Runoff Quality/Peak Rate BMPs

BMP 6.14: Wet Pond/Retention Basin

Wet Ponds/Retention Basins are stormwater basins that include a substantial permanent pool for water quality treatment and additional capacity above the permanent pool for temporary runoff storage.

Key Design Elements

- Adequate drainage area (usually 5 to 10 acres minimum)
- Natural high groundwater table
- Maintenance of permanent water surface
- High length to width ratio
- Robust and diverse vegetation surrounding wet pond
- Relatively impermeable soils
- Forebay for sediment collection and removal
- Dewatering mechanism

Potential Applications

Residential:	YES
Commercial:	YES
Ultra Urban:	YES
Industrial:	YES
Retrofit:	YES
Highway/Road:	YES

Stormwater Functions

Volume Reduction:	Low
Recharge:	Low
Peak Rate Control:	High
Water Quality:	Medium

Pollutant Removal

TSS:	70%
TP:	60%
NO_3:	30%

Description

Wet Detention Ponds are stormwater basins that include a permanent pool for water quality treatment and additional capacity above the permanent pool for temporary storage. Wet Ponds should include one or more forebays that trap course sediment, prevent short-circuiting, and facilitate maintenance. The pond perimeter should generally be covered by a dense stand of emergent wetland vegetation. While they do not achieve significant groundwater recharge or volume reduction, they can be effective for pollutant removal and peak rate mitigation. Wet Ponds (WPs) can also provide aesthetic and

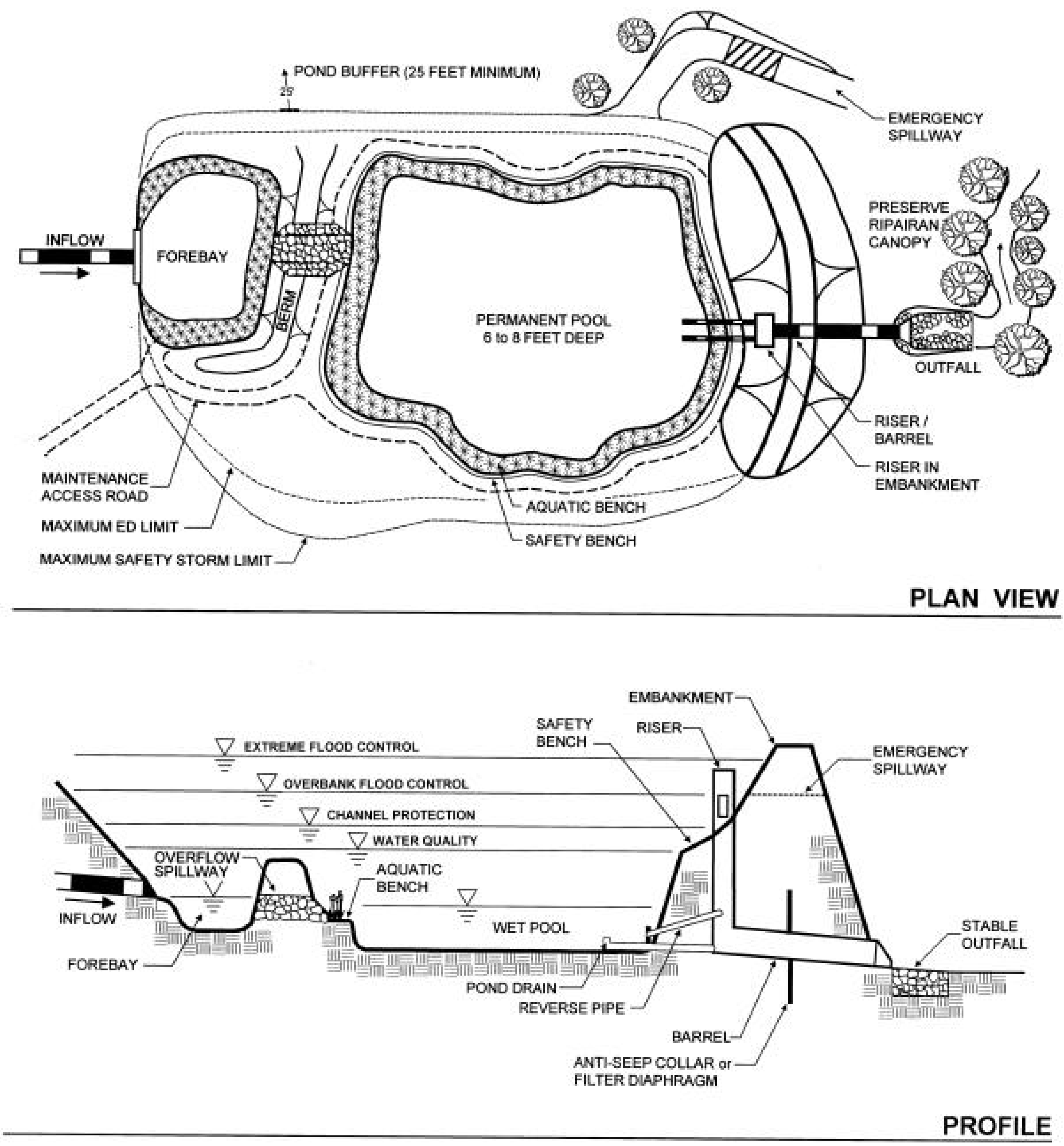

Figure 6.14-1. Wet Detention Pond (New York State Stormwater Manual, 2001)

wildlife benefits. WPs require an adequate source of inflow to maintain the permanent water surface. Due to the potential to discharge warm water, wet ponds should be used with caution near temperature sensitive waterbodies. Properly designed and maintained WPs generally do not support significant mosquito populations (O'Meara).

Variations

Wet Ponds can be designed as either an online or offline facilities. They can also be used effectively in series with other sediment reducing BMPs that reduce the sediment load such as vegetated filter strips, swales, and filters. Wet Ponds may be a good option for retrofitting existing dry detention basins. WPs are often organized into three groups:

- Wet Ponds primarily accomplish water quality improvement through displacement of the permanent pool and are generally only effective for small inflow volumes (often they are placed offline to regulate inflow).
- Wet Detention Ponds are similar to Wet Ponds but use extended detention as another mechanism for water quality and peak rate control.
- Pocket Wet Ponds are smaller WPs that serve drainage areas between approximately 5 and 10 acres and are constructed near the water table to help maintain the permanent pool. They often include extended detention as well.

This BMP focuses on Wet Detention Ponds as described above because this tends to be the most common and effective type of Wet Pond. For more information on other types of wet ponds, please consult the "References and Additional Resources" list.

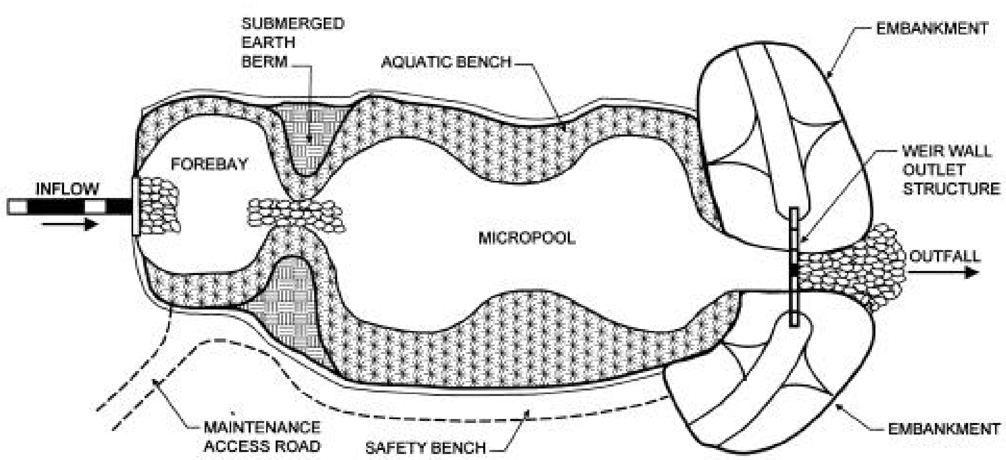

Figure 6.14-2. Pocket Wet Pond (Maryland Stormwater Manual, 2000)

Applications

- **Wet Ponds**
- **Wet Detention Ponds**
- **Pocket Wet Pond**
- **Offline Wet Pond**
- **Retrofit for existing detention basins**

Figure 6.14-3. Wet Pond at Delaware County Community College

Design Considerations

1. HYDROLOGY. Wet Ponds must be able to receive and retain enough flow from rain, runoff, and groundwater to ensure long-term viability. A permanent water surface in the deeper areas of the WP should be maintained during all but the driest periods. A relatively stable permanent water surface elevation will reduce the stress on vegetation in an adjacent to the pond. A WP should have a drainage area of at least 10 acres (5 acres for Pocket Wet Ponds) or some means of sustaining constant inflow. Even with a large drainage area, a constant source of inflow can improve the biological health and effectiveness of a Wet Pond while discouraging mosquito growth. Pennsylvania's precipitation is generally well distributed throughout the year and is therefore suited for WPs.
2. UNDERLYING SOILS. Underlying soils must be identified and tested. Generally hydrologic soil groups "C" and "D" are suitable without modification, "A" and "B" soils may require modification to reduce permeability. Soil permeability must be tested in the proposed Wet Pond location to ensure that excessive infiltration will not cause the WP to dry out.
3. PLANTING SOIL. Organic soils should be used for shallow areas within Wet Ponds. Organic soils can serve as a sink for pollutants and generally have high water holding capacities. They will also facilitate plant growth and propagation and may hinder invasion of undesirable species.
4. SIZE AND VOLUME. The area required for a WP is generally 1 to 3 percent of its drainage area. WPs should be sized to treat the water quality volume and, if necessary, to mitigate the peak rates for larger events.
5. VEGETATION. Vegetation is an integral part of a Wet Pond system. Vegetation in and adjacent to a pond may enhance pollutant removal, reduce algal growth, limit erosion, improve aesthetics, create habitat, and reduce water warming (Mallin et al., 2002; NJ DEP,

2004; University of Wisconsin, 2000). Wet Ponds should have varying depths to encourage vegetation in shallow areas. The emergent vegetation zone (areas not more than 18" deep) generally supports the majority of aquatic vegetation and should include the pond perimeter. Robust, non-invasive, perennial plants that establish quickly are ideal for WPs. The designer should select species that are tolerant of a range of depths, inundation periods, etc. Monoculture planting must be avoided due to the risk from pests and disease. See local sources for recommended plant lists.

6. CONFIGURATION.
    a. General. Wet Ponds should be designed with a length to width ratio of at least 2:1 wherever possible. If the length to width ratio is lower, the flow pathway through the WP should be maximized. A wedge-shaped pond with the major inflows on the narrow end can prevent short-circuiting and stagnation. WPs should not be constructed within 10 feet of the property line or within 50 feet of a private well or septic system. Slopes in and around Wet Ponds should be 4:1 to 5:1 (horizontal:vertical) or flatter whenever possible (10:1 max. for safety/aquatic benches, see 6.d. below). Wet Ponds should have an average depth of 3 to 6 feet and a maximum depth of 8 feet. This should be shallow enough to minimize thermal stratification and short-circuiting and deep enough to prevent sediment resuspension, reduce algal blooms, and maintain aerobic conditions.
    b. Forebay/Inflows. Wet Ponds should have a forebay at all major inflow points to capture coarse sediment, prevent excessive sediment accumulation in the remainder of the WP, and minimize erosion by inflow. The forebays should contain 10 to 15 percent of the total permanent pool volume and should be 4 to 6 feet deep. They should be physically separated from the rest of the pond by a berm, gabion wall, etc. Flows exiting the forebay must be non-erosive to the newly constructed WP. Vegetation within forebays can increase sedimentation and reduce resuspension/erosion. The forebay bottom can be constructed of hardened materials to facilitate sediment removal. Forebays should be installed with permanent vertical markers that indicate sediment depth. Inflow channels should be fully stabilized. Inflow pipes can discharge to the surface or be partially submerged. WPs must be protected from the erosive force of the inflow.
    c. Outlet. Outlet control devices should draw from open water areas 5 to 7 feet deep to prevent clogging and allow the WP to be drained for maintenance. Outlet devices are generally multistage structures with pipes, orifices, or weirs for flow control. A reverse slope pipe terminating 2 to 3 feet below the normal water surface, minimizes the discharge of warm surface water and is less susceptible to clogging by floating debris. Orifices, if used, should be at least 2.5 inches in diameter and should be protected from clogging. Outlet devices should be installed in the embankment for accessibility. If possible, outlet devices should enable the normal water surface to be varied. This allows the water level to be adjusted (if necessary) seasonally, as the WP accumulates sediment over time, if desired grades are not achieved, or for mosquito control. A pond drain should also be included which allows the permanent pool to be completely drained for maintenance within 24 hours. The outlet pipe should generally be fitted with an anti-seep collar through the embankment. Online facilities should have an emergency spillway that can safely pass the 100-year storm with 1 foot of freeboard. All outflows should be conveyed downstream in a safe and stable manner.

   d. Safety/Aquatic Benches. All areas that are deeper than 4 feet should have two safety benches, totaling 15 feet in width. One should start at the normal water surface and extend up to the pond side slopes at a maximum slope of 10 percent. The other should extend from the water surface into the pond to a maximum depth of 18 inches, also at slopes no greater than 10 percent.

7. WET POND BUFFER. To enhance habitat value, visual aesthetics, water temperature, and pond health, a 25-foot buffer should be added from the maximum water surface elevation. The buffer should be planted with trees, shrubs, and native ground covers. Accept in maintenance access areas, turf grass should not be used. Existing trees within the buffer should be preserved. If soils in the buffer will become compacted during construction, soil restoration should take place to aid buffer vegetation.
8. MAINTENANCE ACCESS. Permanent access must be provided to the forebay, outlet, and embankment areas. It should be at least 9 feet wide, have a maximum slope of 15%, and be stabilized for vehicles.
9. PLAN ELEMENTS. The plans detailing the Wet Ponds should clearly show the WP configuration, inlets and outlets, elevations and grades, safety/aquatic benches, and the location, quantity, and propagation methods of pond/buffer vegetation. Plans should also include site preparation techniques, construction sequence, as well as maintenance schedules and requirements.
10. REGULATION. Wet Ponds that have drainage areas over 100 acres, embankments greater than 15 feet high, or a capacity greater than 50 acre-feet may be regulated as a dam by PADEP (see Title 25, Chapter 105 of the Pennsylvania Code). Once established, portions of WPs may be regulated as Wetlands.

Figure 6.14-4. Wet Pond at Applebrook Golf Course, East Goshen Township, Chester County, PA

Detailed Stormwater Functions

Volume Reduction Calculations

Although not typically considered a volume-reducing BMP, Wet Ponds can achieve some volume reduction through infiltration and evapotranspiration, especially during small storms. According to the International Stormwater BMP Database, wet ponds have an average annual volume reduction of 7 percent (Strecker et al., 2004). Hydrologic calculations that should be performed to verify that the WP will have a viable amount of inflow can also predict the water surface elevation under varying conditions. The volume stored between the predicted water level and the lowest outlet elevation will be removed from the storm that occurs under those conditions.

Peak Rate Mitigation Calculations

Peak rate is primarily controlled in Wet Ponds through the transient storage above the normal water surface. See Section 9 for Peak Rate Mitigation methodology.

Water Quality Improvement

Wet Ponds improve runoff quality through settling, filtration, uptake, chemical and biological decomposition, volatilization, and adsorption. WPs are relatively effective at removing many common stormwater pollutants including suspended solids, heavy metals, total phosphorus, total nitrogen, and pathogens. The pollutant removal effectiveness varies by season and may be affected by the age of the WP. It has been suggested that this type of BMP does not provide significant nutrient removal in the long term unless vegetation is harvested because captured nutrients are released back into the water by decaying plant material. Even if this is true, nutrients are usually released gradually and during the non-growing season when downstream susceptibility is generally low (Hammer, 1990). See Section 9 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Separate wet pond area from contributing drainage area:
    a. All channels/pipes conveying flows to the WP must be routed away from the WP area until it is completed and stabilized.
    b. The area immediately adjacent to the WP must be stabilized in accordance with the PADEP's *Erosion and Sediment Pollution Control Program Manual* (2000 or latest edition) prior to construction of the WP.

2. Clearing and Grubbing:
    a. Clear the area to be excavated of all vegetation.
    b. Remove all tree roots, rocks, and boulders.
    c. Fill all stump holes, crevices and similar areas with impermeable materials.

3. Excavate bottom of WP to desired elevation (Rough Grading).

4. Install surrounding embankments and inlet and outlet control structures.

5. Grade and prepare subsoil.

6. Apply and grade planting soil.
   a. Matching design grades is crucial because aquatic plants can be very sensitive to depth.

7. Apply erosion-control measures, if applicable.

8. Seed, plant and mulch according to Planting Plan

9. Install any anti-grazing measures, if necessary.

10. Follow required maintenance and monitoring guidelines.

Maintenance Issues

Wet Ponds must have a maintenance plan and privately owned facilities should have an easement, deed restriction, or other legal measure to prevent neglect or removal. During the first growing season or until established, vegetation should be inspected every 2 to 3 weeks. WPs should be inspected at least 4 times per year and after major storms (greater than 2 inches in 24 hours) or rapid ice breakup. Inspections should access the vegetation, erosion, flow channelization, bank stability, inlet/outlet conditions, embankment, and sediment/debris accumulation. The pond drain should also be inspected and tested 4 times per year. Problems should be corrected as soon as possible. Wet Pond and buffer vegetation may require support – watering, weeding, mulching, replanting, etc. – during the first 3 years. Undesirable species should be carefully removed and desirable replacements planted if necessary.

Once established, properly designed and installed Wet Ponds should require little maintenance. Vegetation should maintain at least an 85 percent cover of the emergent vegetation zone and buffer area. Annual harvesting of vegetation may increase the nutrient removal of WPs; if performed it should generally be done in the summer so that there is adequate regrowth before winter. Care should be taken to minimize disturbance, especially of bottom sediments, during harvesting. The potential disturbance from harvesting may outweigh its benefits unless the WP receives a particularly high nutrient load or discharges to a nutrient sensitive waterbody. Sediment should be removed from the forebay before it occupies 50 percent of the forebay, typically every 5 to 10 years.

Cost Issues

The construction cost of Wet Ponds can vary greatly depending on the configuration, location, site-specific conditions, etc. Typical construction costs in 2004 dollars range from approximately $25,000 to $50,000 per acre-foot of storage (based on USEPA, 1999). Costs are generally most dependent on the amount of earthwork and the planting. Annual maintenance costs have been reported to be approximately 3 to 5 percent of the capital costs although there is little data available to support this.

Specifications:

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Excavation**
    a. The area to be used for the WP should be excavated to the required depth below the desired bottom elevation to accommodate any required impermeable liner, organic matter, and/or planting soil.
    b. The compaction of the subgrade and/or the installation of any impermeable liners will follow immediately.
2. **Subsoil Preparation**
    a. Subsoil shall be free from hard clods, stiff clay, hardpan, ashes, slag, construction debris, petroleum hydrocarbons, or other undesirable material. Subsoil must not be delivered in a frozen or muddy state.
    b. Scarify the subsoil to a depth of 8 to 10 inches with a disk, rototiller, or similar equipment.
    c. Roll the subsoil under optimum moisture conditions to a dense seal layer with four to six passes of a sheepsfoot roller or equivalent. The compacted seal layer shall be at least 8 inches thick.
3. **Planting Soil (Topsoil)**
    a. See Appendix C for Planting Soil requirements.
    b. Use a minimum of 12 inches of topsoil in the emergent vegetation zone (less than 18" deep) of the pond. If natural topsoil from the site is to be used it must have at least 8 percent organic carbon content (by weight) in the A-horizon for sandy soils and 12% for other soil types.
    c. If planting soil is being imported it should be made up of equivalent proportions of organic and mineral materials.
    d. Lime should not be added to planting soil unless absolutely necessary as it may encourage the propagation of invasive species.
    e. The final elevations and hydrology of the vegetative zones should be evaluated prior to planting to determine if grading or planting changes are required.
4. **Vegetation**
    a. Plant Lists for WPs can be found locally. No substitutions of specified plants will be accepted without prior approval of the designer. Planting locations shall be based on the Planting Plan and directed in the field by a qualified wetland ecologist.
    b. All Wet Pond plant stock shall exhibit live buds or shoots. All plant stock shall be turgid, firm, and resilient. Internodes of rhizomes may be flexible and not necessarily rigid. Soft or mushy stock shall be rejected. The stock shall be free of deleterious insect infestation, disease and defects such as knots, sun-scald, injuries, abrasions, or disfigurement that could adversely affect the survival or performance of the plants.
    c. All stock shall be free from invasive or nuisance plants or seeds.
    d. During all phases of the work, including transport and onsite handling, the plant materials shall be carefully handled and packed to prevent injuries and desiccation. During transit and onsite handling, the plant material shall be kept from freezing and shall be kept covered, moist, cool, out of the weather, and out of the wind and sun.

Plants shall be watered to maintain moist soil and/or plant conditions until accepted.

e. Plants not meeting these specifications or damaged during handling, loading, and unloading will be rejected.
f. Detailed planting specifications can be found locally, and in Appendix B.

5. Outlet Control Structure

a. Outlet control structures shall be constructed of non-corrodible material.
b. Outlets shall be resistant to clogging by debris, sediment, floatables, plant material, or ice.
c. Materials shall comply with applicable specifications (PennDOT or AASHTO, latest edition)

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Runoff Quality/Peak Rate BMPs

BMP 6.15: Dry Extended Detention Basin

A dry extended detention basin is an earthen structure, constructed either by impoundment of a natural depression or excavation of existing soil, that provides temporary storage of runoff and functions hydraulically to attenuate stormwater runoff peaks. The dry detention basin, as constructed in countless locations since the mid-1970's and representing the primary BMP measure until now, has served to control the peak rate of runoff, although some water quality benefit accrued by settlement of the larger particulate fraction of suspended solids. This extended version is intended to enhance this mechanism in order to maximize water quality benefits.

The basin outlet structure must be designed to detain runoff from the stormwater quality design storm for extended periods. Some volume reduction is also achieved by a dry basin through initial saturation of the soil mantle, even when compacted, and some evaporation takes place during detention. The net volume reduction for design storms is minimal, especially if the precedent soil moisture is assumed as in other volume reduction BMPs.

Key Design Elements

- Extended detention basins shall have a minimum contributing area of 10 acres or more (25 or more are recommended).
- Detention basins are typically designed to control runoff peak rates for rainfall events with return frequencies of 2 years, 5 years, 10 years and 25 years. Some local ordinances may require control of less frequent storms, such as the 50 and 100-year storms.
- A forebay and micropool should be incorporated into the design in order to maximize water quality control, through increased sedimentation and extended detention/ retention of runoff volume from the water quality design storm.
- Low flow channels are not recommended except where severe ponding is anticipated due to in situ soil conditions.
- Compaction of the basin bottom should be avoided. In the event that compaction should occur, soils shall be restored/amended as per BMP 4.3 – Soils Amendment.
- It is recommended that detention basin bottoms be vegetated with a variety of native species, including trees, woody shrubs and herbaceous plants. The use of turf lawn is not recommended.

Potential Applications

Residential:	**YES**
Commercial:	**YES**
Ultra Urban:	**LIMITED***
Industrial:	**YES**
Retrofit:	**LIMITED**
Highway/Road:	**YES**

***May be limited by sizing constraints and the ability to meet water quality standards.**

Stormwater Functions

Volume Reduction:	**Low**
Recharge:	**Low**
Peak Rate Control:	**High**
Water Quality:	**Medium**

Pollutant Removal

TSS:	**60%**
TP:	**40%**
NO_3:	**20%**

Description

Dry extended detention basins are surface stormwater structures which provide for the temporary storage of stormwater runoff to prevent downstream flooding impacts. Water quality benefits may be achieved with extended detention of the runoff volume from the water quality design storm.

- The primary purpose of the detention basin is the attenuation of stormwater runoff peaks.
    - Detention basins should be designed to control runoff peak rates for rainfall events with return frequencies of 2 years, 5 years, 10 years, 25 years, and 50 years.
    - Inflow and discharge hydrographs should be calculated for each selected design storm. Hydrographs should be based on the 24-hour rainfall event. Specifically, the NRCS 24-hour type II rainfall distribution should be utilized to generate hydrographs.

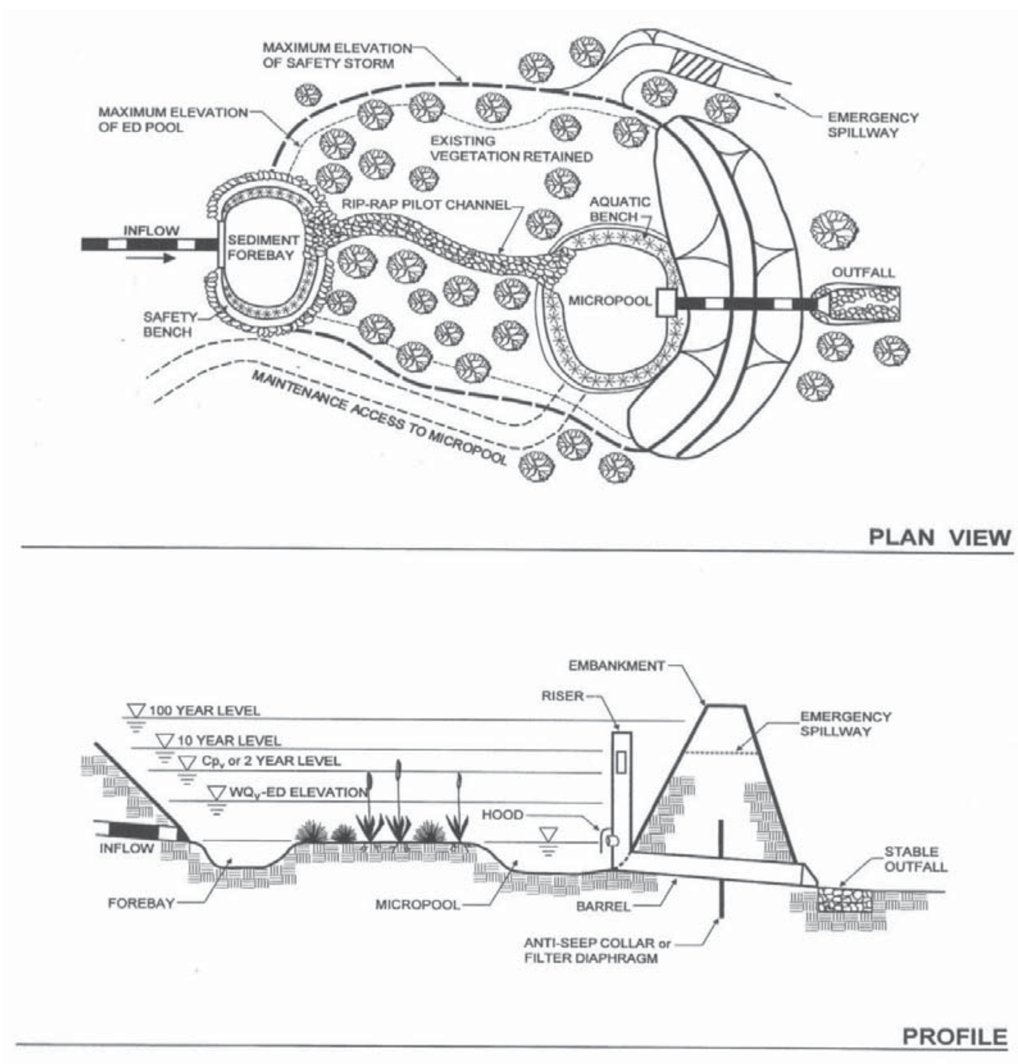

Figure 6.15-1 Typical Dry Extended Detention Basin Design: Plan and Profile (Maryland BMP Manual, 2000)

- Basins shall be designed to provide water quality treatment storage to capture the computed runoff volume of the water quality design storm.
    - Detention basins shall have a sediment forebay or equivalent upstream pretreatment. The forebay shall consist of a separate cell, formed by an acceptable barrier and will require periodic sediment removal.
    - A micropool storage area shall be designed where feasible for the extended detention of runoff volume from the water quality design storm.
    - Flow paths from inflow points to outlets shall be maximized.

