Volume 4
BEST MANAGEMENT PRACTICES

STORMWATER MANAGEMENT MANUAL

Prepared for

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Section 1
INTRODUCTION

1.1 Background and Purpose

This volume presents a brief introduction to stormwater Best Management Practices (BMPs). It describes how they should be selected, and contains a series of focused and concise fact sheets for each type of BMP to be used in the Metropolitan Nashville and Davidson County (Metro) area. It is part of the Stormwater Management Manual, which is composed of the following volumes:

Volume 1 – Regulations
Volume 2 – Procedures
Volume 3 – Theory
Volume 4 – Best Management Practices (BMP)

The intent of this volume is to provide guidance on BMP selection, design, and implementation to plan submitters, reviewers, construction site operators, and site inspectors. There is special emphasis on Erosion Prevention and Sedimentation Control (EP&SC) during construction and long-term (or permanent) stormwater quality treatment devices and facilities after construction is complete. There are also guidance materials for activities at commercial and industrial facilities.

The fact sheets are categorized, focused, and concise so that they may be used as quick references for design, inspection, and maintenance guidance. In this way, the fact sheets are designed to be stand-alone documents that may be distributed to facilitate focused discussion about design and/or implementation of the management practice. Many of the practices are considered structural practices in that they involve construction. However, several of the BMPs cover non-structural practices where normal activities are performed in a different manner with stormwater quality in mind.

The original version of this manual was released in March 2000. It was prompted by requirements in Metropolitan Nashville and Davidson County's National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit issued by the Tennessee Department of Environment and Conservation (TDEC). In 2005, Metro updated the manual, including the PTP section of this volume. Other sections within this volume were not revised. Metro Water Services has the authority to change any provisions in Volume 4 so long as it is in support of policies and regulations defined in Volume 1 of the Stormwater Management Manual. Any future release of this manual supersedes any and all previous manual releases. Each page is dated to indicate the release date.

1.2 Stormwater Quality and Quantity Management

Since 2000, Metro has been requiring that stormwater quality management techniques be applied to new development and redevelopment in the form of structural and non-structural Best Management Practices (BMPs). In 2005, Metro revised its stormwater program to require a uniform, specific, post-construction pollution reduction goal for new development and redevelopment sites. Stormwater quality management involves pollutant control, capture, and treatment. There are two pollutant delivery categories: Point sources and non-point sources. Point sources deliver pollutants in the form of regulated discharges, spills, dumping, illicit connections, etc. Non-point sources deliver pollutants through stormwater runoff from different types of land uses. This volume briefly discusses minimizing the chance of unregulated point sources, but primarily focuses on nonpoint source pollution.

Nonpoint source pollution comes in the form of particulate or dissolved pollutant matter being picked up by runoff over surfaces and conveyed to Metro's separate storm sewer system, creeks, and waterways. This principally includes sediment eroded from denuded areas during construction and other pollutants from impervious surfaces after construction. Nonpoint source pollution is most prevalent in runoff from small frequent storm events. Typically these events are less than 1.25-inches of rainfall and that fact was used in preparing the selection, sizing, approach, and maintenance criteria presented in the BMP fact sheets.

1.3 Erosion Prevention and Sediment Control (EP&SC)

1.3.1 Erosion Process

Short-term stormwater quality management predominately focuses on erosion prevention and sedimentation control (EP&SC) for construction sites. However, for some fully developed sites EP&SC can also be a concern. Soil erosion is the process by which soil particles are removed from land surfaces by wind, water or gravity. Natural erosion generally occurs at slow rates. However, the rate of erosion increases when land is cleared or altered and left disturbed. Erosion rates will increase when flow rates and velocities discharged from a site exceed the erosive range.

Clearing and grubbing activities during construction remove vegetation and disrupt the structure of the soil surface, leaving the soil susceptible to rainfall erosion, stream and channel erosion, and wind erosion if left untreated. Ultimately, the material suspended by erosion settles during sedimentation in downstream reaches. This can lead to increased maintenance needs and flooding problems.

1.3.1.1 Water Erosion

The rainfall erosion process begins when raindrops impact the soil surface and dislodge minute soil particles. These soil particles then become suspended in the water droplet. The sediment laden water droplets accumulate on the soil surface until a sufficient quantity has developed to begin flowing under the forces of gravity.

The initial flow of sediment-laden water generally consists of a thin, slow-moving sheet, known as sheet flow. While sheet flow is generally not highly erosive on its own, it does begin the transport of previously suspended sediment. Due to irregularities in the soil surface and uneven topography, sheet flow will usually begin to concentrate into rivulets, where the flow picks up velocity and erosive energy as a result of gravitational forces.

The increasing erosive energy of water flowing in rivulets will begin to cut small grooves, or rills, in the soil surface. Rill erosion of the soil surface tends to concentrate more flows, which then flow faster and gain erosive energy as a result of gravitational forces. In turn, the rills become deeper and larger, and may join together with adjacent rills. Typically, rills run parallel to the slope and each other, are small enough to be stepped across, and are generally enlarged by direct erosion of the rill's sides and bottom by the action of flowing water.

The joining together of several adjacent rills, or sufficient enlargement of a single rill, begins gully erosion. Gully erosion of the soil surface tends to concentrate more flows, which then flow faster and gain erosive energy as a result of gravitational forces. Typically, gullies run parallel to the slope, may have one or more lateral branches, and are enlarged by four key actions. First, gullies often have a "head cut" at the upstream end which progresses its way upstream as water flowing into the gully erodes away the lip of the head. This mechanism is similar to a waterfall working its way upstream. Second, the flow in a gully tends to under cut the banks. Once sufficiently under cut, the banks collapse into the gully where the collapsed soil is then washed away. Third, when banks collapse into the gully, flowing water is diverted around the temporary blockage of soil. This temporary blockage of soil increases velocities along one or both banks, which results in increased bank erosion. Fourth, the concentration of flows in the gully can result in scour of the gully floor until a stable slope is obtained.

1.3.1.2 Stream and Channel Erosion

One or more of the following factors that disrupt the delicate balance required for stable streams and channels generally precipitate erosion within streams and channels.

1. Construction activities can disturb the banks of streams and channels. Once vegetation or other bank protection measures are disturbed, flows may begin to erode the unprotected soil, causing an "unraveling" of the stream or channel. One of the benefits of Metro's water quality buffer program is that it mandates an undisturbed area along the top of the stream

bank or floodway, reducing the potential for stream bank disturbances during construction activities.

2. Construction activities can disturb the flow within a stream or channel. However, these types of activities should be avoided and the disturbance should be minimized. Stream or channel disturbances are often necessary when traversing banks with temporary stream crossings, culvert installations, bridge construction, etc. By diverting flows within the channel, velocities are generally increased in some areas to compensate for decreases in other areas. The increases in velocity may exceed those normally experienced by the channel, resulting in bank erosion and bottom scour. These issues should be addressed in the development plans and minimized to the extent feasible.

3. Development can increase the quantity and rate of flow to streams and channels. The increased quantity and rate of flow can cause bank erosion and bottom scour. Metro's detention policies address this issue for new development.

1.3.1.3 Wind Erosion

Dust is defined as solid particles or particulate matter small enough to remain suspended in the air for a period of time and large enough to eventually settle out of the air. Dust from a construction site originates as inorganic particulate matter from rock and soil surfaces and material storage piles. The majority of dust generated and emitted into the air at a construction site is related to earth moving, demolition, construction traffic on unpaved surfaces, and wind over disturbed soil surfaces.

1.3.1.4 Factors Influencing Erosion

There are five primary factors that influence erosion: soil characteristics, vegetative cover, topography, climate, and rainfall.

1. Soil characteristics that determine the erodibility of the soil include particle size, particle gradation, organic content, soil structure, and soil permeability. Soil characteristics affect soil stability and infiltration capacity. The less permeable the soil, the higher the likelihood for increased runoff and erosion. Soils with a high percentage of silt and clays are generally the most erodible.

   The soil characteristics play a different role for channel flow. The tractive-force or shear stress developed by flowing water over the channel banks and bottom can cause the soil particles to move and become suspended into the runoff. The "permissible shear" stress indicates the stress that the channel banks and bottom can sustain without compromising stability. Protecting the channel bottom and banks with a variety of "soft/green" or "hard" armoring increases the permissible shear stress in the channel.

2. Vegetative cover plays an important role in controlling erosion by shielding the soil surface from the impacts of falling rain, and slowing the velocity of runoff. This permits greater infiltration, maintains the soil's capacity to absorb water, and holds soil particles in place. Vegetative root structures create a favorable soil structure, improving its stability and permeability.

3. Topography, including slope length and steepness are key elements in determining the volume and velocity of runoff. As slope length, and /or steepness increases, so does the rate of runoff and the erosion potential.

4. Climate is a key factor that influences erosion. High rainfall areas and areas with freeze/thaw cycles have significant effects on soil stability and structure.

5. Rainfall, including the frequency, intensity, and duration are fundamental factors in determining the amounts of erosion produced. When storms are frequent, intense, or of long duration, erosion risks are high. In Tennessee, the erosion risk period is typically highest in the wet season (typically December through May) which coincides with the period of minimal vegetative cover.

1.3.2 Sedimentation Process

Once soil particles are eroded by and suspended in water or wind, they can be carried from a few inches or feet to many miles before conditions are such that the forces of gravity will cause the soil particles to settle. The settling of soil particles is known as the process of sedimentation. Excessive levels of sedimentation can plug storm drains, block streams and channels, damage habitat, and in some cases result in formation of habitats in undesirable locations. Generally, sedimentation can be forced to occur by creating conditions that slow the flow of water or air, allowing particles to settle. However, it is more effective to control erosion than to control sedimentation.

1.4 Other Pollutant Sources and Impacts

Sediment from erosion is the pollutant most frequently associated with construction activities. However, other pollutants include nutrients, metals, pesticides, oil and grease, fuels, other toxic chemicals, and miscellaneous wastes. These pollutants originate from a variety of activities including paving operations, demolition, materials storage, equipment fueling, and other daily activities necessary for project construction or site (commercial or industrial) management. By taking an activities inventory, the contractor/operator can identify potential pollutant sources and then select appropriate BMPs to address these sources. Appropriate BMPs are usually specific to the construction activity or site (commercial or industrial) management activity.

1.4.1.1 Nutrients

Phosphorous and nitrogen from fertilizers, pesticides, construction chemicals, and solid waste are often generated by site activities. These nutrients can result in excessive or accelerated growth of vegetation or algae resulting in impaired use of water in lakes and other sources of water supply through taste and odor problems. Excess algae can also deplete dissolved oxygen levels resulting in fish kills. Collectively, the problems associated with excessive levels of nutrients in a receiving water are referred to as eutrophication impacts.

1.4.1.2 Oxygen Demanding Substances

Lower dissolved oxygen (DO) levels are often the cause of fish kills in streams and reservoirs. The degree of DO depletion is measured by the biochemical oxygen demand (BOD) test that expresses the amount of easily oxidized organic matter present in water. The chemical oxygen demand (COD) test measures all the oxidizable matter present in urban runoff. BOD is caused by the decomposition of organic matter in stormwater that depletes DO. Other non-organic materials in the water can intensify DO depletion.

1.4.1.3 Metals

Many artificial surfaces (e.g., galvanized metal, paint, or preserved wood) contain metals that can enter stormwater as the surfaces corrode, flake, dissolve, decay, or leach. However, significant portions of metals in urban runoff are from cars and trucks. Over half the trace metal load carried in stormwater is associated with sediments to which these eroded metals attach. Heavy metals are of concern because they are toxic to aquatic organisms, can be bioaccumulative, and have the potential to contaminate drinking water supplies.

1.4.1.4 Pesticides

Herbicides, insecticides and rodenticides (collectively termed pesticides), are commonly used on construction sites, lawns, parks, golf courses, etc. Unnecessary, excessive, or improper application of these pesticides may result in direct water contamination, indirect water pollution by aerosol drift, or erosion of treated soil and subsequent transport into surface waters.

1.4.1.5 Oil, Grease and Fuels

These products are widely used and can be spilled/leaked/dumped on the ground where they can wash into waterways. Sources include leakage during normal vehicle use, hydraulic line failure, spills during fueling, and inappropriate disposal of drained fluids. These products can cause harm to plant and animal life.

1.4.1.6 Other Toxic Chemicals

Often synthetic organic compounds (adhesives, cleaners, sealants, solvents, etc.) are widely applied and may be improperly stored and disposed. Accidental spills and leakage or deliberate dumping of these chemicals onto the ground or into storm drains causes environmental harm in receiving waters.

1.4.1.7 Miscellaneous Wastes

Miscellaneous wastes include wash water from concrete mixers, paints and painting equipment cleaning activities, solid organic wastes resulting from trees and shrubs removed during land clearing, wood and paper materials derived from packaging of building products, food containers, such as paper, aluminum, and metal cans, industrial or heavy commercial process wash/cooling water, vehicle washing, other commercial or industrial wastes and sanitary wastes. The discharge of these wastes can lead to unsightly and polluted receiving waters.

1.5 Temporary and Permanent BMPs

Temporary BMPs are intended to address construction activities while permanent BMPs address long-term stormwater management objectives / requirements. Both temporary and permanent BMPs should be included in the grading plan and SWPPP.

Temporary BMPs may include a variety of "good housekeeping" measures and short-term EP&SC activities. A licensed professional engineer must design BMPs. The temporary management practices should be designed and submitted to the plan review engineer with the Department of Water Services. The permit holder is responsible for identifying an EPSC professional that will act as the contact person for Metro and that will ensure that temporary practices are properly constructed, implemented and maintained and will seek guidance when the measures do not appear to be meeting the stormwater management objectives (namely that sediment and other pollutants do not leave the construction site).

Permanent BMPs may include swales, sediment or detention ponds, and a variety of other features. These permanent management practices must be selected by licensed professional civil engineers and incorporated into the plans and specifications for the project. The short- and long-term maintenance responsibilities must be identified.

Permanent BMPs are the final improvements to and configuration of the project. They are designed to convey and control stormwater long-term. Permanent BMPs are normally selected in the planning phase in conjunction with the approval of the tentative map designed during the design phase of a project and completed to the satisfaction of Metro prior to issuing a grading permit. Occasionally, unforeseen natural or manmade factors may require revisions to or additions of permanent BMPs during the construction phase.

During construction, the grading permit holder must ensure that the post-construction BMPs are installed properly and that any maintenance that may be necessary during construction is performed. After the project is complete it will then be the responsibility of the private or public owner (or other entity formally identified) to provide for long-term operation and maintenance, as required by the maintenance agreement.

1.6 Temporary and Permanent BMP Selection Process

1.6.1 Define BMP Objectives

Each new development site is unique. Therefore, an understanding of the natural features within the project boundaries and the pollution risks related to the construction activity and land use is essential for selecting and implementing BMPs. Identifying these features and risks requires review of the characteristics of the site and the nature of the construction. This information should be assembled for the construction plans. Once these natural features and pollution risks are defined, BMP objectives can be effectively developed, and BMPs selected. The BMP objectives for new development projects are as follows:

1. Practice Good Housekeeping: Perform activities in a manner which keeps potential pollutants from coming into contact with stormwater by containing potential pollutant sources and modifying construction activities.

2. Contain Waste: Dispose of all construction waste in designated areas, and keep stormwater from flowing on to or off of these areas.

3. Minimize Disturbed Areas: Only clear land which will be actively under construction in the near term (e.g., within the next 3-4 months), minimize new land disturbance during the rainy season, and do not clear or disturb sensitive areas (e.g., steep slopes, buffers and natural watercourses) and other areas where site improvements will not be constructed.

4. Control Erosion: Provide temporary stabilization of disturbed soils whenever active construction is not occurring on a portion of the site. Provide permanent stabilization as phases are brought to the final grade and landscape the site. Focus stabilization efforts on slopes and areas of concentrated flow.

5. Protect Slopes and Channels: Outside of the approved grading plan area, avoid disturbing steep or unstable slopes. Safely convey runoff from the top of the slope, and stabilize disturbed slopes as quickly as possible. Avoid disturbing natural channels. Stabilize temporary and permanent channel crossings as quickly as possible, and ensure that increases in runoff velocity caused by the project do not erode the channel.

6. Control Site Perimeter: Upstream runoff from other developments or sites should be diverted around or safely conveyed through the construction project. Such diversions must not cause downstream property damage. Runoff from the project site should be free of excessive sediment and other constituents.

7. Control Sedimentation: Detain sediment laden waters from disturbed, active areas within the site to minimize the risk that sediment will have the opportunity to leave the site.

8. Protect Natural Features: Identify natural features such as wetlands, streams, sinkholes, and springs. Install BMPs to protect these features. Consider leaving natural features within areas that are not to be disturbed.

9. Implement Better Site Design Principles: Design a development to minimize the roadway length and width and parking lot size. Use pervious materials, such as pervious pavers or permeable concrete, where possible. Use grass-lined channels where site conditions allow.

10. Reduce Pollutants from the Development After Construction (Post-Construction Water Quality): Long-term BMP selection must be based upon the ability to meet Metro's requirement of an 80% TSS reduction of an average annual urban pollutant load. Select permanent treatment practices based upon the TSS reduction provided, the proposed land use, and the level of maintenance required.

Site characteristics and contractor activities affect both the potential for erosion and contamination by other constituents used on the construction site. Before identifying BMPs, you should carefully consider:

1. Site conditions that affect erosion and sedimentation including:

   a. Soil type, including underlying soil strata that are likely to be exposed to stormwater.
   b. Natural terrain and slope.
   c. Final slopes and grades.
   d. Location of concentrated flows, storm drains, sinkholes, and streams.
   e. Existing vegetation and ground cover.

2. Climatic factors, which include:

   a. Seasonal rainfall patterns.
   b. Appropriate design storm
      i. quantity of rainfall
      ii. intensity of rainfall
      iii. duration of rainfall

3. Type of construction activity.
4. Construction schedules, construction sequencing and phasing of construction.
5. Size of construction project and area to be graded.
6. Location of the construction activity relative to adjacent uses and public improvements.
7. Cost-effectiveness considerations.
8. Types of construction materials and potential pollutants present or that will be brought on-site.
9. Floodplain, Floodway, and buffer requirements.

1.6.2 Identify BMP Categories

Once the overall BMP objectives are defined, it is necessary to identify BMPs best suited to meet each objective.

To determine where to place BMPs, a map of the project site should be prepared with sufficient topographic detail to show existing and proposed drainage patterns and existing and proposed permanent stormwater control structures. The project site map should identify the following:

1. Locations where stormwater enters and exits the site. Include both sheet and channel flow for the existing and final grading contours.

2. Identify locations subject to higher rates of erosion such as steep slopes and unlined channels. Long, steep slopes over 100 feet in length are considered as areas of moderate to high erosion potential.

3. Categorize slopes as:

   a. Low Erosion Potential (0 to 5 percent slope)
   b. Moderate Erosion Potential (5 to 10 percent slope)
   c. High Erosion Potential (slope greater than 10 percent)

4. Identify wetlands, springs, sinkholes, floodplains, floodways, sensitive areas or buffers which must not be disturbed, as well as other areas where site improvements will not be constructed. Establish clearing limits around these areas to prevent disturbance by the construction activity.

5. Identify the boundaries of tributary areas for each stormwater outfall location. Then calculate the approximate area of each tributary area.

6. Define areas where various contractor activities have a likely risk of causing a runoff or pollutant discharge.

With this site map in hand, BMPs can be selected and located. It is more cost-effective to prevent erosion/pollution than to remove sediment/pollutants. Erosion prevention is achieved most cost-effectively by planning before construction begins and phasing once construction activities begin.

Once the BMP objectives and categories are identified, the BMP Treatment Train illustrated in Figure 1-1 can be utilized. It can focus the search for specific BMPs to match the site specific conditions and characteristics.

BMPs that can achieve more than one BMP objective should be taken into account when selecting BMPs to achieve maximum cost-effectiveness. For instance, it is not always necessary to install extensive sediment trapping controls during construction. In fact, sediment trapping should be used only as a short-term measure for active construction areas, and replaced by permanent stabilization measures as soon as possible. However, it should be noted that perimeter/outfall control in the form of permanent detention ponds should be built first and used as temporary sediment control by placing a filter on the outlet. After construction is complete and tributary area is stabilized, the permanent outlet configuration can be reestablished.

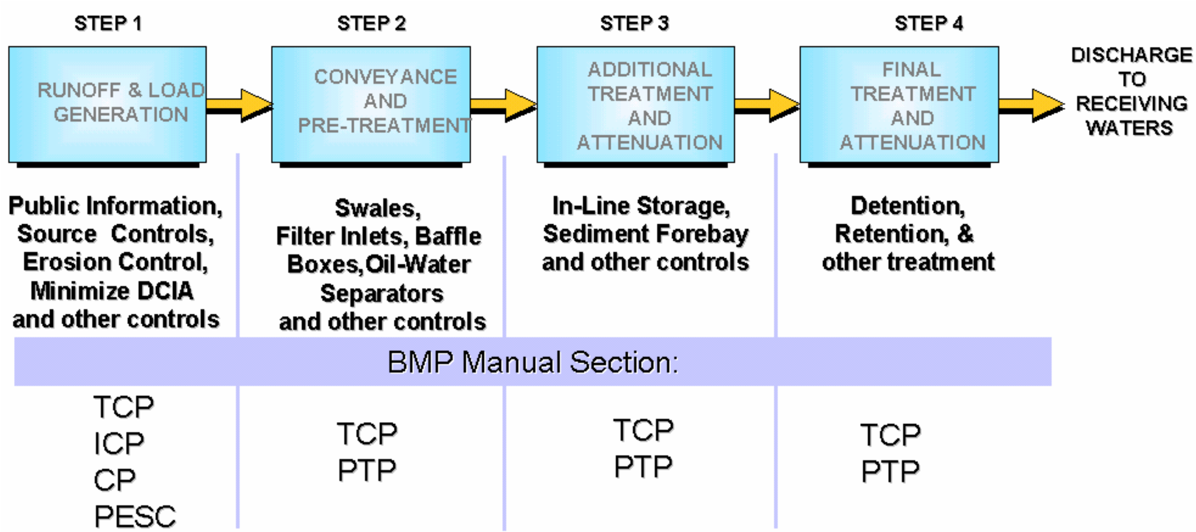

Figure 1-1: Development planning from construction through post-construction

1.6.3 Selecting BMPs for Contractor Activities (Sections CP, TCP and ICP)

Certain contractor activities may cause pollution if not properly managed. Not all of the BMPs will apply to every construction site. However, all of the suggested BMPs should be considered, and those which are appropriate for the project at hand should be selected. Considerations for selecting BMPs for contractor activities include the following:

1. Is it expected to rain? BMPs may be different on rainy days vs. dry days, winter vs. summer, etc. For instance, a material storage area may be covered with a tarp during the rainy season, but not in the summer. However, it should be noted that plans should be made for some amount of rain even if it is not expected to generate a flooding event.

2. How much material is used? Less intensive BMP implementation may be necessary if a “small” amount of pollutant containing material is used (however, remember that different materials pollute in different amounts).

3. How much water is used? The more water used and wastewater generated, the more likely that pollutants transported by this water will reach the stormwater system or be transported off-site. Washing out one concrete truck on a flat area of the site may be sufficient (as long as the concrete is safely removed later), but a pit should be constructed if a number of trucks will be washed out at the same site.

4. What are the site conditions? BMPs selected will differ depending on whether the activity is conducted on a slope or flat ground, near a stormwater structure or watercourse, etc. Anticipating problems and conducting activities away from certain sensitive areas will reduce the cost and inconvenience of performing BMPs.

5. What about accidents? Pre-establishing a BMP for each conceivable pollutant discharge may be very costly and significantly disrupt construction. As a rule of thumb, establish controls for common (daily or weekly) activities and be prepared to respond quickly to accidents. Define the difference, not everything can be called an accident and maybe classified as negligent disregard of proper practices.

Therefore, keep in mind that the BMPs for contractor activities are suggested practices which may or may not apply in every case. Construction personnel should be instructed to develop additional or alternative BMPs which are more cost-effective for a particular project. The best BMP is a construction work force aware of the pollution potential of their activities and committed to a clean worksite.

1.6.4 Selection of Erosion Prevention and Sediment Control (EP&SC) Activities (Sections TCP and PESC)

Effective EP&SC management first minimizes erosion by keeping the soil protected (e.g. minimize disturbed areas) as long as possible (EP) and second, directs runoff from disturbed areas to locations where suspended soil materials can be removed prior to discharge from the site (SC). The use of source control BMPs to control erosion before its starts is the preferred method of long-term sediment control. However, on active construction areas, there may not be sufficient time for EP BMPs to become established to the point at which they are fully effective before the onset of erosive events. In these situations, SC BMPs can provide a more immediate level of protection by removing suspended sediment from flows before being transported. However, the best protection on active construction sites is generally obtained through simultaneous application of both EP BMPs and SC BMPs. This combination of controls is effective because it prevents most erosion before it starts and has the ability to capture sediments that become suspended before the transporting flows leave the construction site.

BMPs for erosion and sediment control are selected to meet the BMP objectives based on specific site conditions, construction activities, and cost-effectiveness. Different BMPs may be needed at different times during construction since construction activities are constantly changing site conditions.

The following general items are provided to aid in preparing the project plans and choosing appropriate erosion and sediment control BMPs.

1.6.4.1 Minimize Disturbed Areas

The first step for selecting BMPs is to compare the project layout and schedule with on-site management measures that, where appropriate, can limit the exposure of the project site to erosion and sedimentation. Scheduling and planning considerations are the least expensive way to limit the need for EP&SC controls. Consider the following BMPs:

1. Do not disturb any portion of the site unless an improvement is to be constructed there.

2. The staging and timing of construction can minimize the size of exposed areas and the length of time the areas are exposed and subject to erosion.

3. The staging of grading operations should limit the amount of areas exposed to erosion at any one time. Only the areas that are actively involved in cut and fill operations or are otherwise being graded should be exposed. Exposed areas should be stabilized as soon as grading is complete in that area.

4. Retain existing vegetation and ground cover where feasible, especially along watercourses and along the downstream perimeter of the site.

5. Do not clear any portion of the site until active construction begins.

6. Construct outfall detention or perimeter sedimentation control (with filter weirs/berms and temporary sedimentation control barriers first).

7. Quickly complete construction on each portion of the site.

8. Install landscaping and other improvements that permanently stabilize each part of the site immediately after the land has been graded to its final contour.

9. Minimize the amount of denuded areas and any new grading activities during the wet months of December through May.

10. Construct permanent stormwater control facilities (e.g., detention basins) early in the project and use for sediment trapping, slope stabilization, velocity reduction, etc. during the construction period.

1.6.4.2 Stabilize Disturbed Areas

The purpose of site stabilization BMPs is to prevent erosion by covering disturbed soil. This covering may be vegetative, chemical, or physical. Any exposed soil is subject to erosion—either by rainfall striking the ground, runoff flowing over the soil, wind blowing across the soil, and vehicles driving on the soil. Thus all exposed soils should be stabilized except where active construction is in progress. Locations on a construction site which are particularly subject to erosion and should be stabilized as soon as possible include:

1. Slopes
2. Highly erosive soils
3. Construction entrances
4. Stream channels
5. Soil stockpiles

1.6.4.3 Site Perimeter

1. Disturbed areas or slopes that drain toward adjacent properties, storm drain inlets or receiving waters, should be protected with temporary linear barriers (continuous berms, silt fences, sand bags, etc.) to reduce or prevent sediment discharge while construction in the area is active. In addition, the contractor should be prepared to stabilize those soils with EP measures prior to the onset of rain.

2. When grading has been completed, the areas should be protected with EP controls such as mulching, seeding, planting, or emulsifiers. The combination of EP measures and SC measures should remain in place until the area is permanently stabilized.

3. Significant offsite flows (especially concentrated flows) that drain onto disturbed areas or slopes should be controlled through use of continuous berms, earth dikes, drainage swales, and lined ditches that will allow for controlled passage or containment of flows.

4. Concentrated flows that are discharged off of the site should be controlled through outlet protection and velocity dissipation devices in order to prevent erosion of downstream areas.

5. Perimeter controls should be placed everywhere runoff enters or leaves the site. They are usually installed just before clearing, grubbing and rough grading begin. Perimeter controls for all but the smallest projects will become overloaded by both runoff and sediment. Additional controls within the interior of the construction site should supplement perimeter controls once rough grading is complete.

1.6.4.4 Internal Swales and Ditches

1. More often, flows are directed toward internal swales, curbs, and ditches. Until the permanent facilities are constructed, temporary stormwater facilities will be subjected to erosion from concentrated flows.

2. These facilities should be stabilized through temporary check dams, geotextile mats, and under extreme erosive conditions by lining with concrete.

3. Long or steep slopes should be terraced at regular intervals (per local requirements). Terraces will slow down the runoff and provide a place for small amounts of sediment to settle out.

4. Slope benches may be constructed with either ditches along them or back-sloped at a gentle angle toward the hill. These benches and ditches intercept runoff before it can reach an erosive velocity and divert it to a stable outlet.

5. Overland flow velocities can be reduced by creating a rough surface for runoff to cross (e.g. tall grass).

1.6.4.5 Internal Erosion

Once all other erosion and sediment control BMPs have been exhausted, excessive sediment should be removed from the stormwater both within and along the perimeter of the project site. The appropriate controls work on the same principle: the velocity of sediment-laden runoff is slowed by temporary barriers or traps which pond the stormwater to allow sediments to settle out. Appropriate strategies for implementing sedimentation controls include:

1. Direct sediment-laden stormwater to temporary sediment traps.

2. Locate sediment basins and traps at low points below disturbed areas.

3. Protect all existing or newly-installed storm drainage structures from sediment clogging by providing inlet protection for area drains and curb inlets.

4. Construct temporary sediment traps or ponds at the stormwater outfall(s) for the site.

5. Excavate permanent stormwater detention ponds early in the project, use them as sedimentation ponds during construction, remove accumulated sediment, and landscape the ponds when the upstream drainage area is stabilized.

6. Temporary sediment barriers such as:
   a. Continuous Berms
   b. Silt Fences
   c. Straw Bale Barriers
   d. Sand Bag Barriers
   e. Brush or Rock Filter

   These barriers should only be used in areas where sheet flow runoff occurs. They are less effective or ineffective if the runoff is concentrated into rill or gully flow.

1.6.4.6 Stormwater Inlets and Outfalls

1. Stormwater inlets, including drop inlets, and pipe inlets, should be protected from sediment intrusion if the area draining to the inlet has been disturbed.

2. Stormwater inlet protection can utilize sand bags, sediment traps, or other similar devices.

3. Internal outfalls must also be protected to reduce scour from high velocity flows leaving pipes or other drainage facilities.

1.6.5 Selection of Permanent Treatment Practices (Sections PESC and PTP)

Most permanent BMPs will be proposed by the developer early in the planning stage of a project. For most projects, there will be no single BMP which addresses all the long-term stormwater quality problems. Instead, a multi-level strategy will be worked out with Metro Water Services, which incorporates source controls, a series of on-site treatment controls, and community-wide treatment controls. This was demonstrated in Section 1.6.2 in the discussion on the BMP Treatment Train.

In most cases permanent BMPs can be implemented most effectively when they can be integrated into other aspects of the project design. This requires that conceptual planning consider stormwater controls rather than as an afterthought to site design. The following should be considered early in the design process.

1. Is a detention/retention facility required for flood control? Often, facilities are required to maintain peak runoff at predevelopment levels to reduce downstream conveyance system damage and other costs associated with flooding. Most permanent BMPs can be incorporated into flood control detention/retention facilities with modest design refinements and limited increases in land area and cost.

2. Planned open space which will be relatively flat (e.g., final grade slopes less than 5 percent) may be merged with stormwater quality/quantity facilities. Such integrated, multi-use areas may achieve several objectives at a modest cost.

3. Infiltration BMPs may serve as groundwater recharge facilities, detention/retention areas may be created in landscaped areas of the project, and vegetated swales/filters may be used as roadside/median or parking lot median vegetated areas.

References

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SECTION 6
PERMANENT TREATMENT PRACTICES (PTP)

Section 6
PERMANENT TREATMENT PRACTICES
(PTP)

6.1 Introduction

This section presents the BMP fact sheets for Permanent Treatment Practices (PTP). PTPs are intended to treat stormwater runoff in the long-term. Some of these BMPs can be designed to achieve both stormwater quantity and quality management objectives.

This section contains the following BMP fact sheets.

PTP – 01	Stormwater Wet Ponds
PTP – 02	Constructed Wetlands
PTP – 03	Bioretention
PTP – 04	Surface Sand Filters
PTP – 05	Water Quality Swales
PTP – 06	Dry Ponds
PTP – 07	Filter Strips
PTP – 08	Grass Channels
PTP – 09	Greenroofs
PTP – 10	Underground Sand Filters
PTP – 11	Perimeter Sand Filters
PTP – 12	Organic Filters
PTP – 13	Gravity (Oil-Grit) Separators
PTP – 14	Infiltration Trenches
PTP – 15	Permeable Pavements

Each fact sheet has a quick reference guide indicating what pollutant constituents the BMP is targeting and implementation requirements.

The BMPs presented in this section are intended to serve as permanent treatment measures. Additional details are provided in sections covering Temporary Construction Site Management Practices (TCPs) for practices that are intended to function on a short-term basis (lasting only as long as construction activities) and covering Permanent Erosion Prevention and Sediment Control (PESC) that are intended to function on a long-term basis.

The BMPs found in the PTP section are listed in Table 1. BMPs have been categorized as either General Application or Limited Application BMPs. General Application BMPs meet the post-construction water quality program's pollutant reduction goal by themselves, if designed, built, and maintained according to MWS specifications. On the other hand, Limited Application BMPs, may only be suitable for some sites for one or more reasons: 1) they do not meet the pollutant reduction goal of 80 percent TSS removal 2) they are only suitable for sites with certain conditions 3) they require intensive and or frequent maintenance in order to function properly.

Since some BMPs do not have established removal data, and new structural BMPs are being introduced in to the market every year, Metro has established a set of testing standards, requirements and protocol in order that qualifying devices may be added to Metro's pre-approved BMP list.

Structural Stormwater Control Removal Efficiency for Total Suspended Solids (TSS)	
Structural Control	**TSS Removal (%)**
General Application Structural Stormwater Controls	
Stormwater Pond	80
Stormwater Wetland	80
Bioretention Area	80
Surface Sand Filter	80
Water Quality Swales	80
Limited Application Structural Stormwater Controls	
Filter Strip	50
Grass Channel	50
Organic Filter	80
Underground Sand Filter	80
Infiltration Trench	80
Gravity (Oil-Grit) Separator	40
Proprietary Structural Control	Based on Testing (see Volume 1, Section 7.5)
Dry Detention / Dry ED Basin	60
Perimeter Sand Filter	80

6.2 Calculations for BMPs in a Series

Some BMPs that do not meet Metro's pollutant reduction goal alone, and may be used with another BMP to meet the goal. That is, water may pass through one treatment device, into another in a "treatment train" to achieve added treatment. It is necessary to calculate the cumulative pollutant removal from BMPs in a series with an equation that accounts for the fact that the majority of the heavy (easily removed) suspended pollutants and particulate matter are removed by the first structural control in a series. The runoff that enters the second and subsequent controls contains sediment with much smaller particles, which are more difficult for the control to remove. Thus, the second control has a pollutant removal efficiency that is less than it would ordinarily have. The following equation accounts for the cumulative pollutant removal of BMPs in a series.

$$\boldsymbol{TR = A + (1 - A) * B}$$

Where:
TR = Total Removal
A = 1st structural control in series
B = 2nd structural control in series

Notes:
1) When runoff flows from a more efficient structure (one with a higher removal rate) to a less efficient structure (one with a lower removal rate), the cumulative pollutant removal of a structure does not increase. The reason is that a structure with a lower removal efficiency that follows a structure with a higher removal efficiency does not have an appreciable affect on cumulative pollutant reduction.

6.2.1 Example Calculation

A site is planned to have a manufactured pretreatment device that ia pprovde for a 50% TSS removal credit, followed by a dry detention basin designed, built, and maintained as required by Metro regulations to achieve a 60% removal credit. The calculation is as follows:

$$TR = A_{MD} + (1 - A_{MD}) * B_{DD}$$

Where:
TR = Total Removal
A_{MD} = 1st structural control—manufactured device
B_{DD} = 2nd structural control—dry detention basin

TR = 0.5 + (1-0.5)*0.6
TR = 0.5 + (0.5)*0.6
TR = 0.5 + 0.3
TR = 0.8

Total Removal equals 80%. The site meets Metro’s requirements of 80% TSS removal for the site.

Wet Ponds

Description: Constructed stormwater detention basin that has a permanent pool (or micropool). Runoff from each rain event is captured and treated in the pool primarily through settling and biological uptake mechanisms.

Variations: Wet extended detention, micropool extended detention, multiple pond system.

Components:

- Permanent pool – prevents resuspension of solids
- Live storage above permanent pool – sized for a percentage of water quality volume and flow attenuation. Percentage depends on type of wet pond chosen
- Forebay – settles out larger sediments in an area where sediment removal will be easier
- Spillway system – spillway system(s) provides outlet for stormwater runoff when large storm events occur and maintains the permanent pool

Advantages/Benefits:

- Moderate to high pollutant removal
- Can be designed as a multi-functional BMP
- Cost effective
- Can be designed as an amenity within a development
- Wildlife habitat potential
- High community acceptance when integrated into a development

Disadvantages/Limitations:

- Potential for thermal impacts downstream
- May require additional permitting through TDEC for ARAP or Safe Dams
- Community perceived concerns with mosquitoes and safety

Design considerations:

- Minimum contributing drainage area of 25 acres; 10 acres for micropool extended detention (Unless water balance calculations show support of permanent pool by a smaller drainage area)
- Sediment forebay or equivalent pretreatment must be provided
- Minimum length to width ratio = 3:1
- Maximum depth of permanent pool = 8’
- 3:1 side slopes or flatter around pond perimeter

Selection Criteria:

- ✓ **Water Quality 80 % TSS Removal**
- ✓ **Quantity Control**

Land Use Considerations:

- ✓ **Residential**
- ✓ **Commercial**
- ✓ **Industrial**

Maintenance:

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

M — **Maintenance Burden**

L = Low M = Moderate H = High

General Description

Stormwater ponds are constructed stormwater basins that can be designed to serve multiple functions, including stormwater quality treatment, peak flow attenuation, and wildlife habitat creation. Stormwater quality treatment is achieved in the storage provided both within the permanent pool and the live pool volume, depending on the type of wet pond design. The permanent pool (or micropool for micropool extended detention design) provides the majority of the volume used for settling particulates. A well-designed and landscaped pond can be an aesthetic feature when planned and located properly.

Figure 1.1 illustrates a typical wet pond, showing the components found in the pond variations, described in the next section. Figures 1.2, 1.3, and 1.4 are schematics for wet pond variations that are allowed in Metro.

Stormwater wet ponds must be designed by a licensed professional engineer.

Components

Sediment forebay. The forebay is a pretreatment BMP that allows heavier sediments to settle out before they reach the permanent pool. Often, the floor of the forebay is concrete or other hardened surface so that periodic sediment removal is easier. The forebay treatment area can provide for a portion of the required water quality treatment volume for a site.

Permanent pool. The permanent pool, or dead storage, provides the mechanism for settling out solids from stormwater runoff, as well as providing the setting for biological uptake of some pollutants. As new stormwater runoff enters the permanent pool, stormwater stored in the permanent pool is replaced. A micropool is a type of permanent pool

Live storage. The storage area provided above the permanent pool is used to capture and slowly release the first flush volume. In some pond variations, such as the wet extended detention pond, the water quality treatment volume is split between the permanent pool and the live storage area. Larger storm events can also be treated for peak flow attenuation within the live storage volume.

Spillway systems. Spillway systems are typically made up of emergency spillways and primary spillway systems, designed as channels, riser and barrel structures, or a combination of the two. Spillway systems for wet ponds typically have multiple outlets to control different design storms. The spillway system must also include an emergency drain to allow complete draining of the pond within 24 hours.

Design Variations

The following design variations are allowed as stormwater quality treatment BMPs in Metro:

Design Variations (continued)

Wet pond. Stormwater wet ponds are built with a permanent pool, or dead storage, equal to the water quality volume. Stormwater runoff displaces the water already in the pool. Temporary storage is provided above the permanent pool elevation for attenuation of larger storm events.

Wet extended detention (ED) pond. In a wet extended detention (ED) pond, the water quality volume is split evenly between the permanent pool and extended detention (ED) storage provided above the permanent pool. During storm events, water is detained above the permanent pool elevation for 24-48 hours. This design provides the same pollutant reduction but consumes less space.

Micropool extended detention pond. Variation of the ED pond, where a micropool is maintained below the outlet of the pond. The micropool volume is calculated as 0.1 inch per impervious acre or 20% of the water quality volume (WQ_v), whichever is greater. The remainder of the required water quality volume is stored above the micropool in the live pool storage. The micropool prevents resuspension of solids and prevents clogging of low flow orifices. The live pool storage above the micropool is also used for the attenuation of larger storm events. The water quality volume stored in the live pool area must be detained for 24 hours. This pond most resembles the "dry pond" design. The difference in this style pond and the wet ED pond is the storage location of the water quality volume (WQ_v).

Multiple pond systems. Multiple ponds in series, that provide longer flow paths and two or more storage cells for water quality and quantity treatment. Pollutant reduction of ponds in series provides more than 80% TSS removal (see Volume 4, Section 6 Introduction, section 6.2 for guidance on pollutant removal reductions for BMPs in series).

Site and Design Considerations

The following design and site considerations must be incorporated into the BMP plan:

General design

1. A licensed professional engineer must design all types of wet ponds.
2. Ponds must not be constructed in or located on a stream.
3. All components of a stormwater wet pond, including access, must be located in a drainage easement.
4. Access to the forebay, permanent pool and spillways must be considered in the planning and design. Permanent access must be provided from a public road and maintained throughout the life of the structure.
5. A minimum drainage area of 25 acres is needed for wet ponds and wet ED ponds to maintain the permanent pool. The minimum drainage area for micropool ED ponds is 10 acres. A smaller drainage area may be acceptable with an adequate water balance (refer to PTP-02 *Constructed Wetlands*

Site and Design Considerations (continued)

Design Procedures Step #2 for water balance calculations) and an anti-clogging pond outlet.

6. The space required to construct a wet pond is approximately 2-3% of the tributary drainage area.
7. Stormwater ponds should be located to provide for maximum runoff storage at a minimal construction cost.
8. Stormwater ponds should not be located on slopes that are equal to or greater than 15%.

Pretreatment

9. All stormwater ponds must incorporate a sediment forebay or pretreatment device at the point or points of inflow. The purpose of the pretreatment is to settle out heavier solids in an area that is easier to clean out than the permanent pool.
10. The forebay must consist of a separate cell from the permanent pool, separated by an acceptable barrier.
    a. For maintenance purposes in larger ponds, the bottom of the forebay should be hardened (e.g., concrete lined) to make sediment removal easier and width of the forebay should accommodate a small piece of equipment, such as a Bobcat.
    b. The forebay must be sized to contain 0.1 inches per impervious acre contributing drainage and should be a minimum of 4-6 feet deep. The forebay storage volume counts toward the total WQ_v requirement and may be subtracted from the WQ_v for subsequent calculations.
    c. A fixed vertical sediment depth marker must be installed in the forebay to visually indicate sediment depth over time.
    d. Exit velocities from the forebay must be non-erosive.
11. Although forebays are preferred for pretreatment because they require less maintenance, other acceptable pretreatment devices include baffle boxes or stormwater quality inlets.

