Pennsylvania Stormwater Best Management Practices Manual

Appendix C – Site Evaluation and Soil Testing

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Protocol 1
Site Evaluation and Soil Infiltration Testing

A. Purpose of this Protocol

The purpose of the *Site Evaluation and Soil Infiltration Testing Protocol* is to describe evaluation and field testing procedures to:

a. Determine if Infiltration BMPs are suitable at a site, and at what locations.
b. Obtain the required data for infiltration BMP design.

B. When to Conduct Testing

Designers are encouraged to conduct the Soil Evaluation and Investigation early in the site planning and design process. The Site Development process outlined in Chapters 4 and 5 of this Manual describe a process for site development and BMPs. Soil Evaluation and Investigation should be conducted early in the preliminary design of the project so that information developed in the testing process can be incorporated into the design. Adjustments to the design can be made as necessary. It is recommended that Soil Evaluation and Investigation be conducted following the development of an early Preliminary Plan. The Designer should possess a preliminary understanding of potential BMP locations prior to testing. Prescreening test may be carried out in advance to site potential BMP locations.

C. Who Should Conduct Testing

Qualified professionals who can substantiate by qualifications/experience their ability carry out the evaluation should conduct test pit soil evaluations. A professional, experienced in observing and evaluating soils conditions is necessary to ascertain conditions that might affect BMP performance, which can not be thoroughly assessed with the testing procedures. Such professionals must conduct these evaluations in risk areas, or areas indicated in the guidance as non-preferred locations for testing or BMP implementation.

D. Importance of Stormwater BMP Areas

Sites are often defined as unsuitable for Infiltration BMPs and soil based BMPs due to proposed grade changes (excessive cut or fill) or lack of suitable areas. Many sites will be constrained and unsuitable for infiltration BMPs. However, if suitable areas exist, these areas should be identified early in the design process and should not be subject to a building program that precludes infiltration BMPs. An exemption should not be provided for “full build-outs” where suitable soils otherwise exist for infiltration.

E. Safety

As with all field work and testing, attention should be given to all applicable OSHA regulations and local guidelines related to earthwork and excavation. Digging and excavation should never be conducted without adequate notification through the Pennsylvania One Call system (**PA OneCall** 1-800-242-1776 or www.paonecall.org). Excavations should never be left unsecured and unmarked, and all applicable authorities should be notified prior to any work.

INFILTRATION TESTING: A MULTI-STEP PROCESS

Infiltration Testing is a four-step process to obtain the necessary data for the design of the stormwater management plan. The four steps include:

1. Background Evaluation
    - Based on available published and site specific data
    - Includes consideration of proposed development plan
    - Used to identify potential BMP locations and testing locations
    - Prior to field work (desktop)
    - On-site screening test
2. Test Pit (Deep Hole) Observation
    - Includes Multiple Testing Locations
    - Provides an understanding of sub-surface conditions
    - Identifies limiting conditions
3. Infiltration Testing
    - Must be conducted on-site
    - Different testing methods available
    - Alternate methods for - additional-Screening and Verification testing
4. Design Considerations
    - Determination of a suitable infiltration rate for design calculations
    - Consideration of BMP drawdown
    - Consideration of peak rate attenuation

Step 1. Background Evaluation

Prior to performing testing and developing a detailed site plan, existing conditions at the site should be inventoried and mapped including, but not limited to:

- Existing mapped individual soils and USDA Hydrologic Soil Group classifications.
- Existing geology, including the location of any dikes, faults, fracture traces, solution cavities, landslide prone strata, or other features of note.
- Existing streams (perennial and intermittent, including intermittent swales), water bodies, wetlands, hydric soils, floodplains, alluvial soils, stream classifications, headwaters and 1st order streams.
- Existing topography, slope, and drainage patterns.
- Existing and previous land uses.
- Other natural or man-made features or conditions that may impact design, such as past uses of site, existing nearby structures (buildings, walls), etc.