Variations

Sub-surface extended detention

Extended detention storage can also be provided in a variety of sub-surface structural elements, such as underground vaults, tanks, large pipes or other structural media placed in an aggregate filled bed in the soil mantle. All such systems are designed to provide runoff peak rate mitigation as their primary function, but some pollutant removal may be included. Regular maintenance is required, since the structure must be drained within a design period and cleaned to assure detention capacity for subsequent rainfall events. These facilities are usually intended for space-limited applications and are not intended to provide significant water quality treatment.

- Underground vaults are typically box shaped underground stormwater storage facilities constructed of reinforced concrete, while tanks are usually constructed of large diameter metal or plastic pipe. They may be situated within a building, but the use of internal space is frequently not cost beneficial.
    - Storage design and routing methods are the same as for surface detention basins.
    - Underground vaults and tanks do not provide water quality treatment and must be used in combination with a pretreatment BMP.

- Underground detention beds can be constructed by excavating a subsurface area and filling with uniformly graded aggregate for support of overlying land uses.
    - This approach may be used where space is limited but subsurface infiltration is not feasible due to high water table conditions or shallow soil mantle.
    - As with detention vaults and tanks, this facility provides minimal water quality treatment and must be used in combination with a pretreatment BMP.
    - It is recommended that underground detention facilities not be lined to allow for even minimal infiltration, except in the case where toxic contamination is possible.

Applications

- **Low Density Residential Development**
- **Industrial Development**
- **Commercial Development**
- **Urban Areas**

Design Considerations

1. **Storage Volume, Depth and Duration**

    a. Extended detention basins are usually designed to mitigate runoff peak rates for the 2-year, 5-year, 10-year, 25-year, and 50-year rainfall events.
    b. An emergency outlet or spillway which is capable of conveying the spillway design flood (SDF) must be included in the design. The SDF is usually equal to the 100-year design flood
    c. Extended detention basins should be designed to treat the runoff volume produced by the water quality design storm.
    d. The detention time is defined as the time from when the maximum storage volume is achieved until only 10 percent of that volume remains in the basin. In order to achieve a 60 percent total suspended solids removal rate, a 24-hour detention time is required within an extended detention basin.
    e. The lowest elevation within an extended dry detention basin shall be at least 2 feet above the seasonal high water table. If high water table conditions are anticipated, then the design of a wet pond, constructed wetland or bioretention facility should be considered.
    f. The maximum water depth of the basin shall not exceed 10 feet.

2. **Dry Extended Detention Basin Location**

    a. Extended detention basins shall be located down gradient of disturbed or developed areas on the site. The basin must collect as much site runoff as possible, especially from the site's impervious surfaces (roads, parking, buildings, etc.).
    b. Extended detention basins shall not be constructed on steep slopes, nor shall slopes be significantly altered or modified to reduce the steepness of the existing slope, for the purpose of installing a basin.
    c. Extended detention basins shall not worsen the runoff potential of the existing site by removal of trees for the purpose of installing a basin.
    d. Extended detention basins shall not be constructed in areas with high quality and/or well draining soils, which are adequate for the installation of BMPs capable of achieving stormwater infiltration.
    e. Extended detention basins shall not be constructed within jurisdictional waters, including wetlands.
    f. The use of extended detention basins within Exceptional Value or High Quality watersheds as defined by Chapter 93 of Pennsylvania's Code is not recommended and may be prohibited by local ordinances.

3. **Basin Sizing and Configuration**

    a. Basins should be shaped to maximize the length of stormwater flow pathways and minimize short-circuited inlet-outlet systems. Basins shall have a minimum width of 10 feet. A minimum length-to-width ratio of 2:1 is recommended to maximize sedimentation.
    b. Irregularly shaped basins are encouraged and appear more natural, or less "engineered".

c. If site conditions inhibit construction of a long, narrow basin, baffles constructed from earthen berms or other materials can be incorporated into the pond design to “lengthen” the stormwater flow path.
d. Low flow channels shall not be incorporated in the design, except where there is a concern for severe ponding due to in situ soils. In this case, low flow channels shall always be vegetated with a maximum slope of 3 percent to encourage sedimentation. Alternatively, other BMPs may be considered such as wet ponds, constructed wetlands or bioretention.

4. **Embankments**

a. Vegetated embankments less than or equal to 3 feet in height are recommended, however embankments must be less than 15 feet in height and shall have side slopes no steeper than 3:1 (horizontal to vertical).
b. The basin shall have a minimum freeboard of 1 foot above the SDF elevation.
c. Woody vegetation can be planted in the immediate embankment area, unless the root system will compromise the structural integrity.

5. **Inlet Structures**

a. Inlet structures to basin shall not be submerged at the normal pool depth.
b. Erosion protection measures shall be utilized to stabilize inflow structures and channels.

6. **Outlet Design**

a. In order to meet designs storm requirements, dry extended detention basins will have a multistage outlet structure. Three elements are typically included in this design:
    1. A low-flow outlet that controls the extended detention and functions to slowly release the water quality design storm.
    2. A primary outlet that functions to attenuate the peak of larger design storms.
    3. An emergency overflow outlet/spillway
b. The primary outlet structure should incorporate weirs, orifices, pipes or a combination of these to control runoff peak rates for required design storms. Water quality storage shall be provided below the invert of the primary outlet. When routing basins, the low-flow outlet should be included in the depth-discharge relationship.
c. Energy dissipaters are to be placed at the end of the primary outlet to prevent erosion. If the basin discharges to a channel with dry weather flow, care shall be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone between the outlet and natural channel. Where feasible, a multiple orifice outlet system is preferred to a single pipe.
d. The low-flow orifice shall typically be no smaller than 2.5 inches in diameter. However, the orifice diameter may be reduced to 1 inch if adequate protection from clogging is provided.
e. The hydraulic design of all outlet structures must consider any significant tailwater effects of downstream waterways.
f. The primary and low flow outlet shall be protected from clogging by an external trash rack.

7. **Sediment Forebay**

   a. Forebays shall be incorporated into the extended detention design. The forebay storage volume is included for the water quality volume requirement.
   b. Forebays shall be vegetated to improve filtering of runoff, to reduce runoff velocity, and to stabilize soils against erosion. Forebays are typically constructed as shallow marsh areas and should adhere to the following design criteria:
      1. It is recommended that forebays have a minimum length of 10 feet.
      2. Storage shall be provided to trap sediment over a period of 2 to 10 years.

Figure 6.15-2 Picture of a sediment forebay created with a riprap berm. Although not shown, it is recommended that sediment forebays be vegetated with a minimum of native wet meadow planting, however more substantial plantings are preferred. (Chester County Conservation District photo, 2002)

8. **Vegetation and Soils Protection**
   a. Care shall be taken to prevent compaction of in situ soils in the bottom of the extended detention basin in order to promote healthy plant growth and to encourage infiltration. If soils compaction is not prevented during construction, soils shall be restored as discussed in BMP 6.19 – Soils Amendment & Restoration.
   b. It is recommended that basin bottoms be vegetated in a diverse native planting mix to reduce maintenance needs, promote natural landscapes, and increase infiltration potential. Vegetation may include trees, woody shrubs and meadow/wetland herbaceous plants.
   c. Woody vegetation can be planted on the embankments or within 25 feet of the emergency overflow spillway, unless the root system will compromise the structural embankment.
   d. Meadow grasses or other deeply rooted herbaceous vegetation is recommended on the interior slope of embankments.
   e. Fertilizers and pesticides shall not be used.

9. **Special Design Considerations**
   a. Ponds that have embankments higher than 15 feet or will impound more that 50 acre-feet of runoff during the high-water condition will be regulated as dams by

PADEP. The designer shall consult Pennsylvania Chapter 105 to determine which provisions may apply to the specific project in question.

b. Extended detention ponds shall never be utilized as recreation areas due to health and safety issues. Design features that discourage access are recommended.

Detailed Stormwater Functions

Peak Rate Mitigation

Inflow and discharge hydrographs must be calculated for each design storm. Hydrographs should be based on a 24-hour rainfall event. The Natural Resources Conservation Service's (NRCS) 24-hour Type II rainfall distribution should be utilized.

The predevelopment and post-development hydrographs for the drainage area shall be calculated using the NRCS's methodology described in the NRCS National Engineering Handbook. The NRCS's method uses a non-dimensional unit hydrograph and the soil cover complex method to predict runoff peak rates. Once the hydrograph has been computed, it can be routed manually or with a computer-modeling program.

Water Quality Improvement

Water quality mitigation is partially achieved by retaining the runoff volume from the water quality design storm for a minimum of 24 hours. The low flow orifice shall be sized to detain the calculated water quality runoff volume for at least 24 hours. Sediment forebays should be incorporated into the design to improve sediment removal. The storage volume of the forebay may be included in the calculated storage of the water quality design volume.

Construction Sequence

1. Install all temporary erosion and sedimentation controls.
    a. The area immediately adjacent to the basin must be stabilized in accordance with the PADEP's *Erosion and Sediment Pollution Control Program Manual* (2000 or latest edition) prior to basin construction.
2. Prepare site for excavation and/or embankment construction.
    a. All existing vegetation should remain if feasible and shall only be removed if necessary for construction.
    b. Care should be taken to prevent compaction of the basin bottom.
    c. If excavation is required, clear the area to be excavated of all vegetation. Remove all tree roots, rocks, and boulders only in excavation area
3. Excavate bottom of basin to desired elevation (if necessary).
4. Install surrounding embankments and inlet and outlet control structures.
5. Grade subsoil in bottom of basin, taking care to prevent compaction. Compact surrounding embankment areas and around inlet and outlet structures.
6. Apply and grade planting soil.
7. Apply geo-textiles and other erosion-control measures.
8. Seed, plant and mulch according to Planting Plan
9. Install any anti-grazing measures, if necessary.

Maintenance Issues

Maintenance is necessary to ensure proper functionality of the extended detention basin and should take place periodically on an annual basis. A basin maintenance plan should be developed which includes the following measures:

- All basin structures expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris and sediment accumulation at least four times per year, as well as after every storm greater than 1 inch.
    - Structures include basin bottoms, trash racks, outlets structures, riprap or gabion structures, and inlets.
- Sediment removal should be conducted when the basin is completely dry. Sediment should be disposed of properly and once sediment is removed, disturbed areas need to be immediately stabilized and revegetated.
- Mowing and/or trimming of vegetation should be performed as necessary to sustain the system, but all detritus must be removed from the basin.
    - Vegetated areas should be inspected annually for erosion.
    - Vegetated areas should be inspected annually for unwanted growth of exotic/ invasive species.
    - Vegetative cover should be maintained at a minimum of 95 percent. If vegetative cover has been reduced by 10%, vegetation should be reestablished.

Cost Issues

The construction costs associated with dry extended detention basins can range considerably. One recent study evaluated the cost of all pond systems (Brown and Schueler, 1997). Adjusting for inflation, the cost of dry extended detention ponds can be estimated with the equation:

$$C = 12.4V^{0.760}$$

Where:

C = Construction, Design and Permitting Cost
V = Volume needed to control the 10-year storm (cubic feet)
Using this equation, a typical construction costs are:
$ 41,600 for a 1 acre-foot pond
$ 239,000 for a 10 acre-foot pond
$ 1,380,000 for a 100 acre-foot pond

Dry extended detention basins utilizing highly structural design features (rip-rap for erosion control, etc.) are more costly than naturalized basins. There is an installation cost savings associated with a natural vegetated slope treatment which is magnified by the additional environmental benefits provided. Long-term maintenance costs are reduced when more naturalized approaches are utilized due to the ability of native vegetation to adapt to local weather conditions and a reduced need for maintenance, such as mowing and fertilization.

Normal maintenance costs can be expected to range form 3 to 5 percent of the construction costs on an annual basis.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Site Preparation**
    a. All excavation areas, embankments, and where structures are to be installed shall be cleared and grubbed as necessary, but trees and existing vegetation shall be retained and incorporated within the dry detention basin area where necessary. Under no circumstances shall trees be removed.
    b. Where feasible, trees and other native vegetation shall be protected, even in areas where temporary inundation is expected. A minimum 10-foot radius around the inlet and outlet structures can be cleared to allow construction.
    c. Any cleared material shall be used as mulch for erosion control or soil stabilization.
    d. Care shall be taken to prevent compaction of the bottom of the reservoir. If compaction should occur, soils shall be restored and amended.

2. **Earth Fill Material & Placement**
    a. The fill material shall be taken from approved designated excavation areas. It shall be free of roots, stumps, wood, rubbish, stones greater than 6 inches, or other objectionable materials. Materials on the outer surface of the embankment must have the capability to support vegetation.
    b. Areas where fill is to be placed shall be scarified prior to placement. Fill materials for the embankment shall be placed in maximum 8-inch lifts. The principal spillway must be installed concurrently with fill placement and not excavated into the embankment.
    c. The movement of the hauling and spreading equipment over the site shall be controlled. For the embankment, the entire surface of each lift shall be traversed by not less than one tread track of heavy equipment or compaction shall be achieved by a minimum of four complete passes of a sheepsfoot, rubber tired or vibratory roller. Fill material shall contain sufficient moisture so that if formed in to a ball it will not crumble, yet not be so wet that water can be squeezed out.
3. **Embankment Core**
    a. The core shall be parallel to the centerline of the embankment as shown on the plans. The top width of the core shall be at least four feet. The height shall extend up to at least the 10-year water elevation or as shown on the plans. The side slopes shall be 1 to 1 or flatter. The core shall be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability. The core shall be placed concurrently with the outer shell of the embankment.
4. **Structure Backfill**
    a. Backfill adjacent to pipes and structures shall be of the type and quality conforming to that specified for the adjoining fill material. The fill shall be placed in horizontal layers not to exceed four inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material shall fill completely all spaces under and adjacent to the pipe. At no time during the backfilling operation shall driven equipment be allowed to operate closer than four feet to any part of the

structure. Equipment shall not be driven over any part of a concrete structure or pipe, unless there is a compacted fill of 24 inches or greater over the structure or pipe.

b. Structure backfill may be flowable fill meeting the requirements of the PADOT Standard Specifications for Construction. Material shall be placed so that a minimum of 6 inches of flowable fill shall be under (bedding), over and, on the sides of the pipe. It only needs to extend up to the spring line for rigid conduits. Average slump of the fill material shall be 7 inches to assure flowability of the mixture. Adequate measures shall be taken (sand bags, etc.) to prevent floating the pipe. When using flowable fill all metal pipe shall be bituminous coated. Adjoining soil fill shall be placed in horizontal layers not to exceed 4 inches in thickness and compacted by hand tampers or other manually directed compaction equipment.

5. **Pipe Conduits**
   a. Corrugated Metal Pipe – All of the following criteria shall apply for corrugated metal pipe:
      i. Materials **-** Polymer coated steel pipe, Aluminum coated steel pipe, Aluminum pipe –This pipe and its appurtenances shall conform to the requirements of AASTO Specifications with watertight coupling bands or flanges.
      ii. Coupling bands, anti-seep collars, end sections, etc., must be composed of the same material and coatings as the pipe. Metals must be insulated from dissimilar materials with use of rubber or plastic insulating materials at least 24 mils in thickness.
      iii. Connections – All connections with pipes must be completely watertight. The drain pipe or barrel connection to the riser shall be welded all around when the pipe and riser are metal. Anti-seep collars shall be connected to the pipe in such a manner as to be completely watertight. Dimple bands are not considered to be watertight.
      iv. Bedding – The pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material shall be removed and replaced with suitable earth compacted to provide adequate support.
      v. Backfilling shall conform to “Structure Backfill”.
      vi. Other details (anti-seep collars, valves, etc.) shall be as shown on drawings.
   b. Reinforced Concrete Pipe - All of the following criteria shall apply for reinforced concrete pipe:
      i. Materials – Reinforced concrete pipe shall have bell and spigot joints with rubber gaskets and shall equal or exceed ASTM Standards.
      ii. Bedding – Reinforced concrete pipe conduits shall be laid in a concrete bedding/cradle for their entire length. This bedding/cradle shall consist of high slump concrete placed under the pipe and up the sides of the pipe at least 50% of its outside diameter with a minimum thickness of 6 inches. Where a concrete cradle is not needed for structural reasons, flowable fill may be used as described in the “Structure Backfill” section of this specification. Gravel bedding is not permitted.
      iii. Laying pipe – Bell and spigot pipe shall be placed with the bell end upstream. Joints shall be made in accordance with recommendations of the manufacturer of the material. After the joints are sealed for the entire line,

the bedding shall be placed so that all spaces under the pipe are filled. Care shall be exercised to prevent any deviation from the original line and grade of the pipe.

iv. Backfilling shall conform to "Structure Backfill".

v. Other details (anti-seep collars, valves, etc.) shall be as shown on drawings.

c. Plastic Pipe

i. Materials – PVC pipe shall be PVC-1120 or PVC-1220 conforming to ASTM Standards. Corrugated High Density Polyethylene (HDPE) pipe, couplings and fittings shall meet the requirements of AASHTO Specifications.

ii. Joints and connections to anti-seep collars shall be completely watertight.

iii. Bedding – The pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material shall be removed and replaced with suitable earth compacted to provide adequate support.

iv. Backfilling shall conform to "Structure Backfill".

v. Other details (anti-seep collars, valves, etc.) shall be as shown on drawings.

d. Drainage Diaphragms – When a drainage diaphragm is used, a registered professional engineer will supervise the design and construction inspection.

6. **Rock Riprap**

a. Rock riprap shall meet the requirements of Pennsylvania Department of Transportation Standard Specifications.

7. **Stabilization**

a. All borrow areas shall be graded to provide proper drainage and left in a sightly condition. All exposed surfaces of the embankment, spillway, spoil and borrow areas, and berms shall be stabilized by seeding, planting and mulching in accordance with the Natural Resources Conservation Service Standards and Specifications or as shown on the accompanying drawings.

8. **Operation and Maintenance**

a. An operation and maintenance plan in accordance with Local or State Regulations will be prepared for all basins. As a minimum, a dam and inspection checklist shall be included as part of the operation and maintenance plan and performed at least annually.

References

AMEC Earth and Environmental Center for Watershed Protection et al. *Georgia Stormwater Management Manual*. 2001.

Brown, W. and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for: Chesapeake Research Consortium. Edgewater, MD. Center for Watershed Protection. Ellicott City, MD.

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Commonwealth of PA, Department of Transportation. *Pub 408 - Specifications*. 1990. Harrisburg, PA.

Maryland Department of the Environment. *Maryland Stormwater Design Manual*. 2000.

Milner, George R. 2001. *Conventional vs. Naturalized Detention Basins: A Cost/Benefit Analysis*. Prepared for: The Illinois Association for Floodplain and Stormwater Management. Park Forest, IL

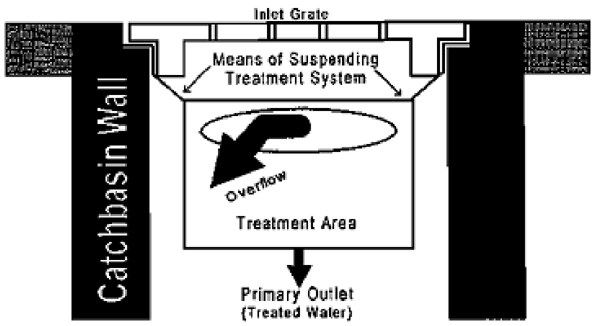
New Jersey Department of Environmental Protection. *New Jersey Stormwater Best Management Practices Manual*. 2004.

Stormwater Management Fact Sheet: Dry Extended Detention Pond – www.stormwatercenter.net

Vermont Agency of Natural Resources. *The Vermont Stormwater Management Manual*. 2002.

Washington State Department of Ecology. *Stormwater Management Manual for Eastern Washington (Draft)*. Olympia, WA: 2002.

Runoff Quality/Peak Rate BMPs
BMP 6.16: Water Quality Filter



A broad spectrum of BMPs have been designed to remove NPS pollutants from runoff as a part of the runoff conveyance system. These structural BMPs vary in size and function, but all utilize some form of settling and filtration to remove particulate pollutants from the turbid flow, a difficult task given the concentrations and flow rates experienced. Regular maintenance is critical for this BMP. Many water quality filters and are catch basin inserts are commercially available (manufactured) devices. They are generally configured to remove particulate contaminants, including coarse sediment, oil and grease, litter, and debris.

Key Design Elements

- Choose WQI that (collectively) has the hydraulic capacity to treat the WQ storm
- Regular Maintenance is necessary
- Evaluation of the device chosen should be balanced with cost
- Hydraulic capacity controls effectiveness
- Most useful in small drainage areas (< 1 Acre)
- Ideal in combination with other BMP's

Potential Applications

Residential: YES
Commercial: YES
Ultra Urban: YES
Industrial: YES
Retrofit: YES
Highway/Road: YES

Stormwater Functions

Volume Reduction: None
Recharge: None
Peak Rate Control: Low
Water Quality: Medium

Pollutant Removal

TSS: 60%
TP: 50%
NO_3: 20%

Description

Water Quality Inlets are stormwater inlets that have been fitted with a proprietary product (or the proprietary product replaces the catch basin itself), designed to reduce large sediment, suspended solids, oil and grease, and other pollutants, especially pollutants conveyed with sediment transport. They can provide “hotspot” control and reduce sediments loads to infiltration devices. They are commonly used as pretreatment for other BMP’s. The manufacturer usually provides the mechanical design, construction, and installation instructions. Selection of the most appropriate device and development of a maintenance plan should be carefully considered by the Designer.

The size of a water quality inlet limits the detention time; the hydraulic capacity influences the effectiveness of the water quality insert. Most products are designed for an overflow in large storm events, which is necessary hydraulically and still allows for a “first flush” treatment.

Regular maintenance according to application and manufacturer’s recommendations is essential for continued performance.

Variations

Tray types
Allows flow to pass through filter media that is contained in a tray located around the perimeter of the inlet. Runoff enters the tray and leaves via weir flow under design conditions. High flows pass over the tray and into the inlet unimpeded.

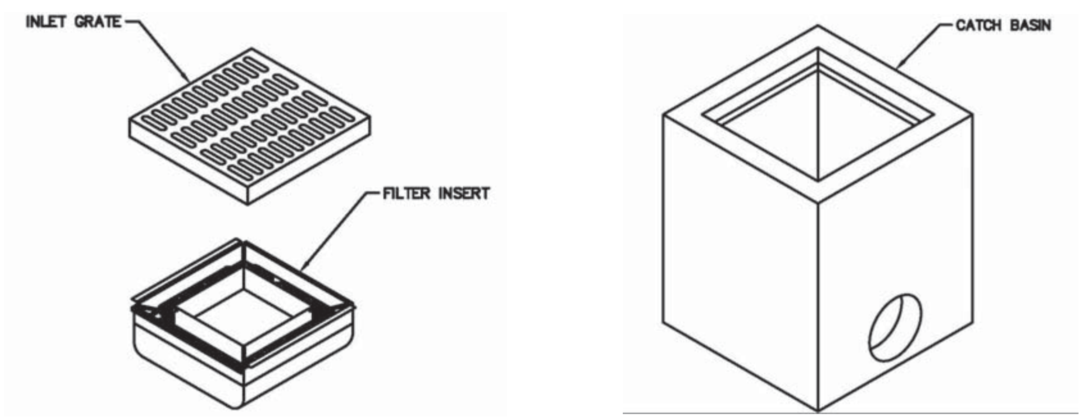


Figure 6.16-1. Water Quality Insert Tray

Bag types

Insert is made of fabric and is placed in the drain inlet around the perimeter of the grate. Runoff passes through the bag before discharging into the drain outlet pipe. Overflow holes are usually provided to pass larger flows without causing a backwater at the grate. Certain manufactured products include polymers intended to increase pollutant removal effectiveness.

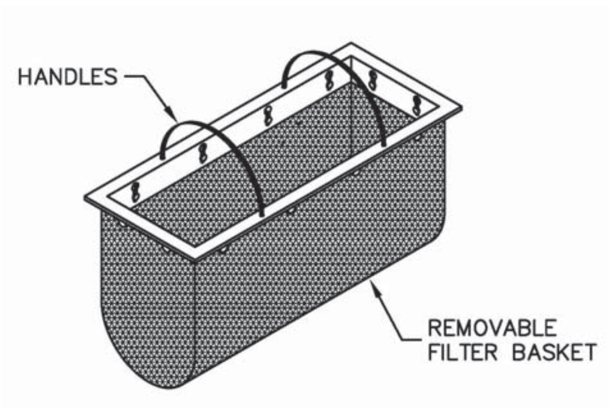


Figure 6.16-2. Filter Bag

Figure 6.16-3. Filter Bag Installation (Full Circle Ag, Inc., http://www.fullcircleag.com/pages/954364/)

Baskets types

The insert consists of "basket type" insert that sets into the inlet and has a handle to remove basket for maintenance. Small orifices allow small storm event to weep through, larger storms overflow the basket. Primarily useful for debris and larger sediment, and requires consistent maintenance.

Figure 6.16-4. Example of a german basket-type water quality inlet, (CA, 2001).