Permanent Pool

12. The maximum depth of the permanent pool is 8 feet. The objective is to avoid thermal stratification that could result in odor problems associated with anaerobic conditions.
13. In general, stormwater pond designs will be unique for each site. However, the following should be observed to meet the pollutant removal goals:
    a. Permanent pool:
        - Standard wet ponds: 100% of the water quality treatment volume (1.0 WQ_v).
        - Wet ED pond: 50% of the water quality treatment volume (0.5 WQ_v), the other 50% is accounted for in the live pool volume.
        - Micropool pond: Approximately 0.1 inch per impervious acre or 20% of the water quality treatment volume (0.1 IA) or (0.2 WQ_v), whichever is greater.

Site and Design Considerations (continued)

b. Short-circuiting of the pond should be avoided by designing stormwater ponds with a length to width ratio of 3:1 or greater. Baffles, pond shaping, or islands can be added to the permanent pool area to create a longer flow path.

c. Side slopes of the pond should not exceed 3H:1V, or additional safety precautions must be provided, and should terminate on a safety bench (see Figure 1.5). The safety bench requirement may be waived if the side slopes are 4H:1V or flatter.

14. The perimeter of all pool areas that are 6 feet or deeper must be surrounded by two benches: a safety bench and an aquatic bench. The safety bench extends at least 15 feet outward from the permanent pool water edge to the toe of the pond slope. The maximum slope of the safety bench is 6%. The aquatic bench should extend inward from the permanent pool edge a minimum of 15 feet and should have a maximum depth of 18 inches below the permanent pool surface elevation.
15. Bedrock must be considered in the Nashville area because excavation may be required for a permanent pool. If there is highly fractured bedrock or karst topography, then the feasibility of a wet pond should be carefully considered because it may not hold water and the additional water flow and/or weight could intensify karst activity.
16. To maintain a permanent pool, excessive losses through infiltration must be avoided. Depending on the soils, infiltration losses can be minimized through compaction, the addition of a clay liner or an artificial liner.

Live Pool

17. Live pool volumes are dependent upon the need for storm attenuation. Hydrograph routing must be completed for the 2- through 100-year events to determine the required volume and to demonstrate that post-construction flow rates are equal to or smaller than pre-construction rates for each event. Wet ED ponds and micropool ED ponds require that a percentage of the WQ_v be treated in the live-pool volume. This volume can also be included as volume required for storm attenuation.

Outlet Structures

18. Flow control from a stormwater pond is typically accomplished with the use of a concrete or corrugated metal riser and barrel. The riser should be located within the stormwater pond embankment for maintenance access, safety, floatation prevention, and aesthetics. See Figures 1.6 through 1.8 for typical pond outlet structures.
19. To control different storm events, outlets at varying elevations on the riser pipe should be used. The number of orifices varies and is usually a function of the pond design parameters. Additional information for outlet design is provided in Volume 2, Chapter 8.

Site and Design Considerations (continued)

For example, a wet pond riser configuration is typically comprised of multiple small storm outlets (usually orifices) and the 25- and 100- year outlets (often slots or weirs).

20. Water quality outlet designs require additional outlet configurations, separate from the storm attenuation/flood control outlet. For wet ponds, the water quality volume is fully contained in the permanent pool, no additional orifice sizing is necessary for this volume. For larger volumes, orifice sizing guidance is included in the Design Procedures and Figures 1.8 and 1.9. As runoff from a water quality event enters the wet pond, it simply displaces that same volume through a smaller storm event orifice. Thus an off-line wet pond providing *only* water quality treatment can use a simple overflow weir as the outlet structure. On-line wet ponds may or may not require multi-stage riser configurations, depending on the need for storm attenuation. In the case of wet ED ponds and micropool ED ponds, there is an additional outlet (usually an orifice) that is sized to pass the extended detention water quality volume on top of the permanent pool. Flow will first pass through this orifice, which is sized to release the water quality ED volume in 24-48 hours. The preferred design is a reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond. The next outlet is sized for the release of other smaller storm events (2- or 10-yr). The primary outlet (often an orifice) invert is located at the maximum elevation associated with the extended detention water quality volume and is sized through routing to release flow at or below the pre-100-yr levels.

    The following types of orifices that may be encountered in a typical pond design are as follows:
    1. Pond drain (to allow maintenance and construction)
    2. Permanent pool orifice (to control volume and allow drawdown)
    3. WQ_v orifice (for ED and MicroPool to control live pool elevation)
    4. Outlets at required flow attenuation levels to control peaks.

    Alternative hydraulic control methods to an orifice can be used and include the use of a broad-crested rectangular, V-notch, or proportional weir, or an outlet pipe protected by a hood that extends at least 12 inches below the permanent pool.
21. The water quality outlet (if designed for a wet ED or micropool ED pond) must be fitted with adjustable gate valves or other mechanism that can be used to adjust detention time.
22. Higher flows pass through openings or slots protected by trash racks further up the riser.
23. Anti-seep collars must be installed on the outlet barrel and an anti-vortex device must be incorporated into the outlet barrel. An energy dissipater must be installed at the stormwater pond pipe outlet to prevent scour at the outlet.

Site and Design Considerations (Continued)

24. Stormwater ponds must have a bottom drain with an adjustable valve that can completely drain the pond within 24 hours. The pond drain should be sized one pipe size larger than the calculated design diameter. The drain valve is typically a handwheel activated knife or gate valve. Valve controls must be located inside of the riser at a point where they will not likely be inundated and can be operated in a safe manner.
25. Access to the riser must be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

Outlet Design Considerations

26. Proper hydraulic design of the outlet is critical to achieving good performance of the stormwater pond. The two most common outlet problems that occur are: 1) the capacity of the outlet is too great resulting in partial filling of the basin and less than the intended drawdown time and 2) the outlet clogs because it is not adequately protected against trash and debris. To avoid these problems, two alternative outlet types are recommended for use: 1) Notched weir and 2) perforated riser. The notched weir will not clog as easily, and is therefore preferred. Details for designing outlets/orifices are found in the Design Procedures Step # 6 and in Volume 2, Chapter 8.

Emergency spillway

27. An emergency spillway must be included in the stormwater pond design to safely pass large storm events. The spillway prevents overtopping of the embankment in large storm events and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
28. A minimum of 2 feet of freeboard must be provided, measured from the top of the water surface elevation for the 100-year storm event to the lowest point on the top of berm. The emergency spillway crest elevation will be slightly below the 100-year storm elevation, determined by the amount of flow calculated over the weir to match post- to pre-conditions.

Landscaping

29. Aquatic vegetation can play an important role in pollutant removal in a stormwater pond. In addition, vegetation can enhance the appearance of the pond, stabilize the side slopes and serve as wildlife habitat. Therefore, wetland plants are encouraged in a pond design, along with the aquatic bench (fringe wetlands), the safety bench and side slopes, and within shallow areas of the pool itself. The best elevations for establishing wetland plants, either by transplantation or volunteer colonization, are within 6 inches (plus or minus) of the permanent pool elevation. Information about wetland plants can be found at TVA's Native Plant Selector that can be found at: http://www.tva.gov/river/landandshore/stabilization/plantsearch.htm.
30. Woody vegetation must not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment and within 25 feet from the principle spillway.

Site and Design Considerations (Continued)

31. Fish such as *Gambusia affinis* can be stocked for mosquito control if necessary.
32. A fountain or aerator may be beneficial for oxygenating water in the permanent pool. Considerations must be given in the design of this fountain or aerator not to disturb settling within the pond or prevent settling. Use of such fountains is discouraged during storm events.

As-Built Certification

An as-built certification of the pond by a registered professional engineer, must be submitted to Metro prior to the release of the site's bond or issuance of a Use and Occupancy permit. The as-built certification must verify that the BMP was installed as designed and approved. If components of the stormwater pond constructed in the field differ from the design approved by Metro, the as-built certification must:

1. Note any differences between the measure in the field and the design approved by Metro;
2. Demonstrate that the design meets the requirements of Metro's stormwater program; and/or
3. Propose additional measures to be included on the site to mitigate the differences.

The following components should be addressed in the as-built certification:

- Sediment forebay of sufficient size to pretreat runoff.
- Access to all components of the pond.
- Sufficient water depth to prevent the creation of stagnant water.
- Depth of treatment area.
- Side slopes and benches created as noted in the plans.
- Properly functioning spillway systems.

Operation and Maintenance

Each BMP on a site must be addressed in the overall Operations and Maintenance (O&M) Agreement (refer to Volume 1, Appendix C) for the development and submitted to Metro for approval with the plans submittal. This information should be included in the O&M Agreement for the development.

The O&M Agreement is to be used by the BMP owner or owners in performing routine inspections. The owner is responsible for the cost of maintenance and annual inspections, and maintaining and updating the BMP operations and maintenance plan at least annually. At a minimum, the operations and maintenance plan must address:

1. The inspection of the embankment and spillway components;
2. The removal of sediment deposits from the forebay and permanent pool area;
3. The removal of spillway blockages or dead vegetation.

Design Procedures

Design Procedures for standard wet pond, extended detention, and micropool extended detention ponds are described separately below. Some of the steps for extended detention and micropool extended detention ponds are the same as for a standard wet pond and these common steps will refer back to the standard wet pond design steps.

Design Procedures for Wet Pond

Wet Pond

Step 1. Compute the Water Quality Volume.

Calculate (WQ_v).

$$WQ_v = P \times Rv \times A/12$$

Where:

WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.015 + 0.0092I$$

Where:

I = site impervious cover, % (for example, 50% imperviousness is 50)

Step 2. Determine if the development site and conditions are appropriate for the use of the wet pond.

Consider the Site and Design Considerations discussed previously in this section. Available land area and drainage area are key components.

Step 3. Determine pretreatment volume.

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

$$F_v = 0\ .1 \text{ inches} \times A_I \text{ acres} \times .0833$$

Where:

F_v = Forebay volume (ac-ft)
A_I = Impervious area of drainage basin, acres
0.0833 = conversion factor of acre inches to acre feet

Design Procedures for Wet Pond (Continued)

Often, it is more manageable to work with forebay volumes in cubic feet rather than acre feet, because they are small volumes. To convert F_v in acre feet to cubic feet, multiply F_v by 43560 square feet.

Step 4. Determine permanent pool volume.

Size permanent pool volume to 1.0 WQ_v.

Step 5. Determine pond preliminary geometry and storage available for pool areas.

Establish contours and determine the stage-storage relationship for the pond. Include safety and aquatic benches. Any live pool volume is dependent on the necessity for flow attenuation only. If no flow attenuation is necessary, no live pool is necessary.

Step 6. Size the outlet system for other storm events.

If the pond is to serve as a multifunctional pond addressing flow attenuation, the downstream impacts must be considered for the 2- through 100-year storm events. Determine the downstream point in the watershed where the proposed site makes up 10% or less of the total drainage area to the point in question (considered the 10% point). Check the peak discharge for pre- and post-development runoff rates at the 10% point and at major junctions within the downstream watershed. Where an increase is realized, the stormwater pond can be designed for flow attenuation to the pre-development runoff rate or less through the use of multiple orifices in the primary spillway structure. (See Volume 2, Chapter 8).

Establish a stage-storage-discharge relationship for the design storms of interest, based upon the downstream analysis (see Section 6.6.1 in Volume 1).

Step 7. Design embankment and spillway.

Size emergency spillway for any overtopping of pond in case of rain event in excess of 100-year and for instances of malfunction/clogging of primary outlet structure.

Step 8. Investigate potential dam hazard classification.

The design and construction of ponds in Tennessee must follow the requirements of the Safe Dams Act. Contact the Tennessee Department of Environment and Conservation, Division of Water Supply for more information about building dams in Tennessee.

Design Procedures for Wet Pond (Continued)

Step 9. Design inlets, sediment forebays, outlet structures, maintenance access and safety features.

See the *Site and Design Considerations* section for information on design.

Step 10. Prepare the vegetation and landscaping plan.

See the Landscaping section of *Site and Design Considerations* section.

Design Procedures for Wet Extended Detention (ED) Pond

Wet Extended Detention (ED) Pond

Step 1. Compute the Water Quality Volume.

Calculate (WQ_v).

$$WQ_v = P \times Rv \times A/12$$

Where:

WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.015 + 0.0092I$$

Where:

I = site impervious cover, % (for example, 50% imperviousness is 50)

Step 2. Determine if the development site and conditions are appropriate for the use of the wet ED pond.

See standard Wet Pond Design Procedures Step 2.

Step 3. Determine pretreatment volume.

See standard Wet Pond Design Procedures Step 3.

Step 4. Determine permanent pool volume.

Size permanent pool volume to 0.5 WQ_v. Size extended detention volume to 0.5 WQ_v.

Design Procedures for Wet Extended Detention (ED) Pond (Continued)

Step 5. Determine pond preliminary geometry and storage available for pool areas.

Establish contours and determine the stage-storage relationship for the pond. Include safety and aquatic benches.

Set permanent pool elevation and live pool elevation based on volume calculated previously.

Step 6. Compute extended detention orifice release rate(s).

Based on the elevations established in Step 5 for the extended portion of the water quality volume, the water quality orifice is sized to release this extended detention volume in 24-48 hours. The water quality orifice should have a minimum diameter of 3 inches or use the perforated riser pipe and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool, is a recommended design. Adjustable gate valves can also be used to achieve this equivalent diameter.

Three different types of control structures are listed below. More information can be found on the design of outlet structures in Volume 2, Chapter 8.

Flow Control Using a "V" Notch Weir
The outlet control "V" notch weir should be sized using the following formula (Metro, 2000). See Figure 1.8

$$Q = C_1 H^{5/2} \tan\left(\frac{\theta}{2}\right)$$

Where

θ = notch angle, in degrees
H = head or elevation of water over the weir, ft
C_1 = discharge coefficient (see Figure 1.9)

The notch angle should be 20^o or more. If calculations show that a notch angle of less than 20^o is appropriate, then the outlet should be designed as a uniform width notch. This will generally necessitate some sort of floatables control such as a skimmer on the outlet or trash rack on the inlet.

Flow Control Using a Single Orifice
The outlet control orifice should be sized using the following equation (Metro, 2000).

$$a = \frac{2A(H - H_o)^{0.5}}{3600CT(2g)^{0.5}}$$

Design Procedures for Wet Extended Detention (ED) Pond (Continued)

Where:
a = area of orifice (ft^2)
A = average surface area of the pond (ft^2)
C = orifice coefficient, 0.66 or 0.80
T = drawdown time of pond (hrs)(must be greater than 24 hours)
g = gravity (32.2 ft/sec^2)
H = elevation when pond in full (ft)
H_o= final elevation when pond is at permanent pool elevation (ft)

With a drawdown time of 40 hours the equation becomes:

$$a = \frac{(1.75x10^{-5})A(H-H_o)^{0.5}}{CT}$$

Care must be taken in the selection of “C”: 0.60 is most often recommended and used. However, based on actual tests the following is recommended:

C = 0.66 for thin materials, that is, the thickness is equal to or less than orifice diameter
C= 0.80 when the material is thicker than the orifice diameter

Drilling the orifice into an outlet structure that is made of concrete can result in considerable impact on the coefficient, as does the beveling of the edge.

Flow Control Using the Perforated Riser
For outlet control using the perforated riser as the outflow control, incorporate flow control for the small storms in the perforated riser but also provide an overflow outlet for large storms, as illustrated in Figure 1.10. If properly designed, see Table 1.1, the facility can be used for both water quality and quantity control by: 1) sizing the perforated riser as indicated for water quality control; 2) sizing the outlet pipe to control peak outflow rate from the 2-year storm; and 3) using a spillway in the pond berm to control the discharge from larger storms up to the 100-year storm. To prevent clogging of an orifice and the bottom orifices of the riser pipe, wrap the bottom three rows of orifices with geotextile fabric and a cone of one to three inch rock.

Table 1.1 Perforated Riser Sizing Guidance *(Metro, 2000)*

Riser Pipe Diameter	Vertical Spacing Between Rows (Center to Center)	Number of Perforations	Perforation Diameter
6 in. (15.2 cm)	2.5 in. (6.4 cm)	9 per row	1 in. (2.54 cm)
8 in. (20.3 cm)	2.5 in. (6.4 cm)	12 per row	1 in. (2.54 cm)
10 in. (25.4 cm)	2.5 in. (6.4 cm)	16 per row	1 in. (2.54 cm)

Design Procedures for Wet Extended Detention (ED) Pond (Continued)

Step 7. Size the primary spillway system for other storm events.

See standard Wet Pond Design Procedures Step 6.

Step 8. Design embankment and spillway.

Size emergency spillway for any overtopping of pond in case of rain event in excess of 100-year and for instances of malfunction/clogging of primary outlet structure.

Step 9. Investigate potential dam hazard classification.

The design and construction of ponds in Tennessee must follow the requirements of the Safe Dams Act. Contact the Tennessee Department of Environment and Conservation, Division of Water Supply for more information about building dams in Tennessee.

Step 10. Design inlets, sediment forebays, outlet structures, maintenance access and safety features.

See the *Site and Design Considerations* section for information on designing these features

Step 11. Prepare the vegetation and landscaping plan.

See the Landscaping section of *Site and Design Considerations* section.

Design Procedures for Micropool ED Pond

Micropool ED Pond

Step 1. Compute the Water Quality Volume.

Calculate (WQ_v).

$$\mathbf{WQ_v = P \times Rv \times A/12}$$

Where:

WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.015 + 0.0092I$$

Where:

I = site impervious cover, % (for example, 50% imperviousness is 50)

Design Procedures for Micropool ED Pond (Continued)

Step 2. Determine if the development site and conditions are appropriate for the use of the wet pond.

See standard Wet Pond Design Procedures Step 2.

Step 3. Determine pretreatment volume.

See standard Wet Pond Design Procedures Step 3.

Step 4. Determine permanent pool volume.

Size permanent pool volume to minimum of either 20% of WQ_v or 0.1 inch per impervious acre. Size extended detention volume (live pool) to remainder of WQ_v.

Step 5. Determine pond preliminary geometry and storage available for pool areas.

Establish contours and determine the stage-storage relationship for the pond. Include safety and aquatic benches.

Set micropool permanent pool elevation and live pool elevation based on volume calculated previously.

Step 6. Compute extended detention orifice release rate(s).

See standard Wet ED Design Procedures Step 6.

Step 7. Size the primary spillway system for other storm events.

See standard Wet Pond Design Procedures Step 6.

Step 8. Design embankment and spillway.

Size emergency spillway for any overtopping of pond in case of rain event in excess of 100-year and for instances of malfunction/clogging of primary outlet structure.

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Size emergency spillway for any overtopping of pond in case of rain event in excess of 100-year and for instances of malfunction/clogging of primary outlet structure.

Design Procedures for Micropool ED Pond (continued)

Step 9. Investigate potential dam hazard classification.

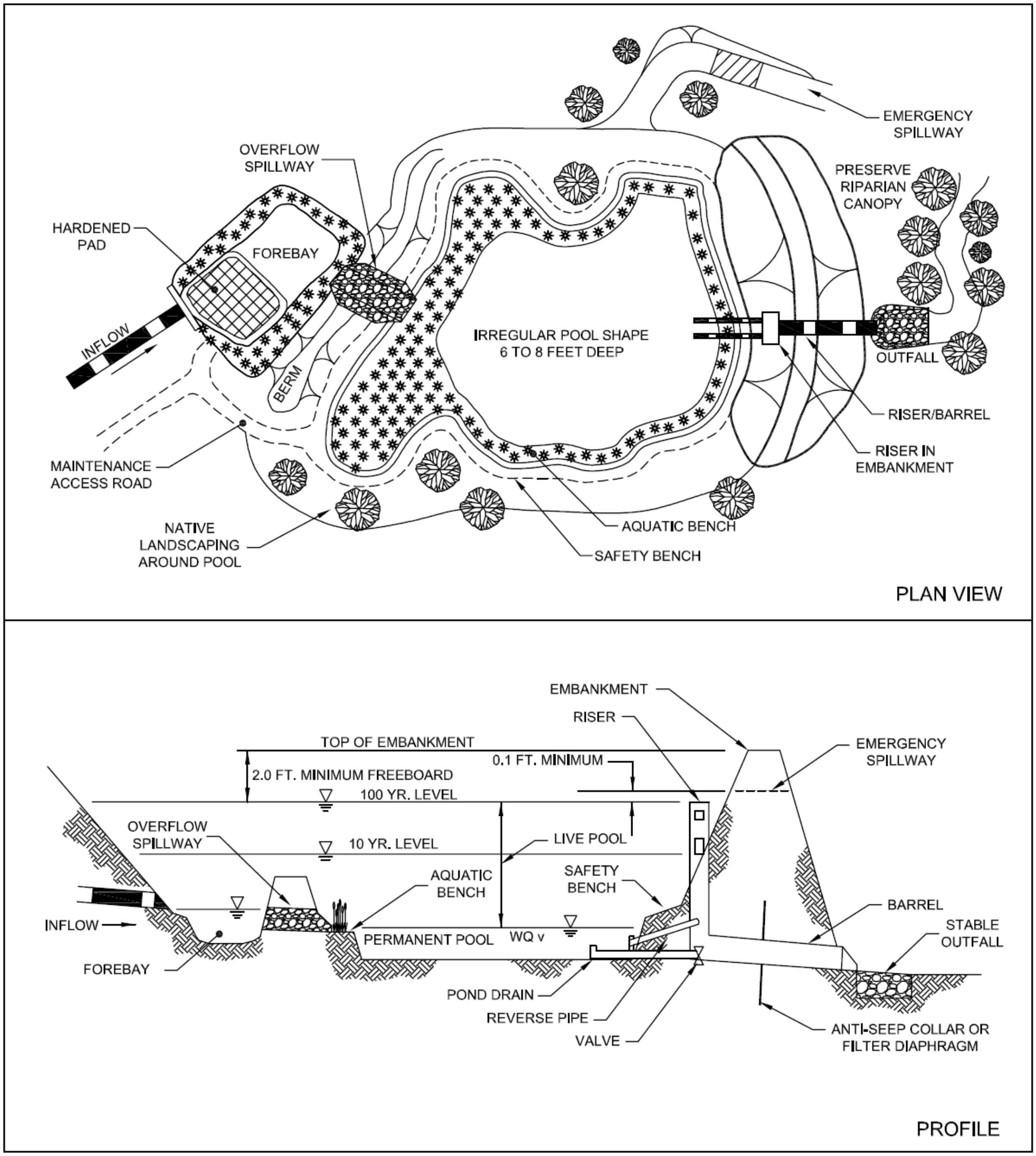
The design and construction of ponds in Tennessee must follow the requirements of the Safe Dams Act. Contact the Tennessee Department of Environment and Conservation, Division of Water Supply for more information about building dams in Tennessee.

Step 10. Design inlets, sediment forebays, outlet structures, maintenance access and safety features.

See the *Site and Design Considerations* section for information on designing these features.

Step 11. Prepare the vegetation and landscaping plan.

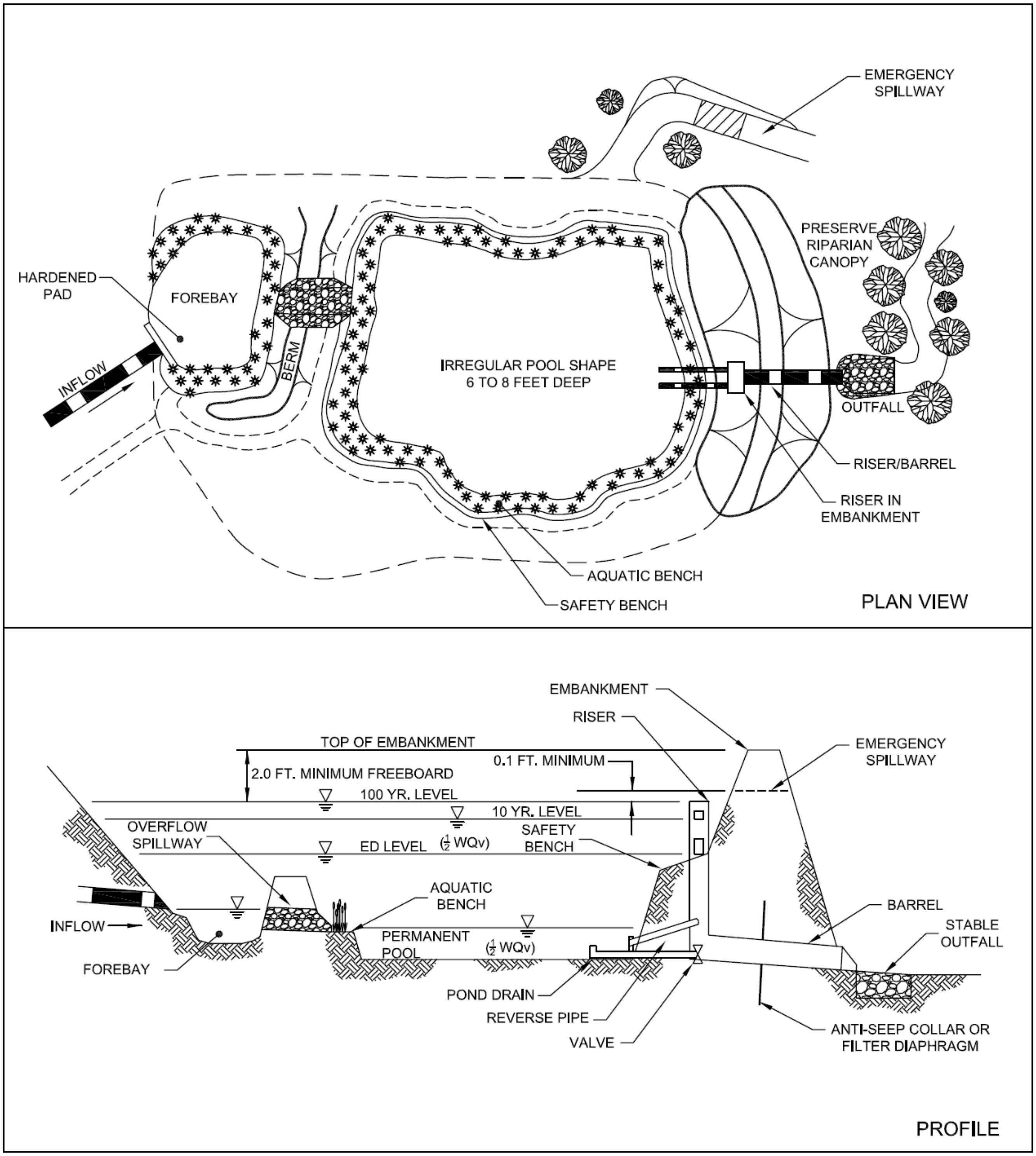
See the Landscaping section of *Site and Design Considerations* section.



Note: Storm attenuation levels vary depending on site detention requirements.

(Adapted from the Center for Watershed Protection)

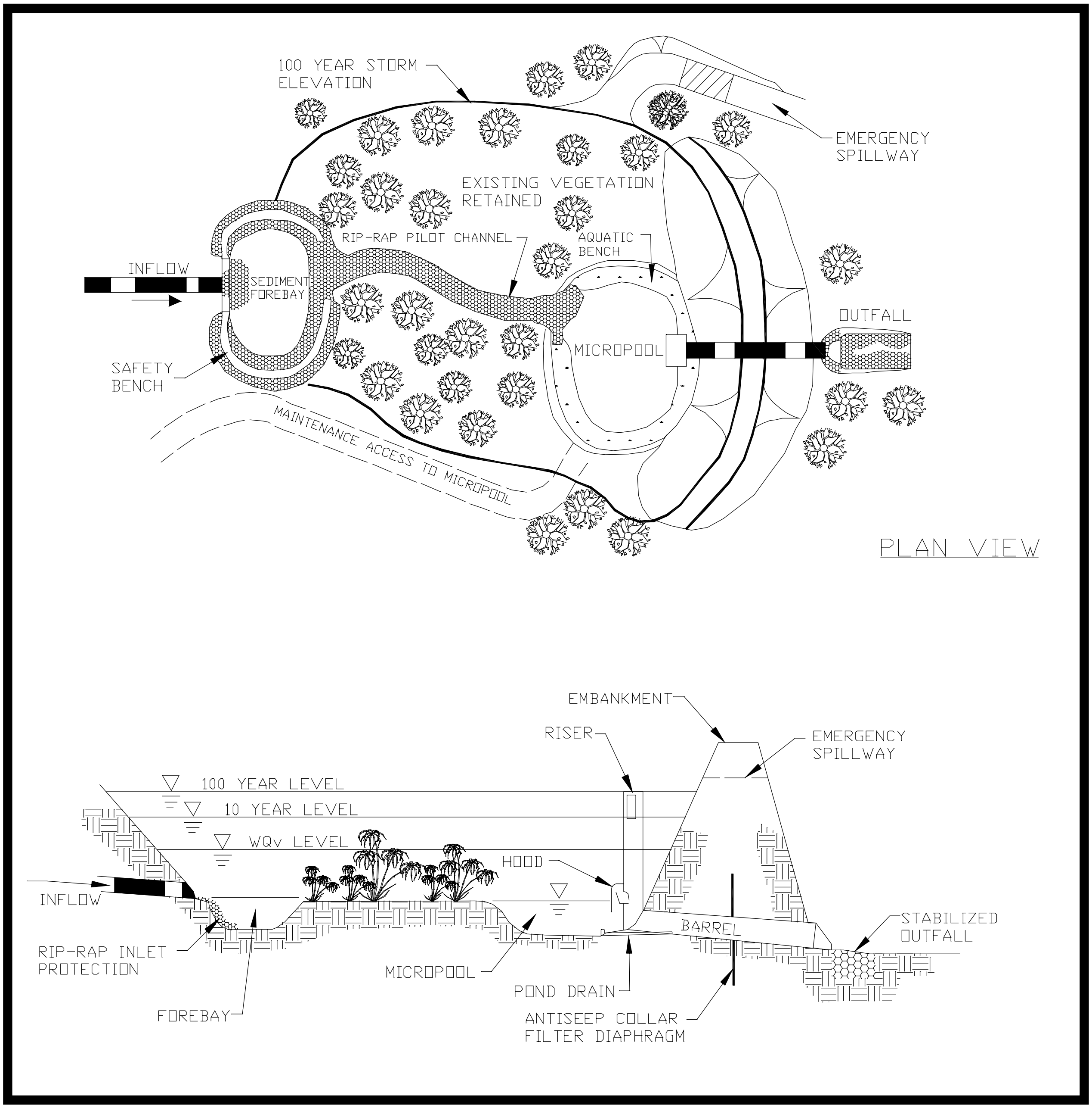
Figure 1.1 Typical Schematic for a Wet Pond



Note: Storm attenuation levels vary depending on site detention requirements.

(Adapted from the Center for Watershed Protection)

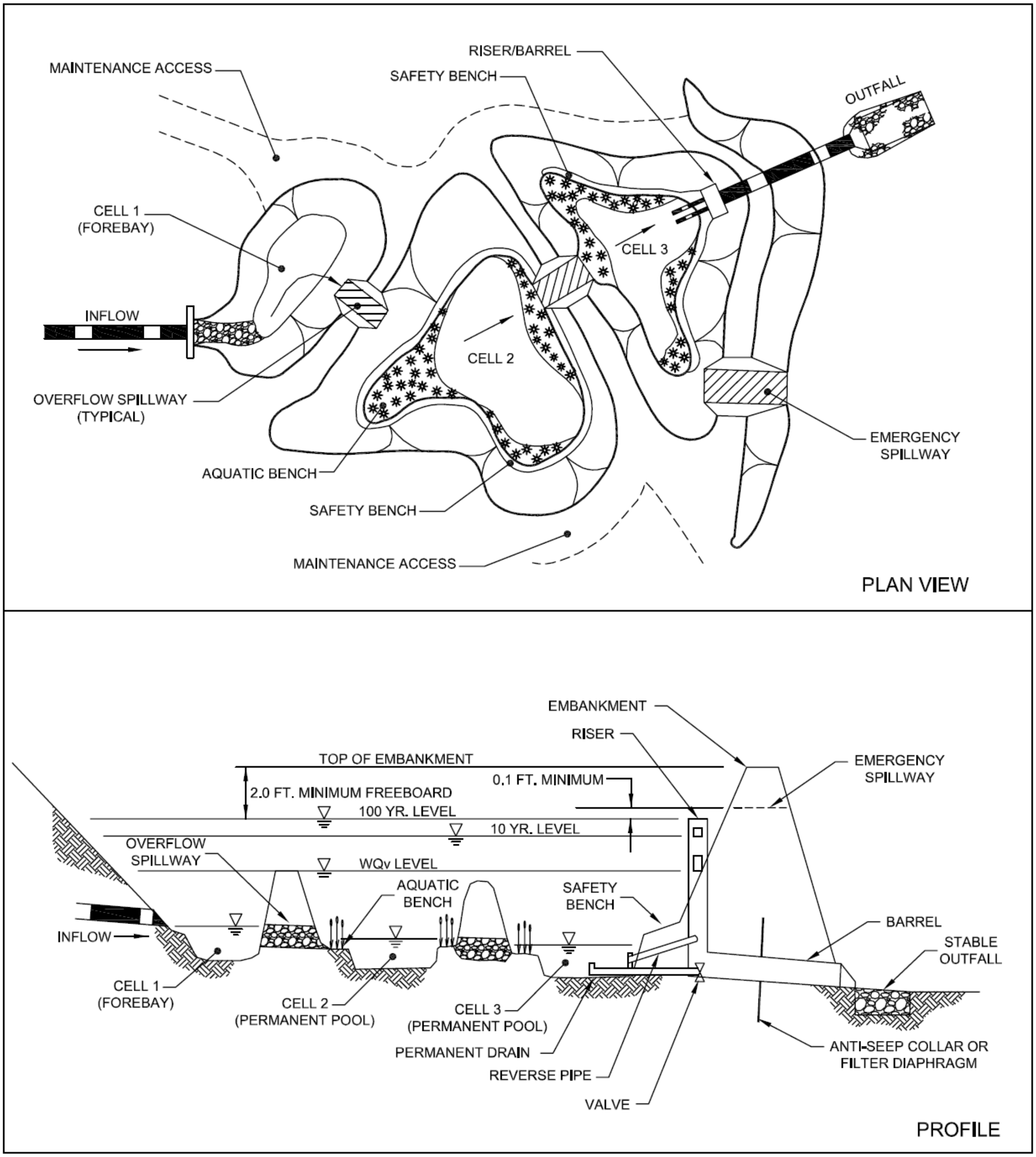
Figure 1.2 Wet Extended Detention Pond



Note: Storm attenuation levels vary depending on site detention requirements.

(Source: Center for Watershed Protection)

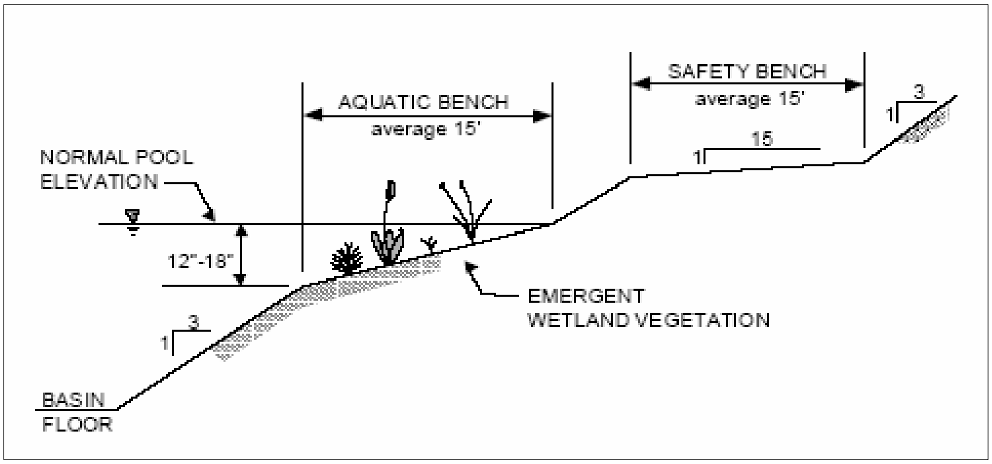
Figure 1.3 Micropool Extended Detention Pond



Note: Storm attenuation levels vary depending on site detention requirements.

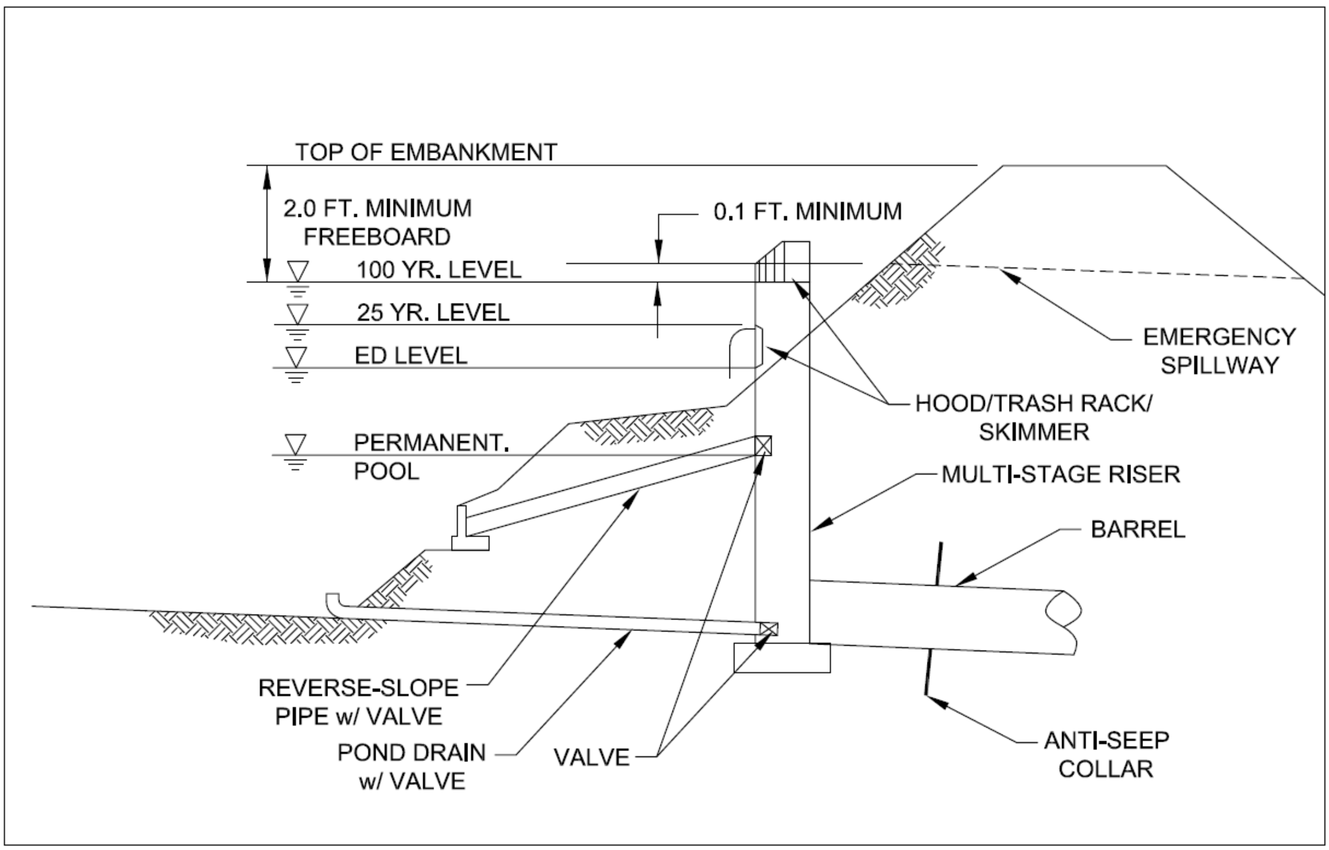
(Adapted from the Center for Watershed Protection)

Figure 1.4 Multiple Pond System



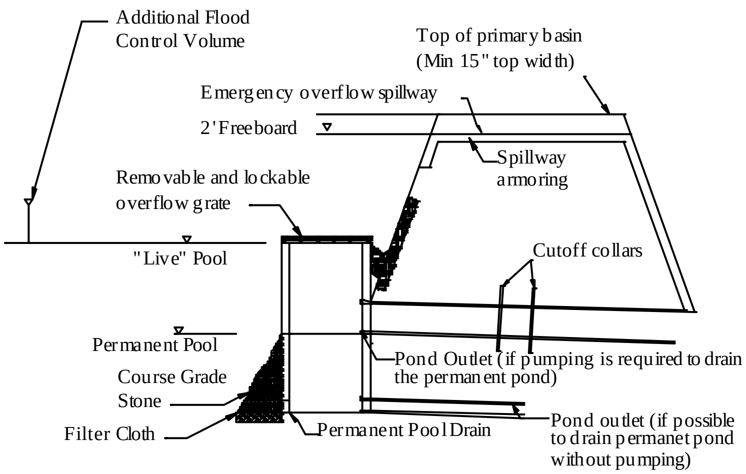
(Adapted from the Center for Watershed Protection)

Figure 1.5 Stormwater Pond Cross-Section with Benches

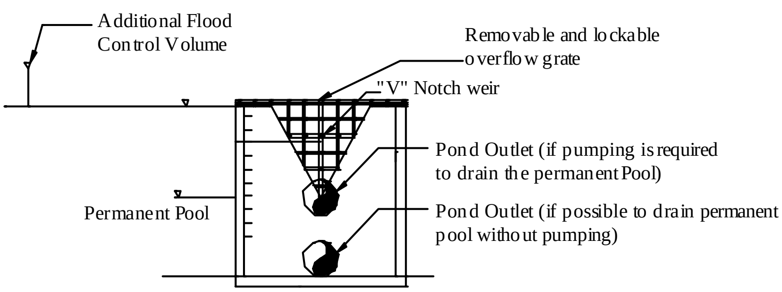


(Adapted from the Center for Watershed Protection)

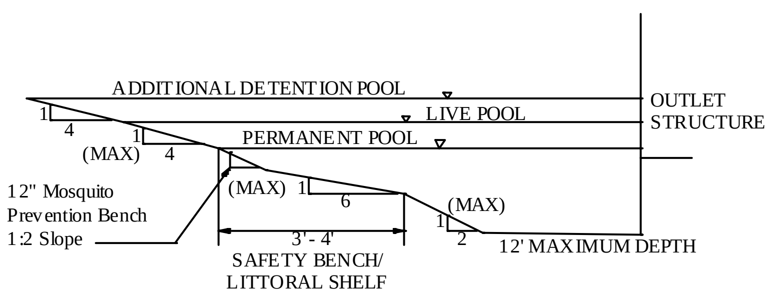
Figure 1.6 Outlet Configuration (Includes Extended Detention Level)



SECTION OUTLET STRUCTURE
NTS



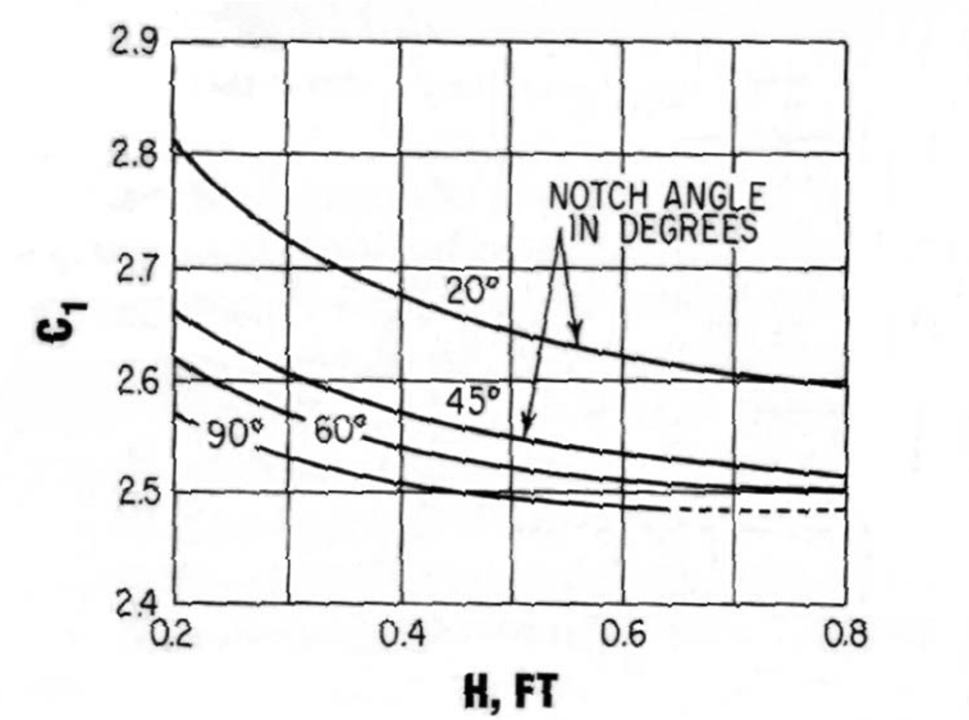
PROFILE OUTLET STRUCTURE
NTS



POND GRADING
NTS

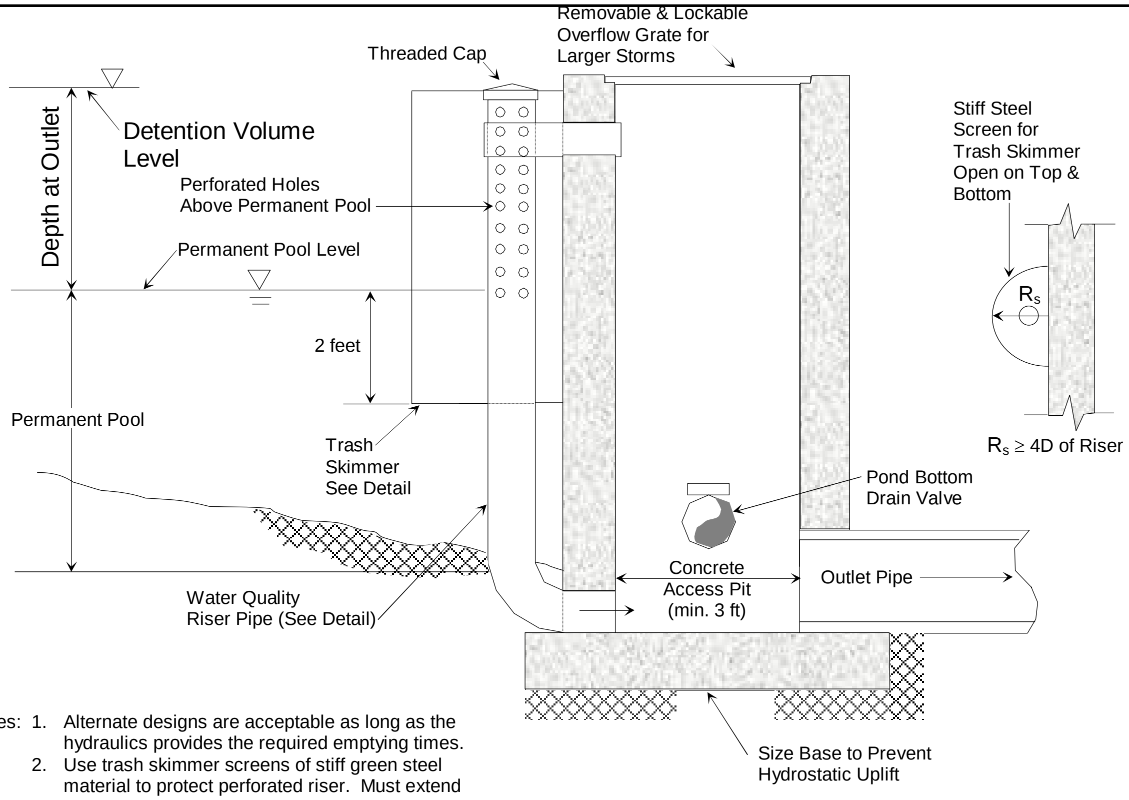
(Source: Metro, 2000)

Figure 1.7 V-Notch Weir Outlet Structure



(Source: Metro, 2000)

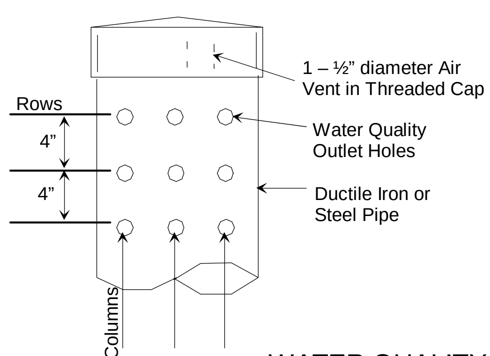
Figure 1.8 Sharp-Crested V-Notch Weir Discharge Coefficients



Notes: 1. Alternate designs are acceptable as long as the hydraulics provides the required emptying times.
2. Use trash skimmer screens of stiff green steel material to protect perforated riser. Must extend from the top of the riser to 2 ft. below the permanent pool level.

