A Risk-Based Approach for Sizing Stormwater Infiltration BMPs:

By Domenic Rocco, P.E., CPESC, CPSWQ
Chief, Stormwater Section
Watershed Management Program, PADEP – Southeast Region

TABLE OF CONTENTS

1.0 FOREWARD:

When originally drafted, this paper was intended to simply provide additional guidance to the *loading ratio* approach of sizing infiltration BMPs as described in the *PA Stormwater Best Management Practices (BMP) Manual (2006)*. As this document progressed, it was discovered that the topic was much broader than originally thought. One of the delays in finalizing this document has been due to continuous advancements and changes in the stormwater profession. Stormwater Management has been going through a paradigm shift and renaissance. This is expected to continue at this pace for quite some time. Therefore, the purpose of this paper has been modified slightly from merely discussing loading ratios to providing a more wholistic aid to designers and regulatory reviewers in establishing acceptable criteria for sizing infiltration BMPs. In its current form, it has been written to be consistent with the Manual since that document identifies loading ratios as the primary means for infiltration BMP sizing. Many of the ideas discussed in the document can also easily be applied to a site-specific approach to Infiltration BMP sizing.

2.0 BACKGROUND:

The following information has been prepared by the Pennsylvania Department of Environmental Protection (DEP) as supplemental guidance to the recommended criteria for loading ratios for sizing infiltration BMPs in the PA Stormwater Best Management Practices (BMP) Manual (Dec. 26, 2006). It's primary intent is for projects facing site constraints and associated challenges in meeting the volume control guidelines described in Chapter 3 of the BMP Manual. Another purpose of this document is to provide ideas on how to size infiltration BMPs from a site-specific view point in contrast to a loading ratio approach.

Users of the BMP Manual and this document are strongly encouraged to follow the progression of prevention first and mitigation second – since dealing with stormwater volume can be much more burdensome after the fact. Several non-structural BMP credits may be utilized for this purpose.[1] Also, it should be emphasized that there are other volume control alternatives besides infiltration, including: (1) Capture and Reuse and (2) Vegetated Systems that provide Evapotranspiration (ET). (BMP Manual, Section 3.3.2) More discussion is included later in this document regarding the benefits of multifunctional BMPs, such as those that provide both infiltration and ET. (See Potential Risk Level)

In general, the BMP Manual is a tool to help achieve stormwater discharge compliance with water resource protection requirements. It is a tool to meet post construction stormwater management performance standards that derive from the Antidegradation Requirements in the Chapter 93 Rules and Regulations relating to *Water Quality Standards*. Though the Manual itself is not regulation, it is provided as a guideline to assist permit applicants in meeting the regulatory requirements.

Alternate BMPs, control strategies and methodologies not listed in the Manual, or variations of BMPs included in the Manual, may also be utilized provided that (1) they meet water resources protection requirements, and (2) they are based on acceptable engineering practices. However, proposals to utilize alternate BMPs or deviations from current control guidelines may be subject to additional evaluation during regulatory review (state, county or local) and must demonstrate their effectiveness through appropriate supporting analysis, calculations, test results or other documentation. It should be noted that the burden of proof will be on the applicant. Additional documentation will be necessary and the process will be more complicated; therefore, any person using an alternative BMP approach should meet and discuss their proposals with regulators to avoid longer review and permit processing time. Utilizing the recommendations by soil and/or geologic professionals discussed later in this document, and as noted in Appendix A and B, may make the process run more smoothly and prevent unnecessary delays.

Conflicts with design criteria can commonly occur when designers push established thresholds and/or tolerance limits of infiltration BMPs. Design criteria is set to protect the sensitive functions of these BMPs. The

[1] Non-Structural BMPs can be found in Chapter 5 of the Manual. Supporting information, such as worksheets and checklists, can also be found in Chapter 8 of the Manual.

success of infiltration BMPs requires thinking "outside of the box" and setting aside conventional stormwater practices, which have focused on addressing flood control through limiting peak flow rates. Those who do not follow these recommendations may significantly increase the risk of a conflict arising with the sizing of infiltration BMPs and associated technical criteria in the Manual, including **loading ratios.**

The Manual states (Appendix C, pg. 15 of 21):

> *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 (IDA:IA), or the ratio of total drainage area to infiltration area (TDA:IA). 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. (The Manual does not provide a recommendation for total drainage area to infiltration area for Karst areas.)*
>
> (Also see *Computing Loading Ratios.*)

Infiltration BMPs should be conservatively designed using low **loading rates** because the pores in the media and surrounding soil tend to become clogged. Rejuvenation of the pore space requires "rest" periods between runoff events. (Source: British Columbia – Ministry of the Environment)

The recommended loading ratios in the Manual, along with the general criteria listed below, have been provided as a guide to designers and as a way to mitigate for the **risk** of problems or failures of infiltration BMPs during their expected service life (~20 years). (see Potential Risk Levels)

Loading ratios, for all intents and purposes, are a "rule of thumb" approach for the design of stormwater infiltration systems. Loading ratios were not intended to be a rigid requirement.[2] The loading ratio concept is a well-intended idea that has resulted in an unintended consequence and, as a result, DEP and county conservation districts are continuously working with design engineers on alternative and equitable sizing criteria for infiltration BMPs to overcome the various pitfalls of the loading ratio approach and to provide fair and flexible guidance to the design community for infiltration BMP sizing which is protective of our water resources.