A sketch plan or preliminary layout plan for development should be evaluated, including:

- The preliminary grading plan and areas of cut and fill.
- The location and water surface elevation of all existing and location of proposed water supply sources and wells.
- The location of all existing and proposed on-site wastewater systems.
- The location of other features of note such as utility right-of-ways, water and sewer lines, etc.
- Existing data such as structural borings, drillings, and geophysical testing.

- The proposed location of development features (buildings, roads, utilities, walls, etc.).
  In Step 1, the Designer should determine the potential location of infiltration BMPs. The approximate location of these BMPs should be located on the proposed development plan and should serve as the basis for the location and number of tests to be performed on-site.

Important: If the proposed development program is located on areas that may otherwise be suitable for BMP location, or if the proposed grading plan is such that potential BMP locations are eliminated, the Designer is *strongly* encouraged to revisit the proposed layout and grading plan and adjust the development plan as necessary. Full build-out of areas suitable for infiltration BMPs should *not* preclude the use of BMPs for volume reduction and groundwater recharge.

Step 2. Test Pits (Deep Holes)

A Test Pit (Deep Hole) allows visual observation of the soil horizons and overall soil conditions both horizontally and vertically in that portion 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. The use of soil borings as a substitute for Test Pits strongly is discouraged, as visual observation is narrowly limited in a soil boring and the soil horizons cannot be observed in-situ, but must be observed from the extracted borings. Borings and other procedures, however, might be suitable for initial screening to develop a preliminary plan for testing, or verification testing.

A Test Pit consists 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 or fully saturated conditions are encountered. The trench should be benched at a depth of 2-3 feet for access and/or infiltration testing.

At each Test Pit, the following conditions shall be noted and described. Depth measurements should be described as depth below the ground surface:

___ Soil Horizons (upper and lower boundary)

___ Soil Texture and Color for each horizon

___ Color Patterns (mottling) and observed depth

___ Depth to Water Table

___ Depth to Bedrock

___ Observance of Pores or Roots (size, depth)

___ Estimated Type and Percent Coarse Fragments

___ Hardpan or Limiting Layers

___ Strike and dip of horizons (especially lateral direction of flow at limiting layers)

___ Additional comments or observations

The Sample Soil Log Form at the end of this protocol may be used for documentation of each Test Pit.

At the Designer's discretion, soil samples may be collected at various horizons for additional analysis. Following testing, the test pits should be refilled with the original soil and the surface replaced with the original topsoil. A Test Pit should *never* be accessed if soil conditions are unsuitable for safe entry, or if site constraints preclude entry. OSHA regulations should always be observed.

It is important that the Test Pit 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. However, *such depths are discouraged, especially in Karst topography.* Except for surface discharge BMPs (filter strips, etc.) the designer is cautioned regarding the proposal of systems that are significantly lower than the existing topography. The suitability for infiltration may decrease, and risk factors are likely to increase. *Locations that are not preferred* for testing *and* subsurface infiltration BMPs include swales, the toe of slopes for most sites, and soil mantels of less than three feet in Karst topography.

The designer and contractors should reducing grading and earthwork as needed to reduce site disturbance and compaction so that a greater opportunity exists for testing and stormwater management.

The number of Test Pits varies depending on site conditions and the proposed development plan. General guidelines are as follows:

- For single-family residential subdivisions with on-lot BMPs, one test pit per lot is recommended, preferably within 25 feet of the proposed BMP area. Verification testing should take place when BMPs are sited at greater distances.
- For multi-family and high density residential developments, one test pit per BMP area or acre is recommended.
- For large infiltration areas (basins, 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.

The recommendations above are guidelines. Additional tests should be conducted if local conditions indicate significant variability in soil types, geology, water table levels, bedrock, topography, etc. Similarly, uniform site conditions may indicate that fewer test pits are required. Excessive testing and disturbance of the site prior to construction is not recommended.