Simple, "sumps" in inlets

Space created in inlets below the invert of the pipes for sediment and debris to deposit, usually leaving 6-inches to 12-inches at the bottom of an inlet. Small weep holes should be drilled into the bottom of the inlet to prevent standing water for long periods of time. Regular maintenance is required.

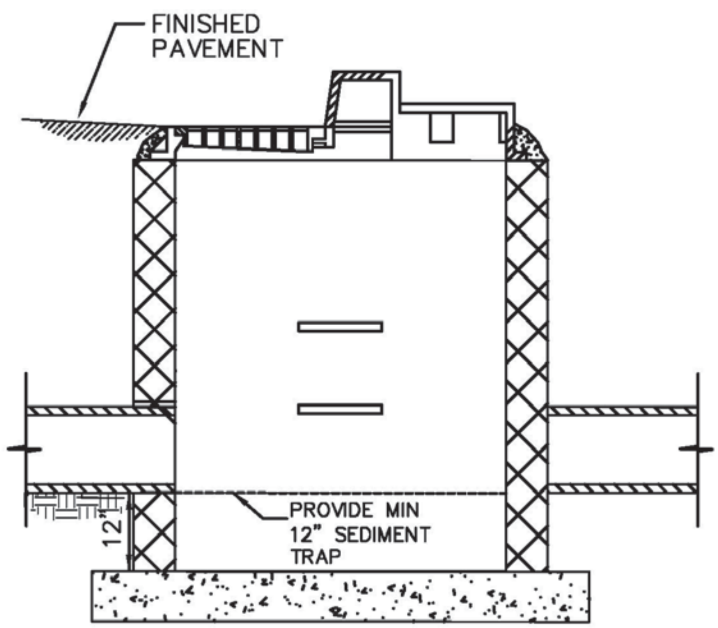
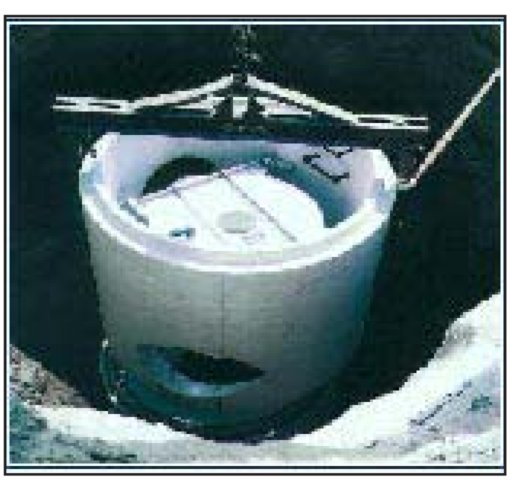
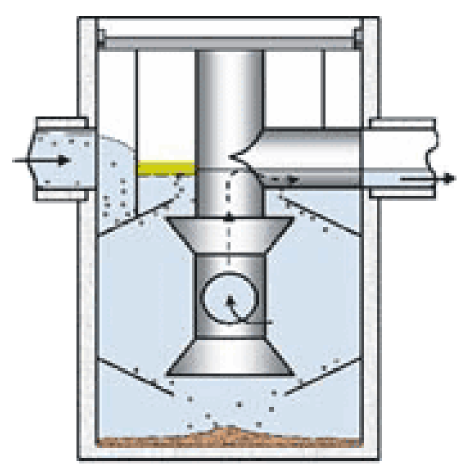


Figure 6.16-5. Sediment sump incorporated with a standard inlet.

Vortex Separators

These units are not truly inserts, but separate devices designed to serve in concert with inlets and storm sewer. A variety of products are available from different manufacturers. The primary purpose is to use centrifugal force to remove sediments and pollutants.





Figures 6.16-6. Vortex separator (http://www.hydrointernational.biz/nam/ind_storm.html)

Applications

Any existing or proposed inlet where the contributing runoff may contain significant levels of sediment and debris, for example: parking lots, gas stations, golf courses, streets, driveways, industrial or commercial facilities, and municipal corporation yards. Commonly used as pretreatment before other stormwater BMPs.

Design Considerations

1. Match site considerations with manufacturer's guidelines/specifications (i.e. land use will determine specific pollutants to be removed from runoff).

2. Prevent re-suspension of particles by using small drainage areas and good maintenance.

3. Retrofits should be designed to fit existing inlets.

4. Placement should be accessible to maintenance.

5. If used as part of Erosion & Sedimentation Control during construction, insert should be reconfigured (if necessary) per manufacture's guidelines.

6. Overflow should be designed so that storms in excess of the device's hydraulic capacity bypass the treatment and is treated by another quality BMP.

Detailed Stormwater Functions

Volume Reduction Calculations
N/A

Peak Rate Mitigation Calculations
N/A

Water Quality Improvement
If sized to treat the WQ storm, removal rates above can be applied to that volume of water.

Construction Sequence

1. Stabilize all contributing areas before installing and connecting pipes to these inlets.

2. Follow manufacturer's guidelines for installation. Do not use water quality inserts during construction unless product is designed for it. (Some products have adsorption components that should be installed post-construction.)

Maintenance Issues

Follow the manufacturer's guidelines for maintenance, also taking into account expected pollutant load and site conditions. Inlets should be inspected weekly during construction. Post-construction, they should be emptied when full of sediment (and trash) and cleaned at least twice a year. They should also be inspected after significant precipitation. Maintenance is crucial to the effectiveness of this BMP. The more frequent a water quality insert is cleaned, the more effective it will be. One study (Pitt, 1985) found that WQI's can store sediment up to 60% of its sump volume, and after that, the inflow resuspends the sediments into the stormwater. Some sites have found keeping a log of sediment amount date removed helpful in planning a maintenance schedule. The EPA has a monitoring program, Environmental Technology Verification (ETV) Program, (www.epa.gov/etv), that may be available to assist with the development of a monitoring plan.

Disposal of removed material will depend on the nature of the drainage area and the intent and function of the water quality insert. Material removed from water quality inserts that serve "Hot Spots" such as fueling stations or that receive a large amount of debris should be handling according to DEP regulations for solid waste, such as a landfill that is approved by DEP to accept solid waste. Water quality inserts that primary catch sediment and detritus from areas such as lawns may reuse the waste on site, which is recommended by the DEP.

Vactor trucks may be an efficient cleaning mechanism.

Winter Concerns: There is limited data studying cold weather effects on water quality insert effectiveness. Freezing may result in more runoff bypassing the treatment system and overflowing. Salt stratification may also reduce detention time. Colder temperatures reduce the settling velocity of particles, which can result in fewer particles being "trapped". Salt and sand and significantly increased in the winter, and may warrant more frequent maintenance, but sometimes freezing makes accessing devices for maintenance difficult

Figure 6.16-7. Maintenance of a bag type water quality insert, (Full Circle Ag, Inc., http://www.fullcircleag.com/pages/954364/).

Cost Issues

Inserts range from $400 - $10,000
Pre cast range from $2000 - $3000

Specifications

See manufacturer's instructions and specific specifications in Appendix E.

References

Brzozowski, C., 2003. "Inlet Protection – Strategies for Preserving Water Quality," Stormwater magazine.

Lee, F. "The Right BMP's? Another Look at Water Quality." Stormwater magazine.

New Hampshire Watershed Management Bureau, Watershed Assistance Section, 2002. "Innovative Stormwater Treatment Technologies BMP Manual."

Pitt, 1985.

6.7 Restoration BMPs

Restoration BMPs

BMP 6.17: Riparian Buffer Restoration

A riparian forest buffer is a permanent area of trees and shrubs located adjacent to streams, lakes, ponds, and wetlands. Riparian forests are the most beneficial type of buffer for they provide ecological and water quality benefits. Restoration of this ecologically sensitive habitat is a responsive action from past activities that may have eliminated any vegetation.

Key Design Elements

- Reestablish buffer perennial, intermittent, and ephemeral streams
- Plant native, diverse tree and shrub vegetation
- Buffer width is dependant on project preferred function (water quality, habitat creation, etc.)
- **Minimum** recommended buffer width is 35’ from top of stream bank, with 100’ preferred.
- Create a short-term maintenance and long-term maintenance plan
- Mature forest as a vegetative target
- Clear, well-marked boundary

Potential Applications

Residential:	**YES**
Commercial:	**YES**
Ultra Urban:	**YES**
Industrial:	**YES**
Retrofit:	**YES**
Highway/Road:	**Limited**

Stormwater Functions

Volume Reduction:	**Medium**
Recharge:	**Medium**
Peak Rate Control:	**Low/Med.**
Water Quality:	**Med./High**

Pollutant Removal

TSS:	**65%**
TP:	**50%**
NO_3:	**50%**

Description

The USDA Forest Service estimates that over one-third of the rivers and streams in Pennsylvania have had their riparian areas degraded or altered. This fact is sobering when one considers the important stormwater functions that riparian buffer provides. The non-structural BMP, Riparian Forest Buffer Protection, addresses the importance of protecting the three-zone system of existing riparian buffers.

The values of riparian buffers – economic, environmental, recreational, aesthetic, etc. – are well documented in scientific literature and numerous reports and thus will not be restated here in this BMP sheet. Rather, this BMP serves to provide a starting point for the designer that seeks to restore the riparian buffer. Important reports are cited consistently throughout this section and should be mentioned upfront as sources for additional information to a designer seeking to restore a riparian buffer. The first, the *Chesapeake Bay Riparian Handbook: a Guide for Establishing and Maintaining Riparian Forest Buffers* was prepared by the US Department of Agriculture (USDA) Forest Service for the Chesapeake Bay Program in 1997. The second, the *Pennsylvania Stream ReLeaf Forest Buffer Toolkit* was developed by the Alliance for the Chesapeake Bay specifically for the Pennsylvania streams in 1998. A third and often-referenced report, is the *Riparian Forest Buffers* series written by Robert Tjaden for the Maryland Cooperative Extension Service in 1998.

Riparian buffers are scientifically proven to provide a number of economic and environmental values. Buffers are characterized by high species density, high species diversity, and high bio-productivity as a transition between aquatic and upland environments. Project designer should take into account the benefits or services provided by the buffer and apply these to their project goals. Priorities for riparian buffer use must be established early on in the planning stages. Some important considerations when establishing priorities are:

- **Habitat** – Restoring a buffer for habitat enhancement will require a different restoration strategy than for restoring a buffer for increased water quality.
- **Stream Size** – A majority of Pennsylvania's stream miles is comprised of small streams (first, second, and third order), which may be priority areas to reduce nutrients. Establishing riparian buffers along these headwater streams will reduce the high nutrient loads relative to flow volumes typical of small streams.
- **Continuous Buffers** - Establishing continuous riparian forest buffers in the landscape should be given a higher priority than establishing larger but fragmented buffers. Continuous buffers provide better stream shading and water quality protection, as well as corridors for the movement of wildlife.
- **Degree of Degradation** – Urban streams are usually buried or piped. Streams in areas without forests, such as pastures, may benefit the most from buffer restoration, as sources of headwater streams. Highly urbanized/altered streams may not be able to provide high levels of pollution control.
- **Loading Rates** - The removal of pollutants may be highest where nutrient and sediment loading are the highest.
- **Land Use** – Adjacent land uses will influence Buffer Width and Vegetation types used to establish a riparian buffer. While the three-zone riparian-forested buffers described earlier are the ideal, they may not always be feasible to establish, especially in urban situations.

Preparation of a *Riparian Buffer Restoration Plan* is critical to ensuring long-term success of the project and should be completed before any planting is to occur.   It is essential that site conditions are well understood, objectives of the landowner are considered, and the appropriate plants chosen for the site, tasks that are completed in the planning stages. Below is a summary of the nine steps that PADEP/PADCNR advocates groups/designers/engineers/volunteers/etc., undertake during the planning stages of a buffer restoration project.

1. Obtain Landowner Permission and Support

Landowner commitment is essential for the success of the project. Landowner must be aware of all maintenance activities that will occur once buffer is planted.

2. Make Sure Site is Suitable for Restoration

If streambanks are extensively eroded, consider alternative location. Rapidly eroding streambanks may undermine seedlings. Streambank restoration may need to occur prior to riparian buffer restoration. Obtain professional help in evaluating need for streambank restoration.

3. Analyze Site's Physical Conditions

The most important physical condition of the site is the soil, which will control plant selection. Evaluate the soil using the County soil survey book to determine important soil characteristics such as flooding potential, seasonal high water table, topography, soil pH, soil moisture, etc. Also, a simple field test can suffice, with direct observation of soil conditions.

4. Analyze Site's Vegetative Features

Existing vegetation present at the restoration site should be examined to determine the strategy for buffer establishment. Strategies will differ whether pre-restoration conditions are pasture, overgrown abandoned field, mid-succession forest, or any other setting.

- *Identify Desirable Species*: Native tree and shrub species that thrive in riparian habitats in Pennsylvania should be used. These species should be identified in the restoration site and protected for their seed bank potential. Several native vines and shrubs (blackberry, greenbriar, poison ivy, Virginia creeper, and spicebush) can provide an effective ground cover during establishment of the buffer, though should be selectively controlled for herbaceous competition.
- *Identify Undesirable Species:* Consider utilizing undesirable species such as the black locust for their shade function during buffer establishment. Consider controlling invasive plants prior to buffer planting.
- *Identify Sensitive Species*: Since riparian zones are rich in wildlife habitat and wetland plant species to be aware of any rare, threatened or endangered plant (or animal) species.

5. Draw a Map of the Site (Data collection)

Prepare a sketch of the site that denotes important existing features, including stream width, length, streambank condition, adjacent land uses and stream activities, desired width of buffer, discharge pipes, obstructions, etc.

6. Create a Design that Meets Multiple Objectives

Ideally, the three-zone system should be incorporated into the design, in a flexible manner to obtain water quality and landowner objectives.

- *Consider landowner objectives*: Consider the current use of the buffer by the landowner, especially if the buffer will be protected in perpetuity. Consider linking the buffer to an existing (or planned trail system).
- *Buffer width*: Riparian buffer areas do not have a fixed linear boundary, but vary in shape, width, and vegetative type and character. The function of the buffer (habitat, water quality, etc) is the overriding criterion in determining buffer width (Figure 1). Many factors including slope, soil type, adjacent land uses, floodplain, vegetative type, and water shed condition influence what can be planted. The most commonly approved minimum buffer widths for water quality and habitat maintenance are 35 – 100 feet. Buffers less than 35 feet do not protect aquatic resources long term.

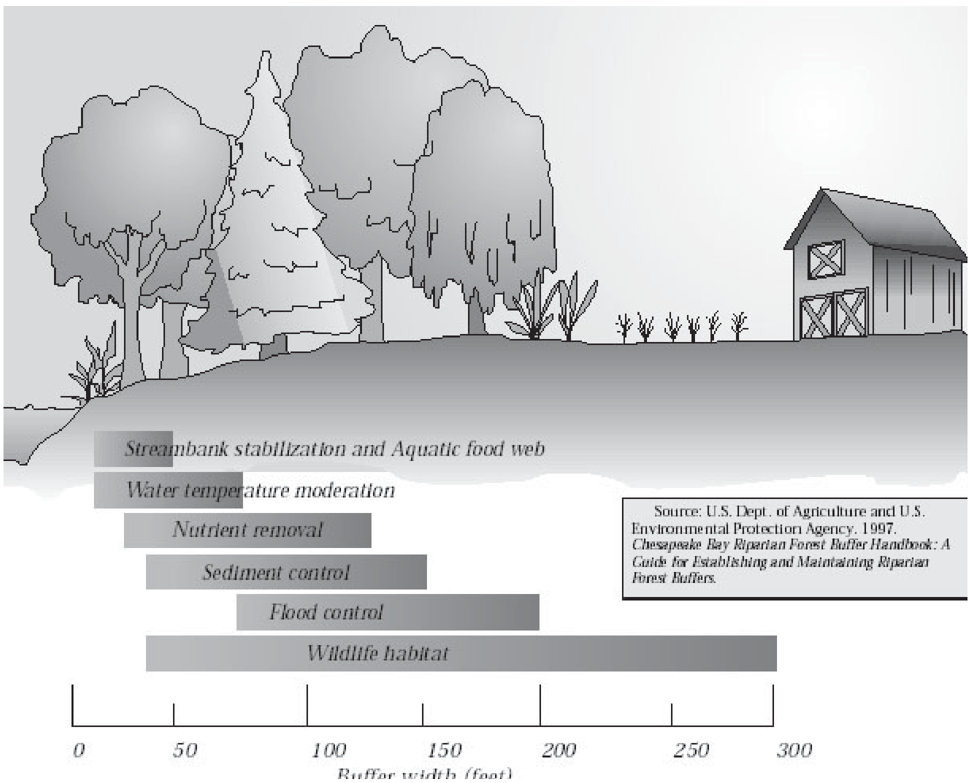


Figure 6.17-1. Range of minimum widths for meeting specific buffer objectives (Maryland Cooperative Extension, Fact Sheet 725)

- *Consider costs:* The planting design (density, type, mix, etc.) will ultimately be based on the financial constraints of the project. See discussion below for estimating direct costs for planting and maintenance.
- *Choose the appropriate plants:* This manual encourages the use of native plants in stormwater management facilities. Since they are best suited to our local climate, native species have distinct genetic advantages over non-native species. Ultimately using native plants translates into greater survivorship with less replacement and maintenance – a cost benefit to the landowner. Please refer to the plant list in Appendix B for a comprehensive list of native trees and shrubs available for stormwater management facility planting.

<u>Plant Size</u>: Choice of planting stock (seeds, container seedling, bare-root seedlings, plugs, etc.) is ultimately determined by funding resources. Larger material will generally cost more, though will generally establish more rapidly.

7. Draw a Planting Plan

Planting Density: Trees should be planted at a density sufficient to provide 320 trees per acres at maturity. To achieve this density, approximately 436 (10 x 10 feet spacing) to 681 (8 x 8 feet spacing) trees per acre should be planted initially. Some rules of thumb for tree spacing and density based on plant size at installation:

Seedlings	6-10 feet spacing (~700 seedlings / acre)
Bare Root Stock	14-16 feet spacing (~200 plants / acre)
Larger & Container	16 – 18 feet spacing (~150 plants/acre)

Formula for Estimating Number of Trees and Shrubs:
Plants = length x width of corridor (ft) / 50 square feet

This formula assumes each tree will occupy an average of 50 sq. ft., random placement of plants approximately 10 feet apart, and mortality rate of up to 40% that can be absorbed by the growing forest system.

Alternatively, Table 1 below can be utilized to estimate the number of trees per acre needed for various methods of spacing.

Table 6.17-1. Number of Trees per Acre by Various Methods of Spacing (USDA Forest Service)

Spacing (feet)	Trees (number)	Spacing (feet)	Trees (number)	Spacing (feet)	Trees (number)
2x2	10,890	7x9	691	12x15	242
3x3	4,840	7x10	622	12x18	202
4x4	2,722	7x12	519	12x20	182
4x5	2,178	7x15	415	12x25	145
4x6	1,815	8x8	681	13x13	258
4x7	1,556	8x9	605	13x15	223
4x8	1,361	8x10	544	13x20	168
4x9	1,210	8x12	454	13x25	134
4x10	1,089	8x15	363	14x14	222
5x5	1,742	8x25	218	14x15	207
5x6	1,452	9x9	538	14x20	156
5x7	1,245	9x10	484	14x25	124
5x8	1,089	9x12	403	15x15	194
5x9	968	9x15	323	15x20	145
5x10	871	10x10	436	15x25	116
6x6	1,210	10x12	363	16x16	170
6x7	1,037	10x15	290	16x20	136
6x8	908	10x18	242	16x25	109
6x9	807	11x11	360	18x18	134
6x10	726	11x12	330	18x20	121
6x12	605	11x15	264	18x25	97
6x15	484	11x20	198	20x20	109
7x7	889	11x25	158	20x25	87
7x8	778	12x12	302	25x25	70

Planting Layout: Given planting density and mix, drawing the planting plan is fairly straightforward. The plan can vary from a highly technical drawn to scale plan, or a simple line drawing of the site. Any plan must show the site with areas denoted for trees and shrub species with notes for plant spacing and buffer width.

8. Prepare Site Ahead of Time
   Existing site conditions will determine the degree of preparation needed prior to planting. Invasive infestation and vegetative competition are extremely variable, and therefore must be considered in the planning stages. Site preparation should begin in the fall prior to planting. Enlist professional to determine whether use of chemical controls are necessary to prepare site for planting. Release desired existing saplings from competition by undesired species with either herbicide application (consult a professional) or physical removal. If utilizing a highly designed planting layout, mark site ahead of time with flags, spray paint, or other markers so that the appropriate plant is put in the right place.

9. Determine Maintenance Needs
   An effective buffer restoration project should include management and maintenance guidelines, as well as distinctions of allowable and unallowable uses in the buffer. Buffer boundaries should be well defined with clear signs or markers. Weed control is essential for the survival and rapid growth of trees and shrubs, and can include any of the following:

   - Organic mulch
   - Weed control fabrics
   - Shallow cultivation
   - Pre-emergent herbicides
   - Mowing

Non-chemical weed control methods are preferred since chemicals can easily enter the water system. If possible, avoid working in the riparian area between April 15 and August 15, the mating and newborn period for local wildlife.

Variations

See Applications

Applications

- **Forested Landscape**

Figure 6.17-2 Recently planted riparian buffer in a forested landscape (image courtesy of Rutgers Cooperative Extension)

- **Agricultural Landscape**

Figure 6.17-3 Riparian buffer shown in an agricultural setting (image courtesy of North Carolina Cooperative Extension)

- **Suburban / Developing Landscap**

Figure 6.17-4 Cross section showing suburban riparian forest buffer and functions provided (image courtesy of Chesapeake Bay Program: Riparian Buffer Manual)

Figure 6.17-5 Recently planted riparian buffer in Hackettstown, New Jersey (image courtesy of Rutgers Cooperative Extension)

- **Urban Landscape**

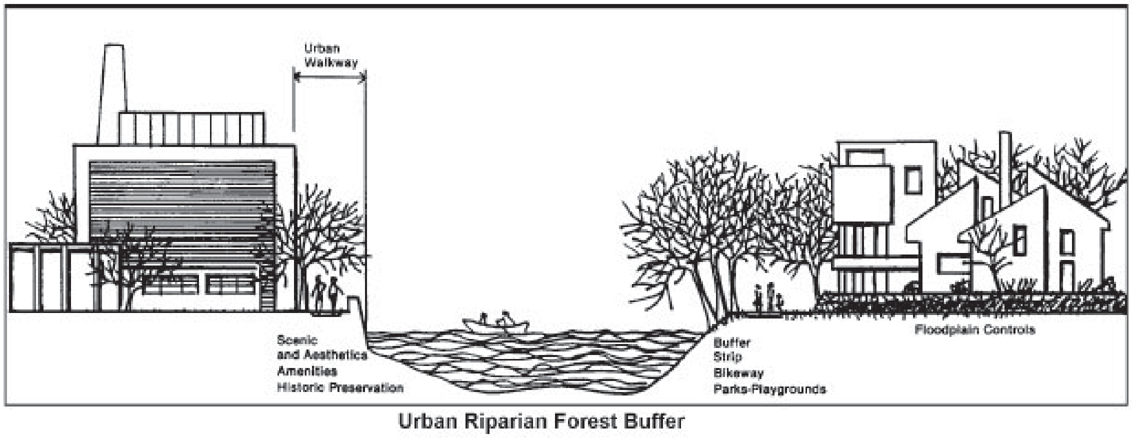


Figure 6.17-6 Urban riparian forest buffer (image courtesy of Chesapeake Bay Riparian Handbook)

Design Considerations

The considerations listed below should all be taken into account during the planning stage. There are many potential threats to the long-term viability of riparian plant establishment and with proper foresight, these problems can be eliminated or addressed.

1. Deer Control

    a. Look for signs of high deer densities, including an overgrazed understory with a browse line 5-6 feet above the ground.

2. Tree Shelters

    a. Recommended for riparian plantings where deer predation or human intrusion may be a problem.
    b. Plastic tubes that fit over newly planted trees that are extremely successful in protecting seedlings.
    c. Protect trees from accidental strikes from mowing or trimming
    d. Create favorable microclimate for seedlings
    e. Secure with wooden stake and place netting over top of tree tube
    f. Remove tree shelters 2 to 3 years after plants emerge

3. Stream Buffer Fencing

    a. Deer can jump fences up to 10 feet high, preferring to go under barriers.
    b. Farm animals cause greatest damage to stream banks – consider permanent fencing like high-tensile smooth wire fencing or barbed fencing.
    c. The least expensive is 8 foot plastic fencing, which are effective against deer and easily repaired.

4. Vegetation

    a. Consider using plants that are able to survive frequent or prolonged flooding conditions. Plant trees that can withstand high water table conditions. Figure 7 shows tree species that fit into the moisture conditions of a streamside area.
    b. Soil disturbance can allow for unanticipated infestation by invasive plants.