Using loading ratios blindly disregards site and project specific characteristics in the design process. While rule-of-thumb ratios may be adequate for planning and preliminary design, it is more appropriate to size an infiltration facility based on the actual physical capabilities of the individual system, as determined by on-site soils testing, geologic investigations and detailed calculations.

The information in this document has been compiled to provide a list of decisive factors that may be acceptable should a project be faced with challenges in meeting the recommended loading ratios in the Manual. They may be utilized as weighting factors with respect to the recommended loading ratios (See section on *Maximum Thresholds)* or in a site-specific manner. These factors will vary on a site-to-site basis and much will depend on the judgment of the professional(s) preparing the design. Unfortunately, there is no guarantee that regulatory approval will be granted for requests to exceed recommended values, but it is anticipated that a designer who follows the criteria in this document while maintaining an acceptable level of conservatism will be able to get through the regulatory process with relative ease. To accomplish this, it is imperative that the

[2] While it was generally agreed during the development of the Manual that the principle behind this approach was a "good idea", it received considerable criticism from many committee members for not being scientifically-based and for not going through proper peer scrutiny before becoming finalized in the Manual.

design team meet early in the process with state and local regulators to discuss site constraints and any strategies that deviate from the Manual (e.g. loading ratio approach).

3.0 GENERAL CRITERIA:

During the preparation of this document, it quickly became apparent that there are several related terms dealing with *infiltration* that are often intermingled and/or misused. Definitions for the following terms, as they apply to the current version of the BMP manual, are listed below to provide clarity. Further clarification of infiltration testing protocols and/or redefining of these terms may occur in the future when the BMP Manual is updated, but will not occur in this document.

Infiltration Rate – a measure of the rate at which water moves through soil at the soil-air interface, commonly expressed in units of inches/hour. This rate can differ due to variations in apparatus and testing protocol. Although the units of Infiltration rate and hydraulic conductivity of soils are similar, there is a distinct difference between the two quantities and they should not be used interchangeably. (ASTM D3385-03) Infiltration rate is also not the same as a percolation rate[3].

Measured Rate – the field measured infiltration rate while utilizing a testing practice that is consistent with the Departments Infiltration Testing Protocol.

Design Rate – the infiltration rate used for design of an infiltration BMP (based on the measured rate) after considering a reasonable factor of safety (minimum FOS = 2).

Hydraulic Conductivity (K) - A coefficient of proportionality describing the rate at which water can move through a permeable medium. It is a function of the porous medium and the fluid and is determined using an appropriate soil testing procedure and applying Darcy's Law. Hydraulic conductivity is a constant physical property of soil or rock, one of several components responsible for the dynamic phenomenon of flow. A separate K can be found for changes in the porous medium through the soil mantle.

Permeability - The ease of movement of water downward through a soil material. Also described as the ability of a material to transmit fluid through its pores when subjected to a difference in head. In other states, this term is sometimes used as "permeability rate", however this is not the same as an infiltration rate and has limited to no applicability in Pennsylvania.

For the sake of consistency and to avoid confusion, references to "rate" in this document will apply to "infiltration rate" unless otherwise specified. The reader may also refer to the Glossary at the end of the BMP Manual for more definitions.

Reference is made to Protocol 2, *Infiltration Systems Design and Construction Guideline* (Appendix C) and to relevant sections of Chapter 6 – Structural BMPs, where the following upper limits are identified for the design of infiltration BMPs:

1. Maximum 2-foot hydraulic head or "effective" depth of water above the bed bottom[4],
2. Maximum 72-hour drawdown time (time taken to dewater BMP once it is full),
3. Maximum 10 in./hr. soil infiltration rate (measured rate), and
4. Minimum factor of safety of 2.0 for design. (Also see *Factor of Safety.*)

Following these criteria may ultimately influence the loading ratio for any given infiltration BMP and likely prevent any exceedances to the recommended values, particularly those sites with modest infiltration rates.

[3] Percolation (Perc) Rate – In Pennsylvania, this term has been coupled with the percolation test (perc test) - an empirical soil infiltration testing protocol adopted from the Act 537 Sewage Facilities Planning Program. Consequently, this term is often erroneously used in place of infiltration rate (see Appendix C for more info.). The perc test has a very limited application for stormwater infiltration (small BMPs) and may be removed as an acceptable practice all together once the BMP manual is updated. When the perc test is utilized (and acceptable), an appropriate reduction factor and factor of safety are required.