Step 3. Infiltration Tests/Permeability Tests

A variety of field tests exist for determining the infiltration capacity of a soil. Laboratory tests are strongly discouraged, as a homogeneous laboratory sample does not represent field conditions. Infiltration tests should be conducted in the field. Tests should not be conducted in the rain or within 24 hours of significant rainfall events (>0.5 inches), or when the temperature is below freezing. However, the preferred testing *is* between January and June, the wet season. This is the period when infiltration is likely to be diminished by saturated conditions. Percolation tests carried out between June 1 and December 31 should use a 24 hour presoaking before the testing. This procedure is not required for Infiltrometer testing, or permeometer testing

At least one test should be conducted at the proposed bottom elevation of an infiltration BMP, and a minimum of two tests per Test Pit is recommended. More tests may be warranted if the results for first two tests are substantially different. The highest rate (inches/hour) for test results should be discarded when more than two are employed for design purposes. The geometric mean should be used to determine the average rate following multiple tests.

Based on observed field conditions, the Designer may elect to modify the proposed bottom elevation of a BMP. Personnel conducting Infiltration Tests should be prepared to adjust test locations and depths depending upon observed conditions.

Methodologies discussed in this protocol include:

- Double-ring Infiltrometer tests.
- Percolation tests (such as for on-site wastewater systems and described in Pa Code Chapter 73).

There are differences between the two methods. A Double-ring Infiltrometer test estimates the vertical movement of water through the bottom of the test area. The outer ring helps to reduce the lateral movement of water in the soil. A percolation test allows water movement through both the bottom and sides of the test area. For this reason, the measured rate of water level drop in a percolation test must be adjusted to represent the discharge that is occurring on both the bottom and sides of the percolation test hole.

For *infiltration basins*, it is *strongly* advised that an Infiltration Test be carried out with an infiltrometer (not percolation test) to determine the saturated hydraulic conductivity rate. This precaution is taken to account for the fact that only the surface of the basin functions to infiltrate, as measured by the test. Alternatively, permeability test procedures that yield a saturated hydraulic conductivity rate can be used (see formulas developed by Elrick and Reynolds (1992), or others for computation of hydraulic conductivity and saturated hydraulic conductivity).

Other testing methodologies and standards that are available but not discussed in detail in this protocol include (but are not limited to):

- Constant head double-ring infiltrometer
- Testing as described in the Maryland Stormwater Manual Appendix D.1 using 5-inch diameter casing.
- 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.
- Guelph Permeameter
- Constant Head Permeameter (Amoozemeter)

a. Methodology for Double-Ring Infiltrometer Field Test

A Double-ring Infiltrometer consists of two concentric metal rings. The rings are driven into the ground and filled with water. The outer ring helps to prevent divergent flow. The drop in water level or volume in the inner ring is used to calculate an infiltration rate. The infiltration rate is determined as the amount of water per surface area and time unit that penetrates the soils. The diameter of the inner ring should be approximately 50% to 70% of the diameter of the outer ring, with a minimum inner ring size of 4-inches, preferably much larger. (Bouwer, 1986). Double-ring infiltrometer testing equipment that is designed specifically for that purpose may be purchased. However, field testing for stormwater BMP design may also be conducted with readily available materials.

Equipment for Double-Ring Infiltrometer Test:

___ Two concentric cylinder rings 6-inches or greater in height. Inner ring diameter equal to 50% - 70% of outer ring diameter (i.e., an 8-inch ring and a 12-inch ring). Material typically available at a hardware store may be acceptable.

___ Water supply

___ Stopwatch or timer

___ Ruler or metal measuring tape

___ Flat wooden board for driving cylinders uniformly into soil

___ Rubber mallet

___ Log sheets for recording data

Procedure for Double-Ring Infiltrometer Test

___ Prepare level testing area.

___ Place outer ring in place; place flat board on ring and drive ring into soil to a minimum depth of two inches.

___ Place inner ring in center of outer ring; place flat board on ring and drive ring into soil a minimum of two inches. The bottom rim of both rings should be at the same level.

