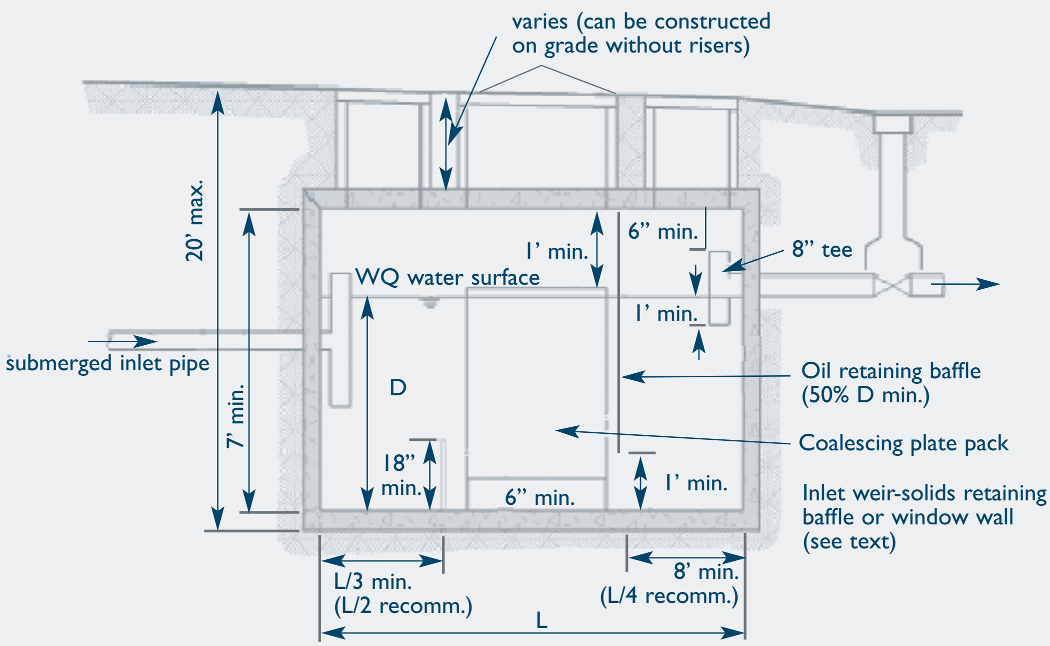


Source: Adapted from Connecticut DEP Vehicle Maintenance Wastewater General Permit, January 2001.

Figure 11-S4-4 Example of Coalescing Plate Separator Design



Plan View



Section View

Source: Washington, 2000.

monthly and typically need to be cleaned every one to six months. Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment using a vacuum truck or other ordinary catch basin cleaning equipment.

Plans for oil/particle separators should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

Sediment Disposal: Polluted water or sediment removed from separators should be properly handled and disposed of in accordance with local, state, and federal regulations. Before disposal, appropriate chemical analysis of the material should be performed to determine proper methods for storage and disposal.

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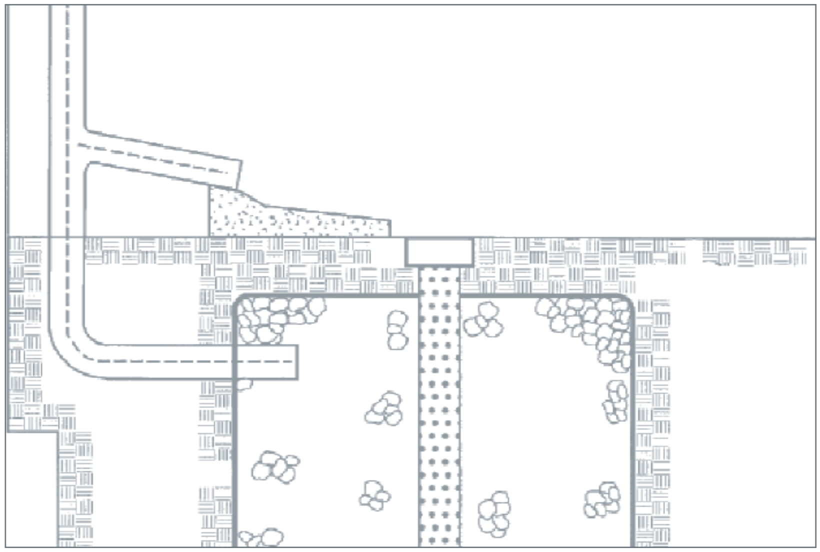
Dry Wells



Source: Adapted from Center for Watershed Protection, 2000.

Treatment Practice Type

Primary Treatment Practice
Secondary Treatment Practice ●

Stormwater Management Benefits

Pollutant Reduction	
Sediment	Partial Benefit
Phosphorus	Partial Benefit
Nitrogen	Partial Benefit
Metals	Partial Benefit
Pathogens	Low or Unknown Benefit
Floatables	Low or Unknown Benefit
Oil and Grease	Low or Unknown Benefit
Dissolved Pollutants	Partial Benefit
Runoff Volume Reduction	
Runoff Capture	Significant Benefit
Groundwater Recharge	Significant Benefit
Stream Channel Protection	Partial Benefit
Peak Flow Control	Partial Benefit

Key: Significant Benefit; Partial Benefit; Low or Unknown Benefit

Suitable Applications

Pretreatment	Low or Unknown Benefit
Treatment Train	Significant Benefit
Ultra-Urban	Low or Unknown Benefit
Stormwater Retrofits	Significant Benefit
Other	Low or Unknown Benefit

Description

Dry wells are small excavated pits filled with aggregate, which receive clean stormwater runoff primarily from building rooftops. Dry wells function as infiltration systems to reduce the quantity of runoff from a site and recharge groundwater. Dry wells treat stormwater runoff through soil infiltration, adsorption, trapping, filtering, and bacterial degradation. The use of dry wells is applicable for small drainage areas with low sediment or pollutant loadings and where soils are sufficiently permeable to allow reasonable rates of infiltration. **Figure 11-S5-1** shows a schematic of a typical dry well design. **Figure 11-S5-2** depicts an alternative precast concrete dry well design.

Reasons for Limited Use

- *Applicable to small drainage areas (one acre or less).*
- *Potential failure due to improper siting, design, construction, and maintenance.*
- *Susceptible to clogging by sediment.*
- *Risk of groundwater contamination depending on subsurface conditions, land use, and aquifer susceptibility.*
- *Not suitable for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads.*
- *Can drain wetlands or vernal pools if roof water is captured and released in another drainage area or below the wetland/vernal pool area.*

Suitable Applications

- *For infiltration of rooftop runoff that is unlikely to contribute significant loadings of sediment or pollutants (i.e., non-industrial, non-metallic roofs). Dry wells are not recommended for infiltrating parking lot runoff without pretreatment to remove sediment, hydrocarbons, and other pollutants.*
- *These systems can be installed under parking lots and other developed areas, provided that the system can be accessed for maintenance purposes.*
- *Useful in stormwater retrofit applications where space is limited and where additional runoff control is required.*
- *Where storm drains are not available and where adequate pretreatment is provided.*

Design Considerations

Dry wells are small-scale infiltration systems similar to the primary treatment infiltration practices described in previous sections of this chapter. Many of the siting, design, construction, and maintenance considerations for dry wells are similar to those of infiltration trenches, which are summarized below.

Soils: Dry wells should only be used with soils having suitable infiltration capacity (as confirmed through field testing). The minimum acceptable field-measured soil infiltration rate is 0.3 inches per hour. Field-measured soil infiltration rates should not exceed 5.0 inches per hour. This generally restricts application to soils of NRCS Hydrologic Soil Group A. Some Group B soils may be suitable if field-measured infiltration rates exceed 0.3 inches per hour. Refer to the Infiltration Practices section of this chapter for recommended field measurement techniques. One infiltration test and test pit or soil boring is recommended at the proposed location of the dry well. An observation well consisting of a well-anchored, vertical perforated PVC pipe with lockable aboveground cap should be installed to monitor system performance.

Land Use: Dry wells should only be used to infiltrate relatively clean runoff such as rooftop runoff. Dry wells should not be used to infiltrate runoff containing significant solids concentrations or concentrations of soluble pollutants that could contaminate groundwater, without adequate pretreatment. Appropriate pretreatment (e.g., filter strip, oil/particle separator, hydrodynamic device, roof washer for cisterns and rain barrels, catch basin inserts, or other secondary or primary treatment practices) should be provided to remove sediment, floatables, and oil and grease.

Drainage Area: The contributing drainage area to a dry well should be restricted to one acre or less.

Water Table/Bedrock: The bottom of the dry well should be located at least 3 feet above the seasonally high water table as documented by on-site soil testing and should be at least 4 feet above bedrock.

Size/Depth: Dry wells should be designed to completely drain the water quality volume (or larger runoff volumes for additional groundwater recharge) into the soil within 48 hours after the storm event. Dry wells should completely dewater between storms. A minimum draining time of 6 to 12 hours is recommended to ensure adequate pollutant removal. Dry wells should be equipped with overflows to handle larger runoff volumes or flows.

Miscellaneous: Dry wells should not be placed over fill materials, should be located a minimum of 10 feet from building foundations and, unless otherwise required or recommended by the DEP or the state or local health department should be located at least 75 feet away from:

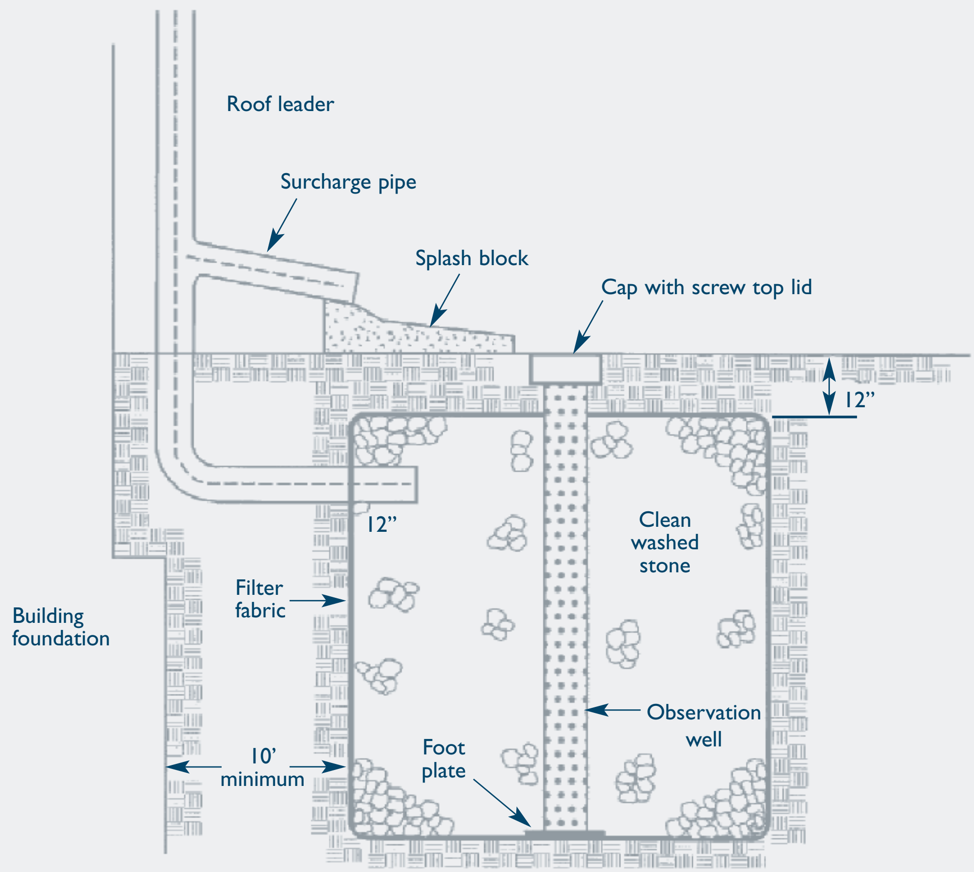
- *Drinking water supply wells*
- *Septic systems (any components)*
- *Surface water bodies*
- *Building foundations (at least 100 feet upgradient and at least 25 feet downgradient from building foundations)*

Construction: Refer to the Infiltration Practices section of this chapter for construction recommendations. The dry well should be filled with 1.5 to 3.0-inch diameter clean washed stone and be wrapped with filter fabric. The dry well should be covered by a minimum of 12 inches of soil.