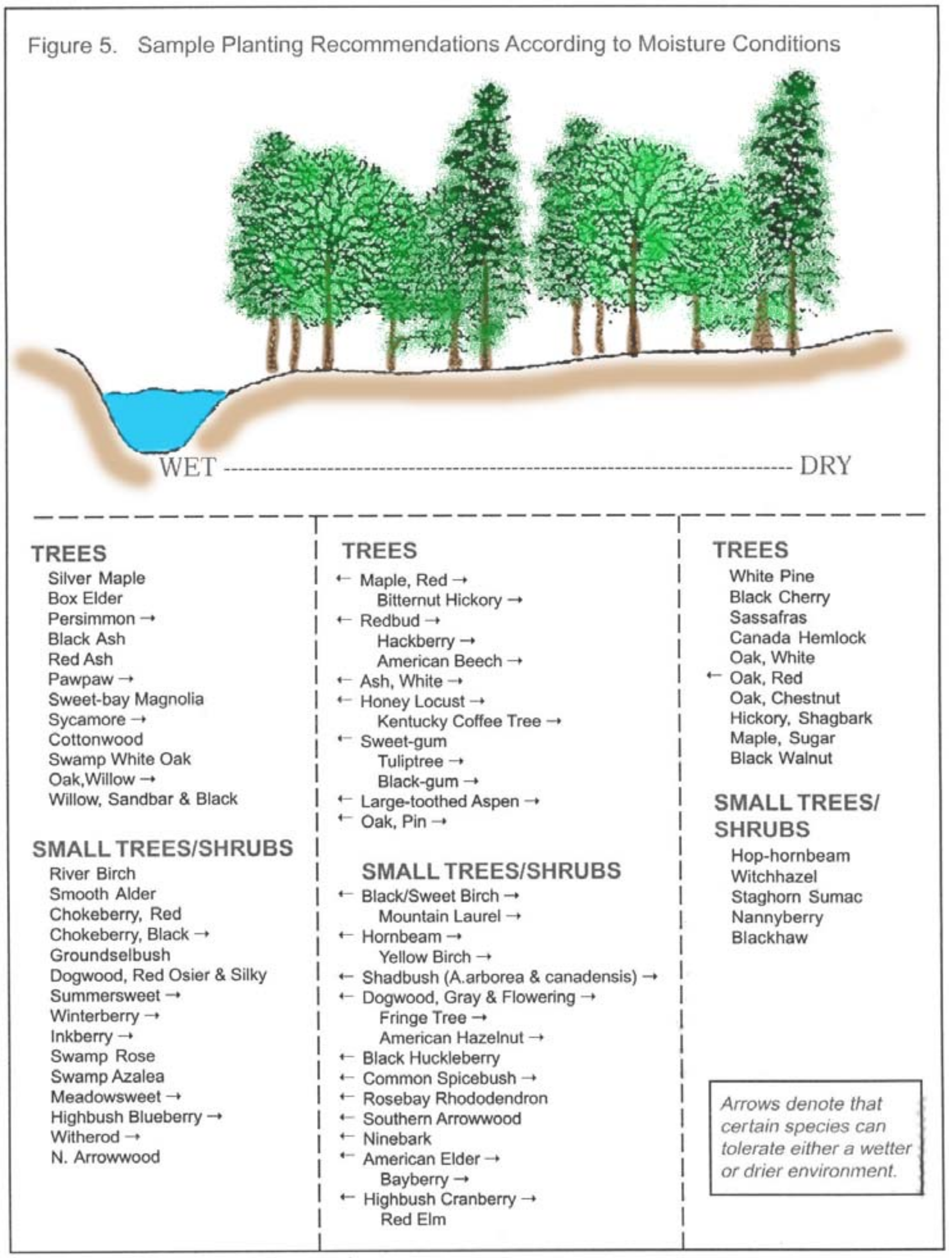


Figure 6.17-7 Sample planting recommendations according to moisture conditions (Source: PA Stream ReLeaf Forest Buffer Toolkit)

Construction Sequence

The PA Stream ReLeaf project provides a checklist that can substitute for a construction sequence for riparian buffer restoration. A slightly modified version follows:

1. SELECT SITE
    - Confirm site is suitable for restoration
    - Obtain landowner permission
2. ANALYSE SITE
    - Evaluate site's physical conditions (soil attributes, geology, terrain)
    - Evaluate site's vegetative features (desirable and undesirable species, native species, sensitive habitats)
    - Sketch or map site feature
3. DESIGN BUFFER
    - Consider landowner objectives in creating buffer design
    - Determine desired functions of buffer in determining buffer width
    - Match plant species to site conditions (hardiness zone, moisture, soil pH)
    - Match plant Species to objectives of buffer functions (water quality, wildlife, recreation, etc.)
    - Match plant sizes to meet budget limitations
    - Develop sketch of planting plan
4. PREPARE SITE
    - Eliminate undesirable species ahead of planting date
    - Mark planting layout at the site
    - Purchase plants and planting materials (mulch, tree shelters)
5. SITE PLAN SHOULD INCLUDE:
    - Site map with marked planting zones
    - Plant species list
    - Planting directions (spacing, pattern of planting)
    - Equipment/tool list
    - Site preparation directions
    - Maintenance schedule
6. PLANTING DAY
    - Keep plants moist and shaded
    - Provide adequate number of tools
    - Document with photos of site during planting

7. SITE MAINTENANCE (additional information below)

    - Assign responsibilities watering, weeding, mowing, and maintenance
    - Monitor site regularly for growth and potential problems

Maintenance Issues

The riparian buffer is subject to many threats, including:

- Herbivory
- Invasion by exotic species
- Competition for nutrients by adjacent herbaceous vegetation
- Human disturbance

Proper awareness of these issues is critical to ensure the long-term effectiveness of a restored riparian buffer.

The most critical period during buffer establishment is maintenance of the newly planted trees during canopy closure, typically the first 3 to 5 years. Ongoing maintenance practices are necessary for both small seedlings and larger plant materials. Maintenance and monitoring plans should be prepared for the specific site and caretakers need to be advised of required duties during the regular maintenance period.

Maintenance measures that should be performed regularly:

Watering

- Plantings need deep regular watering during the first growing season, either natural watering via rainfall, or planned watering, via caretaker.
- Planting in the fall increases the likelihood of sufficient rain during planting establishment.

Mulching

- Mulch will assist in moisture retention in the root zone of plantings, moderate soil temperature, provide some weed suppression, and retard evaporation
- Use coarse, organic mulch that is slow to decompose in order minimize repeat application
- Apply 2-4 inch layer, leaving air space around tree trunk to prevent fungus growth.
- Use combination of woodchips, leaves, and twigs that are stockpiled for six months to a year.

Weed control

- Weed competition limits buffer growth and survival, therefore weeds should be controlled by either herbicides, mowing, or weed mats:

  Herbicides

  This is a short-term maintenance technique (2-3 years) that is generally considered less expensive and more flexible than mowing, and will result in a quicker establishment of the buffer. Herbicide use is regulated by the PA Department of Agriculture. Proper care should be taken to ensure that proximity to water features is considered.

Mowing

Mowing controls the height of the existing grasses, yet increases nutrient uptake, therefore competition for nutrients will persist until the canopy closure shades out lower layers. A planting layout similar to a grid format will facilitate ease of mowing yet yield an unnaturally spaced community. Mowing may result in strikes on the trunk unless protective measures are utilized. Mowing should occur twice each growing season. Mower height should be set between 8 –12 inches.

Weed Mats

Weed mats are geo-textile fabrics that are used to suppress weed growth around newly planted vegetation by providing shade and preventing seed deposition. Weed mats are installed after planting, and should be removed once the trees have developed a canopy that will naturally shade out weeds.

Deer damage

- Deer will browse all vegetation within reach, generally between 5-6 feet above the ground
- Approaches to minimize damage include: 1) selecting plants that deer do not prefer (ex. Paper Birch, Beech, Ash, Common Elderberry) 2) homemade deer repellants 3) tree shelters

Tree shelters

- Repair broken stakes
- Tighten stake lines
- Straighten leaning tubes
- Clean debris from tube
- Remove netting as tree grows
- Remove when tree is approximately 2 inches wide

Invasive Plants

- Monitor restoration sight regularly for any signs of invasive plants.
- Appendix B contains common invasive plants found in Pennsylvania.
- Choice of control method is based on a variety of considerations, but falls into three general categories:
    - Mechanical
    - Mechanical with application of herbicide
    - Herbicide

Special Maintenance Considerations

Riparian buffer restoration sites should be monitored to maximize wildlife habitat and water quality benefits, and to discover emerging threats to the project. During the first four years, the new buffer should be monitored four times annually (February, May, August, and November are recommended) and inspected after any severe storm. Repairs should be made as soon as possible.

Depending on restoration site size, the buffer area should be sampled to approximate survival rate. Data derived should consider survival of the planted material and natural regeneration to determine if in-fill planting should occur to supplement plant density.

Survival rates of up to 70% area deemed to be successful. Calculate percent survival by the following equation:

(# of live plants / # of installed plants) 100 = % survival

Cost Issues

Establishment and maintenance costs should be considered up front in the riparian buffer plan design. Installing a forest riparian buffer involves site preparation, tree planting, second year reinforcement planting, and additional maintenance. Both the USDA Riparian Handbook and the PADEP/PADCNR Stream ReLeaf Forest Buffer Toolkit utilize the following basic outline for estimating costs for establishment and maintenance:

Costs may fluctuate based on numerous variables including whether or not volunteer labor is utilized, whether plantings and other supplies are donated or provided at a reduced cost.

Specifications

The USDA Forest Service developed a riparian forest buffer specification, which outlines three distinct zones and establishes the minimally acceptable requirements for reforestation by landowners.

Definition

An area of trees and other vegetation located in areas adjoining and upgradient from surface water bodies and designed to intercept surface runoff, wastewater, subsurface flow, and deeper groundwater flows from upland sources for the purpose of removing or buffering the effects of associated nutrients, sediment, organic matter, pesticides, or other pollutants prior to entry into surface waters and ground water recharge areas.

Scope

This specification establishes the minimally acceptable requirements for the reforestation of open lands, and renovation of existing forest to be managed as Riparian Forest Buffers for the purposes stated.

Purpose

To remove nutrients, sediment, animal-derived organic matter, and some pesticides from surface runoff, subsurface flow, and near root zone groundwater by deposition, absorption, adsorption, plant uptake, denitrification, and other processes, thereby reducing pollution and protecting surface water and groundwater quality.

Conditions Where Practice Applies

Subsurface nutrient buffering processes, such as denitrification, can take place in the soil wherever carbon energy, bacteria, oxygen, temperature, and soil moisture is adequate. Nutrient uptake by plants occurs where the water table is within the root zone. Surficial filtration occurs anywhere surface vegetation and forest litter are adequate.

The riparian forest buffer will be most effective when used as a component of a sound land management system including nutrient management and runoff, and sediment and erosion control practices. Use of this practice without other nutrient and runoff, sediment and erosion control practices can result in adverse impacts on buffer vegetation and hydraulics including high maintenance costs, the need for periodic replanting, and the carrying of excess nutrients and sediment through the buffer by concentrated flows.

This practice applies on lands:

1. adjacent to permanent or intermittent streams which occur at the lower edge of upslope cropland, grassland or pasture;

2. at the margins of lakes or ponds which occur at the lower edge of upslope cropland, grassland or pasture;

3. at the margin of any intermittent or permanently flooded, environmentally sensitive, open water wetlands which occur at the lower edge of upslope cropland, grassland or pasture;

4. on karst formations at the margin of sinkholes and other small groundwater recharge areas occurring on cropland, grassland, or pasture.

Note: In high sediment production areas (8-20 in./100 yrs.), severe sheet, rill, and gully erosion must be brought under control on upslope areas for this practice to function correctly.

Riparian Buffer Installation Costs - Estimation per Acre

				Cost, ea.	Number	Cost, Total
Phase 1: Establishment						
	Preparation					
		Light site preparation (mow, disking)		-	-	$ 12.00
	Planting					
		Tree Seedlings (12" - 18" Hardwoods)		$ 1.15	430	$ 494.50
		Tree Shelters	(optional)	$ 5.00	430	$ 2,150.00
		Fencing (1 ac = 282 ft)	(optional)			$ 564.00
			Subtotal			**$ 3,220.50**
Phase 2: Maintenance						
	Reinforcement Planting					
		Tree Seedlings in Year 2		$ 1.15	50	$ 57.50
		Herbicide Treatment	(optional)			$ 54.00
		Mowing	(optional)			$ 12.00
			Subtotal			**$ 123.50**
Total Costs, no options						**$ 564.00**
Total Costs, with options						**$ 3,344.00**

Design Criteria

Riparian Forest Buffers

Riparian forest buffers will consist of three distinct zones and be designed to filter surface runoff as sheet flow and downslope subsurface flow, which occurs as shallow groundwater. For the purposes of these buffer strips, shallow groundwater is defined as: saturated conditions which occur near or within the root zone of trees, and other woody vegetation and at relatively shallow depths where bacteria, oxygen, and soil temperature contribute to denitrification. Streamside Forest Buffers will be designed to encourage sheet flow and infiltration and impede concentrated flow.

Zone 1

Location
Zone 1 will begin at the top of the streambank and occupy a strip of land with a fixed width of fifteen feet measured horizontally on a line perpendicular to the streambank.

Purpose
The purpose of Zone 1 is to create a stable ecosystem adjacent to the water's edge, provide soil/water contact area to facilitate nutrient buffering processes, provide shade to moderate and stabilize water temperature encouraging the production of beneficial algal forms, and to contribute necessary detritus and large woody debris to the stream ecosystem.

Requirements
Runoff and wastewater to be buffered or filtered by Zone 1 will be limited to sheet flow or subsurface flow only. Concentrated flows must be converted to sheet flow or subsurface flows prior to entering Zone 1. Outflow from subsurface drains must not be allowed to pass through the riparian forest in pipes or tile, thus circumventing the treatment processes. Subsurface drain outflow must be converted to sheet flow for treatment by the riparian forest buffer, or treated elsewhere in the system prior to entering the surface water.

Dominant vegetation will be composed of a variety of native riparian tree and shrub species and such plantings as necessary for streambank stabilization during the establishment period. A mix of species will provide the prolonged stable leaf fall and variety of leaves necessary to meet the energy and pupation needs of aquatic insects.

Large overmature trees are valued for their detritus and large woody debris. Zone 1 will be limited to bank stabilization and removal of potential problem vegetation. Occasional removal of extreme high value trees may be permitted where water quality values are not compromised. Logging and other overland equipment shall be excluded except for stream crossings and stabilization work.

Livestock will be excluded from Zone 1 except for designed stream crossings.

Zone 2

Location
Zone 2 will begin at the edge of Zone 1 and occupy an additional strip of land with a minimum width of 60 feet measured horizontally on a line perpendicular to the streambank. Total minimum width of Zones 1 & 2 is therefore 75 feet. Note that this is the minimum width of Zone 2 and that the width of Zone 2 may have to be increased as described in the section "Determining the Total Width of Buffer" to create a greater combined width for Zones 1 & 2.

Purpose
The purpose of Zone 2 is to provide necessary contact time and carbon energy source for buffering processes to take place, and to provide for long term sequestering of nutrients in the form of forest

trees. Outflow from subsurface drains must not be allowed to pass through the riparian forest in pipe or tile, thus circumventing the treatment processes. Subsurface drain outflow must be converted to sheet flow for treatment by the riparian forest buffer, or treated elsewhere in the system prior to entering the surface water.

Requirements

Runoff and wastewater to be buffered or filtered by Zone 2 will be limited to sheet flow or subsurface flow only. Concentrated flows must be converted to sheet flow or subsurface flows prior to entering Zone 2.

Predominant vegetation will be composed of riparian trees and shrubs suitable to the site, with emphasis on native species, and such plantings as necessary to stabilize soil during the establishment period. Nitrogen-fixing species should be discouraged where nitrogen removal or buffering is desired. Species suitability information should be developed in consultation with state and federal forestry agencies, Natural Resources Conservation Service, and USDI Fish and Wildlife Service.

Specifications should include periodic harvesting and timber stand improvement (TSI) to maintain vigorous growth and leaf litter replacement, and to remove nutrients and pollutants sequestered in the form of wood in tree boles and large branches. Management for wildlife habitat, aesthetics, and timber are not incompatible with riparian forest buffer objectives as long as shade levels and production of leaf litter, detritus, and large woody debris are maintained. Appropriate logging equipment recommendations shall be determined in consultation with the state and federal forestry agencies.

Livestock shall be excluded from Zone 2 except for necessary designed stream crossings.

Zone 3

Location

Zone 3 will begin at the outer edge of Zone 2 and have a minimum width of 20 feet. Additional width may be desirable to accommodate land-shaping and mowing machinery. Grazed or ungrazed grassland meeting the purpose and requirements stated below may serve as Zone 3.

Purpose

The purpose of Zone 3 is to provide sediment filtering, nutrient uptake, and the space necessary to convert concentrated flow to uniform, shallow, sheet flow through the use of techniques such as grading and shaping, and devices such as diversions, basins, and level lip spreaders.

Requirements

Vegetation will be composed of dense grasses and forbs for structure stabilization, sediment control, and nutrient uptake. Mowing and removal of clippings are necessary to recycle sequestered nutrients, promote vigorous sod, and control weed growth.

Vegetation must be maintained in a vigorous condition. The vegetative growth must be hayed, grazed, or otherwise removed from Zone 3. Maintaining vigorous growth of Zone 3 vegetation must take precedence and may not be consistent with wildlife needs.

Zone 3 may be used for controlled intensive grazing when conditions are such that earthen water control structures will not be damaged.

Zone 3 may require periodic reshaping of earth structures, removal or grading of accumulated sediment, and reestablishment of vegetation to maintain effectiveness of the riparian buffer.

Determining Need For Protection

Buffers should be used to protect any body of water which will not be:

- treated by routing through a natural or artificial wetland determined to be adequate treatment;
- treated by converting the flow to sheet flow and routing it through a forest buffer at a point lower in the watershed.

Determining Total Width of the Buffer

Note that while not specifically addressed, slope and soil permeability are components of the following buffer width criteria.

Each of the following criteria is based on methods developed, or used by persons conducting research on riparian forests.

Streamside Buffers

The minimum width of streamside buffer areas can be determined by any number of methods suitable to the geographic area.

1. Based on soil hydrologic groups as shown in the county soil survey report, the width of Zone 2 will be increased to occupy any soils designated as Hydrologic Group D and those soils of Hydrologic Group C which are subject to frequent flooding. If soils of Hydrologic Groups A or B occur adjacent to intermittent or perennial streams, the combined width of Zones 1 & 2 may be limited to the 75 foot minimum.
2. Based on area, the width of Zone 2 should be increased to provide a combined width of Zones 1 & 2 equal to one third of the slope distance from the streambank to the top of the pollutant source area. The effect is to create a buffer strip between field and stream which occupies approximately one third of the source area.
3. Based on the Land Capability Class of the buffer site as shown in the county soil survey, the width of Zone 2 should be increased to provide a combined width of Zones 1 & 2 as shown below.

Capability Class	Buffer Width
Cap. I, II e/s, V	75'
Cap. III e/s, IV e/s	100'
Cap. VI e/s, VII e/s	150'

Pond and Lake-Side Buffer Strips

The area of pond or lake-side buffer strips should be at least one-fifth the drainage area of the cropland and pastureland source area. The width of the buffer strip is determined by creating a uniform width buffer of the required area between field and pond. Hydrologic Group and Capability Class methods of determining width remain the same as for streamside buffers. Minimum widths apply in all cases.

Environmentally Sensitive Wetlands
Some wetlands function as nutrient sinks. When they occur in fields or at field margins, they can be used for renovation of agricultural surface runoff and/or drainage. However, most wetlands adjoining open water are subject to periodic flushing of nutrient-laden sediments and, therefore, require riparian buffers to protect water quality.

Where open water wetlands are roughly ellipsoid in shape, they should receive the same protection as ponds.

Where open water wetlands exist in fields as seeps along hillslopes, buffers should consist of Zones 1, 2 & 3 on sides receiving runoff and Zones 1 & 3 on the remaining sides. Livestock must be excluded from Zones 1 & 2 at all times and controlled in Zone 3. Where Zones 1 & 3 only are used, livestock must be excluded from both zones at all times, but hay removal is desirable in Zone 3.

Vegetation Selection
Zone 1 & 2 vegetation will consist of native streamside tree species on soils of Hydrologic Groups D and C and native upland tree species on soils of Hydrologic Groups A and B.

Deciduous species are important in Zone 2 due to the production of carbon leachate from leaf litter which drives bacterial processes that remove nitrogen, as well as, the sequestering of nutrients in the growth processes. In warmer climates, evergreens are also important due to the potential for nutrient uptake during the winter months. In both cases, a variety of species is important to meet the habitat needs of insects important to the aquatic food chain.

Zone 3 vegetation should consist of perennial grasses and forbs.

Species recommendations for vegetated buffer areas depend on the geographic location of the buffer. Suggested species lists should be developed in collaboration with appropriate state and federal forestry agencies, the Natural Resources Conservation Service, and the USDI Fish and Wildlife Service. Species lists should include trees, shrubs, grasses, legumes, forbs, as well as site preparation techniques. Fertilizer and lime, helpful in establishing buffer vegetation, must be used with caution and are not recommended in Zone 1.

Maintenance Guidelines

General

Buffers must be inspected annually and immediately following severe storms for evidence of sediment deposit, and erosion, or concentrated flow channels. Prompt corrective action must be taken to stop erosion and restore sheet flow.

The following should be avoided within the buffer areas: excess use of fertilizers, pesticides, or other chemicals; vehicular traffic or excessive pedestrian traffic; and removal or disturbance of vegetation and litter inconsistent with erosion control and buffering objectives.

Zone 1 vegetation should remain undisturbed except for removal of individual trees of extremely high value or trees presenting unusual hazards such as potentially blocking culverts.

Zone 2 vegetation, undergrowth, forest floor, duff layer, and leaf litter shall remain undisturbed except for periodic cutting of trees to remove sequestered nutrients; to maintain an efficient filter by fostering vigorous growth; and for spot site preparation for regeneration purposes. Controlled burning for site preparation, consistent with good forest management practices, could also be used in Zone 2.

Zone 3 vegetation should be mowed and the clippings removed as necessary to remove sequestered nutrients and promote dense growth for optimum soil stabilization. Hay or pasture uses can be made compatible with the objectives of Zone 3.

Zone 3 vegetation should be inspected twice annually, and remedial measures taken as necessary to maintain vegetation density and remove problem sediment accumulations.

Stable Debris

As Zone 1 reaches 60 years of age, it will begin to produce large stable debris. Large debris, such as logs, create small dams which trap and hold detritus for processing by aquatic insects, thus adding energy to the stream ecosystem, strengthening the food chain, and improving aquatic habitat. Wherever possible, stable debris should be conserved.

Where debris dams must be removed, try to retain useful, stable portions which provide detritus storage.

Deposit removed material a sufficient distance from the stream so that it will not be refloated by high water.

Planning Considerations

1. Evaluate the type and quantity of potential pollutants that will be derived from the drainage area.

2. Select species adapted to the zones based on soil, site factors, and possible commercial goals such as timber and forage.

3. Plan to establish trees early in the dormant season for maximum viability.

4. Be aware of visual aspects and plan for wildlife habitat improvement if desired.

5. Consider provisions for mowing and removing vegetation from Zone 3. Controlled grazing may be satisfactory in Zone 3 when the filter area is dry and firm.

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Restoration BMPs
BMP 6.18: Landscape Restoration

Landscape Restoration is the general term used for actively sustainable landscaping practices that are implemented outside of riparian (or other specially protected) buffer areas. Landscape Restoration includes the restoration of forest (i.e. reforestation) and/or meadow and the conversion of turf to meadow. In a truly sustainable site design process, this BMP shall be considered only after the areas of development that require landscaping and/or revegetation are minimized. The remaining areas that do require landscaping and/or revegetation shall be driven by the selection and use of vegetation (i.e., native species) that does not require significant chemical maintenance by fertilizers, herbicides, and pesticides.

Key Design Elements

- Minimize traditional turf lawn area
- Maximize landscape restoration area planted with native vegetation
- Protect landscape restoration area during construction
- Prevent post-construction erosion through adequate stabilization
- Reduce landscape maintenance
- Eliminate fertilizer and chemical-based pest control programs
- Creates and maintains porous surface and healthy soil.
- Minimal mowing (two times per year)
- Reduced maintenance cost compared to lawn

Potential Applications

Residential: YES
Commercial: YES
Ultra Urban: LIMITED
Industrial: YES
Retrofit: YES
Highway/Road: YES

Stormwater Functions

Volume Reduction: Low/Med
Recharge: Low/Med
Peak Rate Control: Low/Med
Water Quality: Very High

Pollutant Removal

TSS: 85%
TP: 85%
NO_3: 50%

Other Considerations

- Soil Investigation Required
- Soil Restoration may be necessary

Description

In an integrated stormwater management plan, the landscape is a vital factor not only in sustaining the aesthetic and functional resources of a site, but also in mitigating the volume and rate of stormwater runoff. Sustainable landscaping, or Landscape Restoration, is an effective method of improving the quality and reducing the volume of site runoff. This often overlooked, but essential BMP includes the restoration of forest and/or meadow or the conversion of turf to meadow.

Figure 6.18-1 Example of meadow restoration (Photo courtesy of Rolf Sauer & Partners)

Landscape Restoration involves the careful selection and use of vegetation that does not require significant chemical maintenance by fertilizers, herbicides and pesticides. Implicit in this BMP is the assumption that native species have the greatest tolerance and resistance to pests and require less fertilization and chemical application than do nonnative species. Furthermore, since native grasses and other herbaceous materials often require less intensive maintenance efforts (i.e. mowing or trimming), their implementation on a site results in less biomass produced.

Native species are customarily strong growers with stronger and denser root and stem systems, thereby generating less runoff. If the objective is revegetation with woodland species, the longer-term effect is a significant reduction in runoff volumes, with increases in infiltration, evapotranspiration, and recharge, when contrasted with a conventional lawn planting. Peak rate reduction also is achieved. Similarly, meadow reestablishment is also more beneficial than a conventional lawn planting, although not so much as the woodland landscape. Again, these benefits are long term in nature and will not be forthcoming until the species have had an opportunity to grow and mature (one advantage of the meadow is that this maturation process requires considerably less time than a woodland area). Native grasses also tend to have substantially deeper roots and more root mass than turf grasses, which results in:

- A greater volume of water uptake (evapotranspiration)
- Improved soil conditions through organic material and macropore formation
- Provide for greater infiltration

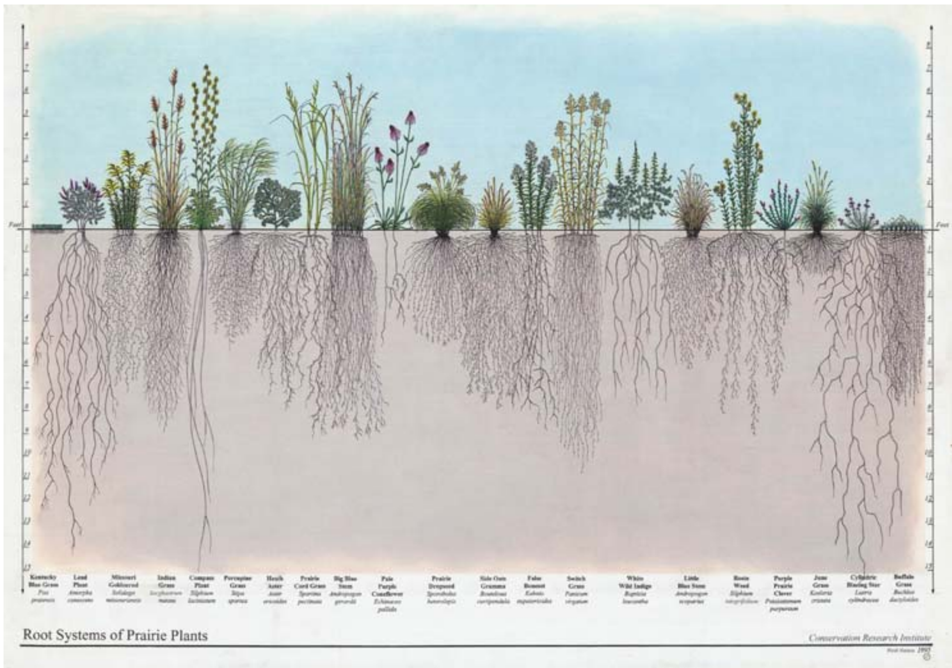


Figure 6.18-2 Native meadow species are more deeply rooted than turf grass.