___ The test area should be presoaked immediately prior to testing. Fill both rings with water to water level indicator mark or rim at 30 minute intervals for 1 hour. The minimum water depth should be 4-inches. The drop in the water level during the last 30 minutes of the presoaking period should be applied to the following standard to determine the time interval between readings:

- If water level drop is 2-inches or more, use 10-minute measurement intervals.
- If water level drop is less than 2-inches, use 30-minute measurement intervals.

___ Obtain a reading of the drop in water level in the center ring at appropriate time intervals. After each reading, refill both rings to water level indicator mark or rim. Measurement to the water level in the center ring shall be made from a fixed reference point and shall continue at the interval determined 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 drop that occurs in the center ring during the final period or the average stabilized rate, expressed as inches per hour, shall represent the infiltration rate for that test location.

b. Methodology for Percolation Test

Equipment for Percolation Test:

___ Post hole digger or auger

___ Water supply

___ Stopwatch or timer

___ Ruler or metal measuring tape

___ Log sheets for recording data

___ Knife blade or sharp-pointed instrument (for soil scarification)

___ Course sand or fine gravel

___ Object for fixed-reference point during measurement (nail, toothpick, etc.)

Procedure for Percolation Test

This percolation test methodology is based largely on the Pennsylvania Department of Environmental Protection (PADEP) criteria for on-site sewage investigation of soils (as described in Chapter 73 of the Pennsylvania Code). This should include the 24 hour presoak procedure between June 1 and December 31. The presoak is done primarily to simulate saturated conditions in the environment (generally Spring) and to minimize the influence of unsaturated flow. If a presoak procedure is not employed between June1 and December 31, than the rate reduction formula described by Elrick and Reynolds (1992), or Fritton, et.,al. (1986) is recommended to account for the influence of unsaturated conditions in the test.

Prepare level testing area.

___ Prepare hole having a uniform diameter of 6 to 10 inches and a depth of 8 to 12-inches. The bottom and sides of the hole should 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 should be removed from the hole.

___ (Optional) 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.

___ Test holes should be presoaked immediately prior to testing. Water should be placed in the hole to a minimum depth of 6 inches over the bottom and readjusted every 30 minutes for 1 hour.

___ The drop in the water level during the last 30 minutes of the final presoaking period should 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 should be 30 minutes.
- If no water remains in the hole, the interval for readings during the percolation test may be reduced to 10 minutes.

___ After the final presoaking period, water in the hole should again be adjusted to a minimum depth of 6-inches and readjusted when necessary after each reading. A nail or marker should be placed at a fixed reference point to indicate the water refill level. The water level depth and hole diameter should be recorded.

___ Measurement to the water level in the individual percolation holes should be made from a fixed reference point and should 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 drop that occurs in the percolation hole during the final period, expressed as inches per hour, shall represent the percolation rate for that test location.

___ The average measured rate must be adjusted to account for the discharge of water from both the sides and bottom of the hole and to develop a representative infiltration rate. The average/final percolation rate should be adjusted for each percolation test according to the following formula:

Infiltration Rate = (Percolation Rate) / (Reduction Factor)

Where the Reduction Factor is given by**:

$$R_f = \frac{2d_1 - \Delta d}{DIA} + 1$$

With:

d_1	=	Initial Water Depth (in.)
Δd	=	Average/Final Water Level Drop (in.)
DIA	=	Diameter of the Percolation Hole (in.)