[4] Experience has shown that effective depth may be able to be increased in certain situations to meet engineering constraints. In areas with good soil conditions (infiltration rate > 1 in/hr), subsurface systems and non-residential surface systems may be designed up to 4 feet deep. This will need concurrence from the regulatory authority.

As a matter of fact, a designer following this process may find that a given BMP may not receive enough water (or not achieve enough residence time), depending on the corresponding infiltration rate.

Consider the following example:

Drainage Area = 1 acre
% impervious = 100%
Hydrologic Method: Soil Cover Complex Method (CN Method)

In this scenario, 11,350 cu. ft. of runoff volume would be anticipated during a 2-year 24-hour storm (using CN = 98 and P = 3.36 inches). For the sake of simplifying this example, assume that the design would need to handle this entire volume. If we adhere to a loading ratio of 5:1, this would yield a BMP base area of 8,712 s.f. (43560 s.f. / 5). The paradox here is that if the measured infiltration rate is greater than **0.435 in/hr**, the amount of potential infiltration volume will surpass the amount of anticipated runoff volume reaching the BMP during the 2-year 24-hour storm – essentially making it oversized. That is, if the designer decreases the size of the bed or increases the amount of drainage area, it will increase the loading ratio above the recommended value (5:1), which may not be a true representation of the design conditions. Hence, it is very important to be aware of the balancing act that can occur with these designs. Modification of the infiltration facility's dimensions and other design parameters may have disproportional effects on the loading ratio, thereby requiring a trial-and-error type analysis of the optimum facility dimensions. This is an area where good engineering judgment combined with a proper site-specific characterization of the soil and underlying geology is crucial – particularly for the larger (higher risk) BMPs - see *Potential Risk Level*.

As previously stated, the BMP Manual recommends maximum loading ratios for different circumstances. However, this can vary depending on certain factors; several of which have been listed below and which should be considered when the designed **loading ratio** is a primary constraint. Each of these factors is discussed in further detail.

- Potential risk level
- Computing loading ratios
- Pretreatment
- Drainage area
- Soils and Geology
- Transmissivity
- Mounding analysis
- Siting
- Factors of safety
- Special protection watersheds
- Erosion control considerations

4.0 POTENTIAL RISK LEVEL:

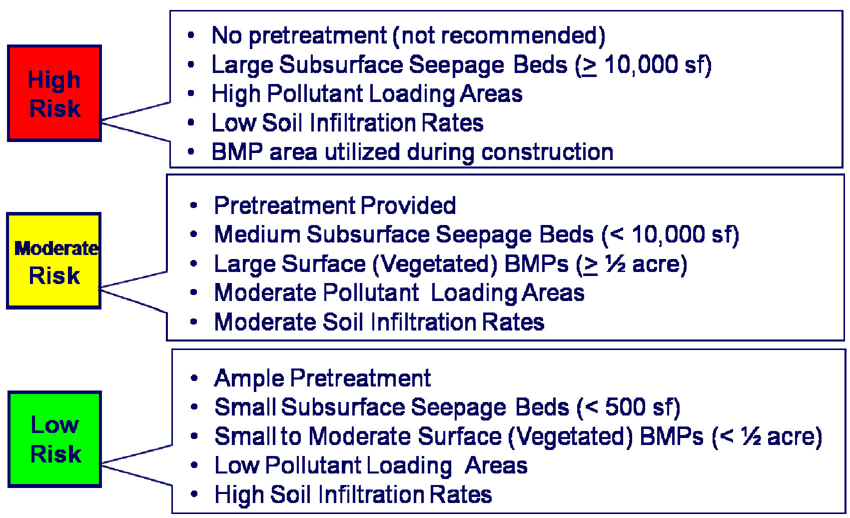
Risk is defined as a state of uncertainty where some of the possibilities involve a loss, catastrophe, or other undesirable outcome. Risk is an intrinsic trait for almost any infiltration BMP and there are risks of various degrees and proportions. Risk level in non-karst areas is mostly attributed to the threat of failure of a BMP from stresses due to either hydraulic loading or pollutant loading (e.g. sediment clogging). There are also potential risks to groundwater and adjacent dwellings which are not covered in this discussion, but the Manual currently provides setbacks for these scenarios to help mitigate these risks. For the sake of this discussion, undesirable outcomes may include: (1) impaired performance/effectiveness, (2) reduced service life and (3) ultimate failure. The "Common Causes of Infiltration BMP Failures" are discussed in further detail in the BMP Manual (Append. C, Page 18). The key issue for the stormwater designer is to get a firm handle on the level of risk associated with their site and BMP selection.