Operation and Maintenance: Refer to the Infiltration Practices section of this chapter for operation and maintenance recommendations.

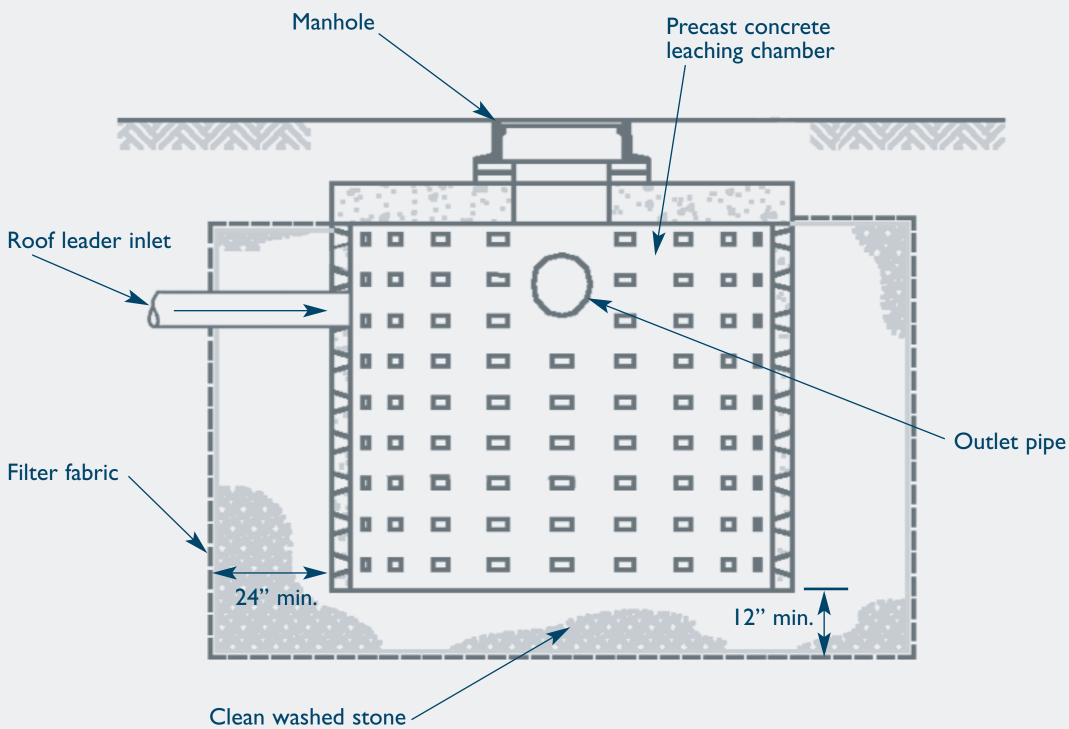
Plans for dry wells should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

Figure 11-S5-1 Schematic of a Dry Well



Source: Adapted from Center for Watershed Protection, 2000.

Figure 11-S5-2 Precast Concrete Dry Well Design



Source: Fuss & O'Neill, Inc.

References

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Permeable Pavement

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Primary Treatment Practice

Secondary Treatment Practice ●

Stormwater Management Benefits

Benefit	
Pollutant Reduction	
Sediment	▩
Phosphorus	▩
Nitrogen	▩
Metals	▩
Pathogens	□
Floatables	□
Oil and Grease	□
Dissolved Pollutants	□
Runoff Volume Reduction	
Runoff Capture	■
Groundwater Recharge	■
Stream Channel Protection	▩
Peak Flow Control	▩

Key: ■ Significant Benefit
▩ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Application	
Pretreatment	■
Treatment Train	■
Ultra-Urban (low traffic)	■
Stormwater Retrofits	■
Other	□

Description

Permeable pavement is designed to allow rain and snowmelt to pass through it, thereby reducing runoff from a site, promoting groundwater recharge, and filtering some stormwater pollutants. Permeable paving materials are alternatives to conventional pavement surfaces and include:

- *Modular concrete paving blocks*
- *Modular concrete or plastic lattice*
- *Cast-in-place concrete grids*
- *Soil enhancement technologies*
- *Other materials such as gravel, cobbles, wood, mulch, brick, and natural stone*

These practices increase a site's load bearing capacity and allow grass growth and infiltration (Metropolitan Council, 2001). Modular paving blocks or grass pavers consist of interlocking concrete or plastic units with spaces planted with turf or gravel for infiltration. The pavers are typically placed in a sand bed and gravel sub-base to enhance infiltration and prevent settling. Modular paving systems also include plastic lattice that can be rolled, cut to size, and filled with gravel or turfgrass. Cast-in-place concrete pavement incorporates gaps filled with soil and grass and provides additional structural capacity. Soil enhancement technologies have also been developed in which a soil amendment such as synthetic mesh is blended with a permeable soil medium to create an engineered load-bearing root zone (Metropolitan Council, 2001). Other traditional materials with varying degrees of infiltration capacity such as gravel, cobbles, wood, mulch, and stone can be used for driveways, walking trails, and other similar low traffic surfaces. **Figure 11-S6-1** illustrates examples of common permeable pavement applications.

Porous asphalt or concrete (i.e., porous pavement), which look similar to traditional pavement but are manufactured without fine materials and incorporate additional void spaces, are only recommended for certain limited applications in Connecticut due to their potential for clogging and high failure rate in cold climates. Porous pavement is only recommended for sites that meet the following criteria:

- *Low traffic applications (generally 500 or fewer average daily trips or ADT).*
- *The underlying soils are sufficiently permeable (see Design Considerations below).*
- *Road sand is not applied.*
- *Runoff from adjacent areas is directed away from the porous pavement by grading the surrounding landscape away from the site or by installing trenches to collect the runoff.*
- *Regular maintenance is performed (sweeping, vacuum cleaning).*

Reasons for Limited Use

- *Not recommended in areas with high traffic volumes (generally greater than 500 ADT).*
- *Susceptible to clogging by sediment.*
- *Does not provide significant levels of pollutant removal. Some treatment is provided by the adsorption, filtration, and microbial decomposition at the base-subgrade interface (Schueler et al., 1992).*
- *Snow removal is difficult since plows may not be used, sand application can lead to premature clogging, and salt can result in groundwater contamination.*
- *Applicable to small drainage areas.*
- *Not applicable to low permeability soils or soils prone to frost action.*
- *Potential failure due to improper siting, design, construction, and maintenance.*
- *Risk of groundwater contamination depending on subsurface conditions, land use, and aquifer susceptibility. Should not be used in public drinking water aquifer recharge areas except in certain "clean" residential settings where measures are taken to protect groundwater quality.*
- *Not suitable for land uses or activities with the potential for high sediment or pollutant loads or in areas with subsurface contamination.*
- *May not be suitable for areas that require wheelchair access due to the pavement texture.*

Suitable Applications

- *In combination with alternative site design or Low Impact Development techniques to reduce stormwater runoff volumes and pollutant loads.*
- *Low traffic (generally 500 ADT or less) areas of parking lots (i.e., overflow parking for malls and arenas), driveways for residential and light commercial use, walkways, bike paths, and patios.*
- *Roadside rights-of-way and emergency access lanes.*
- *Useful in stormwater retrofit applications where space is limited and where additional runoff control is required.*
- *In areas where snow plowing is not required.*

Design Considerations

Permeable pavement is a type of infiltration practice similar to the primary treatment infiltration practices described in previous sections of this chapter. Many of the siting, design, construction, and maintenance considerations for permeable pavement are similar to those of other infiltration practices. In addition, modular pavers and grids should be installed and maintained in accordance with the manufacturer's instructions. General considerations for permeable pavement are summarized below:

Soils: Permeable pavement should only be used with soils having suitable infiltration capacity as confirmed through field testing. Field-measured soil infiltration rates should be at least 0.3 inches per hour. Field-measured soil infiltration rates should not exceed 5.0 inches per hour to allow for adequate pollutant attenuation in the soil. This generally restricts application to soils of NRCS Hydrologic Soil Group A. Some Group B soils may be suitable if field-measured infiltration rates exceed 0.3 inches per hour. Refer to the Infiltration Practices section of this chapter for recommended field measurement techniques. Permeable pavement should not be used on fill soils or soils prone to frost action.

Land Use: Permeable pavement should not be used in public drinking water aquifer recharge areas or where there is a significant concern for groundwater contamination. Exceptions may include certain "clean" residential applications where measures are taken to protect groundwater quality (e.g., residential drive

Figure 11-S6-1 Examples of Permeable Pavement Applications

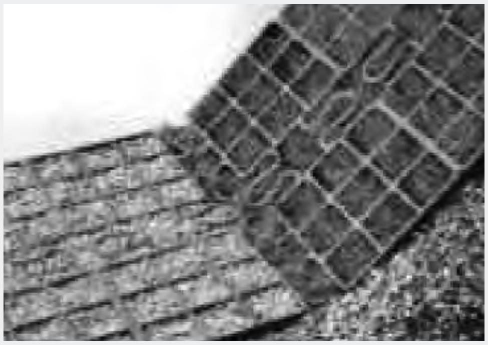
Modular Concrete Pavers

Parking Lot with Porous Surface

Overflow Parking Area

Concrete Paver Driveway

Low Use Parking Area



Plastic lattice Turf Pavement

Source: Nonpoint Education for Municipal Officials (NEMO) web site.

ways or walkways graded to drain away from the permeable pavement). Permeable pavement is not appropriate for land uses where petroleum products, greases, or other chemicals will be used, stored, or transferred. Except where recommended by local or state health departments or the Department of Environmental Protection, permeable paving materials should not be used in areas that receive significant amounts of sediment or areas that require sand and salt application for winter deicing.

Slope: Permeable pavement should not be used in areas that are steeply sloped (>15%), such as steep driveways, as this may lead to erosion of the material in the voids.

Water Table/Bedrock: The seasonally high water table as documented by on-site soil testing, should be at least 3 feet below grade. Bedrock should be at least 4 feet below grade. Except where recommended by local or state health departments or the Department of Environmental Protection, permeable pavement should be located at least 75 feet from drinking water wells.