Landscape architects specializing in the local plant community are usually able to identify a variety of species that meet these criteria. As the selection of such materials begins at the conceptual design stage, where lawns are eliminated or avoided altogether and landscaping species selected, Landscape Restoration can generally result in a site with reduced runoff volume and rate, as well as significant nonpoint source load reduction/prevention.

Landscape Restoration can improve water quality preventively by minimizing application of fertilizers and pesticides/herbicides. Given the high rates of chemical application which have been documented at newly created maintained areas for both residential and nonresidential land uses, eliminating the opportunity for chemical application is important for water quality – perhaps the most effective management technique. Of special importance here is the reduction in fertilization and nitrate loadings. For example, Delaware's *Conservation Design for Stormwater Management* lists multiple studies that document high fertilizer application rates, including both nitrogen and phosphorus, in newly created landscapes in residential and nonresidential land developments. Expansive lawn areas in low density single-family residential subdivisions as well as large office parks – development which has and continues to proliferate in Pennsylvania municipalities - typically receives intensive chemical application, both fertilization and pest control, which can exceed application rates being applied to agricultural fields. Avoidance of this nonpoint pollutant source is an important water quality objective.

Variations

- Meadow
- No-mow lawn area
- Woodland restoration
- Removal of existing lawn to reduce runoff volume
- Buffers between lawn areas and wetlands or stream corridors
- Replacement of “wet” lawn areas difficult to mow
- Replacement of hard to maintain lawns under mature trees

Applications

- Forested Landscape/Restoration
- Suburban / Developing Landscape
- Urban Landscape
- Meadow Restoration
- Conversion of Turf to Meadow

Design Considerations

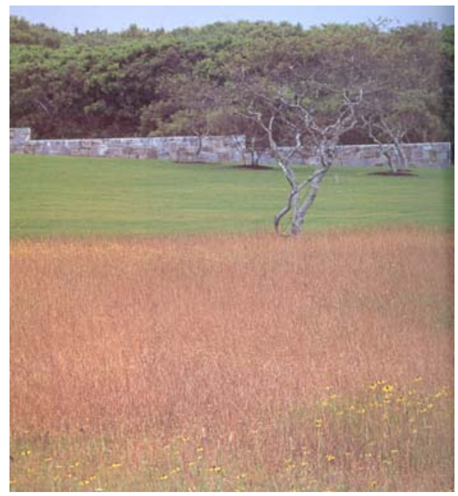
1. The recommended guidelines for Landscape Restoration are very closely related to those of Riparian Buffer Restoration (RBR). Specifically, Landscape Restoration overlaps with the guidelines for Zones 2 and 3 in typical RBR. As with RBR, it is essential for successful Landscape Restoration that site conditions are well understood, objectives of the landowner are considered, and the appropriate plants are chosen for the site. These are all tasks that are completed in the early planning stages of a project. For a summary of the nine steps that PADEP/DCNR advocates during the planning stages of a restoration project, see BMP 6.17- Riparian Buffer Restoration. Included in this nine-step process are: analysis of site soils/natural vegetative features/habitat significance/topography/etc., determination of restoration suitability, and site preparation.

2. In those sites where soils have been disturbed or determined inadequate for restoration (based on analysis), soil amendments are required. Soil amendment and restoration is the process of restoring compromised soils by subsoiling and/or adding a soil amendment, such as compost, for the purpose of reestablishing its long-term capacity for infiltration and pollution removal. For more information on restoring soils, see BMP 6.19 Soil Amendments.

3. “Native species” is a broad term. Different types of native species landscapes may be created, from meadow to woodland areas, obviously requiring different approaches to planting. A native landscape may take several forms in Pennsylvania, ranging from reestablishment of woodlands with understory plantings to reestablishment of meadow. It should be noted that as native landscapes grow and mature, the positive stormwater benefits relating to volume control and peak rate control increase. So, unlike highly maintained turf lawns, these landscapes become much more effective in reducing runoff volumes and nonpoint source pollutants over time.

4. Minimizing the extent of lawn is one of the easiest and most effective ways of improving water quality. Typical (i.e. compacted) lawns on gentle slopes can produce almost as much runoff as pavement. In contrast to turf, "natural forest soils with similar overall slopes can store up to 50 times more precipitation than neatly graded turf." (Arendt, Growing Greener, pg. 81)

   The first step in sustainable site design is to limit the development footprint as much as possible, preserving natural site features, such as vegetation and topography. If lawn areas are desired in certain areas of a site, they should be confined to those areas with slopes less than 6%.

Figures 6.18-3 and 6.18-4 More examples of landscape restoration (Photo courtesy of Rolf Sauer & Partners)

5. Meadow restoration can be performed to reduce turf or in combination with a forest restoration. The native meadow landscape provides a land management alternative that benefits stormwater management by reducing runoff volume and nonpoint source pollutant transport. Furthermore, meadow landscapes vastly reduce the need for maintenance, as they do not require frequent mowing during the growing season. Because native grasses and flowers are almost exclusively perennials, properly installed meadows are a self-sustaining plant community that will return year after year.

   Meadows can be constructed as a substitute to turf on the landscape, or they can be created as a buffer between turf and forest. In either situation, the meadow restoration acts to reduce runoff as well as reduce erosion and sedimentation. Meadow buffers along forests also help reduce off-trail trampling and help to direct pedestrian traffic in order to avoid "desire-lines" which can further concentrate stormwater.

   The challenge in restoring meadow landscapes is a lack of effective establishment and maintenance methods. Native grasses and flowers establish more slowly than weeds and turf grass. Therefore, care must be taken when creating meadow on sites where weed or other vegetative communities are well established. It may take a year or more to prepare the site and to get weeds under control before planting. Erosion prone sites should be planted with a nurse crop (such as annual rye) for quick vegetation establishment to prevent seed and soil loss. Steep slopes and areas subject to water flow should be stabilized with erosion blankets, selected to mitigate expected runoff volumes and velocities. Hydro-seeding is not recommended. Additionally, seed quality is extremely important to successful establishment. There is tremendous variation among seed suppliers, seeds should be chosen with a minimum percent of non-seed plant parts.

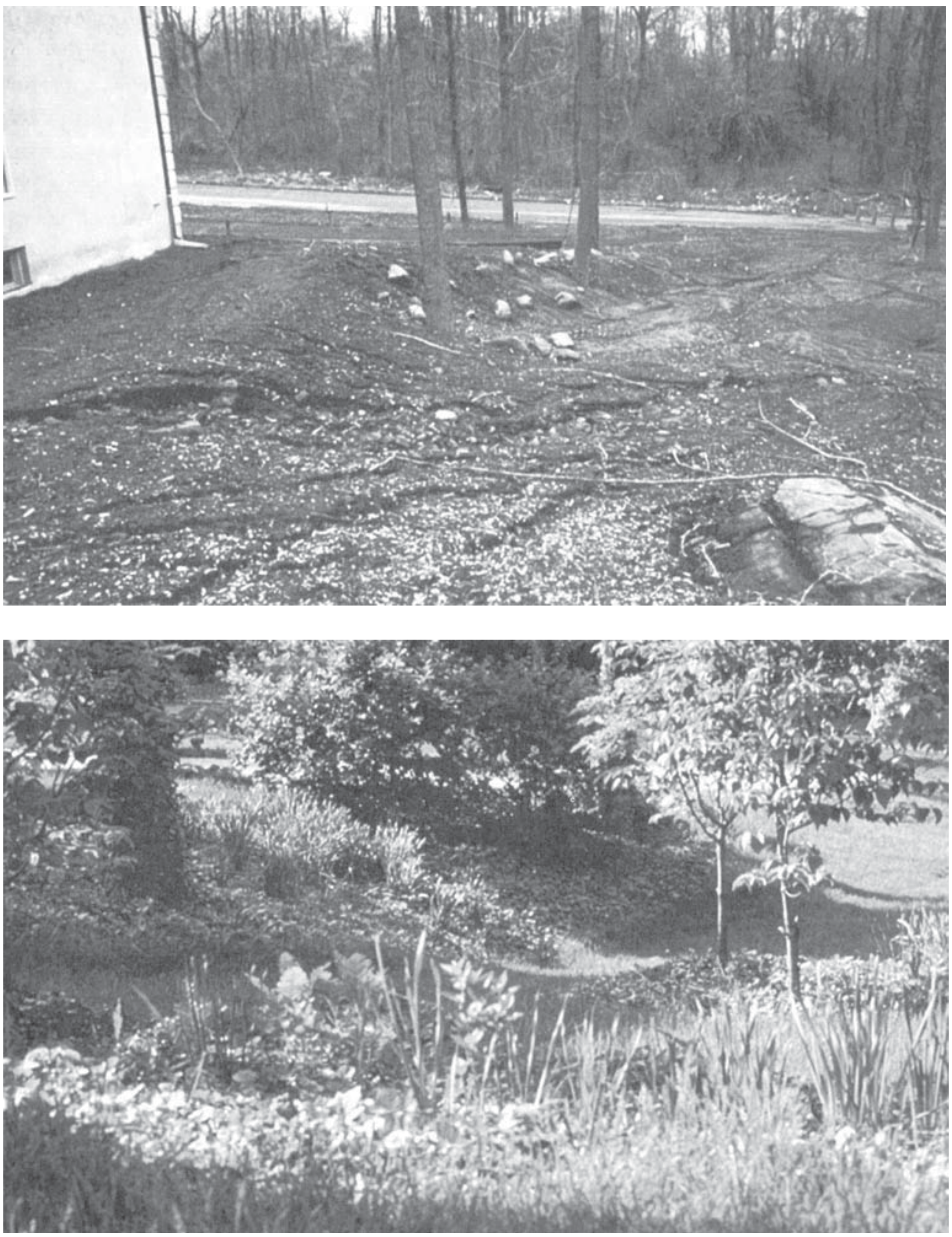


Figure 6.18-5. Example of Reforestation (Sauer, 1998)

6. Conversion of turf grass areas to meadow is relatively simple and has enormous benefits for stormwater management. Though turf is inexpensive to install, the cost of maintenance to promote an attractive healthy lawn is high (requiring mowing, irrigation, fertilizer, lime and herbicides) and its effects are detrimental to water quality. Turf areas are good candidates for conversion to meadow as they typically have lower density of weed species. The conversion of turf to meadow requires that all turf be killed before planting, and care must be taken to control weed establishment prior to planting.

7. Forest restoration includes planting of appropriate tree species (small saplings) with quick establishment of an appropriate ground cover around the trees in order to stabilize the soil and prevent colonization of invasive species. Reforestation can be combined with other volume control BMPs such as retentive berming, vegetated filter strips and swales.

   Plant selection should mimic the surrounding native vegetation and expand on the native species composition already found on the site. A mixture of native trees and shrubs is recommended and should be planted once a ground cover is established.

8. In terms of woodland areas, DNREC's *Conservation Design for Stormwater Management* states, "…a mixture of young trees and shrubs is recommended…. Tree seedlings from 12 to 18 inches in height can be used, with shrubs at 18 to 24 inches. Once a ground cover crop is established (to offset the need for mowing), trees and shrubs should be planted on 8-foot centers, with a total of approximately 430 trees per acre. Trees should be planted with tree shelters to avoid browse damage in areas with high deer populations, and to encourage more rapid growth." (p.3-50). Initial watering and weekly watering during dry periods may be necessary during the first growing season. As tree species grow larger, both shrubs and ground covers recede and yield to the more dominant tree species. The native tree species mix of small inexpensive saplings should be picked for variety and should reflect the local forest communities. Annual mowing to control invasives may be necessary, although the quick establishment of a strong-growing ground cover can be effective in providing invasive control. Native meadow planting mixes also are available. A variety of site design factors may influence the type of vegetative community that is to be planned and implemented. In so many cases, the "natural" vegetation of Pennsylvania's communities is, of course, woodlands.

9. Ensure adequate stabilization. Adequate stabilization is extremely important as native grasses, meadow flowers, and woodlands establish more slowly than turf. Stabilization can be achieved for forest restoration by establishing a ground cover before planting of trees and shrubs. When creating meadows, it may be necessary to plant a fast growing nurse crop with meadow seeds for quick stabilization. Annual rye can be planted in the fall or spring with meadow seeds and will establish quickly and usually will not present a competitive problem. Erosion prone sites should be planted with a nurse crop and covered with weed-free straw mulch, while steep slopes and areas subject to runoff should be stabilized with erosion control blankets suitable for the expected volume and velocity of runoff.

Volume Reduction Calculations and Peak Rate Mitigation

Areas designated for landscape restoration should be considered as “Meadow, good condition” in stormwater calculations.

Water Quality Improvement

See Section 9 for Water Quality Improvement methodology, which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

Forest restoration installation follows closely the procedure outlined in BMP 6.17- Riparian Buffer Restoration. Refer to BMP 6.17 for detailed information, with the understanding that species selection for upland forest restoration will differ from that for riparian restoration.

Meadow installation should proceed as follows:

1. SELECT SITE

- Confirm site is suitable for restoration, should be sunny, open and well-ventilated. Meadow plants require at least a half a day of full sun.
- Obtain landowner permission

2. ANALYZE SITE

- Evaluate site’s physical conditions (soil attributes, geology, terrain)
- Evaluate site’s vegetative features (desirable and undesirable species, native species, sensitive habitats). Good candidates for meadow plantings include areas presently in turf, cornfields, soybean fields, alfalfa fields and bare soils from new construction.
- Areas with a history of heavy weed growth may require a full year or longer to prepare for planting.
- Beware of residual herbicides that may have been applied to agricultural fields. Always check the herbicide history of the past 2-3 years and test the soils if in doubt.

3. PLANT SELECTION

- Select plants that are well adapted to the specific site conditions. Meadow plants must be able to out compete weed species in the first few years as they become established.

4. PREPARE SITE

- All weeds or existing vegetation must be eliminated prior to seeding.
- Perennial weeds may require year long smothering, repeated sprayings with herbicides, or repeated tillage with equipment that can uproot and kill perennial weeds.

5. PLANTING DAY

- Planting can take place from Spring thaw through June 30 or from September 1 through soil freeze-up (“dormant seeding”)
- Planting in July and August is generally not recommend due to the frequency of drought during this time.
- Seeding can be accomplished by a variety of methods: no-till seeder for multi-acre planting; broadcast seeder; hand broadcast for small areas of one acre or less.
- Seed quality is critical and a seed mix should be used with a minimum percentage of non-seed plant parts.

7. SITE MAINTENANCE (additional information below)
- Assign responsibilities watering, weeding, mowing, and maintenance
- Monitor site regularly for growth and potential problems

Maintenance Issues

Meadows and Forests are low maintenance but not "no maintenance". They usually require more frequent maintenance in the first few years immediately following installation.

Forest restoration areas planted with a proper cover crop can be expected to require annual mowing in order to control invasives. Application of a carefully selected herbicide (Roundup or similar glyphosate herbicide) around the protective tree shelters/tubes may be necessary, reinforced by selective cutting/manual removal, if necessary. This initial maintenance routine is necessary for the initial 2 to 3 years of growth and may be necessary for up to 5 years until tree growth and tree canopy begins to form, naturally inhibiting weed growth (once shading is adequate, growth of invasives and other weeds will be naturally prevented, and the woodland becomes self-maintaining). Review of the new woodland should be undertaken intermittently to determine if replacement trees should be provided (some modest rate of planting failure is usual).

Meadow management is somewhat more straightforward; a seasonal mowing or burning may be required, although care must be taken to make sure that any management is coordinated with essential reseeding and other important aspects of meadow reestablishment. In the first year weeds must be carefully controlled and consistently mowed back to 4-6 inches tall when they reach 12 inches in height. In the second year, weeds should continue to monitored and mowed and rhizomatous weeds should be hand treated with herbicide. Weeds should not be sprayed with herbicide as the drift from the spray may kill large patches of desirable plants, allowing weeds to move in to these new open areas. In the beginning of the third season, the young meadow should be burned off in mid-spring. If burning is not possible, the meadow should be mowed very closely to the ground instead. The mowed material should be removed from the site to expose the soil to the sun. This helps encourage rapid soil warming which favors the establishment of "warm season" plants over "cool season" weeds.

Cost Issues

Landscape restoration cost implications are minimal during construction. Seeding for installation of a conventional lawn is likely to be less expensive than planting of a "cover" of native species, although when contrasted with a non-lawn landscape, "natives" often are not more costly than other nonnative landscape species. In terms of woodland creation, somewhat dated (1997) costs have been provided by the *Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers*:

$860/acre trees with installation
$1,600/acre tree shelters/tubes and stakes
$300/acre for four waterings on average

In current dollars, these values would be considerably higher, well over $3,000/acre for installation costs. Costs for meadow reestablishment are lower than those for woodland, in part due to the elimination of the need for shelters/tubes. Again, such costs can be expected to be greater than installation of conventional lawn (seeding and mulching), although the installation cost differences diminish when conventional lawn seeding is redefined in terms of conventional planting beds.

Cost differentials grow greater when longer term operating and maintenance costs are taken into consideration. If lawn mowing can be eliminated, or even reduced significantly to a once per year requirement, substantial maintenance cost savings result, often in excess of $1,500 per acre per year. If chemical application (fertilization, pesticides, etc.) can be eliminated, substantial additional savings result with use of native species. These reductions in annual maintenance costs resulting from a native landscape reestablishment very quickly outweigh any increased installation costs that are required at project initiation. Unfortunately, because developers pay for the installation costs and longer term reduced maintenance costs are enjoyed by future owners, there is reluctance to embrace native landscaping concepts.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. Topsoil – See Appendix C
2. Vegetation – See Appendix B

References

Bowman's Hill Wildflower Preserve, Washington Crossing Historic Park, PO Box 685, New Hope, PA 18938-0685, Tel (215) 862-2924, Fax (215) 862-1846, Native plant reserve, plant sales, native seed, educational programs, www.bhwp.org

Morris Arboretum of the University of Pennsylvania; 9414 Meadowbrook Avenue, Philadelphia, PA 19118, Tel (215) 247-5777, www.upenn.edu/morris, PA Flora Project Website: Arboretum and gardens (some natives), educational programs, PA Flora Project, www.upenn.edu/paflora

Pennsylvania Department of Conservation and Natural Resources; Bureau of Forestry; PO Box 8552, Harrisburg, PA 17105-8552, Tel (717)787-3444, Fax (717)783-5109, Invasive plant brochure; list of native plant and seed suppliers in PA; list of rare, endangered, threatened species.

Pennsylvania Native Plant Society, 1001 East College Avenue, State College, PA 16801 www.pawildflower.org

Western Pennsylvania Conservancy; 209 Fourth Avenue, Pittsburgh, PA 15222, Tel (412) 288-2777, Fax (412) 281-1792, www.paconserve.org

Conservation Design for Stormwater Management (DNREC and EMC)

Stream ReLeaf Plan and Toolkits

The Once and Future Forest – Leslie Sauer

Forestry Best Management Practices for Water Quality – Virginia Department of Forestry

Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers (1997)

Growing Greener, Arendt

Diboll, Neil. Five Steps to Successful Prairie Meadow Establishment. Windstar Wildlife Institute.

Penn State College of Agricultural Sciences, Agricultural Research and Cooperation Extension. " Pennsylvania Wildlife No. 12: Warm-season Grasses and Wildlife" and "Pennsylvania Wildlife No. 5: Meadows and Prairies: Wildlife-friendly Alternatives to Lawn"

Arendt, Growing Greener, pg. 81

Restoration BMPs
BMP 6.19: Soil Amendment & Restoration

Soil amendment and restoration is the process of restoring disturbed soils by restoring soil porosity and/or adding a soil amendment, such as compost, for the purpose of reestablishing the soil's long-term capacity for infiltration and pollution removal.

Key Design Elements

- Existing soil conditions should be evaluated before forming a restoration strategy.
- Physical loosening of the soil, often called subsoiling, or tilling, can treat compaction.
- The combination of subsoiling and soil amendment is often the more effective strategy.
- Compost amendments increase water retention.

Potential Applications

Residential: YES
Commercial: YES
Ultra Urban: YES
Industrial: YES
Retrofit: YES
Highway/Road: YES

Stormwater Functions

Volume Reduction: Low/Med
Recharge: Low
Peak Rate Control: Med
Water Quality: Med

Pollutant Removal

TSS: 85%
TP: 85%
NO_3: 50%

Problem Description

Animals, farm equipment, trucks, construction equipment, cars, and people cause compaction. Wet soil compacts easier than dry soil. Natural compaction occurs due to special chemical or physical properties, and these occurrences are called "hard pans". A typical soil after compaction has strength of about 6,000 kPa, while studies have shown that root growth is not possible beyond 3,000 kPa.

Figure 6.19-1. Soil compaction and cutting during construction.

Different Types of Compaction

1) Minor Compaction – surface compaction within 8-12" due to contact pressure, axle load > 10 tons can compact through root zone, up to 1' deep

2) Major Compaction – deep compaction, contact pressure and total load, axle load > 20 tons can compact up to 2' deep (usually large areas compacted to increase strength for paving and foundation with overlap to "lawn" areas)

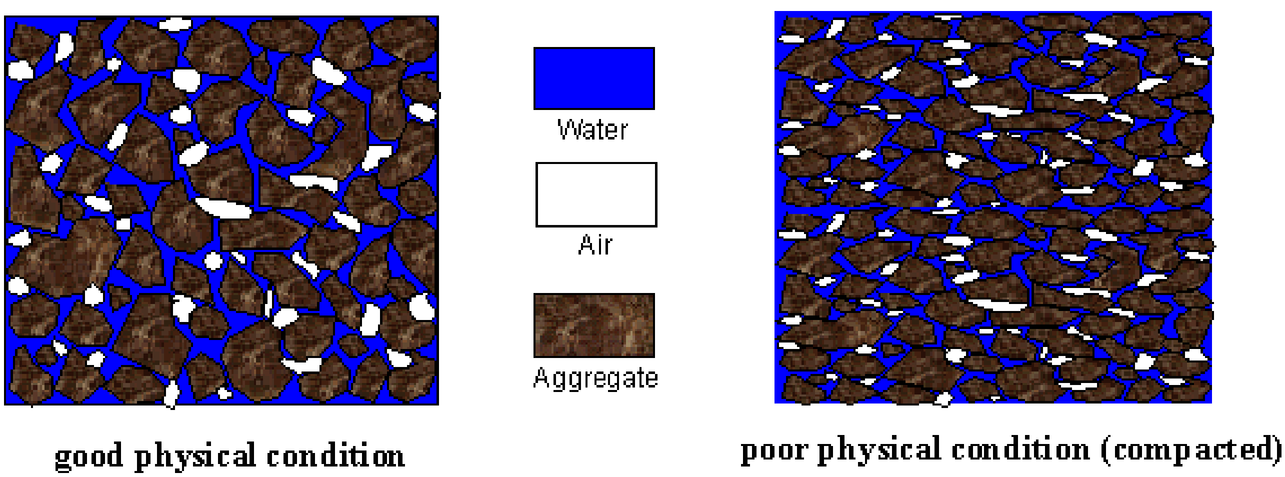


Figure 6.19-2. Comparison showing good to poor physical soil conditions

In general, compaction problems occur when airspace drops to 10-15% of total soil volume. Compaction affects the infiltrating and water quality capacity of soils. When soils are compacted, the soil particles are pressed together, reducing the pore space necessary to move air and water throughout the soil. (Figure 2 above.) This decrease in porosity causes an increase in bulk density (weight of solids per unit volume of soil). The greater the bulk density, the lower the infiltration and therefore the larger volume of runoff.

Different types of soils have bulk density levels at which compaction starts to limit root growth. When root growth is limited, the uptake of water and nutrients by vegetation is reduced.

Soil organisms are also affected by compaction; biological activity is greatly reduced, decreasing their ability to intake and release nutrients.

The best soil restoration is the complete revegetation of woodlands, as “A mature forest can absorb as much as 14 times more water than an equivalent area of grass.” (DNREC and Brandywine Conservancy, 1997) (See Structural BMP 6.18 Landscape Restoration and use in combination with this BMP)

Soil Restoration Methodology

Soil amendment is a technique that can be used to restore and enhance compacted soils by physical treatment and/or mixture with additives such as compost. Soil amendment has been shown to alter soil properties known to affect water relations of soils, including water holding capacity, porosity, bulk density and structure. Two methods have been proven to restore the characteristics of soils that are damaged by compaction, subsoiling and amendments with compost or other materials.

One of the options for soil amendment is compost, which has many benefits. It improves the soil structure, creating and enhancing (by growth) passageways in the soil for air water that have been lost due to compaction. This recreates a better environment for plant growth. Compost also supplies a slow release of nutrients to plants, specifically nitrogen, phosphorous, potassium, and sulfur. Using compost reuses natural resources, reducing waste and cost.

Soil amendment with compost has been shown to increase nutrients in the soil, such as phosphorus and nitrogen, which provides plants with needed nutrients, reducing or eliminating the need for fertilization. This increase in nutrients results in an aesthetic benefit as turf grass and other plantings establish and proliferate more quickly, with less maintenance requirements. Soil amendment with compost increases water holding and retention capacity, improves infiltration, reduces surface runoff, increases soil fertility, and enhances vegetative growth. Soil amendment also increases pollutant-binding properties of the soil properties, which improves the quality of the water passing through the soil mantle and into the groundwater.

Table 6.19-1 Bulk Densities of Different Soil Types (Protecting Urban Soil Quality, USDA-NRCS)

Soil Texture	Ideal Bulk densities	Bulk densities that may afffect root growth	Bulk densities that restrict root growth
	g/cm3	g/cm3	g/cm3
Sands, loamy sands	<1.60	1.69	1.8
Sandy loams, loams	<1.40	1.63	1.8
Sandy clay loams, loams, clay loams	<1.40	1.6	1.75
Slilt, silt loams	<1.30	1.6	1.75
Silt loams, silty clay loams	<1.10	1.55	1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	1.58
Clays (>45% clay)	<1.10	1.39	1.47

The second method is tilling, which involves the digging, scraping, and mixing, and ripping of soil with the intent of circulating air into the soil mantle in various layers. Compaction down to 20 inches often requires ripping for soil restoration. Tilling exposes compacted soil devoid of oxygen to air and recreates temporary air space.

Bulk density field tests indicate the compaction level of soils.

Variations

- Soil amendment media can include compost, sand, and manufactured microbial solutions.
- Seed can be included in the soil amendment to save application time.

Applications

- **New Development (Residential, Commercial, Industrial)** – new lawns can be amended with compost and not heavily compacted before planting, to increase the porosity of the soils.

- **Urban Retrofits** - Tilling of soils that have been compacted before it is converted into meadow, lawn, or a stormwater facility is recommended.