OUTLET WORKS
NOT TO SCALE

Notes: 1. Minimum number of holes = 8
2. Minimum hole diameter = 1/8" Dia.



WATER QUALITY
RISER

See Table 1.1, page 13 for perforated riser design guidance.

(Adapted from Metro, 2000)

Figure 1.9 Perforated Riser Outlet Structure

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Urban Drainage and Flood Control District, Denver, Colorado, "Urban Storm Drainage Criteria Manual – Volume 3 – Best Management Practices – Stormwater Quality", September 1992.

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Constructed Wetlands

Description: Constructed wetland systems that are designed specifically for the purpose of managing stormwater. Runoff volume is stored and pollutants are removed in the wetland facility.

Variations: Pocket wetland, pond/wetland system, shallow wetland, extended detention shallow wetland.

Components:

- Ponding area – for water quality treatment through settling, biological, and chemical processes
- Marsh area – for water quality treatment through plant uptake; provides some filtering as well
- Forebay – settles larger sediments before entering pond; aids maintenance
- Spillway system(s) – provides control of pond discharge

Advantages/Benefits:

- High removal of typical urban stormwater pollutants
- Provides habitat for wildlife
- Can be designed for multi-objective use, including water quantity control
- Can be designed to treat stormwater from multiple developments

Disadvantages/Limitations:

- Requires a large amount of land to construct
- Can cause nuisance problems if not properly designed, installed and maintained
- Needs constant source of water to maintain function
- Wetland area can quickly become filled with sediment, causing the wetland to fail
- Warm water discharged from wetland can cause habitat degradation downstream

Design considerations:

- Minimum drainage area is 25 acres; 5 acres for pocket wetland
- Flow path through the wetland system should be 2:1 (length: width); may need serpentine system to be created internally
- Must design marsh area and ponding area through a water balance to ensure wetland does not fail in droughts

Selection Criteria:

- ✓ **Water Quality 80 % TSS Removal**
- ✓ **Accepts Hotspot Runoff**
- ✓ **Residential Subdivision**
- ✓ **High Density / Ultra Urban Use**

Maintenance:

- Remove accumulated sediments
- Remove invasive vegetation
- Harvest vegetation every 5 years to prevent overgrowth of plants and a reduced water storage

Maintenance Burden

M	Shallow Wetland
M	ED Shallow Wetland
H	Pocket Wetland
M	Pond/Wetland

L = Low M = Moderate H = High

General Description

Constructed wetlands, or stormwater wetlands, are constructed basin marsh systems that are designed to both treat urban stormwater for pollutants and control runoff volumes. The basin has a sediment forebay for coarse sediments. Runoff then flows through shallow marsh (also called, high marsh) and deep marsh (also called, low marsh) areas (see Figure 2.1). As stormwater runoff flows through the wetland facility, pollutant removal is achieved through settling and uptake by marsh vegetation. Wetlands are among the most effective stormwater practices for pollutant removal and they offer aesthetic value and wildlife habitat. Constructed stormwater wetlands differ from natural wetland systems because they are engineered facilities designed specifically for the purpose of treating stormwater runoff and typically have less biodiversity than natural wetlands both in terms of plant and animal life. However, as with natural wetlands, stormwater wetlands require a continuous base flow or a high water table to support aquatic vegetation.

There are several design variations of the stormwater wetland. Each design differs in the relative amounts of shallow and deep water, and dry storage above the wetland. These include the shallow wetland, the extended detention shallow wetland, pond/wetland system and pocket wetland. Below are descriptions of each design variant.

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

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

Pond/Wetland Systems – The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland, where stormwater flows receive additional treatment. Information on designing wet ponds is found in PTP-01. Less land is required for a pond/wetland system than for the shallow wetland or the ED shallow wetland systems.

Pocket Wetland – A pocket wetland is intended for smaller drainage areas of 5 to 10 acres and typically requires excavation down to the water table

Site and Design Considerations

for a reliable water source to support the wetland system.

Location and Siting

1. Stormwater wetlands should normally have a minimum contributing drainage area of 25 acres or more. For a pocket wetland, the minimum drainage area is 5 acres.
2. A continuous base flow or high water table is required to support wetland vegetation. A water balance must be performed to demonstrate that a stormwater wetland can withstand a 30-day drought at summer evaporation rates without completely drawing down. (See Step #2 of Design Procedure for water balance calculation).
3. Wetland siting should also take into account the location and use of other site features such as natural depressions, buffers, and undisturbed natural areas, and should attempt to aesthetically "fit" the facility into the landscape. Bedrock close to the surface may prevent excavation.
4. Stormwater wetlands cannot be located within navigable waters of the U.S., including wetlands, without obtaining a Section 404 permit under the Clean Water Act, and any other applicable State permit. In some isolated cases, a wetlands permit may be granted to convert an existing degraded wetland in the context of local watershed restoration efforts.
5. A wetland facility may be designed as either an on-line or off-line system. It is recommended that higher flows be slowed to prevent erosion and wetland vegetation mortality.
6. For various reasons, it is suggested that wetlands be setback from certain areas. Some suggested minimum setbacks for stormwater wetland facilities are as follows:
   1. From a property line – 10 feet
   2. From a private well – 100 feet; if well is down gradient from a hotspot land use then the minimum setback is 250 feet
   3. From a septic system tank/leach field – 50 feet
7. All utilities should be located outside of the wetland site.

General Design

8. A well-designed stormwater wetland consists of:
   1) Shallow marsh areas, which vary in depth, with wetland vegetation,
   2) Permanent micropool, and
   3) Overlying zone in which runoff control volumes are stored.
9. Pond/wetland systems include a stormwater pond (see PTP-01 for design information).
10. In addition, **all wetland designs must include a sediment forebay at the inflow** to the facility to allow heavier sediments to drop out of suspension before the runoff enters the wetland marsh. (See sediment forebay design information in PTP-01).
11. Additional pond design features include an **emergency spillway, maintenance access, safety bench, wetland buffer, and appropriate wetland vegetation and native landscaping**.

Site and Design Considerations (Continued)

12. Figures 2.2 through 2.5 provide plan view and profile schematics for the designs of shallow, ED shallow, pond/wetland, and pocket wetlands.

Physical Specifications/Geometry

13. In general, wetland designs are unique for each site and application. However, there are number of geometric ratios and limiting depths for the design of a stormwater wetland that must be observed for adequate pollutant removal, ease of maintenance, and improved safety. Table 2.1 provides the recommended physical specifications and geometry for the various stormwater wetland design variants.

Table 2.1 Recommended Design Criteria for Stormwater Wetlands

Modified from Massachusetts DEP, 1997; Schueler, 1992

Design Criteria	Shallow Wetland	ED Shallow Wetland	Pond/ Wetland	Pocket Wetland
Length to Width Ratio (minimum)	2:1	2:1	2:1	2:1
Extended Detention (ED)	No	Yes	Optional	Optional
Allocation of WQ_v Volume (pool/marsh/ED) in %	25/75/0	25/25/50	70/30/0 (includes pond volume)	25/75/0
Allocation of Surface Area (deepwater/low marsh/high marsh/semi-wet) in %	20/35/40/5	10/35/45/10	45/25/25/5 (includes pond surface area)	10/45/40/5
Forebay	Required	Required	Required	Optional
Micropool	Required	Required	Required	Required
Outlet Configuration	Reverse-slope pipe or hooded broad-crested weir	Reverse-slope pipe or hooded broad-crested weir	Reverse-slope pipe or hooded broad-crested weir	Hooded broad-crested weir

Depth:
Deepwater: 1.5 to 6 feet below permanent pool elevation
Low marsh: 6 to 8 inches below permanent pool elevation
High marsh: 6 inches or less below permanent pool elevation
Semi-wet zone: Above permanent pool elevation

Site and Design Considerations (Continued)

14. The stormwater wetland should be designed with the recommended proportion of "depth zones." Each of the four wetland design variants has depth zone allocations which are given as a percentage of the stormwater wetland surface area. Target allocations are found in Table 2.1. The four basic depth zones are:
    - **Semi-wet zone** Those areas above the permanent pool that are inundated during larger storm events. This zone supports a number of species that can survive flooding
    - **High marsh zone** From the permanent pool to 6 inches below the permanent pool. This zone will support a greater density and diversity of wetland species than the low marsh zone. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone.
    - **Low marsh zone** From 6 to 18 inches below the permanent pool or water surface elevation. This zone is suitable for the growth of several emergent wetland plant species.
    - **Deepwater zone** From 1.5 to 6 feet deep to the top of the permanent pool elevation. Includes the outlet micropool and deepwater channels through the wetland facility. This zone supports little emergent wetland vegetation, but may support submerged or floating vegetation.

    .
15. A minimum dry weather flow path of 2:1 (length to width) is required from inflow to outlet across the stormwater wetland and should ideally be greater than 3:1. This path may be achieved by constructing internal dikes or berms, using marsh plantings, and by using multiple cells. Finger dikes are commonly used in surface flow systems to create serpentine configurations and prevent short-circuiting. Microtopography (contours along the bottom of a wetland or marsh that provide a variety of conditions for different species needs and increases the surface area to volume ratio) is encouraged to enhance wetland diversity.
16. A 4 to 6 foot deep micropool must be included in the design at the outlet to prevent the outlet from clogging and resuspension of sediments, and to mitigate thermal effects.
17. Maximum depth of any permanent pool areas should generally not exceed 6 feet.
18. The volume of the extended detention must not comprise more than 50% of the total WQ_v, and its maximum water surface elevation must not extend more than 3 feet above the permanent pool. Storage for larger storms can be provided above the WQ_v elevation.
19. The perimeter of all deep pool areas (4 feet or greater in depth) should be surrounded by safety and aquatic benches similar to those for stormwater ponds (see Stormwater Ponds, PTP-01).
20. The perimeter of the wetland should be irregular to provide a more natural landscaping effect.

Site and Design Considerations (Continued)

Pretreatment/Inlets

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

Outlet Structures

25. Flow control from a stormwater wetland is typically accomplished with the use of a concrete or corrugated metal riser and barrel. The riser is a vertical pipe or inlet structure that is attached to the base of the micropool with a watertight connection. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment. The riser should be located within the embankment for maintenance access, safety and aesthetics.
26. A number of outlets at varying depths in the riser provide internal flow control for routing runoff volumes. The number of orifices can vary and is usually a function of the pond design.
27. For shallow and pocket wetlands, the riser configuration is typically comprised of a flood protection outlet (often a slot or weir).

    Since the water quality volume is fully contained in the permanent pool, no orifice sizing is necessary for this volume. An off-line shallow or pocket wetland providing *only* water quality treatment (not ED) can use a simple overflow weir as the outlet structure.

    In the case of an extended detention (ED) shallow wetland, there is generally a need for an additional outlet (usually an orifice) that is sized to pass the extended detention water quality volume that is surcharged on top of the permanent pool. Flow will first pass through this orifice, which is sized to release the water quality ED volume in 24 hours. The

Site and Design Considerations (Continued)

preferred design is a reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond. The outlet (often an orifice) invert is located at the maximum elevation associated with the extended detention water quality volume.

Alternative hydraulic control methods to an orifice can be used and include the use of a broad-crested rectangular, V-notch, or proportional weir, or an outlet pipe protected by a hood that extends at least 12 inches below the normal pool. (Refer to Stormwater Ponds, PTP-01 for orifice equations.)

28. The water quality outlet (if design is for an ED shallow wetland) should be fitted with adjustable gate valves or other mechanism that can be used to adjust detention time.
29. Higher flows pass through openings or slots protected by trash racks further up on the riser.
30. After entering the riser, flow is conveyed through the barrel and is discharged downstream. Anti-seep collars should be installed on the outlet barrel to reduce the potential for pipe failure.
31. Riprap, plunge pools or pads, or other energy dissipaters are to be placed at the outlet of the barrel to prevent scouring and erosion. If a wetland facility daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance.
32. The wetland facility must have a bottom drain pipe located in the micropool with an adjustable valve that can completely or partially dewater the wetland within 24 hours.
33. The wetland drain should be sized one pipe size greater than the calculated design diameter. The drain valve is typically a handwheel activated knife or gate valve. Valve controls shall be located inside of the riser at a point where they will not normally be inundated and can be operated in a safe manner.
34. See the design procedures in Volume 2 – Procedures of the Stormwater Management Manual for additional information and specifications on pond routing and outlet hydraulics. Orifice sizing is also presented in Stormwater Ponds, PTP-01.

Site and Design Considerations (Continued)

Emergency Spillway

35. An emergency spillway is to be included in the stormwater wetland design to safely pass flows that exceed the design storm flows. The spillway prevents the wetland's water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
36. A minimum of 2 feet of freeboard must be provided, measured from the top of the maximum design storm elevation to the lowest point of the dam embankment, not counting the emergency spillway.

Maintenance Access

37. A maintenance right of way or easement must be provided to the wetland facility from a public or private 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.
38. The maintenance access must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.
39. Access to the riser is to be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls.

Safety Features

40. All embankments and spillways must be designed to State of Tennessee guidelines for dam safety.
41. Fencing of wetlands is not generally desirable, but it may be infeasible to leave them unfenced because of community concerns. A preferred method is to manage the contours of deep pool areas through the inclusion of a safety bench (see above) to eliminate drop-offs and reduce the potential for accidental drowning.
42. The principal spillway opening should not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.

Landscaping

A landscaping plan should be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of landscaping zones, selection of corresponding plant species, planting plan, sequence for preparing wetland bed (including soil amendments, if needed) and sources of plant material. Landscaping zones include low marsh, high marsh, and semi-wet zones. The low marsh zone ranges from 6 to 18 inches below the permanent pool. This zone is suitable for the growth of several emergent plant species. The high marsh zone ranges from 6 inches below the permanent pool up to the permanent pool.

Site and Design Considerations (Continued)

This zone will support greater density and diversity of emergent wetland plant species. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone. The semi-wet zone refers to those areas above the permanent pool that are inundated on an irregular basis and can be expected to support wetland plants.

43. The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers.
44. Woody vegetation may not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure.
45. The wetland shall have a 15-foot setback to structures.
46. To discourage resident geese populations, the area surrounding the constructed wetland can be planted with trees, shrubs and native ground covers. The soils of a wetland buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration and therefore may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites and backfill these with uncompacted topsoil.

Other Constraints

- Karst – Requires poly or clay liner to sustain a permanent pool of water and protect aquifers; limits on ponding depth; geotechnical tests may be required
- Hydrologic group “A” soils and some group “B” soils may require liner (not relevant for pocket wetland)

Design Procedures

Step 1. Compute the Water Quality Volume.

Calculate the Water Quality Volume (WQ_v).

$$WQ_v = P \times Rv \times A/12$$

Where: WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.05 + 0.0092I$$

Where: I = site impervious cover, % (i.e., 50% imperviousness = 50)

Step 2. Determine if the development site and conditions are appropriate for the constructed wetland.

See the *Site and Design Considerations* in the section, above.
Perform Water Balance calculations to ensure that drainage basin has characteristics to support permanent pool. See Volume 2, Section 8.8.1 for an example water balance calculation.

Step 3. Confirm design criteria and applicability to site.

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

Step 4. Determine pretreatment volume.

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

$$F_v = 0\ .1 \text{ inches} \times A_I \text{ acres} \times .0833$$

Where:
F_v = Forebay volume (ac-ft)
A_I = Impervious area of drainage basin, acres
0.0833 = conversion factor of acre inches to acre feet

Design Procedures (Continued)

Often, it is more manageable to work with forebay volumes in cubic feet rather than acre feet, because they are small volumes. To convert F_v in acre feet to cubic feet, multiply F_v by 43560 square feet.

Step 5. Allocate the WQ_v among marsh, micropool, and ED volumes.

Use recommended criteria from Table 2.1

Step 6. Determine wetland location and preliminary geometry, including distribution of wetland depth zones.

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

Determine if constructed wetland is on-line or off-line. Off-line wetlands require a diversion structure to divert low flows towards wetland and high flows away from wetlands. See Figure 2.6 for example diversion structure and Figure 2.7 for an example of an off-line system.

See the Physical Specifications/Geometry section (pages 4 to 6) of *Site and Design Considerations* for more details.

Step 7. Compute extended detention orifice release rate(s) and size(s), and establish WQ_v elevation.

Shallow Wetland, Pocket Wetland and ED Shallow Wetland: Based on the elevations established in Step 6 for the extended detention portion of the water quality volume, the water quality orifice is sized to release this extended detention volume in 24 hours. The water quality orifice should have a minimum diameter of 3 inches or use a perforated riser, and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged one foot below the elevation of the permanent pool, is a recommended design. Adjustable gate valves can also be used to achieve this equivalent diameter.

*An off-line shallow or pocket wetland providing only water quality treatment can employ a simple overflow weir.

Step 8. Calculate 100-year storm release rate and water surface elevation.

Set up a stage-storage-discharge relationship for the control structure for the extended detention orifice(s) and the 100-year storm.

Design Procedures (Continued)

Step 9. Design embankment(s) and spillway(s).

Size emergency spillway to pass flows larger than the maximum design storm and to pass flows when the inlet bypass (for off-line systems) or outlet structures malfunction. Attenuation may not be required.

Step 10. Design safe design velocity for on-line systems.

For on-line systems, scour and erosion and wetland vegetation mortality may be of concern. Flow velocities must be minims to prevent these conditions. Limit in-flow velocities to less that five feet per second into the wetland area. Energy dissipaters should be used to reduce flow velocities.

Step 11. Investigate potential pond/wetland hazard classification.

The design and construction of ponds in Tennessee must follow the requirements of the Safe Dams Act. Contact the Tennessee Department of Environment and Conservation, Division of Water Supply for more information about building dams in Tennessee.

Step 12. Design inlets, sediment forebay(s), outlet structures, maintenance access, and safety features.

See the *Site and Design Considerations* section for information on design.

Step 13. Prepare Vegetation and Landscaping Plan.

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

Operations and Maintenance

Each BMP must have an Operations and Maintenance agreement that is submitted to Metro for approval and is maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the Operation and Maintenance Agreement for wetlands, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with site plans. The O&M Agreement is to be used by the BMP owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

1. Clean and remove debris from inlet and outlet structures.
2. Mow side slopes. Periodic mowing of the 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.
3. Monitor wetland vegetation and perform replacement planting as necessary.
4. Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season.

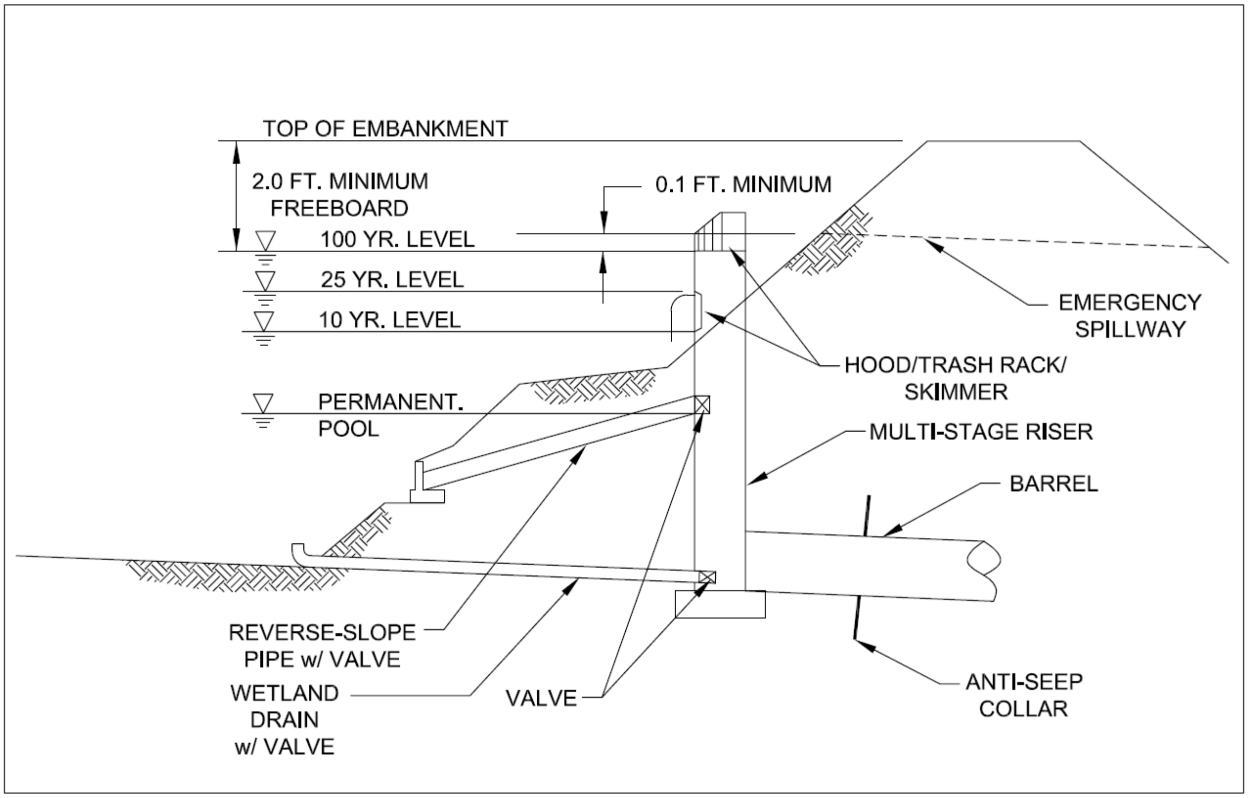
Maintenance (Continued)

5. Examine stability of the original depth zones and microtopographical features. Inspect for invasive vegetation, and remove where possible.
6. Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. Note signs of hydrocarbon build-up, and remove appropriately.
7. Monitor for sediment accumulation in the facility and forebay.
8. Examine to ensure that inlet and outlet devices are free of debris and operational.
9. Repair undercut or eroded areas.
10. Harvest wetland plants that have been "choked out" by sediment build-up. A sediment marker should be located in the forebay to determine when sediment removal is required. Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.
11. Maintenance requirements for constructed wetlands are particularly high while vegetation is being established. Monitoring during these first years is crucial to the future success of the wetland as a stormwater structural control. Wetland facilities should be inspected after major storms (greater than 2 inches of rainfall) during the first year of establishment to assess bank stability, erosion damage, flow channelization, and sediment accumulation within the wetland. For the first 3 years, inspections should be conducted at least twice a year.
12. Sediments excavated from stormwater wetlands that do not receive runoff from designated hotspots are not considered toxic or hazardous material and can be safely disposed of by either land application or landfilling. Sediment testing may be required prior to sediment disposal when a hotspot land use is present.

As-Built Certification

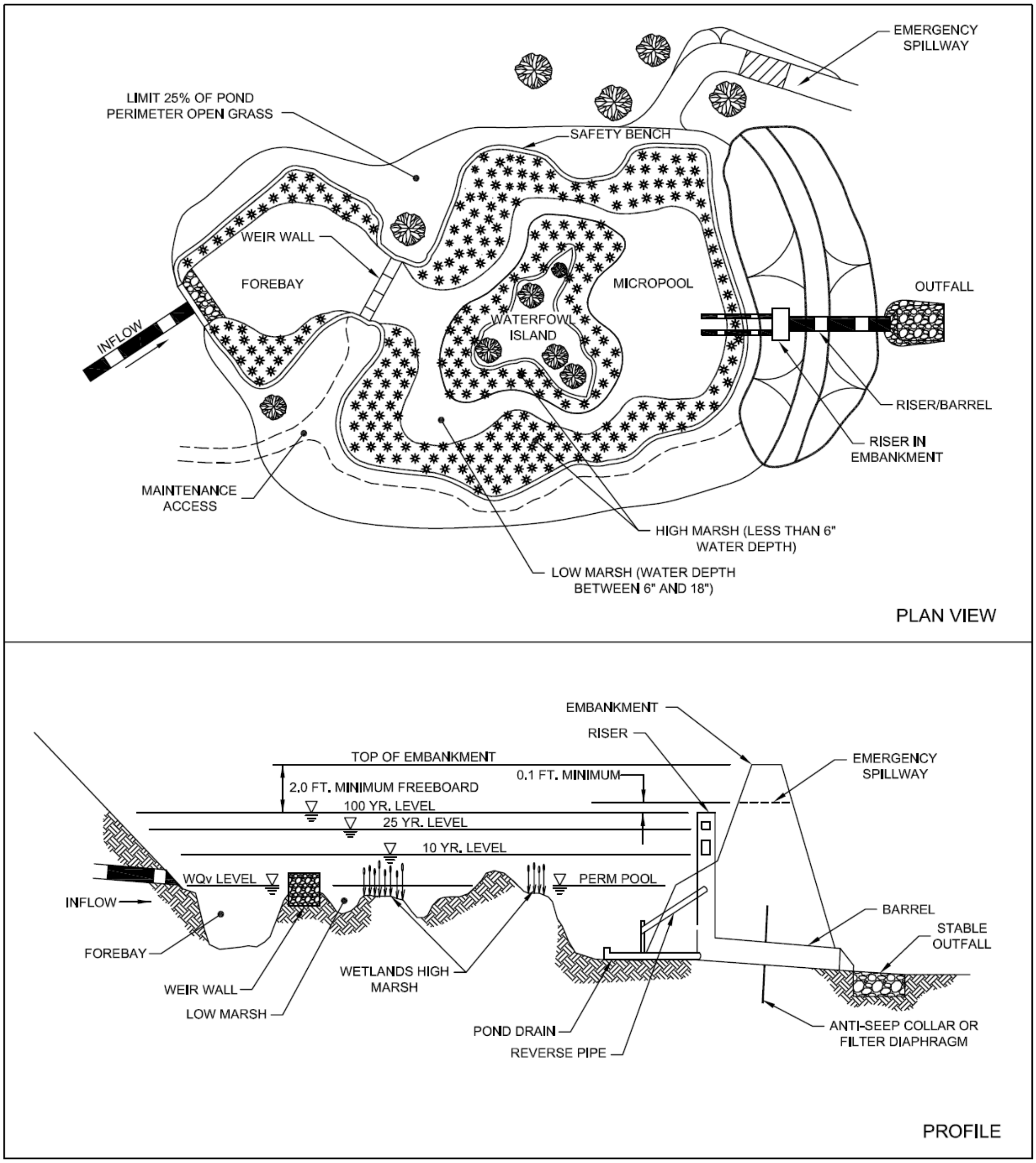
An as-built certification of the constructed wetland performed by a registered Professional Engineer must be submitted to Metro prior to the release of the site's bond or issuance of a Use and Occupancy permit. The as-built certification verifies that the BMP was installed as designed and approved. If components of the stormwater wetland constructed in the field differ from the design approved by Metro, the as-built certification must: (1) Note the differences between the measure in the field and the design approved by Metro; (2) Demonstrate that the design meets the requirements of Metro's stormwater program; and/or (3) Propose additional measures to be included on the site to mitigate the differences.
The following components should be addressed in the as-built certification:

- Sediment forebay of sufficient size to pretreat runoff.
- Access to all components of the wetland for maintenance
- Sufficient water depth to prevent the creation of stagnant water.
- Depth of treatment area.
- Side slopes and benches created as noted in the plans.
- Properly functioning spillway systems.



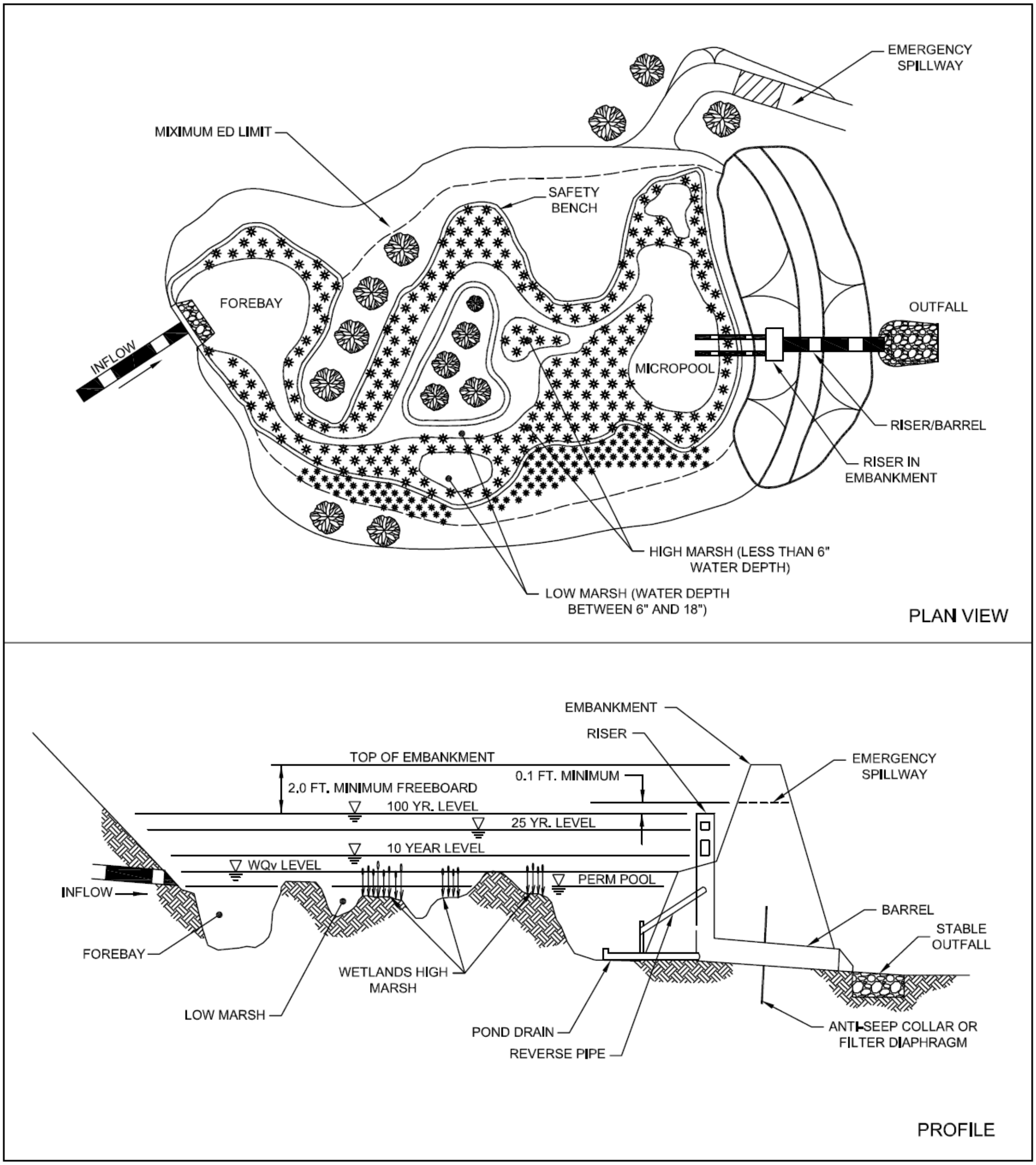
(Adapted from Center for Watershed Protection)

Figure 2.1 Typical Wetland Facility Outlet Structure



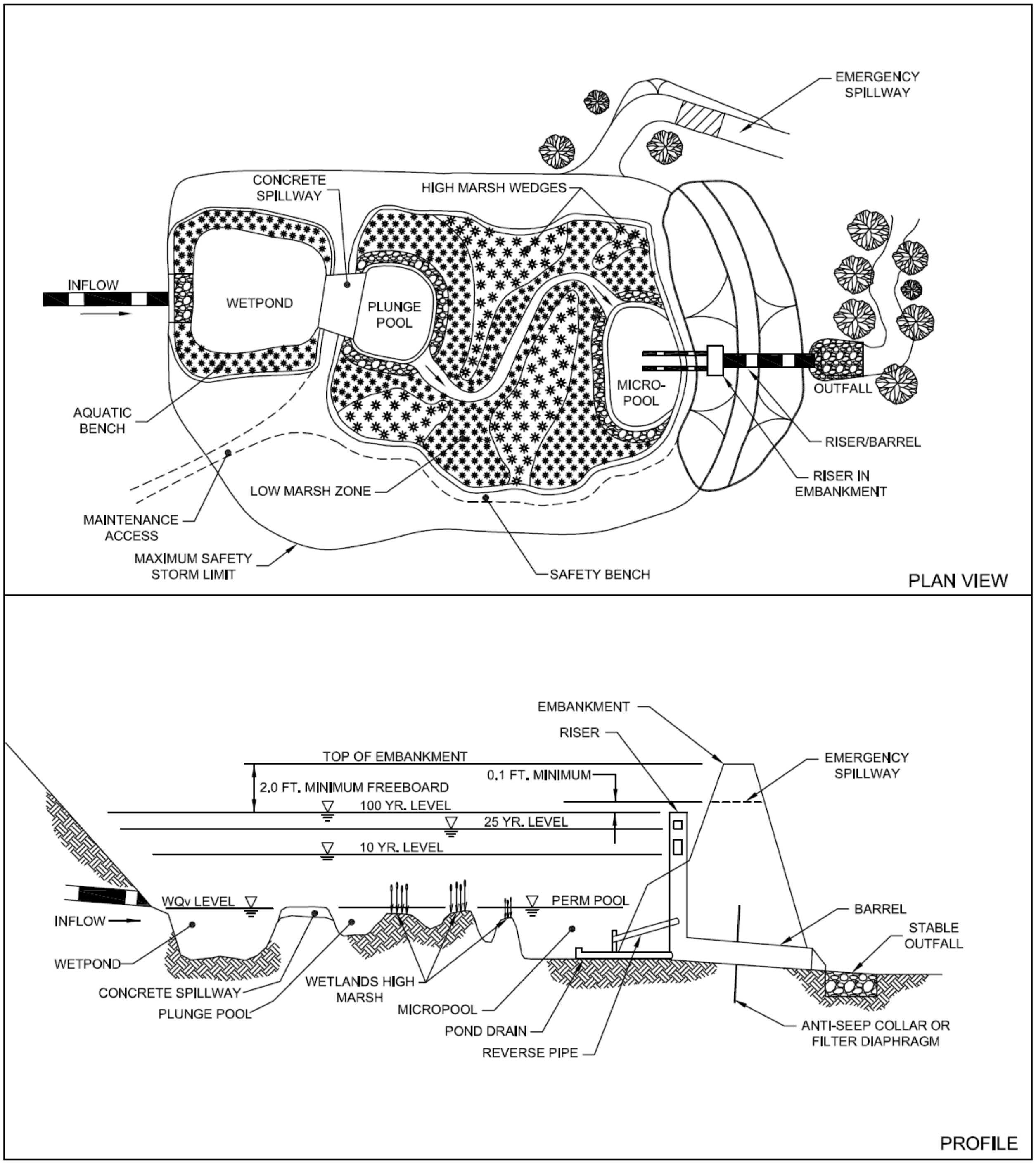
(*Source: Center for Watershed Protection)*

Figure 2.2 Schematic of Shallow Wetland



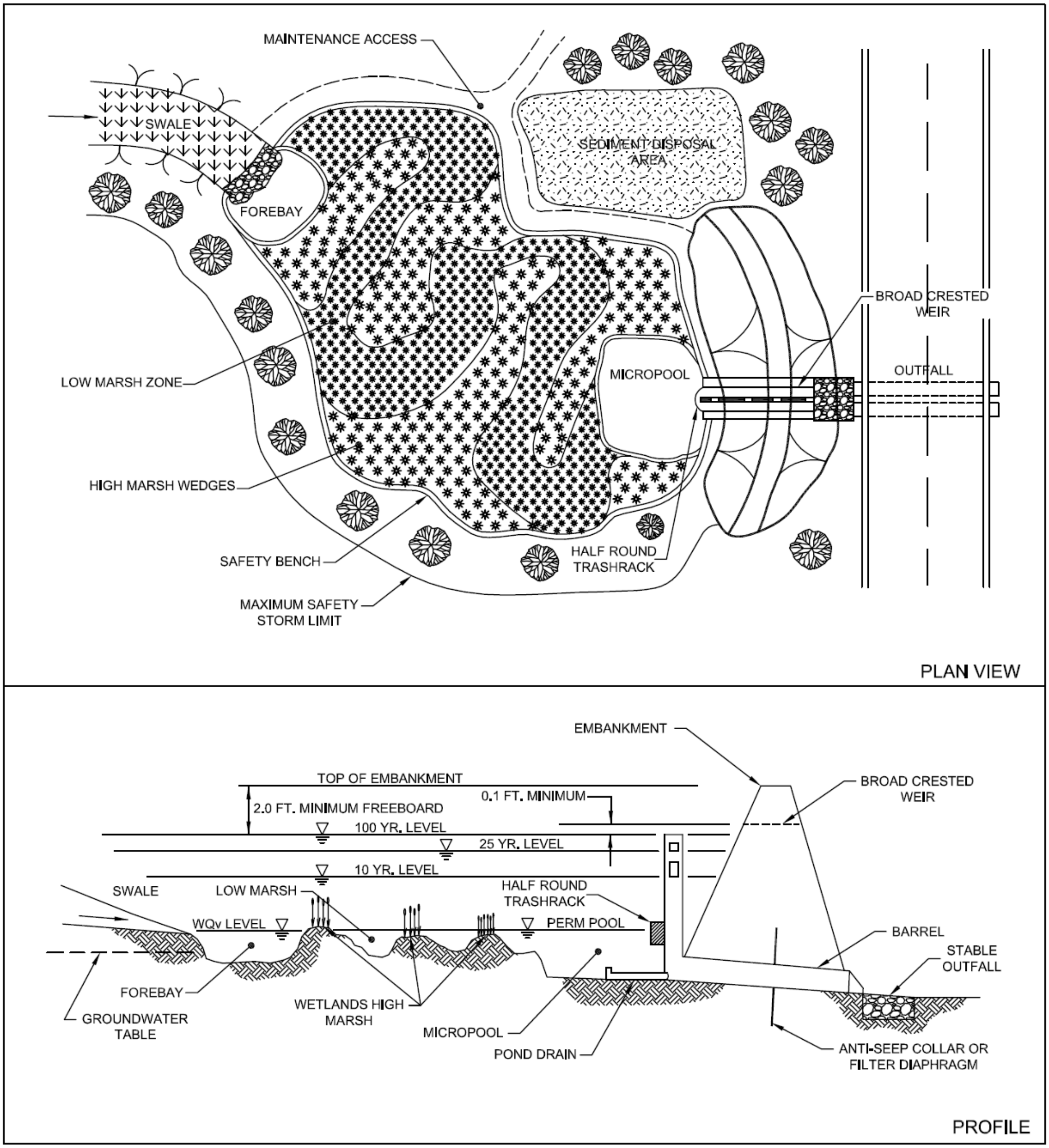
(Adapted from Center for Watershed Protection)