Factors that influence risk include, but may not be limited to, *scale*, *functionality*, *site/project characteristics*, and *constructability*.

Scale includes BMP size and drainage area which are directly proportional and discussed in more detail later in this document. (See *Drainage Area*)

Functionality can include level of pretreatment, the type/function of the BMP, and sustainability. For instance, a bioinfiltration BMP (such as a rain garden or vegetated swale) is multifunctional and will have dual physical processes at work to deal with volume - infiltration and evapotranspiration (ET). ET is often an ignored parameter because it is difficult to quantify and model. However, in natural vegetated areas it is documented that ET can account for 50% (+/-) of the annual water budget. Therefore having these BMPs at the surface and vegetated can have significant ancillary benefits including making them more readily visible and accessible for maintenance. This approach could also make these BMPs more tolerant to pollutant loading since filtration and water quality treatment are integrated. Conversely, a subsurface system (such as a stone seepage bed) has one physical process at work to deal with volume – infiltration. These BMPs are also less visible, less likely to receive maintenance, and therefore more likely to experience problems. These systems typically require more pretreatment for sustainability and may also come with a higher price tag. Expected service life of these systems should be 20 years of more. It is clear to see how functionality affects risk.

Figure 1: Risk According to Scale, Functionality (BMP Type) and Other Factors



Site and project characteristics can include various factors, but commonly include geology, soils, topography, surface cover and their correlation with the proposed project. It is essential that the designer understand the limitations of their site and the associated risk with the proposed project. For instance, a former industrial site may be faced with soil contamination issues which pose an elevated risk of pollution to either surface or groundwater resources. Another example of a high risk factor in this category would be a site with a relatively shallow depth of soil to a limiting zone.

Risk related to *Constructability* can include any potential drawback or other factor affecting a BMP during construction. This is normally out of the control of the designer; however some BMPs have certain innately higher risk factors than others. For instance, underground seepage beds have fairly strict construction criteria, such as the use of uniformly-graded washed stone, properly selected filter fabric and protection from sediment laden water. If any of these steps are missed or done inadequately, it can significantly jeopardize the functionality of the BMP. A higher level of construction oversight and quality control of materials is a suitable counter measure for this risk, but it comes with an additional cost.

Risk in Karst Areas: For the purposes of this document, all infiltration practices within Karst areas will be considered as having an elevated risk requiring additional soil and/or geologic investigation. Recommendations are included in the Appendices of this document to assist in this endeavor, which was a collaborative effort between DEP, engineering consultants, the Pennsylvania Association of Professional Soil Scientists and the Pennsylvania Council of Professional Geologists. Risks of infiltration practices in Karst areas are not exclusive to the function or sustainability of the BMP, but may also include affects to their immediate surroundings. Generally, a higher level of diligence is necessary, particularly with the proximity of infiltration BMPs to structures and utilities. Presence of existing sinkholes, thickness of the soil mantle, and the measured infiltration rate may be used as risk indicators.

Risk level associated with groundwater contamination from pollutant loading is important in all areas. In Karst areas, additional attention is also given to hydraulic loading due to public safety concerns associated with the risk of subsidence and the formation of sinkholes. Ideally, infiltration BMPs in Karst Areas should simply mimic the pre-development loading ratio – such as using pervious pavement. In reality, both the change of surface vegetation and the creation of impervious surfaces increase the amount of runoff that the remaining land surface (or subsurface) must manage in some manner. For this reason, the Manual as currently written recommends a maximum loading ratio of 3:1 for Karst Areas. For more discussion on infiltration in Karst areas, see *Soils and Geology* and *Appendix A & B*.

5.0 COMPUTING LOADING RATIOS:

Though loading ratios may be difficult at times to apply in the design process, the computations are simple and can be expressed as follows:

Loading Ratio = Drainage Area (sf)**/ Infiltration Area** (sf)

Where,

Drainage Area includes all the contributory drainage to the infiltration BMP, including the area of the BMP itself. Depending on the specific circumstance and the value sought – the drainage area can either be the Total Drainage Area (TDA) or the Impervious Drainage Area (IDA).

Infiltration Area (IA) includes the base area of the BMP designed to infiltrate or having natural infiltration characteristics. These BMPs normally involve an impoundment of storage volume that is infiltrated over a certain length of time. (i.e. drawdown time or infiltration period usually a maximum of 72 hours) The infiltration area can take many forms including, but not limited to, a natural vegetated surface, an engineered stone bed, or the base of filter media, such as a rain garden.

