Chapter

3.0

Performance Criteria for Urban BMP Design

3.0 Performance Criteria for Urban BMP Design

This chapter outlines performance criteria for five groups of structural water quality stormwater BMPs that include ponds, wetlands, infiltration practices, filtering systems and open channels.

Each set of BMP performance criteria, in turn, is based on six factors:

- General Feasibility
- Conveyance
- Pretreatment
- Treatment/Geometry
- Environmental/Landscaping
- Maintenance

One significant caveat applies to all performance criteria. The criteria represent a set of conditions that ensure an effective and durable BMP. In this chapter, *Mandatory* performance criteria are distinguished from suggested design criteria (the former is required at all sites in Maryland, while the latter are only recommended for most sites and conditions). Thus, in the text, mandatory performance criteria are indicated by *italics*, whereas suggested design criteria are shown in normal typeface.

IMPORTANT NOTES:

1) Any stormwater management BMP that uses an embankment for impounding water is required to follow the latest version of the NRCS-MD 378 Pond Code Standards And Specifications For Small Pond Design (Appendix B.1) and obtain approval from the local Soil Conservation District (SCD) or appropriate review authority.

2) In USE III watersheds, temperature increases caused by development are a primary impact to the quality of receiving waters. Stormwater BMPs may contribute to this problem. Therefore, to minimize temperature increases caused by new development in USE III watersheds, stormwater BMP designs should:
   a) Minimize permanent pools,
   b) Limit extended detention times for Cp_v to 12 hours (see Appendix D.11),
   c) Provide shading for pools and channels,
   d) Maintain existing forested buffers, and
   e) Bypass available baseflow and/or springflow.

Section 3.1 Stormwater Ponds

Definition: Practices that have a permanent pool, or a combination of extended detention or shallow wetland with a permanent pool equivalent to the entire WQ_v. Design variants include:

- P-1 micropool extended detention pond (Figure 3.1)
- P-2 wet pond (Figure 3.2)
- P-3 wet extended detention pond (Figure 3.3)
- P-4 multiple pond system (Figure 3.4)
- P-5 pocket pond (Figure 3.5)

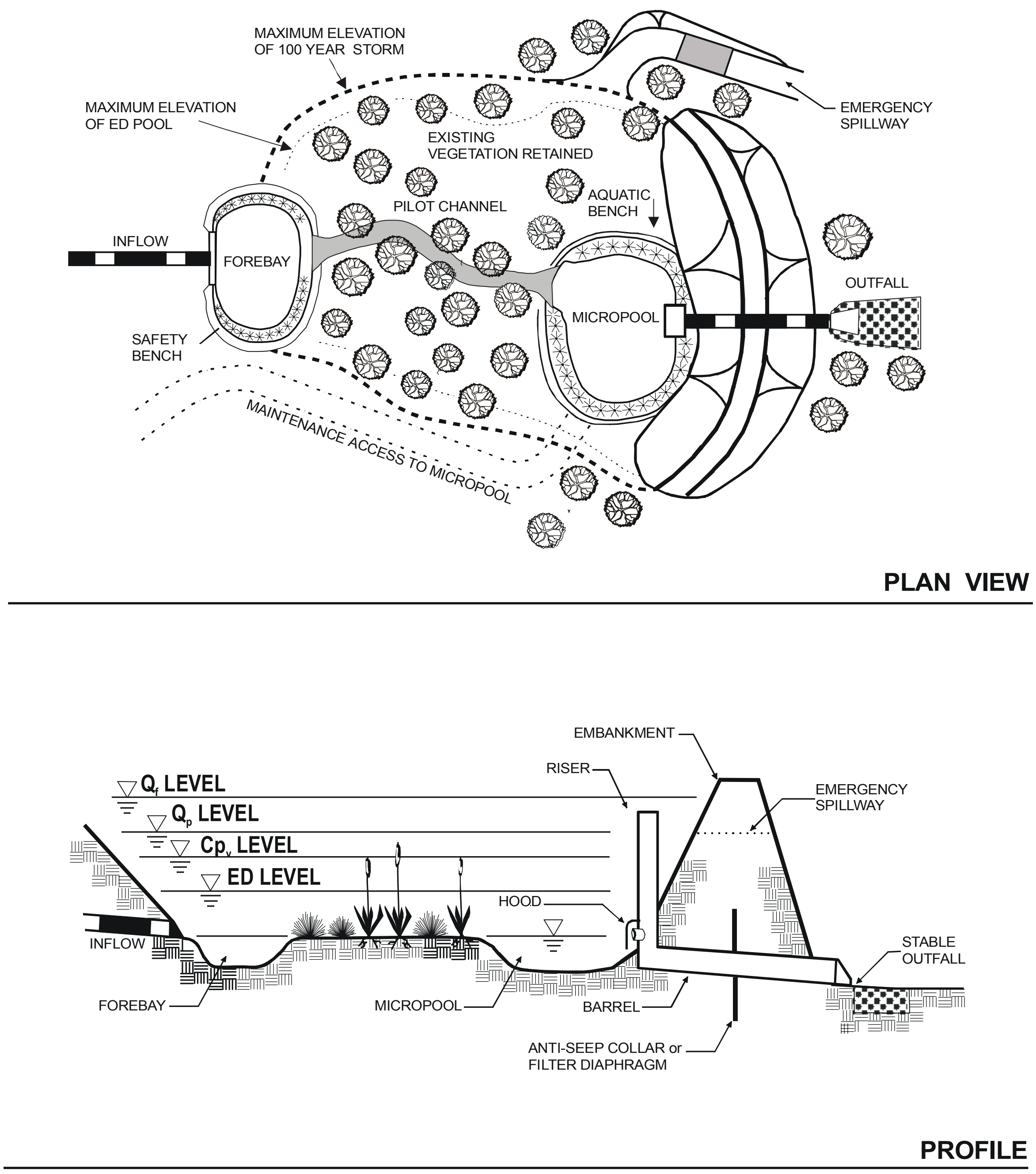
The term "pocket" refers to a pond or wetland that has such a small contributing drainage area that little or no baseflow is available to sustain water elevations during dry weather. Instead, water elevations are heavily influenced and, in some cases, maintained by a locally high water table.

Dry extended detention ponds that have no permanent pool are not considered an acceptable option for meeting WQ_v.

Stormwater ponds may also provide storage for the Cp_v, Q_p and/or Q_f above the WQ_v storage elevation.

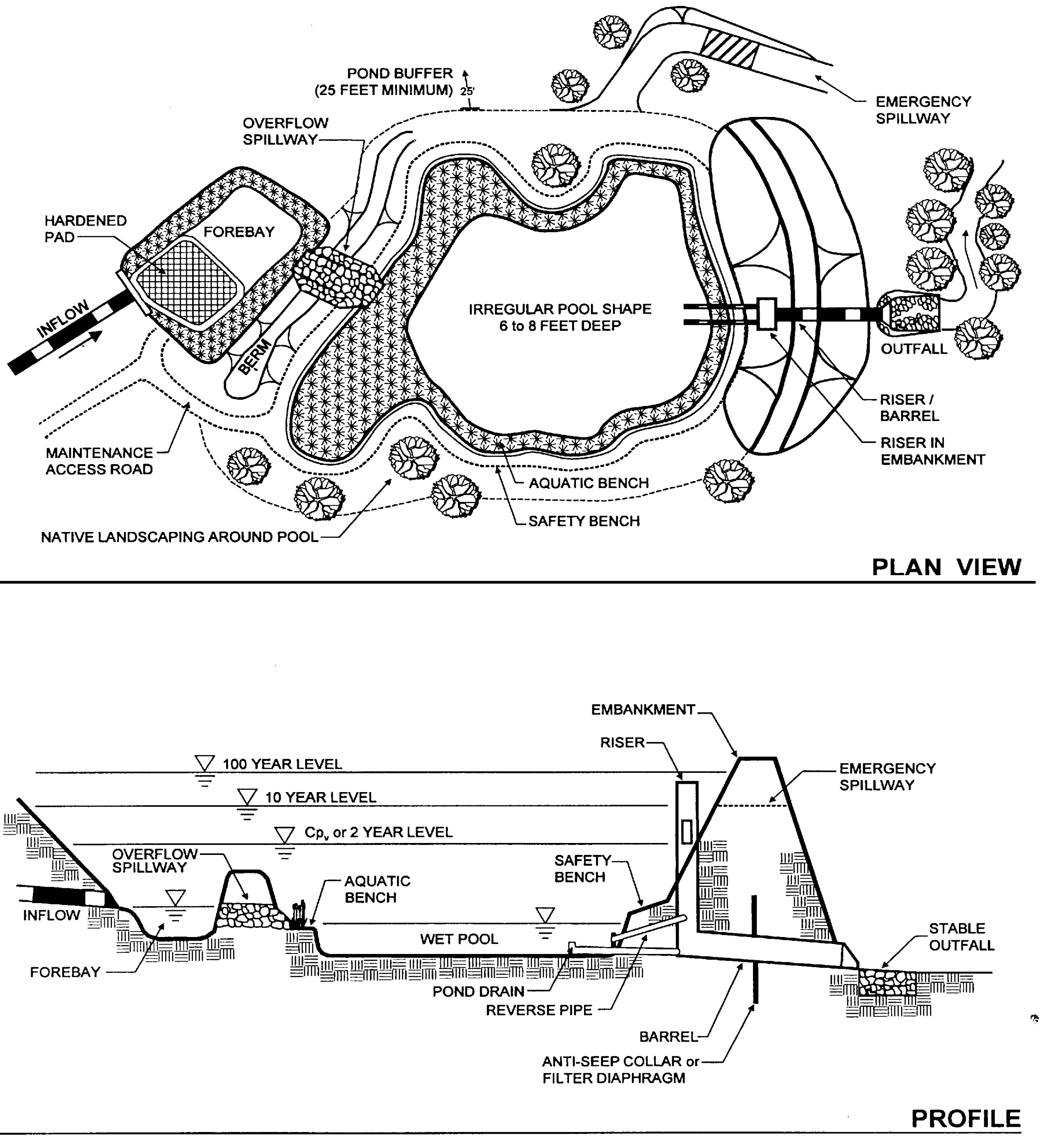
IMPORTANT NOTE: Any stormwater management BMP that uses an embankment for impounding water is required to follow the latest version of the NRCS-MD 378 Pond Code Standards And Specifications For Small Pond Design (Appendix B.1) and obtain approval from the local Soil Conservation District (SCD) or appropriate review authority.

P-1	**Figure 3.1** Example of “Micropool” Extended Detention Pond	P-1



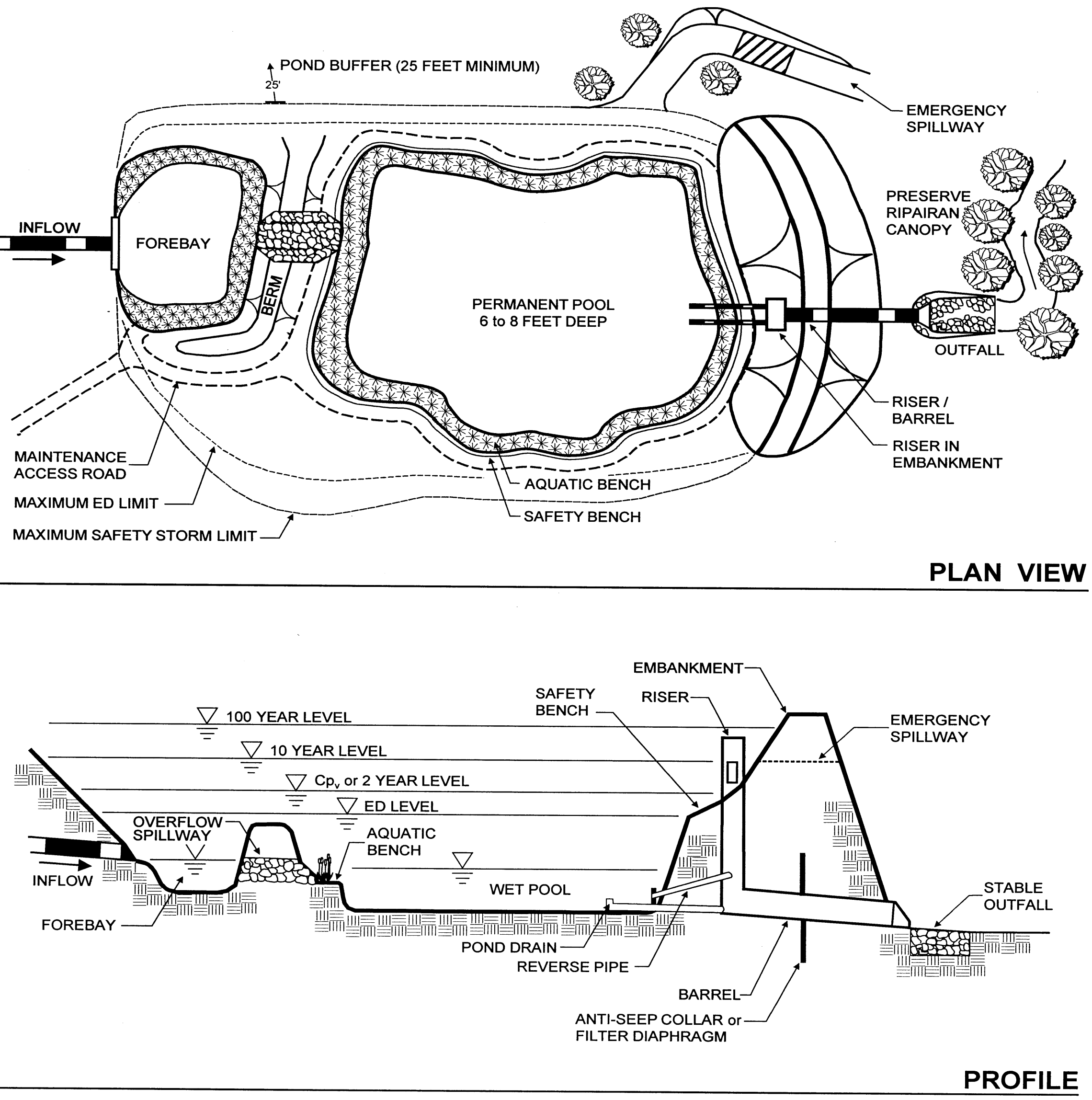
A micropool is provided in an extended detention pond to prevent resuspension of previously settled sediments and prevent clogging of the low flow orifice.