Construction: Manufacturer's guidelines should be followed for installation. Generally, the following procedures are followed for construction of modular pavement systems:

Site Preparation

- *Site must be excavated and fine graded to the depth required by the base design.*
- *Roller pressure should be applied to compact soils.*
- *Base rock (3" to 6" of 3/4" clean gravel) is then installed and compacted to approximately 95 percent of Standard Proctor Density.*
- *A 1" sand layer is placed on top of the gravel layer and compacted.*
- *The pavers are then installed according to manufacturer's requirements.*

Planting

- *At least 1/8" to 1/4" of the paver must remain above the soil to bear the traffic load.*
- *Sod or seeding method may be used.*
- *If sod is used, the depth of backfill required will depend on the depth of the sod. Sod is laid over the pavers, watered thoroughly, and then compressed into the cells of the pavers.*
- *If grass is planted from seed, the appropriate soil should be placed in the cells, tamped into the cells, and then watered thoroughly so that the appropriate amount of paver is exposed. The soil is then ready for planting with a durable grass seed.*
- *Traffic should be excluded from the area for at least a month to allow for establishment of grass.*

Operation and Maintenance: Permeable pavement is easiest to maintain in areas where access to the pavement is limited and controlled and where pavement maintenance can be incorporated into a routine site maintenance program, such as commercial parking lots, office buildings, and institutional buildings (Pennsylvania Association of Conservation Districts et al., 1998). Turf pavers can be mowed, irrigated, and fertilized like other turf areas. However, fertilizers and other chemicals may adversely affect concrete products, and the use of such chemicals should be minimized. Pavers should be inspected once per year for deterioration and to determine if soil/vegetation loss has occurred. Soil or vegetation should be replaced or repaired as necessary. Care must be exercised when removing snow to avoid catching the snow plow on the edges of the pavers. Permeable pavement should be regularly cleared of tracked mud or sediment and leaves.

Plans for permeable pavement should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

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Vegetated Filter Strips and Level Spreaders

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Treatment Practice Type	
Primary Treatment Practice	
Secondary Treatment Practice	●

Stormwater Management Benefits

Pollutant Reduction	
Sediment	▩
Phosphorus	▩
Nitrogen	▩
Metals	▩
Pathogens	□
Floatables	□
Oil and Grease	□
Dissolved Pollutants	□
Runoff Volume Reduction	
Runoff Capture	▩
Groundwater Recharge	▩
Stream Channel Protection	▩
Peak Flow Control	□

Key: ■ Significant Benefit
▩ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Pretreatment	■
Treatment Train	■
Ultra-Urban	□
Stormwater Retrofits	■
Other	□

Description

Vegetated filter strips, also known as filter strips and grass filters, are uniformly graded vegetated surfaces (i.e., grass or close-growing native vegetation) located between pollutant source areas and downstream receiving waters or wetlands. Vegetated filter strips typically treat sheet flow directly from adjacent impervious surfaces, or small concentrated flows can be distributed along the width of the strip using a level spreader. Vegetated filter strips are designed to slow runoff velocities, trap sediment, and promote infiltration, thereby reducing runoff volumes.

Vegetated filter strips are commonly used as pretreatment prior to discharge to other filtering practices or bioretention systems. They can also be placed downgradient of stormwater outfalls equipped with outlet protection and level spreaders to reduce flow velocities and promote infiltration/filtration. Filter strips are effective when used in the outer zone of a stream buffer (see Chapter Four) to provide pretreatment of runoff from adjacent developed areas (EPA, 1999). In general, vegetated filter strips are relatively inexpensive to install, have relatively low maintenance requirements, but require large amounts of land.

Reasons for Limited Use

- *Provide limited pollutant removal. Filter strips are difficult to monitor, and therefore there is limited data on their pollutant removal effectiveness (Metropolitan Council, 2001). Little or no treatment is provided if the filter strip is short-circuited by concentrated flows.*
- *Applicable to small drainage areas.*
- *Proper maintenance required for maintaining a healthy stand of dense vegetation and preventing formation of concentrated flow.*
- *Poor retrofit option due to large land requirements.*
- *Effective only on drainage areas with gentle slopes (<15 percent).*
- *Improper grading can render the practice ineffective for pollutant removal (EPA, 2002).*

- *Not suitable for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads due to the risk of groundwater contamination or damage to vegetation.*

Suitable Applications

- *In conjunction with other stormwater management practices to treat runoff from highways, roads, and small parking lots.*
- *To infiltrate and filter runoff from residential areas such as roof downspouts, driveways, and lawns. Filter strips are relatively easy to incorporate into most residential developments.*
- *To reduce directly connected impervious areas, and thus runoff volume and peak flows.*
- *In stormwater retrofit applications where land is available. Existing outfalls may be suitable candidates for installation of level spreaders to distribute flow and reduce erosive velocities. Use of filter strips and level spreaders at large outfalls or outfalls with significant flow velocities is not recommended due to the difficulty associated with converting erosive concentrated flows into sheet flow.*
- *In conjunction with bioretention areas or stream buffer systems to provide pretreatment and reduce erosive runoff velocities.*
- *As side slopes of grass drainage channels or water quality swales, particularly where sufficient land area is available such as highway medians and shoulders.*

Design Considerations

Slope: Should be designed on slopes between 2 and 6 percent. Steeper slopes encourage the formation of concentrated flow. Flatter slopes encourage ponding and potential mosquito breeding habitat (EPA, 2002).

Soils: Should not be used on soils with high clay content due to limited infiltration, or on soils that cannot sustain grass cover.

Drainage Area: The contributing drainage area to vegetated filter strips is generally limited to one acre or less. The length of flow, rather than the drainage area, is considered to be the limiting design factor due to the formation of high-velocity concentrated flow. Without the use of a level spreader, the maximum overland flow lengths to the filter strip generally should be limited to 150 feet for pervious surfaces and 75 feet for impervious surfaces. Longer overland flow lengths are acceptable if a level spreader is used.

Water Table/Bedrock: Vegetated filter strips should be separated from seasonally high groundwater and bedrock by between 2 and 4 feet, as documented by on-site soil testing, to reduce the potential for groundwater contamination and saturated soil conditions between storms.

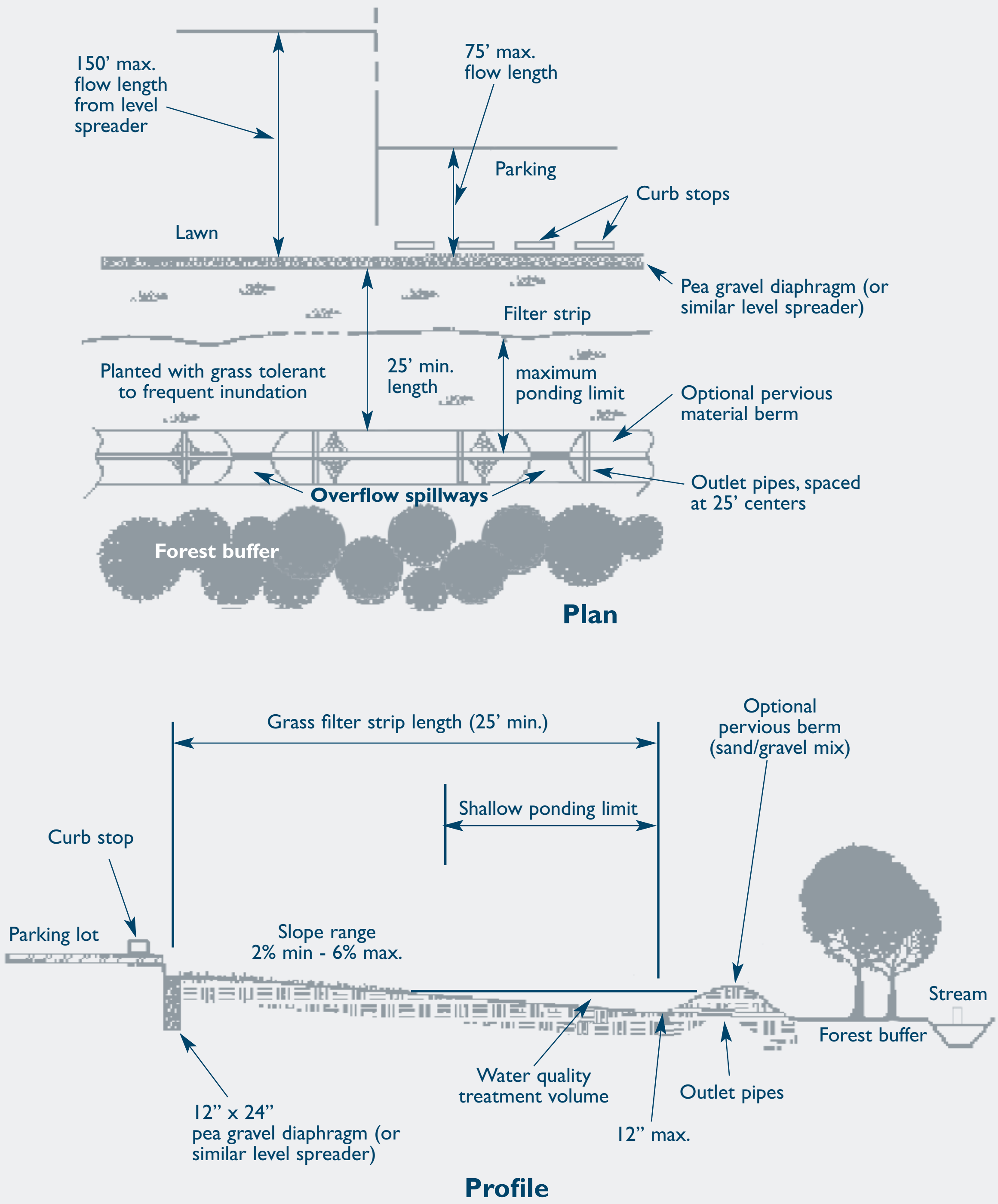
Size: The top and toe of slope should be designed as flat as possible to encourage sheet flow and infiltration. The filter strip should be at least 25 feet long and generally as wide as the area draining to the strip. The filter strip should be designed to drain within 24 hours after a storm. The design flow depth should not exceed 0.5 inches. The design should incorporate a bypass system to accommodate flows from larger storms (i.e., 2 year storm or larger). A pervious berm of sand or gravel can be added at the toe of the slope to enhance pollutant removal. In this design, the filter strip should be sized to provide surface storage of the water quality volume behind the berm. **Figure 11-S7-1** shows a common filter strip design for the edge of a lawn or parking lot.

Vegetation: Grasses should be selected to withstand relatively high flow velocities and both wet and dry conditions.

Level Spreader: A level spreader should be used at the top of slope to distribute overland flow or concentrated runoff (see the maximum overland flow length guidelines above) evenly across the entire length of the filter strip. Many level spreader design variations exist, including level trenches (e.g., pea gravel diaphragms, see **Figure 11-S7-1**), curbing, concrete weirs, etc. The key to any level spreader design is a continuous overflow elevation along the entire width of the filter strip. Velocity dissipation (i.e., riprap) may be required for concentrated flows. **Figure 11-S7-2** and **Figure 11-S7-3** show examples of two concrete level spreader designs.