The infiltration area can be confusing to determine and is dependent on the BMP type selected. For a seepage bed, it would merely be the bottom area. However for a surface impoundment, the infiltration surface will vary with depth. In these instance, the infiltration areas can be shown in two different ways, one based on *contour area* and the other based on *wetted surface area*. The contour area method calculates the amount of infiltration by multiplying the infiltration rate times the contour area at each stage or elevation. This method of calculation is more conservative than the wetted surface method because it applies the infiltration rate to a flat area in only one direction. The calculation for wetted surface applies the infiltration rate in all directions along any portion of the facility below the water surface elevation. This is illustrated in Figure 2, where infiltration is shown occurring along the entire wetting front and is not just limited vertically at the bottom of the facility. These surface areas could vary significantly with facilities having side slopes (typically 3H:1V). Therefore, limiting design computations to the bottom area could inaccurately portray the actual functions of the system.

Loading Ratio is a unitless parameter, intended to reflect hydraulic proportionality between the drainage area and the infiltration area, expressed as *X*:1. It is further defined in the opening of this document.

Figure 2: Illustration of Wetting Front for Infiltration Basins

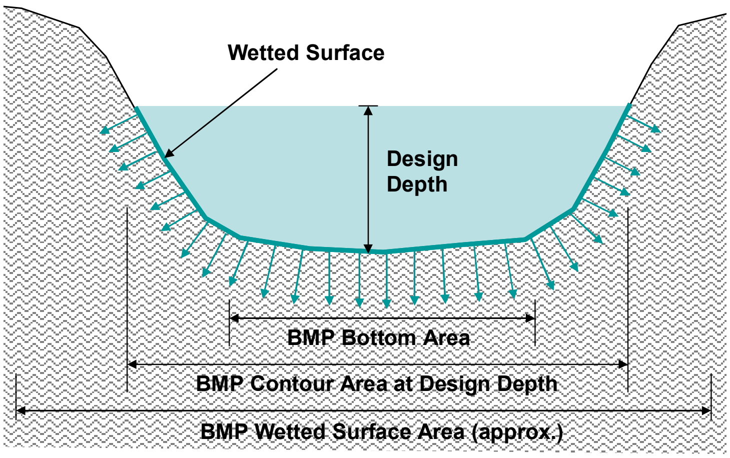
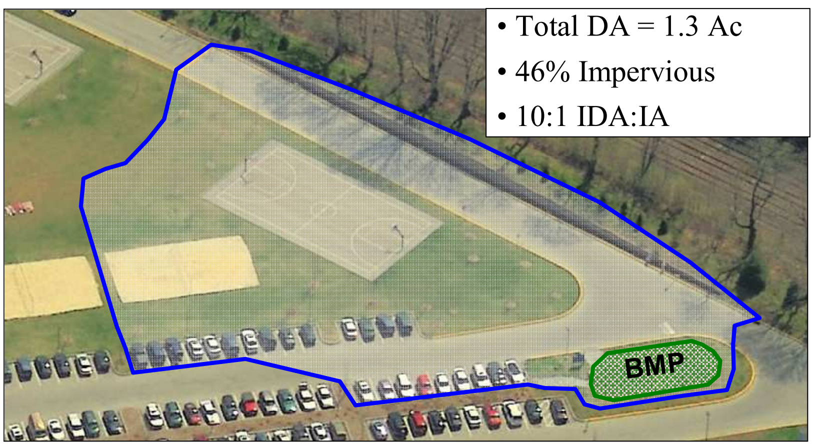


Figure 3: Sample birds-eye view of an infiltration BMP and its respective drainage area.



Source: Villanova University – Bioinfiltration Traffic Island

Figure 3 demonstrates a bioinfiltration[5] BMP and its respective drainage area. In this example, the recommended loading ratios from the BMP Manual have been exceeded by a moderate amount; yet ongoing research has shown that this BMP is continuing to maintain its infiltration function over the past several years and through seasonal variation. It is also a good example of a multifunctional BMP that has been able to take advantage of infiltration and evapotranspiration. More information on research for this infiltration BMP and several others can be found at www.villanova.edu/VUSP. (Also see *Pretreatment*)

Land Use Adjustment:

Considering the beneficial effects of disconnected impervious areas and reduced earth disturbance, the calculation of loading ratio may be adjusted to take into account these positive attributes and the fact that different land uses will produce different amounts of runoff. (Pretreatment is discussed in a different section, which would also look at the different types of pollutants from different land uses.) Therefore, the relative percentage of drainage areas used to calculate loading ratio may be modified as follows*:

[5] Note that the distinction between bioinfiltration and bioretention is that the former is designed to infiltrate while the latter is more of a water quality BMP, though bioretention has been found to have volume control benefits and volume reduction is provided in the Manual.

Land Use Type	Percent of Measured Area
Existing Impervious Areas to Remain**	100
Disturbed Areas to be made Impervious**	100
Disturbed Areas to be made Pervious – Lawn***	85
Disturbed Areas to be made Pervious – Meadow***	60
Undisturbed Lawn****	75
Undisturbed Meadow****	50
Undisturbed Woodlands****	40

* For Loading Ratio purposes only. The total drainage area will still need to be utilized in hydrologic computations for design.