P-2	Figure 3.2 Example of Wet Pond	P-2



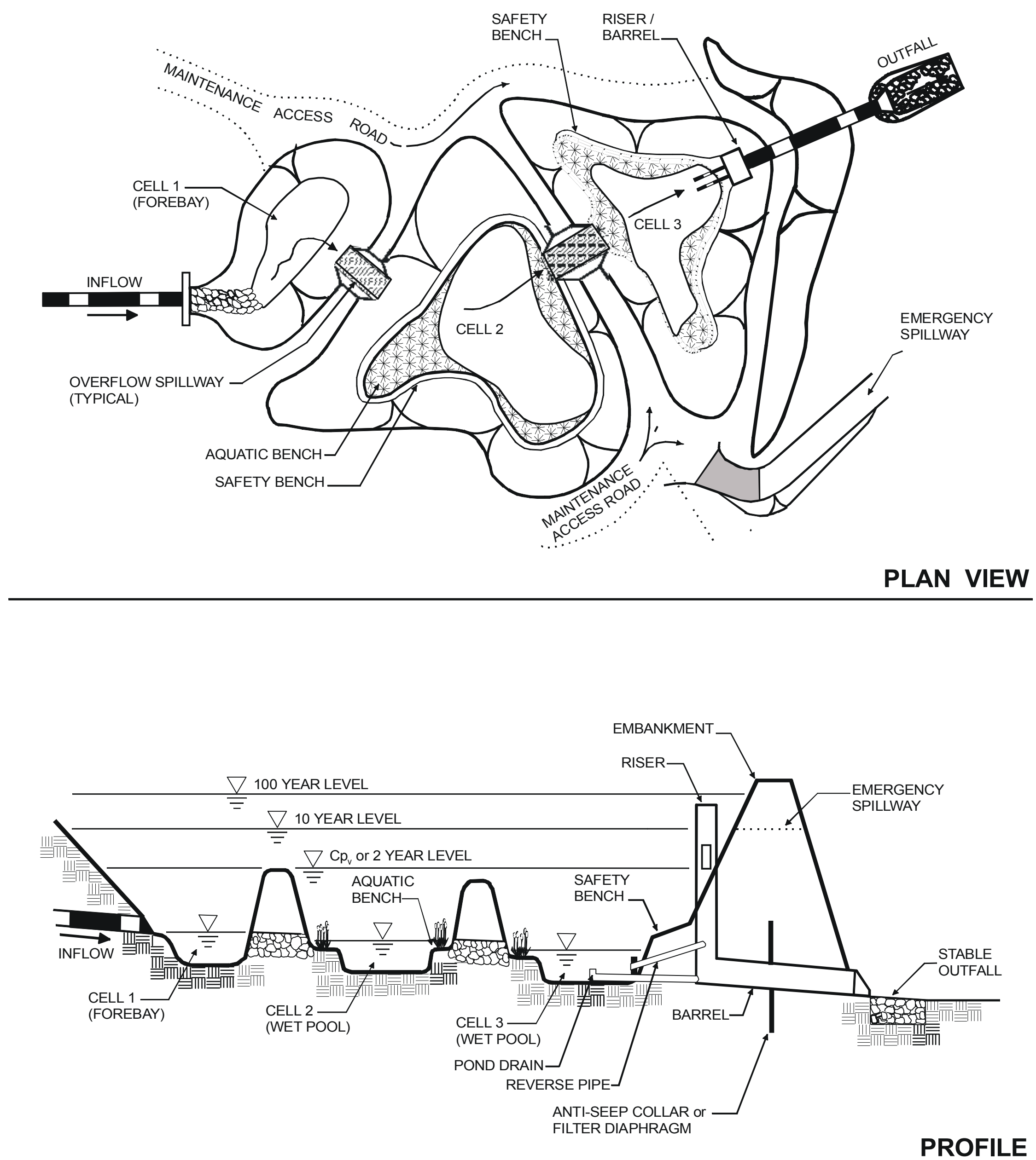
A wet pond provides all of water quality volume storage in a permanent pool.

P-3	**Figure 3.3** Example of Wet Extended Detention Pond	P-3



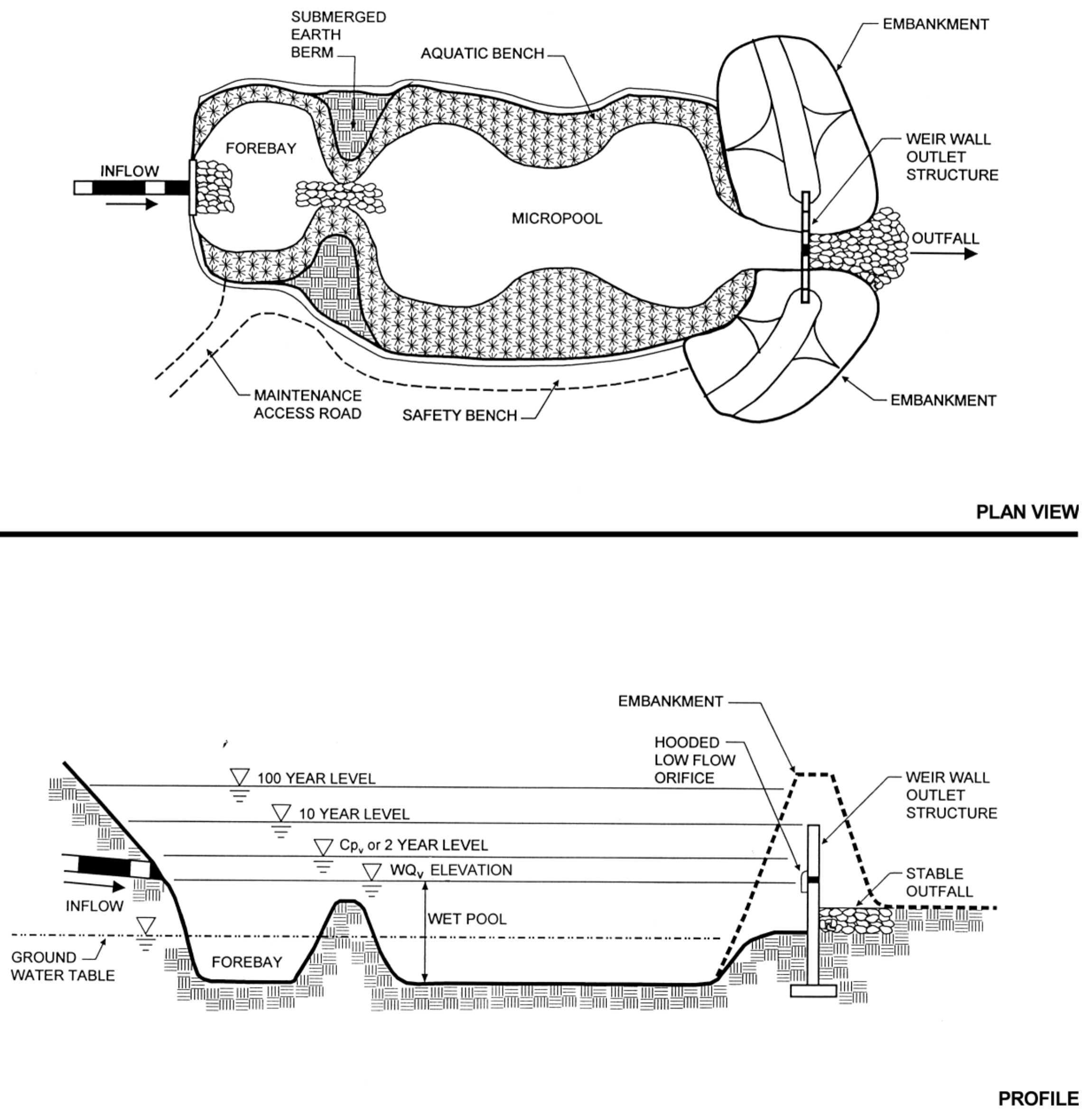
The wet ED pond provides water quality storage through a combination of permanent pool and extended detention storage.

P-4	**Figure 3.4** Example of Multiple Pond System	P-4



Multiple pond systems provide WQ_v storage in two or more cells that create longer pollutant removal pathways.

P-5	**Figure 3.5** Example of Pocket Pond	P-5



A high water table or groundwater interception maintains permanent pool level in a pocket pond. However, excavation to groundwater interception should be avoided where the land uses draining to the pond may contaminate drinking water supplies.

3.1.1 Pond Feasibility Criteria

Stormwater ponds shall have a minimum contributing drainage area of ten acres or more (25 or more are preferred)*, unless groundwater is confirmed as the primary water source (e.g., pocket pond).*

Stormwater ponds cannot be located within jurisdictional waters, including wetlands, without obtaining a Section 404 permit under the Clean Water Act and a State of Maryland wetlands and waterway permit (See Chapter 4, Section 4.6.).

Stormwater ponds located within USE III watersheds shall require a small pond review and approval from the MDE Dam Safety Division.

The use of stormwater ponds on coldwater streams capable of supporting trout (Use III and IV) may be prohibited. Stormwater ponds located in Use III and IV watersheds should be designed to significantly reduce and/or eliminate thermal impacts (See Chapter 4, Section 4.1).

The design and construction of stormwater management ponds are required to follow the latest version of the NRCS-MD 378 Pond Code Standards and Specifications for Small Pond Design (Appendix B.1) and obtain approval from the local Soil Conservation District (SCD) or appropriate review authority.

Pages 1 and 2 of the NRCS-MD 378 Pond Code Standards and Specifications for Small Pond Design (MD-378) describe the conditions for exemption from formal review by the local SCD. **While not required to meet all conditions of MD-378, facilities that are exempt shall be approved by the appropriate authority and conform to the following minimum design and construction criteria:**

1) *design for a stable outfall using the ten year design storm (or two year design storm if the pond is an off-line structure providing* WQ_v *storage only).*

2) *dams shall meet class A dam safety hazard classification,*

3) *principal spillway/riser shall provide anti-floatation, anti-vortex, and trash-rack designs.*

4) *one (1) foot of freeboard shall be provided above the design high water for the 10 year storm.*

5) *material and construction specifications for the principal spillway shall be in accordance with MD 378 code.*

6) *material and construction specifications for the embankment shall be in accordance with MD 378 code, except that fill material for the embankment shall conform to Unified Soil Classification GC, SC, SM, MH, ML, CH, or CL, and no cutoff trench is required.*

7) *woody vegetation is prohibited on the embankment.*

A pond structure requires review and approval by the MDE Dam Safety Division if any of the following conditions apply:

a) *the proposed embankment is twenty feet or greater in height from the upstream toe to the top of dam, or*

b) *the contributing drainage area is a square mile (640 acres) or greater, or*

c) *the structure is classified as "high" or "intermediate" hazard, according to the MD Dam Safety Manual, or*

d) *the proposed pond is in USE III waters.*

3.1.2 Pond Conveyance Criteria

When reinforced concrete pipe is used for the principal spillway to increase its longevity, "O-ring" gaskets (ASTM C-361) should be used to create watertight joints and should be inspected during installation.

Inlet Protection

Inlet pipes to the pond should not be fully submerged at normal pool elevations.

A forebay shall be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond.

Adequate Outfall Protection

Flared pipe sections that discharge at or near the stream invert or into a step-pool arrangement should be used at the spillway outlet.

The channel immediately below the pond outfall shall be modified to prevent erosion and conform to natural dimensions in the shortest possible distance, typically by use of large rip-rap placed over filter cloth.

A stilling basin or other outlet protection should be used to reduce flow velocities from the principal spillway to non-erosive velocities (see Appendix D.12 for critical non-erosive velocities for grass and soil).

If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided to reduce stream warming.

Pond Liners

When a pond is located in karst topography, gravelly sands or fractured bedrock, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include: (a) 6 to 12 inches of clay soil (minimum 15% passing the #200 sieve and a maximum permeability of 1 x 10^{-5} cm/sec), (b) a 30 mil poly-liner, (c) bentonite, (d) use of chemical additives (see NRCS Agricultural Handbook No. 387, dated 1971, Engineering Field Manual), or (e) other suitable materials approved by the appropriate review authority.

3.1.3 Pond Pretreatment Criteria

Sediment Forebay

Each pond shall have a sediment forebay or equivalent upstream pretreatment. The forebay shall consist of a separate cell, formed by an acceptable barrier.

The forebay shall be sized to contain 0.1 inches per impervious acre of contributing drainage. The forebay storage volume counts toward the total WQ_v requirement. Exit velocities from the forebay shall be non-erosive.

Direct maintenance access for appropriate equipment shall be provided to the forebay.

The bottom of the forebay may be hardened (e.g., using concrete, paver blocks, etc.) to make sediment removal easier.

A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time.

3.1.4 Pond Treatment Criteria

Minimum Water Quality Volume (WQ_v)

Ponds shall be designed to capture and treat the computed WQ_v through any combination of permanent pool, extended detention (ED) or wetland. If treated separately, the Re_v may be subtracted from the WQ_v for pond design.

It is generally desirable to provide water quality treatment off-line when topography, head and space permit (e.g., apart from stormwater quantity storage).

Water quality storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and wetland).

If ED is provided in a pond, storage for WQ_v and Cp_v shall be computed and routed separately (e.g., the WQ_v requirement cannot be met simply by providing Cp_v storage for the one-year storm).

Minimum Pond Geometry

Flowpaths from inflow points to outlets shall be maximized. Flowpaths of 1.5:1 (length relative to width) and irregular shapes are recommended.

3.1.5 Pond Landscaping Criteria

Pond Benches

The perimeter of all deep permanent pool areas (four feet or greater in depth) shall be surrounded by two benches with a combined minimum width of 15 feet:

- *A safety bench* that extends outward from the normal water edge to the toe of the pond side slope. The maximum slope of the safety bench shall be 6%.