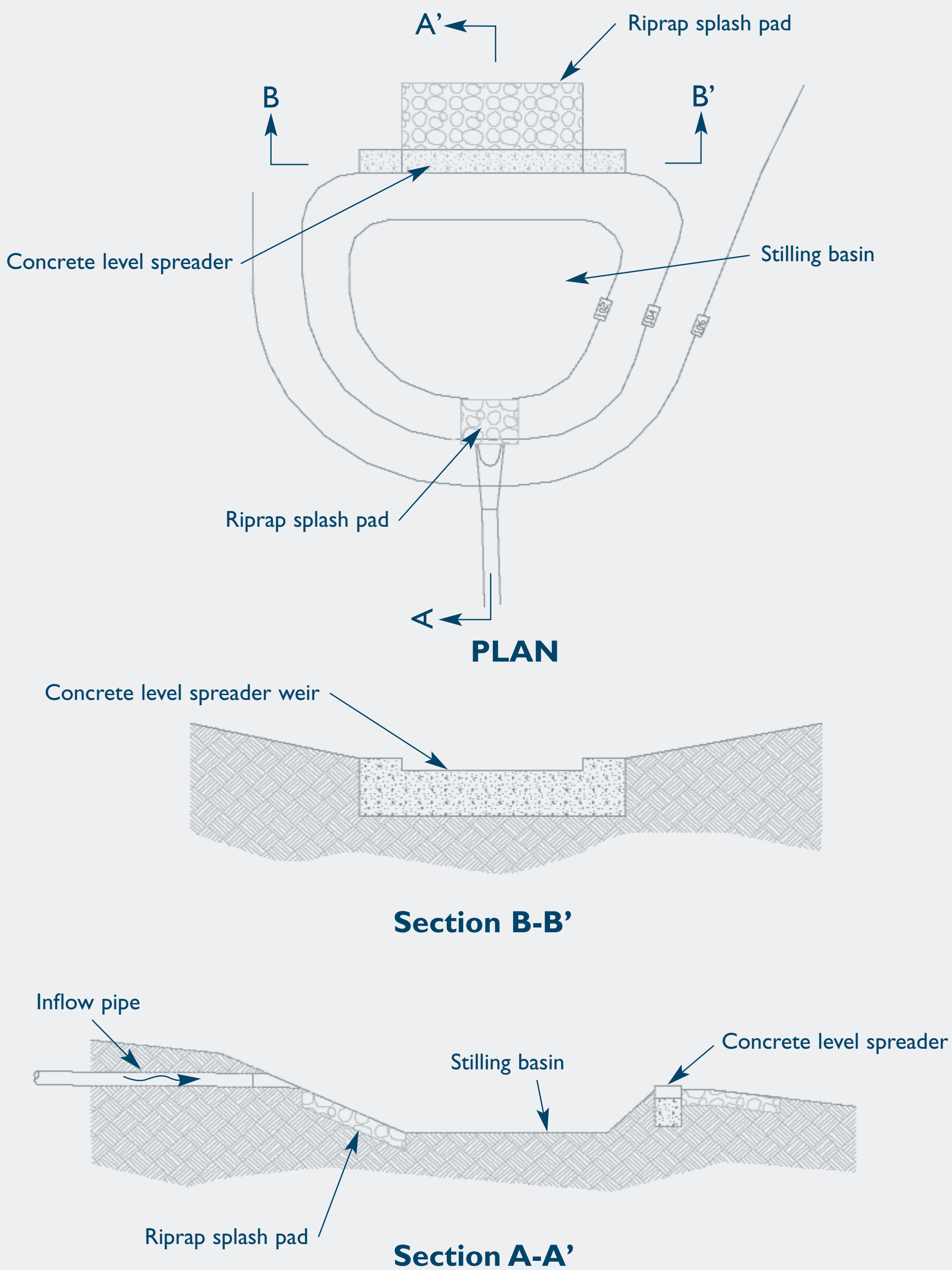
Construction: Proper grading is essential to establish sheet flow from the level spreader and throughout the filter strip. Soil stabilization measures should be implemented until permanent vegetation is established.

Figure 11-S7-1 Vegetated Filter Strip Schematic



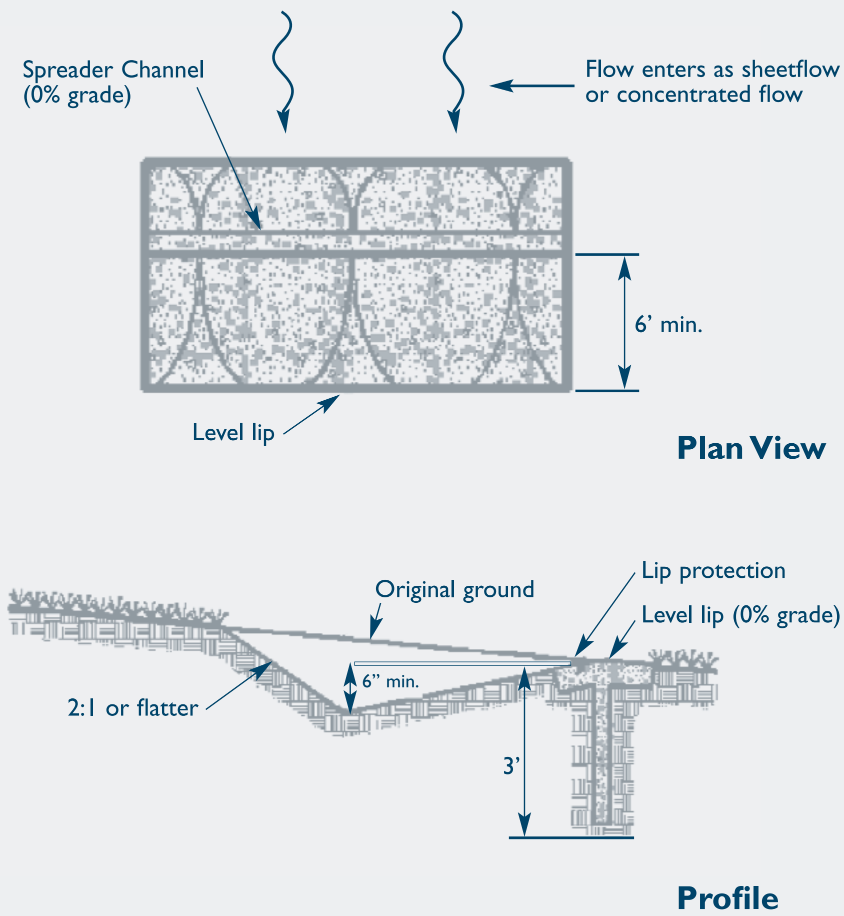
Source: Adapted from Claytor and Schueler, 1996.

Figure 11-S7-2 Concrete Level Spreader Design Example 1



Source: Fuss & O'Neill, Inc.

Figure 11-S7-3 Concrete Level Spreader Design Example 2



Source: Adapted from Center for Watershed Protection, 2000.

Operation and Maintenance: Regular maintenance is critical for the effectiveness of filter strips, especially to ensure that flow does not short-circuit the system. Semi-annual inspections are recommended during the first year (and annually thereafter), including inspection of the level spreader for sediment buildup and inspection of the vegetation for erosion, bare spots, and overall health. Regular, frequent mowing of the grass to a height of 3 to 4 inches is required. Sediment should be removed from the toe of slope or level spreader, and bare spots should be reseeded as necessary.

Plans for vegetated filter strips and level spreaders should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

References

Claytor, R.A. and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Silver Spring, Maryland.

Metropolitan Council. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates*. Prepared by Barr Engineering Company. St. Paul, Minnesota.

New York State Department of Environmental Conservation (NYDEC). 2001. *New York State Stormwater Management Design Manual*. Prepared by Center for Watershed Protection. Albany, New York.

United States Environmental Protection Agency (EPA). 1999. *Preliminary Data Summary of Urban Storm Water Best Management Practices*. EPA 821-R99-012.

United States Environmental Protection Agency (EPA). 2002. *National Menu of Best Management Practices for Stormwater Phase II*. URL: http://www.epa.gov/npdes/menuofbmps/menu.htm, Last Modified January 24, 2002.

Grass Drainage Channels

Source: Nonpoint Education for Municipal Officials (NEMO).

Treatment Practice Type

Primary Treatment Practice
Secondary Treatment Practice ●

Stormwater Management Benefits

Pollutant Reduction

- Sediment ▨
- Phosphorus ▨
- Nitrogen ▨
- Metals ▨
- Pathogens □
- Floatables □
- Oil and Grease □
- Dissolved Pollutants ▨

Runoff Volume Reduction

- Runoff Capture □
- Groundwater Recharge ▨

Stream Channel Protection ▨

Peak Flow Control □

Key: ■ Significant Benefit
▨ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

- Pretreatment ■
- Treatment Train □
- Ultra-Urban (low traffic) □
- Stormwater Retrofits □
- Other ■

Description

Grass drainage channels are traditional vegetated open channels designed for conveyance rather than water quality treatment. Drainage channels provide limited pollutant removal through filtration by grass or other vegetation, sedimentation, biological activity in the grass/soil media, as well as limited infiltration if underlying soils are pervious. However, their primary function is to provide non-erosive conveyance, typically up to the 10-year frequency design flow. Grass drainage channels are typically trapezoidal, triangular, or parabolic in shape and are designed based on peak flow rate rather than a water quality volume approach.

Drainage channels are commonly incorporated into highway and road drainage systems, but can also be used in place of traditional curb and gutter drainage systems in residential and commercial areas to enhance pollutant removal and to provide limited groundwater recharge and runoff volume reduction. **Figure 11-S8-1** depicts a schematic of a typical grass drainage channel.

Reasons for Limited Use

- *Provide limited pollutant removal.*
- *Require more maintenance than traditional curb and gutter drainage systems.*
- *May be impractical in areas with very flat grades, steep topography, or poorly drained soils (Metropolitan Council, 2001).*
- *Large area requirements for highly impervious sites.*

Suitable Applications

- *For runoff conveyance.*
- *As pretreatment in conjunction with other stormwater management practices.*
- *Can replace traditional curb and gutter drainage system for new development or stormwater retrofits.*
- *Linear nature makes drainage channels ideal for highway and residential road runoff, as well as industrial parks and institutional areas.*

Design Considerations

Specific design criteria and procedures for grass drainage channels are beyond the scope of this Manual. Grass drainage channels should be designed in accordance with established open channel flow principles and accepted stormwater drainage design practice, as described in the following recommended references:

- *Connecticut Department of Transportation (ConnDOT),* Connecticut Department of Transportation Drainage Manual, *October 2000.*
- *Connecticut Council on Soil and Water Conservation and the Connecticut Department of Environmental Protection,* 2001 Connecticut Guidelines for Soil Erosion and Sediment Control, DEP Bulletin 34, *2001.*
- *USDA Soil Conservation Service,* National Engineering Field Manual, *Natural Resources Conservation Service, Washington, D.C., 1988.*

Some general design considerations include:

- *For enhanced water quality performance, provide sufficient channel length to retain the water quality volume in the system for at least 10 minutes (using a check dam if necessary), and limit the water quality peak flow to 1 foot per second and a depth of no greater than 4 inches (i.e., the height of the grass). However, most of the pollutant reduction in grass drainage channels has been shown to occur in the first 65 feet of the channel (Walsh et al., 1997). Longer channels designed solely for water quality improvement may not be cost effective.*
- *For enhanced pollutant removal, design the channel side slopes to serve as vegetated filter strips by accepting sheet flow runoff. Pollutant removal that occurs across the channel side slopes (i.e., vegetated filter strip) can exceed the pollutant removal that occurs down the longitudinal length of the channel, particularly for highway medians with side slopes of 25 feet or longer (Walsh et al., 1997).*
- *Design the channel to ensure non-erosive velocities for the soil type and vegetation condition of the channel (see* ***Connecticut Guidelines for Soil Erosion and Sediment Control*** *for maximum permissible velocities).*
- *Design the channel with sufficient capacity and conveyance for the 10-year frequency storm event.*
- *Native grasses are preferred for enhanced biodiversity, wildlife habitat, and drought tolerance. Grass species should be sod-forming, resistant to frequent inundation, rigid and upright in high flows, and salt tolerant if located along a roadway. Wetland species may be used for the bottom of a wet swale. The following grasses perform well in an open channel environment:*
  - *Red Fescue (Festuca rubra)*
  - *Tall Fescue (Festuca arundinacea)*
  - *Redtop (Agrostis alba)*
  - *Smooth Bromegrass (Bromus inermis)*
  - *Reed Canarygrass (Phalaris arundinacea L.).*

References

Claytor, R.A. and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems.* Center for Watershed Protection. Silver Spring, Maryland.