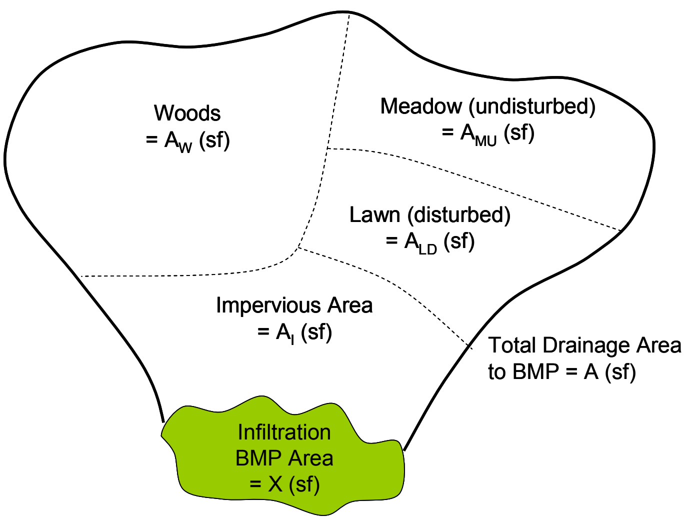
** In many cases, this will refer to the directly connected impervious area (DCIA), since disconnected impervious areas may be directed to another BMP such as a vegetated filter strip.

*** Pervious areas must be uncompacted or insignificantly disturbed. These disturbed areas must follow soil amendment/landscape restoration guidelines in order to achieve this adjustment. It is assumed that woodlands will not form in disturbed areas for several years therefore, they are not given a separate category. (consider "proposed woods" to be lawn or meadow depending on understory) Buildings utilizing *green roofs*, impervious areas draining to a green roof, or *disconnected* impervious areas draining to a minimum 25-foot wide vegetated filter strip may be considered "disturbed areas to be made pervious".

**** Undisturbed pervious areas must be well vegetated to receive this credit. Landscape restoration can be utilized, as needed, to accomplish project goals.

Ideally, infiltration BMPs should be designed to capture increased runoff volume from the source – typically new impervious areas. The above adjustments have been formulated to provide both incentive and design flexibility since it is recognized that many BMPs are multifunctional (e.g. water quality, volume control, rate control, etc.), and may necessitate a diverse treatment approach. Collectively, this land use adjustment should not exceed 40% of the total area when calculating a reduction (or 60% of the total). Figure 4 and the equation below are provided for additional clarification. [Also see section on *Maximum Thresholds*]

Figure 4: Diagram describing the Land Use Adjustment for Loading Ratio.



Where,

A_I = Impervious Area
A_{LD} = Lawn Area (disturbed)
A_{MD} = Meadow Area (disturbed)
A_{LU} = Lawn Area (undisturbed)
A_{MU} = Meadow Area (undisturbed)
A_W = Woods Area

$A = A_I + A_{LD} + A_{MD} + A_{LU} + A_{MU} + A_W$ = Total Area Draining to Infiltration BMP.

$$\textbf{Loading Ratio} = \frac{A_I*1.0 + A_{LD}*0.85 + A_{MD}*0.6 + A_{LU}*0.75 + A_{MU}*0.5 + A_W*0.4}{X}$$

or

$$= \frac{0.60*(A+X)}{X}$$

Whichever is greater

Adjustments can be made based on other criteria, such as Water Quality /Pretreatment. (See Pretreatment)

6.0 PRETREATMENT:

Pretreatment is essential for sustainability of infiltration BMPs. As with most other best management practices, pretreatment can extend the functional life and increase the pollutant removal capability of an infiltration BMP. Pretreatment facilities can have various benefits including reduction of incoming velocities, capturing of sediments, and improved sustainability of the system. This is usually accomplished through such means as vegetative filters, a forebay, grass swales, and/or a manufactured treatment device. For example, forebays

can be included at the inflow points to an infiltration BMP to capture sediments, trash, and debris, which can simplify and reduce the frequency of system maintenance. A forebay should be sized to hold the sediment volume expected between clean-outs. (NJ SWM BMP Manual pg. 9.5-10)

Pretreatment using vegetative filters such as bioretention, vegetated swales and forebays can allow the designer to maximize loading ratios in structural BMPs. Vegetated swales are also very effective in pollutant removal while maintaining a more natural and attractive appearance. Vegetated BMPs have various benefits that often aid and/or complement infiltration. This is most attributable to root growth which sustains desirable soil structure through the establishment and rejuvenation of *macropores*: The BMP Manual states:

> *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*.

Vegetated BMPs also promote filtration and evapotranspiration which, during the growing season, can significantly relieve the volume of water assimilated into surrounding soils. One of the key elements towards reducing the risk of failure for infiltration BMP is to incorporate deep-rooted perennial vegetation and maintain healthy soils within pretreatment and/or primary BMPs.