- **Detention Basin Retrofits** – The inside face of detention basins is usually heavily compacted, and tilling the soil mantle will encourage infiltration to take place. Tilling may be necessary to establish better vegetative cover.

- **Landscape Maintenance** – compost can substitute for dwindling supplies of native topsoil in urban areas.

- **Golf Courses** – Using compost as part of the landscaping upkeep on the greens has been shown to alleviate soil compaction erosion, and turf disease problems.

Design Considerations

1. Treating Compaction by **Soil Amendment**
   a) Soil amendment media can include compost, mulch, manures, sand, and manufactured microbial solutions.
   b) Soils should be amended at about a 2:1 ratio of soil to amendment, unless a proprietary product is used, and in this case the manufacturer’s instructions should be followed in terms of mixing and application rate.
   c) Soil amendments should not be used on slopes greater than 30%. In these areas, deep-rooted vegetation can be used to increase stability.
   d) Soil amendment should not take place within the drip line of a tree to avoid damaging the root system.
   e) On-site soils with an organic content of at least 5 percent can be properly stockpiled (to maintain organic content) and reused to amend soils, saving costs.

f) Procedure: rototill, or rip the subgrade, remove rocks, distribute the compost, spread the nutrients, rototill again.
g) Add 6 inches compost / amendment and till up to 8 inches for minor compaction.
h) Add 10 inches compost / amendment and till up to 20 inches for major compaction.

2. Treating Compaction by **Ripping / Subsoiling / Tilling / Scarification**
   a) Subsoiling is only effective when performed on dry soils.
   b) Ripping, subsoiling, or scarification of the subsoil should be performed where subsoil has become compacted by equipment operation, dried out and crusted, or where necessary to obliterate erosion rills.
   c) Ripping (Subsoiling) should be performed using a solid-shank ripper and to a depth of 20 inches, (8 inches for minor compaction).
   d) Should be performed before compost is placed and after any excavation is completed.
   e) Subsoiling should not be performed within the drip line of any existing trees, over underground utility installations within 30 inches of the surface, where trenching/drainage lines are installed, where compaction is by design, and on inaccessible slopes.

Subsoiling should not be performed with common tillage tools such as a disk or chisel plow because they are too shallow and can compact the soil just beneath the tillage depth.

3. Other methodologies:
   a) Irrigation Management – low rates of water should be applied, as over-irrigation wastes water and may lead to environmental pollution from lawn chemicals, nutrients, and sediment.
   b) Limited mowing – higher grass corresponds to greater evapotranspiration.
   c) Compost can be amended with bulking agents, such as aged crumb rubber from used tires or weed chips. This can be a cost-effective alternative that reuses waste materials.
   d) In areas where compaction is less severe (not as a result of heavy construction equipment), planting with deep-rooted perennials can treat compaction, however restoration takes several years.

Table 2. Mean runoff from unvegetated test plots during a 30 minute high-intensity (~ 4 in/hr) rain storm

	Biosolids	Yard Trimmings	Bio-industrial	Compacted Subsoil	Topsoil
Geometric mean runoff (mm) during 30-minute rainfall	0.13[a]	<0.01[a]	0.08[a]	26.22[b]	15.54[b]

Values with different letters are significantly different statistically ($p<0.05$) from one another.

Table 3. Mean time to initiate runoff from unvegetated test plots

	Biosolids	Yard Trimmings	Bio-industrial	Compacted Subsoil	Topsoil
Mean time (min)	31.08[c]	56.92[d]	32.17[c,d]	4.67[a]	7.83[b]

Values with different letters are significantly different statistically ($p<0.05$) from one another.

Figure 6.19-3. Results showing mean runoff and mean time to initiate runoff from unvegetated test plots, Source: http://www.forester.net/ecm_0405_studies.html

Detailed Stormwater Functions

Infiltration Area (If needed)
The infiltration area will be the entire area restored, depending on the existing soil conditions, and the restoration effectiveness.

Volume Reduction Calculations
Soil Amendments can reduce the need for irrigation by retaining water and slowly releasing moisture, which encourages deeper rooting. Infiltration is increased; therefore the volume of runoff is decreased.

Compost amended soils can significantly reduce the volume of stormwater runoff. For soils that have either been compost amended according to the recommendations of their BMP, or subject to restoration such that the field measured bulk densities meet the Ideal Bulk Densities of Table 1, the following volume reduction may be applied:

Amended Area (ft^2) x 0.50in x 1/12 = Volume (cf)

Peak Rate Mitigation
See Section 9 for peak rate mitigation.

Water Quality Improvement
See Section 9 for water quality improvement.

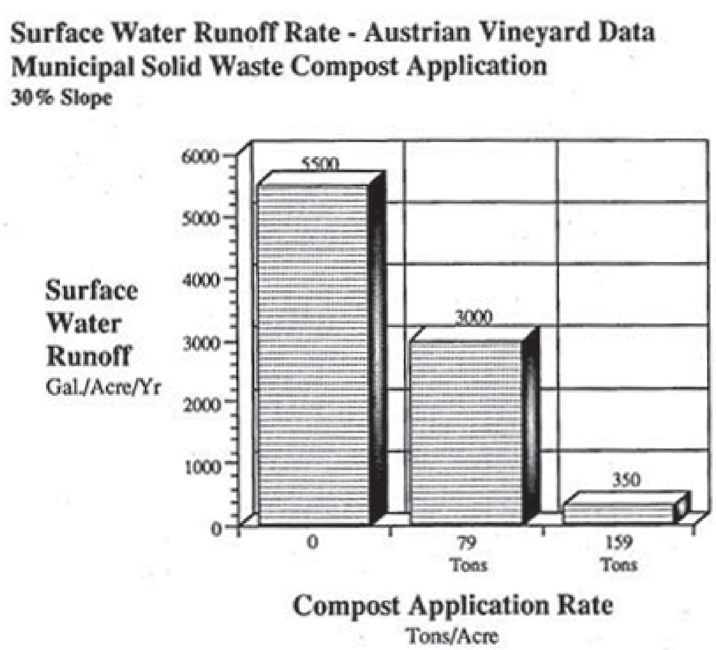


Figure 6.19-4. Surface runoff rates reduced by compost application (http://www.tucson.ars.ag.gov/icrw/Proceedings/Tyler.pdf)

Table 4. Adsorbed Mass of Nutrients and Metals in Unvegetated Plot Runoff From 30-Minute, High-Intensity (100-mm/hr.) Rainstorm

	Compost Treatments			Conventional Treatments	
	Biosolids	Yardwaste	Bioindustrial Compost	Compacted Subsoil	Topsoil
Element	Geometric Mean (mg)				
Chromium	0.01[b]	<0.01[a]	<0.01[b]	0.92[c]	0.76[c]
Copper	0.02[b]	<0.01[a]	0.01[b]	1.03[c]	0.66[c]
Nickel	<0.01[b]	<0.01[a]	<0.01[b]	0.96[c]	0.67[c]
Lead	0.01[b]	<0.01[a]	<0.01[b]	1.82[c]	0.95[c]
Zinc	0.10[b]	<0.01[a]	0.03[b]	6.55[c]	3.99[c]
Nitrogen	0.47[b]	<0.01[a]	0.09[a,b]	266.65[c]	211.87[c]
Phosphorus	0.45[b]	<0.01[a]	0.09[a,b]	36.47[c]	29.07[c]
Potassium	0.17[b]	<0.01[a]	0.09[a,b]	103.94[c]	71.57[c]

Means within the same row with different letter designations are significantly different ($p<0.05$).

	Highest	Medium	Lowest

Figure 6.19-5. Results showing adsorbed nutrient and metal mass in unvegetated plot runoff (Source: http://www.forester.net/ecm_0405_studies.html)

Construction Sequence

1. All construction should be completed and stabilized before beginning soil restoration.

Maintenance Issues

The soil restoration process by need to be repeated over time, due to compaction by use and/or settling. (For example, playfields or park areas will be compacted by foot traffic.)

Cost Issues

Tilling costs, including scarifying sub-soils, range from $800/ac to $1000/ac.

Compost amending of soil ranges in cost from $860/ac to $1000/ac.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. SCOPE

    a. This specification covers the use of compost for soil amendment and the mechanical restoration of compacted, eroded and non-vegetated soils. Soil amendment and restoration is necessary where existing soil has been deemed unhealthy in order to restore soil structure and function, increase infiltration potential and support healthy vegetative communities.

    b. Soil amendment prevents and controls erosion by enhancing the soil surface to prevent the initial detachment and transport of soil particles.

2. COMPOST MATERIALS

    a. Compost products specified for use in this application are described in Table 1. The product's parameters will vary based on whether vegetation will be established on the treated slope.

    b. Only compost products that meet all applicable state and federal regulations pertaining to its production and distribution may be used in this application. Approved compost products must meet related state and federal chemical contaminant (e.g., heavy metals, pesticides, etc.) and pathogen limit standards pertaining to the feedstocks (source materials) in which it is derived.

    c. Very coarse compost should be avoided for soil amendment as it will make planting and crop establishment more difficult.

    d. **Note 1 -** Specifying the use of compost products that are certified by the U.S. Composting Council's Seal of Testing (STA) Program (www.compostingcouncil.org) will allow for the acquisition of products that are analyzed on a routine basis, using the specified test methods. STA participants are also required to provide a standard product label to all customers, allowing easy comparison to other products.

3. SUB-SOILING TO RELIEVE COMPACTION

    a. Before the time the compost is placed and preferably when excavation is completed, the subsoil shall be in a loose, friable condition to a depth of 20 inches below final topsoil grade and there shall be no erosion rills or washouts in the subsoil surface exceeding 3 inches in depth.

    b. To achieve this condition, subsoiling, ripping, or scarification of the subsoil will be required as directed by the owners s representative, wherever the subsoil has been compacted by equipment operation or has become dried out and crusted, and where necessary to obliterate erosion rills. Sub-soiling shall be required to reduce soil compaction in all areas where plant establishment is planned. Sub-soiling shall be performed by the prime or excavating contractor and shall occur before compost placement.

c. Subsoiled areas shall be loosened to less than 1400 kPa (200 psi) to a depth of 20 inches below final topsoil grade. When directed by the owner's representative, the Contractor shall verify that the sub-soiling work conforms to the specified depth.

d. Sub-soiling shall form a two-directional grid. Channels shall be created by a commercially available, multi-shanked, parallelogram implement (solid-shank ripper). The equipment shall be capable of exerting a penetration force necessary for the site. No disc cultivators chisel plows, or spring-loaded equipment will be allowed. The grid channels shall be spaced a minimum of 12 inches to a maximum of 36 inches apart, depending on equipment, site conditions, and the soil management plan. The channel depth shall be a minimum of 20 inches or as specified in the soil management plan. If soils are saturated, the Contractor shall delay operations until the soil will not hold a ball when squeezed. Only one pass shall be performed on erodible slopes greater than 1 vertical to 3 horizontal. When only one pass is used, work shall be at right angles to the direction of surface drainage, whenever practical.

e. Exceptions to sub-soiling include areas within the drip line of any existing trees, over utility installations within 30 inches of the surface, where trenching/drainage lines are installed, where compaction is by design (abutments, footings, or in slopes), and on inaccessible slopes, as approved by the owner's representative. In cases where exceptions occur, the Contractor shall observe a minimum setback of 20 feet or as directed by the owner's representative. Archeological clearances may be required in some instances.

4. COMPOST SOIL AMENDMENT QUALITY

a. The final, resulting compost soil amendment must meet all of the mandatory criteria in Table 2.

5. COMPOST SOIL AMENDMENT INSTALLATION

a. Spread 2-3 inches of approved compost on existing soil. Till added soil into existing soil with a rotary tiller that is set to a depth of 6 inches. Add an additional 4 inches of approved compost to bring the area up to grade.

b. After permanent planting/seeding, 2-3 inches of compost blanket will be applied to all areas not protected by grass or other plants

References

"The Compaction of Urban Soils", Technical Note #107 from Watershed Protection Techniques, Article 36, 3(2): 661-665.

Dallas, H. and A. Lewandowski, 2003. Protecting Urban Soil Quality: Examples for Landscape Codes and Specifications. USDA Natural Resources Conservation Services.

OCSCD, 2001. *Impact of Soil Disturbance During Construction on Bulk Density and Infiltration in Ocean County, New Jersey*. Ocean County Soil Conservation District, Schnabel Engineering Assoicates, Inc., USDA Natural Resources Conservation Services. www.ocscd.org.

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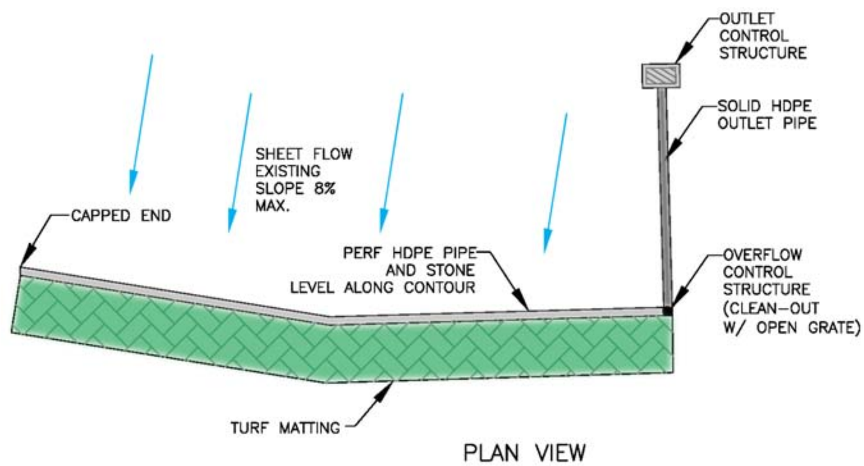
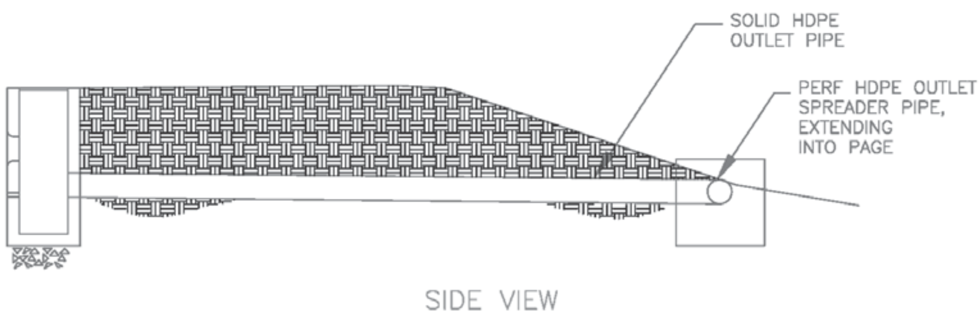
6.8 Other BMPs and Related Structural Measures

Other BMPs and Related Structural Measures
BMP 6.20: Level Spreader



Level Spreaders are measures that reduce the erosive energy of concentrated flows by distributing runoff as sheet flow to stabilized vegetative surfaces. Level Spreaders, of which there are many types, also promote infiltration and improved water quality.



Key Design Elements

- Level spreaders must be level.
- Specific site conditions, such as topography, vegetative cover, soil, and geologic conditions must be considered prior to design; level spreaders are not applicable in areas with easily erodible soils and/or little vegetation.
- Level spreaders shall safely diffuse at least the 10-year storm peak rate; bypassed flows shall be stabilized in a sufficient manner.
- Length of level spreaders is dependent on influent flow rate, pipe diameter (if applicable); number and size of perforations (if applicable), and downhill cover type.
- It is always easier to keep flow distributed than to redistribute it after it is concentrated; multiple outfalls/level spreaders are preferable to a single outfall/level spreader.

Potential Applications

Residential:	**YES**
Commercial:	**YES**
Ultra Urban:	**LIMITED**
Industrial:	**YES**
Retrofit:	**YES**
Highway/Road:	**YES**

Stormwater Functions

Volume Reduction:	**Low**
Recharge:	**Low**
Peak Rate Control:	**Low**
Water Quality:	**Low**

Pollutant Removal

TSS:	**20%**
TP:	**10%**
NO_3:	**5%**

Description

Ensuring distributed, non-erosive flow conditions is an important consideration in any stormwater management strategy and particularly critical to the performance of certain BMPs (e.g. filter strips). Traditionally, stormwater discharges have been stabilized (i.e. diffused) with structural measures such as riprap. While riprap typically affords a high degree of protection for significant flow conditions and requires little maintenance, it can be expensive, result in damaging heat gain in runoff, and may be an unnecessary waste of natural resources. By promoting concentrated releases of runoff, riprap also fails to encourage infiltration or improve water quality, other than diffusing erosive flows. On the contrary, level spreading devices diffuses flows (both low and high), promote infiltration, and improve water quality by evenly distributing flows over a stabilized vegetated surface. There are many different types and functions of level spreaders. Examples include concrete sills (or lips), curbs, earthen berms, and level perforated pipes.

For the purposes of the Manual, there are essentially two categories of level spreaders. The first type of level spreader (Inflow) is meant to evenly distribute flow entering into another structural BMP, such as a filter strip, infiltration basin, or vegetated swale, for example. Examples of this type of level spreader include concrete sills (or lips), curbs, and earthen berms. The second type of level spreader (Outflow) is intended to reduce the erosive force of high flows while at the same time enhancing natural infiltration opportunities. Examples of this second type include a level, perforated pipe in a shallow aggregate trench (similar to an Infiltration Trench) and earthen berms. While the first type of level spreader can be a very effective measure, it is already discussed in some detail as a design consideration in other structural BMPs and particularly in BMP 6.10 Infiltration Berms. This section therefore, focuses primarily on the second category of level spreaders.

Outflow level spreaders, the second category, are often used in conjunction with other structural BMPs, such as BMP 6.2 Infiltration Basins and BMP 6.3 Subsurface Infiltration Bed. However, in certain situations, they can be used as “stand alone” BMPs to “treat” runoff from roofs or other impervious areas. In either case, level spreaders will account for some level of volume and rate reduction, the degree to which depends on the specific design, natural infiltration rate of the soil, amount of influent runoff, vegetation density and slope of downhill area, and extent (length). Specific credit, as defined in BMPs 5.11 and 5.12, is given to stand alone level spreaders for impervious areas greater than 500 square feet.

A typical level spreader that is used in conjunction with another structural BMP is a level perforated pipe in a shallow aggregate trench. Though the actual design will vary, a “level spreader pipe” shall be designed to at least distribute to the 10-year storm. Depending on the computed flow rate and available space, the designer may provide enough length of pipe to distribute the 100-year storm (see Design Considerations). If space is limited, then flows above the 10-year storm may be allowed to bypass the level spreader. The level spreader pipe must be installed evenly along a contour at a shallow depth in order to ensure adequate flow distribution and discourage channelization. In some cases, a level spreader pipe may be “upgraded” to an Infiltration Trench if additional volume and rate reduction is required (see BMP 6.4, Infiltration Trench).

The condition of the area downhill of a level spreader must be considered prior to installation. For instance, the slope, density and condition of vegetation, natural topography, and length (in the direction of flow) will all affect the effectiveness of a distributed flow measure. Areas immediately downhill from a level spreader may need to be stabilized, especially if they have been recently disturbed. Erosion control matting and/or compost blanketing are the recommended measures for temporary and permanent downhill stabilization. Manufacturer's specifications shall be followed for chosen stabilization measure.

Variations

- **Inflow Level Spreaders**
  Evenly distribute flow entering into another structural BMP, such as a filter strip, infiltration basin, or vegetated swale. Examples include concrete sills (or lips), curbs, concrete troughs, ½ pipes, short standing PVC-silt fence, aggregate trenches, and earthen berms (see Infiltration Berms and Filter Strips). To ensure even distribution of flow, it is critical that these devices be installed as levelly as possible. More rigid structures (concrete, wood, etc.) are often preferable to earthen berms, which have the potential to erode.

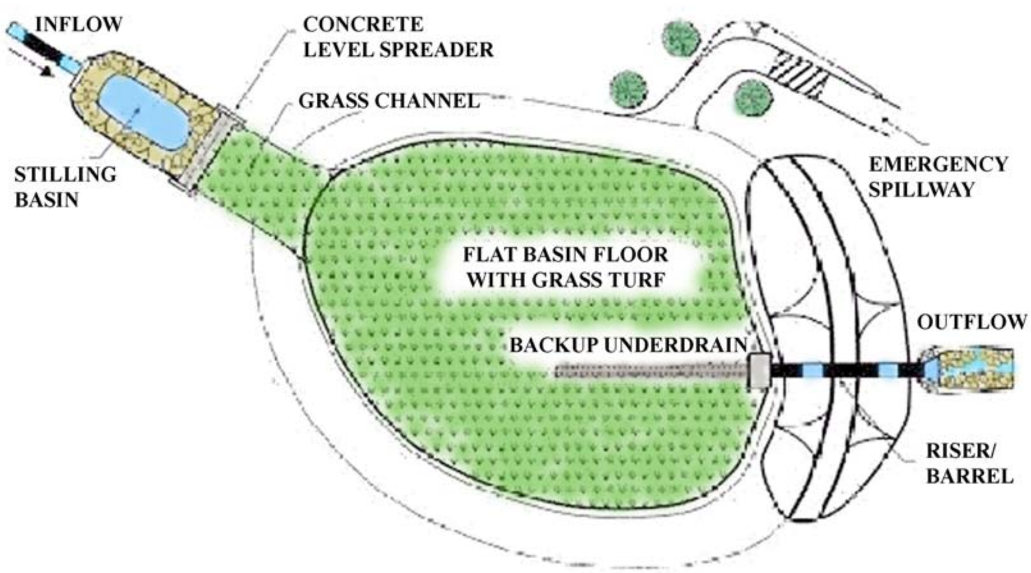


Figure 6.20-1. Concrete Level Spreader distributes flow entering infiltration basin

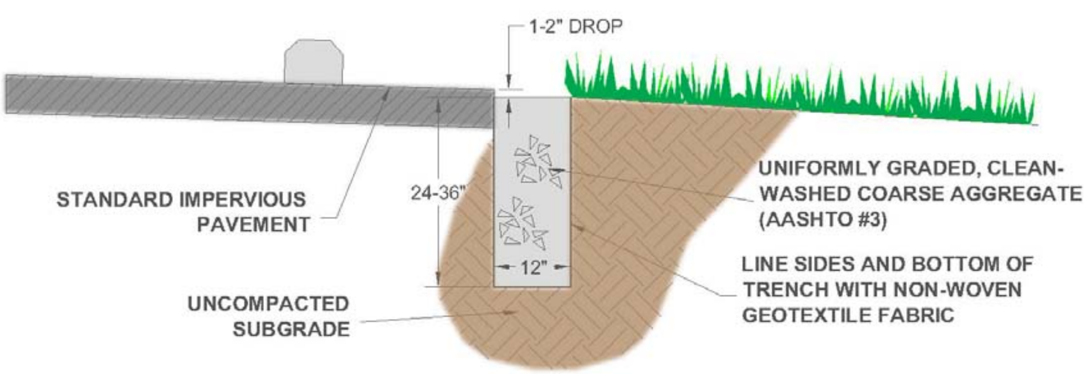


Figure 6.20-2. Aggregate Trench Level Spreader distributes flow entering filter strip

- **Outflow Level Spreaders (in conjunction with structural BMP)**
  Reduces the erosive force of high flows while at the same time enhancing natural infiltration opportunities. Examples of this second type include a level perforated pipe in a shallow aggregate trench (similar to an Infiltration Trench) and earthen berms.

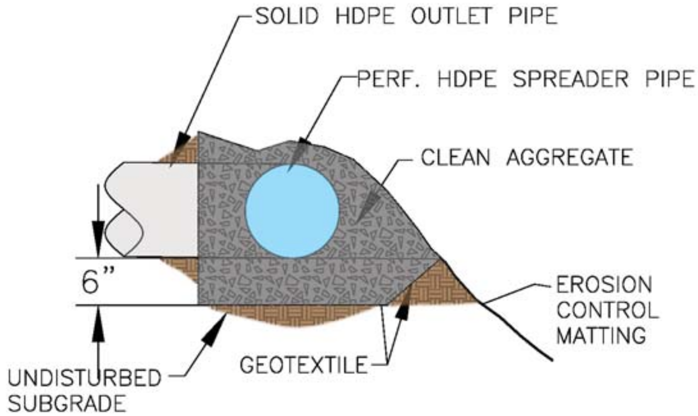


Figure 6.20-3. Level Spreader Perforated Pipe in aggregate trench at pipe outlet

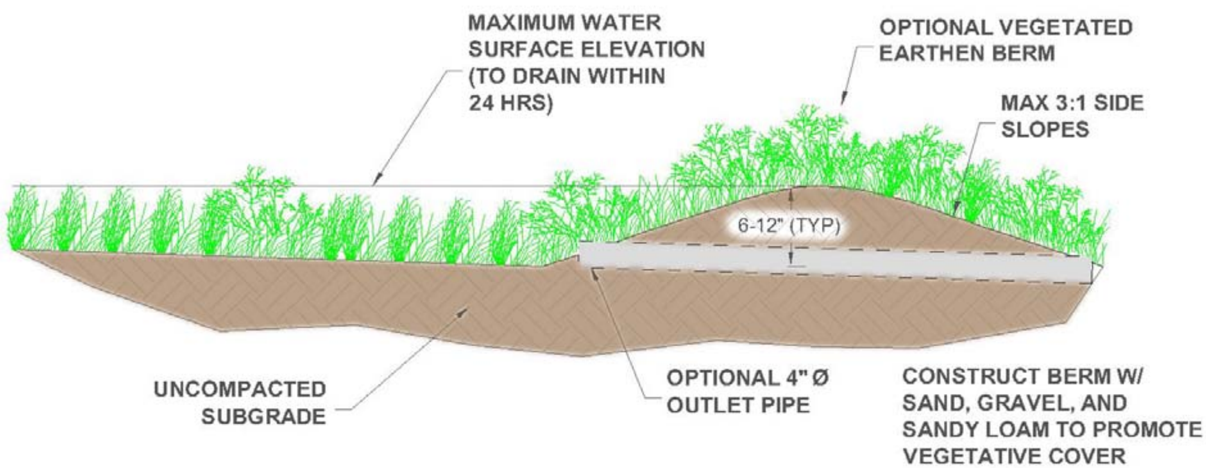


Figure 6.20-4. Earthen Berm Level Spreader at toe of filter strip

- **Outflow Level Spreader (stand alone)**
  Distribute runoff from roofs or other impervious areas of 500 square feet or more. Unless modified to approximate an Infiltration Trench, stand-alone level spreaders do not usually account for substantial volume or rate reductions. However, if designed and installed properly, they still represent effective flow diffusion/infiltration devices with water quality benefits.