Figure 2.3 Schematic of Extended Detention Shallow Wetland



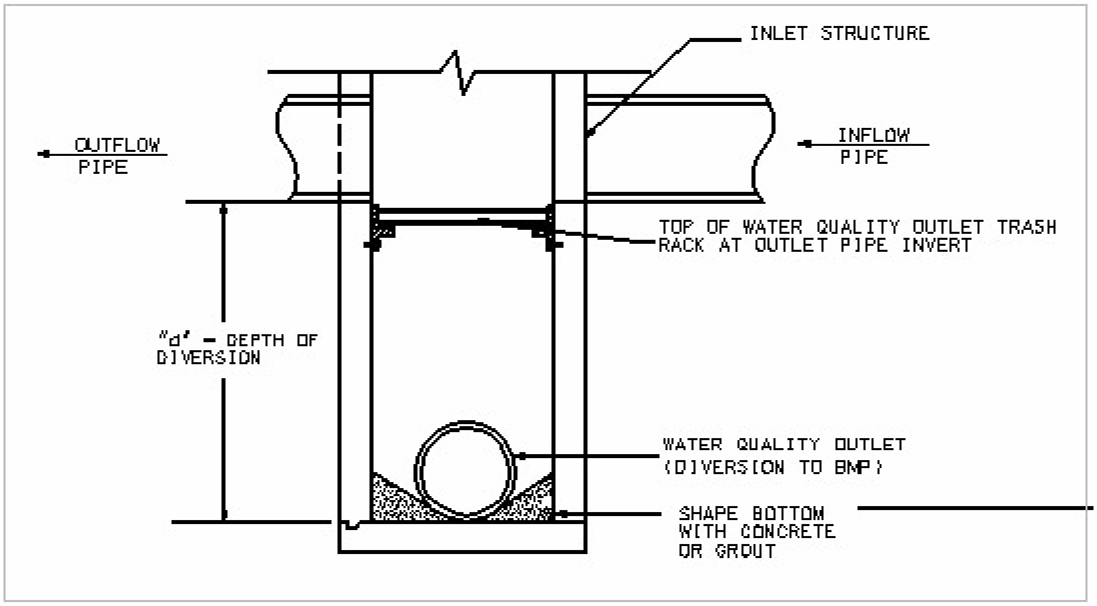
(Adapted from Center for Watershed Protection)

Figure 2.4 Schematic of Pond/Wetland System



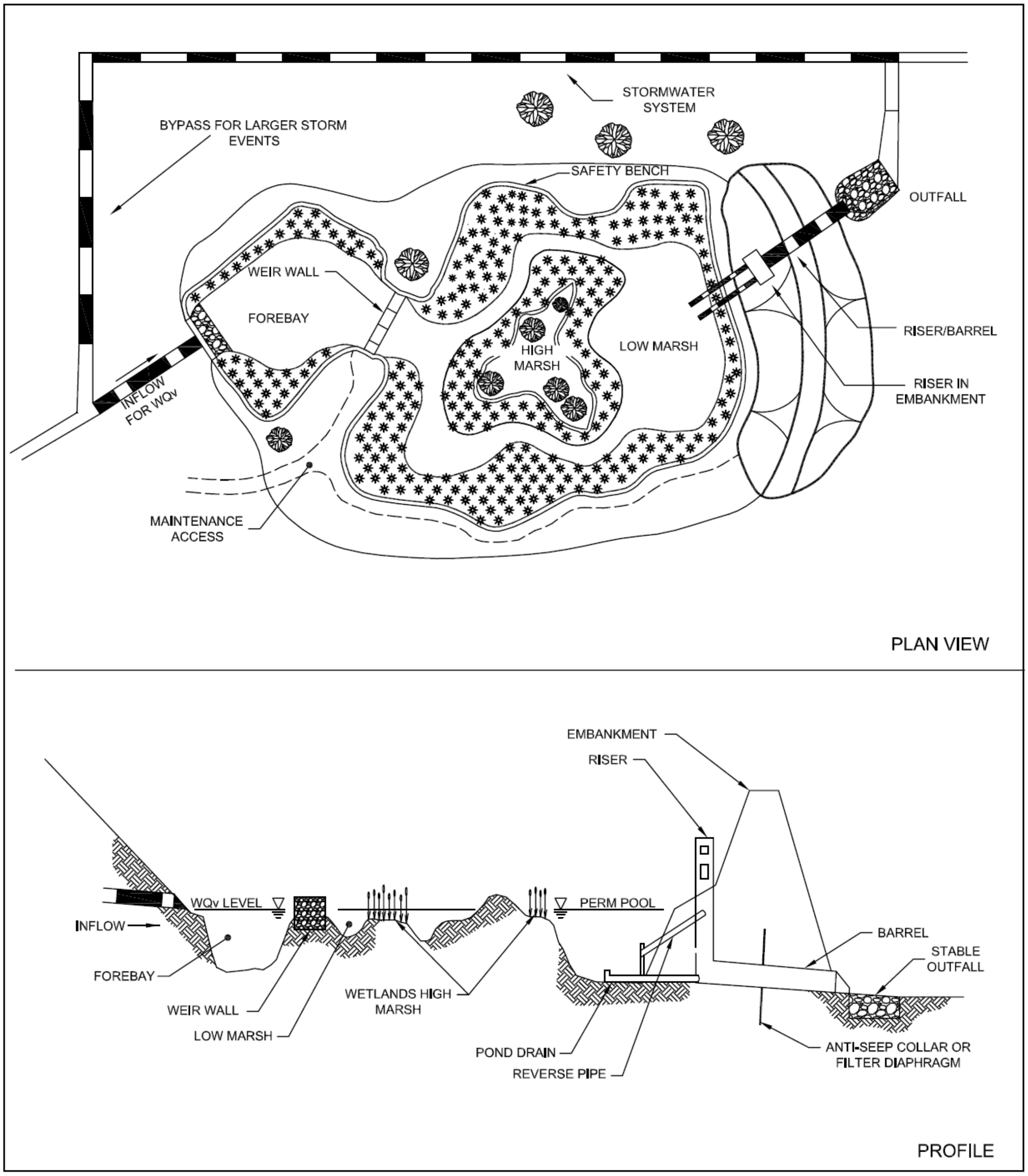
(Source: Center for Watershed Protection)

Figure 2.5 Schematic of Pocket Wetland System



(Source: AMEC)

Figure 2.6 Example Diversion Structure



(Adapted from the Center for Watershed Protection)

Figure 2.7 Example of Off-line Constructed Wetland

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Bioretention Areas

Description: Shallow detention area that employs engineered soils and plants to capture and treat runoff.

Variations: Bioretention areas can be designed as "raingardens," small bioretention areas that serve individual lots or that can be installed in parking lot planting areas or in depressed areas receiving runoff from paved areas.

Components:
- Pretreatment - for coarse sediments that would quickly clog area.
- Ponding area – for water quality treatment through settling and chemical processes
- Soils – water quality treatment through chemical processes and filtering; supports plants
- Mulch – water quality treatment through biological processes; conserves soil moisture between rain events to support plants
- Plants – water quality treatment through biological treatment, plant up-take and filtering
- Spillway system – provides outlet for stormwater runoff when large storm events occur and prevents long-term ponding in planting area

Advantages/Benefits:
- Easily incorporated into new development
- High community acceptance
- Good for highly paved areas such as parking lots
- Good for small drainage areas

Disadvantages/Limitations:
- Sediment-laden runoff can clog soils in bioretention area
- Requires detailed landscape planning
- Not appropriate for steep slopes
- Relatively expensive

Design considerations:
- Maximum drainage area of 5 acres, 2 acres maximum impervious
- Typically requires 5 feet of head
- Underlying soils must have good infiltration or must be replaced
- Underdrain system may be needed to keep planting area from ponding water too long

Selection Criteria:

- ✓ **Water Quality 80 % TSS Removal**
- ✓ **Accepts Hotspot Runoff**
- ✓ **Residential Subdivision**
- ✓ **High Density / Ultra Urban Use**

Maintenance:

- Replace mulch as needed to maintain depth of mulch
- Replace plant material as needed
- Replace soil if it becomes clogged
- Clean spillway system(s)

M **Maintenance Burden**

L = Low M = Moderate H = High

General Description

Bioretention areas, sometimes known as rain gardens, are structural stormwater controls that capture and temporarily store the WQ_v while using soils and vegetation in landscaped areas to remove pollutants from stormwater runoff. Bioretention areas are engineered facilities in which runoff is conveyed as sheet flow to the "treatment area," consisting of a grass buffer strip, ponding area, organic or mulch layer, planting soil, and vegetation. An optional sand bed can be included in the design to provide aeration and drainage of the planting soil. The filtered runoff is typically collected and returned to the conveyance system, though it can be exfiltrated into the surrounding soil in areas with porous soils.

There are numerous design applications, both on- and off-line, for bioretention areas. These include use on single-family residential lots (rain gardens), as off-line facilities adjacent to parking lots, along highways and road drainage swales, within larger landscaped pervious areas, and as landscaped islands in impervious or high-density environments. However, the structures are not designed to serve as regional stormwater BMPs.

Bioretention facilities can provide a limited amount of water quantity control, with the storage provided by the facility included in the design of any downstream detention structures. However, bioretention areas should be designed so that larger flows bypass them.

Bioretention areas are designed for intermittent flow and to drain and aerate between rainfall events. Sites with continuous flow from groundwater, sump pumps or other areas are not acceptable for bioretention areas.

Components

Figure 3.1 illustrates a bioretention area. Bioretention areas consist of:

1. Grass filter strip between the contributing drainage area and the ponding area;
2. Ponding areas containing vegetation with a planting soil bed,
3. Organic/mulch layer,
4. Planting soil and vegetation, and
5. Gravel and perforated pipe underdrain system to collect runoff that has filtered through the soil layers (bioretention areas can optionally be designed to infiltrate into the soil).

Optional design components include:

1. Sand filter layer to spread flow, filter runoff and aid in aeration and drainage of the planting soil;
2. Stone diaphragm at the beginning of the grass filter strip to reduce velocities and spread flow into the grass filter;
3. Inflow diversion or an overflow structure.

Site and Design Considerations

The following design and site considerations must be incorporated into the BMP plan including bioretention areas:

1. The drainage area (contributing or effective) must be 5 acres or less, though 0.5 to 2 acres is preferred.
2. The minimum size for facility is 200 ft^2, with a length to width ratio of 2:1. Slope of the area immediately adjacent to the facility must be no more than 20%, but must be more than 2% to ensure proper drainage.
3. The planting soil filter bed is sized using a Darcy's Law equation with a filter bed drain time of 48 hours and a coefficient of permeability (k) of 0.5 ft/day. The planting soil bed must be at least 2 feet deep. Planting soils must be sandy loam, loamy sand or loam texture per USDA textural triangle with a clay content rating from 10 to 25 percent. The soil must have an infiltration rate of at least 0.5 inches per hour and a pH between 5.5 and 6.5. In addition, the planting soil should have a 1.5 to 3 percent organic content and a maximum 500-ppm concentration of soluble salts. For bioretention areas using in situ soils, the depth criteria does not apply.
4. The maximum ponding depth in bioretention areas is 6 inches.
5. The mulch layer must consist of 2-4 inches of commercially available fine shredded hardwood mulch or shredded hardwood chips.
6. The sand bed, if used, must be 12-18 inches thick. Sand must be clean and have less than 15% silt or clay content.
7. Pea gravel for the diaphragm and curtain, where used, must be ASTM D 448 size No. 6 (1/8 inches to 1/4 inches).
8. The underdrain collection system must be equipped with 6-inch perforated pipe in an 8-inch gravel layer. The pipe must have 3/8-inch perforations, spaced on 6-inch centers with a minimum of 4 holes per row. The pipe is spaced at a maximum of 10 feet on center, and a minimum grade of 0.5 percent must be maintained. A permeable filter fabric can be placed between the gravel layer and the planting soil bed.
9. The required elevation difference needed from the inflow to the outflow is 5 feet.
10. The depth from the bottom of the bioretention facility to the seasonally high water table must be a minimum of 2 feet.
11. Runoff captured by facility must enter as sheet flow to prevent erosion of the organic or mulch layer. Velocities entering the mulch layer must be between 1 and 2 feet per second.
12. Continuous flow from groundwater, sump pumps or other areas to the bioretention area is prohibited.
13. An overflow structure and a non-erosive overflow channel must be provided to safely pass the flow from the bioretention area that exceeds the storage capacity to a stabilized downstream area. The high flow structure within the bioretention area can consist of a yard drain catchbasin, with the throat of the catchbasin inlet typically 6 inches above the elevation of the shallow ponding area.
14. All components of the BMP must be located within an easement. Access to the BMP must be located within the easement.
15. The area that will house bioretention must not be used as sediment control measure during active construction.

Landscaping Bioretention Areas

Landscaping is critical to the performance and function of the bioretention area. A dense and vigorous groundcover must be established over the contributing pervious drainage area before runoff can be diverted into the facility.

1. The bioretention area should be vegetated like a terrestrial forest ecosystem, with an eventual tree canopy, subcanopy of understory trees, scrub layer and herbaceous ground cover. Three species of each tree and shrub type should be planted.
2. The tree-to-shrub ratio should be 2:1 to 3:1. On average, trees should be spaced 8 feet apart. Plants should be placed at regular intervals to replicate a natural forest. Woody vegetation should not be planted at inflow locations.
3. After the trees and shrubs are established, the ground cover and mulch should be established.

Use native plants, selected based upon hardiness and hydric tolerance.

As-Built Certification Considerations

After the bioretention area has been constructed, the developer must have an as-built certification of the bioretention area conducted by a registered Professional Engineer. The as-built certification verifies that the BMP was installed as designed and approved.

The following components are vital to ensure that the bioretention area works properly and they must be addressed in the as-built certification:

1. Pretreatment, such as a grass filter strip, for coarser sediments must be provided to prevent premature clogging of the system. Design guidance for grass filter strips used as pretreatment is provided in PTP-07 Filter Strip.
2. Surrounding drainage areas must be stabilized to prevent sediment from clogging the filter media.
3. Correct ponding depths and infiltration rates must be maintained to prevent killing vegetation.

A mechanism for overflow for large storm events must be provided.

Maintenance

Each BMP must have an Operations and Maintenance (O&M) agreement that is submitted to Metro for approval and is maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the O&M Agreement for bioretention areas, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with site plans. The O&M Agreement is to be used by the BMP owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP O&M plan. At a minimum, the operations and maintenance plan must require:

1. Inspect and repair/replace treatment components.
2. Perform annual verification of infiltration rates.
3. Remove debris or dead vegetation.

Design Procedures

Step 1. Compute the Water Quality Volume.

Calculate the Water Quality Volume (WQ_v).

$$WQ_v = P \times Rv \times A/12$$

Where:
WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85^{th} percentile storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.015 + 0.0092I$$

Where:
I = site impervious cover, % (for example, 50% imperviousness = 50)

Step 2. Determine if the development site and conditions are appropriate for the use of bioretention area.

See the *Site and Design Considerations* in this section, above.

Step 3. Confirm additional requirements and watershed applicability.

Check with Metro Water Services and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply to the site.

Step 4. Compute WQ_v flow rate.

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

$$Q = C * I * A$$

Where:
Q =Peak discharge (cfs) for the 3 month storm
C = Runoff coefficient
I = 2.45 in/hour
A = site area, acres

Design Procedures (Continued)

Step 5. Size flow regulator, if needed.

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

Size flow regulator to pass the water quality flow rate, computed in Step 4.

Step 6. Determine size of bioretention ponding/filter area.

The required planting soil filter bed area is computed using the following equation (based on Darcy's Law):

Af = (WQ_v) (df) / [(k) (hf + df) (tf)] where:

Af = surface area of ponding area (ft^2)

WQ_v = water quality volume in cubic feet (or total volume to be captured)
df = filter bed depth (2 feet minimum)
k = coefficient of permeability of filter media (ft/day) (must be at least 0.5 ft/day)
hf = average height of water above filter bed (ft)
(typically 3 inches, which is half of the 6-inch ponding depth)
tf = design filter bed drain time (days)
(2.0 days or 48 hours is recommended maximum)

Step 7. Set design elevations and dimensions of facility.

See *Site and Design Considerations* section.

Step 8. Design conveyances to bioretention area.

See Figure 3.2 for examples of conveyance types for different applications.

Step 9. Design pretreatment.

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

Design Procedures (Continued)

Step 10. Size underdrain system

See *Site and Design Considerations*.

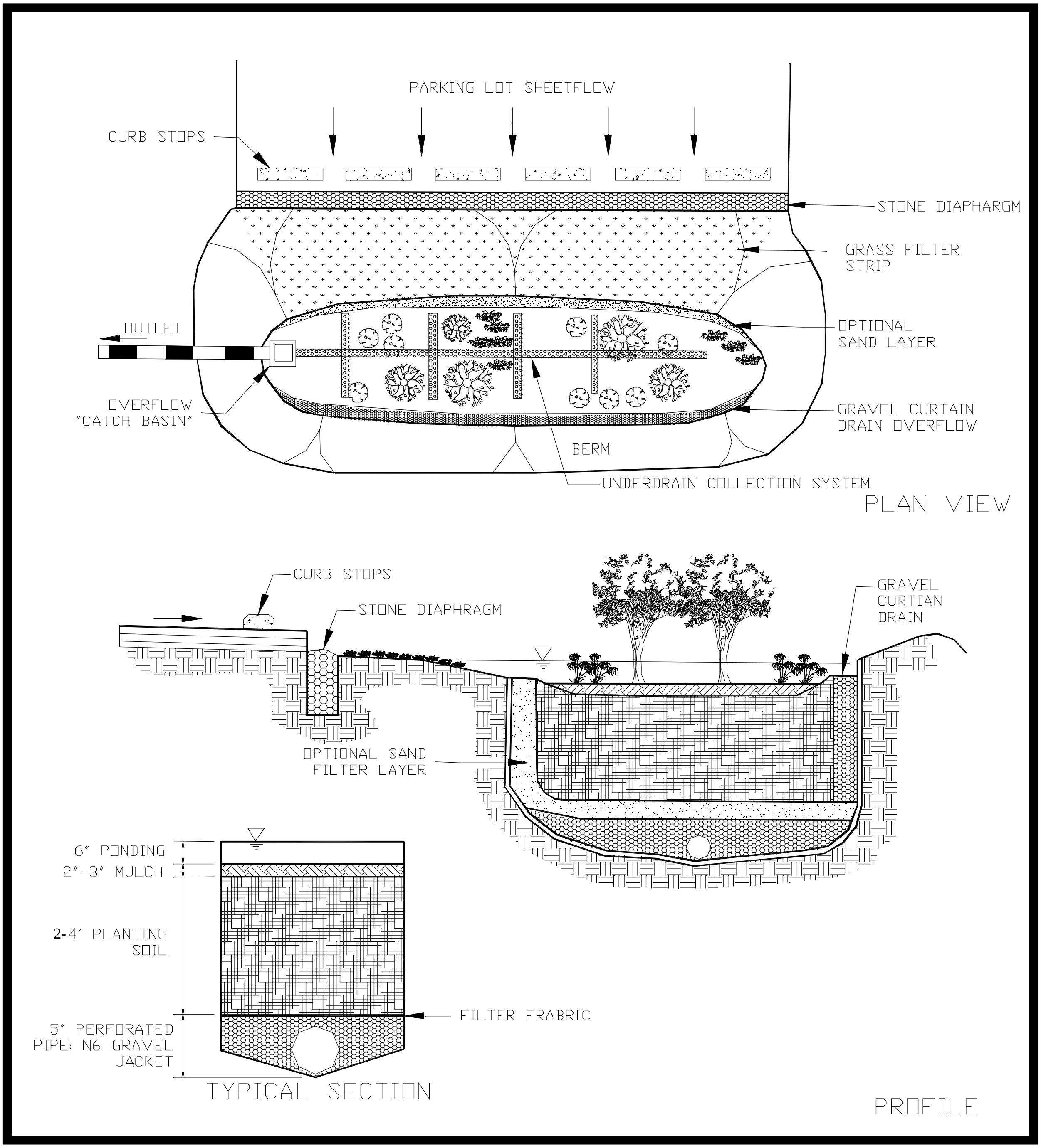
Step 11. Design emergency overflow.

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

Step 12. Prepare Vegetation and Landscaping Plan.

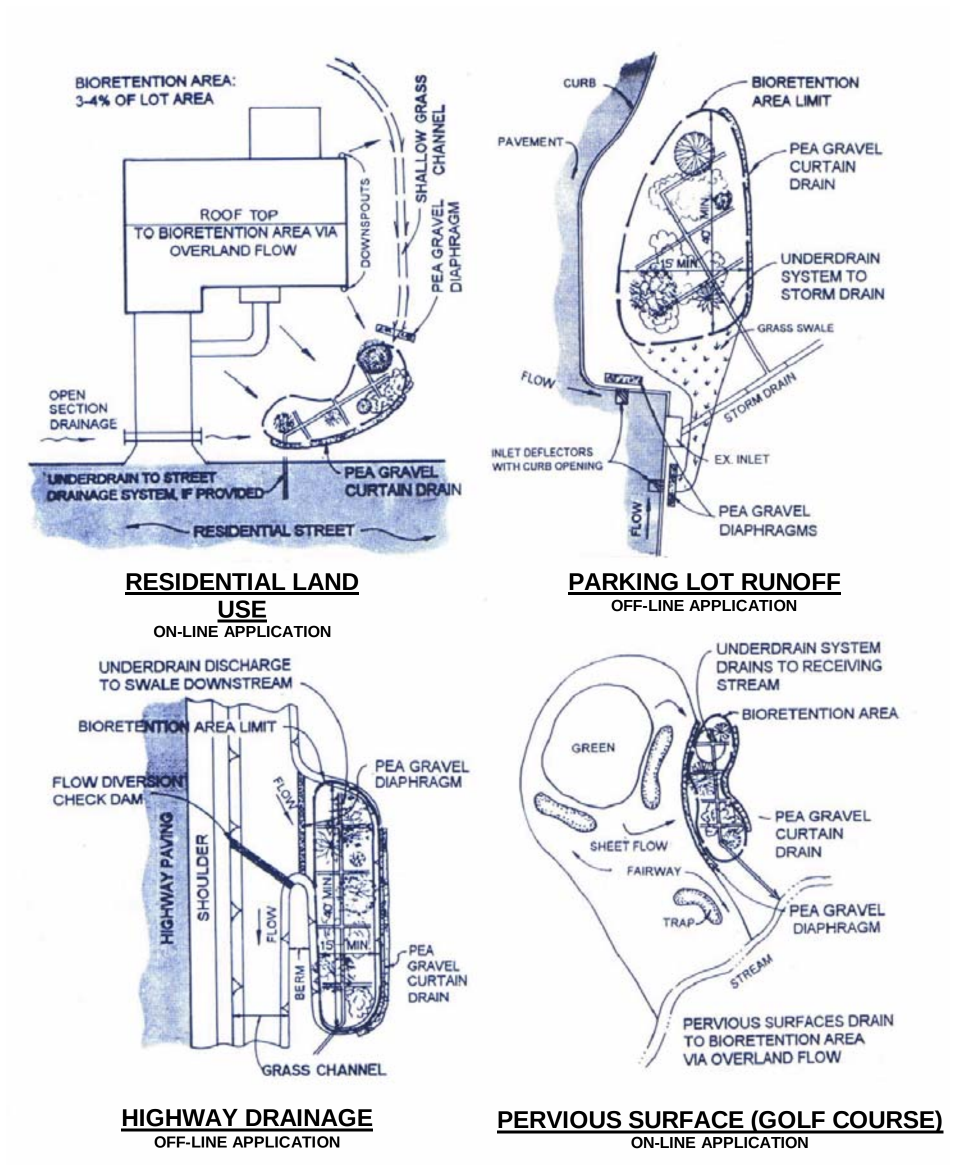
A landscaping plan for the bioretention area should be prepared to indicate how it will be established with vegetation.

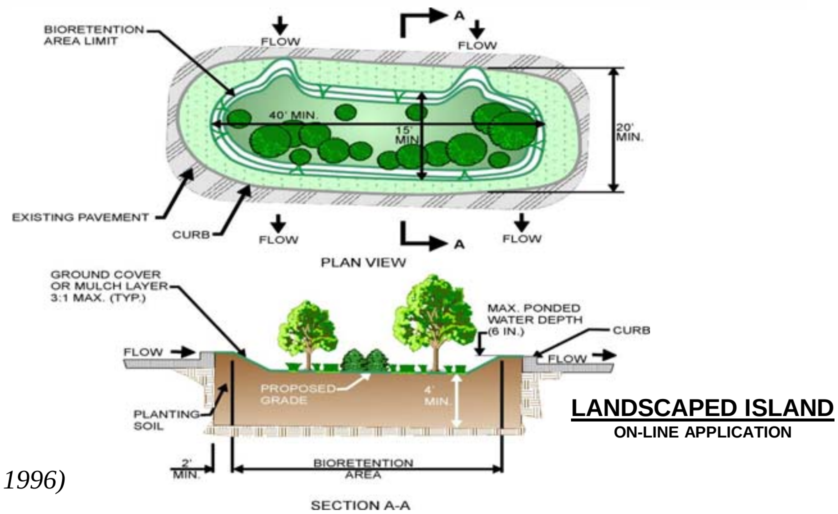
See the *Landscaping Bioretention Areas* section for more details.



(Source: Center for Watershed Protection)

Figure 3.1 Bioretention Area





(Adapted from Claytor and Scheuler, 1996)

Figure 3.2 Applications of Bioretention Areas

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Sand Filters

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

Variations: Underground Sand Filter (see PTP-10), Perimeter Sand Filter (see PTP-11), and Organic Filter (PTP-12)

Components:
- Forebay (or sedimentation chamber)—settles coarse particles and trash
- Sand bed (or Filtration) chamber—provides water quality treatment by filtering other pollutants
- Spillway system(s)— provide discharge control

Advantages/Benefits:
- Applicable to small drainage areas
- Good for highly impervious areas
- Good for water quality retrofits to existing developments

Disadvantages/Limitations:
- High maintenance burden
- Not recommended for areas with high sediment content in stormwater or clay/silt runoff areas
- Relatively costly
- Possible odor problems
- Typically needs to be combined with other controls to provide water quantity control

Design considerations:
- Typically requires 2 to 6 feet of head
- Maximum contributing drainage area of 10 acres
- In karst areas use polyliner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure

Selection Criteria:

- [x] **Water Quality 80 % TSS Removal**
- [x] **Accepts Hotspot Runoff**
- [ ] **Residential Subdivision**
- [x] **High Density / Ultra Urban Use**

Maintenance:

- Inspect for clogging—rake first inch of sand
- Remove sediment from forebay-chamber
- Replace sand filter media as needed
- Clean spillway system(s)

H **Maintenance Burden**

L = Low M = Moderate H = High

General Description

Sand filters (also referred to as *filtration basins*) are structural stormwater controls that capture and temporarily store stormwater runoff and treat it by filtering it through a bed of sand. The surface sand filter is a ground-level open air structure that consists of a pretreatment sediment forebay and a sand bed chamber. This system can treat drainage areas up to 10 acres in size and is an off-line device in which flows larger than the water quality volume by-pass the system. Surface sand filters can be designed as an excavation with earthen embankments or as a concrete or block structure. The filtered runoff is collected and returned to the conveyance system, or it can also be partially or fully exfiltrated into the surrounding soil in areas with porous soils. A schematic of a surface sand filter is shown in Figure 4.1.

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

A design variant, the *underground sand filter*, is intended primarily for extremely space limited and high density areas and is thus considered a limited application structural control. See PTP-10 for more details. Another design variant is the *perimeter sand filter*, which is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area such as a parking lot. See PTP-16 for information on the perimeter sand filter.

In surface sand filter systems, stormwater pollutants are removed through a combination of gravitational settling, filtration, and adsorption. The filtration process effectively traps suspended solids and particulates. As solids are trapped in the sand bed, some reduction of associated pollutants such as biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants may be achieved.

Site and Design Considerations

Location and Siting

1. Surface sand filters should have a contributing drainage area of 10 acres or less.
2. Surface sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with less than 50% imperviousness or with high clay/silt sediment loads must not use sand filters without adequate pretreatment because the sediment causes clogging and failure of the filter bed. Any disturbed areas within the sand filter facility drainage area should be identified and stabilized. Filtration controls should only be constructed after the construction site is stabilized.

Site and Design Considerations (Continued)

3. Surface sand filters are used in an off-line configuration where the water quality volume (WQ_v) is diverted to the filter facility. Stormwater flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
4. Sand filter systems are designed for intermittent flow and must be allowed to drain and aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

General Design

5. A surface sand filter facility consists of a two-chamber open-air structure, which is located at ground-level. The first chamber is the sediment forebay (sedimentation chamber) while the second chamber houses the sand filter bed. Flow enters the forebay chamber where settling of larger sediment particles occurs. Discharge from the forebay chamber flows through a perforated standpipe into the sand bed chamber. The flow is then uniformly distributed across the sand bed chamber via distribution vault or weir. After passing though the filter bed, runoff is collected by a perforated pipe and gravel underdrain system. Figure 4.1 provides plan view and profile schematics of a surface sand filter.

Physical Specifications/Geometry

6. The entire treatment system (including the forebay) must temporarily hold the WQ_v prior to filtration. Table 4.1 presents the design parameters and values for the perimeter sand filter. Figure 4.2 illustrates these design parameters.
7. The forebay chamber must be sized to at least 50% of the computed $WQ_{v,}$ hold this volume for 24 hours, and have a length-to-width ratio of at least 2:1. Inlet and outlet structures should be located at opposite ends of the chamber.
8. The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in 24 hours or fewer.
9. The filter media consists of an 18 to 24 inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand) on top of the underdrain system. Permeable filter fabric is placed both above and below the sand bed to prevent clogging of the sand filter and the underdrain system. Figure 4.3 illustrates a typical media cross section.
10. The filter bed is equipped with a 6-inch perforated pipe (ASTM Schedule 40) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8-inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. Gravel should be clean washed aggregate with a maximum diameter of 3.5

Site and Design Considerations (Continued)

inches and a minimum diameter of 1.5 inches with a void space of about 30%. Do not use aggregate contaminated with soil.

11. The structure of the surface sand filter may be constructed of impermeable media such as concrete, or through the use of excavations and earthen embankments. When constructed with earthen walls/embankments, filter fabric should be used to line the bottom and side slopes of the structures before installation of the underdrain system and filter media. The structure should include an access ramp at 4:1 (H:V) or less for maintenance.

Table 4.1 Surface Sand Filter Design Parameters

Parameter Description	Parameter	Parameter Value
Total Temporary Volume in Forebay and Sand Bed Chamber	WQ_v	WQ_v; See Design Step #1
Approximate Temporary Sand Bed Volume[1]	V_{ST}	(0.5) WQ_v
Minimum Sand Bed Thickness	T_S	18 inches
Sand Bed Design Porosity	n	0.3
Sand Bed Design Permeability	k	3.5 feet/day
Sand Bed Design Drain Time	t_d	1.5 days, 36 hours max
Minimum Sand Bed Chamber Area	A_S	See Design Step #6
Approximate Temporary Forebay Volume[2]	V_{FT}	(0.5) WQ_v
Minimum Forebay Surface Area	A_F	(0.05) WQ_v
Maximum Temporary Sand Bed Depth[3]	D_{ST}	See Design Step #3
Minimum Temporary Forebay Depth	D_{FT}	2 feet
Overall Minimum Length to Width Ratio	L/W	2

1. Includes temporary storage volume in sand.
2. Includes temporary storage volume in sand.
3. Excludes storage volume in forebay permanent pool.
4. Measured from top of sand bed.

(Adapted from the New Jersey Stormwater Best Management Practices Manual)

Site and Design Considerations (Continued)

Pretreatment/Inlets

12. Pretreatment of runoff in a sand filter system is provided by the forebay chamber.
13. Inlets to surface sand filters are to be provided with energy dissipaters. Exit velocities from the forebay chamber must be nonerosive.
14. Figure 4.4 shows a typical inlet pipe from the forebay to the sand bed chamber where the flow is then evenly distributed across the filtration area.

Outlet Structures

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

Emergency Spillway

Surface sand filters are off-line devices and the emergency spillway is provided in case diversion structure fails. The spillway prevents filter water levels from overtopping the embankment and causing structural damage. The emergency spillway should be located so that downstream buildings and structures will not be impacted by spillway discharges.

Maintenance Access

Adequate access through maintenance easements must be provided for all sand filter systems for inspection and maintenance, including the appropriate equipment and vehicles. Facility designs must enable maintenance personnel to easily replace the upper layers of the filter media. Maintenance access ramps at a 4:1 slope or flatter must be provided.

Safety Features

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

Design Procedures

Step 1. Compute the Water Quality Volume.

Calculate the Water Quality Volume (WQ_v), which must be temporarily stored within the perimeter sand filter's entire treatment system.

$$\mathbf{WQ_v = P \times Rv \times A/12}$$

Where:
WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$\mathbf{Rv = 0.015 + 0.0092 * I}$$

Where:
I = site impervious cover, % (for example 50% equals 50)

Step 2. Determine approximate required volumes of the forebay and sand bed.

Each should be equal to approximately 0.5 WQ_v, as shown in Table 4.1.

Step 3. Determine approximate temporary depths in sand bed (D_{ST}) and forebay (D_{FT}) for the WQ_v.

The estimate will depend on and be based on analysis of site conditions including the difference between the invert elevation of the downstream conveyance system and the maximum ground elevation at filter facility. Make sure to include the minimum sand bed thickness (T_{HS}) into the consideration for these temporary depths. Note that the maximum temporary depth in the sand bed zone (D_{ST}) is measured from the top of the sand bed, while the maximum temporary forebay depth (D_{FT}) is measured the bottom of the forebay.

Step 4. Compute minimum forebay surface area (A_F).

The minimum surface area is
$$\mathbf{A_F = 0.05\ (WQ_v)}$$

Where:
A_F = forebay area
0.05 = a multiplier in units per area of volume (L^2/L^3)

Design Procedures Continued

Step 5. Compute total temporary storage volume in the forebay (V_{FT}).

From the maximum temporary depth in the forebay (D_{FT}) from Step 3 and the minimum forebay area (A_F) from Step 4, compute the total temporary storage volume in the forebay (V_{FT}). *Compare* this volume with the approximate required forebay volume computed in Step 2. *Adjust* the maximum temporary forebay depth (D_{FT}) and/or forebay area (A_F) as necessary to achieve a total temporary forebay storage volume (V_{FT}) as close as practical to the required forebay volume from Step 2. While adjusting the forebay surface area (A_F) by varying its length and width, remember that the forebay will be located immediately adjacent to the sand bed zone and that the minimum overall length to width ratio of the combined zone is two to one.

Step 6. Compute **sand bed** chamber area (A_S).

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

$$\mathbf{A_S = (WQ_v)\,(T_S / [(k)\,(D_{ST}/2 + T_S)\,(T_D)]}$$

Where:

A_S = Sand Bed Surface Area (in square feet)
T_S = Thickness of Sand in Sand Bed (typically 18 inches, no more than 24 inches)
k = Coefficient of permeability of filter media (ft/day) (use 3.5 ft/day for sand)
D_{ST} = Maximum Temporary Sand Bed Depth (ft)
t_d = Sand Bed Design Drain Time (1.5 days or 36 hours is recommended maximum)

See the Physical Specifications/Geometry section of the *Site and Design Considerations* for filter media specifications.

Step 7. Compute total temporary storage volume in sand bed.

$$\mathbf{V_{ST} = (A_S)(D_{ST}) + (A_S)(T_S)(n)}$$

Where:

V_{ST} = Temporary Sand Bed Storage Volume (in cubic feet)
A_S = Sand Bed Surface Area (in square feet)
D_{ST} = Maximum Temporary Sand Bed Depth (ft)
T_S = Thickness of Sand in Sand Bed, recommended 18 inches (in feet)
n = Sand Bed Design Porosity, recommended 0.3

Design Procedures (Continued)

Step 8. Compare and adjust areas and volumes to achieve storage of WQ_v within the entire facility.

Compare the total temporary sand bed storage volume (V_{ST}) with the approximate required sand bed zone volume computed in Step 2. As shown on Table 16.1, this temporary sand bed storage volume should be approximately one half of the stormwater quality design storm runoff volume (WQ_v). In addition, add the total temporary sand bed volume (V_{ST}) to the total temporary forebay storage volume (V_{FT}) to determine the total temporary storage volume in the sand filter. As shown in Table 16.1, this total temporary storage volume must equal the stormwater quality design storm runoff volume (WQ_v). Adjust the maximum temporary sand bed depth (D_{ST}) and/or sand bed area (A_S) as necessary to achieve a total temporary sand bed storage volume (V_{ST}) as close as practical to the required sand bed volume from Step 2 and a total filter volume equal to WQ_v. Remember, while adjusting width and length that forebay will be located immediately adjacent to the sand bed zone and that the minimum overall length to width ratio of the combined zone is two to one.

Step 9. Design flow diversion structure.

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

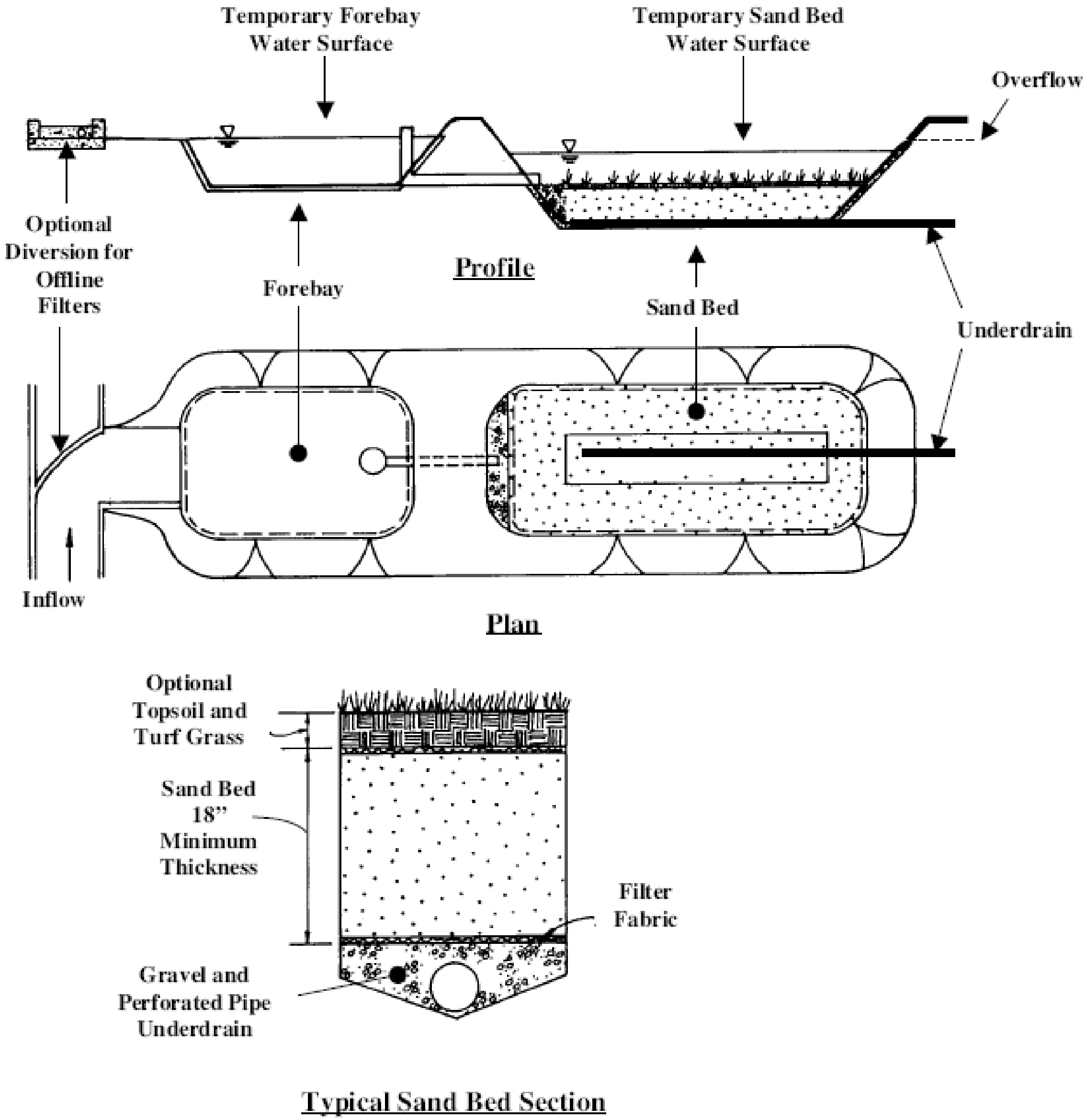
Size low flow orifice, weir, or other device to bypass the 100-year flood.

Step 10. Design inlets, underdrain system, overflow wiers, and outlet structures.

See *Site and Design Considerations* for more information on underdrain specifications and outlet structures. PTP-01 provides more information on sizing orifices, weirs, and outlets.