The Percolation Rate is simply divided by the Reduction Factor as calculated above or shown in the table below to yield the representative Infiltration Rate. In most cases, the Reduction Factor varies from about 2 to 4 depending on the percolation hole dimensions and water level drop – wider and shallower tests have lower Reduction Factors because proportionately less water exfiltrates through the sides. For design purposes additional safety factors are employed (see Protocol 2, Infiltration Systems Design and Construction Guidelines)

*** The area Reduction Factor accounts for the exfiltration occurring through the sides of percolation hole. It assumes that the percolation rate is affected by the depth of water in the hole and that the percolating surface of the hole is in uniform soil. If there are significant problems with either of these assumptions then other adjustments may be necessary.*

Table 1. Sample Percolation Rate Adjustments

Perc. Hole Diameter, DIA (in.)	Initial Water Depth, d_1 (in.)	Ave./Final Water Level Drop, Δd (in.)	Reduction Factor, $\mathbf{R_f}$
6	**6**	0.1	3.0
		0.5	2.9
		2.5	2.6
	8	0.1	3.7
		0.5	3.6
		2.5	3.3
	10	0.1	4.3
		0.5	4.3
		2.5	3.9
8	**6**	0.1	2.5
		0.5	2.4
		2.5	2.2
	8	0.1	3.0
		0.5	2.9
		2.5	2.7
	10	0.1	3.5
		0.5	3.4
		2.5	3.2
10	**6**	0.1	2.2
		0.5	2.2
		2.5	2.0
	8	0.1	2.6
		0.5	2.6
		2.5	2.4
	10	0.1	3.0
		0.5	3.0
		2.5	2.8

Step 4. Design Considerations beginning with *Protocol 2 – Infiltration System Design and Construction Guidelines*

ADDITIONAL POSSIBLE TESTING - BULK DENSITY, OTHERS

Other testing methods are acceptable to assess a soil's suitability for infiltration for early screening and occasionally for verification. They can be especially helpful where consultants wish to cull out the better soils. Percolation testing can also be performed without presoaking as a *pre*-screening procedure.

Alternate tests or investigations can be used for verification. For instance, if the BMPs are not located precisely over the test locations, alternate testing or investigations can be used to verify that the soils are the same as the soils that yielded the earlier test results. However, consultants should document these verification test results or investigations. Professionals with substantiated qualifications should carry out verification procedures.

Bulk Density Tests measure the level of compaction of a soil, which is an indicator of a soils' ability to absorb rainfall. Developed and urbanized sites often have very high bulk densities and therefore possess limited ability to absorb rainfall (and have high rates of stormwater runoff). Vegetative and soil improvement programs can improve, (i.e. lower), the soil bulk density and improve the site's ability to absorb rainfall and reduce runoff.

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 as much as possible. Bulk Density Tests can help determine the relative compaction of soils before and after site disturbance and/or restoration and should be used at the discretion of the designer/reviewer.

Various procedures are available to conduct bulk density tests. The density measurements should be carried out in conjunction with a soil texture analysis. Sandy soils infiltrate well, but tend to have a somewhat higher bulk density than finer soils. Experienced personnel can do the texture analysis manually on site.

Sample Soil Log

Tested by: __________

Test Pit: __________ *Date:* __________ *Elevation:* __________ *Equipment Used:* __________

Geology: __________ *Soil Type:* __________ *Land Use:* __________ *Weather:* __________

Additional comments: __________

Horizon	*Upper Boundary*	*Lower Boundary*	*Soil Textural Class*	*Type, Size, Coarse Fragments, etc.*	*Soil Color*	*Color Patterns*	*Pores, Roots, Rock Structure*	*Depth to Bedrock*	*Depth to Water*	*Comments*

Protocol 2
Infiltration Systems Design and Construction 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.

Infiltration BMPs attempt to 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 runoff 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 2: Infiltration Systems Guidelines
The purpose of this protocol is to provide the designer with specific guidelines for the successful construction and long-term 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 a 2-foot clearance above regularly occurring seasonally high water table**. This reduces the likelihood that temporary groundwater mounding will affect the system, and allows sufficient distance of water movement through the soil to allow adequate pollutant removal. Some minor exceptions for very shallow systems and on grade systems, filter strips, buffers, etc.