Figure 6.20-5. Example of stand-alone Outflow Level Spreader in shallow trench in the woods

Applications

- **Ultimate outlet from structural BMPs**
- **Roof downspout connections (roof area > 500sf**
- **Inlet connections (impervious area > 500sf)**
- **Inflow to structural BMP, such as filter strip, infiltration basin, vegetated swale**

Design Considerations

1. It is always preferable to not initially concentrate stormwater and provide as many outfalls as possible. This can reduce or even eliminate the need for engineered devices to provide even distribution of flow.

2. Receiving soils and land cover should be undisturbed, else sufficiently stabilized with erosion

control matting or compost blanketing. Level spreaders are not applicable in areas with easily erodable soils and/or little vegetation. The slope below the level spreader shall be relatively smooth in the direction of flow to discourage channelization. The minimum length of the receiving area shall be 75 feet.

3. For design considerations of earthen berm level spreaders refer to BMP 6.10 Infiltration Berm.

4. Level spreaders should not be constructed in newly deposited fill dirt. Undisturbed virgin soil is much more resistant to erosion than fill.

5. Most variations of level spreader should not be used for sediment removal. Significant sediment deposition in a level spreader will render it ineffective.

6. A perforated pipe level spreader may range in size from 4 to 12 inches in diameter. The pipe is typically laid in an aggregate envelope, the thickness of which is left to the discretion of the Engineer. As previously stated, a deeper trench will provide additional volume reduction and shall be included in such calculations (see BMP 6.4 Infiltration Trench). Non-woven geotextile is typically placed below the aggregate to discourage clogging by sediment. Leaf litter may be used as an alternative to aggregate.

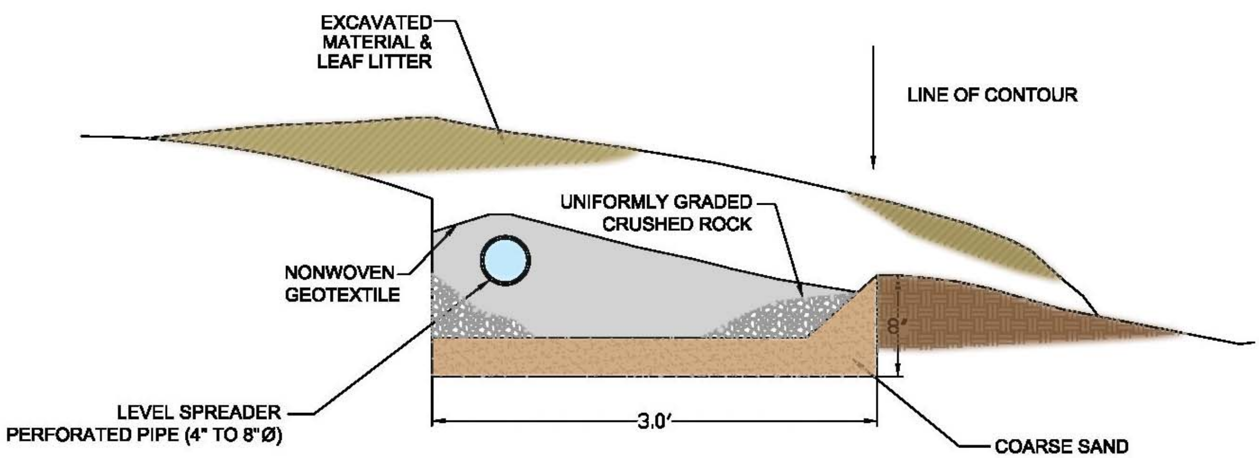


Figure 6.20-6. Example of Level Spreader Pipe

7. The length of level spreaders is primarily a function of the calculated influent flow rate. The level spreader shall be long enough to freely discharge the desired flow rate. At a minimum, the desired flow rate shall be that resulting from a 10-year design storm. This flow rate shall be safely diffused without the threat of failure (i.e. creation of erosion, gullies, or rills). Diffusion of the storms greater than the 10-year storm is possible only if space permits. Generally, level spreaders should have a minimum length of ten feet and a maximum length of 200 feet.

Conventional level spreaders designed to diffuse all flow rates shall be sized based on the following:

For grass or thick ground cover vegetation:

a) 13 linear feet of level spreader for every 1 cfs flow
b) Slopes of 8% or less from level spreader to toe of slope

For forested areas with little or no ground cover vegetation:

a) 100 linear feet of level spreader for every 1 cfs flow
b) Slopes of 6% or less from level spreader to toe of slope

For slopes up to 15% for forested areas and 25% for grass or thick ground cover, level spreaders may be installed in series. The above recommended lengths shall be followed.

The length of a perforated pipe level spreader may be further refined by determining the perforation discharge per linear of pipe. A level spreader pipe shall safely discharge in a distributed manner at the same rate of inflow. Perforated pipe manufacturers' specifications provide the discharge per linear foot of pipe, though it is typically based on the general equation for flow through an orifice. Manufacturer's specifications can be used to find the right combination of length and size of pipe. If the number of perforations per linear foot (based on pipe diameter) and average head above the perforations are known, then the flow can be determined by the following equation:

L (length of level spreader pipe) = Q_P / Q_L

Q_L (discharge per linear foot) = Q_O * # of perforations per linear foot of pipe (provided by manufacturer, based on pipe diameter)

Q_O (perforation flow rate) = $C_d * A * (2 * g * H)^{\wedge 0.5}$

Q = the free outfall flow rate through one perforation (ft^3/sec)
C_d = Coefficient of discharge (typically 0.60)
A = Cross sectional area of one perforation (ft^2)
g = 32.2 ft/sec^2
H = head, average height of water above perforation (ft) (provided by manufacturer)

For example, the 10- and 100-year design flows for a site were determined to be 2 and 5 cfs, respectively. Assuming a 12-in diameter pipe with thirty-six 0.375-in. diameter perforations per linear foot and an H value of 0.418 feet, the discharge per linear foot is calculated at 0.086 cfs/ft. When the two design flows are divided by the discharge per linear foot, the resulting required lengths are 24 and 59 feet, respectively.

This calculation assumes a free flow condition. Since the level spreader pipe is encased in aggregate (which is around 40% void space) this assumption is usually acceptable. However, for this reason and to account for the potential for clogging of perforations over time, the length of pipe should be multiplied by minimum factor of safely of 1.1.

8. Flows (> 10-year storm peak rate) may bypass a level spreader in a variety of ways, including an overflow structure or up-turned ends of pipe. (The ends of the perforated pipe could be turned uphill at a 45-degree angle or more with the ends screened.) Cleanouts/overflow structures with open grates can also be installed along longer lengths of perforated pipe. The designer shall provide stabilization measures for bypassed flows in a manner consistent with the Pennsylvania Erosion and Sedimentation Pollution Control Program Manual.

9. Erosion control matting or compost blanketing is recommended immediately downhill and along the entire length of the level spreader, particularly in those areas that are unstable or have been recently disturbed by construction activities. Generally, low flows that are diffused by a level spreader do not require additional stabilization on an already stabilized and vegetated slope. The installation requirements for erosion control methods will vary according to the manufacturer's specifications.

   There are a variety of permanent erosion control alternatives to riprap currently on the market. Erosion control/reinforcement matting is a manufactured product that combines vegetative growth and synthetic materials to reduce the potential for soil erosion on slopes. It is typically made of synthetic materials that will not biodegrade and will create a foundation for plant roots to take hold, extending the viability of grass beyond its natural limits.

   Compost blankets are an emerging technology that serves a similar function to permanent erosion control matting. When compost is applied as a "blanket" over a disturbed area, it encourages a thicker, more permanent vegetative cover due to its ability to improve the infrastructure of the soil. Compost blankets reduce runoff volume by holding water in its pores and improve water quality by binding and degrading specific chemical contaminants.

Figures 6.20-7 and 6.20-8. Examples of Compost Blanket (Filtrexx) and Permanent Erosion Control Jute Matting (North American Green website)

Detailed Stormwater Functions

Volume Reduction Calculations

In general, level spreaders do not substantially reduce runoff volume. However, for level spreaders designed similar to Infiltration Trenches, a volume reduction can be achieved. Also, for level spreaders serving as stand-alone BMPs (for contributing impervious areas greater than 500 square feet), volume reduction credits, as discussed in BMPs 5.11 and 5.12, can be achieved for runoff disconnection. The true amount of volume reduction will depend on the length of level spreader, the density of vegetation, the downhill length and slope, the soil type of the receiving area, and the design runoff. Large areas with heavy, dense vegetation will absorb most flows, while barren or compacted areas will absorb limited amounts of runoff. See Section 9 for detailed calculation methodologies.

Peak Rate Mitigation Calculations

The influent peak rate to a level spreader will be diffused (or dissipated) over the length of the level spreader; the number of perforations in a level spreader pipe will essentially divide the concentrated flow into many smaller flows. To be conservative, and to allow for the possibility of re-convergence, the peak rate should be taken prior to diffusion from the level spreader. See Section 9 for detailed calculation methodologies.

Water Quality Improvement

Water quality improvements occur if the area down gradient of the level spreader is vegetated, stabilized, and minimally sloped. See Section 9 for Water Quality Improvement methodology, which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Level spreaders are considered a permanent part of a site's stormwater management system. Therefore, the uphill development should be stabilized before any dispersing flow techniques are installed. (If the level spreader is used in the as erosion and sedimentation control measure, it must be reconfigured (flush perforated pipe, clean out all sediment), to its original state before use as a permanent stormwater feature.)

2. All contributing stormwater elements (infiltration beds, inlets, outlet control structures, pipes, etc) shall be installed.

3. Perforated pipe should be installed along a contour, with care taken to construct a level bottom. The pipe can be underground in a shallow infiltration trench (see Infiltration Trench for design guidance), or closer to the surface and covered with a thin layer of aggregate or leaf litter. If the perforated pipe is in a trench, excavate to the design dimensions. If the pipe is to be at or near the surface, some minor excavation or filling may be necessary to maintain a level bottom.

4. If necessary, install erosion control matting along the length of the level spreader and to a distance downhill, as specified by the manufacturer/supplier. Cover the pipe with clean, uniformly graded coarse aggregate (if on the ground surface).

5. For construction sequence of earthen berms, see BMP 6.10 Infiltration Berm.

Maintenance Issues

Compared with other BMPs, level spreaders require only minimal maintenance efforts, many of which may overlap with standard landscaping demands. The following recommendations represent the minimum maintenance effort for level spreaders:

- Catch Basins and Inlets draining to level spreader should be inspected and cleaned on an annual basis.

- The receiving land area should be restored after construction if damaged, to reflect design assumptions about the soil and land cover.

- It is critical that even **sheet flow conditions** are sustained throughout the life of the level spreader, as their effectiveness can deteriorate due to lack of maintenance, inadequate design/location, and poor vegetative cover.

    - **Inspection** - The area below a level spreader should be inspected for clogging, density of vegetation, damage by foot or vehicular traffic, excessive accumulations, and channelization. Inspections shall be made on a quarterly basis for the first two years following installation, and then on a biannual basis thereafter. Inspections shall also be made after every storm event greater than 1-inch during the establishment period.

    - **Removal** - Sediment and debris shall be routinely removed (but never less than bi-annually), or upon observation, when buildup occurs in the clean outs. Regrading and reseeding may be necessary in the areas below the level spreader. Regrading may also be required when pools of standing water are observed along the slope. (In no case shall standing water be tolerated for longer than 72 hours.)

    - **Vegetation** - Maintaining a vigorous vegetative cover on the areas below a level spreader is critical for maximizing pollutant removal efficiency and erosion prevention. If vegetative cover is not fully established within the designated time, it may need to be replaced with an alternative species. (It is standard practice to contractually require the contractor to replace dead vegetation.) Unwanted or invasive growth shall be removed on an annual basis. Biweekly inspections are recommended for at least the first growing season, or until the vegetation is permanently established. Once the vegetation is established, inspections of health, diversity, and density shall be performed at least twice per year, during both the growing and non-growing season. Vegetative cover should be sustained at 85% and reestablished if damage greater than 50% is observed.

Cost Issues

As there are various types of level spreaders, their associated costs will vary. Generally speaking, level spreaders are relatively easy to construct and inexpensive, especially when compared to riprap. Per foot material and equipment cost will range from $5 to $20 depending on the type of level spreader desired. Concrete level spreaders may cost significantly more than perforated pipes or berms. (For more detailed cost information in BMP 6.4 Infiltration Trenches and BMP 6.10 Infiltration Berms.)

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Stone** shall be 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size number 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids ≥ 35% as measured by ASTM-C29.

2. **Non-Woven Geotextile** shall consist of needled non-woven polypropylene fibers and meet the following properties:
   a. Grab Tensile Strength (ASTM-D4632) ≥ 120 lbs
   b. Mullen Burst Strength (ASTM-D3786) ≥ 225 psi
   c. Flow Rate (ASTM-D4491) ≥ 95 gal/min/ft^2
   d. UV Resistance after 500 hrs (ASTM-D4355) ≥ 70%
   e. Heat-set or heat-calendared fabrics are not permitted

   Acceptable types include Mirafi 140N, Amoco 4547, and Geotex 451.

3. **Topsoil** amend with compost (See BMP 6.19, Soil Amendment & Restoration)

4. **Pipe** shall be solid or continuously perforated, smooth interior, with a minimum inside diameter of 4-inches. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S.

5. **Vegetation** see Native Plant List in Appendix B.

References

Maine BMP Manual

NC Division of Water Quality

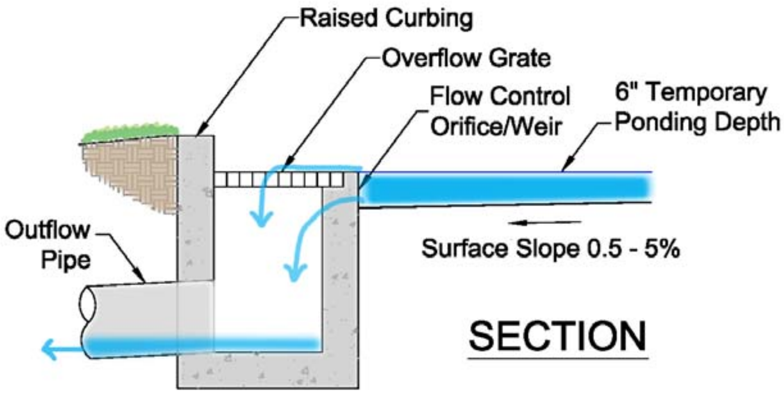
Idaho Catalog of Stormwater Best Management Practices

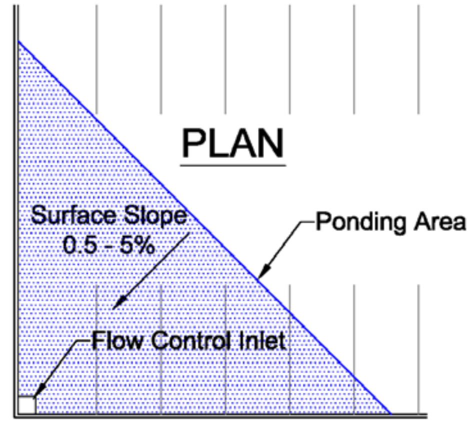
Australia EPA (www.environment.sa.gov.au/epa/pdfs/bccop1.pdf)

US EPA, NPDES, *Construction Site Storm Water Runoff Control – Permanent Diversions*

Designing Level Spreaders to Treat Stormwater Runoff (W.F. Hunt, D.E. Line, R.A. McLaughlin, N.B. Rajbhandari, R.E. Sheffield; North Carolina State University, 2001.)

Other BMPs and Related Structural Measures
BMP 6.21: Special Detention Areas - Parking Lot, Rooftop





Areas such as parking lots and rooftops that are primarily intended for other uses but that can be designed to temporarily detain stormwater for peak rate mitigation.

Key Design Elements

- Almost entirely for peak rate control
- Water quality and quantity are not addressed
- Short duration storage; rapid restoration of primary uses
- Minimize safety risks, potential property damage, and user inconvenience
- Emergency overflows
- Maximum ponding depths
- Flow control structures
- Adequate surface slope to outlet
- Waterproofing (rooftop storage)

Potential Applications

Residential:	**LIMITED**
Commercial:	**YES**
Ultra Urban:	**YES**
Industrial:	**YES**
Retrofit:	**YES**
Highway/Road:	**LIMITED**

Stormwater Functions

Volume Reduction:	**Very Low**
Recharge:	**Very Low**
Peak Rate Control:	**Med./Low**
Water Quality:	**Low**

Pollutant Removal

TSS:	**0%**
TP:	**0%**
NO_3:	**0%**

Description

Special Detention Areas are places such as parking lots and rooftops that are primarily intended for other uses but that can be designed to temporarily detain stormwater for peak rate mitigation. Generally detention is achieved through the use of a flow control structure that allows runoff to temporarily pond. In most cases, ponding depths should be kept less than one foot. Special Detention Areas can be very effective at reducing peak rates of runoff but do little in terms of water quality and almost nothing to reduce the volume of runoff. Therefore, Special Detention Areas should be combined with other BMPs that address water quality, quantity, and groundwater recharge.

Variations

Special Detention is especially suited for:

- Large gently-sloping parking lots

Figure 6.21-1. Potential Application of Parking Lot Storage

- Flat rooftops

Figure 6.21-2. Potential Application of Rooftop Storage

- Recessed plazas

Figure 6.21-3. Potential Application of Plaza Storage

- Athletic fields

Figure 6.21-4. Potential Application of Athletic Field Storage

Applications

Detention areas can be created in parking lots in depressed areas or along curbs by controlling flow at stormwater inlets and/or using raised curbing. Rooftop runoff storage can be achieved by restricting flow at scuppers, drains, parapet wall openings, etc. Recessed plazas and athletic fields can be designed with detention through the use of flow control structures and/or berms (for fields). Special Detention Areas can be used effectively to attenuate flows reaching other BMPs and thereby increase their performance; they can also be used to meet release rate requirements from Act 167 plans or municipal ordinances.

Design Considerations

1. General

    a. Emergency overflows should be designed to prevent excessive depths from occurring during extreme events or if the primary flow control structures are clogged. Emergency overflows must be designed to safely convey flows downstream.
    b. Storage areas should be adequately sloped towards outlets to ensure complete drainage after storm events.
    c. Flow control structures should be designed to discharge stored runoff in a timely manner so that the primary use of the area can be restored.

2. Parking Lot Storage

    a. Locate storage in areas so that ponding will not significantly disrupt typical traffic or pedestrian flow. Remote areas of large commercial parking lots, overflow parking areas, and other under-utilized parking areas are prime locations.
    b. Minimize potential safety risks and property damage due to ponding. Detention areas should be identified with signage or pavement markings or their use should be restricted during storms.
    c. Storage depths must be no greater than 1 foot.
    d. The area used for detention should be sloped towards the flow control structure at a least 0.5% to ensure adequate drainage after storms. Slopes greater than 5% tend to be inefficient because storage volume is much lower for a given ponding depth.

3. Rooftop Storage

    a. The roof structure must be able to support the additional load created by ponded water. Most roofs designed for snow load will be able to support runoff storage.
    b. Ponding depths should generally be less than 6 inches and stored water should not cause damage to any HVAC equipment on the roof.
    c. The areas utilized for storage must have adequate waterproofing.
    d. Emergency overflows can be provided by openings in the parapet wall or by additional drains.

Detailed Stormwater Functions

Volume Reduction Calculations

Special Detention Areas generally do not achieve significant volume reduction.

Peak Rate Mitigation Calculations

Peak rate of runoff is reduced in Special Detention Areas through the transient storage provided. See in Section 9 for Peak Rate Mitigation methodology.

Water Quality Improvement

Although they may provide some quality improvement through settling, Special Detention Areas do not appreciably address water quality.

Construction Sequence

Not applicable.

Maintenance Issues

Special Detention Areas generally require little maintenance. Maintenance activities should include inspection and cleaning of flow control structures, clearing debris/sediment from detention areas (as necessary), and inspecting waterproofing in rooftop storage areas.

Cost Issues

Special Storage Areas can be a very economical means of reducing peak rates of runoff because they require little additional material and take up no additional space on a site.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. Flow Control Structures

    a. Flow control structures shall be constructed of non-corrodible material.
    b. Structures shall be resistant to clogging by debris, sediment, floatables, plant material, or ice.
    c. Materials shall comply with applicable specifications (PennDOT or AASHTO, latest edition)

2. Waterproofing

    a. Waterproofing shall prevent all water migration into the building.
    b. Waterproofing must comply with applicable state and local building codes.
    c. Waterproofing shall have an expected service life of at least 25 years.

References

2001, Georgia Stormwater Management Manual; Volume Two: Technical Handbook

2003, Ontario Stormwater Management Planning & Design Manual

Iowa Statewide Urban Design Standards Manual

1992, Michigan - Index of Individual BMPs

6.9 Protocols for Structural BMPs

6.9 Protocols for Structural BMPs

Protocol 1: Infiltration Systems Guidelines

Role of Infiltration BMPs

The phrase "infiltration BMPs" describes a wide range of stormwater management practices aimed at infiltrating some fraction of stormwater runoff from developed surfaces into the soil horizon and eventually into deeper groundwater. In this manual the major infiltration strategies are grouped into four categories or types, based on construction and performance similarities:

- Surface Infiltration Basins
- Subsurface Infiltration Beds
- Bioretention Areas/Rain Gardens
- Other BMPs that support infiltration (vegetated filter/buffer strips, level spreaders, and vegetated swales)

Infiltration BMPs are one of the most beneficial approaches to stormwater management for a variety of reasons including:

- Reduction of the peak rate of runoff
- Reduction of the volume of runoff
- Removal of a significant portion of the particulate-associated pollutants and some portion of the solute pollutants.
- Recharge of groundwater and maintenance of stream baseflow.

Quantitatively, infiltration BMPs replicate the natural hydrologic regime. During periods of rainfall, infiltration BMPs reduce the volume of runoff and help to mitigate potential flooding events. During periods of reduced rainfall, this recharged water serves to provide baseflow to streams and maintain in stream water quality. Qualitatively, infiltration BMPs are known to remove nonpoint source pollutants from runoff through a complex mix of physical, chemical, and biological removal processes. Infiltration promotes maintenance of the natural temperature regimes of stream systems (cooler in summer, warmer in winter), which can be critical to the aquatic ecology. Because of the ability of infiltration BMPs to reduce the volume of runoff, there is also a corresponding reduction in erosive "bankfull" conditions and downstream erosion and channel morphology changes.

Infiltration BMPs are designed to infiltrate some portion of runoff during every storm event. During small storm events, a large percentage of the runoff may infiltrate, whereas during large storm events, the volume that infiltrates may only be a small portion of the total runoff. However, because most of the rainfall in Pennsylvania occurs in small (less than 1-inch) rainfalls, the annual benefits of an infiltration system may be significant.

Purpose of Protocol 1 Infiltration Systems Guidelines

The purpose of this protocol is to provide the designer with specific guidelines for the successful construction and longterm performance of Infiltration BMPs. These guidelines fall into three categories:

1. Site conditions and constraints
2. Design considerations
3. Construction requirements

All of these guidelines are important, and successful infiltration is dependent on careful consideration of site conditions, careful design, and careful construction.

1. SITE CONDITIONS and CONSTRAINTS

a) It is desirable to **maintain at least a 2-foot clearance above the seasonally high water table**. This assures unimpeded permeability in the sub-soil, and allows sufficient distance of water movement through the soil to assure adequate pollutant removal.

b) Maintain a minimum depth to bedrock of 2-feet to assure adequate pollutant removal. In special circumstances, filter media may be employed to remove pollutants if adequate soil mantle does not exist.

c) It is desired that **soils underlying infiltration devices should have infiltration rates between 0.1 and 10 inches per hour**, which in most development programs should not result in an infiltration system which is excessively sized. Where soil permeability is extremely low, infiltration is possible but the surface area required may be large, and other volume reduction methods may be required. Undisturbed Hydrologic Soil Groups B and C often fall within this range and cover most of the state. Soils with rates in excess of 6.0 inches per hour may require an additional soil buffer (such as an organic layer over the bed bottom) if the Cation Exchange Capacity (CEC) is less than 5. In carbonate soils, excessively rapid drainage may increase the risk of sinkhole formation, and some compaction or additional soil may be appropriate.

d) Infiltration BMPs should be sited so that they present no threat to groundwater quality, at least 50 feet from individual water supply wells, and 100 feet from community or municipal water supply wells. Horizontal separation distances or buffers may also be appropriate from Special Geologic Features, such as fractures traces and faults, depending on water supply sources.

e) Infiltration BMPs should be sited so that they present no threat to sub-surface structures, at least 20 feet downgradient or 100 feet upgradient from building basement foundations, and 50 feet from septic system drainfields.

In general, soils of Hydrologic Soil Group D will not be suitable for infiltration. Similarly, areas of floodplains and areas of close proximity to wetlands and streams will not be suitable for infiltration. In developing areas that were previously used for agricultural purposes, the designer should consider the past patterns of land use. Areas that were suitable for cultivation will likely be suitable for some level of infiltration. Areas that were left out of cultivation often indicate locations that are too wet or too rocky, and will likely not be suitable for infiltration.