Connecticut Department of Transportation (DOT). 2000. *Connecticut Department of Transportation Drainage Manual.*

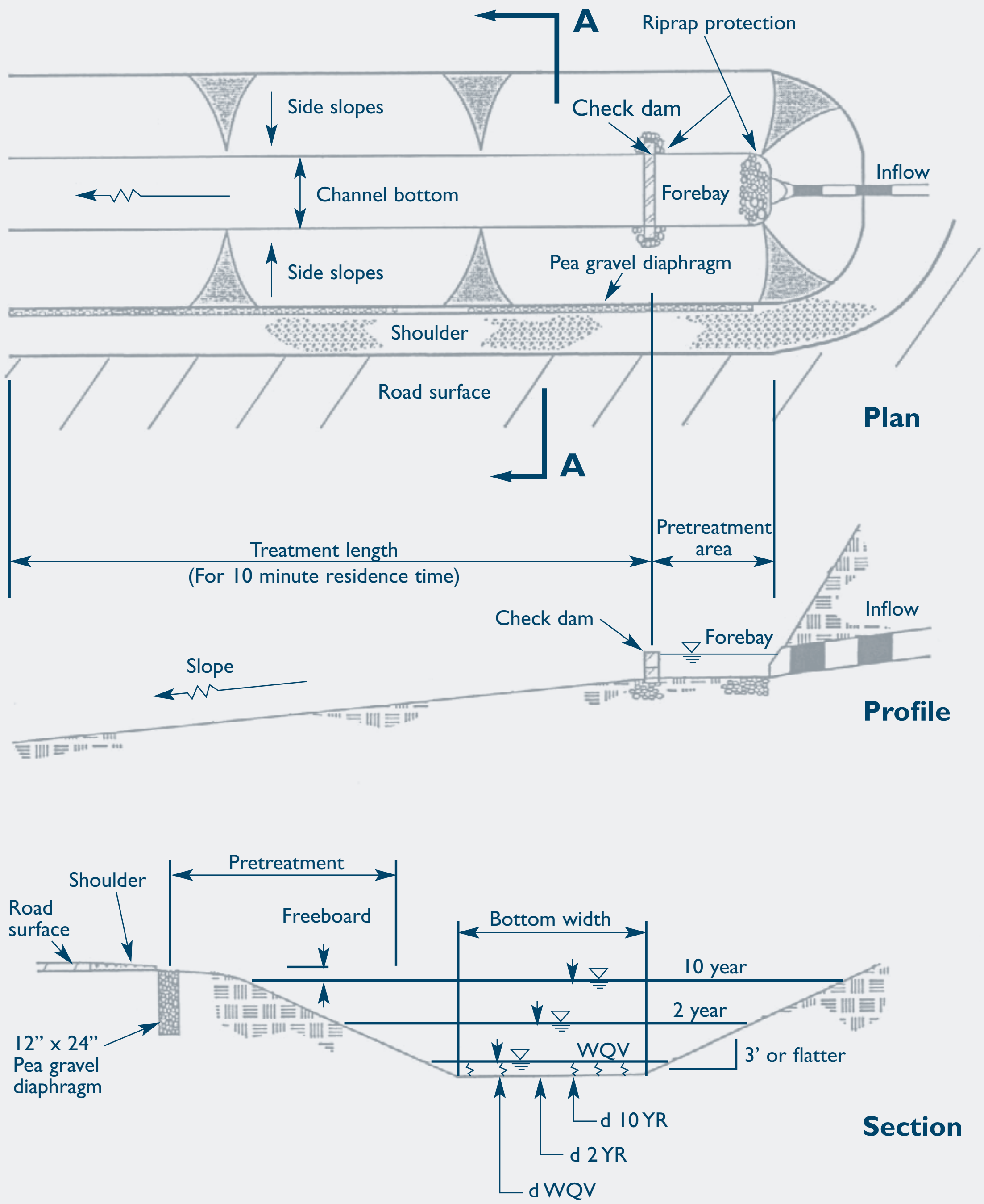
Connecticut Council on Soil and Water Conservation and the Connecticut Department of Environmental Protection. 2002. *2001 Connecticut Guidelines for Soil Erosion and Sediment Control*, DEP Bulletin 34.

Metropolitan Council. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates.* Prepared by Barr Engineering Company. St. Paul, Minnesota.

USDA Soil Conservation Service. 1988. National Engineering Field Manual. Natural Resources Conservation Service. Washington, D.C.

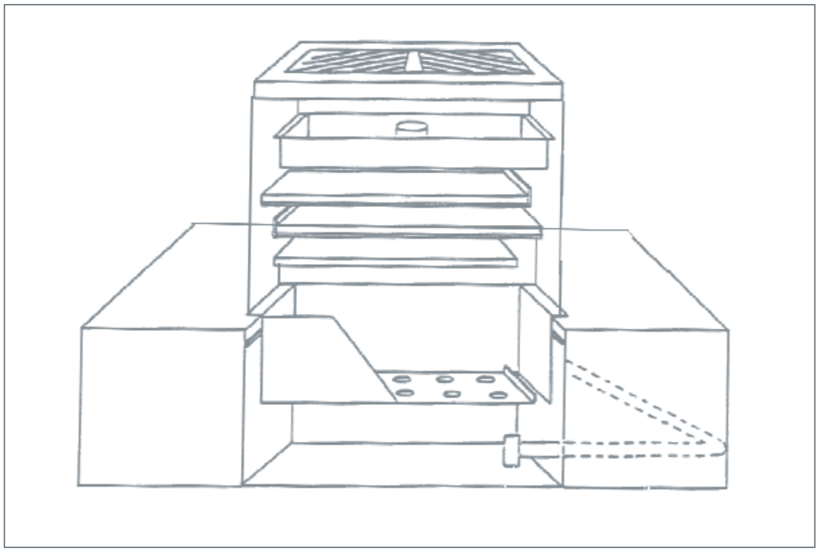
Walsh, P. M., Barrett, M.E., Malina, J.F., and R. Charbeneau. 1997. *Use of Vegetative Controls for Treatment of Highway Runoff.* Center for Research in Water Resources. Bureau of Engineering Research. University of Texas at Austin. Austin, TX.

Figure 11-S8-1 Schematic of a Grass Drainage Channel



Source: Adapted from Center for Watershed Protection, 2000.

Catch Basin Inserts



Source: City of Knoxville, 2001.

Treatment Practice Type

Primary Treatment Practice
Secondary Treatment Practice ●

Stormwater Management Benefits

Pollutant Reduction

Sediment	Partial Benefit
Phosphorus	Low or Unknown Benefit
Nitrogen	Low or Unknown Benefit
Metals	Partial Benefit
Pathogens	Low or Unknown Benefit
Floatables	Partial Benefit
Oil and Grease	Partial Benefit
Dissolved Pollutants	Low or Unknown Benefit

Runoff Volume Reduction

Runoff Capture	Low or Unknown Benefit
Groundwater Recharge	Low or Unknown Benefit

Stream Channel Protection	Low or Unknown Benefit
Peak Flow Control	Low or Unknown Benefit

Key: ■ Significant Benefit
■ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Pretreatment	Significant Benefit
Treatment Train	Significant Benefit
Ultra-Urban	Significant Benefit
Stormwater Retrofits	Significant Benefit
Other	Low or Unknown Benefit

Description

Catch basin inserts are a general category of proprietary devices that have been developed in recent years to filter runoff entering a catch basin. Catch basin inserts function similarly to media filters, but on a much smaller scale. Catch basin inserts typically consist of the following components:

- *A structure (e.g. screened box, tray, basket,) which contains a pollutant removal medium*
- *A means of suspending the structure in a catch basin*
- *A filter medium such as sand, carbon, fabric, bag, etc.*
- *A primary inlet and outlet for the stormwater*
- *A secondary outlet for bypassing flows that exceed design flow.*

(Washington, 2000). The two basic varieties of catch basin inserts include filter trays and filter fabric. The tray design consists of a series of trays, with the top tray serving as an initial sediment trap, and the underlying trays composed of media filters. The filter fabric design uses filter fabric as the filter media for pollutant removal. Depending on the insert medium, solids, organics (including oils), and metals can be removed. However, due to their small volume, catch basin inserts have very limited retention times and require frequent cleaning or replacement to be effective. **Figure 11-S9-1** and **Figure 11-S9-2** illustrate several examples of generic catch basin insert designs.

Reasons for Limited Use

- *Limited peer-reviewed performance data available. (See Chapter Six for a description of the recommended evaluation criteria and protocols for consideration of these technologies as primary treatment practices.)*

- *Require frequent maintenance and replacement. Can become a source of pollutants unless maintained frequently.*
- *Susceptible to clogging. Can aggravate flooding when clogged.*
- *Do not provide peak flow attenuation, runoff volume reduction, or groundwater recharge.*

Suitable Applications

- *To provide pretreatment for other stormwater treatment practices.*
- *For retrofit of existing conventional catch basins that lack sumps or have undersized sumps.*
- *May be considered in specialized small drainage applications such as industrial sites for specific target pollutants where clogging of the medium will not be a problem.*
- *As temporary sediment control devices and pretreatment at construction sites.*
- *For oil control at small sites where the insert medium has sufficient hydrocarbon loading capacity and rate of removal, and the solids and debris will not prematurely clog the insert.*
- *Can be used in unpaved areas for inlet protection.*

Design Considerations

Due to the proprietary nature of these products, catch basin inserts should be designed according to the manufacturer's recommendations. Some general design considerations for catch basin inserts include:

High Flow Bypass: A high flow bypass or other design feature to allow stormwater runoff into the drain system in the event of clogging and runoff in excess of the water quality design flow to bypass the system without danger of local flooding.

Maintenance: Should be inspected and maintained in accordance with manufacturer's recommendations. Since catch basin inserts require frequent inspection and maintenance, they should only be used where a full-time maintenance person is on-site.

Plans for catch basin inserts should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

Sediment Disposal: Sediment removed from catch basin inserts should be properly handled and disposed in accordance with local, state, and federal regulations. Before disposal, appropriate chemical analysis of the material should be performed to determine proper methods for storage and disposal.

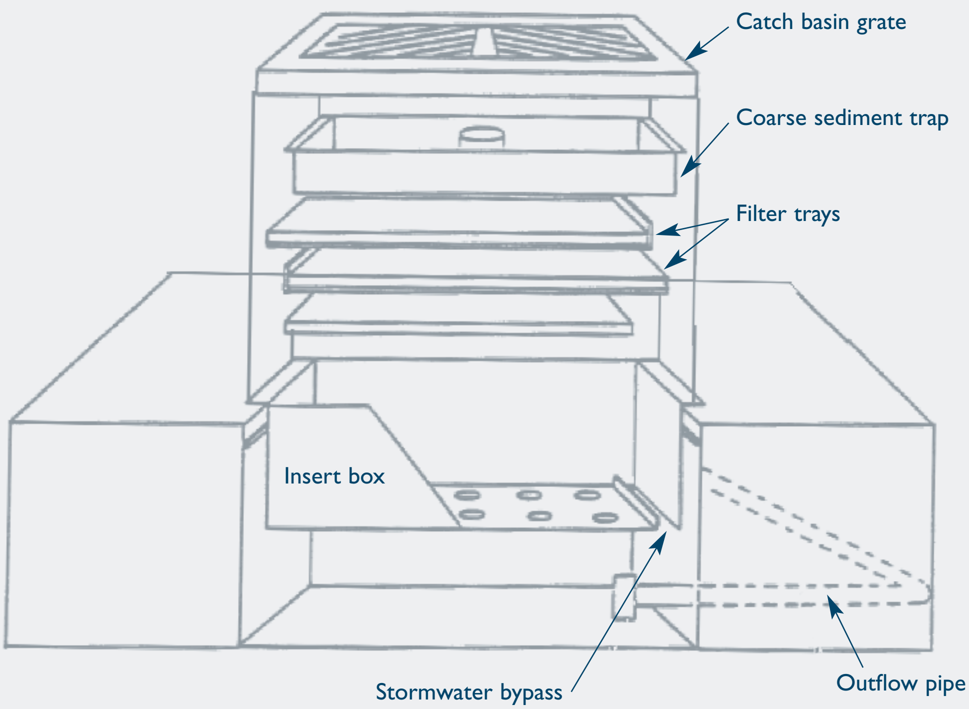
References

City of Knoxville. 2001. *Knoxville BMP Manual*, City of Knoxville Engineering Department. Knoxville, Tennessee.