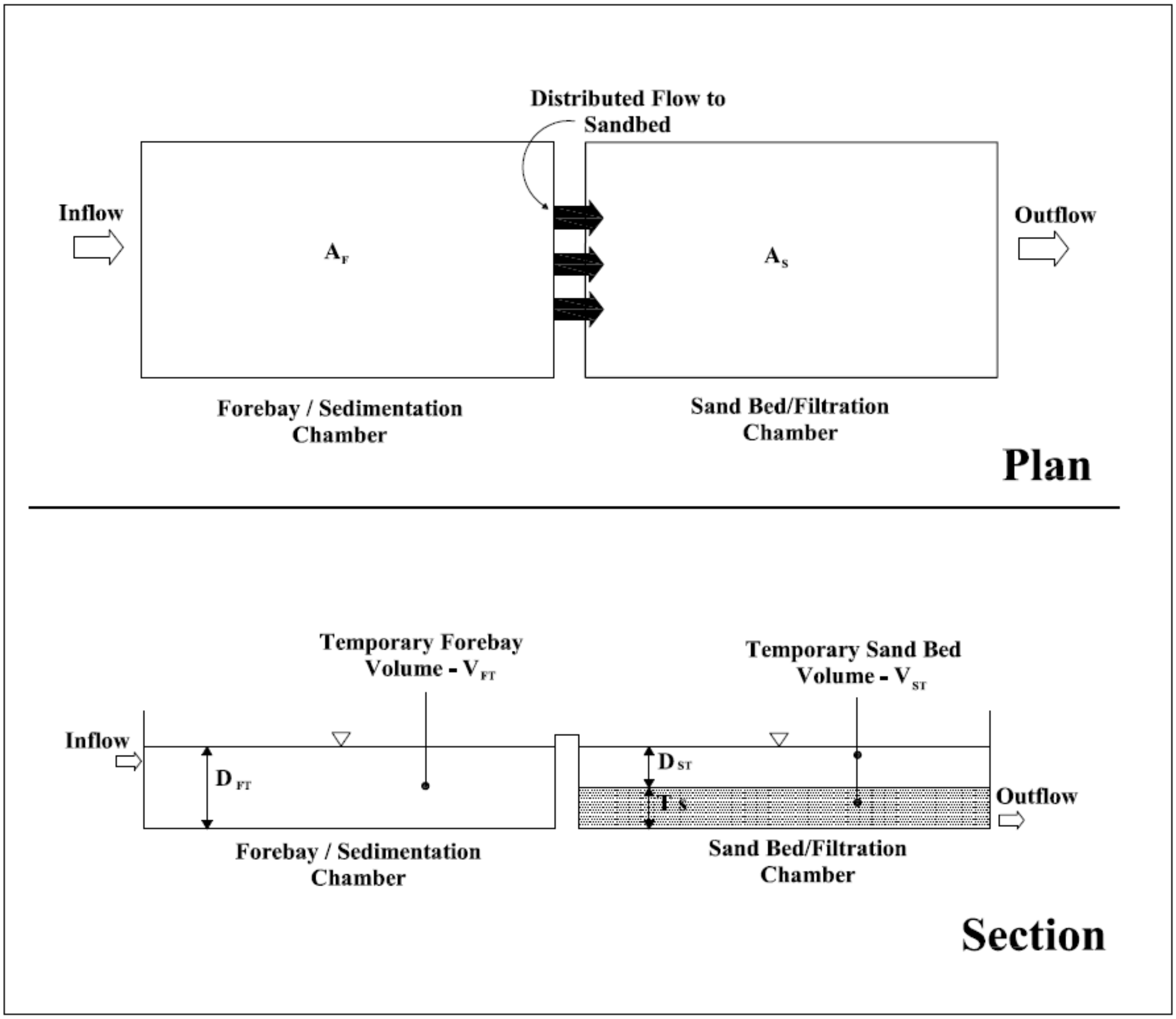
Step 11. Design emergency overflow.

An overflow must be provided in case of a failure in the diversion structure. Non-erosive velocities need to be ensured at the outlet point.



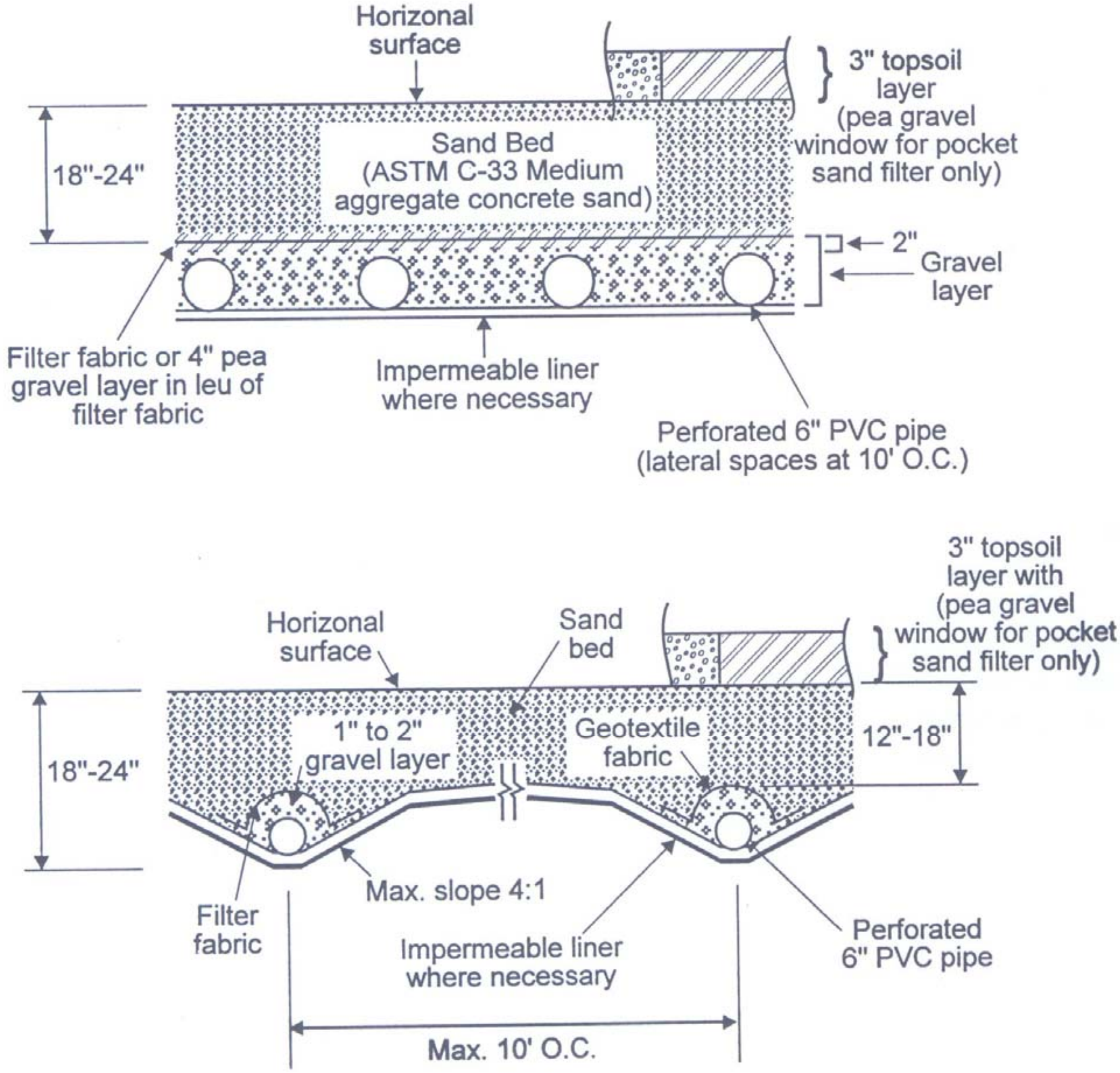
(Source: New Jersey Stormwater Best Management Practices Manual, 2003)

Figure 4.1 Surface Sand Filter Schematic



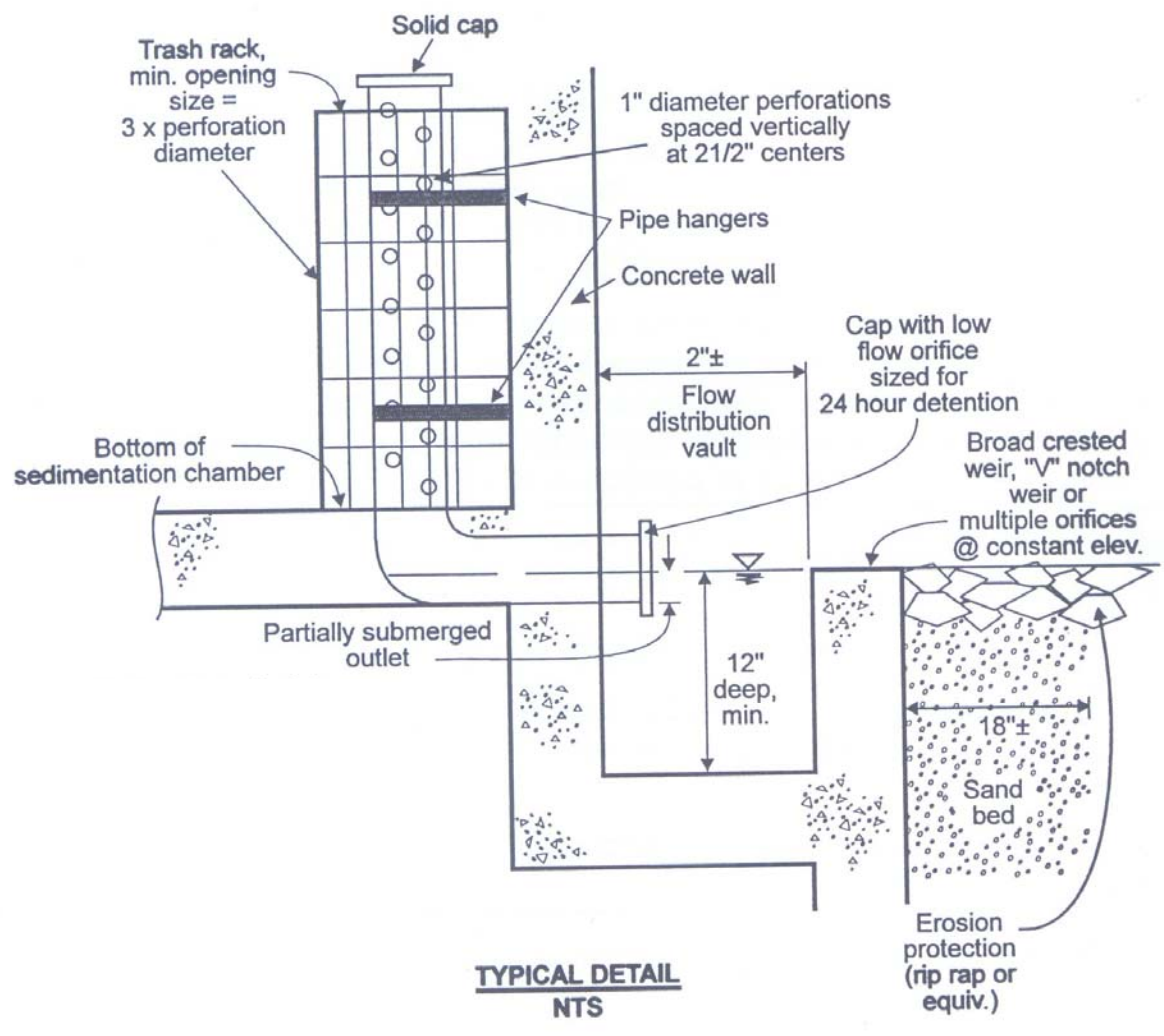
(Source: New Jersey Stormwater Best Management Practices Manual, 2003)

Figure 4.2 Schematic of Surface Sand Filter Showing Design Parameters



(Source: Claytor and Schueler, 1996)

Figure 4.3 Typical Sand Filter Media Cross Sections



(Source: Claytor and Schueler, 1996)

Figure 4.4 Surface Sand Filter Perforated Stand-Pipe

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Water Quality Swales

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

Variations: Swales can be wet or dry.

Components:
- Open trapezoidal or parabolic channel sized to store entire WQ_V. Dry swale infiltrates full WQ_V and wet swale retains WQ_V.
- Filter bed of permeable, engineered soils
- Underdrain system for impermeable soils (dry swale only)
- Wet cells created by check dams (wet swale only)
- Level spreaders every 50 feet, if length exceeds 100 feet.

Advantages/Benefits:
- Stormwater treatment combined with runoff conveyance
- Less expensive than curb and gutter
- Reduces runoff velocity
- Promotes infiltration

Disadvantages/Limitations:
- Higher maintenance than curb and gutter
- Cannot be used on steep slopes
- High land requirement
- Vector concerns (wet water quality swale)
- Requires ≈ 3 feet of head

Design considerations:
- Longitudinal slopes less than 4%
- Bottom channel width of 2 to 8 feet
- Underlying soils must have good infiltration or must be replaced (dry swale)
- Side slopes of 3:1 or flatter; 4:1 recommended
- Convey the 10-year storm event with minimum 6 inches of freeboard.

Selection Criteria:

- ✓ **Water Quality 80 % TSS Removal**
- ✓ **Accepts Hotspot Runoff (impermeable liner required)**
- ✓ **Residential Subdivision**
- ☐ **High Density / Ultra Urban Use**

Maintenance:

- Maintain grass heights
- Remove sediment from forebay and channel
- Remove accumulated trash
- Re-establish plants as needed

M — **Maintenance Burden**

L = Low M = Moderate H = High

General Description

Water quality swales, also known as “enhanced swales” or vegetated open channels, are channels that capture and treat the water quality volume for a site. They are specifically engineered to perform pollutant removal functions. Water quality swales have specific features that allow them to treat the Water Quality Volume (WQ_v). Water quality swales are designed with gradual longitudinal slopes that force runoff to slow down, which allow sediment to settle out while limiting channel erosion. Check dams or other mechanisms are installed perpendicular to the flow to further allow sediment to settle out and runoff to infiltrate.

There are two types of water quality swales, dry and wet:

<u>Dry water quality swales:</u> The dry swale is a vegetated channel that includes a filtering bed of permeable soils overlying an underdrain system. Dry swales are designed to filter or infiltrate the entire WQ_v through this filter bed and underdrain system. Dry swales rely primarily on the filtration mechanism to remove stormwater pollutants. *If it can be demonstrated that the swale can infiltrate the WQ_v within 24 to 48 hours (24 hours is preferred) without an underdrain, the swale may be designed without the underdrain.*

<u>Wet water quality swale:</u> The wet swale is a vegetated channel, also called a wetland channel that acts as a shallow wetland system that retains the WQ_v. The channel supports wetland vegetation in shallow marshy conditions. Usually impermeable or poorly drained soils are necessary to support the sufficient retention of water. Wet swales remove pollutants through sediment settling and biological removal. A wet swale does not require an underdrain.

Enhanced swales can be used in a variety of development types; however, they are primarily applicable to residential and institutional areas of low to moderate density where the impervious cover in the contributing drainage area is relatively low. They can also be used along roads and highways. Dry swales are mainly used in moderate to large lot residential developments, small impervious areas (parking lots and rooftops), and along rural highways. Wet swales tend to be used for highway runoff applications, small parking areas, and in commercial developments as part of a landscaped area. Because of their relatively large land requirement, enhanced swales are generally not used in higher density areas. In addition, wet swales may not be desirable for some residential applications, due to the presence of standing water, which may create nuisance odor or mosquito problems.

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

Site and Design Considerations

The following design and site considerations must be incorporated into the design for a water quality swale:

Location:

1. Channels must be sited so that the longitudinal slope is less than 4%. *Drop structures*, which disrupt flow by producing a pool of water behind them and a short drop in the surface gradient for water flowing over the structure, may be used to reduce the velocity of water in areas with greater slopes. Drop structures include check dams.
2. The water quality swale should have a contributing drainage area of five acres or less to prevent problems with distributing flow evenly across the swale.
3. Wet swales may be used where the water table is very high (at or near the surface of the soil) *or* where the water balance in poorly drained soils will support wetland vegetation.

General Design:

4. Both wet and dry water quality swales are designed to treat for water quality, but also to pass larger storms. Runoff enters the channel through a pretreatment forebay. In addition, distributed flow can enter along the sides of the channel after passing through a flow spreader such as a pea gravel diaphragm, level 2 x 12 timbers, or other level spreader along the bank of the channel.
5. <u>Dry water quality swale:</u> consists of an open channel with a filter bed of permeable soils overlaying an underdrain system. Water flows into the channel where it is filtered through the permeable bed. After being filtered, the runoff is conveyed through a perforated pipe and underdrain system to the outlet. A schematic is found in Figure 5.1.
6. <u>Wet water quality swale:</u> consists of an open channel excavated to the water table or to poorly drained soils. Check dams divide the channel into cells. A schematic is found in Figure 5.2.

Physical Specifications*:*

7. Swales can incorporate raised inlets (4 to 6 inches) to allow for the retention of initial runoff volume.
8. Channel slopes of 1% to 2% and no greater than 4% are recommended. If steeper slopes are necessary, 6 to 12 inch drop structures (see #1 above) can be used to limit runoff energy. Energy dissipators must be installed below drop structures and drop structures must be no closer than 50 feet. The depth of the water at the downstream end of the swale must not exceed 18 inches.
9. Both dry and wet water quality swales must have a bottom channel width of 2 to 8 feet. Wider channels may be installed if designed with berms, walls, or a multi-level cross-section that prevent the channel from meandering and eroding.
10. Cross-sections of dry and wet swales are to be parabolic or trapezoidal with moderate slopes of no greater than 3:1. More gentle slopes of 4:1 are recommended.

Site and Design Considerations (Continued)

11. Minimum width should be determined using Manning's equation, with an n of 0.2 to 0.24.
12. Maximum length of the swale shall be 100 feet unless level spreaders are used. Level spreaders shall be placed at least every 50 feet. Maximum length without a level spreader is 80 feet.
13. The maximum ponding depth of the WQ_v must be no greater than 18 inches at the downstream end of the swale. The average ponding depth should be 12 inches.
14. The maximum velocity should be no more than 0.9 feet per second.

Physical Specifications—Dry Swale:

15. Dry swale channels are sized to store and infiltrate the entire water quality volume (WQ_v) with less than 18 inches of ponding and allow for full filtering through the permeable soil layer. The maximum ponding time is 48 hours, though a 24-hour ponding time is more desirable. Refer to PTP-01 for orifice sizing.
16. The bed of the dry swale consists of a permeable soil layer of at least 30 inches in depth, above a 4-inch diameter perforated pipe (AASHTO Schedule 40) longitudinal underdrain in a 6-inch gravel layer. The soil media should have an infiltration rate of at least 0.5 inches/hour (maximum 0.75 inches/hour) and contain a high level of organic material to facilitate pollutant removal. A permeable filter fabric is placed between the gravel layer and the overlying soil.

Table 5.1 Infiltration Rates of Common Soil Types

Common Soil Types	Infiltration Rates (inches/hour)
Coarse Sand	¾ to 2
Fine Sand	½ to 1
Fine Sandy Loam	1/3 to ¾
Silt Loam	¼ to 4/10
Clay Loam	1/10 to ¼

(Source: NRCS, USDA www.soils.usda.gov)

17. The channel and underdrain excavation should be limited to the width and depth specified in the design. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and scarified prior to placement of gravel and permeable soil. The sides of the channel shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling.

Physical Specifications—Wet Swale:

18. Wet swale channels are sized to retain the entire water quality volume (WQ_v) with less than 18 inches of ponding at the maximum depth point.
19. Check dams can be used to achieve multiple wetland cells. V-notch weirs in the check dams can be utilized to direct low flow volumes.

Site and Design Considerations (Continued)

Pretreatment/Inlets

20. Inlets to enhanced swales must be provided with energy dissipators such as riprap.
21. Pretreatment of runoff in both a dry and wet swale system is typically provided by a sediment forebay located at the inlet. The pretreatment volume should be equal to 0.1 inches per impervious acre. This storage is usually obtained by providing check dams at pipe inlets and/or driveway crossings.
22. Enhanced swale systems that receive direct concentrated runoff may have a 6-inch drop to a flow spreader at the upstream end of the control.
23. A flow spreader and gentle side slopes should be provided along the top of channels to provide pretreatment for lateral sheet flows.

Outlet Structures

24. *Dry water quality swale* underdrain system must discharge to the storm drainage infrastructure or a stable outfall.
25. *Wet water quality swales* must have outlet protection at any outlet so that scour and downstream erosion do not occur.

Other Considerations

26. Water quality swales must be designed to safely pass flows that exceed the design storm flows.
27. Maintenance access must be provided for all swales.
28. Landscaping must specify grass species and/or wetland plants that will thrive under the hydric and soils conditions at the particular site.

As-Built Certification Considerations

After the water quality swale has been constructed, the developer must have an as-built certification of the swale prepared by a registered Professional Engineer and submit it to Metro. The as-built certification verifies that the BMP was installed as designed and approved.

The following components must be addressed in the as-built certification:

1. Appropriate underdrain system for dry swales.
2. Correctly sized treatment volume.
3. Poor soils or groundwater table interface for wet swales.
4. Adequate vegetation in place.
5. Overflow system in place for high flows.

Maintenance

Each BMP must have an Operations and Maintenance agreement that is submitted to Metro for approval and is maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the Operation and Maintenance Agreement for swales areas, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with site plans. The BMP owner must maintain and update the BMP operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

Maintenance (Continued)

1. Inspection and repair/replacement of treatment components.
2. Maintain vegetation at heights of 8 inches or less to prevent thinning of vegetative cover, which lessens swale effectiveness.
3. Removal of debris or dead vegetation.

Landscaping

Dry Swale: Turf grass species appropriate for Metro conditions should be used for dry swale vegetation.

Wet Swale: Emergent vegetation should be planted or wetland soils can be spread on the swale bottom for seeding. Where wetland swales do not intercept the groundwater table, a water balance calculation should be performed to ensure that the swale has a water budget adequate to support wetland species. The water balance calculation is found in the stormwater Constructed Wetland BMP, PTP-02.

Design Procedures

Step 1. Compute the Water Quality Volume.

Calculate the Water Quality Volume (WQ_v), which is the volume that must be stored in the swale.

$$WQ_v = P \times Rv \times A/12$$

Where:
WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85th percentile storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.015 + 0.0092I$$

Where:
I = site impervious cover, % (for example, 50% equals 50)

Step 2. Determine if the development site and conditions are appropriate for the use of an enhanced swale system (dry or wet swale).

See the *Site and Design considerations*, above.

Step 3. Determine pretreatment volume.

The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage. The forebay storage volume (F_v) counts toward the total WQ_v requirement and may be subtracted from the WQ_v for subsequent calculations.

$$F_v = 0.1 \text{ inches} \times A_I \text{ acres} \times .0833$$

Design Procedures (Continued)

Where:
F_v = Forebay volume (ac-ft)
A_I = Impervious area of drainage basin, acres
0.0833 = conversion factor of acre inches to acre feet

Often, it is more manageable to work with forebay volumes in cubic feet rather than acre feet, because they are small volumes. To convert F_v in acre feet to cubic feet, multiply F_v by 43560 square feet.

Step 4. Determine swale dimensions.

Size bottom width, depth, length, and slope necessary to store WQ_v with less than 18 inches of ponding at the downstream end.

Channel slope cannot exceed 4% (1% to 2% recommended). For more steeply sloped areas, swale must be "stepped" with check dams or similar structures to maintain slope.

Bottom width should range from 2 to 8 feet

Length to width ratio of 5:1 is suggested.

Ensure that side slopes are no greater than 3:1 (4:1 recommended)

See *Site and Design Considerations*, above.

Step 5. Compute number of check dams or similar structures required to detain WQ_v.

Step 6 Calculate drawdown time in the swale.

Dry Swale: Planting soil, 30 inches, should pass a maximum rate of 1.5 feet/day and must completely filter WQ_v in 48 hours.

Wet Swale: Must hold WQ_v.

Step 7 Check 2-year velocity erosion potential and provide 6 inches of freeboard above 10-year storm.

Step 8 Design low flow orifice at downstream headwalls and checkdams.

Design orifice to pass WQ_v in six hours. See PTP-01 Stormwater Ponds for information on orifice sizing.

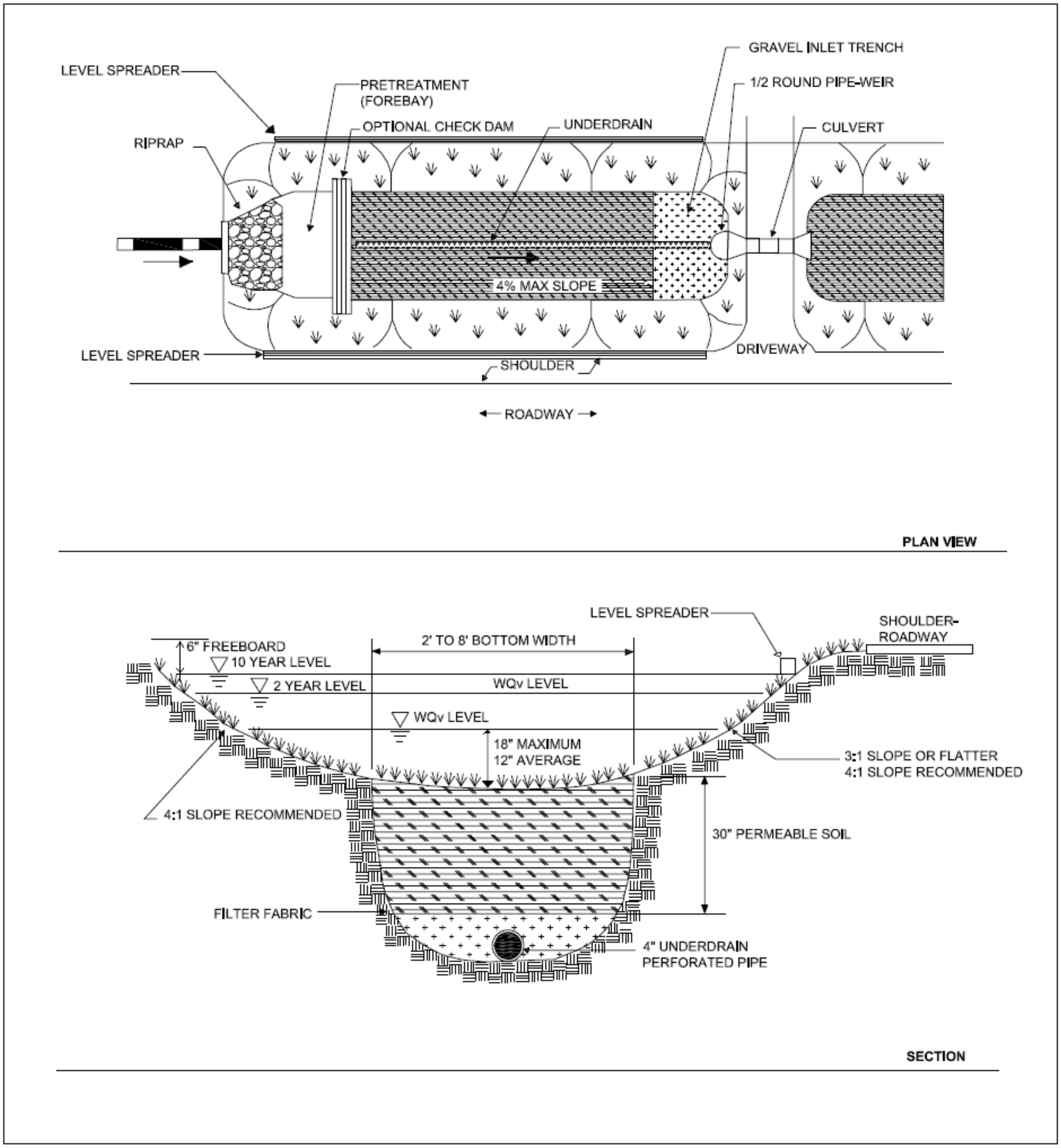
Design Procedures (Continued)

Step 9. Design inlets, sediment forebays and underdrain system (dry swale).

See *Site and Design Considerations,* above.

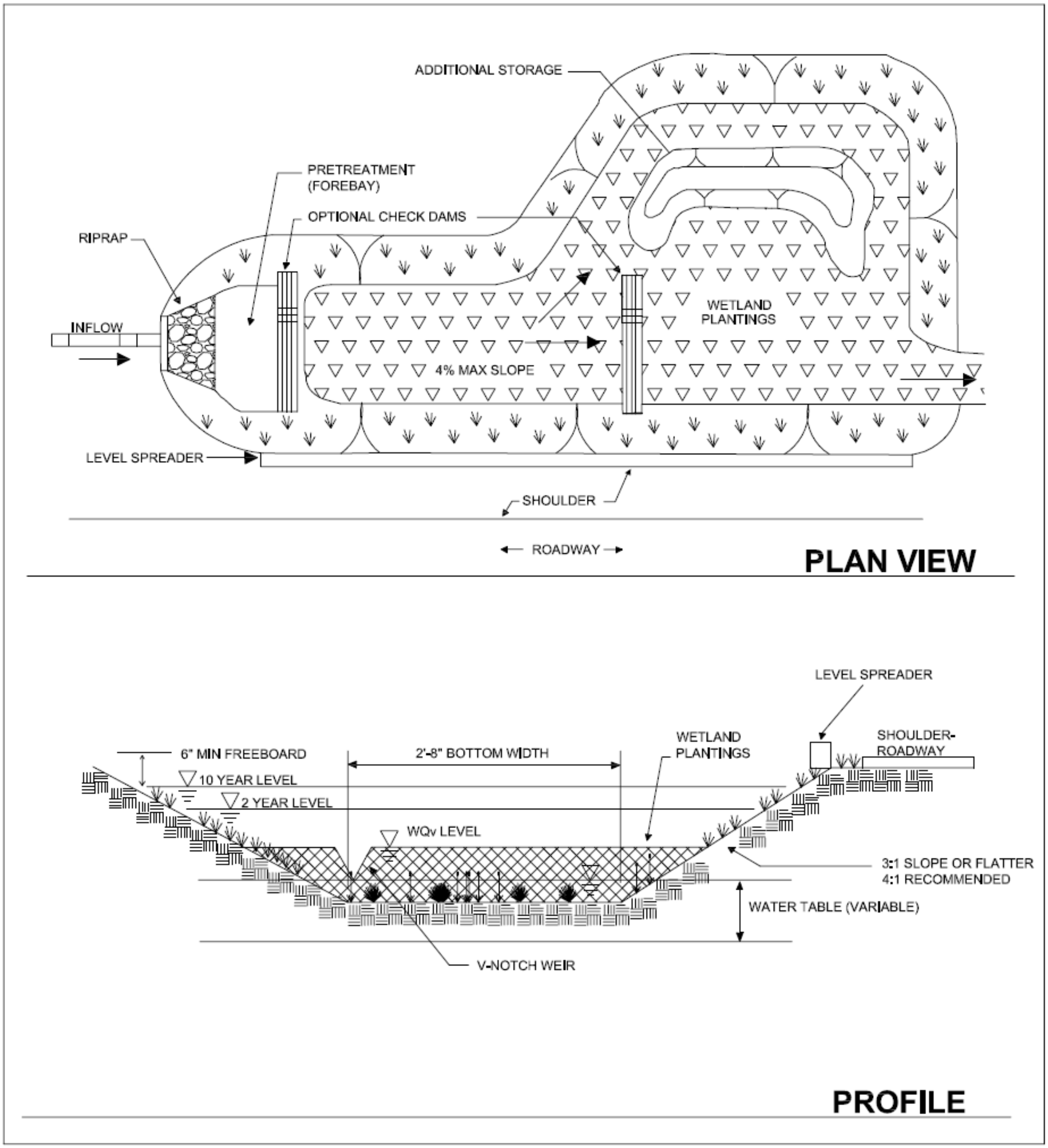
Step 10 Prepare Vegetation and Landscaping Plan.

A landscaping plan for a dry or wet swale should indicate how the enhanced swale system will be stabilized and established with vegetation.



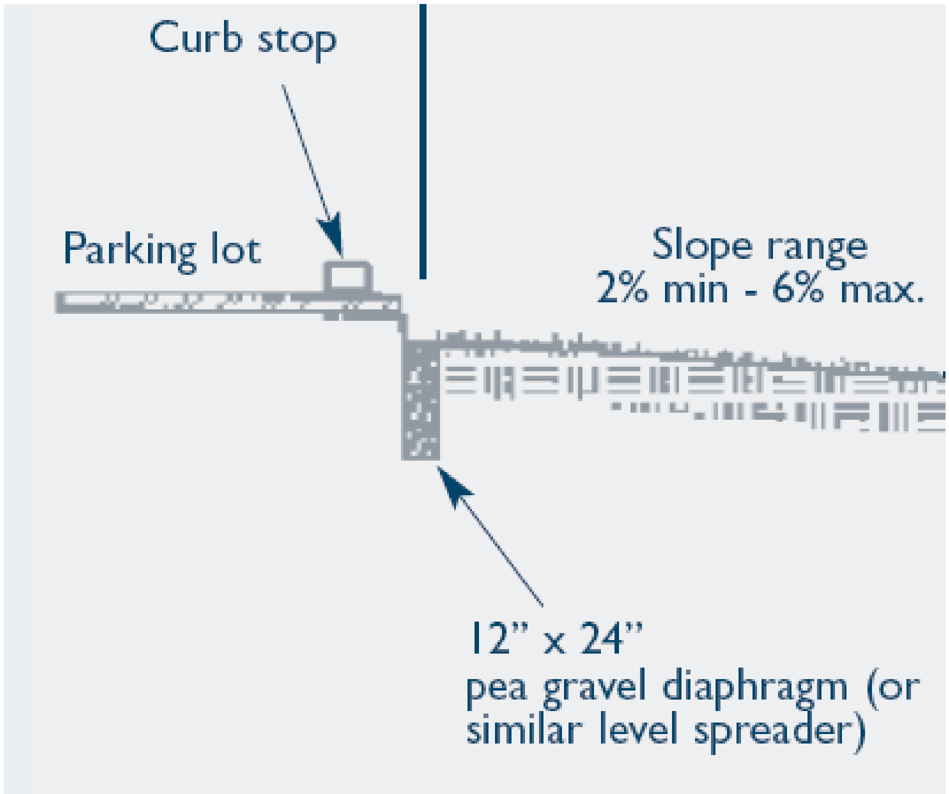
(Adapted from the Center for Watershed Protection)

Figure 5.1 Dry Water Quality Swale

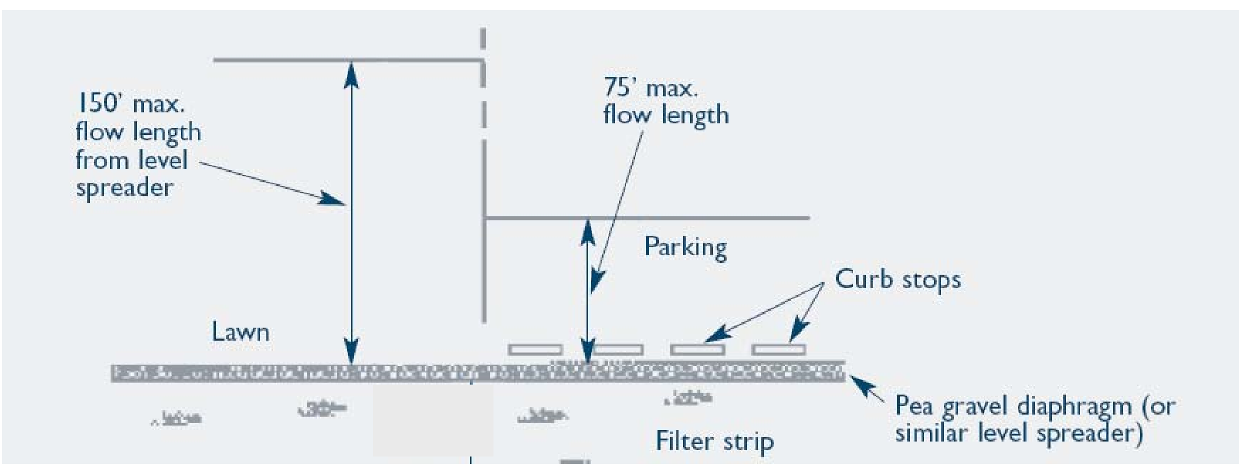


(Adapted from the Center for Watershed Protection)

Figure 5.2 Wet Water Quality Swale



PLAN VIEW



PROFILE

(Source: Connecticut Stormwater Management Manual)

Figure 5.3 Example of Level Spreader
(for Swales Receiving Directly Connected Runoff)

References

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Suggested Reading

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Maryland Department of the Environment, 2000. Maryland Stormwater Design Manual, Volumes I and II. Prepared by Center for Watershed Protection (CWP).

Metropolitan Washington Council of Governments (MWCOG), March, 1992, "A Current Assessment of Urban Best Management Practices: Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone".

Dry Ponds

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

Components:
- Pool area –fills during a storm and releases water slowly through bottom outlet
- Forebay – settles out larger sediments in an area where sediment removal (maintenance) will be easier
- Spillway system – provides outlet for stormwater runoff when large storm events occur

Advantages/Benefits:
- Typically less costly than stormwater (wet) ponds for equivalent flood storage, as less excavation is required
- Provides recreational and other open space opportunities between storm runoff events

Disadvantages/Limitations:
- Controls for stormwater quantity—not intended to provide for total water quality treatment; assumed to achieve 60% TSS removal
- Must be used in conjunction with other water quality controls
- Tends to re-suspend sediment

Design considerations:
- Applicable for drainage areas up to 75 acres
- Drawdown of 24 to 48 hours
- Shallow pond with large surface area performs better than deep pond of same volume
- Assumed to provide 60% TSS removal

Selection Criteria:

- ☐ **Water Quality 80 % TSS Removal**
- ☐ **Accepts Hotspot Runoff**
- ☑ **Residential Subdivision**
- ☑ **High Density / Ultra Urban Use**

Maintenance:

- Remove debris from basin surface
- Remove sediment buildup
- Repair and revegetate eroded areas.
- Perform structural repairs to inlet and outlets.
- Mow unwanted vegetation

L **Maintenance Burden**

L = Low M = Moderate H = High

General Description

Dry extended detention (ED) basins, as shown in Figure 6.1, are surface facilities intended to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts. These facilities temporarily detain stormwater runoff, releasing the flow over a period of time. They are designed to completely drain following a storm event and are normally dry between rain events. For the purposes of this application, dry detention and dry extended detention are considered the same treatment.

Dry detention basins, when used for flow attenuation, can be designed to control the 100-year storm event, the detention requirement for Metro.

Dry detention basins provide limited pollutant removal benefits and are not intended for sole water quality treatment. Detention-only facilities must be used in a treatment train approach with other structural controls that provide treatment of the WQ_v. This type of facility is assumed to provide 60% TSS removal. While the ponds may be providing peak flow attenuation in addition to water quality treatment (in-line ponds), the other water quality treatment controls in the treatment train must be off-line.

Compatible multi-objective use of dry detention facilities is strongly encouraged.

Site and Design Considerations

Location

1. Dry detention basins are to be located downstream of other structural stormwater controls providing treatment of the water quality volume (WQ_v). See Volume 4, PTP Section 6 Introduction, sub-section 6.2 for more information on the use of multiple structural controls in a treatment train.
2. The maximum contributing drainage area to be served by a single dry detention basin is 75 acres.

General Design

3. Dry detention basins can be sized to hold the WQ_v or, if used for flow attenuation, they can be sized to temporarily store the 100-year storm. Routing calculations must be used to demonstrate that the storage volume is adequate for flow attenuation. See Volume 2 for procedures on the design of detention storage.
4. Tennessee Safe Dams Act may apply to ponds with storage volumes and embankment heights large enough to fall under the regulation.
5. Vegetated embankments shall be less than 20 feet in height and shall have side slopes no steeper than 3:1 (horizontal to vertical). Riprap-protected embankments shall be no steeper than 2:1. Geotechnical slope stability analysis is recommended for embankments greater than 10 feet in height and is mandatory for embankment slopes steeper than those given above. All embankments must be designed to Tennessee state

Site and Design Considerations (Continued)

guidelines for dam safety, as applicable.

6. The maximum depth of the basin should not exceed 10 feet.
7. Areas above the normal high water elevations of the detention facility (that is, the largest event for which the facility is sized) should be sloped toward the basin to allow drainage and to prevent standing water. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. A low flow or pilot channel across the facility bottom from the inlet to the outlet (often constructed with riprap) is recommended to convey low flows and prevent standing water conditions.
8. Adequate maintenance access must be provided for all dry basins.

Inlet and Outlet Structures

9. Inflow channels are to be stabilized with flared riprap aprons, or the equivalent. A sediment forebay sized to 0.1 inches per impervious acre of contributing drainage should be provided for dry detention basins.
10. For a dry detention basin used for flow attenuation, the outlet structure is sized for 100-year peak flow control (based upon hydrologic routing calculations) and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure. Small outlets that will be subject to clogging or are difficult to maintain are not acceptable. A low flow orifice capable of releasing the WQ_v over 24 hours must be provided.
11. Seepage control or anti-seep collars should be provided for all outlet pipes.
12. Riprap, plunge pools or pads, or other energy dissipaters are to be placed at the end of the outlet to prevent scouring and erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance.
13. An emergency spillway is to be included in the stormwater pond design to safely pass the extreme flood flow. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be designed to State of Tennessee dam safety requirements and must be located so that downstream structures will not be affected by spillway discharges.
14. A minimum of two feet of freeboard must be provided, measured from the top of the water surface elevation for the 100-year storm, to the lowest point of the dam embankment not counting the emergency spillway.

As-Built Certification Considerations

After the pond is constructed, an as-built certification of the pond, performed by a registered Professional Engineer, must be submitted to Metro. The as-built certification verifies that the BMP was installed as designed and approved. The following components must be addressed in the as-built certification:

1. Pretreatment for coarse sediments must be provided.
2. Surrounding drainage areas must be stabilized to prevent sediment from clogging the filter media.
3. Correct ponding depths and infiltration rates must be maintained to prevent killing vegetation.
4. A mechanism for overflow for large storm events must be provided.

Maintenance

Each BMP must have an Operations and Maintenance (O&M) Agreement submitted to Metro for approval and maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the Operation and Maintenance Agreement for dry detention ponds, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with site plan. The O&M agreement is for the use of the BMP owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

1. Inspect and repair/replace treatment components.
2. Perform annual verification of infiltration rates.
3. Remove debris or dead vegetation.

Design Procedures

Refer to PTP-01 Wet Ponds for further information on pond design.

Step 1. Compute the Water Quality Volume to Receive 60% TSS Credit.

Calculate (WQ_v). *If flow attenuation is not required, the pond can be sized for the WQ_v only.*

$$WQ_v = P \times Rv \times A/12$$

Where:

WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.015 + 0.0092I$$

Where:
I = site impervious cover, % where 50% is 50

Step 2. Determine if the development site and conditions are appropriate for the use of a dry pond.

Consider the *Site and Design Considerations* previously in this section. This type of treatment must be used in conjunction with another water quality measure in order to achieve 80% TSS removal.

Step 3. Determine pretreatment volume.