- *An aquatic bench* that extends inward from the normal shoreline and has a maximum depth of eighteen inches below the normal pool water surface elevation. An aquatic bench is not required in forebays.

Landscaping Plan

A landscaping plan for a stormwater pond and its buffer shall be prepared to indicate how aquatic and terrestrial areas will be vegetatively stabilized and established. Landscaping guidance for stormwater ponds is provided in Appendix A.

Wherever possible, wetland plants should be encouraged in a pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes (emergent wetlands) or within shallow areas of the pool itself.

The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within six inches (plus or minus) of the normal pool.

The soils of a pond buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration, and therefore, may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites, and backfill these with uncompacted topsoil.

As a rule of thumb, planting holes should be at least six inches larger than the diameter of the rootball (of balled and burlap stock), and three inches wider for container grown stock. This practice should enable the stock to develop unconfined root systems. Avoid species that require full shade, are susceptible to winterkill, or are prone to wind damage. Extra mulching around the base of the tree or shrub is strongly recommended as a means of conserving moisture and suppressing weeds.

Pond Buffers and Setbacks

A pond buffer should be provided that extends 25 feet outward from the maximum water surface elevation of the pond. The pond buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers). An additional setback may be provided to permanent structures.

Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers.

Woody vegetation may not be planted on nor allowed to grow within 15 feet of the toe of the embankment and 25 feet of the principal spillway structure.

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.

3.1.6 Pond Maintenance Criteria

Maintenance Measures

Maintenance responsibility for a pond and its buffer shall be vested with a responsible party by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval or local permitting processes.

The principal spillway shall be equipped with a trash rack that provides access for maintenance.

Sediment removal in the forebay shall occur when 50% of the total forebay capacity has been lost.

Sediments excavated from stormwater ponds that do not receive runoff from designated hotspots are not considered toxic or hazardous material and can be safely disposed by either land application or land filling. Sediment testing may be required prior to sediment disposal when a hotspot land use is present.

Sediment removed from stormwater ponds should be disposed of according to current erosion and sediment control regulations.

Maintenance Access

A maintenance right-of-way or easement shall extend to a pond from a public or private road.

Maintenance access should be at least 12 feet wide; have a maximum slope of no more than 15%; 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

The low flow orifice shall have a minimum diameter of 3 inches and shall be adequately protected from clogging by an acceptable external trash rack. Two examples of approved external trash racks are provided in Detail No. 1 and 2 of Appendix D.8. *The low flow orifice diameter may be reduced to one inch if an internal orifice is used* (e.g., an over-perforated vertical standpipe that is protected by hardware cloth and a stone filtering jacket). A schematic design of an acceptable internal orifice protection design is provided in Detail No. 3 of Appendix D.8.

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 corrugated metal pipe (CMP) or similar device that extends at least 12 inches below the normal pool. (See Detail No. 7 of Appendix D.8.)

The use of horizontal perforated pipe protected by geotextile and gravel is not recommended.

Vertical pipes may be used as an alternative if a permanent pool is present.

Riser

The riser shall be located within the embankment for maintenance access, safety and aesthetics.

Access to the riser is to be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls. Riser openings should be fenced with pipe or rebar to prevent trash accumulation.

Pond Drain

Each pond shall have a drain pipe that can completely or partially drain the pond within 24 hours. This requirement is waived for the Lower Eastern Shore where positive drainage is difficult to achieve due to very low relief.

Care should be exercised during pond drawdowns to prevent downstream discharge of sediments or anoxic water and slope instability caused by rapid drawdown.

The approving jurisdiction shall be notified before draining a pond.

Valves

The pond drain shall be equipped with an adjustable valve (typically a handwheel activated knife or gate valve).

The pond drain should be sized one pipe size greater than the calculated design diameter.

Valve controls shall be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner.

To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step or other fixed object.

Safety Features

Fencing of ponds is not generally desirable but may be required by the local review authority. A preferred method is to manage the contours of the pond to eliminate dropoffs and other safety hazards.

Internal side slopes to the pond should not exceed 3:1 (h:v) and should terminate on a safety bench. Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool. The bench requirement may be waived if slopes are 4:1 or gentler.

Riser openings shall not permit unauthorized access. Riser tops that are four feet or greater above the ground shall include railings for safety. Endwalls above pipe outfalls greater than 48 inches in diameter shall be fenced to prevent injury.

Warning signs prohibiting swimming and skating should be posted.

Section 3.2 Stormwater Wetlands

Definition: Practices that create shallow wetland areas to treat urban stormwater and often incorporate small permanent pools and/or extended detention storage to achieve the full WQ_v. Design variants include:

- W-1 shallow wetland (Figure 3.6)
- W-2 ED shallow wetland (Figure 3.7)
- W-3 pond/wetland system (Figure 3.8)
- W-4 pocket wetland (Figure 3.9)

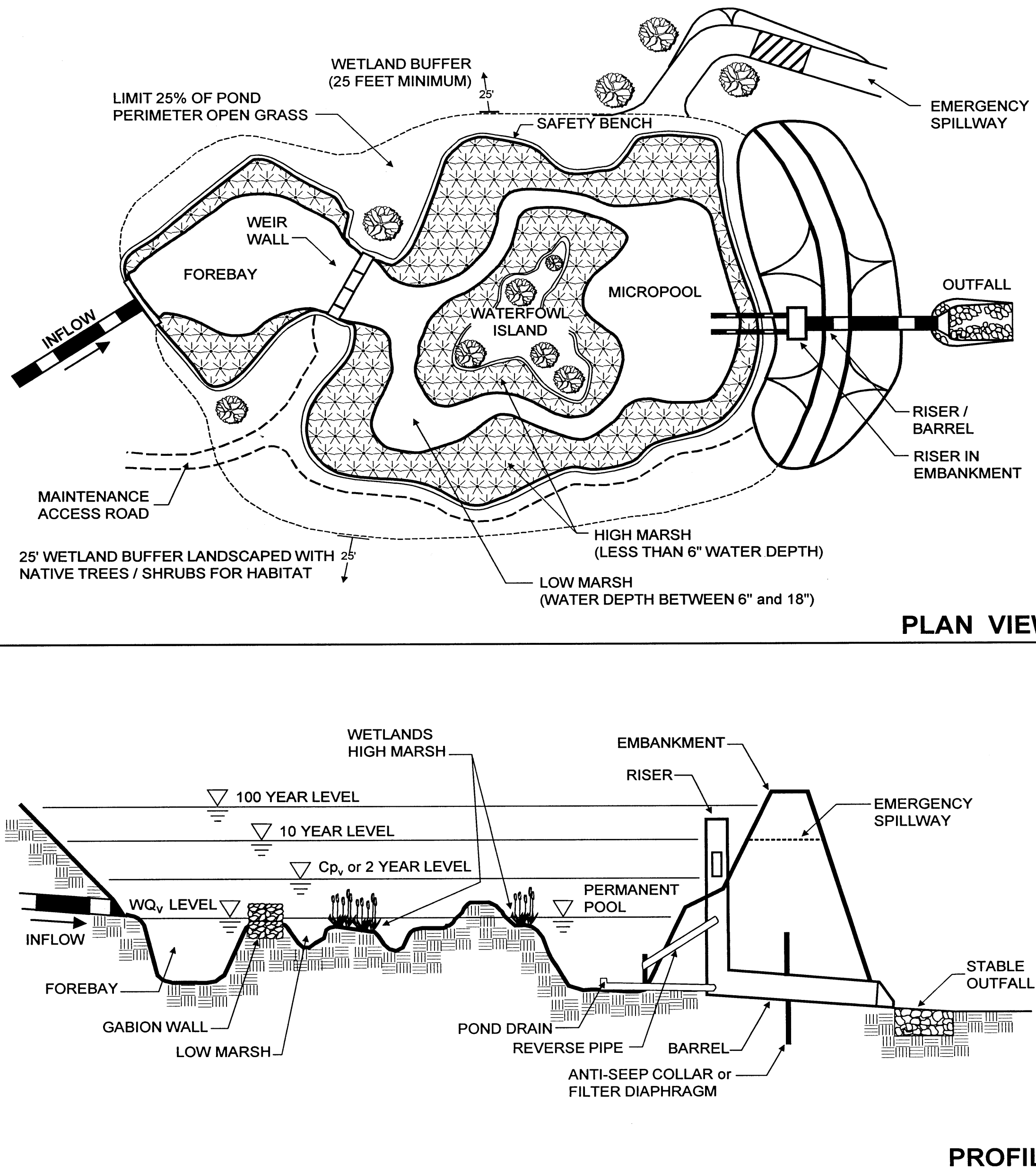
Stormwater wetlands may also provide Cp_v and Q_p storage above the WQ_v storage.

IMPORTANT NOTES:

1) Except for specific minimum contributing drainage area and the use of these practices in coldwater streams (USE III AND IV), all of the pond performance criteria presented in section 3.1 also apply to the design of stormwater wetlands. Additional criteria that govern the geometry and establishment of created wetlands are presented in this section.

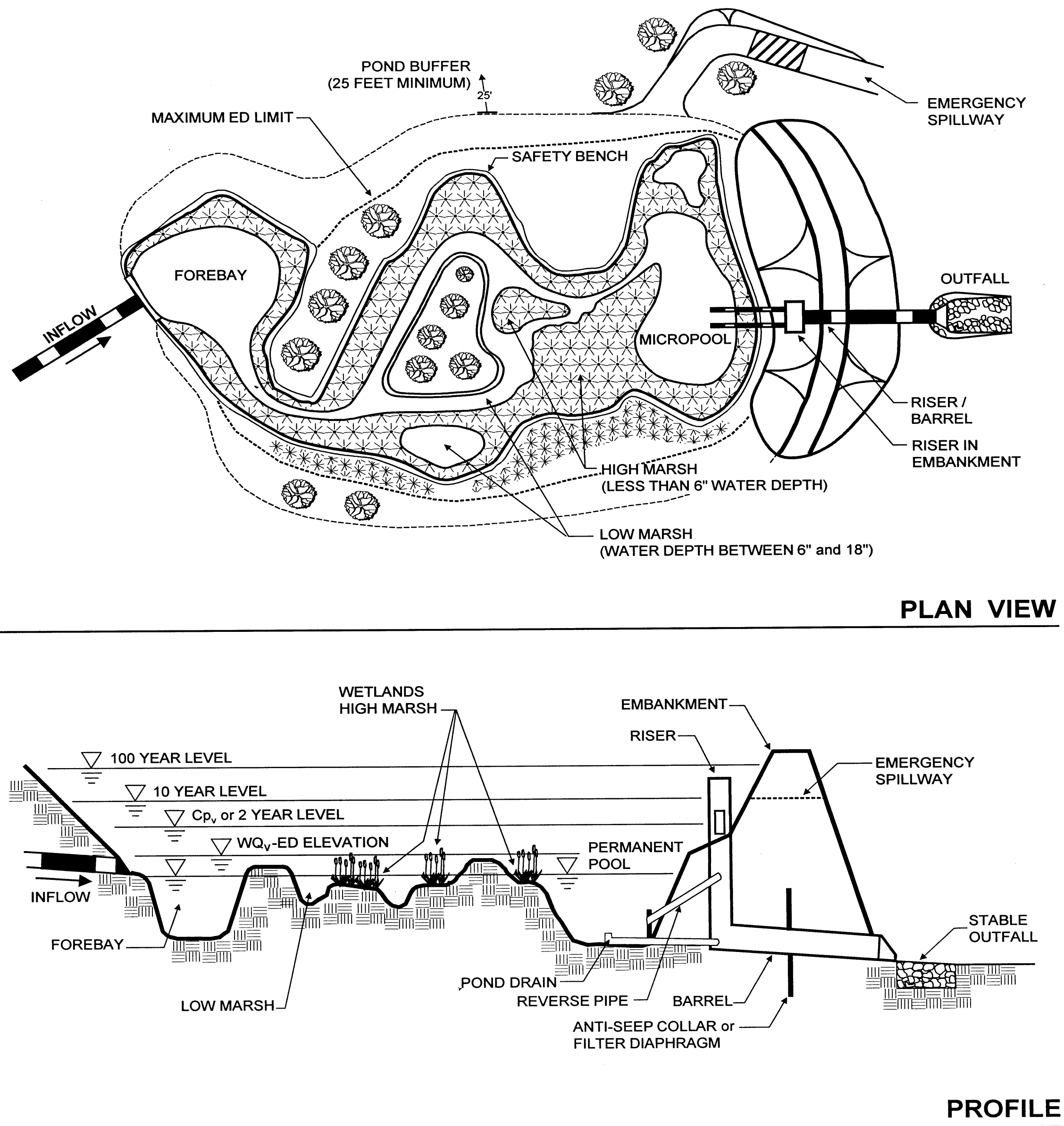
2) Any stormwater management BMP that uses an embankment for impounding water is required to follow the latest version of the NRCS-MD 378 Pond Code Standards And Specifications For Small Pond Design (Appendix B.1) and obtain approval from the local SCD or appropriate review authority.