United States Environmental Protection Agency (EPA). 2002. *National Menu of Best Management Practices for Stormwater Phase II*. URL: http://www.epa.gov/npdes/menuofbmps/menu.htm, Last Modified January 24, 2002.

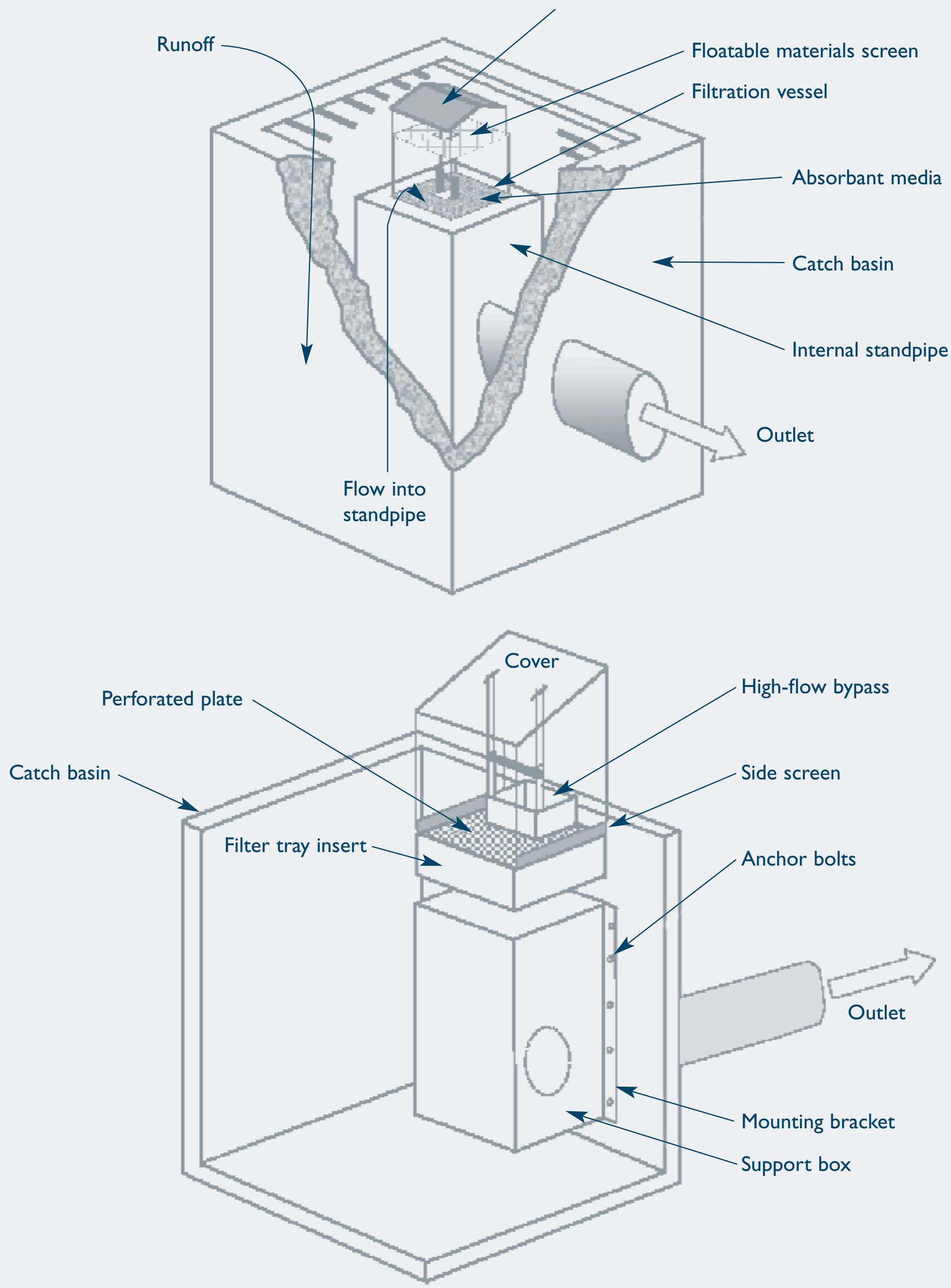
Washington State Department of Ecology (Washington). 2000. *Stormwater Management Manual for Western Washington, Final Draft*. Olympia, Washington.

Figure 11-S9-1 Example of Tray-Type Catch Basin Insert



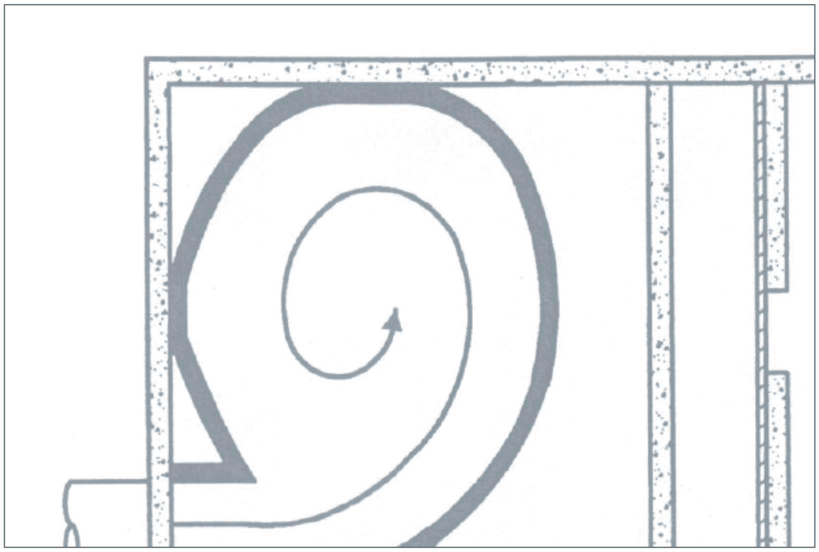
Source: City of Knoxville, 2001.

Figure 11-S9-2 Example of Clog-Resistant Media Filter Catch Basin Inserts



Source: City of Knoxville, 2001.

Hydrodynamic Separators



Source: Adapted from City of Knoxville, 2001.

Treatment Practice Type

Primary Treatment Practice
Secondary Treatment Practice ●

Stormwater Management Benefits

Pollutant Reduction	
Sediment	■
Phosphorus	▣
Nitrogen	▣
Metals	▣
Pathogens	□
Floatables	■
Oil and Grease	■
Dissolved Pollutants	□
Runoff Volume Reduction	
Runoff Capture	□
Groundwater Recharge	□
Stream Channel Protection	□
Peak Flow Control	□

Key: ■ Significant Benefit
▣ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Pretreatment	■
Treatment Train	■
Ultra-Urban	■
Stormwater Retrofits	■
Other (Industrial applications)	■

Description

This group of stormwater treatment technologies includes a wide variety of proprietary devices that have been developed in recent years. These devices, also known as swirl concentrators, are modifications of traditional oil/particle separators that commonly rely on vortex-enhanced sedimentation for pollutant removal. They are designed to remove coarse solids and large oil droplets and consist primarily of cylindrical-shaped devices that are designed to fit in or adjacent to existing stormwater drainage systems (Washington, 2000). In these structures, stormwater enters as tangential inlet flow into the cylindrical structure. As the stormwater spirals through the chamber, the swirling motion causes the sediments to settle by gravity, removing them from the stormwater (EPA, 2002). Some devices also have compartments or chambers to trap oil and other floatables. **Figure 11-S10-1** shows several examples of common hydrodynamic separator designs (no endorsement of any particular product is intended).

Although swirl concentration is the most common technology used in hydrodynamic separators, others use circular screening systems or engineered cylindrical sedimentation. Circular screened systems use a combination of screens, baffles, and inlet and outlet structures to remove debris, large particle total suspended solids, and large oil droplets. Structures using engineered cylindrical sedimentation use an arrangement of internal baffles and an oil and sediment storage compartment. Other proprietary technologies incorporate an internal high flow bypass with a baffle system in a rectangular structure to simulate plug flow operation. When properly engineered and tested, these systems can also be an improvement over conventional oil/particle separators and offer removal efficiencies similar to swirl chamber technologies. Sorbents can also be added to these structures to increase removal efficiency (Washington, 2000).

Reasons for Limited Use

- *Limited peer-reviewed performance data. Some independent studies suggest only moderate pollutant removal. (See Chapter Six for a description of the recommended evaluation criteria and protocols* *for consideration of these technologies as primary treatment practices).*

- *Cannot effectively remove soluble pollutants or fine particles.*
- *Can become a source of pollutants due to re-suspension of sediment unless maintained regularly. Maintenance often neglected ("out of sight and out of mind").*

Suitable Applications

- *Where higher sediment and pollutant removal efficiencies are required over a range of flow conditions, as compared to conventional oil/particle or oil/grit separators.*
- *For limited removal of trash, debris, oil and grease, and sediment from stormwater runoff from relatively small impervious areas with high traffic volumes or high potential for spills such as:*
  - *Parking lots*
  - *Streets*
  - *Truck loading areas*
  - *Gas stations*
  - *Refueling areas*
  - *Automotive repair facilities*
  - *Fleet maintenance yards*
  - *Commercial vehicle washing facilities*
  - *Industrial facilities*
- *To provide pretreatment for other stormwater treatment practices.*
- *For retrofit of existing stormwater drainage systems, particularly in highly developed (ultra-urban) areas where larger conventional treatment practices are not feasible or where aboveground treatment practices are not an option.*

Design Considerations

Due to the proprietary nature of these products, hydrodynamic separators should be designed according to the manufacturer's recommendations. Some general design considerations for these devices include:

Drainage Area: The recommended maximum contributing drainage area to individual devices varies by manufacturer, model, etc.

Sizing/Design: In most instances, hydrodynamic separators should be used in an off-line configuration to treat the design water quality flow (peak flow associated with the design water quality volume). Upstream diversion structures can be used to bypass higher flows around the device. Sizing based on flow rate allows these devices to provide treatment within a much smaller area than conventional volume-based stormwater treatment practices such as ponds, wetlands, and infiltration practices. Potential mosquito entry points should be sealed (adult female mosquitoes can use openings as small as 1/16 inch to access water for egg laying). To avoid funneling amphibians into treatment chambers, where they are killed, Hydrodynamic separators should be used in conjunction with Cape Cod curbing or other similar curbing that allows amphibians to climb.

Performance: Performance is dependent on many variables such as particle size, sediment concentration, water temperature, and flow rate. Hydrodynamic separators should be sized and compared based on performance testing of comparable size particles, influent concentrations, and testing protocols. Comparative performance testing that establishes a performance curve over the full operating range of the technology should be considered a prerequisite to any meaningful performance based sizing.