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

$$F_v = 0.1 \times A_I \times 3630$$

Where:
F_v = Forebay volume (ft^3)
A_I = Impervious area of drainage basin, acres
3630 = conversion factor from Ac/in to cubic feet

Step 4. Size the outlets for storm events.

If the pond is to serve as a multifunctional pond addressing peak flow attenuation, the downstream impacts must be considered for the 2- through 100-year events.

Design Procedures (Continued)

Establish a stage-storage-discharge relationship for the design storms of interest, based upon the downstream analysis (see Section 6.8.1 in Volume 1).

Refer to PTP-01 Stormwater Ponds and Volume 2, Chapter 8 for more information on design of outlet orifices and weirs.

Step 5. Size the low flow outlet for the water quality volume.

Size low flow orifice using the following equation. If different equation is used or different type of low flow orifice is used, provide supporting calculations.

$$a = \frac{2A(H - H_o)^{0.5}}{3600CT(2g)^{0.5}}$$

a = area of orifice (ft^2)
A = average surface area of the pond (ft^2)
C = orifice coefficient, 0.66 for thin, 0.80 for materials thicker than orifice diameter
T = drawdown time of pond (hrs)(must be greater than 24 hours)
g = gravity (32.2 ft/sec^2)
H = elevation when pond in full (ft)
H_o= final elevation when pond is empty (ft)

Step 6. Design embankment and emergency spillway.

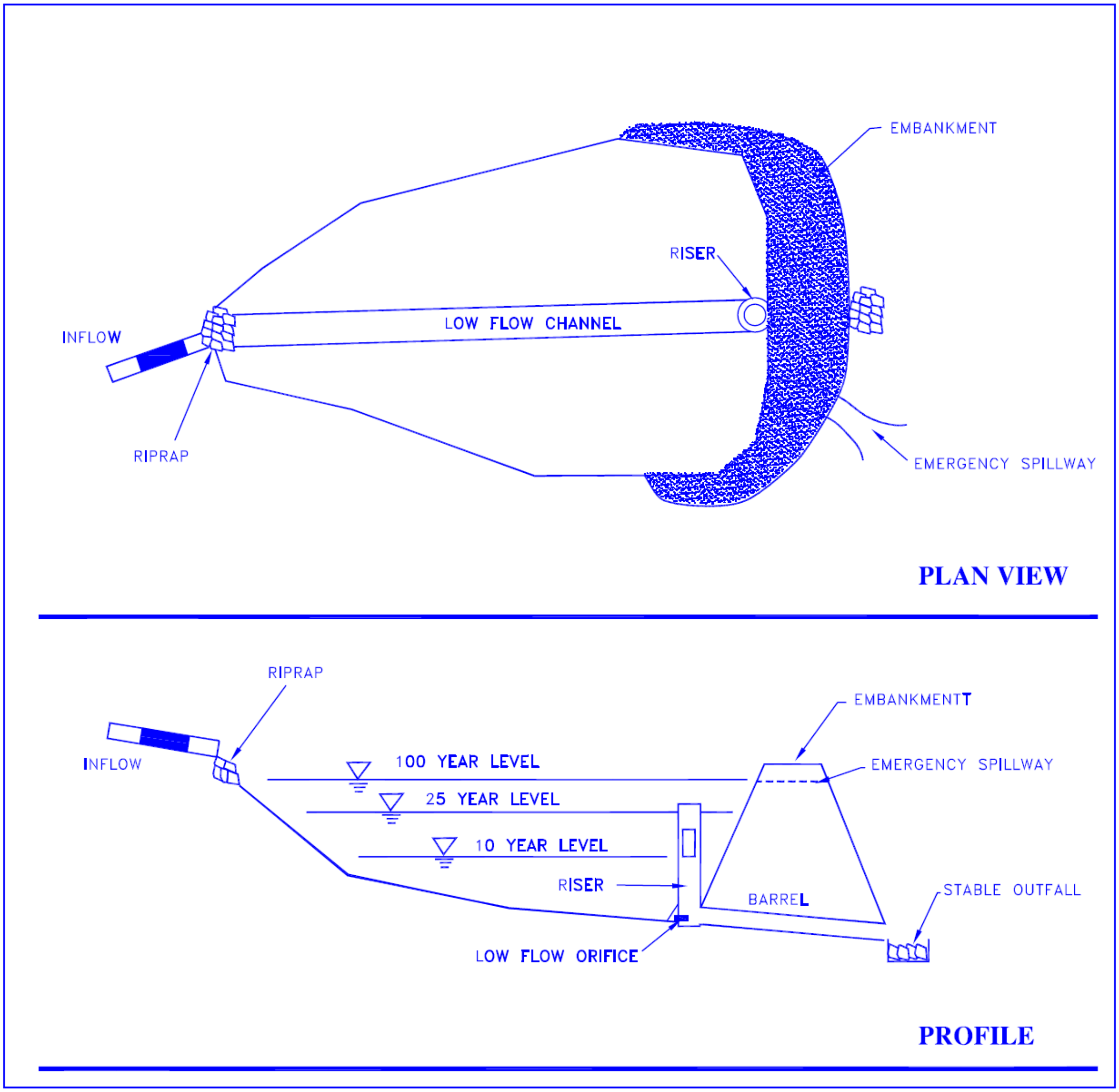
Size emergency spillway for any overtopping of pond in case of rain event in excess of 100-year storm and for instances of malfunction or clogging of primary outlet structure.

Step 7. Investigate potential dam hazard classification.

The design and construction of ponds in Tennessee must follow the requirements of the Safe Dams Act. Contact the Tennessee Department of Environment and Conservation, Division of Water Supply for more information about building dams in Tennessee.

Step 8. Design inlets, sediment forebays, outlet structures, maintenance access and safety features.

See the *Site and Design Considerations* section for information on design.



Note: Storm attenuation levels vary depending on site detention requirements.

(*Adapted from the Center for Watershed Protection)*

Figure 6.1 Schematic of Dry Extended Detention Basin

References

ARC, 2001. Georgia Stormwater Management Manual Volume 2 Technical Handbook.

CDM, 2000. Metropolitan Nashville and Davidson County Stormwater Management Manual Volume 4 Best Management Practices.

Suggested Reading

California Storm Water Quality Task Force, 1993. California Storm Water Best Management Practice Handbooks.

City of Austin, TX, 1988. Water Quality Management. Environmental Criteria Manual. Environmental and Conservation Services.

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Filter Strip

Description: Uniformly graded section of land that is densely vegetated and is designed to treat runoff through vegetative filtering and infiltration. Water enters the filter strip along its width and runs across the length of the filter strip.

Components:

- Vegetation – provides water quality treatment through filtering and plant uptake; vegetation can be grasses or other deep-rooted plants
- Land with gradual slope – minimal slopes allow for some amount of water quality treatment through infiltration
- Level spreader – ensures runoff over the vegetated filter is in sheet flow (shallow, uniform flow length) as opposed to concentrated (channelized) flow

Advantages/Benefits:

- High community acceptance in any type of setting
- Easy to maintain once ground cover and/or trees established
- Can be used as pre-treatment for other BMPs, similar to sediment forebay
- Filter strips are easily incorporated into new construction/ development designs

Disadvantages/Limitations:

- Cannot meet the 80% total suspended solids goal without another BMP in a treatment train. Fifty foot strip is assumed to achieve 50% TSS removal, while 25 foot strip used as a pretreatment control is assumed to achieve 10% TSS removal
- Filter strip and level spreaders have limited drainage areas
- It can be difficult to construct a level lip on level spreaders

Design considerations:

- Must have slopes between 2% and 6%
- Must maintain sheet flow across entire filter strip
- Minimum 25 foot flow length; the longer the flow length, the higher the pollutant removal, if sheet flow is maintained.

Selection Criteria:

☐	**Water Quality 80% TSS Removal**
✓	**Accepts Hotspot Runoff**
✓	**Residential Subdivision**
☐	**High Density / Ultra Urban Use**

Maintenance:

- Maintain a dense, healthy stand of grass and other vegetation
- Repair erosion
- Periodic sediment removal
- Revegetate as needed

L	**Maintenance Burden**

L = Low M = Moderate H = High

General Description

Filter strips are uniformly graded, densely vegetated areas of land that are designed to remove pollutants from runoff through vegetative filtration and infiltration. Filter strips are suited for treating runoff from roads and highways, small parking lots, pervious areas, and roof downspouts. They are also well-suited as the outer zone of a stream buffer and as pretreatment for other structural controls. Filter strips that fulfill Metro requirements can be used as credits against the stormwater quality volume for a site (see Volume 1, Chapter 7.8).

The vegetation can be grassed or a combination of grass and woody plants. Pollutant removal efficiencies are based upon a 50-foot long strip. Filter strips with shorter flow lengths are considered to have lower removal efficiencies and should be used as coarse sediment settling areas for other structural controls. Filter strips are and considered to be an integral component of those controls, similar to sediment forebays for stormwater wet ponds (see PTP-01). Uniform sheet flow must be maintained through the filter strip to provide pollutant reduction and to avoid erosion. To obtain sheet flow when discharging runoff from a developed area, a level spreader may be required.

Components

Figure 7.1 illustrates a filter strip. Filter strips consist of the following components:

1. Sheet flow spreader that allows flow to enter the filter strip as sheet flow.
2. Uniformly graded area with 2 to 6 percent slopes, with a minimum width of 15 feet, and a minimum length (flow path) of 50 feet for a 50% TSS removal credit (Volume 4, Section 6.1) and 25 feet for a settling or pretreatment control, with a lesser credit of 10% TSS removal.
3. Dense vegetation that can withstand relatively high velocity flows.
4. Optional berm.

Site and Design Considerations

The following design and site considerations must be incorporated into the filter strip design:

1. Filter strips should be used to treat small drainage areas, ordinarily with a maximum of 75 feet for impervious surfaces, and 150 feet for pervious surfaces (CWP, 1996). For longer flow paths, special provision must be made to ensure design flows spread evenly across the filter strip. .
2. Flow must enter the filter strip as sheet flow spread out over the width of the strip, generally no deeper than 1 to 2 inches.
3. Filter strips should be integrated into site designs.
4. Filter strips should be constructed outside the natural stream buffer area whenever possible to maintain a more natural buffer along the streambank.
5. Filter strips should be designed for slopes between 2% and 6%. Greater slopes than this would encourage the formation of concentrated flow. Flatter slopes would encourage standing water.
6. Filter strips should not be used on soils that cannot sustain a dense grass cover with high retardance. Designers should choose a grass that can withstand relatively high velocity flows at the entrances, and both wet and dry periods.
7. The filter strip should be at least 15 feet long to provide filtration and contact time for water quality treatment. 25 feet is preferred, though length will normally be dictated by design method. 50 feet is necessary to achieve the 50% TSS removal credit.
8. Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.
9. An effective flow spreader a pea gravel diaphragm located at the top of the slope (ASTM D 448 size no. 6, 1/8" to 3/8"). The pea gravel diaphragm is a small trench running along the top of the filter strip. It serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the filter strip. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip. Other types of flow spreaders include long timbers, a concrete sill, curb stops, or curb and gutter with "sawteeth" cut into it.
10. Ensure that flows in excess of design flow move across or around the strip without damaging it. Often a bypass channel or overflow spillway with protected channel section is designed to handle higher flows.
11. Maximum discharge loading per foot of filter strip width (perpendicular to flow path) is found using the Manning's equation:

$$q = \frac{0.00236}{n} Y^{\frac{5}{3}} S^{\frac{1}{2}}$$

Where: q = discharge per foot of width of filter strip (cfs/ft)
Y = allowable depth of flow (inches)
S = slope of filter strip (percent)
n = Manning's "n" roughness coefficient
(Use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

Site and Design Considerations (Continued)

12. Using q, computed above, The minimum width of a filter strip is:

$$W_{fMIN} = \frac{Q}{q}$$

Where: W_{fMIN} = minimum filter strip width perpendicular to flow (feet)
Q = water quality flow rate (see PTP-03 Bioretention, page 5, Design Step #4).

Filter Strips without Berm

13. Size filter strip (parallel to flow path) for a contact time of 5 minutes minimum.
14. Equation for filter length is based on the SCS TR-55 travel time equation (SCS, 1986):

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

Where: L_f = length of filter strip parallel to flow path (25 ft minimum)
T_t = travel time through filter strip (5 minutes minimum)
P2-24 = 2-year, 24-hour rainfall depth (3.39 inches)
S = slope of filter strip (2-6 percent preferred)
n = Manning's "n" roughness coefficient
(Use 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

(Source for equations in items 11 through 14: Georgia Stormwater Management Manual)

Filter Strips with Berm

15. Size outlet pipes to ensure that the bermed area drains within 24 hours. Refer to PTP-01 Stormwater Wet Ponds for orifice sizing equations.
16. Specify grasses resistant to frequent inundation within the shallow ponding limit.
17. Berm material should consist of sand, gravel and sandy loam to encourage grass cover (Sand: ASTM C-33 fine aggregate concrete sand 0.02"-0.04", Gravel: AASHTO M-43 ½" to 1").
18. Size filter strip to contain the WQ_v within the wedge of water backed up behind the berm.
19. Maximum berm height is 12 inches.

Filter Strips for Pretreatment

20. A number of other structural controls, including bioretention areas and infiltration trenches, may utilize a filter strip as a pretreatment measure. The required length of the filter strip depends on the drainage area, imperviousness, and the filter strip slope. Table 7.1 provides sizing guidance for using filter strips for pretreatment. Filter strips used as pretreatment for coarse sediment for bioretention areas and infiltration trenches are not credited with removing TSS above and beyond the main treatment BMP.

Site and Design Considerations (Continued)

Table 7.1 Sizing of Filter Strips for Pretreatment Only

Parameter	Impervious Areas*				Pervious Areas (Lawns, etc)**			
Maximum inflow approach length (feet)	35		75		75		150	
Filter strip slope (max = 6%)	< 2%	> 2%	< 2%	> 2%	< 2%	> 2%	< 2%	> 2%
Filter strip minimum length (feet)***	10	15	20	25	10	12	30	36

* 75 feet maximum impervious area flow length to filter strip.
** 150 feet maximum pervious area draining to filter strip.
***At least 25 feet is *required* for minimum pretreatment credit of 10% TSS removal. Fifty feet is required for obtaining 50% TSS removal credit.
(*Adapted from Georgia Stormwater Management Manual)*

As-Built Certification Considerations

After the filter strip has been constructed, the developer must have an as-built certification of the filter strip conducted by a registered Professional Engineer. The as-built certification verifies that the BMP was installed as designed and approved.

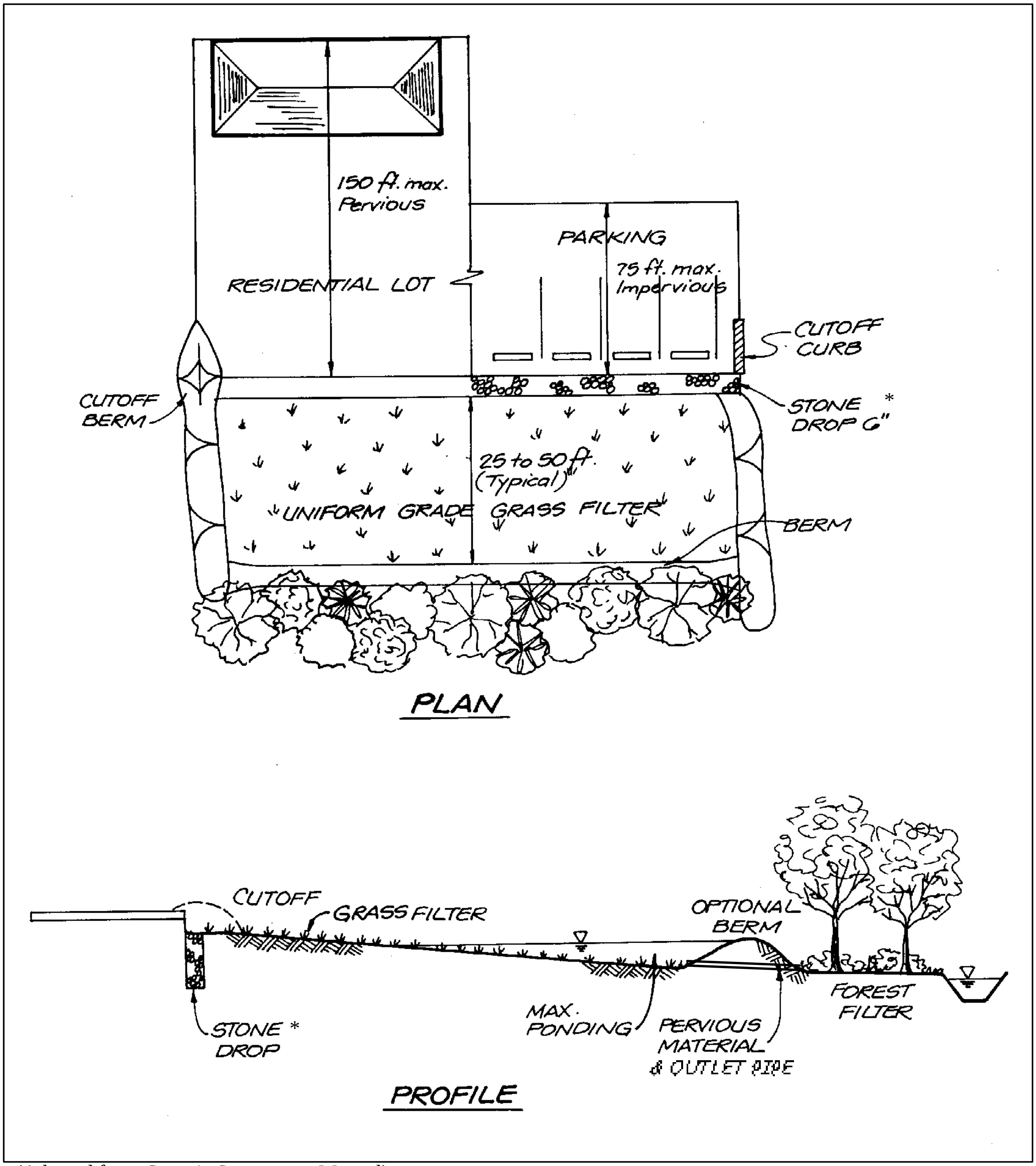
The following components must be addressed in the as-built certification:

1. Ensure design flows spread evenly across filter strip.
2. Ensure design slope is between 2% and 6%.
3. Verify dimensions of filter strip.

Maintenance

Each BMP must have an Operations and Maintenance (O&M) Agreement that is submitted to Metro for approval and is maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the Operation and Maintenance Agreement for filter strips, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with site plans. The O&M Agreement is to be used by the BMP owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

1. Maintain a dense, healthy stand of grass and other vegetation by frequent mowing: grass heights of 3 to 5 inches should be maintained, with a maximum grass height of 8 inches;
2. Repair erosion;
3. Periodic sediment removal; and
4. Revegetate as needed.



(Adapted from Georgia Stormwater Manual)

* Stone drop or some other acceptable type of level spreader to achieve sheet flow.

Figure 7.1 Filter Strip

References

ARC, 2001. Georgia Stormwater Management Manual Volume 2 Technical Handbook.

CDM, 2000. Metropolitan Nashville and Davidson County Stormwater Management Manual Volume 4 Best Management Practices.

Suggested Reading

California Storm Water Quality Task Force, 1993. California Storm Water Best Management Practice Handbooks.

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Grass Channels

Description: Limited application structural control. Open channels that are vegetated and are designed to filter stormwater runoff, as well as slow water for treatment by another structural control.

Components:
- Broad bottom channel on gentle slope (4% or less)
- Gentle side slopes (3:1 (H:V) or less)
- Dense vegetation that assists in stormwater filtration
- Check dams can be installed to maximize treatment

Advantages/Benefits:
- Provides pretreatment if used as part of runoff conveyance system
- Provides partial infiltration of runoff in pervious soils
- Less expensive than curb and gutter
- Good for small drainage areas
- Relatively low maintenance requirements

Reasons for Limited Use:
- Cannot alone achieve 80% removal of TSS; Fifty foot long channel is assumed to achieve 50% removal of TSS
- Must be carefully designed to achieve low flow rates in the channel (< 1.0 ft/s)
- May re-suspend sediment
- May not be acceptable for some areas because of standing water in channel

Design considerations:
- Maximum drainage area of 5 acres
- Require slopes of 4% or flatter
- Runoff velocities must be non-erosive
- Appropriate for all but the most impermeable soils
- Requires vegetation that can withstand both relatively high velocity flows and wet and dry periods.

Selection Criteria:

- ☐ **Water Quality 80% TSS Removal**
- ☑ **Pretreatment**
- ☑ **Residential Subdivision**
- ☑ **High Density / Ultra Urban Use**

Other: Replaces curb and gutter

Maintenance:
- Mow grass to 3 or 4 inches high
- Clean out sediment accumulation in channel
- Inspect for and correct formation of rills and gullies
- Ensure that vegetation is well-established

Maintenance Burden: L

L = Low M = Moderate H = High

General Description

Grass channels, sometimes called biofilters, are conveyance channels that are designed to provide some treatment of runoff, as well as to slow down runoff velocities for treatment in other structural controls. Grass channels are appropriate for a number of applications including treating runoff from paved roads and from pervious areas.

Grass channels do not provide full water quality treatment because they are not designed with engineered filtration areas, as water quality swales (PTP-06) are. Because they are not enhanced for increased filtration and infiltration, they provide a lower TSS removal and are appropriate for limited application in combination with other structural controls.

Grass channels are able to infiltrate some runoff from small storms when situated in pervious soils. They provide other ancillary benefits such as reduction of impervious cover, accenting natural features, and reduced cost when compared with traditional curb and gutter.

The most important considerations when designing a grass channel are the channel capacity and erosion prevention. Runoff velocities must not exceed 1.0 foot per second during the peak discharge associated with the 2-year design storm. In addition, the vegetation height should provide 5 minutes of residence time in the channel.

Figure 8.1 illustrates a grass channel. A grass channel consists of the following elements:

1. A broad bottomed, trapezoidal or parabolic channel on a gentle slope (4% or less);
2. Gently sloping sides (3:1 (H:V) or less);
3. Hardy vegetation that can withstand relatively high velocities as well as a range of moisture conditions from very wet to dry; and
4. Optional check dams to increase residence time.

Site and Design Considerations

The following design and site considerations must be incorporated into the grass channel design:

General Considerations

1. The drainage area (contributing or effective) must be 5 acres or less. Runoff flows and volumes from larger drainage areas prevent proper filtration and infiltration of stormwater.
2. Grass channels should be designed on areas with slope of less than 4%. Slopes of 1% to 2% are recommended.
3. Grass channels can be used on most soils with some restrictions on the most impermeable soils. Grass channels should not be used on soils with infiltration rates less than 0.27 inches per hour if infiltration of small runoff flows is intended.
4. A grass channel should be designed to accommodate the water quality flow. Calculations for the water quality flow are as follows:

   $$Qp = C * I * A$$

   Where:
   Qp = the peak flow through the proprietary BMP in cfs
   C = runoff coefficient
   I = rainfall intensity, 2.45 in/hr
   A = the contributing drainage area for the BMP, in acres

   Larger flows should be accommodated by the channel if dictated by the surrounding conditions. For instance, Metro requires site drainage to accommodate the 10-year design storm.
5. The channel should accommodate the 2-year, 24-hour storm without eroding.
6. Grass channels should have a trapezoidal or parabolic cross section with relatively flat side slopes (generally 3:1 or flatter).
7. The bottom of the channel should be between 2 and 6 feet wide. The minimum width ensures a minimum filtering surface for water quality treatment, and the maximum width prevents braiding, which is the formation of small channels within the swale bottom. The bottom width is a dependent variable in the calculation of velocity based on Manning's equation. If a larger channel is needed, the use of a compound cross section is recommended.
8. Runoff velocities must be nonerosive. The full-channel design velocity will typically govern.
9. A 5-minute residence time is recommended for the water quality peak flow. Residence time may be increased by check dams, reducing the slope of the channel, increasing the wetted perimeter, or planting a denser grass (raising the Manning’s n).
10. The depth from the bottom of the channel to the groundwater should be at least 2 feet to prevent a moist swale bottom, or contamination of the groundwater.

Site and Design Considerations (Continued)

11. Incorporation of check dams within the channel will maximize retention time.
12. Designers should choose a grass that can withstand relatively high velocity flows at the entrances, and both wet and dry periods.
13. A forebay is recommended in order to minimize the volume of sediment in the channel. (Refer to PTP-01 for forebay design.)
14. Provide an overflow for larger storm events.
15. Refer to Volume 2, Chapter 3 for design of open channel hydraulics.

Grass Channel as Pretreatment

A number of structural controls such as bioretention areas and infiltration trenches may be supplemented by a grass channel that serves as pretreatment for runoff flowing to the device. The lengths of grass channels vary based on the drainage area imperviousness and slope. Channels must be no less than 20 feet long. Table 8.1 below gives the minimum lengths for grass channels based on slope and percent imperviousness:

Table 8.1 Grass Channel Length Guidance
(Source: Georgia Stormwater Management Manual)

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

As-Built Certification Considerations

After the grass channel has been constructed, an as-built certification of the grass channel must be prepared by a registered Professional Engineer and submitted to Metro. The as-built certification verifies that the BMP was installed as designed and approved.

The following components must be addressed in the as-built certification:

1. The channel must be adequately vegetated.
2. The channel flow velocities must not exceed 1.0 foot per second.
3. A mechanism for overflow for large storm events must be provided.

Maintenance

Each BMP must be addressed in the overall Operations and Maintenance (O&M) Agreement (refer to Volume 1, Appendix C) for the development and submitted to Metro for approval with site plans.

Maintenance requirements for grass channels include the following:

1. Maintain grass height of 3 to 4 inches.
2. Remove sediment build up in channel bottom when it accumulates to 25% of original total channel volume.
3. Ensure that rills and gullies have not formed on side slopes. Correct if necessary.
4. Remove trash and debris build up.
5. Replant areas where vegetation has not been successfully established.

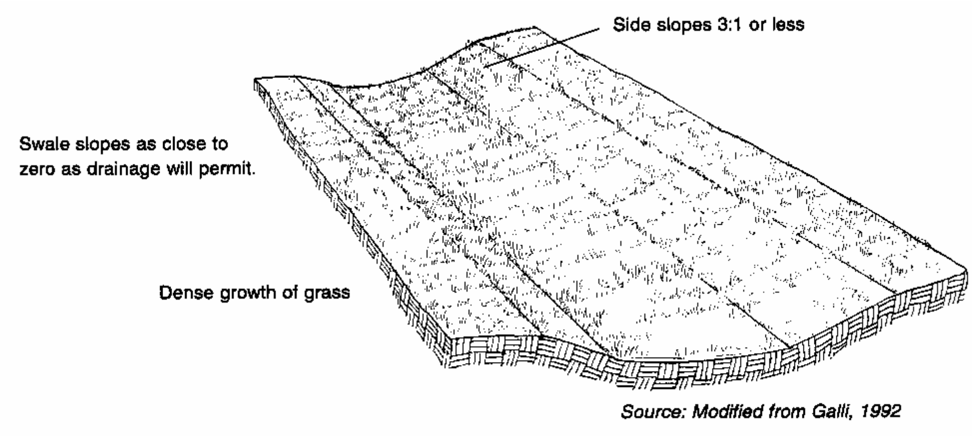
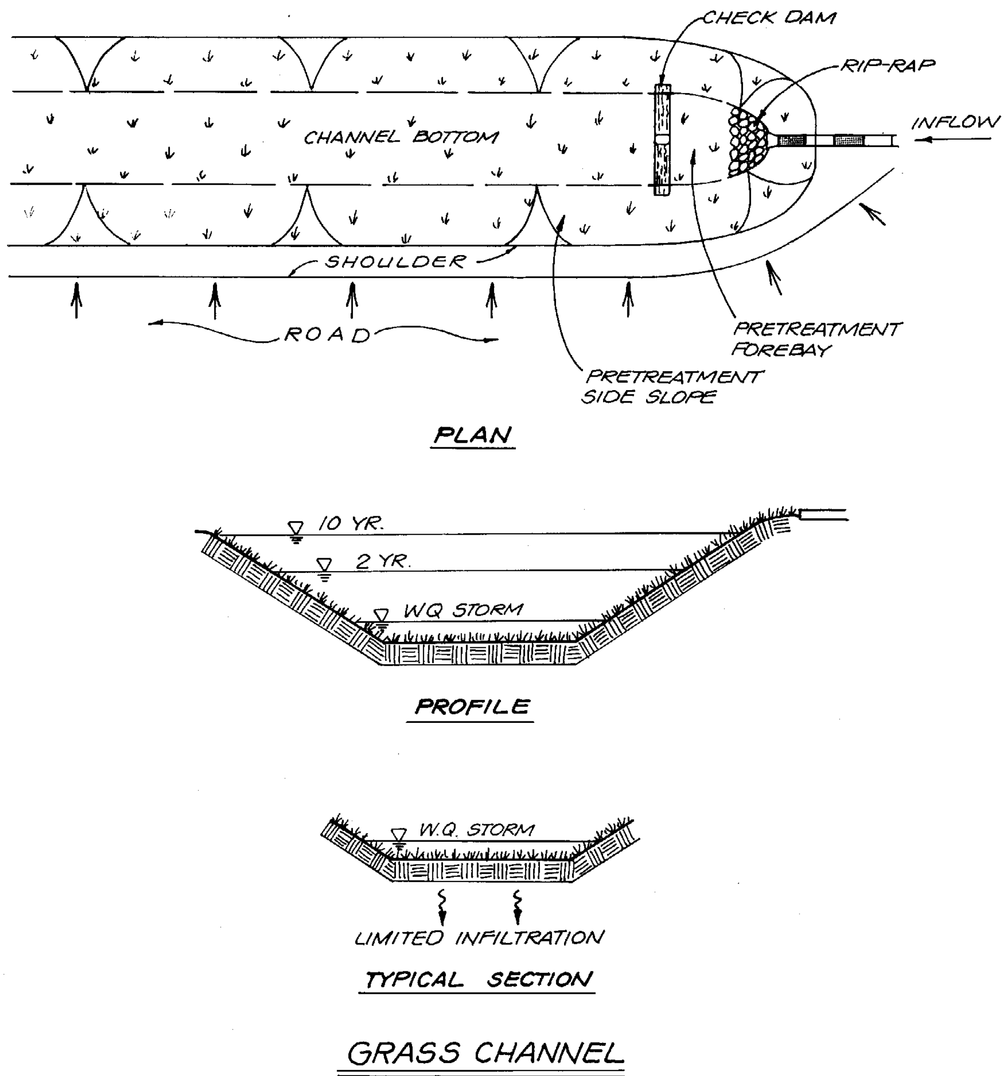


Figure 8.1 Typical Grass Channel



(Source: Center for Watershed Protection)

Figure 8.2 Grass Channel Schematic

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Greenroofs

Description: A vegetated roof cover composed of hardy plants growing in an engineered plant medium, filter cloth, drainage layer, and waterproofing membrane. Greenroofs provide benefits such as reducing runoff volume and peak discharge rate, reducing building cooling costs, and prolonging roof life.

Variations: Lightweight extensive roof covers and heavier-weight intensive roof covers, or "roof gardens." Can be accessible or inaccessible.

Components:

- Vegetation selected for its ability to thrive in rooftop climate.
- Engineered planting medium, not soil, typically composed of expanded clay or a mixture of clay and other materials.
- Filter layer.
- Containment (in modular systems refers to plant containers; in non-modular systems refers to barriers at roof perimeter and drainage structures).
- Drain layer, sometimes with built-in water reservoirs.
- Water proofing layer or roof membrane with root repellant.

Advantages/Benefits:

- Reduces site imperviousness for water quality treatment calculation
- Reduces Rational C number for overall site
- Energy savings: greenroofs keep buildings cool
- Stormwater retention and water quality treatment
- Possible amenity space for public or users
- Prolongs roof life
- Sound absorption
- Life cycle costs comparable to traditional roof

Disadvantages/Limitations:

- For retrofits, strengthening structure may be required
- If leaks occur, may be harder to trace
- Design and installation require specialized knowledge
- Installation costs higher than for traditional roof

Design considerations:

- Good waterproofing material and installation are essential.
- Materials used must be lightweight.
- Building structure must be able to support saturated weight.
- Roofs with moderate to flat slopes are most appropriate. Maximum roof slope of 15%.

Selection Criteria:

- ✓ **Water Quality 80 % TSS Removal**
- NA **Accepts Hotspot Runoff**
- ✓ **Residential Subdivision**
- ✓ **High Density / Ultra Urban Use**

Maintenance:

- Watering and fertilization until well-established
- Occasional weeding
- Inspection for proper drainage
- Ordinary life cycle roof replacement

L **Maintenance Burden**

L = Low M = Moderate H = High

General Description

A greenroof is a vegetated roof cover that allows the roof to provide several environmental benefits. Although modern greenroofs have only recently been embraced in urban American design, they have been used for centuries both as functional elements (to provide insulation to homes) and as amenities (to provide enjoyable "roof garden" space for city residents).

There are two classes of roof top vegetation systems: extensive and intensive. Each of these types can be further classified as accessible or inaccessible greenroofs. Extensive systems, also known as low-profile, performance, or eco-roofs, are composed of a waterproof membrane covered with a shallow layer (4-6 inches) of growing medium and low growing vegetation. Intensive systems, also known as high profile or roof gardens are heavier weight systems that consist of a waterproof membrane covered with a deeper layer (6 to 24 inches) of growing medium and a variety of vegetation including some deeper-rooted vegetation (even trees). Either of these types of greenroofs can be made accessible to the residents or users of a building or the general public and provide a green space and amenity to the users. However, it is more common for intensive greenroofs to be designed as accessible space, while extensive greenroofs are often only accessed for inspections and maintenance.

Greenroofs provide numerous economic and environmental benefits. Greenroofs prolong roof life by reducing temperature fluctuations on rooftops, thus reducing the stress caused by expansion and contraction of roofing materials and supports in variable temperatures. In addition, greenroofs provide insulation to buildings, which reduces heating and cooling costs. The vegetation itself cools the rooftop as well. An accessible greenroof can increase the unit value of apartments, condominiums, or office space.

While greenroofs provide environmental benefits such as cleaning fine, airborne particles from the air (improving air quality), cooling buildings (reducing the urban heat island effect), and providing habitat for various types of plants and animals, the main focus of their use in Metro is the benefit to stormwater. The vegetated roof covers provide various stormwater benefits. Because greenroofs are permeable surfaces, they slow runoff, attenuating the peak runoff rate. In addition, greenroofs retain water, reducing runoff volumes from the roof. Finally, water quality off of greenroofs is improved through the filtering of stormwater.

Key design considerations include structural capacity and the waterproofing layer.

The components of a greenroof are as follows:

1. Structural roof support sufficient to hold greenroof weight. For retrofit projects, an architect, structural engineer, or roof consultant must determine if added support to the building structure is needed.

General Description (Continued)

2. Waterproof membrane appropriate for greenroof. These impermeable materials come in a number of forms, such as large sheets, rolls, or liquid form; and materials, such as bituminous membranes and liquid polymer-modified asphalt products, synthetic thermoset, hypalon, and reinforced thermoplastic resin. During construction, protective material for the waterproof membrane is necessary so that it is not punctured or damaged during the greenroof installation stage. The protective layer also prevents breakdown from UV rays.
3. Root barrier, if not integral to membrane. Some waterproof membranes are equipped with an integral root barrier, which prevents the membrane from being compromised. However, other membrane products need an added root barrier.
4. Drainage layer. The drainage layer prevents damage to the waterproof membrane by draining excess rainfall off the roof through roof drains. In addition, it keeps the vegetation from drowning or rotting. The drainage can consist of a manufactured mat or a layer of gravel.
5. Filter fabric between the drainage layer and the growing medium prevents clogging.
6. Growing medium. A lightweight, well-drained engineered medium in which the vegetation grows. Typical components include: pumice perlite, expanded clay, sand, shale, compost, and coir.
7. Vegetation. Extensive greenroofs must have hardy drought-tolerant plants such as succulents. These perennial plants should require little maintenance except while they are being established. Intensive greenroofs that are used as amenity spaces can support a wider variety of plants, even shrubs and trees, since they are maintained areas, but hardy species are advisable.

Design and Implementation Considerations

The following design and implementation considerations must be incorporated into greenroofs:

Structure
The structural capacity of the building must be sufficient to support the saturated weight of the greenroof system. On new construction, it is relatively inexpensive to incorporate the structural requirements of the green roof at the outset. An existing building should be able to hold an additional 10 to 30 psf (for an extensive greenroof). Structural retrofits to existing buildings can be costly.

Slope
The maximum slope for a roof with a vegetated system should be 15 percent. Studies have shown that gently sloping or flat roofs retain more runoff and thus fulfill the intended stormwater functions better. Note that steeper roofs require that the planting medium and vegetation layers do not slump or slip under their own weight, especially when wet, through the use of strapping or other methods.

Use
The intended function of the greenroof affects design. Greenroofs in Metro should be designed to perform stormwater functions of retention, peak flow attenuation, and filtration. It may also be desired that greenroofs serve as green space, in which case accessibility and aesthetics will also be important design considerations.

Roof Climate
The microclimate on the roof, which is affected by the height of the roof, wind exposure, orientation to the sun, shading by other buildings, rainfall, temperatures, and humidity are important factors in greenroof design, particularly in vegetation selection.

Waterproof Membrane
The waterproof membrane is a crucial component of the greenroof system. Membranes come in various materials: bitumens, synthetic thermoset, hypalon and reinforced thermoplastic resin. If the membrane contains any organic material (bitumen is most common), a root barrier is necessary to prevent root penetration and destructive micro-organic activity. Many roof membranes are manufactured with root repellant as an integral component. Membranes with pesticides as an integral component are not permitted.

Drainage
Although greenroofs retain a great deal of stormwater, drainage from the entire system is still a necessary design component so that the roofing membrane is not compromised and so that the vegetation does not drown or rot. Proper drainage can be provided in a number of ways. Commonly, drainage mat systems with pockets for water storage are used. The drainage layer must be protected by filter

Design and Implementation Considerations (Continued)

fabric. The drainage layer directs excess rainfall off of the roof through roof drains and downspouts. When impervious areas drain to the roof, flow directed to the greenroof from these areas must be distributed evenly to prevent scour.

Protection
Parapets, edges, flashing, skylights, vents, chimneys, and mechanical systems must be well protected with a gravel skirt, and sometimes with a weep hole.

Growing Medium
Growing medium should be a lightweight mineral-based mix. Common components include pumice perlite, expanded clay, sand, shale, compost, and coir.

Vegetation
Vegetation must be suitable for harsh rooftop climates unless shading, irrigation, and fertilization will be provided. Plants must thoroughly cover the soil, at least 90% coverage. On extensive roofs, it is most practical to install hardy and indigenous plants such as succulents, sedums, mosses, sempervivíums, and festucas that can survive with little maintenance aside from watering and fertilization in the short term, while the plants establish themselves. On intensive greenroofs, a wide variety of plants, bushes, and even trees can make up the vegetation. Intensive greenroofs require more maintenance than extensive greenroofs.

Vegetation Installation
There are common methods of establishing vegetation on greenroofs:

Method	Description/Advantages	Disadvantages
Vegetation Mats	Sod-like mats with pregerminated seeds. Provide full coverage, erosion control, with little maintenance or weeding requirements.	Little flexibility in design.
Plugs or potted plants	Well-rooted seedlings raised in a nursery and then planted on the greenroof.	Take longer to achieve coverage, erosion control, need more watering and weeding.
Sprigs	Cuttings that are hand broadcast.	More maintenance than mats.
Seeds	Can be handbroadcast or hydroseeded.	More maintenance than mats.

Access
Access to the greenroof is important, not only for maintenance but for the initial installation of the greenroof. Materials including the membrane, drainage materials, growing medium, and plants will need to be brought up to the roof. This will be easiest if there is an elevator that goes to the roof. Otherwise,

Design and Implementation Considerations (Continued)

material must be hauled up via stairs, utility ladders, or even a crane. New buildings should be designed with easy access to the roof.

If the greenroof is designed to be accessible, the access must not only be convenient for installation and maintenance purposes but also must adhere to Metro Building Codes and other regulations for access and safety.

Construction and Installation
It is best to choose a roof installer who has experience in working with greenroof systems. Because an industry has built up around greenroofs, it is possible to find companies that specialize in greenroofing. Some companies specialize in handling the whole greenroofing process from re-roofing to installation and initial maintenance, some have experience with design of greenroofs, while others have created special components for use on greenroofs.

As-Built Certification Considerations

After the greenroof has been constructed, the developer must have an as-built certification of the greenroof conducted by a registered professional engineer. The as-built certification verifies that the BMP was installed as designed and approved.

The following components are vital components of a properly working greenroof and must be addressed in the as-built certification:

1. Protection of vulnerable areas (abutting vertical walls, roof vent pipes, outlets, air conditioning units, and perimeter areas) from leakage;
2. Profile view of facility including typical cross-sections with dimensions;
3. Growing medium specification including dry and saturated weight;
4. Filter fabric specification;
5. Drainage layer specification;
6. Waterproof membrane specification, including root barriers;
7. Stormwater piping associated with the site, including pipe materials, sizes, slopes, invert elevations at bends and connections; and
8. Planting and irrigation plan.

Operation and Maintenance

Each BMP on a site must be addressed in the overall Operations and Maintenance (O&M) Agreement (refer to Volume 1, Appendix C) for the development and submitted to Metro for approval with the plans submittal. The components of the O&M Agreement can be found in Section 6.7.1 of Volume 1. This section generally outlines the inspection and maintenance needs specific to greenroofs. More detailed inspection and maintenance information can be found in Appendix C of Volume 1 in the form of an inspection and maintenance checklist. This information should be included in the O&M Agreement for the development.