2. DESIGN CONSIDERATIONS

a) Do Not Infiltrate in Compacted Fill. Infiltration in native soil without prior fill or disturbance is preferred but not always possible**.** Areas that have experienced historic disturbance or fill are suitable for infiltration provided sufficient time has elapsed and the Soil Testing indicates the infiltration is feasible. In disturbed areas it may be necessary to infiltrate at a depth that is beneath soils that have previously been compacted by construction methods or long periods of mowing, often 18-inches.

b) A Level Infiltration Area (1% or less slope) is preferred. Bed bottoms should always be graded into the existing soil mantle, with terracing as required to construct flat structures. Sloped bottoms tend to pool and concentrate water in small areas, reducing the overall rate of infiltration and longevity of the BMP. Infiltration areas should be flat or nearly so.

c) The soil mantle should be preserved to the maximum extent possible, and excavation should be minimized. Those soils that do not need to be disturbed for the building program should be left undisturbed. Macropores provide the primary mechanism for water movement in infiltration systems, and the extent of macropores often decreases with depth. Therefore, excessive excavation for the construction of infiltration systems is strongly discouraged.

d) Isolate "hot spot areas". Site plans that include 'hot spots' need to be considered. 'Hot spots' are most often associated with some industrial uses and high traffic – gasoline stations, vehicle maintenance areas, and high intensity commercial uses (fast food restaurants, convenience stores, etc.). These "hot spots" are defined in the Section 3.3, Stormwater Standards for Special Areas. Infiltration may occur in areas of hot spots provided pretreatment is suitable to address concerns. Pretreatment requirements need to be analyzed, especially for 'hot spots' and areas that produce high sediment loading. Pretreatment devices that operate effectively in conjunction with infiltration include grass swales, vegetated filter strips, settling chambers, oil/grit separators, constructed wetlands, and sediment sumps. Selection of pretreatment should be guided by the pollutants of greatest concern, site by site, depending upon the nature and extent of the land development under consideration. Selection of pretreatment techniques will vary depending upon whether the pollutants are of a particulate (sediment, phosphorus, metals, etc.) versus soluble (nitrogen and others) nature. Types of pretreatment (i.e., filters) should be matched with the nature of the pollutants expected to be generated.

e) The Loading Ratio of impervious area to bed bottom area must be considered. One of the more common reasons for infiltration system failure is the design of a system that attempts to infiltrate a substantial volume of water on a very small area. Infiltration systems work best when the water is "spread out". The Loading Ratio describes the ratio of imperious drainage area to infiltration area, or the ratio of total drainage area to infiltration area. In general, the following Loading Ratios are recommended:

- A Loading Ratio of 5:1 relating impervious drainage area to infiltration area.
- A Loading Ratio of 8:1 relating total drainage area to infiltration area.

f) The Hydraulic Head or Depth of Water should be limited. The total effective depth of water should generally not be greater than two feet to avoid compaction of the bed bottom. Often the water depth is limited by the Loading Ratio and Drawdown Time and is not an issue.

g) Drawdown Time must be considered. In general, infiltration BMPs should be designed so that infiltration occurs within a 72-hour period in most situations.

h) All infiltration BMPs should be designed with a positive overflow that discharges excess volume in a non-erosive manner, and allows for controlled discharge during extreme rainfall events or frozen bed conditions. Infiltration BMPs should never be closed systems dependent entirely upon infiltration in all situations.

i) **Geotextiles must be incorporated into the design as necessary in certain infiltration BMPs**. Infiltration BMPs that are subject to soil movement and deposition must be constructed with suitably well-draining non-woven geotextiles to prevent to movement of fines and sediment into the infiltration system. The designer is encouraged to err on the side of caution and use geotextiles as necessary at the soil/BMP interface.

3. CONSTRUCTION REQUIREMENTS

a) **Do not compact soil infiltration beds during construction**. Prohibit all heavy equipment from the infiltration area and minimize all other traffic. Equipment use should be limited to vehicles that will not cause compaction, such as tracked vehicles.

b) **Protect the infiltration area from sediment until the surrounding site is completely stabilized.** Methods to prevent sediment from washing into BMPs should be clearly shown on plans. Where geo-textile is used as a bed bottom liner, this should be extended several feet beyond the bed and folded over the edge to protect from sediment wash into the bed during construction, and then trimmed. Runoff from construction areas should never be allowed to drain to infiltration BMPs. This can usually be accomplished by diversion berms and immediate vegetative stabilization. The infiltration area may be used as a temporary sediment trap or basin during earlier stages of construction. However, if an infiltration area is also to be utilized as a temporary sediment basin, excavation should be limited to within 1 foot of the final bottom invert of the infiltration BMP to prevent clogging and compacting the soil horizon, and final grade removed when the contributing site is fully stabilized. All infiltration BMPs should be finalized at the end of the construction process, when upstream soil areas have a dense vegetative cover.

c) **Provide thorough construction oversight.** Long-term performance of infiltration BMPs is dependent on the care taken during construction. Plans and specifications must be followed precisely. The designer is encouraged to meet with the contractor to review the plans and construction sequence prior to construction, and to inspect the construction at regular intervals and prior to final acceptance of the BMP.

d) **Provide Quality Control of Materials.** As with all BMPs, the final product is only as good as the materials and workmanship that went into it. The designer is encouraged to review and approve materials and workmanship, especially as related to aggregates, geotextiles, soil and topsoil, and vegetative materials.

BMP Effectiveness

Infiltration BMPs produce excellent pollutant removal effectiveness because of the combination of a variety of natural functions contained within the soil mantle, complemented by existing vegetation (where this vegetation is preserved). Soil functions include physical filtering, chemical interactions (e.g., ion exchange, adsorption), as well as a variety of forms of biological processing, conversion, and uptake. The inclusion of native vegetation as filter strips, recharge gardens, and some vegetated infiltration basins, reinforces the work of the soil by reducing velocity and erosive forces, soil anchoring, and further uptake of nonpoint source pollutants. In many cases, even the more difficult-to-remove soluble nitrates can be reduced as well. It should be noted that infiltration BMPs tend to be excellent for removal of many pollutants, especially those that are in particulate form; however, there are limitations to the removal of highly solubilized pollutants, such as nitrate, which can be transmitted through the soil.

In addition to the removal of chemical pollutants, infiltration can address thermal pollution. Maintaining natural temperatures in stream systems is recognized as an issue of increasing importance for protection of overall stream ecology. Detention facilities tend to discharge heated runoff flows. The return of runoff to the groundwater through use of infiltration BMPs guarantees that these waters will be returned at natural groundwater temperatures, considerably cooler than ambient air in summer and warmer in winter, so that seasonal extreme fluctuations in stream water temperature are minimized. Fish, macroinvertebrates, and a variety of other biota will benefit as the result.

Although precise data on pollutant removal efficiencies is somewhat limited, infiltration BMPs have been shown to have excellent efficiencies for a wide range of pollutants. In fact, recent EPA guidance has suggested that infiltration BMPs can be considered 100 percent effective at removing pollutants from surface water for the fraction of water that infiltrates (EPA, 1999a). Other more conservative removals are reported in a variety of other sources. Table 5-1 displays average annual pollutant removal efficiencies for infiltration BMPs that are designed for the 2-yr storm (3.1 inches / 24 hr.). BMPs that treat less than the 2-year storm may have lower efficiencies than those reported in Table 5-1 because less runoff is allowed to infiltrate.

Fate of Infiltrated Contaminants

The protection of groundwater quality is of utmost importance in any PA watershed. The potential to contaminate groundwater by infiltrating stormwater in properly designed and constructed BMPs with proper pretreatment is low, if come common sense rules are followed, as discussed above. Numerous studies have shown that stormwater infiltration BMPs have a minor risk of contaminating either groundwater or soil. Perhaps the most comprehensive research was conducted by the U.S. Environmental Protection Agency, summarized in “Potential Groundwater Contamination from Intentional and Nonintentional Stormwater Infiltration” (Pitt et al., 1994). A table is presented which identifies the potential of pollutants to contaminate groundwater as either low, low/moderate, moderate, or high. Of the 25 physical pollutants listed, only one has a “high” potential (chloride), and only two have even “moderate” potential (fluoranthene and pyrene) for polluting groundwater through the use of shallow infiltration systems with some sediment pretreatment. Pentachlorophenol, cadmium, zinc, chromium, lead, and all the pesticides listed are classified as having a “low” contamination potential. Even nitrate which is soluble and mobile (discussed further below) is only given a “low/moderate” potential.

Legret et al. (1999) simulated the long term effects of heavy metals in infiltrating stormwater and concluded that the “long-term pollution risks for both soil and groundwater are low,” and “metals are generally well retained in the upper layers of the soil (0-20 cm) [0-8 inches]…” Barraud et al. (1999) studied a thirty year-old infiltration BMP and found that both metal and hydrocarbon concentrations in the soil under the infiltration device decreased rapidly with depth “to a low level after a few decimeters down [3 decimeters = 1 foot]…” A study concerning the infiltration of highway runoff (Dierkes and Geiger, 1999) found that polycyclic aromatic hydrocarbons (PAH) were effectively removed in the upper 4 inches of the soil and that runoff that had passed through 14 inches of soil met drinking water standards for cadmium, zinc, and copper. This extremely high pollutant removal and retention capacity of soils is the result of a multitude of natural processes including physical filtering, ion exchange, adsorption, biological processing, conversion, and uptake.

Several studies have also found that porous pavement and stone-filled subsurface infiltration beds can significantly reduce the pollutant concentrations (especially hydrocarbons and heavy metals) of stormwater runoff before it even reaches the underlying soil due to adsorption, filtering, sedimentation, and bio-degradation by a diverse microbial community in the pavement and infiltration beds (Legret and Colandini, 1999; Balades et al., 1995; Swisher, 2002; Newman et al., 2002; and Pratt et al., 1999).

Common Causes of Infiltration BMP "Failures"

The concept of failure is simple – a design no longer provides the benefit or performance anticipated. With respect to stormwater infiltration BMPs, the term requires some qualification, since the net result of "failure" may be a reduction in the volume of runoff anticipated or the discharge of stormwater with excessive levels of some pollutants. Where the system includes built structures, such as porous pavements, failure may include loss of structural integrity for the wearing surface, whereas the infiltration function may continue uncompromised. For infiltration systems with vegetated surfaces, such as play fields or rain gardens, failure may include the inability to support surface vegetation, caused by too much or too little water.

The primary causes of reduced performance appear to be:

a) Poor construction techniques, especially soil compaction/smearing, which results in significantly reduced infiltration rates.
b) A lack of site soil stabilization prior to the BMP receiving runoff, which greatly increases the potential for sediment clogging from contiguous land surfaces.
c) Inadequate pretreatment, especially of sediment-laden runoff, which can cause a gradual reduction of infiltration rates.
d) Lack of proper maintenance (erosion repair, re-vegetation, removal of detritus, catch basin cleaning, vacuuming of pervious pavement, etc.), which can reduce the longevity of infiltration BMPs.

Infiltration systems should always be designed such that failure of the infiltration component does not compromise the peak rate attenuation capability of the BMP. Because the rate of design infiltration is usually extremely small in comparison to the peak flow rates during large storm events, this is usually not an issue. Because infiltration BMPs are designed to infiltrate small, frequent storms, the loss or reduction of this capability does not usually significantly impact the storage and peak rate mitigation of the BMP during extreme events.

Consideration of Infiltration Rate in Design and Modeling Application

For the purposes of site suitability, areas with tested soil infiltration rates as low as 0.1 inches per hour may be used for infiltration BMPs. However, in the design of these BMPs and the sizing of the BMP, the designer should incorporate a safety factor. For tested infiltration rates that are less than 1.0 inches per hour as determined by percolation tests, the designer should incorporate a safety factor of two in sizing and designing the BMP. Therefore a measured infiltration rate of 0.5 inches per hour should be considered as a rate of 0.25 inches per hour in design.

If several percolation tests have been conducted, an average rate should be calculated and a safety factor applied as appropriate.

As discussed in Section 9 of this Manual, infiltration systems can be modeled similarly to traditional detention basins. The marked difference with modeling infiltration systems is the inclusion of the infiltration rate, which can be considered as another outlet. For modeling purposes, it is convenient to develop infiltration rates that vary with elevation for inclusion in the Stage-Storage-Discharge table. The following equation may be used to relate infiltration rate to head:

$$I = f_c A(1.5h_{eff}+1)(1/43200)$$

where:
I = infiltration flow rate at respective storage depth, cubic feet per second
h_{eff} = storage depth - average percolation testing depth (typically 6 to 8 inches; when storage depth is less than h_{eff}, consider h_{eff} equal to zero), feet
A = bed bottom area, square feet (side slopes are generally not considered in calculation to be conservative)
f_c = minimum infiltration rate, inches per hour (reduced by safety factor)

References

Balades et al., 1995.

Barraud et al. 1999.

Dierkes and Geiger, 1999.

EPA, 1999a.

Legret and Colandini, 1999.

Legret et al. 1999.

Newman et al., 2002.

Pitt et al., 1994. "Potential Groundwater Contamination from Intentional and Nonintentional Stormwater Infiltration"

Pratt et al., 1999.

Swisher, 2002.

Protocol 2. Soil Evaluation and Investigation for Infiltration BMP's

Purpose of this Protocol

The Soil Evaluation and Testing for Infiltration BMP's Protocol is a critical component of the design of infiltration BMP's and is intended to be used in conjunction with another protocol, Guidelines for Infiltration Systems. Generally, the purpose of the Guidelines for Infiltration Systems is to provide a methodology for the stormwater designer to determine if infiltration BMP's are feasible at a site to design those systems properly. The purpose of the Soil Evaluation and Investigation Protocol is to obtain the required data for infiltration BMP design. This process will also assist the designer in the appropriate selection and location of infiltration BMP's at a site.

The Guidelines for Infiltration Systems includes a general Site Evaluation process (also discussed in Section 4) intended to assist the designer in determining the appropriate location for BMP's, including Infiltration BMP's. This initial site evaluation includes the following steps:

1. Identify soil types and locations
2. Identify site conditions that affect Infiltration BMP design
3. Identify areas suitable for infiltration BMP's
4. Identify areas not suitable for Infiltration BMP's

Based on the initial evaluation of areas that may be suitable for infiltration, detailed testing can then be performed. This detailed testing includes the following steps:

1. Conduct Soil Investigation Tests (Deep Hole Tests)
2. Conduct Soil Infiltration Rate Tests

All Soil Evaluation and Infiltration Investigation shall be performed under the supervision of a professional Soils Scientist, Engineer, or Geologist licensed in the State of Pennsylvania.

Designers are encouraged to conduct Soil Evaluation and Investigation early in the site planning and design process. Full build-out of site areas otherwise deemed to be suitable for infiltration does not provide an exemption or waiver from volume control, which can be provided through cost effective infiltration BMP's. Testing site soils and understanding how the site is functioning is fundamentally important early on in the site planning process, and municipalities are encouraged to require completion of all testing prior to Preliminary Plan approval.

The Site Planning and Design Process: Site Evaluation for Infiltration BMP's and Their Location

As part of the site planning and design process, existing conditions at the site should be inventoried and evaluated including, but not limited to:

- Existing soils and USDA Hydrologic Soil Group classifications
- Existing geology, including the location of any dikes, contacts, or other features of note
- Existing streams (perennial and intermittent, including intermittent swales), water bodies, wetlands, hydric soils, floodplains and alluvial soils, stream classifications, headwaters and 1st order streams
- Existing topography, slope, drainage patterns

- The proposed layout plan for development
- The location of all existing and proposed water supply sources and wells.
- The location of all existing and proposed on-site wastewater systems.
- The location of any other features of note such as utility right-of-ways.

The designer should research existing soil conditions at the project site prior to testing, including soil formation, series associations, soils descriptions, Hydrologic Soil Group classification, and so forth. Especially important are limiting factors such as depth to bedrock and depth to seasonal high water table, as well as any published information relating to the rated permeability of the soil type, lacking any actual soil testing results from the site itself. Any additional data available, such as structural boring data, should also be considered. All available information should be compiled and overlaid on the site plan, with feasibility constraints clearly marked. As the result of this process, the designer shall determine the preliminary location and type of infiltration BMP's for the proposed development plan, assuming feasibility. The approximate location of these infiltration BMP's shall be located on the Proposed Development Plan. The approximate locations for infiltration BMP's shall serve as the basis for the location and number of tests to be performed, as set forth below.

Types of Soil Investigation

All soils tests shall include both Test Pits (Deep Holes) and Infiltration Rate tests. The use of Test Pits is strongly encouraged as a Test Pit allows the Designer to visually observe the soil horizons and overall soil conditions both horizontally and vertically in that general area of the site. An extensive number of Test Pit observations can be made across a site at a relatively low cost and in a short time period. This provides the designer with a valuable understanding of site conditions. The use of soil borings as a substitute for Test Pits is discouraged, as the available area for visual observation is narrowly limited.

1. Test Pits (Deep Holes)
A Deep Hole shall consist of a backhoe-excavated trench, 2-1/2 to 3 feet wide, to a depth of between 72 inches and 90 inches, or until bedrock is encountered. The trench should be benched at a depth of 2-3 feet for access and/or multiple percolation tests. Soil horizons are to be identified and described in depth (in inches) from the surface.

At each Deep Hole, the following conditions shall be noted:

- Upper and Lower boundary of Horizon, soil textural class, soil texture modifier (if applicable), estimated type, percent and size of coarse fragments, soil color, color patterns (mottling), pores, roots, soil and/or rock structure, consistency.
- Name, date, elevation, location, test number, equipment used, depth to water, depth to bedrock, geology, soil map unit, land use, additional comments.

At the Engineer's discretion, soil samples may be collected at various horizons for additional analysis. Following testing, the deep holes are to be refilled with the original soil and the surface replaced with the original topsoil.

The Form shown in Figure 6.8-1 may be used for documentation of each Deep Hole.

Figure 1 Deep Hole Test Indicating Multiple Horizons.

It is important that the Deep Hole provide information related to conditions at the bottom of the proposed Infiltration BMP. If the BMP depth will be greater than 90 inches below existing grade, deeper excavation will be required. The Designer is cautioned regarding the proposal of systems that are significantly lower than the existing topography, as the suitability for infiltration is likely to decrease. The Designer is encouraged to consider reducing grading and earthwork as needed to reduce site disturbance and provide greater opportunity for stormwater management.

Figure 2 Deep Hole Test

2. Infiltration Tests

There are several techniques for determining the infiltration capacity of a soil. Fields tests are strongly encouraged, while laboratory tests are strongly discouraged, as laboratory testing cannot adequately evaluate the macropore system in a soil. Macropores occur primarily in the upper soil horizons and are formed by plant roots (both living and decaying), soil fauna such as insects, the weathering processes caused by the movement of water, the freeze-thaw cycle, soil shrinkage due to desiccation of clays, chemical processes, and other mechanisms. These macropores provide an important mechanism for infiltration prior to development, extending vertically and horizontally for considerable distances. It is the intent of good engineering and design practice to maintain these macropores in the installation of Infiltration BMPs.

When a sample is taken to the laboratory and evaluated for hydraulic conductivity based on a homogeneous sample, the macropore system is compromised. Darcy's Law is based on the assumption of a homogeneous soil sample and cannot be used to adequately represent the movement of water through macropores. While macropores may represent a small percentage of total porosity, they allow for significant movement of water through natural soil systems. For this reason, infiltration tests should be conducted in the field.

Infiltration tests may consist of:

- Percolation tests (such as for on-site wastewater systems and Pa Chapter 73 (ref))
- Infiltrometer or Double-ring Infiltrometer tests
- ASTM 2003 Volume 4.08, Soil and Rock (I): Designation D 3385-03, Standard Test Method for Infiltration Rate of Soils in Field Using a Double-Ring Infiltrometer.
- ASTM 2002 Volume 4.09, Soil and Rock (II): Designation D 5093-90, Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring.

There are differences between the methods. An Infiltrometer test measures the movement of water through the bottom of the test area, whereas a percolation test allows water movement through both the bottom and sides of the test area. For this reason, infiltrometer tests are considered to be a more conservative, and possibly more accurate, estimate of potential infiltration capability.

The limitation of Infiltrometer tests is that the required equipment can be costly, and an infiltrometer is required for every test location. For a site with multiple test locations, such as a residential development considering on-lot infiltration, the testing requirements can be extensive. For this reason the continued use of percolation tests should be considered acceptable. Multiple percolation tests can be performed to provide a broader perspective of site soil conditions. The rate of infiltration may also be affected by the head of water. However, for the methodologies described herein, the effects are negligible.

Number and Location of Tests Required

Based upon the proposed location of BMPs, Soil Evaluation and Investigation shall be conducted. All soils tests shall include both Test Pits (Deep Holes) and Infiltration Rate tests. Deep Hole Tests shall be required as follows:

- For single-family residential subdivisions, one test pit per lot is required at proposed BMP

location.
- For large infiltration areas (commercial, institutional, industrial, and other proposed land uses), multiple test pits should be evenly distributed at the rate of four (4) to six (6) tests per acre of BMP area.
- Additional tests should be conducted if local conditions indicate significant variability in soils, geology, topography, etc.

Infiltration Tests are required at the rate of two per Deep Hole. The Designer is encouraged to perform at least one test at the proposed bed bottom elevation (if known). Tests may be performed in different soil horizons to provide the Designer with additional information.

Infiltration tests should not be conducted in the rain or within 24 hours of significant rainfall events (>0.5 inches).

Background Materials/Actions Needed for Soils Tests

1. PA OneCall 1-800-242-1776 or www.paonecall.org

Soil investigators are required to contact PA-OneCall to have the existing utilities marked in proposed testing locations at least 3 business days prior to digging.

Below is a list of questions you will be asked when you call (blue = required questions). The location of existing underground utilities may affect the proposed test pits locations. Prior to field-testing, have alternative test pit sites marked on the plan in the event that underground utilities lie within in your test pit locations.

- What is your telephone number with the area code first?
- Your name?
- If you have not called in before, you will be asked for company information.
- Who is the contact person at the dig site? Their phone number?
- What is the best time to call the contact person?
- In what county will the work be done?
- In what city, twp or borough will the work be done?
- In Erie, Pgh, Allentown or Phila, What is the ward #.
- What is the starting address number?
- What is the ending address number?
- What is the street name for the work site?
- What is the nearest intersecting street name?
- Do you have any other site-specific location information?
- Will the proposed dig site be marked in white?
- If a state road, do you have a PennDOT permit number?
- Latitude?
- Longitude?
- What type of work will be done?
- Approximately how deep will you be digging?
- What type of equipment will be used?

- What are the dimensions (width, length, diameter)?
- Will the work take place in the street?
- Will the work take place on the sidewalk?
- Will the work take place on public property?
- Will the work take place on private property?
- Where on private property? (use drop down box)
- Private prop owner or company name working for?
- Work date? (utilities need 3 working days notice) *
- What is the time you will begin the work?
- Is there anything else you would like to add?

2. Safety

Adherence should be paid to all applicable OSHA regulations and local guidelines related to earthwork and excavation. At no time shall a deep hole be left unattended unless secured and marked. No person shall enter a deep hole at a depth greater than hip level.

- The deep hole is not to be accessed if soil conditions are unsuitable for safe entry, or if site constraints preclude entry.

- If it is necessary to leave the deep hole unfilled and unattended for any reason, plywood sheets of 1/4 inch thickness shall be secured over the opening, and the hole shall be clearly marked and secured with caution tape at all sides.

3. Equipment

The following is a list of equipment that is commonly used in Infiltration Testing:

- Backhoe
- Post hole digger or auger, if required
- Clean water source (preferably on site; approximately 5-10 gallons per deep hole)
- 5-gallon container(s)
- Hard-hat, caution tape, cones, etc., and other required safety elements
- Test Log sheets
- Measuring tape stick
- Knife blade or sharp-pointed instrument (for soil scarification)
- Coarse sand or fine gravel
- Object for fixed-reference point during measurement (nail, toothpick, etc.)
- Stopwatch for time measurement
- Infiltrometer, if desired

Methodology

This percolation test methodology largely follows the Pennsylvania Department of Environmental Protection (PADEP) criteria for on-site sewage investigation of soils (as described in Chapter 73 of the Pennsylvania Code).

For each test pit excavated as part of the infiltration testing, a minimum of two infiltration tests shall be done. At least one test shall be located within the expected horizon of the bottom of the proposed infiltration BMP. The Designer should conduct infiltration tests at alternate depths if the test pits/ auger holes indicate that the soils are more suitable at a different depth (i.e., if a clay horizon is identified and more suitable soils are located beneath the horizon, an infiltration test should be performed in the suitable horizon).

1. Deep Hole Execution and Investigation

- Locations for deep hole investigations shall be determined by the Designer based on site conditions and the proposed development plan.
- The deep hole shall consist of a backhoe-excavated trench, 2-1/2 to 3 feet wide, to a depth of between 72 inches and 90 inches, or until bedrock is encountered.
- The trench should be benched at a depth of 2-3 feet for access and/or multiple percolation tests.
- Soil horizons are to be identified and described in depth (in inches) from the surface.
- Depth to water table or perched water table shall be noted, as well as any indications of high water table (i.e., mottled soils).
- Depth to bedrock or weathered bedrock shall be noted if encountered.
- The approximate elevation of the surface shall be recorded, if possible.
- The deep hole is not to be accessed if soil conditions are unsuitable for safe entry, or if site constraints preclude entry.
- Deep holes might be located more frequently if site investigation indicates changes in soil types, geology, water table levels, bedrock bedding, etc.
- Following percolation tests, the deep holes are to be refilled with the original soil and the surface replaced with the original topsoil.
- If it is necessary to leave the deep hole unfilled and unattended for any reason, plywood sheets of 1/4 inch thickness shall be secured over the opening, and the hole shall be clearly marked and secured with caution tape at all sides.
- At the Designer's discretion, soil samples may be collected at various horizons for additional analysis.

Figure 3 Excavation of deep hole by backhoe

2. Percolation Holes

- Holes having a uniform diameter of 6 to 10 inches shall be bored or dug as follows:
- To the depth of the bottom of the proposed infiltration BMP.
- Alternate depths if the test pits/auger holes indicate that soils are more suitable at a different depth (i.e., if a clay horizon is identified and more suitable soils are located beneath the horizon, an infiltration test should be performed in the suitable horizon).

Preparation:

- The bottom and sides of the hole shall be scarified with a knife blade or sharp-pointed instrument to completely remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate.
- Loose material shall be removed from the hole.
- Upon the discretion of the Designer, two inches of coarse sand or fine gravel may be placed in the bottom of the hole to protect the soil from scouring and clogging of the pores.
- Procedure for presoaking: Holes shall be presoaked, according to the following procedure, to approximate normal wet weather or in-use conditions in the soil:
- Immediately before the percolation test, water shall be placed in the hole to a minimum depth of 6 inches over the bottom and readjusted every 30 minutes for 1 hour.

Figure 4 Deep hole with multiple benches

Figure 5 Percolation Hole

3. Measurement

- Determination of measurement interval: The drop in the water level during the last 30 minutes of the final presoaking period shall be applied to the following standard to determine the time interval between readings for each percolation hole:
- If water remains in the hole, the interval for readings during the percolation test shall be 30 minutes.
- If no water remains in the hole, the interval for readings during the percolation test may be reduced to 10 minutes.
- Measurement: After the final presoaking period, water in the hole shall again be adjusted to approximately 6 inches and readjusted when necessary after each reading.
- Measurement to the water level in the individual percolation holes shall be made from a fixed reference point and shall continue at the interval determined from the previous step for each individual percolation hole until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of 1/4 inch or less of drop between the highest and lowest readings of four consecutive readings.
- The stabilized rate of drop in each hole, expressed as inches per hour, shall be used when determining the average percolation rate for the proposed infiltration area. To determine the average percolation rate for an infiltration area, all of the stabilized rates corresponding to the proposed bed bottom elevation shall be averaged.

4. Supplemental Infiltration Testing

It is suggested that a minimum of 10% of the infiltration tests be conducted using a double ring infiltrometer. Locations for infiltrometer testing shall be determined in the field by the Engineer based on observed conditions. This will allow for appropriate determination of a safety factor or adjustment to the percolation test results during infiltration system design.

Figure 6 Turf-Tec Infiltrometer – example of double ring infiltrometer

Figure 7 Turf-Tec Infiltrometer at shallow bench and percolation hole at deeper bench