W-1	**Figure 3.6** Example of Shallow Wetland	W-1



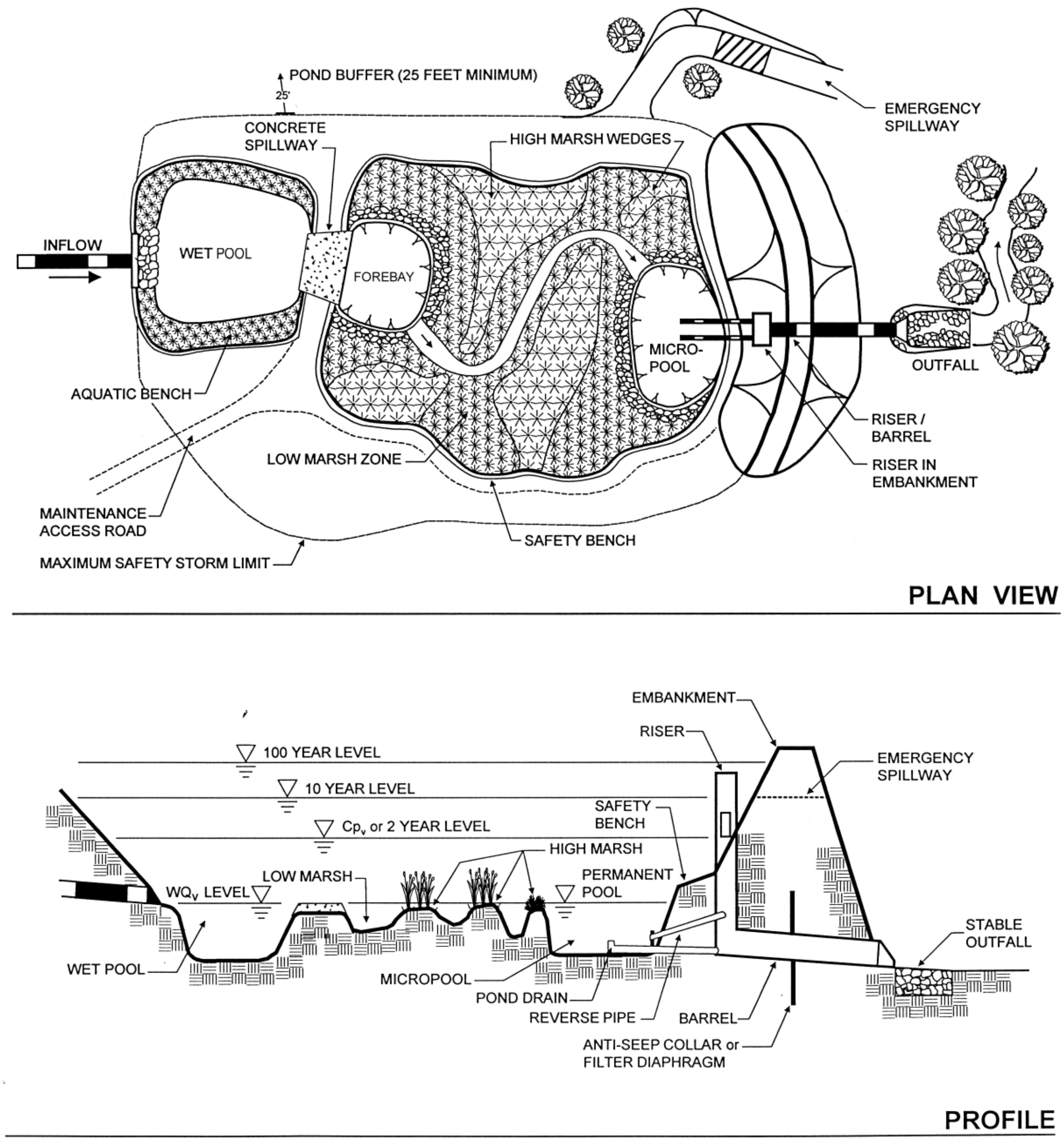
Shallow wetlands provide WQ_v in a shallow pool that has a large surface area.

W-2	**Figure 3.7** Example of Extended Detention Shallow Wetland	W-2



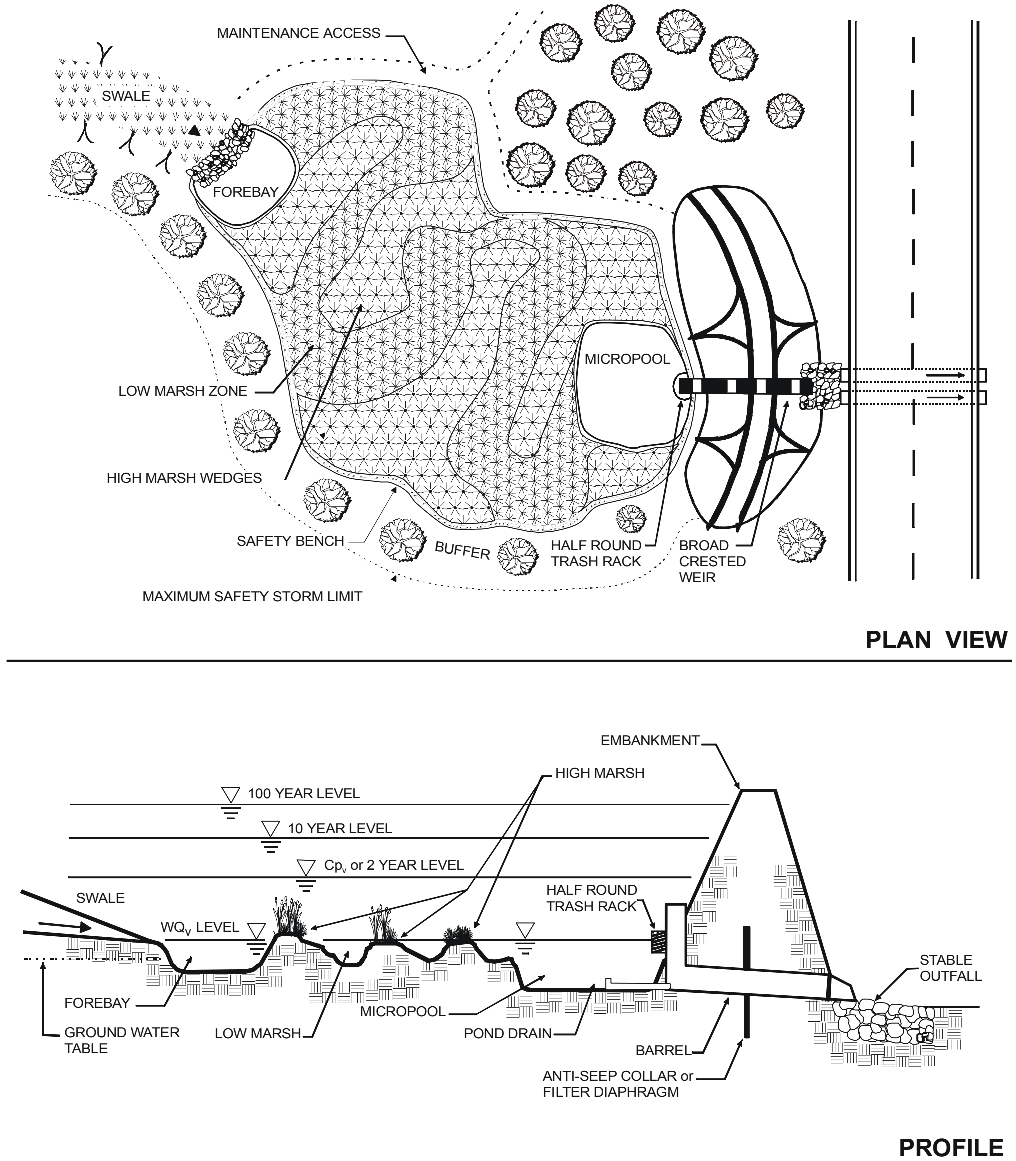
ED shallow wetlands provide water quality storage by a combination of shallow wetland pool and extended detention storage.

W-3	**Figure 3.8** Example of Pond/Wetland System	W-3



In this BMP, a deep permanent pool is placed before the shallow wetland.

W-4	**Figure 3.9** Example of Pocket Wetland	W-4



A high water table or groundwater interception helps maintain the shallow wetland pool in a pocket wetland.

3.2.1 Wetland Feasibility Criteria

A water balance must be performed to demonstrate that a stormwater wetland can withstand a thirty day drought at summer evaporation rates without completely drawing down. See Appendix D.3 for a shortcut assessment method for determining the adequacy of water balance.

Stormwater wetlands may not be located within jurisdictional waters, including wetlands without obtaining a Section 404 permit and/or State of Maryland wetlands and waterways permit (see Chapter 4, Section 4.6.).

In USE III watersheds, stormwater wetlands that include permanent ponds as an integral design component [e.g., pond/wetland systems (W-3)] may require a small pond review and approval from the MDE Dam Safety Division (see Appendix B.1.2).

3.2.2 Wetland Conveyance Criteria

Flowpaths from inflow points to outflow points within stormwater wetlands shall be maximized. Flowpaths of 1.5:1 (length relative to width) and irregular shapes are recommended. These paths may be achieved by constructing internal berms (e.g., high marsh wedges or rock filter cells). Microtopography is encouraged to enhance wetland diversity.

3.2.3 Wetland Pretreatment Criteria

Sediment regulation is critical to sustaining stormwater wetlands. Consequently, *a forebay shall be located at the inlet and a micropool shall be located at the outlet.* Forebays are designed in the same manner as ponds (see Section 3.1.3). A micropool is a three to six foot deep pool used to protect the low flow pipe from clogging and prevent sediment resuspension. Forebays in Use III watersheds should be designed to drain within 24 hours.

3.2.4 Wetland Treatment Criteria

The surface area of the entire stormwater wetland shall be at least one percent of the total drainage area to the facility (1.5% for the shallow wetland design).

At least 25% of the total WQ_v shall be in deepwater zones with a minimum depth of four feet (the forebay and micropool may meet this criteria). This criteria may be reduced if the wetland is located where thermal impacts are a primary concern (e.g., Use III watersheds).

A minimum of 35% of the total surface area shall have a depth of six inches or less and at least 65% of the total surface area shall be shallower than 18 inches.

The bed of the wetland should be graded to create a maximum internal flowpath and microtopography.

If extended detention is utilized in a stormwater wetland, *the ED volume shall not comprise more than 50% of the total wetland design, and the maximum water surface elevation shall not extend more than three feet above the normal pool.* Q_p and/or Cp_v storage can be provided above the maximum WQ_v elevation within the wetland.

To promote greater nitrogen removal, rock beds may be used as a medium for the growth of wetland plants. The rock should be one to three inches in diameter and placed up to the normal pool elevation. Rock beds should also be open to flow-through from either direction.

3.2.5 Wetland Landscaping Criteria

A landscaping plan shall be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of pondscaping zones, selection of corresponding plant species, planting configuration, and sequence for preparing wetland bed (including soil amendments, if needed).

Landscaping plans for stormwater wetlands located within Use III and IV watersheds should incorporate features and plant species commonly found in wooded wetlands.

Structures such as fascines, coconut rolls, or straw bales can be used to create shallow marsh cells in high energy areas of the stormwater wetland.

The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers.

A wetland buffer should extend 25 feet outward from the maximum water surface elevation with an additional 15 foot setback to structures.

Wetland Establishment Guidance

The most common and reliable technique for establishing an emergent wetland community in a stormwater wetland is to transplant nursery stock obtained from local aquatic plant nurseries. The following guidance is suggested when transplants are used to establish a wetland.

The transplanting window extends from early April to mid-June. Planting after these dates is not recommended, as the wetland plants need a full growing season to build the root reserves needed to get through the winter. If at all possible, the plants should be ordered at least three months in advance to ensure the availability of the desired species.

The optimal depth requirements for several common species of emergent wetland plants are often six inches of water or less.

To add diversity to the wetland, 5 to 7 species of emergent wetland plants should be used, drawn from the suggested species listed in Appendix A. Of these, at least three species should be selected from the "aggressive colonizer" group (e.g., bulrush, pickerelweed, arrow arum, three square and rice cutgrass) (MDE, 1986).

The wetland area should be sub-divided into separate planting zones of more or less constant depth. Approximately half the wetland surface area should be planted. One plant species should be planted within each flagged planting zone, based on their approximate depth requirements. Plants should be installed in clumps with individual plants located an average of 18 inches on center within each clump. Individual plants should be spaced 12 inches to 24 inches on center.

Post-nursery care of wetland plants is very important in the interval between delivery of the plants and their subsequent installation, as they are prone to desiccation. Stock should be frequently watered and shaded while on-site.

A wet hydroseed mix should be used to establish permanent vegetative cover in the buffer outside of the permanent pool. For rapid germination, scarify the soil to ½ inch prior to hydroseeding. Alternatively, red fescue or annual rye can be used as a temporary cover for the wet species.

Because most stormwater wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. At these sites, three to six inches of topsoil or wetland mulch should be added to all depth zones in the wetland from one foot below the normal pool to six inches above. Wetland mulch is preferable to topsoil if it is available.

The stormwater wetland should be staked at the onset of the planting season. Depths in the wetland should be measured to the nearest inch to confirm the original planting zones. At this time, it may be necessary to modify the pondscape plan to reflect altered depths or the availability of wetland plant stock. Surveyed planting zones should be marked on an “as-built” or design plan and located in the field using stakes or flags.

The wetland drain should be fully opened at least three days prior to the planting date (which should coincide with the delivery date for the wetland plant stock).

Wetland mulch is another technique to establish a plant community that utilizes the seedbank of wetland soils to provide the propagules for marsh development. The majority of the seedbank is contained within the upper six inches of the donor soils. The mulch is best collected at the end of the growing season. Best results are obtained when the mulch is spread 3 to 6 inches deep over the high marsh and semi-wet zones of the wetland (-6 inches to +6 inches relative to the normal pool).

Donor soils for wetland mulch shall not be removed from natural wetlands without proper permits.

3.2.6 Wetland Maintenance Criteria

If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, a reinforcement planting will be required

Stormwater wetlands that are created in upland areas and away from jurisdictional wetlands are not regulated under the appropriate federal and State laws as long as they are regularly maintained.

Section 3.3 Stormwater Infiltration

Definition: Practices that capture and temporarily store the WQ_v while allowing infiltration into the soil over a prescribed period. Design variants include:

- I-1 infiltration trench (Figure 3.10)
- I-2 infiltration basin (Figure 3.11)

Infiltration practices are an excellent technique for meeting the Re_v requirement and may also provide Cp_v and Q_p storage in certain limited cases.