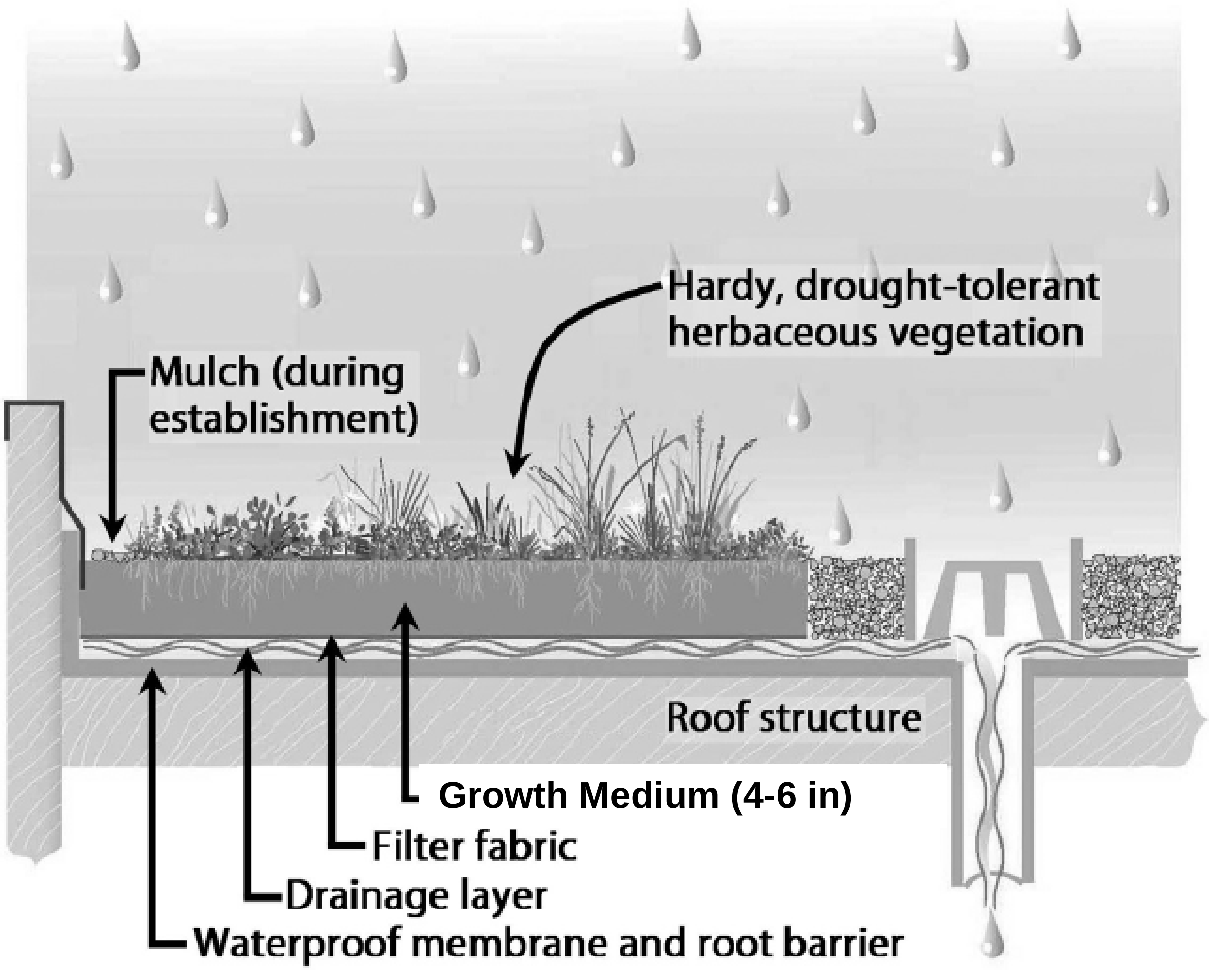
The O&M Agreement is to be used by the BMP owner or owners in performing routine inspections. The owner is responsible for the cost of maintenance and annual inspections, and the BMP owner must maintain and update the BMP operations and maintenance plan at least annually. At a minimum, the operations and maintenance plan must address:

1. Inspect and repair/replace greenroof system components.
2. Ensure survival of vegetation.
3. Remove debris or dead vegetation.

Design Procedures

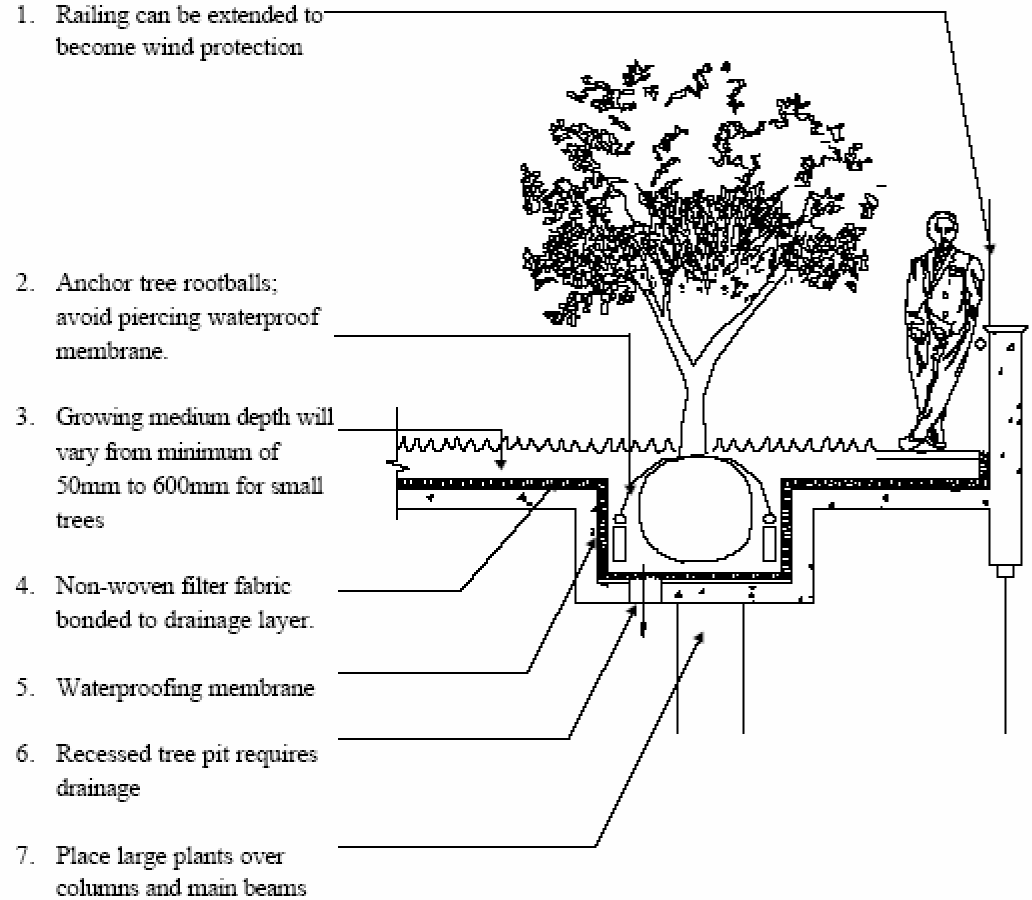
Specialized design and installation companies should be consulted for the design of the greenroof.

For the purposes of water quality volume calculations, the area of the building(s)'s roof that is covered with the greenroof structure is subtracted from the site's impervious area. Thus, the advantage of a greenroof, from a water quality treatment volume standpoint is that the greenroof reduces the WQ_v *through the reduction in site's imperviousness percentage.*



(*Source: Massachusetts Low Impact Development Toolkit)*

Figure 9.1 Extensive Greenroof (4 to 6 inches of growth medium)



Source: Public Works and Government Services Canada, 2002

Figure 9.2 Intensive Greenroof (6 to 24 inches of growth medium)

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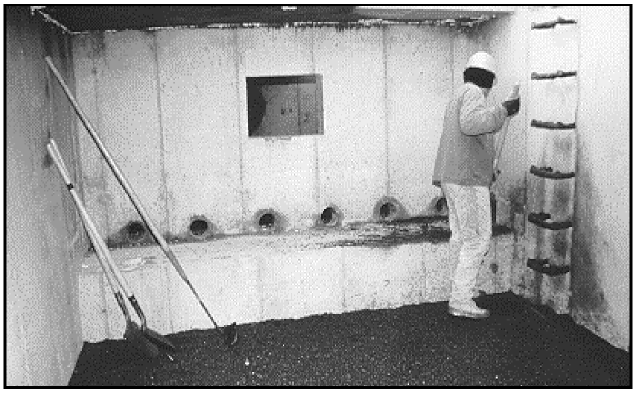
Underground Sand Filter



Description: Design variant of the sand filter, located in an underground vault.

Variations: Surface Sand filter (PTP-04), Perimeter Sand filter (PTP-16)

Components:
Underground vault with three chambers
(1) Sedimentation chamber
(2) Filter chamber with protective screen and perforated drain system to third chamber
(3) Overflow/outlet chamber

Advantages/Benefits:
- High sediment trapping capability
- Additional pollutant removal as a result of sediment removal
- Precast concrete shells available, which decrease construction costs

Disadvantages/Limitations:
- Intended for space-limited applications
- High maintenance requirements

Design considerations:
- Drains highly impervious areas, usually 1 acre or less
- Provide maintenance access to chambers
- Underground chamber must be water tight. Openings must be 1/16th inch or smaller to prevent mosquito intrusion

Selection Criteria:
- [✓] **Water Quality 80 % TSS Removal**
- [✓] **Accepts Hotspot Runoff**
- [ ] **Residential Subdivision**
- [✓] **High Density / Ultra Urban Use**

Maintenance:
- Monitor water level in sand filter chamber.
- Sedimentation chamber should be cleaned out when the sediment depth reaches 12 inches.
- Remove accumulated oil and floatables in sedimentation chamber.

Maintenance Burden: **H**

L = Low M = Moderate H = High

General Description

The underground sand filter is a variant of the sand filter located in an underground vault designed for high-density land use or ultra-urban applications where there is not enough space for a surface sand filter or other structural stormwater controls.

The underground sand filter is a three-chamber system (See Figure 10.1). The initial chamber is a sedimentation chamber that temporarily stores runoff and utilizes a wet pool to capture sediment. The sedimentation chamber is connected to the sand filter chamber by a submerged wall that protects the filter bed from floating oil and trash. The filter bed is 18 to 24 inches deep and may have a protective screen of gravel or permeable geotextile to limit clogging. The sand filter chamber also includes an underdrain system with capped inspection and clean out wells. Perforated drain pipes under the sand filter bed extend into a third chamber that collects filtered runoff. The WQ_v displaces part of the permanent pool as it flows into the facility and creates a temporary pool above the permanent pool. Flows beyond the filter capacity are diverted through an overflow weir.

Due to its location below the surface, underground sand filters have a high maintenance burden and should only be used where adequate inspection and maintenance can be ensured.

Site and Design Considerations

1. Underground sand filters are typically used on highly impervious sites of 1 acre or less. The maximum drainage area that should be treated by an underground sand filter is 5 acres.
2. Underground sand filters are typically constructed on-line, but can be constructed off-line. For off-line construction, the overflow between the second and third chambers is not included.
3. The underground vault should be tested for water tightness prior to placement of filter layers.
4. Adequate maintenance access must be provided to the sedimentation and filter bed chambers.
5. Compute the minimum permanent pool volume required in the sedimentation chamber as:

   $$V_w = A_s * 3 \text{ feet minimum}$$

   Where: $A_s =$ Surface Area, from PTP-04

6. Consult the design criteria for the perimeter sand filter (see PTP-16 for the underground filter sizing and design steps.)

As-Built Certification Considerations

An as-built certification conducted by a registered Professional Engineer must be performed and submitted to Metro. The as-built certification verifies that the BMP was installed as designed and approved.

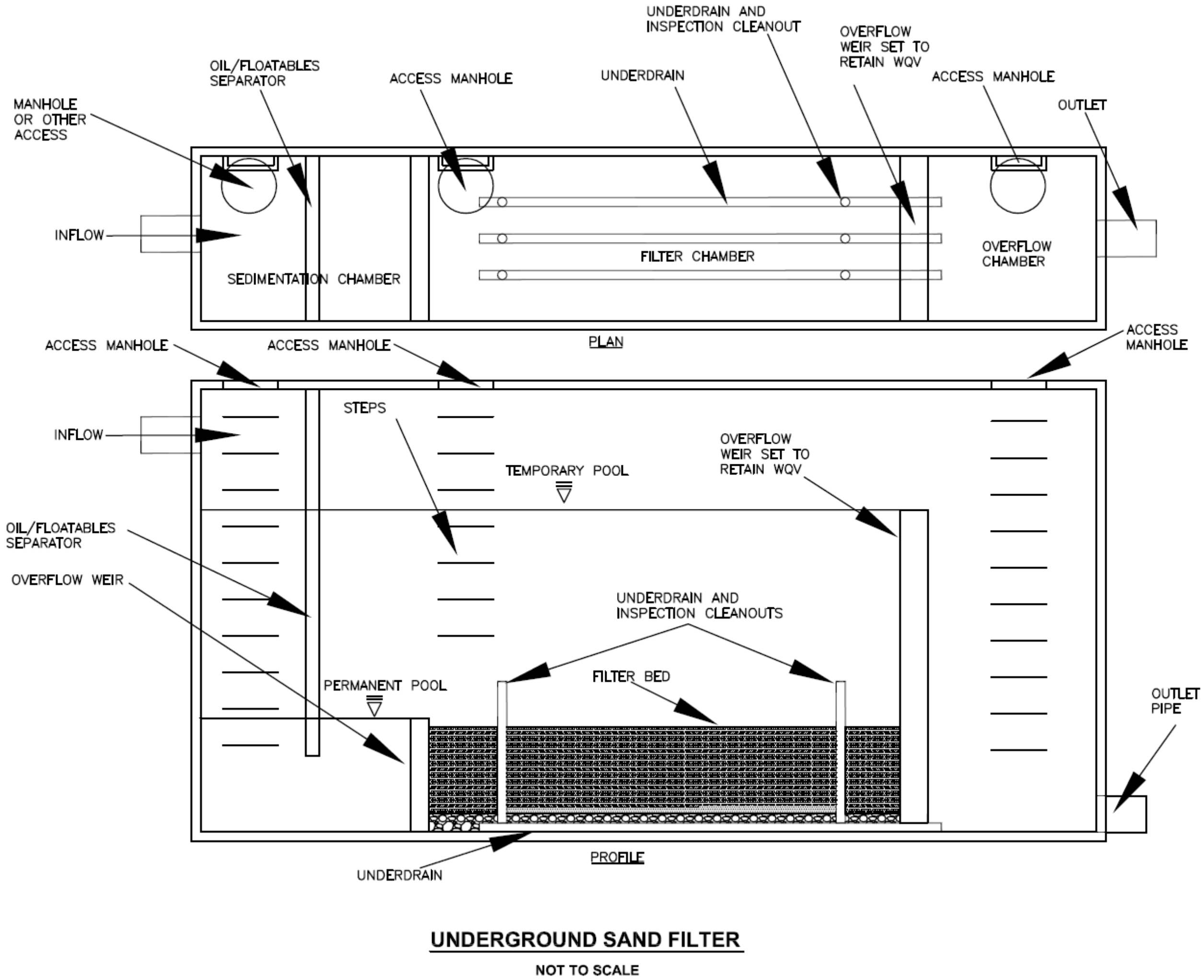
Maintenance

Each BMP must have an Operations and Maintenance (O&M) Agreement that is submitted to Metro for approval and is maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the Operation and Maintenance Agreement for sand filters, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with site plans. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

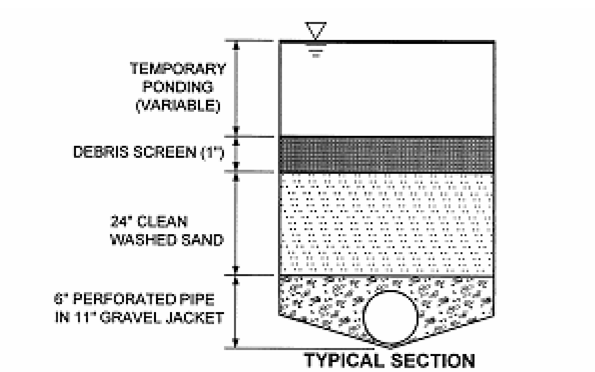
1. Monitor water level in sand filter chamber.
2. Sedimentation chamber should be cleaned out when the sediment depth reaches 12 inches.
3. Remove accumulated oil and floatables in sedimentation chamber.
4. Replace filter media when temporary pool is maintained for 40 hours following design storm (FHWA).

Design Procedures

Consult design criteria for perimeter sand filter (PTP-16) for sizing and design steps.



(Adapted from the Minnesota Stormwater Manual)



(Source: Center for Watershed Protection)

Figure 10.1 Schematic of Underground Sand Filter

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Perimeter Sand Filters

Description: Multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay, a sand bed as its primary filter media and an underdrain collection system (usually). Perimeter sand filters are located along the edge of impervious areas.

Variations: Surface Sand Filter (see PTP-04) and Underground Sand Filter (see PTP-10).

Components:
- Forebay—settles coarse particles and trash
- Sand bed chamber—provides water quality treatment through sand filtration.
- Overflow chamber to outlet for larger storm flows

Advantages/Benefits:
- Applicable to small drainage areas
- Good for highly impervious areas
- Good for water quality retrofits to existing developments

Disadvantages/Limitations:
- Standing water raises mosquito concerns
- High maintenance burden
- Not recommended for areas with high sediment content in stormwater or clay/silt runoff areas
- Relatively costly
- Possible odor problems
- Typically needs to be combined with other controls to provide water quantity control

Design considerations:
- Typically requires 2 to 6 feet of head
- Maximum contributing drainage area of 2 acres

Selection Criteria:

- ✓ **Water Quality 80 % TSS Removal**
- ✓ **Accepts Hotspot Runoff**
- ☐ **Residential Subdivision**
- ✓ **High Density / Ultra Urban Use**

Maintenance:

- Inspect for clogging—rake first inch of sand
- Remove sediment from forebay-chamber
- Replace sand filter media as needed
- Clean spillway system(s)

H — **Maintenance Burden**

L = Low M = Moderate H = High

General Description

The perimeter sand filter is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area such as a parking lot. The filter captures and temporarily stores stormwater runoff, filtering it through a bed of sand. Runoff flows into the structure through a series of inlet grates located along the top of the filter. The system consists of a forebay (sedimentation chamber) and a sand bed (filtration) chamber. The first chamber is a forebay or sedimentation chamber, which removes floatables and heavy sediments. The second is the sand bed or filtration chamber, which removes additional pollutants by filtering the runoff through a sand bed. The filtered runoff is collected and returned to the conveyance system. In addition, since perimeter sand filters receive all runoff, as on-line controls, they include an overflow for flows larger than the water quality volume. A schematic of a perimeter sand filter is shown in Figure 16.1.

Because they have few site constraints beside head requirements, perimeter sand filters can be used on development sites where the use of other structural controls may be precluded. However, perimeter sand filter systems can be relatively expensive to construct and install and they have high maintenance requirements. Because perimeter sand filters have a permanent pool of standing water, they present vector concerns. Their use is limited to situations in which they can be inspected and maintained frequently enough to control mosquito breeding. In addition, although perimeter sand filter systems are designed as on-line systems, they do not control water quantity.

In perimeter sand filter systems, stormwater pollutants are removed through a combination of gravitational settling, filtration and adsorption. The filtration process effectively traps suspended solids and particulates. As solids are trapped in the sand bed, some reduction of associated pollutants such as biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants may be achieved.

Site and Design Considerations

Two design variants of perimeter sand filters are the surface sand filter (PTP-04) and the underground sand filter (PTP-10).

Location and Siting

1. The maximum drainage area for a perimeter sand filter is 2 acres.
2. Perimeter sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with less than 50% imperviousness or with high clay/silt sediment loads must not use sand filters without adequate pretreatment because the sediment causes clogging and failure of the filter bed. Any disturbed areas within the sand filter facility drainage area should be identified and stabilized. Filtration controls should only be constructed after the construction site is stabilized.

Site and Design Considerations (Continued)

3. Perimeter sand filters are typically sited along the edge, or perimeter, of an impervious area such as a parking lot.
4. Perimeter and filter systems are designed for intermittent flow and must be allowed to drain and aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

General Design

5. A perimeter sand filter facility is a vault structure located just below grade level. Runoff enters the device through inlet grates along the top of the structure into the sediment forebay (or sedimentation chamber). Unlike the surface sand filter, the perimeter sand filter sediment forebay contains a permanent forebay volume. Runoff is discharged from the forebay through a weir into the sand bed chamber. After passing though the filter bed, runoff is collected by a perforated pipe and gravel underdrain system. An overflow must be provided for flows larger than the design storm.

Physical Specifications/Geometry

6. The entire treatment system (excluding the permanent pool in the forebay) must temporarily hold the WQ_v prior to filtration. Table 16.1 presents the design parameters and values for the perimeter sand filter. Figure 16.2 illustrates these design parameters.
7. The forebay must be sized to at least 50% of the computed WQ_v.
8. The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in $\leq$ 36 hours.
9. The filter media should consist of a 12- to 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand) on top of the underdrain system. See PTP-04, Figure 4.3 for a typical filter section.
10. The perimeter sand filter is equipped with a 6-inch perforated pipe (ASTM Schedule 40) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8 inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 10 inches on center. A permeable filter fabric should be placed between the gravel layer and the filter media. Gravel should be clean washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches with a void space of about 30%. Aggregate contaminated with soil shall not be used. Gravel layer and perforated underdrain piping must have infiltration rates at least twice as fast as the design infiltration rate of the sand bed.

Pretreatment/Inlets

11. Pretreatment of runoff in a sand filter system is provided by the forebay.
12. Inlets to surface sand filters are to be provided with energy dissipaters.

Site and Design Considerations (Continued)

Outlet Structures

13. Outlet pipe is to be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for emergency overflows and spillways).
14. All flows enter the perimeter sand filter. However, flows larger than the water quality volume are not treated. They pass to an overflow chamber and outlet.

Maintenance Access

15. Adequate access through maintenance easements must be provided for all sand filter systems for inspection and maintenance. Access grates to the filter bed need to be included in a perimeter sand filter design. Facility designs must enable maintenance personnel to easily replace the upper layers of the filter media.

Table 16.1 Perimeter Sand Filter Design Parameters

Parameter Description	*Parameter*	*Parameter Value*
Total Temporary Volume in Forebay and Sand Bed Chamber[1]	WQ_v	WQ_v; See Design Step #1
Approximate Temporary Sand Bed Volume[2]	V_{ST}	(0.5) WQ_v
Minimum Sand Bed Thickness	T_S	18 inches
Sand Bed Design Porosity	n	0.3
Sand Bed Design Permeability	k	3.5 feet/day
Sand Bed Design Drain Time	t_d	1.5 days, 36 hours max
Minimum Sand Bed Chamber Area	A_S	See Design Step #6
Approximate Temporary Forebay and Sand Bed Chamber Volume[3]	V_{FT}	(0.5) WQ_v
Minimum Forebay Surface Area	A_F	(0.05) WQ_v
Maximum Temporary Sand Bed Depth[4]	D_{ST}	See Design Step #3
Maximum Temporary Forebay Depth	D_{FT}	See Design Step #3
Minimum Permanent Forebay Depth	D_{FP}	2 feet

1. Includes temporary storage volume in sand, but excludes storage volume in forebay permanent pool.
2. Includes temporary storage volume in sand.
3. Excludes storage volume in forebay permanent pool.
4. Measured from top of sand bed.

(Adapted from the New Jersey Stormwater Best Management Practices Manual)

Design Procedures

Design of a sand filter is usually a trial and error process because of the number of variables involved.

Step 1. Compute the Water Quality Volume.

Calculate the Water Quality Volume (WQ_v), which must be temporarily stored within the perimeter sand filter's entire treatment system, excluding the forebay permanent pool.

$$WQ_v = P \times Rv \times A/12$$

Where:
WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.015 + 0.0092*I$$

Where:
I = site impervious cover, % (for example 50% equals 50)

Step 2. Determine approximate required volumes of the forebay and sand bed chambers.

Each should be equal to approximately 0.5 WQ_v, as shown in Table 16.1.

Step 3. Determine approximate temporary depths in sand bed (D_{ST}) and forebay (D_{FT}) for the WQ_v.

The estimate will depend on and be based on analysis of site conditions including the difference between the invert elevation of the downstream conveyance system and the maximum ground elevation at filter facility. Make sure to include the minimum sand bed thickness (T_S) and the permanent forebay depth (D_{FP}) into the consideration for these temporary depths. Note that the maximum temporary depth in the sand bed zone (D_{ST}) is measured from the top of the sand bed, while the maximum temporary forebay depth (D_{FT}) is measured from the permanent forebay water surface.

Step 4. Compute minimum forebay surface area (A_F).

The minimum surface area is
$$A_F = 0.05\ (WQ_v)$$

Where:

Design Procedures (Continued)

A_F = forebay area
0.05 = a multiplier in units per area of volume (L^2/L^3)

Step 5. Compute total temporary storage volume in the forebay (V_{FT}).

From the maximum temporary depth in the forebay (D_{FT}) from Step 3 and the minimum forebay area (A_F) from Step 4, compute the total temporary storage volume in the forebay (V_{FT}). *Compare* this volume with the approximate required forebay volume computed in Step 2. *Adjust* the maximum temporary forebay depth (D_{FT}) and/or forebay area (A_F) as necessary to achieve a total temporary forebay storage volume (V_{FT}) as close as practical to the required forebay volume from Step 2. While adjusting the forebay surface area (A_F) by varying its length and width, remember that the forebay will be located immediately adjacent to the sand bed zone.

Step 6. Compute sand bed chamber area (A_S).

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

$$\mathbf{A_S = (WQ_v)\,(T_S / [(k)\,(D_{ST}/2 + T_S)\,(T_D)]}$$

Where:
A_S = Sand Bed Surface Area (in square feet)
T_S = Thickness of Sand in Sand Bed (typically 18 inches, no more than 24 inches)
k = Coefficient of permeability of filter media (ft/day) (use 3.5 ft/day for sand)
D_{ST} = Maximum Temporary Sand Bed Depth (ft)
t_d = Sand Bed Design Drain Time (1.5 days or 36 hours is recommended maximum)

See the Physical Specifications/Geometry section of the *Site and Design Considerations* for filter media specifications.

Step 7. Compute total temporary storage volume in sand bed.

$$\mathbf{V_{ST} = (A_S)(D_{ST}) + (A_S)(T_S)(n)}$$

Where:
V_{ST} = Temporary Sand Bed Storage Volume (in cubic feet)
A_S = Sand Bed Surface Area (in square feet)
D_{ST} = Maximum Temporary Sand Bed Depth (ft)
T_S = Thickness of Sand in Sand Bed, recommended 18 inches (in feet)

Design Procedures (Continued)

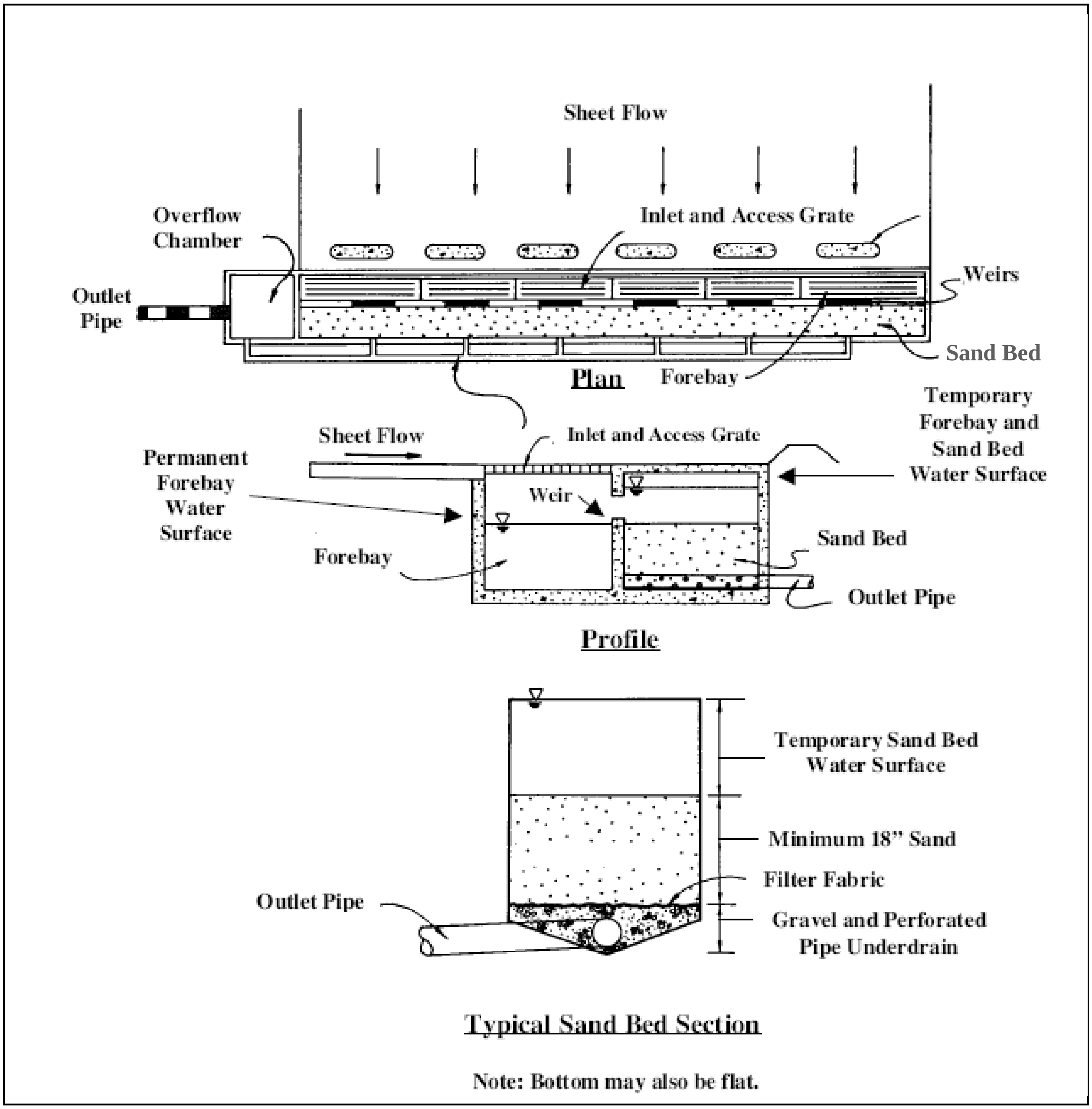
n = Sand Bed Design Porosity, recommended 0.3

Step 8. Compare and adjust areas and volumes to achieve storage of WQ_v within the entire facility.

Compare the total temporary sand bed storage volume (V_{ST}) with the approximate required sand bed zone volume computed in Step 2. As shown on Table 16.1, this temporary sand bed storage volume should be approximately one half of the stormwater quality design storm runoff volume (WQ_v). In addition, add the total temporary sand bed volume (V_{ST}) to the total temporary forebay storage volume (V_{FT}) to determine the total temporary storage volume in the sand filter. As shown in Table 16.1, this total temporary storage volume must equal the stormwater quality design storm runoff volume (WQ_v). Adjust the maximum temporary sand bed depth (D_{ST}) and/or sand bed area (A_S) as necessary to achieve a total temporary sand bed storage volume (V_{ST}) as close as practical to the required sand bed volume from Step 2 and a total filter volume equal to WQ_v.

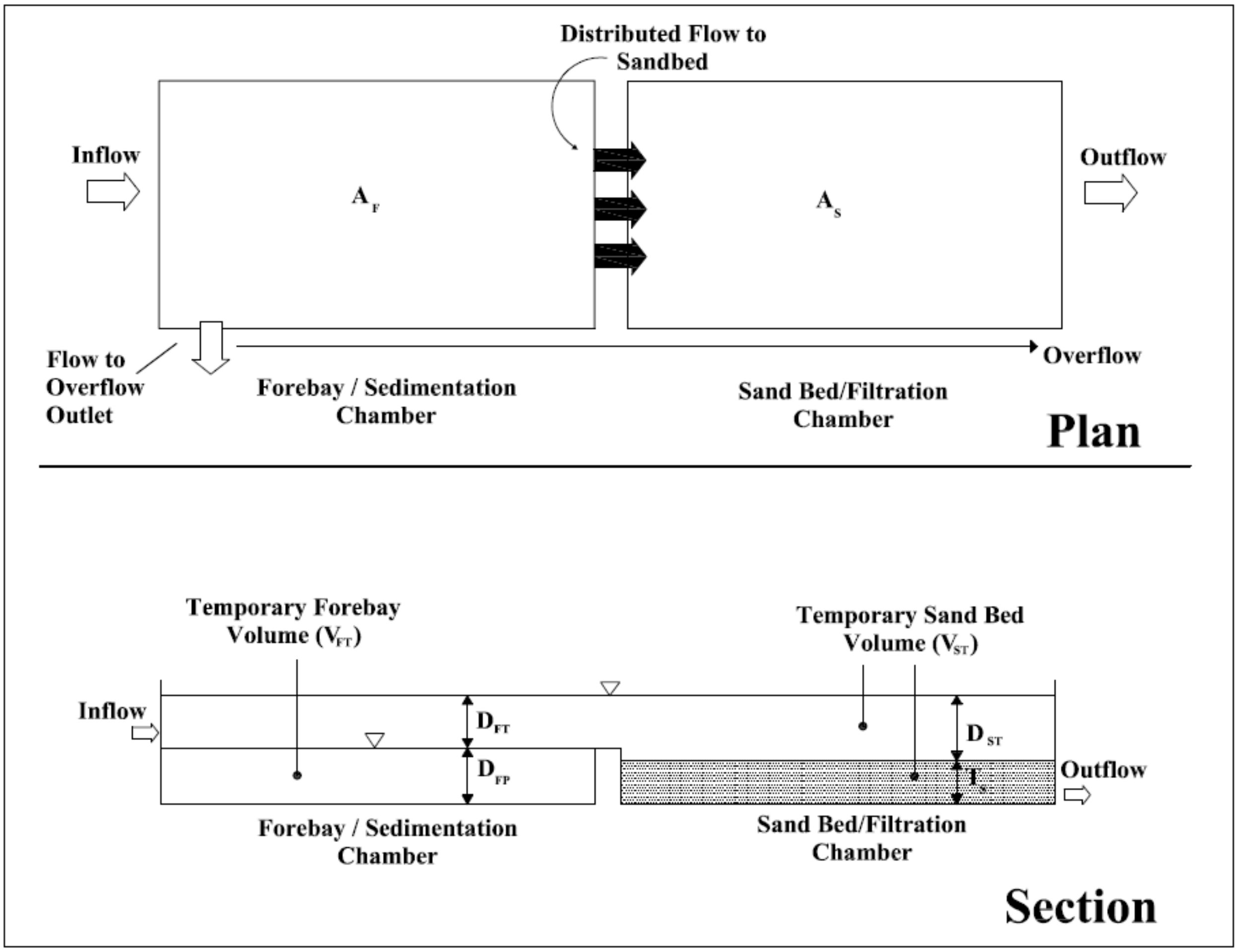
Step 9. Design inlets, underdrain system, overflow wiers, and outlet structures.

See *Site and Design Considerations* for more information on underdrain specifications and outlet structures. PTP-01 provides more information on sizing orifices, weirs, and outlets.



(Source: New Jersey Stormwater Best Management Practices Manual, 2003)

Figure 16.1 Perimeter Sand Filter



(Source: New Jersey Stormwater Best Management Practices Manual, 2003)

Figure 16.2 Schematic of Perimeter Sand Filter Showing Design Parameters

References

ARC, 2001. Georgia Stormwater Management Manual Volume 2 Technical Handbook.

Connecticut Department of Environmental Protection, 2004. Stormwater Quality Manual.

Center for Watershed Protection, Accessed July 2005. Stormwater Manager's Resource Center. Manual Builder. *www.stormwatercenter.net*.

New Jersey Department of Environmental Protection, 2004. Stormwater Best Management Practices Manual.

StormwaterAuthority.com, Accessed January, 2006. "Sand and Organic Filters." www.stormwaterauthority.com .

Suggested Reading

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City of Austin, TX, 1988. Water Quality Management. Environmental Criteria Manual. Environmental and Conservation Services.

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

Maryland Department of the Environment, 2000. Maryland Stormwater Design Manual, Volumes I and II. Prepared by Center for Watershed Protection (CWP).

Metropolitan Washington Council of Governments (MWCOG), March, 1992, "A Current Assessment of Urban Best Management Practices: Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone".

Northern Virginia Regional Commission (NVRC), 1992. The Northern Virginia BMP Handbook. Annandale, VA.

US EPA, 1999. Storm Water Technology Fact Sheet: Sand Filters. EPA 832-F-99-007. Office of Water.

Organic Filter

Description: Usually a two chambered stormwater treatment practice and variant on a sand filter. The first chamber is for settling and the second is a filter bed of organic media. Large particles settle out in the first chamber and finer particles and other pollutants are removed in the second chamber.

Variations: Surface Sand Filter (PTP-04), a general application BMP.

Components:

- Settling chamber—settles coarse particles and trash
- Filter chamber—provides water quality treatment by filtering other pollutants
- Spillway system(s) provide discharge control

Advantages/Benefits:

- High pollutant removal capability
- Removal of dissolved pollutants is greater than sand filters due to cation exchange capacity until exchange capacity is exhausted

Disadvantages/Limitations:

- Intended for hotspot or space-limited applications or for areas requiring enhanced pollutant removal capability
- Filter may require more frequent maintenance than most of the other stormwater controls
- Severe clogging potential if exposed soil surfaces exist upstream

Design considerations:

- Minimum head requirement of 5 to 8 feet
- Contributing drainage area of up to 10 acres for organic filter
- Organic filter media with underdrain system
- In karst areas, use polyliner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure

Selection Criteria:

- ☐ **Water Quality 80 % TSS Removal**
- ☑ **Accepts Hotspot Runoff**
- ☐ **Residential Subdivision**
- ☑ **High Density / Ultra Urban Use**

Maintenance:

- Ensure that inlets and outlets are free from debris and not clogged.
- Check for sediment buildup in gravel bed.
- Remove gravel and sediment from cell; replace gravel and replant vegetation.

H — **Maintenance Burden**

L = Low M = Moderate H = High

General Description

The organic filter is a design variant of the surface sand filter that uses organic materials such as leaf compost or a peat/sand mixture as the filter media. The organic material enhances pollutant removal by providing adsorption of contaminants such as soluble metals, hydrocarbons, and other organic chemicals until the adsorptive capacity is exhausted.

As with the surface sand filter, an organic filter consists of a pretreatment chamber, and one or more filter cells. Each filter cell is a layer of leaf compost or a peat/sand mixture, followed by filter fabric and a gravel/perforated pipe underdrain system. The filter bed and subsoils can be separated by an impermeable polyliner or concrete structure to prevent movement into groundwater.

Organic filters are typically used in densely developed areas, or in areas that require an enhanced pollutant removal ability. Maintenance is typically higher than the surface sand filter facility due to the potential for clogging. In addition, organic filter systems have a higher head requirement than sand filters.

Site and Design Considerations

1. Organic filters are typically used on relatively small sites (up to 10 acres), to minimize potential clogging.
2. The minimum head requirement (elevation difference needed at a site from the inflow to the outflow) for an organic filter is 5 to 8 feet.
3. Organic filters can utilize a variety of organic materials as the filtering media. Two typical media bed configurations are the peat/sand filter and compost filter (see Figure 12.1). The peat filter includes an 18-inch 50/50 peat/sand mix over a 6-inch sand layer and can be optionally covered by 3 inches of topsoil and vegetation. The compost filter has an 18-inch compost layer. Both variants utilize a gravel underdrain system.
4. The type of peat used in a peat/sand filter is critically important. Fibric peat in which undecomposed fibrous organic material is readily identifiable is the preferred type. Hemic peat containing more decomposed material may also be used. Sapric peat made up of largely decomposed matter should *not* be used in an organic filter.
5. Typically, organic filters are designed as "off-line" systems, meaning that the water volume (WQ_v) is diverted to the filter facility through the use of a flow diversion structure or flow splitter. Stormwater flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
6. Consult the design criteria for the surface sand filter (PTP-04, *Sand Filters*) for the organic filter sizing and design steps. The coefficient of permeability for a peat/sand mix is 2.75 feet/day and compost is 8.7 feet/day, while pure sand is 3.5 feet/day (CWP, 1996).

As-Built Certification Considerations

After the organic filter has been constructed, an as-built certification by a registered Professional Engineer must be submitted to Metro. The as-built certification verifies that the BMP was installed as designed and approved.

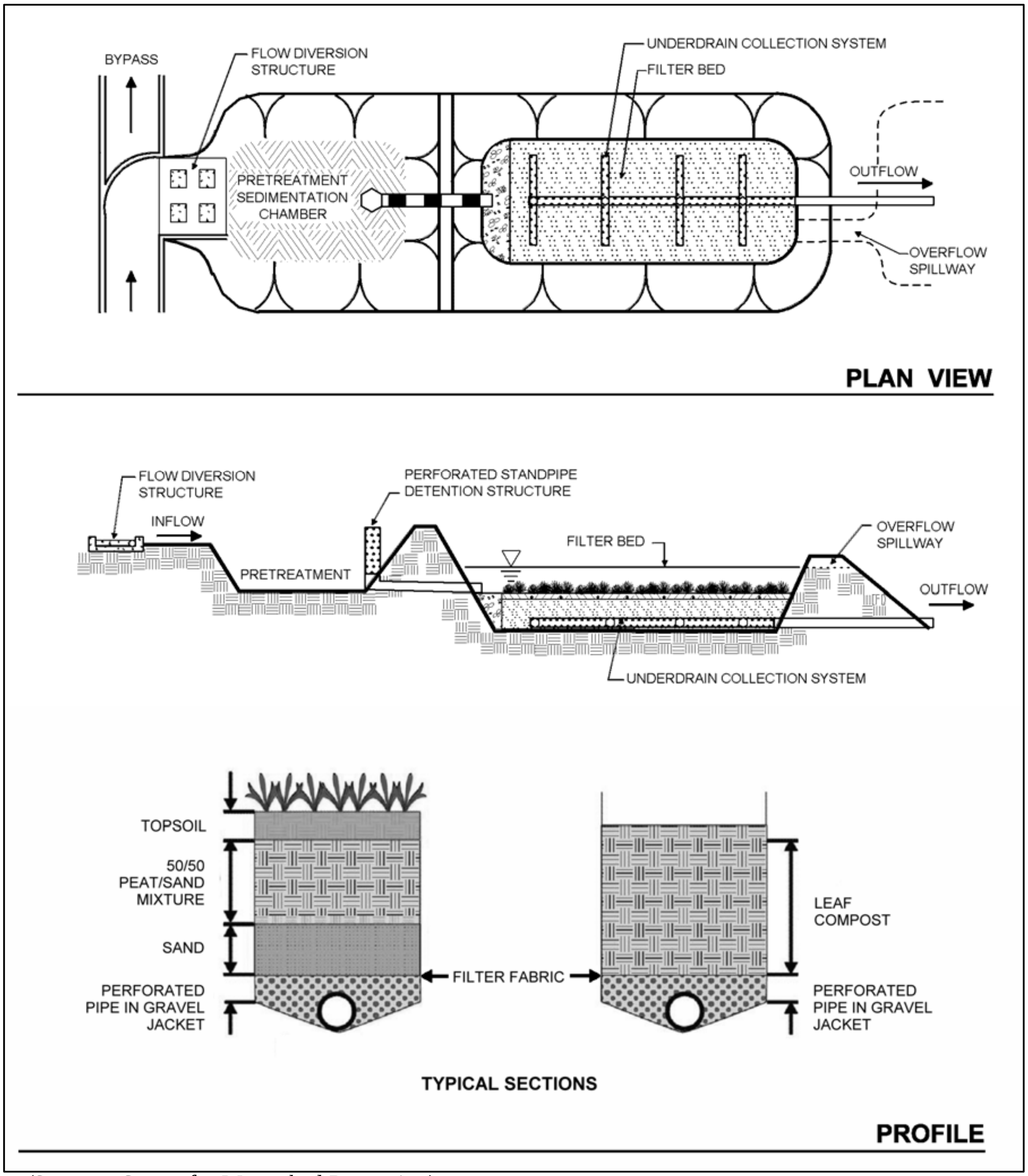
Maintenance

Each BMP must have an Operations and Maintenance (O&M) Agreement submitted to Metro for approval and maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the Operation and Maintenance Agreement, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with grading permit application. The O&M agreement is for the use of the BMP owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

1. Inspect for clogging—rake upper stratum of media as needed.
2. Remove sediment from forebay-chamber.
3. Replace organic filter media as needed.
4. Clean spillway system(s).