The "first flush" of pollutants normally occurs within the first **1 inch** of rainfall. Generally, precipitation patterns in Pennsylvania indicate that most runoff events are less than 1 inch. This means that pretreatment areas will receive and assimilate much of the annual pollutant loading, thus maintaining the hydraulic conductivity and extending the life of structural BMPs. Therefore, ample pretreatment may facilitate the use of higher loading ratios.

Figure 5: Illustration of Bioinfiltration BMP during construction and post-construction

Source: Villanova University – Bioinfiltration Traffic Island

Water Quality Loading Ratio Adjustment:

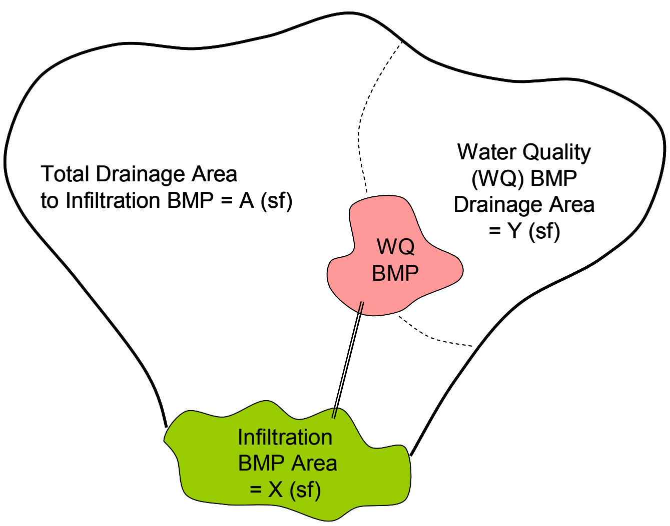
Hydraulic loading ratios for infiltration BMPs utilizing profuse levels of pretreatment (including those that incorporate bioretention/bioinfiltration) can often be higher than the recommended values when a combination of the following attributes are employed:

- measured infiltration rates are at least **1.0** in./hr.;

- appropriate soil amendments with compost and sand are included to maintain or improve ambient soil infiltration characteristics;[6]
- leaf/litter guards and other provisions are included as a preventative maintenance measure;
- sufficient separation distance from limiting zones (**> 3 feet**); and,
- the facility is not located in a Karst area.
- design incorporates at least one water quality pretreatment facility addressing removal efficiency for total suspended solids.

Pursuant to the aforementioned benefits of water quality pretreatment, Figure 6 describes adjustments that can be made to the recommended loading ratio:

Figure 6. Diagram describing Water Quality Adjustment for Loading Ratio



Loading Ratio $= \dfrac{A-(Y*R)+X}{X}$

or, $= \dfrac{0.5 * (A+X)}{X}$

Whichever is greater.

Where,

X = Infiltration BMP Area
Y = WQ BMP Drainage Area
R = WQ BMP Removal Efficiency
A = Total DA to Infiltration BMP

7.0 DRAINAGE AREA:

The size of infiltration BMPs and their associated risk of failure and/or overloading can often be attributed to the corresponding drainage area. Therefore, size/scale plays a significant role in the sustainability of these practices.

Small Drainage Areas (DA ≤ 1 acre) Identifying source control strategies and utilizing compact BMPs to capture runoff from smaller, more controllable areas are crucial for water quality treatment and volume control. Generally speaking, infiltration BMPs with smaller drainage from low source areas exude less risk and can have a higher tolerance for larger loading ratios. For example, runoff from an individual residential roof typically has low anticipated levels of particulates. Infiltration BMPs which are normally utilized for roof runoff (e.g. rain garden, dry well) are relatively small and the prospect for lateral dispersion and absorption of stormwater into the landscape or soil is very good. Therefore, a loading ratio above the recommended value may be acceptable for this type of application with marginal pretreatment. (e.g. leaf gutter guards, etc.) Conversely, small areas with dense-use and/or high source areas (e.g. commercial parking lot, industrial uses) exude higher risk and will likely need to implement ample pretreatment to avoid complications; and these infiltration BMPs will be less tolerant to higher loading ratios. (Also see *Pretreatment* and *Maximum Thresholds*.)

Medium Drainage Areas (1 acre < DA ≤ 5 acres) Many BMPs may find themselves in this category. These medium-sized areas can still be very effective in supporting strategies for source control, but more vigilance

[6] Follow the criteria described in BMP 6.7.3 in the BMP Manual.

should be followed in the design process. Generally, designers should aim to have drainage areas to infiltration BMPs at 5 acres or less to minimize risk.