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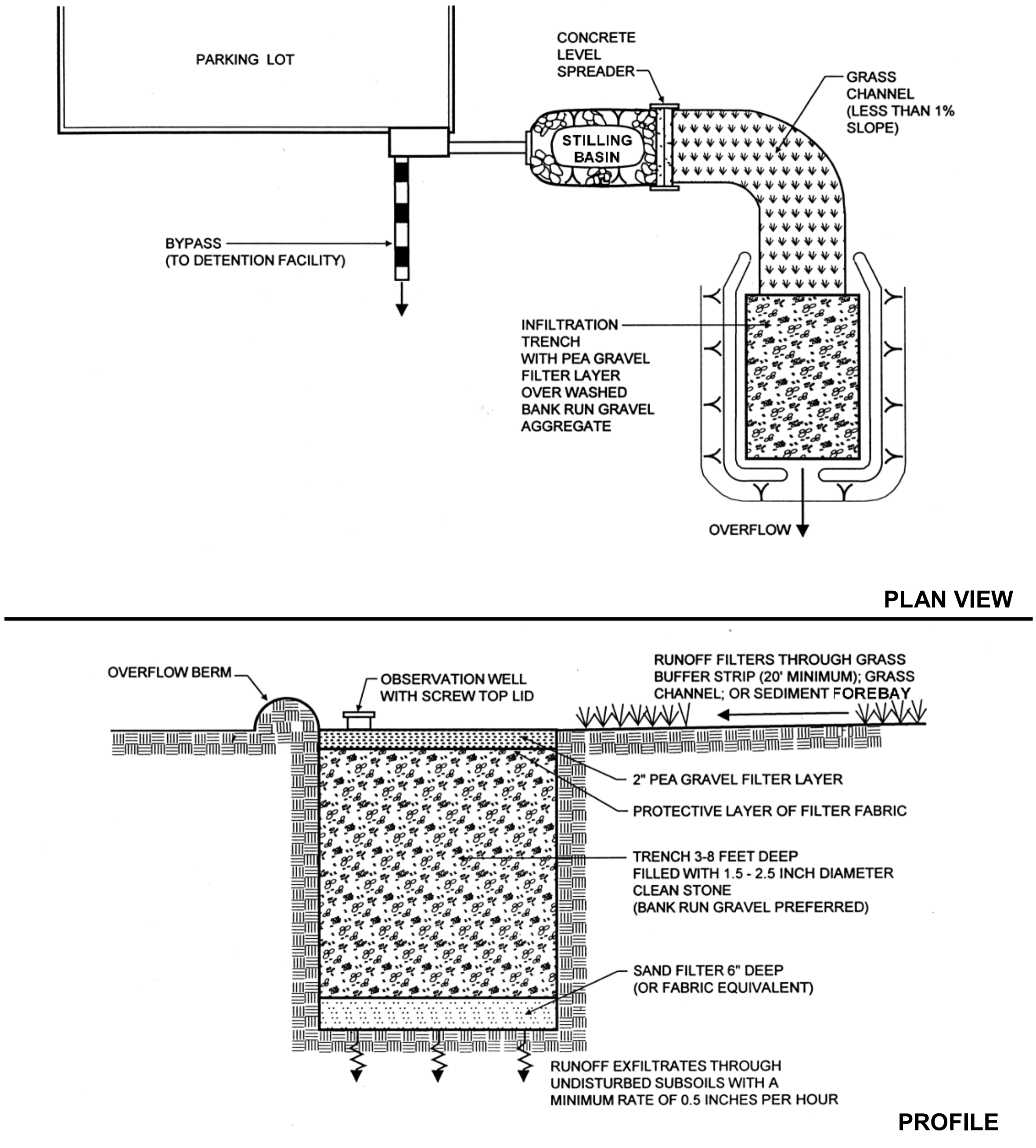
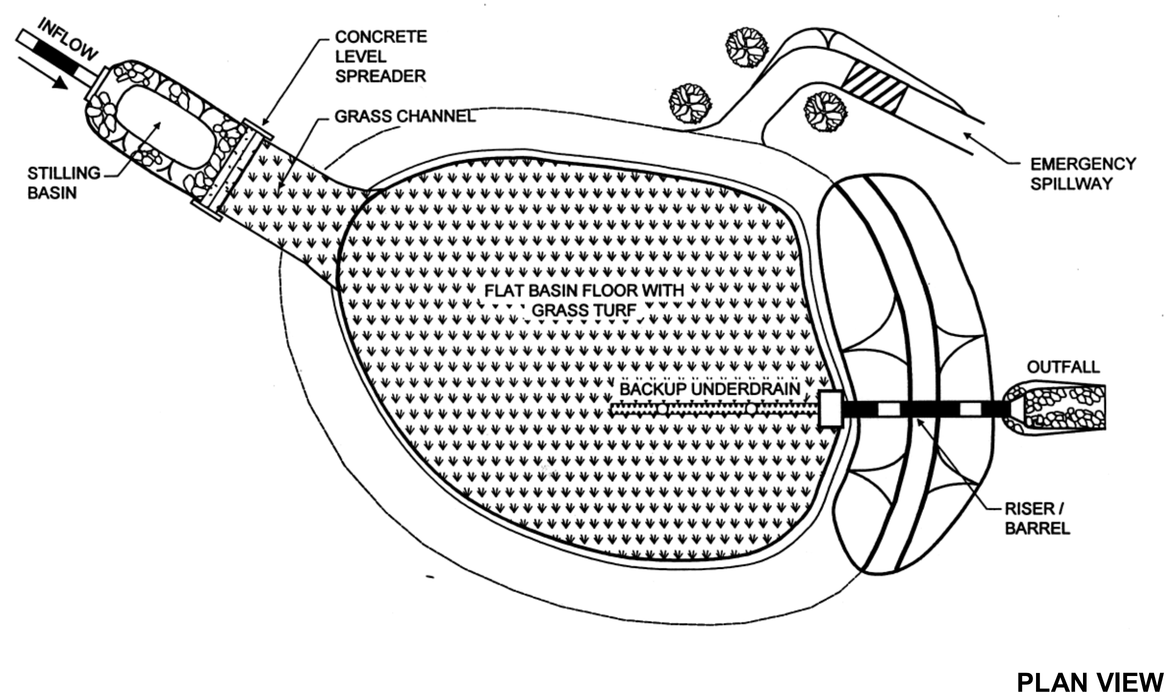
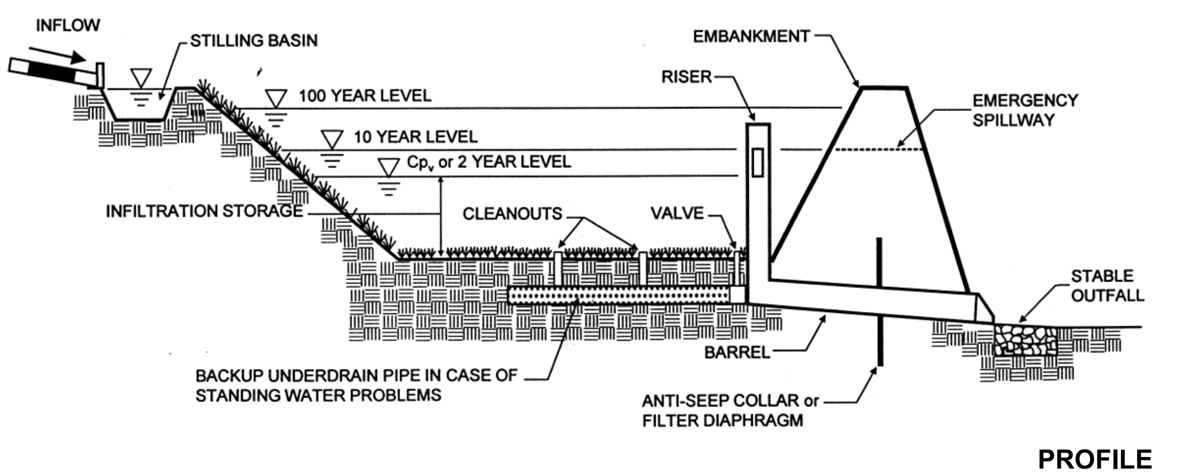
I-1	**Figure 3.10** Example of Infiltration Trench	I-1



The infiltration trench provides Re_v and WQ_v in one location.

I-2	**Figure 3.11** Example of Infiltration Basin	I-2





The WQ_v is retained in an infiltration basin, where it percolates through the floor of the basin in a two day period.

3.3.1 Infiltration Feasibility Criteria

To be suitable for infiltration, underlying soils shall have an infiltration rate (f) of 0.52 inches per hour or greater, as initially determined from NRCS soil textural classification and subsequently confirmed by field geotechnical tests. Approved geotechnical testing procedures for feasibility and design are outlined in Appendix D.1. The minimum geotechnical testing is one test hole per 5000 sf, with a minimum of two borings per facility (taken within the proposed limits of the facility).

Soils should also have a clay content of less than 20% and a silt/clay content of less than 40%.

Infiltration cannot be located on slopes greater than 15% or within fill soils.

To protect groundwater from possible contamination, runoff from designated hotspot land uses or activities cannot be infiltrated without proper pretreatment to remove hydrocarbons, trace metals, or toxicants. A list of designated stormwater hotspots is provided in Section 2.8.

Infiltration may be prohibited within areas of karst topography. If a site overlies karst geology, the local approval authority should be consulted for specific design requirements. Recommended procedures for determining whether a site overlies karst are provided in Appendix D.2.

The bottom of the infiltration facility shall be separated by at least four feet vertically from the seasonally high water table or bedrock layer, as documented by on-site soil testing. This distance is reduced to 2 feet on the Lower Eastern Shore (see Figure 4.1).

Infiltration facilities should be located a minimum of 100 feet horizontally from any water supply well.

The maximum contributing area to an individual infiltration practice should generally be less than 5 acres.

Infiltration practices should not be placed in locations that cause water problems to downgrade properties. Infiltration facilities should be setback 25 feet (10 feet for dry wells) down-gradient from structures.

3.3.2 Infiltration Conveyance Criteria

A conveyance system shall be included in the design of all infiltration practices in order to ensure that excess flow is discharged at non-erosive velocities.

The overland flow path of surface runoff exceeding the capacity of the infiltration system shall be evaluated to preclude erosive concentrated flow. If computed flow velocities do not exceed *the non-erosive threshold, overflow may be accommodated by natural topography (see Appendix D.12 for the critical erosive velocities for grass and soil).*

All infiltration systems shall be designed to fully de-water the entire WQ_v within 48 hours after the storm event.

The truncated hydrograph method shall be used if infiltration is used to control Cp_v or Q_p (see Appendix D.13 for details on this method).

If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice should be designed as an off-line practice. (See Detail No. 5, Appendix D.8 for example of an off-line infiltration practice.)

Adequate stormwater outfalls shall be provided for the overflow associated with the ten-year design storm event (non-erosive velocities on the down-slope).

3.3.3 Infiltration Pretreatment Criteria

Pretreatment Volume

A minimum of 25% of the WQ_v must be pretreated prior to entry to an infiltration facility. If the f for the underlying soils is greater than 2.00 inches per hour, 50% of the WQ_v shall be pretreated prior to entry into an infiltration facility. This can be provided by a sedimentation basin, stilling basin, sump pit or other acceptable measures. *Exit velocities from pretreatment shall be non-erosive during the two-year design storm.*

The Camp-Hazen equation (Chapter 3.4.3) may be used as an acceptable alternative for determining infiltration pretreatment requirements.

Pretreatment Techniques to Prevent Clogging

Each system shall have redundant methods to protect the long term integrity of the infiltration rate. The following techniques, at least three per trench (I-1) and two per basin (I-2), must be installed in every infiltration practice:

- *grass channel* (see Chapter 5 - Credit #5 for example computation and requirements for use)
- *grass filter strip* (minimum 20 feet and only if sheet flow is established and maintained)
- *bottom sand layer*
- *upper sand layer (6" minimum) with filter fabric at the sand/gravel interface.*
- *use of washed bank run gravel as aggregate*

The sides of infiltration trenches shall be lined with an acceptable filter fabric that prevents soil piping but has greater permeability than the parent soil (see Appendix B.2).

3.3.4 Infiltration Treatment Criteria

Infiltration practices shall be designed to exfiltrate the entire WQ_v less the pretreatment volume through the floor of each practice using the design methods outlined in Appendix D.13.

Infiltration practices are best used in conjunction with other BMPs and often downstream detention is still needed to meet the Cp_v and Q_p sizing criteria.

The construction sequence and specifications for each infiltration practice shall be followed, as outlined in Appendix B.2. Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction.

A porosity value "n" ($n = V_v/V_t$) of 0.40 should be used in the design of stone reservoirs for infiltration practices.

3.3.5 Infiltration Landscaping Criteria

A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Infiltration trenches shall not be constructed until all of the contributing drainage area has been completely stabilized.

3.3.6 Infiltration Maintenance Criteria

Infiltration practices may not serve as a sediment control device during the site construction phase. In addition, the erosion and sediment control plan for the site must clearly indicate how sediment will be prevented from entering the infiltration site.

An observation well shall be installed in every infiltration trench, consisting of an anchored six-inch diameter perforated PVC pipe with a lockable cap. (See Detail No. 4, Appendix D.8.)

It is recommended that infiltration designs include dewatering methods in the event of failure. This can be done with underdrain pipe systems that accommodate drawdown.

Direct access shall be provided to all infiltration practices for maintenance and rehabilitation.

Infiltration practices should not be covered by an impermeable surface.

OSHA safety standards should be consulted for trench excavation.