Design Procedures

See PTP-04 *Sand Filter*, surface sand filter sections, for additional guidance.



(Source: Center for Watershed Protection)

Figure 12.1 Schematic of Organic Filter

References

ARC, 2001. Georgia Stormwater Management Manual Volume 2 Technical Handbook.

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Federal Highway Administration (FHWA), United States Department of Transportation. Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. Accessed January 2006. http://www.fhwa.dot.gov/environment/ultraurb/index.htm

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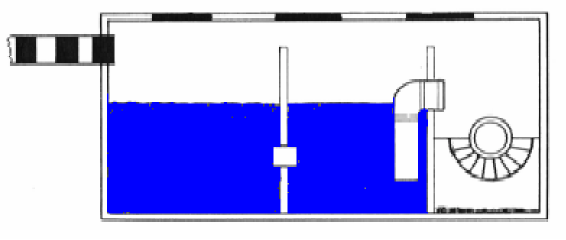
Gravity (Oil-Grit) Separator



Description: Hydrodynamic separation device designed to remove settleable solids, oil and grease, debris and floatables from stormwater runoff through gravitational settling and trapping of pollutants. Facilities with fueling and parking lots containing over 400 spaces require a more advanced separator with coalescing tubes/plates designed to provide a surface that minute oil globules are attracted to and can agglomerate upon. The coalesced oil then rises to the surface to be skimmed.

Components:

- Inlet chamber
- Separation and oil storage chamber
- Enhanced components such as swirl concentrator chamber and Coalescing filter (in high-risk areas)
- Outlet chamber

Advantages/Benefits:

- Good for land uses that are hotspots for hydrocarbons
- Pretreatment for water quality
- Coalescing systems can remove oil particles down to the 20 micron range, while conventional device removes down to the 150 micron level.

Disadvantages/Limitations:

- Cannot alone achieve the 80% TSS removal target
- Intended for hotspot, space-limited or pretreatment applications
- Limited performance data
- Dissolved pollutants are not removed
- Frequent maintenance required

Design considerations:

- Intended for the removal of settleable solids (grit and sediment) and floatable matter, including oil and grease
- Access point for maintenance required
- Performance dependent on design and frequency of inspection and cleanout of unit
- Openings to device must be 1/16 inch or less to prevent mosquito intrusion and breeding.
- Install as an off-line device unless size of separator can be matched to smaller drainage area
- Install inspection/collection manhole on downstream side to provide easy access for sampling of effluent.

Selection Criteria:

- [ ] **Water Quality 80 % TSS Removal**
- [x] **Accepts Hotspot Runoff**
- [ ] **Residential Subdivision**
- [x] **High Density / Ultra Urban Use**

Maintenance:

- Inspect the gravity separator unit
- Clean out sediment, oil and grease, and floatables, using catch basin cleaning equipment (vacuum pumps). Manual removal may be necessary

H **Maintenance Burden**

L = Low M = Moderate H = High

General Description

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

In “hot-spot” areas (fueling areas and large parking lots with over 400 spaces), separators are required to be equipped with coalescing tubes/plates. These tubes/plates provide a media in which minute oil globules can agglomerate to aid in the separation process. Oil that agglomerates around the coalescing tubes/plates can easily be skimmed through the gravity process.

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

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

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

Site and Design Considerations

1. The use of gravity (oil-grit) separators should be limited to the following applications:
   - Pretreatment for other structural stormwater controls

Site and Design Considerations (Continued)

- High-density, ultra urban or other space-limited development sites
- Hotspot areas where the control of grit, floatables, and/or oil and grease are required

2. Gravity separators are typically used for areas less than 5 acres. It is recommended that the contributing area to any individual gravity separator be limited to 1 acre or less of impervious cover.
3. Gravity separator systems can be installed in almost any soil or terrain. Since these devices are underground, appearance is not an issue and public safety risks are low.
4. Gravity separators are flowrate-based devices. This contrasts with most other stormwater structural controls, which are sized based on capturing and treating a specific volume.
5. Gravity separator units are typically designed to bypass runoff flows in excess of the design flow rate. Some designs have built-in high flow bypass mechanisms. Other designs require a diversion structure or flow splitter ahead of the device in the drainage system. An adequate outfall must be provided.
6. The separation chamber should provide for three separate storage volumes:

   (1) A volume for separated oil storage

   (2) A volume for settleable solids accumulation at the bottom of the chamber

   (3) A volume required to give adequate flow-through detention time for separation of oil and sediment from the stormwater flow
7. The total wet storage of the gravity separator unit should be at least 400 cubic feet per contributing impervious acre.
8. The minimum depth of the permanent pools should be 4 feet.
9. Horizontal velocity through the separation chamber should be 1 to 3 ft/min or less. No velocities in the device should exceed the entrance velocity.
10. A trash rack should be included in the design to capture floating debris, preferably near the inlet chamber to prevent debris from becoming oil impregnated.
11. Ideally, a gravity separator design will provide an oil draw-off mechanism to a separate chamber or storage area.
12. Adequate maintenance access to each chamber must be provided for inspection and cleanout of a gravity separator unit.
13. Gravity separator units should be watertight to prevent possible groundwater contamination.
14. The design criteria and specifications of a proprietary gravity separator unit should be obtained from the manufacturer.

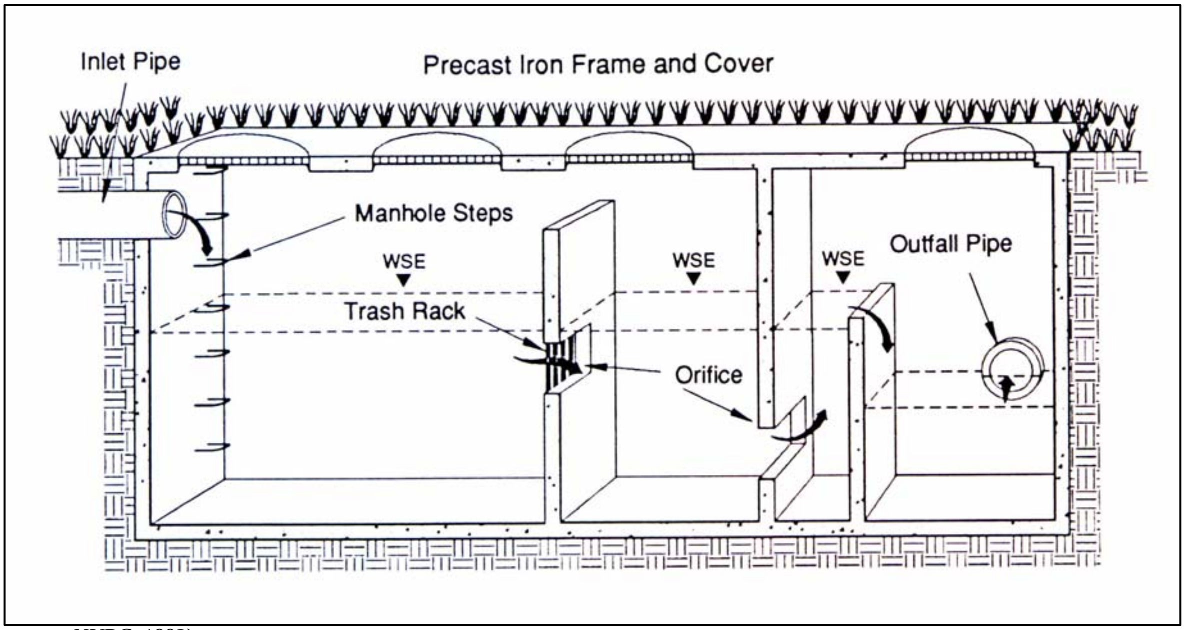
As-Built Certification Considerations

After the hydrodynamic device has been constructed, an as-built certification must be performed by a registered Professional Engineer and submitted to Metro. The as-built certification verifies that the BMP was installed as designed and approved.

Maintenance

Each BMP must have an Operations and Maintenance (O&M) Agreement which is submitted to Metro for approval and is maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the O&M Agreement for separators, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with grading permit application. The O&M agreement is for the use of the BMP owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

1. Additional maintenance requirements for a proprietary system should be obtained from the manufacturer.
2. Proper disposal of oil, solids and floatables removed from the gravity separator must be ensured.



(Sources: NVRC, 1992)

Figure 13.1 Schematics of Gravity (Oil-Grit) Separator

References

ARC, 2001. Georgia Stormwater Management Manual Volume 2 Technical Handbook.

CDM, 2000. Metropolitan Nashville and Davidson County Stormwater Management Manual Volume 4 Best Management Practices.

Suggested Reading

California Storm Water Quality Task Force, 1993. California Storm Water Best Management Practice Handbooks.

Infiltration Trenches

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

Components:

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

Advantages/Benefits:

- Provides for groundwater recharge
- Good for small sites with porous soils

Disadvantages/Limitations:

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

Design considerations:

- 5 acres maximum drainage area
- Space Required – Will vary depending on the depth of the facility
- Site Slope – No more than 6% slope (for pre-construction facility footprint)
- Minimum Head – Elevation difference needed at a site from the inflow to the outflow: 1 foot
- Minimum Depth to Water Table – 4 feet recommended between the bottom of the infiltration trench and the elevation of the seasonally high water table.
- Soils – Infiltration rate of 0.5 inches per hour or greater required (typically hydrologic group “A”, some group “B” soils)

Selection Criteria:

- [✓] **Water Quality 80 % TSS Removal**
- [ ] **Accepts Hotspot Runoff**
- [✓] **Residential Subdivision**
- [✓] **High Density / Ultra Urban Use**

Maintenance:

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

H — **Maintenance Burden**

L = Low M = Moderate H = High

General Description

Infiltration trenches are excavations typically filled with stone to create an underground reservoir for stormwater runoff (see Figure 14.1). The runoff volume gradually exfiltrates through the bottom and sides of the trench into the subsoil over a 2-day period and eventually reaches the water table. By diverting runoff into the soil, an infiltration trench not only treats the water quality volume, but also helps to preserve the natural water balance on a site and can recharge groundwater and preserve baseflow. Due to this fact, infiltration systems are limited to areas with highly porous soils where the water table and/or bedrock are located well below the bottom of the trench. In addition, infiltration trenches must be carefully sited to avoid the potential of groundwater contamination.

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

Using the natural filtering properties of soil, infiltration trenches can remove a wide variety of pollutants from stormwater through sorption, precipitation, filtering, and bacterial and chemical degradation. Sediment load and other suspended solids should be removed from runoff by pretreatment measures on-site before they reach the trench surface.

Site and Design Considerations

Infiltration trenches are generally suited for medium-to-high density residential, commercial and institutional developments where the subsoil is sufficiently permeable to provide a reasonable infiltration rate and the water table is low enough to prevent groundwater contamination. They are applicable primarily for impervious areas where there are not high levels of fine particulates (clay/silt soils) in the runoff and should only be considered for sites where the sediment load is relatively low.

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

To protect groundwater from potential contamination, runoff from designated hotspot land uses or activities must not be infiltrated. Infiltration trenches should not be used for manufacturing and industrial sites, where there is a potential for high concentrations of soluble pollutants and heavy metals. In addition, infiltration should not be considered for areas with a high pesticide concentration. Infiltration trenches are also not suitable in

Site and Design Considerations (Continued)

areas with karst geology without adequate geotechnical testing by qualified individuals and in accordance with local requirements.

1. To be suitable for infiltration, underlying soils should have an infiltration rate (f_c) of 0.5 inches per hour or greater, as initially determined from NRCS soil textural classification and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5,000 square feet, with a minimum of two borings per facility (taken within the proposed limits of the facility). Infiltration trenches cannot be used in fill soils.
2. Infiltration trenches should have a contributing drainage area of 5 acres or less.
3. Soils in the drainage area tributary to an infiltration trench should have a clay content of less than 20% and a silt/clay content of less than 40% to prevent clogging and failure.
4. There should be at least 4 feet between the bottom of the infiltration trench and the elevation of the seasonally high water table.
5. Clay lenses, bedrock or other restrictive layers below the bottom of the trench will reduce infiltration rates unless excavated.
6. Suggested minimum setback requirements for infiltration trench facilities:
   - From a property line – 10 feet
   - From a building foundation – 25 feet
   - From a private well – 100 feet
   - From a public water supply well – 1,200 feet
   - From a septic system tank/leach field – 100 feet
   - From surface waters – 100 feet
   - From surface drinking water sources – 400 feet (100 feet for a tributary)
7. When used in an off-line configuration, the water quality volume (WQ_v) is diverted to the infiltration trench through the use of a flow splitter. Stormwater flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
8. To reduce the potential for costly maintenance and/or system reconstruction, it is strongly recommended that the trench be located in an open or lawn area, with the top of the structure as close to the ground surface as possible. Infiltration trenches shall not be located beneath paved surfaces, such as parking lots.
9. Infiltration trenches are designed for intermittent flow and must be allowed to drain and allow aeration of the surrounding soil between rainfall events. They must not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

Site and Design Considerations (Continued)

General Design
A well-designed infiltration trench consists of:

(1) Excavated shallow trench backfilled with sand, coarse stone, and pea gravel, and lined with a filter fabric;
(2) Appropriate pretreatment measures; and
(3) One or more observation wells to show how quickly the trench dewaters or to determine if the device is clogged.

An example of an on-line infiltration trench is shown in Figure 14.1. Figure 14.2 provides a plan view and profile schematic for the design of an off-line infiltration trench facility.

Physical Specifications/Geometry

10. The required storage volume in the gravel trench is equal to the water quality volume (WQ_v).
11. A trench must be designed to fully dewater the entire WQ_v within 24 to 48 hours after a rainfall event. The slowest infiltration rate obtained from tests performed at the site should be used in the design calculations.
12. Trench depths should be between 3 and 8 feet, to provide for easier maintenance. The width of a trench must be less than 25 feet.
13. Broader, shallow trenches reduce the risk of clogging by spreading the flow over a larger area for infiltration.
14. The surface area required is calculated based on the trench depth, soil infiltration rate, aggregate void space, and fill time (assume a fill time of 2 hours for most designs).
15. The bottom slope of a trench should be flat across its length and width to evenly distribute flows, encourage uniform infiltration through the bottom, and reduce the risk of clogging.
16. The stone aggregate used in the trench should be washed, bank-run gravel, 1.5 to 2.5 inches in diameter with a void space of about 40%. Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 should be used in calculations, unless aggregate specific data exist.
17. A 6-inch layer of clean, washed sand is placed on the bottom of the trench to encourage drainage and prevent compaction of the native soil while the stone aggregate is added.
18. The infiltration trench is lined on the sides and top by an appropriate geotextile filter fabric that prevents soil piping but has greater permeability than the parent soil. The top layer of filter fabric is located 2 to 6 inches from the top of the trench and serves to prevent sediment from passing into the stone aggregate. Since this top layer serves as a sediment barrier, it will need to be replaced more frequently and must be readily separated from the side sections.

Site and Design Considerations (Continued)

19. The top surface of the infiltration trench above the filter fabric is typically covered with pea gravel. The pea gravel layer improves sediment filtering and maximizes the pollutant removal in the top of the trench. In addition, it can easily be removed and replaced should the device begin to clog. Alternatively, the trench can be covered with permeable topsoil and planted with grass in a landscaped area.
20. An observation well must be installed in every infiltration trench and should consist of a perforated PVC pipe, 4 to 6 inches in diameter, extending to the bottom of the trench (see Figure 14.3 for a schematic of an observation well). The observation well will show the rate of dewatering after a storm, as well as provide a means of determining sediment levels at the bottom and when the filter fabric at the top is clogged and maintenance is needed. It should be installed along the centerline of the structure, flush with the ground elevation of the trench. A visible floating marker should be provided to indicate the water level. The top of the well should be capped and locked to discourage vandalism and tampering.
21. The trench excavation should be limited to the width and depth specified in the design. Excavated material should be placed away from the open trench so as not to jeopardize the stability of the trench sidewalls. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and should be scarified prior to placement of sand. The sides of the trench shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling. All infiltration trench facilities should be protected during site construction and should be constructed after upstream areas have been stabilized.

Pretreatment/Inlets

22. Pretreatment facilities must always be used in conjunction with an infiltration trench to prevent clogging and failure
23. For a trench receiving sheet flow from an adjacent drainage area, the pretreatment system should consist of a vegetated filter strip with a minimum 25-foot length. A vegetated buffer strip around the entire trench is required if the facility is receiving runoff from both directions. If the infiltration rate for the underlying soils is greater than 2 inches per hour, 50% of the WQ_v should be pretreated by another method prior to reaching the infiltration trench.
24. For an off-line configuration, pretreatment should consist of a sediment forebay, vault, plunge pool, or similar sedimentation chamber (with energy dissipaters) sized to 25% of the water quality volume (WQ_v). Exit velocities from the pretreatment chamber must be nonerosive for the 2-year design storm.

Site and Design Considerations Continued

Outlet Structures
Outlet structures are not required for infiltration trenches.

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

Maintenance Access
Adequate access in an easement should be provided to an infiltration trench facility for inspection and maintenance.

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

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

Additional Site-Specific Design Criteria and Issues
Not suitable for karst areas without adequate geotechnical testing.

As-Built Certification Considerations

After the infiltration trench has been constructed, an as-built certification must be performed by a registered Professional Engineer and submitted to Metro. The as-built certification verifies that the BMP was installed as designed and approved.

The following components must be addressed in the as-built certification:

1. The infiltration trench cannot be located in a sinkhole area or in karst soils.
2. Infiltration rates must be verified.
3. Proper dimensions for the trench must be verified.
4. A mechanism for overflow for large storm events must be provided.

Maintenance

Each BMP must have an Operations and Maintenance (O&M) Agreement submitted to Metro for approval and maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the Operation and Maintenance Agreement for infiltration trenches, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with grading permit application. The O&M agreement is for the use of the BMP owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

1. Ensure that contributing area, facility and inlets are clear of debris.
2. Ensure that the contributing area is stabilized.
3. Remove sediment and oil/grease from pretreatment devices, as well as overflow structures.
4. Check observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging.
5. Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.
6. Remove trees that start to grow in the vicinity of the trench.
7. Replace pea gravel/topsoil and top surface filter fabric (when clogged).
8. Perform total rehabilitation of the trench to maintain design storage capacity.
9. Excavate trench walls to expose clean soil.

Design Procedures

Step 1. Compute the Water Quality Volume.

Calculate the Water Quality Volume (WQ_v). This volume must be contained in the gravel trench.

WQ_v = P x Rv x A/12

Where:
WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

Rv = 0.015 + 0.0092I

Where:
I = site impervious cover, % (for example, 50% would be 50)

Step 2. Determine if the development site and conditions are appropriate for the use of infiltration trench.

Consider the *Site and Design Considerations* in this section, above.

Step 3. Divert flows above the WQ_v flow rate (Q_{wq}).

Flows exceeding the WQ_v flow are to be diverted from the trench.

$$Qwq = C * I * A$$

Where:
Q_{wq} = the WQ_v flow rate
C = runoff coefficient
I = rainfall intensity, 2.45 inches/hour for Metro for design storm associated with WQ_v
A = the contributing drainage area for the BMP, in acres

Step 4. Size flow diversion structure, if needed.

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

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

Design Procedures (Continued)

Step 5. Size infiltration trench.

The area of the trench can be determined from the following equation:

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

Where:

- A = Surface Area (acres)
- WQ_v = Water Quality Volume (or total volume to be infiltrated)
- n = porosity
- d = trench depth (feet)
- k = percolation (inches/hour)
- T= Fill Time (time for the trench to fill with water), in hours

A porosity value n = 0.32 should be used.

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

A fill time T=2 hours can be used for most designs.

See the Physical Specifications/Geometry section of *Site and Design Considerations* for more details.

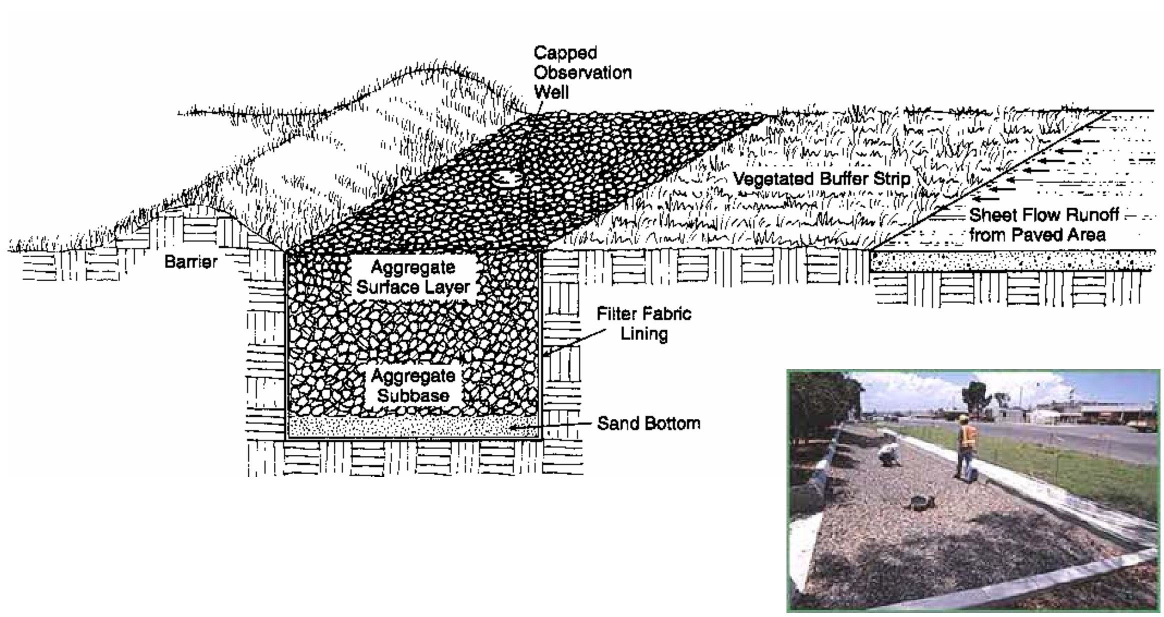
Step 6. Determine pretreatment volume and design pretreatment measures.

Size pretreatment facility to treat 25% of the water quality volume (WQ_v) for off-line configurations.

See the Pretreatment / Inlets section of *Site and Design Considerations* for more details.

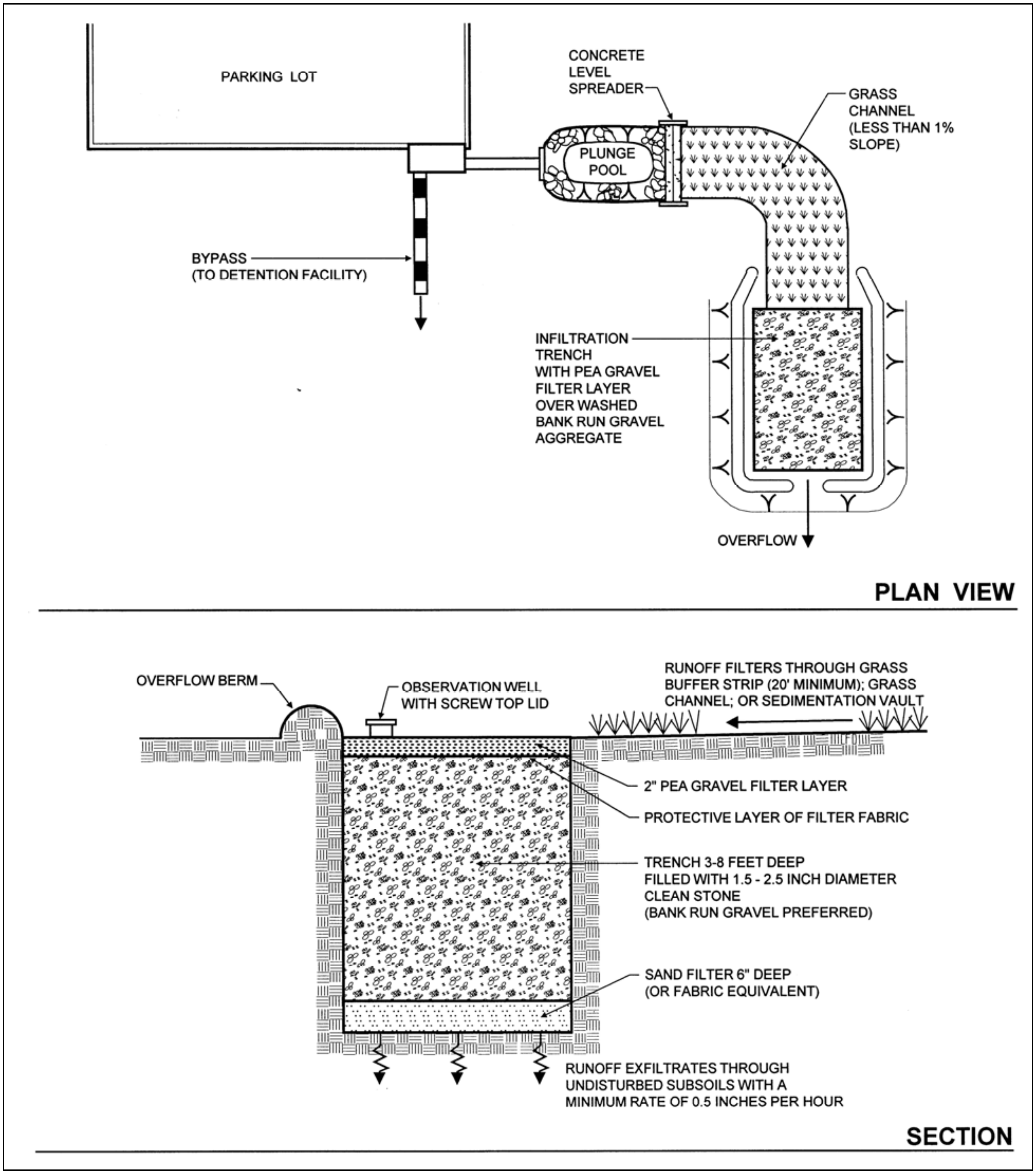
Step 7. Design spillway(s).

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



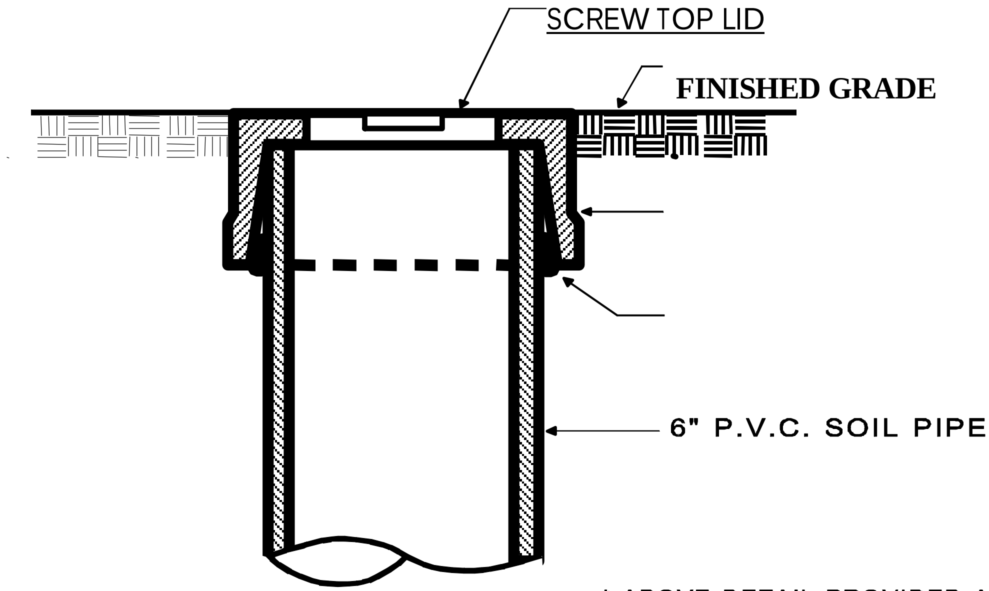
(Source: Georgia Stormwater Management Manual)

Figure 14.1 Infiltration Trench Example



(Source: Center for Watershed Protection)

Figure 14.2 Schematic of Infiltration Trench



* ABOVE DETAIL PROVIDED AS SCHEMATIC SCREW TOP P.V.C. WELL CAP ONLY

EACH OBSERVATION WELL / CLEANOUT SHALL INCLUDE THE FOLLOWING:

1. FOR AN UNDERGROUND FLUSH MOUNTED OBSERVATION WELL / CLEANOUT, PROVIDE A TUBE MADE OF NON-CORROSIVE MATERIAL, SCHEDULE 40 OR EQUAL, AT LEAST THREE FEET LONG WITH AN INSIDE DIAMETER OF AT LEAST 6 INCHES.

2. THE TUBE SHALL HAVE A FACTORY ATTACHED CAST IRON OR HIGH IMPACT PLASTIC COLLAR WITH RIBS TO PREVENT ROTATION WHEN REMOVING SCREW TOP LID. THE SCREW TOP LID SHALL BE CAST IRON OR HIGH OMPACT PLASTIC THAT WILL WITHSTAND ULTRA-VIOLET RAYS.

OBSERVATION WELL DETAIL

(Source: Metro Stormwater Management Manual, 2000)

Figure 14.3 Observation Well Detail

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Permeable Pavements

Description: Infiltration practices that are alternatives to traditional asphalt and concrete surfaces. Stormwater runoff is infiltrated into the ground through a permeable layer of pavement or other stabilized permeable surface.

Variations: Options range from poured-in-place, specially formulated concrete and asphalt that have greater void space than ordinary pavement to systems of interlocking modular pavers cast with void spaces.

Components:

- Open graded pavement mix or pavers with open surfaces
- Settling layer
- Open-graded base material
- Filter fabric
- Underdrain (where required)
- Subgrade with *minimal* compaction

Advantages/Benefits:

- Reduces runoff volume, attenuates peak runoff rate and outflow
- Reduces slick surfaces during rain
- Water quality enhancement from filtration of stormwater

Disadvantages/Limitations:

- Sediment-laden runoff can clog pervious pavement, causing it to fail
- Constant pressure in the same spot (constant vehicle braking) can collapse pores, causing pavement to fail
- Incorrect installation practices can clog pores

Design considerations:

- Same basic considerations as any paved area (soil properties, load-bearing design, hydrologic design of pavement & subgrade)
- Infiltration rate of native soil determines appropriateness and need for underdrain
- Not appropriate for heavy or high traffic areas
- Accessibility, aesthetics, maintainability

Installation considerations:

- Proper installation is crucial to ensure proper functioning
- Subgrade **cannot** be overly compacted
- Construction must be sequenced to avoid compaction and clogging pavement

Selection Criteria:

- ☐ **Water Quality 80 % TSS Removal**
- ☐ **Accepts Hotspot Runoff**
- ☑ **Residential Subdivision**
- ☑ **High Density / Ultra Urban Use**

Maintenance:

- Vacuum or jet wash to increase pavement life and avoid clogging
- Ensure that contributing area is clear of debris and sediment.

M **Maintenance Burden**

L = Low M = Moderate H = High

General Description

Permeable pavements are surfaces that can be driven over while permitting rapid infiltration of water into the underlying soil. Constructed of alternative paving materials, permeable pavements are used to locally infiltrate rainwater and reduce the runoff leaving a site. This can decrease downstream flooding, the frequency of combined sewer overflow (CSO) events, and the thermal pollution of sensitive waters. Use of these materials can also eliminate problems with standing water, provide for groundwater recharge, control erosion of streambeds and riverbanks, facilitate pollutant removal, and provide for a more aesthetically pleasing site.

Permeable pavements can be applied in areas that experience low vehicular traffic including parking lots and overflow parking areas; portions of streets such as residential parking lanes; driveways; plazas; and pedestrian or golf cart paths. There are several different forms of permeable pavements, varying from a permeable layer of paving material to grid systems. Four different types of permeable surfaces are discussed below.

Porous Asphalt: Porous asphalt differs from dense asphalt in its use of open-graded aggregate. Because no fine aggregate fills the voids between the single-sized particles, the material is porous and permeable. Porous asphalt can have a porosity of 15%-20%. A surface of porous asphalt is typically placed over a layer of open-graded gravel and crushed stone, with an underlying layer of permeable soil. There are several modifications to the standard design that can be used to increase storage capacity or pass larger flows, including the installation of a perforated pipe in the gravel sublayer, adding a layer of sand, etc.

Porous Concrete: Considered to be more durable than porous asphalt, porous concrete is a mixture of open-graded aggregate, which creates the voids in the structure, and Portland cement. The void space in porous concrete is in the 15%-22% range compared to 3%-5% for conventional pavements. Porous concrete is thought to have a greater ability than porous asphalt to maintain its porosity in hot weather. The permeable surface of porous concrete is typically installed as the top of several permeable layers, similar to the installation of porous asphalt described above.

General Description (Continued)

Plastic Grid Systems: These systems are often referred to as *geocells* and are defined by manufactured plastic lattices or mattresses that form networks of box-like cells that are filled with earth material. The lattice is typically 1-2 inches thick and the cells are a few inches wide. Porosity and permeability of these systems is entirely dependent on the cells' fill and vegetation. Like any other pavement surface, geocells require a firm gravel base that provides strength and storage capacity as runoff infiltrates. Geocells are lightweight and easy to transport and install. However, they may similarly be jarred easily by moving traffic.

Open-Celled Paving Grids: Commonly called *block pavers or grid pavers*, these grids are structural units, such as concrete blocks or bricks with regularly interdispersed voids that penetrate their entire thickness. Grids are made of concrete or brick and the open cells are filled with porous aggregate or vegetated soil. Block pavers are more rigid and therefore can bear larger traffic loads than plastic grid systems.

Pollutant Removal Capabilities

As they provide for the infiltration of stormwater runoff, permeable pavements trap particulate pollutants and absorb some soluble pollutants. Due to the potential for clogging, porous pavements must not be used for the removal of sediment or other coarse particulate pollutants.

Components

Several options exist for the top layer or surface of permeable pavements and should be chosen depending on strength required due to traffic loads, infiltration needs, and the manufacturers' recommendations. However, the sub layers are generally similar, consisting of four to five layers as shown in Figure 15.1. The aggregate reservoir layer can sometimes be avoided or minimized if the sub-grade is sandy and there is adequate time to infiltrate the necessary runoff volume into the sandy soil without by-passing the water quality volume. Descriptions of each of the layers is presented below:

Permeable Pavement Layer – This layer consists of a porous mixture of concrete or asphalt or a modular pavement grid of plastic, concrete, or brick and an aggregate or a vegetation medium. This layer is usually 2 to 4 inches deep depending on required bearing strength, pavement design requirements, and manufacturer's specifications.

Settling Layer – This layer consists of a 0.5-inch diameter crushed stone to a depth of 1 to 2 inches. This layer serves to stabilize the porous asphalt or concrete layer. Can be combined with reservoir layer using suitable stone.

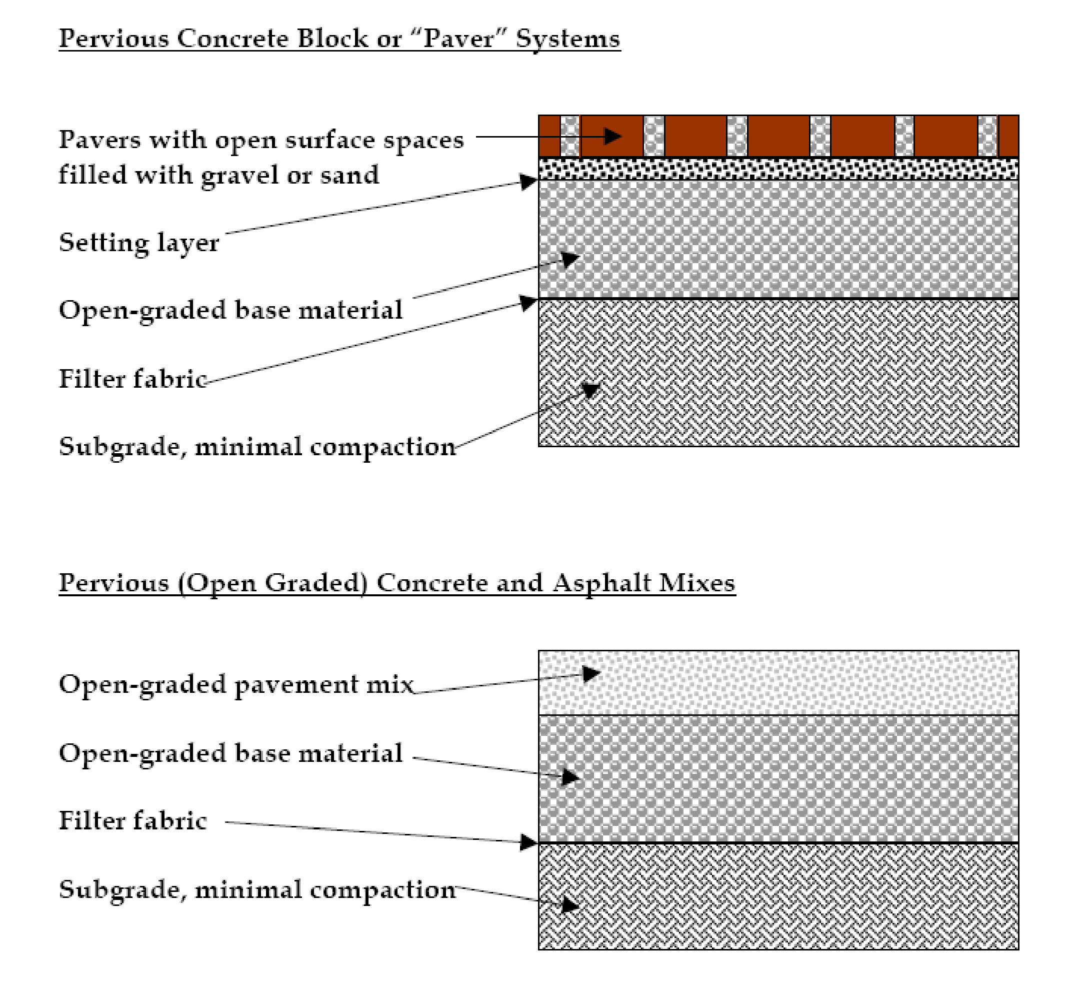
Reservoir Layer or Open Graded Base Material – The reservoir gravel base layer consists of washed, bank-run gravel, 1.5 to 2.5 inches in diameter with a void space of about 40%. The depth of this layer depends on the desired storage volume, which is a function of the soil infiltration rate and void spaces, but typically ranges from two to four feet. The layer must have a minimum depth of nine inches. The layer should be designed to drain completely in 48 hours and should be designed to store, at a minimum, the water quality volume (WQ_v). Aggregate contaminated with soil must not be used.

Bottom Filter Layer (not shown in diagram) – In cases where infiltration needs to be increased, a 6 inch layer of sand or a 2 inch thick layer of 0.5 inch crushed stone can be installed. The layer should be completely flat to promote infiltration across the entire surface. This layer serves to stabilize the reservoir layer, to protect the underlying soil from compaction, and act as the interface between the reservoir layer and the filter fabric covering the underlying soil.

Components (Continued)

Filter Fabric – It is very important to line the entire trench area, including the sides, with filter fabric prior to placement of the aggregate. The filter fabric serves to inhibit soil from migrating into the reservoir and reducing storage capacity.

Underlying Soil – The underlying soil should have an infiltration capacity of at least 0.5-inches/hour but preferably greater than 0.5-inches/hour. Soils at the lower end of this range may not be suited for a full infiltration system or may require additional infiltration measures such as a perforated pipe or additional sand layer. Test borings are recommended to determine the soil classification, seasonal high ground water table elevation, and impervious substrata, and an initial estimate of permeability.



(Source: City of Portland, Oregon, Stormwater Management Manual)

Figure 15.1 Permeable Pavement Layers

Site and Design Considerations

When designing permeable pavement systems, the infiltration rate of the native soil is a key element in determining the depth of base rock for the storage of stormwater, or for determining whether an underdrain system is appropriate. Traffic loading and design speed are important considerations in determining which type of pervious pavement surface is applicable. Pedestrian ADA accessibility, aesthetics, and maintainability are also important considerations.

The following design and site considerations must be incorporated into sites using permeable pavements:

1. The in-situ subsoils should have a high infiltration rate. Permeable pavements are appropriate for all soil types, but will require underdrain systems for soils that do not infiltrate well - hydrologic soil group D or most group C soils, or soils with a high (>30%) clay content. During construction and preparation of the subgrade, special care must be taken to avoid compaction of the soils.
2. Because even infiltration is important, the slope of the site should be less than 10% in all cases, but are not recommended to be more than 2%. Specifications are product-specific and shall comply with manufacturer’s recommendations. Barriers perpendicular to the direction of drainage should be installed in sub-grade material to keep it from washing away, or filter fabric should be placed at the bottom and sides of the aggregate to keep soil from migrating into the aggregate and reducing porosity.
3. Porous pavements should only receive runoff from impervious areas. Runoff containing sediment will clog the porous paver surface.
4. Permeable pavements should not be used on sites with a likelihood of high oil or grease concentrations.
5. Not for use in drinking water aquifer recharge areas.

During construction, **do not** overly compact the soil, and avoid installing pavement during extremely high or low temperatures.

Porous paver system designs must use some method to convey larger storm event flows to the conveyance system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would accept bypass flows that are too large to be infiltrated by the porous pavement or if the system clogs.

As-Built Certification Considerations

After the porous pavement has been installed, an as-built inspection and certification must be performed by a Professional Engineer. The as-built certification must include verification of the infiltration rates of the porous pavement in addition to other design components that ensure the proper performance of the BMPs.

Maintenance

Each BMP must have an Operations and Maintenance (O&M) agreement submitted to Metro for approval and maintained and updated by the BMP owner. Refer to Volume 1 Appendix C for the Operation and Maintenance Agreement, as well as an inspection checklist. The O&M Agreement must be completed and submitted to Metro with the grading permit application. The O&M agreement is for the use of the BMP owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The BMP owner must maintain and update the BMP operations and maintenance plan.

The burden of maintenance is fairly low for permeable pavements. However, failure to maintain and to abide by design and construction standards often results in failure of the measure.

Permeable pavements should be inspected regularly to ensure that the porous surface is free of sediment and that the surrounding area does not have the potential to contribute sediment-laden runoff. The surface should be vacuum swept, followed by high-pressure hosing to keep pores free of sediment. The adjacent, contributing area should be inspected to ensure that it is free of debris and litter, stabilized and mowed, and that clippings have been removed. It would be beneficial to inspect the system during a rain event to ensure that it is dewatering appropriately.

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