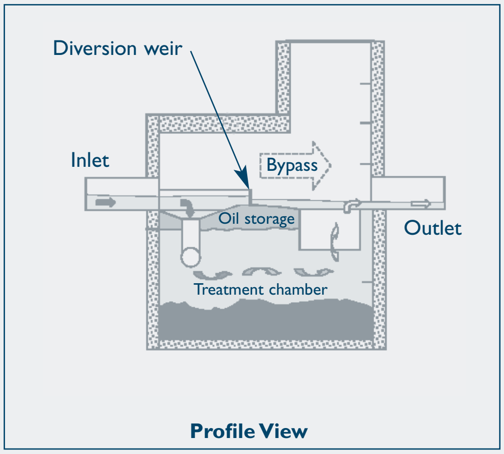
Maintenance: Frequent inspection and cleanout is critical for proper operation of hydrodynamic separators. Structures that are not maintained can be significant sources of pollution. Recommended maintenance requirements and schedules vary with manufacturer, but in general these devices need to be cleaned quarterly. Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment using a vacuum truck or other ordinary catch basin cleaning equipment.

Design plans for hydrodynamic separators should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

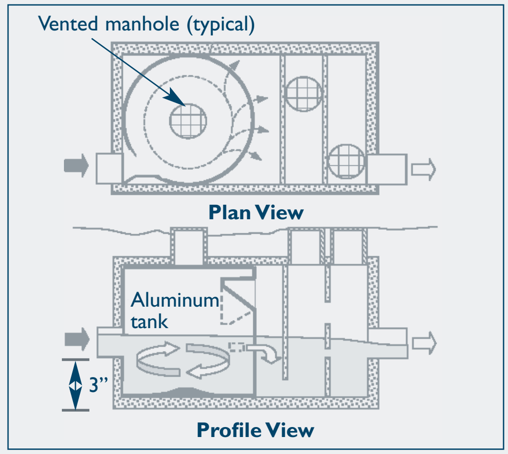
Sediment Disposal: Polluted water or sediment removed from these devices should be properly handled and disposed in accordance with local, state, and federal regulations. Before disposal, a detailed chemical analysis of the material should be performed to determine proper methods for storage and disposal.

Figure 11-S10-1 Examples of Common Hydrodynamic Separator Designs

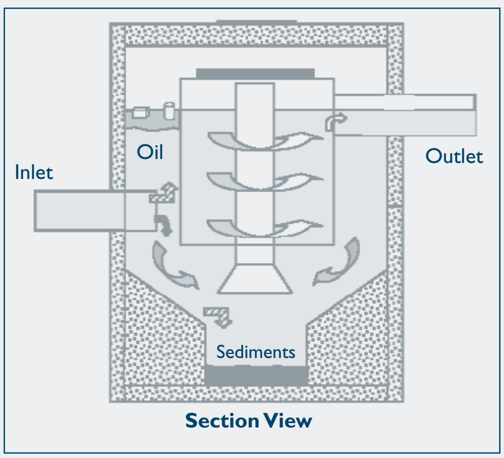
Design Example 1



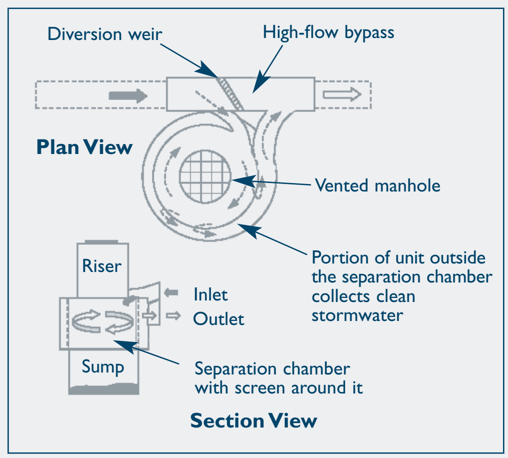
Design Example 2



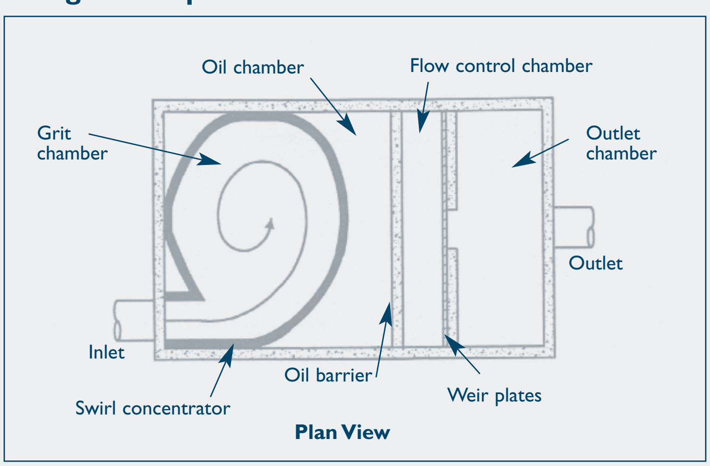
Design Example 3



Design Example 4



Design Example 5



Source: Adapted from City of Knoxville, 2001.

References

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Washington State Department of Ecology (Washington). 2000. *Stormwater Management Manual for Western Washington, Final Draft.* Olympia, Washington.

Media Filters

Source: Adapted from Stormwater Management, Inc.

Treatment Practice Type

Primary Treatment Practice
Secondary Treatment Practice ●

Stormwater Management Benefits

Pollutant Reduction

- Sediment ▣
- Phosphorus ▣
- Nitrogen ▣
- Metals ▣
- Pathogens ▣
- Floatables ▣
- Oil and Grease ▣
- Dissolved Pollutants ▣

Runoff Volume Reduction

- Runoff Capture □
- Groundwater Recharge □

Stream Channel Protection □

Peak Flow Control □

Key: ■ Significant Benefit
▣ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

- Pretreatment ■
- Treatment Train ■
- Ultra-Urban ■
- Stormwater Retrofits ■
- Other (Industrial applications) ■

Description

Media filters are an evolution of fixed bed sand filtration technology. In this type of treatment practice, media is placed within filter cartridges that are typically enclosed in underground concrete vaults. Stormwater is passed through the media, which traps particulates and/or soluble pollutants. Various materials may be used as filter media including pleated fabric, activated charcoal, perlite, amended sand and perlite mixes, and zeolite. Selection of filter media is largely a function of the pollutants targeted for removal. Pretreatment prior to the filter media is typically necessary for stormwater with high total suspended solids, hydrocarbon, and debris loadings that may cause clogging and premature filter failure (Washington, 2000). Maintenance requirements for filter media include sediment removal and replacement of media cartridges. **Figure 11-S11-1** shows an example of a common media filter design (no endorsement of any particular product is intended).

Reasons for Limited Use

- *Limited peer-reviewed performance data available. (See Chapter Six for a description of the recommended evaluation criteria and protocols for consideration of these technologies as primary treatment practices).*
- *Require frequent maintenance and replacement. Can become a source of pollutants unless maintained frequently.*
- *Susceptible to clogging. Pretreatment is required for high solids and/or hydrocarbon loadings and debris that could cause premature failure due to clogging.*

Suitable Applications

- *Specialized applications such as industrial sites for specific target pollutants (i.e., organics, heavy metals, and soluble nutrients) that are not easily removed by other conventional treatment practices.*

- *For retrofit of existing stormwater drainage systems, particularly in highly developed (ultra-urban) areas where larger conventional treatment practices are not feasible or where aboveground treatment practices are not an option.*
- *For pretreatment or as part of a stormwater treatment train in conjunction with other stormwater management practices.*

Design Considerations

Due to the proprietary nature of these products, media filters should be designed according to the manufacturer's recommendations. Some general design considerations for media filters include:

Sizing/Design: Media filters should primarily be used in an off-line configuration to treat either the design water quality volume or the design water quality flow (peak flow associated with the design water quality volume). Upstream diversion structures or bypass systems built into the unit are used to bypass higher flows around the device. The size and number of filter cartridges are determined based upon the anticipated solids loading rate and design water quality flow. Filter media are selected based on pollutants of concern. Potential mosquito entry points should be sealed (adult female mosquitoes can use openings as small as 1/16 inch to access water for egg laying).

Maintenance: Frequent inspection and cleanout is critical for proper operation of media filters. Structures that are not maintained can be significant sources of pollution. Manufacturer's operation and maintenance guidelines should be followed to maintain design flows and pollutant removals. Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment from the filter chamber and replacement of the filter cartridges.

Plans for media filters should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.

Sediment Disposal: Polluted water or sediment removed from these devices should be properly handled and disposed in accordance with local, state, and federal regulations. Before disposal, a detailed chemical analysis of the material should be performed to determine proper methods for storage and disposal.

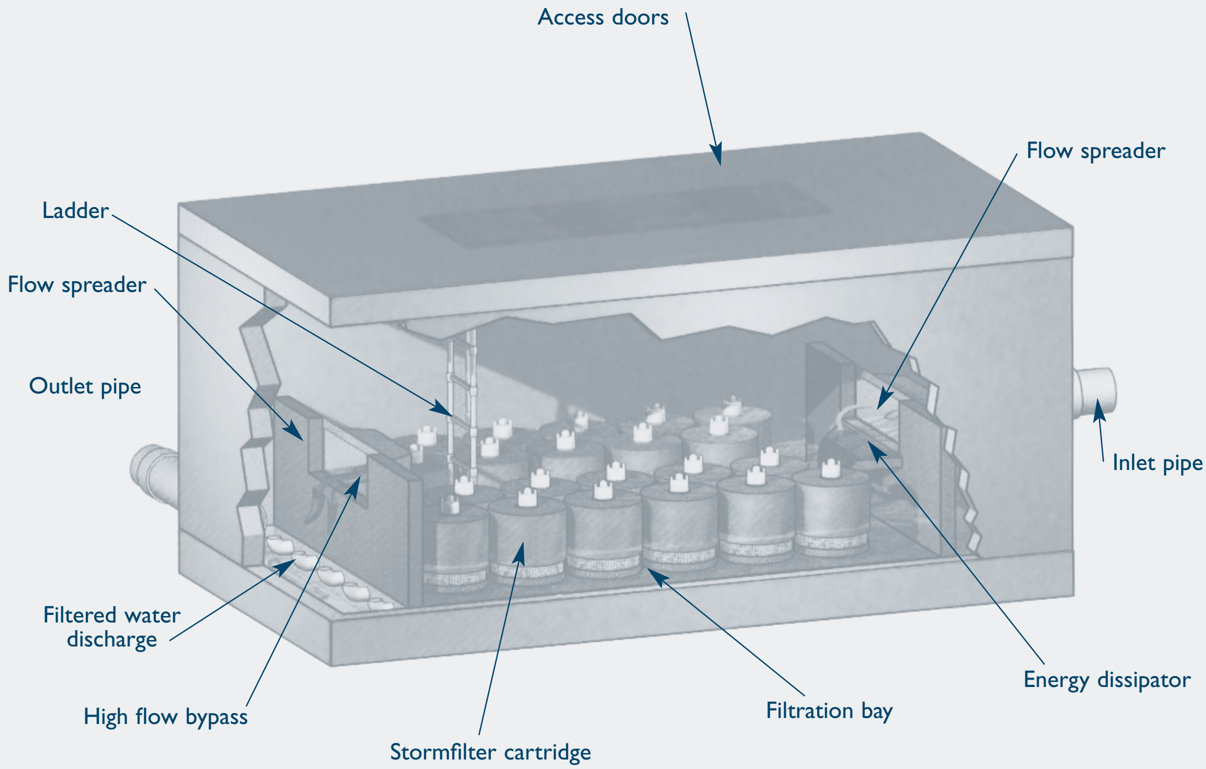
References

Stormwater Management Inc.,
URL: http://www.stormwatermgt.com/.

United States Environmental Protection Agency (EPA). 2002. *National Menu of Best Management Practices for Stormwater Phase II.* URL: http://www.epa.gov/npdes/menuofbmps/menu.htm, Last Modified January 24, 2002.

Washington State Department of Ecology (Washington). 2000. *Stormwater Management Manual for Western Washington, Final Draft.* Olympia, Washington.