Section 3.4 Stormwater Filtering Systems

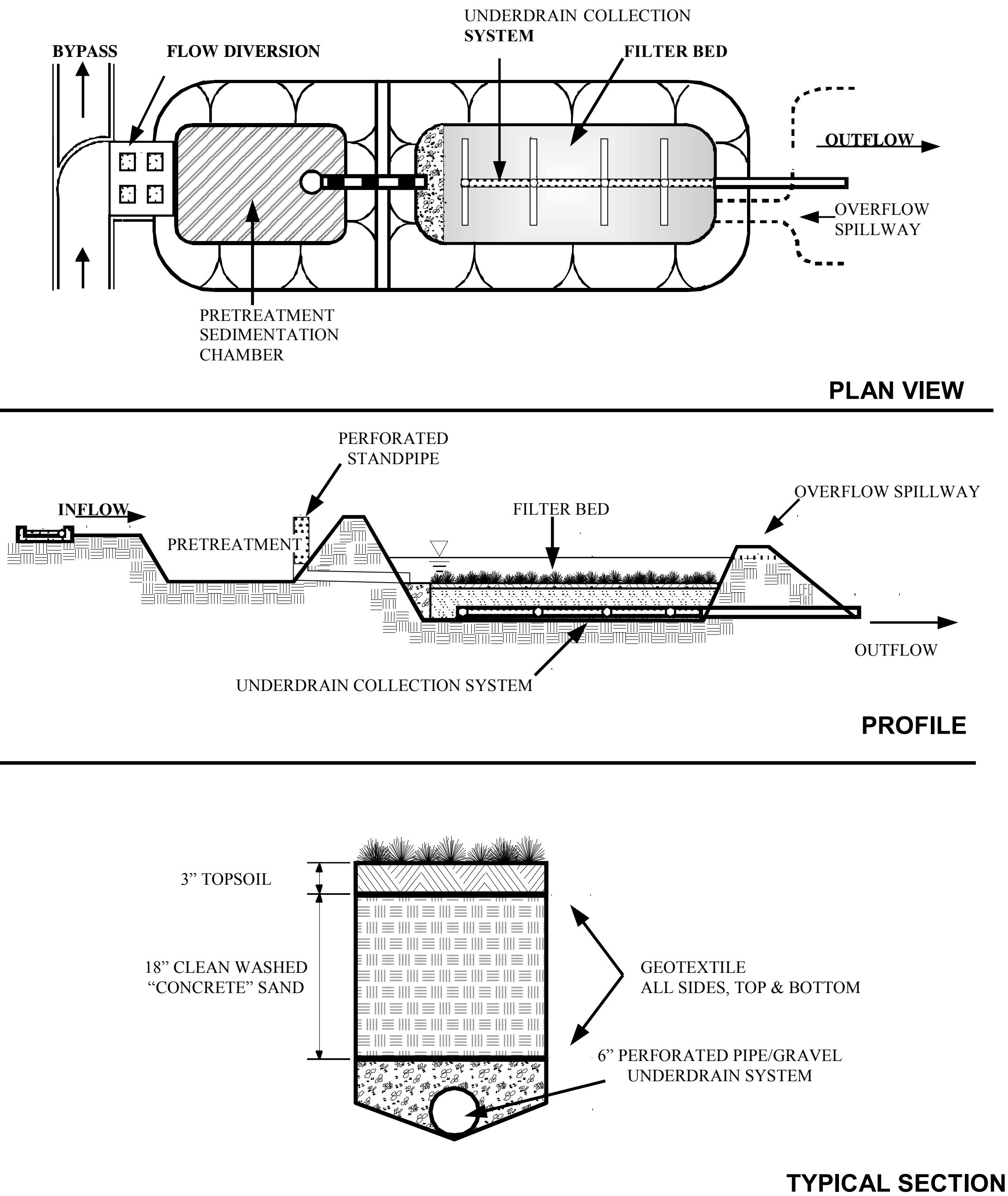
Definition: Practices that capture and temporarily store the WQ_v and pass it through a filter bed of sand, organic matter, soil or other media. Filtered runoff may be collected and returned to the conveyance system or allowed to partially exfiltrate into the soil. Design variants include:

- F-1 surface sand filter (Figure 3.12)
- F-2 underground sand filter (Figure 3.13)
- F-3 perimeter sand filter (Figure 3.14)
- F-4 organic filter (Figure 3.15)
- F-5 pocket sand filter (Figure 3.16)
- F-6 bioretention (Figure 3.17)

Filtering systems shall not be designed to meet Cp_v or Q_p requirements except under extremely unusual conditions. Filtering practices shall generally be combined with a separate facility to provide those controls. Filtering systems may be used to meet the Re_v if designed to exfiltrate into the soil (e.g., if additional storage is provided below the invert of the underdrain).

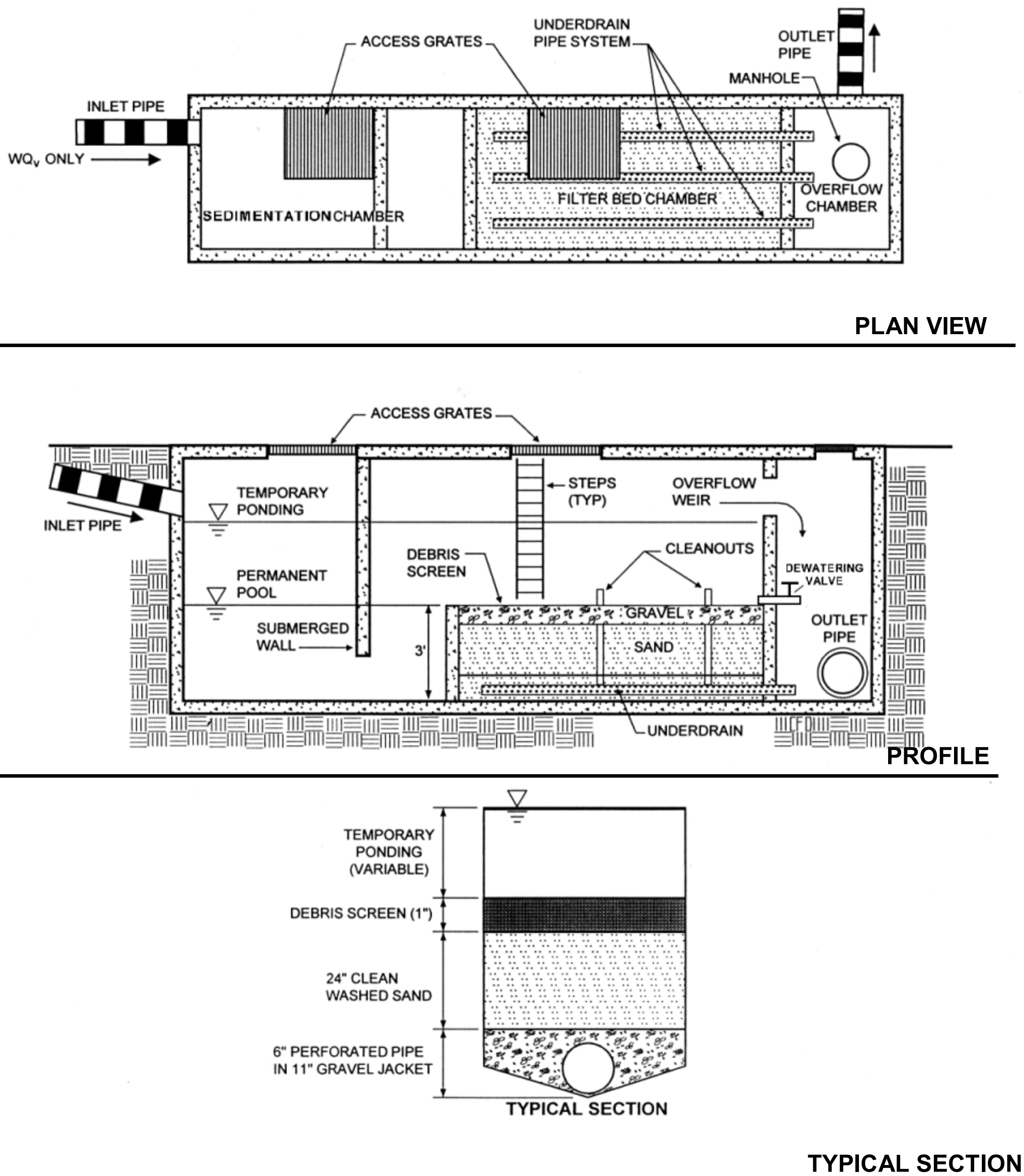
IMPORTANT NOTE: Any stormwater management BMP that uses an embankment for impounding water is required to follow the latest version of the NRCS-MD 378 Pond Code Standards And Specifications For Small Pond Design (Appendix B.1) and obtain approval from the local Soil Conservation District (SCD) or appropriate review authority.

F-1	**Figure 3.12** Example of Surface Sand Filter	F-1



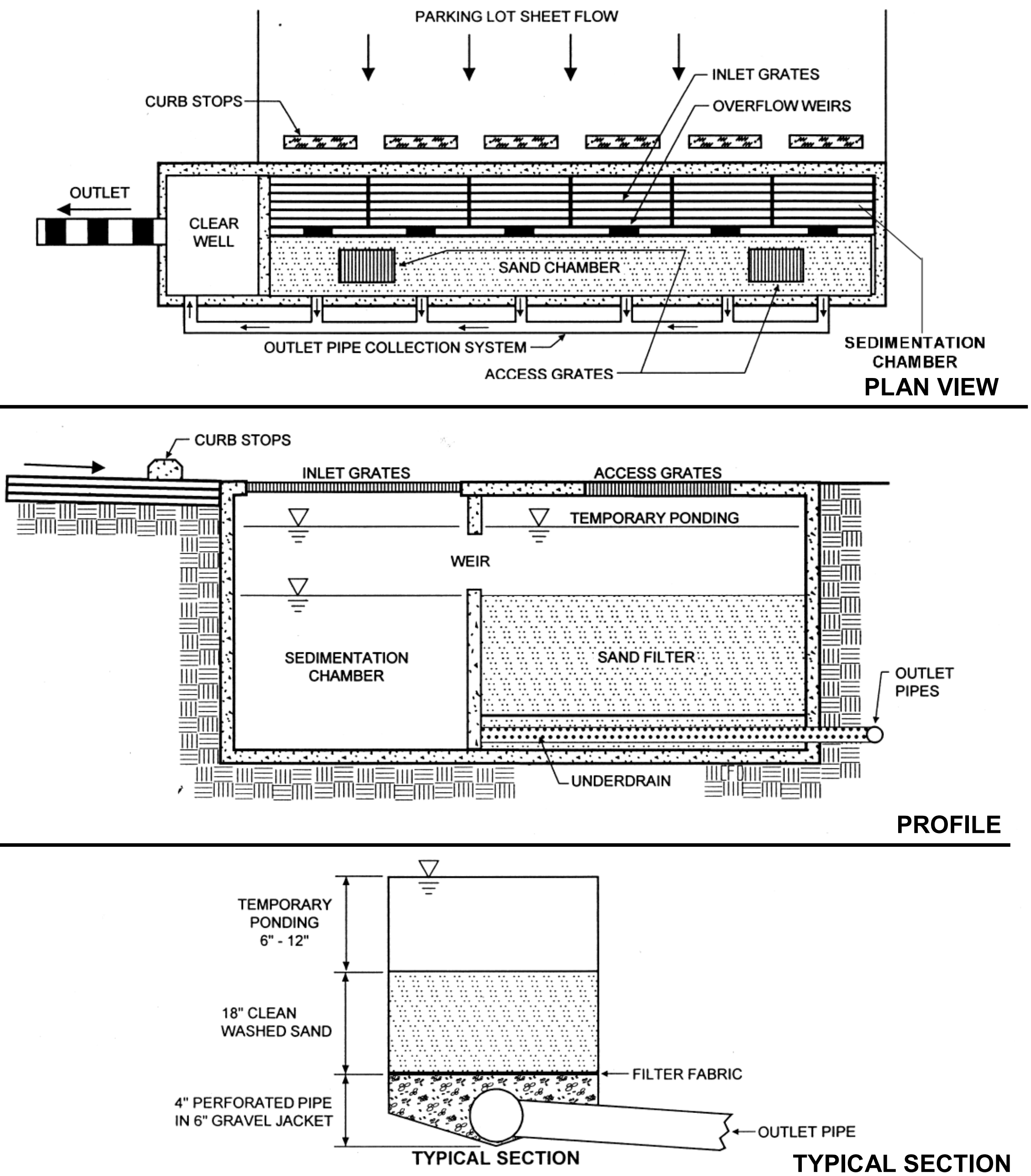
Surface sand filters can treat the largest drainage area of all the filtering systems.

F-2	**Figure 3.13** Example of Underground Sand Filter	F-2



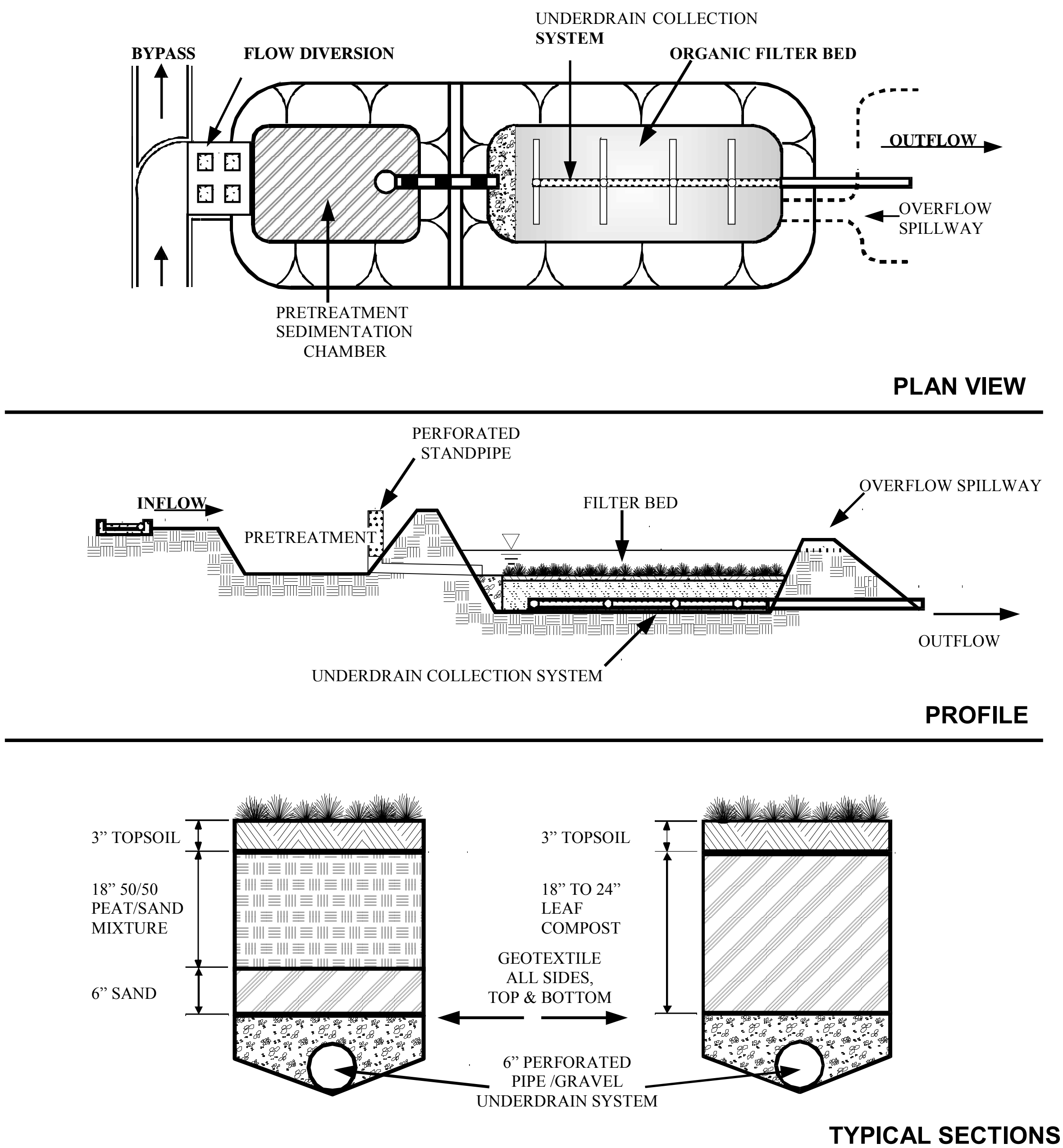
The underground sand filter is an option for providing WQ_v where space is limited.