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 result in reasonably sized infiltration systems. Where soil permeability is extremely low, infiltration may still be possible but the surface area required could be large, and other volume reduction methods may be warranted. 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 and pollutant loading is expected to be significant. 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 any risk to groundwater quality is minimized**, 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 10 feet down gradient or 100 feet up gradient from building basement foundations, and 50 feet from septic system drain fields unless specific circumstances allow for reduced separation distances.

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 generally not be suitable for infiltration (due to high water table and/or low permeability). 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, nearly so, or on contour.

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 can provide a significant mechanism for water movement in infiltration systems, and the extent of macropores often decreases with depth. Maximizing the soil mantle also increases the pollutant removal capacity and reduces concerns about groundwater mounding. 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 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, sediment sumps, and water quality inserts. The pollutants of greatest concern, site by site, should guide selection of pretreatment 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 in 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 Ratio guidelines are recommended:

- Maximum Impervious Loading Ratio of 5:1 relating impervious drainage area to infiltration area.
- A Maximum Total Loading Ratio of 8:1 relating total drainage area to infiltration area.
- Maximum Impervious Loading Ratio of 3:1 relating impervious drainage area to infiltration area for Karst areas.

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 excessive pressure and potential sealing of the bed bottom. Typically 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 they completely empty within the time period specified in Chapter 3.

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 should 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.

j) Avoid severe slopes (>20%), and toes of slopes, where possible. Specific on-site investigations by experienced personnel need to be made to determined acceptability of each case.

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 should be limited to vehicles that will cause the least 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 occurring 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 for filter strips, rain 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 some cases 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. Estimated removals for all BMPs are contained in Section 9.

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). The publication presents a summary table that 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. While chloride can be found in significant quantities due to winter salting, relatively high concentrations are generally safe for both humans and aquatic biota (in fact, chloride is not even included in U.S. EPA's primary drinking water standards and the secondary standard concentration is given as 250 mg/L at http://www.epa.gov/safewater/mcl.html#mcls). 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.
e) Inadequate design

Infiltration systems should always be designed such that failure of the infiltration component does not completely eliminate the peak rate attenuation capability of the BMP. Because infiltration BMPs are designed to infiltrate small, frequent storms, the loss or reduction of this capability may not 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. Safety factors between 1 (no adjustment) and 10 have commonly been used in the design of stormwater infiltration systems, with a factor of two being recommended for most cases.

The <u>minimum safety for design purposes that may used for any type of tests is two (2)</u>. For percolation tests this safety factor is only applicable for soils more coarse than a loam. It should be applied ***after*** (in addition to) using the reduction formula outlined in Protocol 1, Site Evaluation and Soil Infiltration Testing.

For Percolation tests in loams and finer soils (silty loam, clay loams, silty clay loams, sandy clay loams, clays) a <u>minimum design safety factor of three (3)</u> is recommended ***after*** using the reduction formula in Protocol 1, Site Evaluation and Soil Infiltration Testing. This higher factor is to account for the unwanted capillary suction force that can occur from *un*saturated conditions during percolation testing.

Therefore, a percolation rate of 0.5 inches per hour (***after*** reduction formula) should generally be considered as a rate of 0.25 inches per hour when designing an infiltration BMP for a sandy loam. The same rate for a loam would yield a *design* rate of 0.17 inches/hour.

For other test procedures a safety factor of 3 should also be considered for problem or less preferred locations, basins, swales, toe of slopes, loadings greater than 5:1 (drainage area to infiltration area) where saturated hydraulic conductivity rate (Ksat) was **not** determined (A raw infiltration rate was used. The Ksat rate will normally be less than the infiltration rate.)

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 (based on the infiltration area provided as the system fills with runoff) for inclusion in the Stage-Storage-Discharge table.

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