Figure 11-S11-1 Typical Media Filter Design



Source: Adapted from Stormwater Management, Inc.

Underground Infiltration Systems

Source: CULTEC, Inc.

Treatment Practice Type

Primary Treatment Practice
Secondary Treatment Practice ●

Stormwater Management Benefits

Pollutant Reduction	
Sediment	▣
Phosphorus	▣
Nitrogen	▣
Metals	▣
Pathogens	□
Floatables	□
Oil and Grease	□
Dissolved Pollutants	▣
Runoff Volume Reduction	
Runoff Capture	■
Groundwater Recharge	■
Stream Channel Protection	■
Peak Flow Control	■

Key: ■ Significant Benefit
▣ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Pretreatment	□
Treatment Train	■
Ultra-Urban	■
Stormwater Retrofits	■
Other	□

Description

A number of underground infiltration systems, including premanufactured pipes, vaults, and modular structures, have been developed as alternatives to infiltration trenches and basins for space-limited sites and stormwater retrofit applications. Similar to traditional infiltration trenches and basins, these systems are designed to capture, temporarily store, and infiltrate the water quality volume over several days. These devices are typically designed as off-line systems, but can also be used to retain and infiltrate larger runoff volumes. Performance of underground infiltration systems varies by manufacturer and system design. These systems are currently considered secondary treatment practices due to limited field performance data, although pollutant removal efficiency is anticipated to be similar to that of infiltration trenches and basins. **Figure 11-S12-1** shows several examples of common underground infiltration systems.

Reasons for Limited Use

- *Limited available monitoring data and undocumented field longevity.*
- *Potential failure due to improper siting, design (including adequate pretreatment), construction, and maintenance.*
- *Susceptible to clogging by sediment.*
- *Risk of groundwater contamination depending on subsurface conditions, land use, and aquifer susceptibility.*
- *Not suitable for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads.*

Suitable Applications

- *As an alternative to traditional infiltration trenches and basins for space-limited sites. These systems can be installed under parking lots and other developed areas, provided that the system can be accessed for maintenance purposes.*

- *Useful in stormwater retrofit applications or as part of a stormwater treatment train to provide additional groundwater recharge and storage volume to attenuate peak flows.*

Design Considerations

The materials of construction, configuration, and layout of underground infiltration systems vary considerably depending on the system manufacturer. Specific design criteria and specifications for these systems can be obtained from system manufacturers or vendors. General design elements common to most of these systems are summarized below. The reader should refer to the Infiltration Practices section of this chapter for additional information on siting, design, construction, and maintenance considerations.

Siting: Underground infiltration systems are generally applicable to small development sites (typically less than 10 acres) and should be installed in locations that are easily accessible for routine and non-routine maintenance. These systems should not be located in areas or below structures that cannot be excavated in the event that the system needs to be replaced. Similar to infiltration trenches and basins, underground infiltration systems should only be used with soils having suitable infiltration capacity (as confirmed through field testing) and for land uses, activities, or areas that do not pose a risk of groundwater contamination.

Pretreatment: Appropriate pretreatment (e.g., oil/particle separator, hydrodynamic device, catch basin inserts, or other secondary or primary treatment practices) should be provided to remove sediment, floatables, and oil and grease.

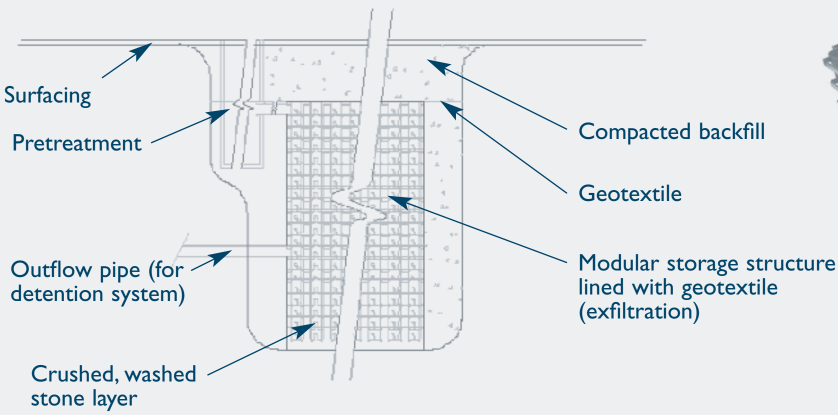
Design Volume: Underground infiltration structures should be designed as off-line practices to infiltrate the entire water quality volume. A flow bypass structure should be located upgradient of the infiltration structure to convey high flows around the structure.

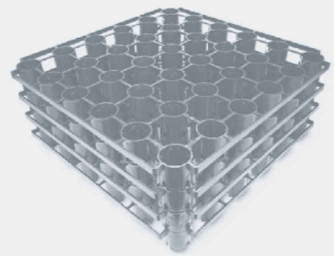
Draining Time: Infiltration structures should be designed to completely drain the water quality volume into the soil within 48 hours after the storm event and completely dewater between storms. A minimum draining time of 6 hours is recommended to ensure adequate pollutant removal. Standing water for longer than 5 days can lead to potential mosquito-breeding problems. Potential mosquito entry points should be sealed (adult female mosquitoes can use openings as small as 1/16 inch to access water for egg laying).

Infiltration Rate: The minimum acceptable field-measured soil infiltration rate is 0.3 inches per hour. Field-measured soil infiltration rates should not exceed 5.0 inches per hour. This generally restricts application to soils of NRCS Hydrologic Soil Group A. Some Group B soils may be suitable if field-measured infiltration rates exceed 0.3 inches per hour.

Figure 11-S12-1 Examples of Underground Infiltration Systems

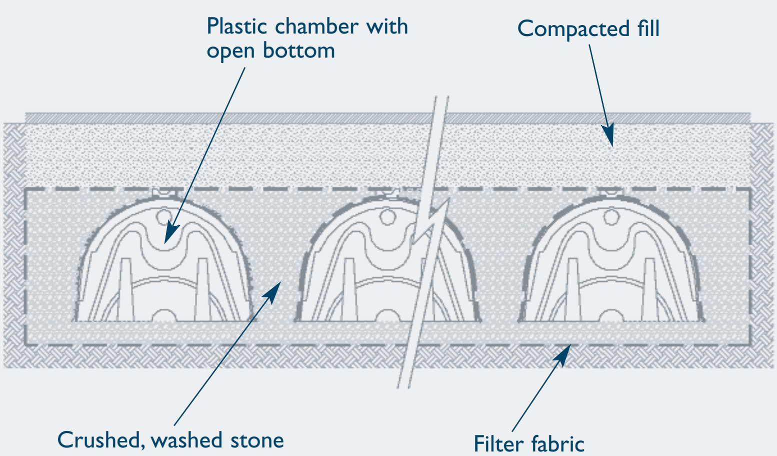
Modular Underground Infiltration System





Elevation

Underground Plastic Chamber System



Elevation

Source: Invisible Structures, Inc. and CULTEC, Inc.

Alum Injection

Source: Photo courtesy of Adell Donaghue.

Treatment Practice Type

Primary Treatment Practice	
Secondary Treatment Practice	●

Stormwater Management Benefits

Pollutant Reduction	
Sediment	Partial Benefit
Phosphorus	Partial Benefit
Nitrogen	Partial Benefit
Metals	Partial Benefit
Pathogens	Low or Unknown Benefit
Floatables	Low or Unknown Benefit
Oil and Grease	Low or Unknown Benefit
Dissolved Pollutants	Partial Benefit
Runoff Volume Reduction	
Runoff Capture	Significant Benefit
Groundwater Recharge	Significant Benefit
Stream Channel Protection	Significant Benefit
Peak Flow Control	Significant Benefit

Key: ■ Significant Benefit
■ Partial Benefit
□ Low or Unknown Benefit

Suitable Applications

Pretreatment	Significant Benefit
Treatment Train	Significant Benefit
Ultra-Urban	Significant Benefit
Stormwater Retrofits	Significant Benefit
Other	Significant Benefit

Description

Alum injection is the addition of aluminum sulfate (alum) solution to stormwater before discharging to a receiving water body or stormwater treatment practice. When alum is injected into stormwater it binds with suspended solids, metals, and phosphorus and forms aluminum phosphate and aluminum hydroxide precipitates. These precipitates settle out of the water column and are deposited in the bottom sediments in a stable, inactive state (referred to as "floc").

The injection of liquid alum into storm sewers has been used to reduce the water quality impacts of stormwater runoff to lakes and other receiving water bodies, particularly to reduce high phosphorus levels and address eutrophic conditions (EPA, 2002). Alum injection systems are commonly used in some parts of the country as stormwater retrofits for existing discharges to lakes and ponds, but may also be used as pretreatment for stormwater ponds and other treatment practices (ASCE, 2001). Alum addition should be considered only after all other best management practices have been implemented.

Reasons for Limited Use

- *Limited long-term performance data.*
- *Requires ongoing operation unlike most other stormwater treatment practices.*
- *Improper dosing of chemicals may have negative impacts on downstream water bodies.*
- *Increases the volume of sediment/floc (and associated pollutant concentrations) that must be disposed of.*
- *Typically not cost effective for drainage areas less than 50 acres.*
- *Alum application may be approved as part of a state stormwater permit or could require an individual state permit. The DEP Water Management Bureau should be contacted for further permit guidance.*

Suitable Applications

- *Best suited to situations where a large volume of water is stored in one area.*
- *As part of a stormwater treatment train or pretreatment step to further reduce turbidity and fine suspended solids.*
- *For existing stormwater discharges to existing ponds and lakes, particularly in highly developed areas, where new stormwater treatment practices or other treatment options are not feasible.*

Design Considerations

Design: Alum injection systems typically consist of a flow-weighted dosing system designed to fit inside a storm sewer manhole, remotely located alum storage tanks, and a downstream pond or treatment practice that allows alum and pollutants to settle out (EPA, 2002). Alum dosage rates generally range between 5 and 10 milligrams per liter of alum solution and are determined on a flow-weighted basis during storm events. Lime is often added to raise the pH (between 8 and 11) and enhance pollutant settling. Jar testing is recommended to determine alum dosing rates and the need for pH control. Injection points in the storm drainage system should be approximately 100 feet upstream of the discharge point (ASCE, 2001). In addition to the settling pond, a separate floc collection pump-out facility is recommended to reduce the chance of resuspension and transport of floc to receiving waters by pumping floc to the sanitary sewer or onto nearby upland areas (with appropriate local, state, and federal regulatory approval, as necessary).

Operation and Maintenance: Typical operation and maintenance requirements for alum injection systems include maintenance of pump equipment, power, chemical replacement, routine inspections, and equipment replacement (doser and pump-out facility). A trained operator should be on-site to adjust the chemical dosage and regulate flows, if necessary. Alum injection systems also require continued monitoring of water quality to detect potential negative impacts to receiving waters. The settling basin or pond should be dredged periodically to dispose of accumulated floc.

Cost Considerations: Alum injection is a relatively expensive and labor-intensive treatment practice. Construction costs depend on watershed size and the number of outfalls treated, but construction costs generally range from $135,000 to $400,000. Due to the high construction cost, alum injection is not cost effective for drainage areas less than 50 acres. Operation and maintenance costs can vary from $6,500 to $50,000 per year depending on the size of the system (Harper and Herr, 1996).

References

American Society of Civil Engineers (ASCE). 2001. *A Guide for Best Management Practice (BMP) Selection in Urban Developed Areas*. Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices. Reston, Virginia.

Harper, H.H. and J.L. Herr. 1996. *Alum Treatment of Stormwater Runoff: The First Ten Years*. Environmental Research and Design. Orlando, Florida.

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