F-3	**Figure 3.14** Example of Perimeter Sand Filter	F-3



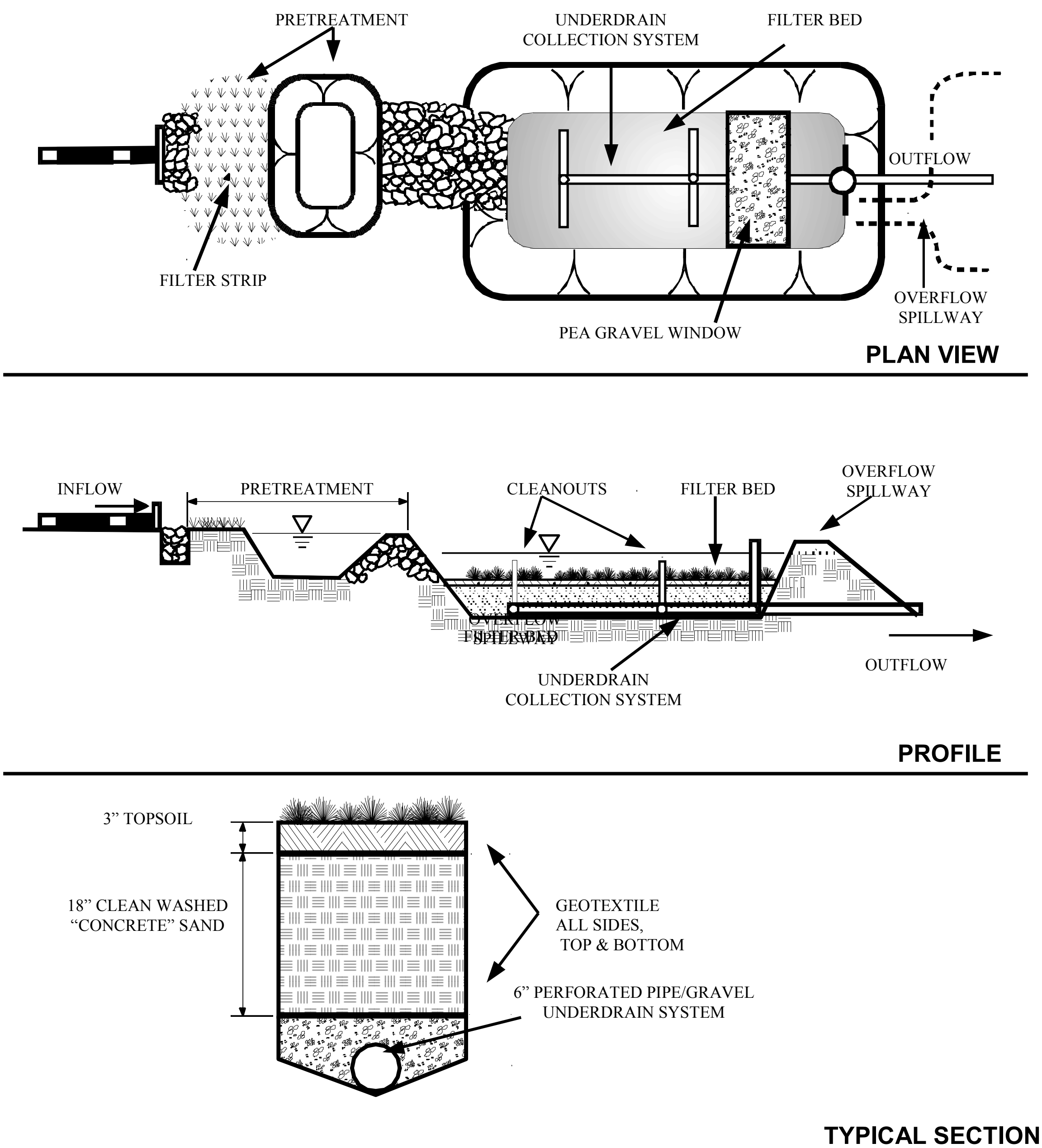
The perimeter sand filter is most practical for small sites with flat terrain or a high water table.

F-4	**Figure 3.15** Example of Organic Filter	F-4



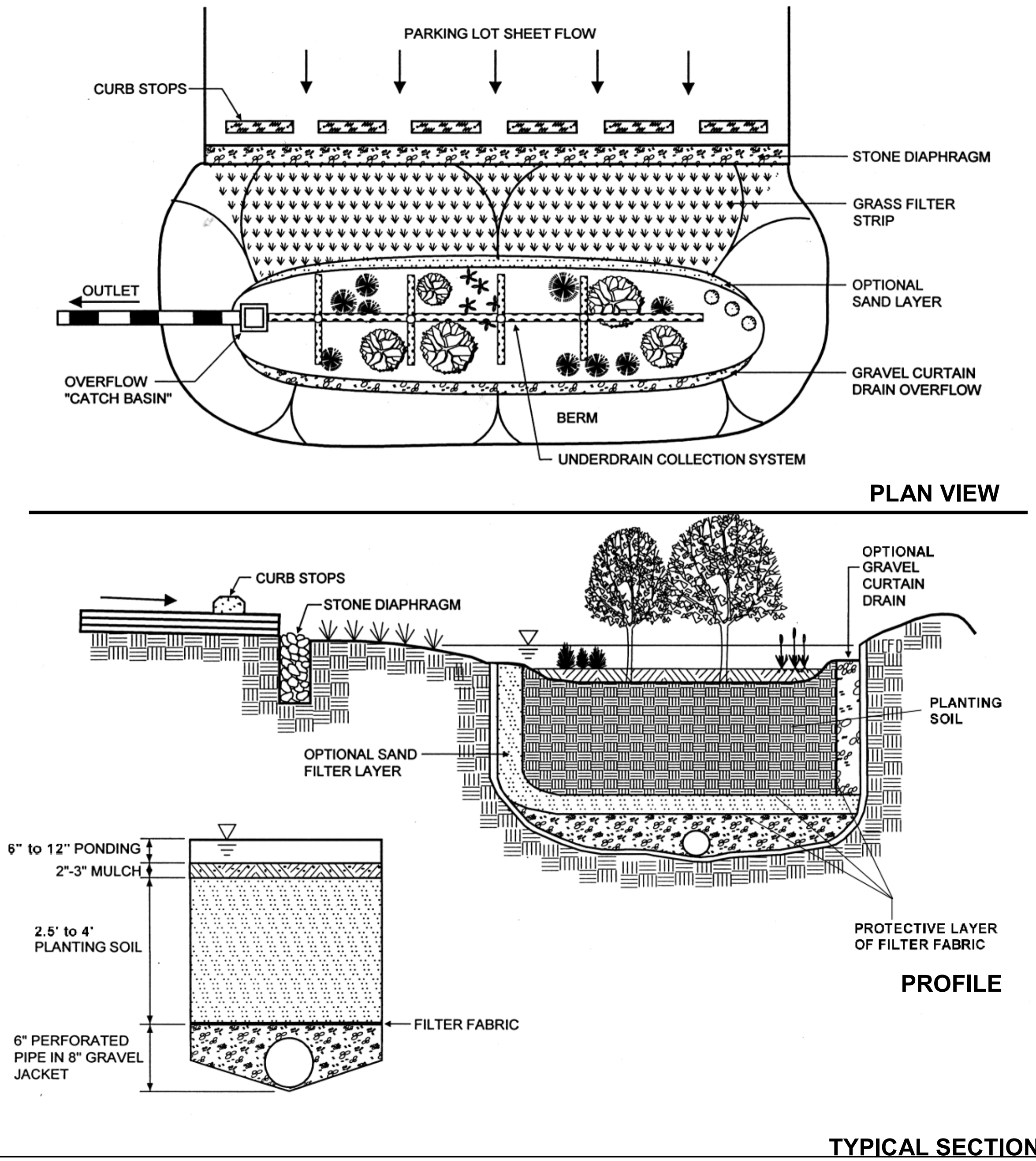
The organic filter is used when maximum nutrient or trace metal removals are desired.

F-5	**Figure 3.16** Example of Pocket Sand Filter	F-5



The pocket sand filter is applied to small sites where sediment loads are expected to be moderate to low. The pea gravel windows allow runoff into the filter if the surface becomes clogged.

F-6	**Figure 3.17** Example of Bioretention	F-6



Bioretention combines open space with stormwater treatment.

3.4.1 Filtering Feasibility Criteria

Most stormwater filters normally require two to six feet of head. However, the perimeter sand filter (F-3) can be designed to function with as little as one foot of head.

The maximum contributing area to an individual stormwater filtering system is usually less than 10 acres.

Sand and organic filtering systems are generally applied to land uses with a high percentage of impervious surfaces. *Drainage areas with imperviousness less than 75% discharging to a filtering practice shall require full sedimentation pretreatment techniques (see Equation on p. 3.39).*

3.4.2 Filtering Conveyance Criteria

If runoff is delivered by a storm drain pipe or is along the main conveyance system, the filtering practice shall be designed off-line. (See Detail No. 5 in Appendix D.8.)

Overflow for the ten-year storm shall be provided to a non-erosive outlet point (e.g., prevent downstream slope erosion). See Appendix D.12 for critical non-erosive velocities for grass and soil.

A flow regulator (or flow splitter diversion structure) shall be provided to divert the WQ_v to the filtering practice (see Detail No. 5, Appendix D.8).

Stormwater filters shall be equipped with a minimum 4" perforated pipe underdrain (6" is preferred) in a gravel layer. A permeable filter fabric (Appendix B.3) shall be placed between the gravel layer and the filter media.

3.4.3 Filtering Pretreatment Criteria

Dry or wet pretreatment equivalent to at least 25% of the computed WQ_v shall be provided prior to filter media. The typical method is a sedimentation basin that has a length to width ratio of 2:1. The Camp-Hazen equation, which accounts for the effects of turbulent flow, is used to compute the required minimum surface area for sand and organic filters for pretreatment (WSDE, 1992).

The required sedimentation basin minimum surface area is computed using the following equation:

$$A_s = \frac{Q_o}{W} \times E'$$

where:

A_s = sedimentation basin surface area (ft^2)
Q_o = discharge rate from basin = (WQ_v/24 hr)
W = particle settling velocity (ft/sec)
for I ≤ 75%, use 0.0004 ft/sec (particle size=20 microns)
for I >75%use 0.0033 ft/sec (particle size=40 microns) [1]
(I = percent impervious)
E' = sediment trapping efficiency constant; for a sediment trapping efficiency (*E)* of 90%, E' = 2.30 [2]

1) Sites with greater than 75% imperviousness have a higher percentage of coarse-grained sediments (Shaver and Baldwin, 1991). Therefore, the target particle size for sedimentation basins may be increased to 40 microns and the surface area reduced.

2) The sediment trapping efficiency constant (*E′)* may be calculated from the sediment trapping efficiency (*E*) using the following equation: $E' = -\ln[1-(E/100)]$

The equation reduces to:

A_{sf} = (0.066) (WQ_v) ft^2 for I ≤ 75%
A_{sp} = (0.0081) (WQ_v) ft^2 for I > 75%

where:

A_{sf} = sedimentation basin surface area full
A_{sp} = sedimentation basin surface area partial

Adequate pretreatment for bioretention systems (F-6) is provided when all of the following are provided: (a) 20’ grass filter strip below a level spreader or optional sand filter layer, (b) gravel diaphragm and (c) a mulch layer.

3.4.4 Filtering Treatment Criteria

The entire treatment system (including pretreatment) shall temporarily hold at least 75% of the WQ_v prior to filtration.

The filter bed typically has a minimum depth of 18". *Sand filters shall have a minimum filter bed depth of 12".*

Filtering practices typically cannot provide Cp_v or Q_p under most site conditions.

The filter media shall conform to the specifications listed in Table B.3.1 (Appendix B.3).

The filter area for filter designs F-1 to F-5 shall be sized based on the principles of Darcy's Law. A coefficient of permeability (k) shall be used as follows:

Sand:	*3.5 ft/day (City of Austin 1988)*
Peat:	2.0 ft/day (Galli 1990)
Leaf compost:	*8.7 ft/day (Claytor and Schueler, 1996)*
Bioretention Soil:	*0.5 ft/day (Claytor and Schueler, 1996)*

Bioretention systems (F-6) shall consist of the following treatment components: A 2½ to 4 foot deep planting soil bed, a surface mulch layer, and a 12" deep surface ponding area.

The required filter bed area (A_f) is computed using the following equation:

$$A_f = (WQ_v)\ (d_f)\ /\ [\ (k)\ (h_f + d_f)\ (t_f)]$$

where:

A_f	=	Surface area of filter bed (ft^2)
WQ_v	=	water quality volume (ft^3)
d_f	=	filter bed depth (ft)
k	=	coefficient of permeability of filter media (ft/day)
h_f	=	average height of water above filter bed (ft)
t_f	=	design filter bed drain time (days)*

*1.67 days is recommended maximum for sand filters, 2.0 days for bioretention

3.4.5 Filtering Landscaping Criteria

A dense and vigorous vegetative cover shall be established over the contributing drainage area before runoff can be accepted into the facility.

Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan shall be provided for bioretention areas per the guidance provided in Appendix-A.

Filters F-1, F-4 and F-5 may have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought (see Appendix A for grass species selection guide).

Planting recommendations for bioretention facilities are as follows:

- Native plant species should be specified over non-native species.
- Vegetation should be selected based on a specified zone of hydric tolerance.
- A selection of trees with an understory of shrubs and herbaceous materials should be provided.

- Woody vegetation should not be specified at inflow locations.

3.4.6 Filtering Maintenance Criteria

The sediment chamber outlet devices shall be cleaned/repaired when drawdown times within the chamber exceed 36 hours. Trash and debris shall be removed as necessary.

Sediment should be cleaned out of the sedimentation chamber when it accumulates to a depth of more than six inches. Vegetation within the sedimentation chamber should be limited to a height of 18 inches.

When the filtering capacity of the filter diminishes substantially (e.g., when water ponds on the surface of the filter bed for more than 72 hours), the top few inches of discolored material shall be removed and shall be replaced with fresh material. The removed sediments should be disposed in an acceptable manner (e.g., landfill). Silt/sediment should be removed from the filter bed when the accumulation exceeds one inch.

Organic filters (F-4) or surface sand filters (F-1) that have a grass cover should be mowed a minimum of 3 times per growing season to maintain maximum grass heights less than 12 inches.

*A drop of at least six inches shall be provided at the inlet of bioretention facilities (F-6) (*stone diaphragm*). Dead or diseased plant material shall be replaced.* Areas devoid of mulch should be re-mulched on an annual basis.

Direct maintenance access shall be provided to the pretreatment area and the filter bed.

Construction of sand filters and bioretention areas shall conform to the specifications outlined in Appendix B.3.

Section 3.5 Open Channel Systems

Definition: Vegetated open channels that are designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means. Design variants include:

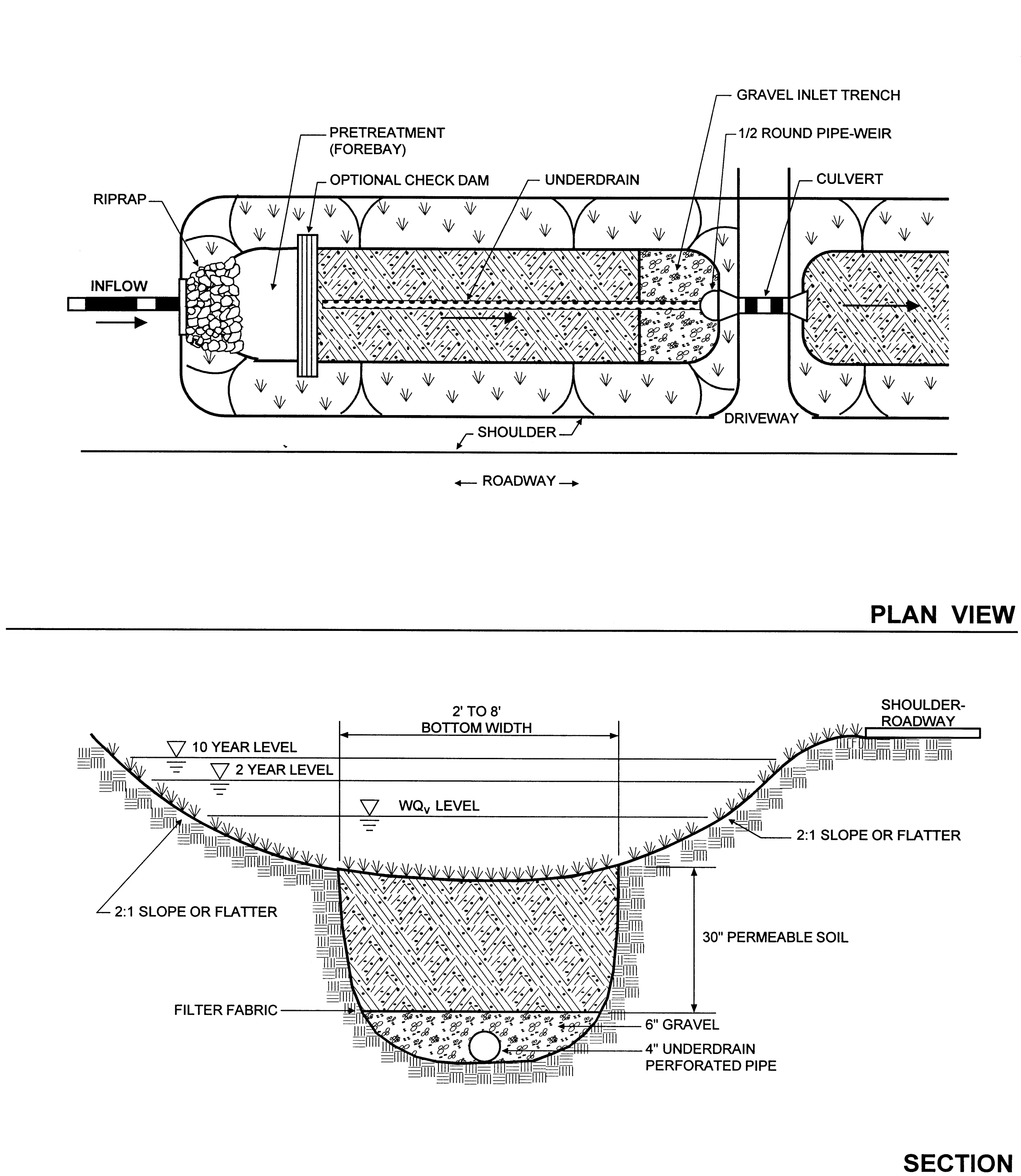
- O-1 dry swale (Figure 3.18)
- O-2 wet swale (Figure 3.19)

Open channel systems shall not be designed to meet Cp_v or Q_p requirements except under extremely unusual conditions. Open channel practices shall generally be combined with a separate facility to provide those controls. Additionally, these systems may be used to meet the Re_v if designed to exfiltrate through the soil (e.g., if additional storage is provided below the invert of the underdrain).

Grass channels (also known as biofilters) that are not designed in accordance with Section 3.5 are not considered an acceptable practice to meet the WQ_v requirements unless designed according to the criteria in Chapter 5.

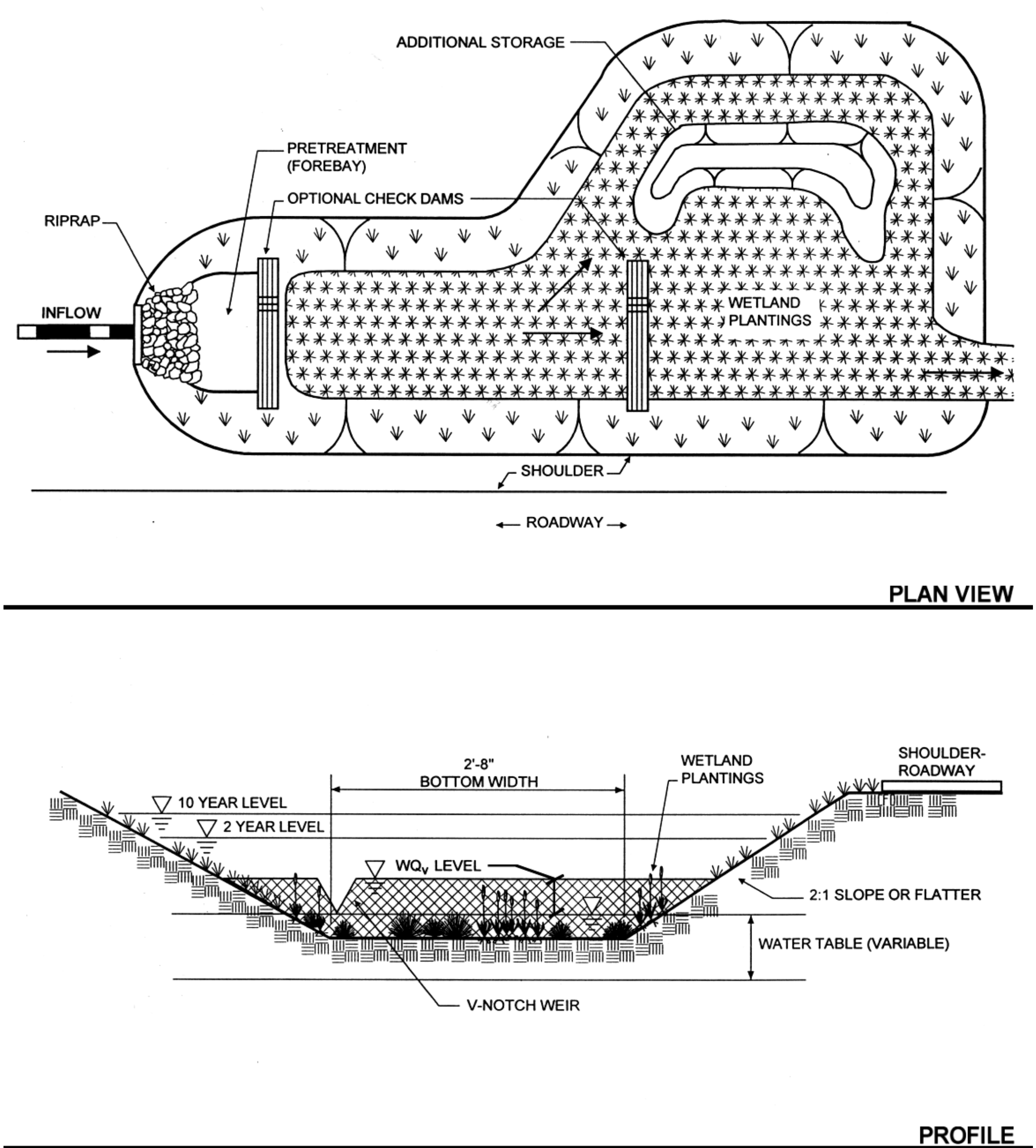
IMPORTANT NOTE: Any stormwater management BMP that uses an embankment for impounding water is required to follow the latest version of the NRCS-MD 378 Pond Code Standards And Specifications For Small Pond Design (Appendix B.1) and obtain approval from the local Soil Conservation District (SCD) or appropriate review authority.

O-1	**Figure 3.18** Example of Dry Swale	O-1



Dry swales are used at low density residential projects or for very small impervious areas.

O-2	**Figure 3.19** Example of Wet Swale	O-2



Wet swales are ideal for treating highway runoff in low lying or flat terrain areas.

3.5.1 Open Channel Feasibility Criteria

Open channel systems shall have longitudinal slopes less than 4.0% to qualify for WQ_v *treatment.*

Open channel systems, designed for WQ_v treatment, are primarily applicable for land uses such as roads, highways, residential development (dry swales only), and pervious areas.

3.5.2 Open Channel Conveyance Criteria

The peak velocity for the ten-year storm shall be non-erosive (see Appendix D.12 for critical non-erosive velocities for grass and soil) for the soil and vegetative cover provided.

Open channels shall be designed to safely convey the ten-year storm. Three inches of freeboard should be provided.

Channels should be designed with moderate side slopes (flatter than 3:1) for most conditions. *In no event may side slopes be steeper than 2:1.*

The maximum allowable ponding time within a channel shall be less than 48 hours. The minimum ponding time of 30 minutes is recommended for meeting WQ_v treatment goals.

Open channel systems which directly receive runoff from impervious surfaces may have a six inch drop onto a protected shelf (pea gravel diaphragm) to minimize clogging of the inlet.

An underdrain system shall be provided for the dry swale to ensure a maximum ponding time of 48 hours.

3.5.3 Open Channel Pretreatment Criteria

Pretreatment storage of 0.1 inch of runoff per impervious acre storage shall be provided. This storage is usually obtained by providing check dams at pipe inlets and/or driveway crossings.

A pea gravel diaphragm and gentle side slopes should be provided along the top of channels to accommodate pretreatment for lateral sheet flows.

Direct discharge of concentrated flow (e.g., by pipe) shall be pretreated.

3.5.4 Open Channel Treatment Criteria

Dry and wet swales shall be designed to temporarily store the WQ_v within the facility for a maximum 48 hour period.

Open channels shall have a bottom width no wider than 8 feet or a meandering drainage pattern shall be established to avoid gullying or channel braiding.

Dry and wet swales should maintain a maximum ponding depth of one foot at the "mid-point" of the channel profile (longitudinal dimension) and a maximum depth of 18" at the downstream end point of the channel (for storage of the WQ_v).

3.5.5 Open Channel Landscaping Criteria

Wet swales are not recommended for residential developments as they can create potential nuisance or mosquito breeding conditions.

Landscape design should specify proper grass species and wetland plants based on specific site, soils and hydric conditions present along the channel (see Appendix A).

3.5.6 Open Channel Maintenance Criteria

Open channel systems and grass filter strips should be mowed as required during the growing season to maintain grass heights in the 4 to 6 inch range. Wet swales, employing wetland vegetation or other low maintenance ground cover do not require frequent mowing of the channel.

Sediment build-up within the bottom of the channel or filter strip shall be removed when 25% of the original WQ_v has been exceeded.

Construction specifications for open channel systems are specified in Appendix B.3.