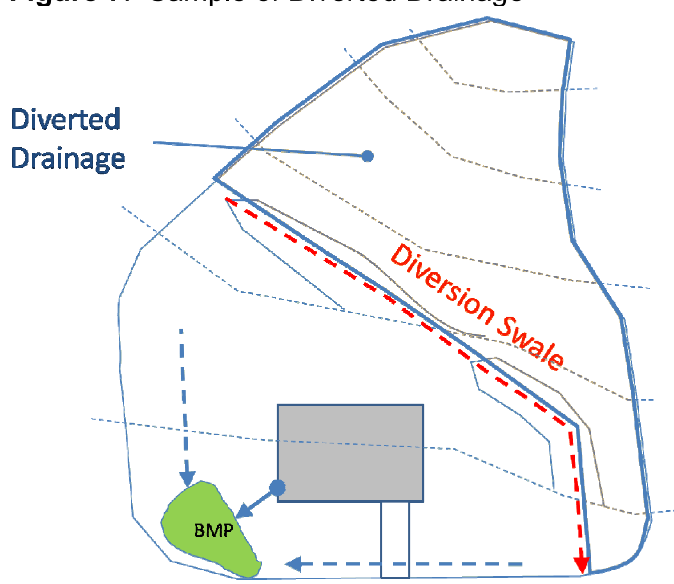
Large Drainage Areas (5 acres < DA ≤ 10 acres) Facilities designed with large drainage areas should follow a more conservation approach and should therefore follow the recommended loading ratios. (i.e. 5:1 or 8:1) In certain instances, they may actually need to be *reduced* for large impervious areas lacking sufficient pretreatment (also see *Pretreatment*) or deficiencies in other key areas. In general, infiltration BMPs handling large drainage areas have a high risk potential and are discouraged. They are also commonly the least cost effective when compared to other alternatives and arrangements. There are also potential issues with sustainability. Off-line infiltration BMPs would be better suited for large drainage areas. (Also see *Siting*.)

The maximum drainage area to a given infiltration BMP should not exceed 10 acres. To minimize the risk of failure, it is recommended that the drainage area be kept to 5 acres or less for the following reasons:

- Large BMP treatment areas may not be well connected to the surrounding landscape for efficient lateral movement of water. (i.e. Lateral dispersion of water becomes negligible as BMP footprint increases.)
- Assimilation of drainage may be difficult because there may not be enough permeable soil depth beneath to absorb and move large loadings, despite what the soil testing shows. (see *Transmissivity*)
- Experience and studies have shown that infiltration BMPs designed to handle large drainage areas are more prone to clogging, failure and issues with operation and maintenance.
- The size of an infiltration BMP increases proportionally with drainage area, often leading to various operation and maintenance issues. Larger BMPs are also seldomly integrated into an effective treatment train. A preferred design approach would be to incorporate several smaller BMPs; each receiving smaller portions of the larger drainage area for volume control. This would also allow more potential for non-structural BMPs to reduce volume. When necessary, separate rate control BMPs may be incorporated at the end of the train utilizing overflow, bypass or flow splitting devices.
- Large infiltration BMPs are considered to have an elevated risk potential and may run into issues such as temporary mounding or other conflicts with soils/geology.
- Design costs may increase since in-depth soil/geologic study from pertinent professionals may be necessary. (see *Mounding Analysis*)

Diverting Flows from Upslope Pervious Areas:
In some instances a designer may face a conflict with the maximum total loading ratio[7] (e.g. 8:1), but within the limits of the maximum impervious loading ratio (e.g. 5:1). In these instances (see Figure 7), the designer may consider diverting upslope pervious areas to other BMPs, such as those providing rate control further down the line. Undisturbed pervious areas are ideal since there is no anticipated increase in volume from those areas. A goal of the BMP manual is to control 90% of disturbed areas with a BMP prior to discharge from the site while also managing the volume generated from the net difference in the 2-year 24-hour storm.

Figure 7: Sample of Diverted Drainage



8.0 SOILS and GEOLOGY:

In recent years, the topic of stormwater management has become much more interdisciplinary since many BMPs (including those incorporating infiltration) have come to rely heavily on favorable parameters of the soil

[7] See Page 20 regarding maximum total loading ratio.

and underlying geology. In many cases, the complexity of a project and/or site may pose a risk that demands the involvement of respective professionals in these areas. These challenges increase dramatically as land development pushes the threshold on complex sites that were previously passed over as "not developable". As previously mentioned, recommendations are included in the appendices of this document to assist in this endeavor, which was a collaborative effort between the DEP, select engineering consultants, the Pennsylvania Association of Professional Soil Scientists (PAPSS) and the Pennsylvania Council of Professional Geologists (PCPG).

Permeable Soil Layer:

Infiltration BMPs produce excellent pollutant removal efficiencies because of a variety of natural functions occurring within the soil mantle, complemented by existing vegetation (where 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 permeable soil layer, known as the vadose or unsaturated zone, constitutes all subsurface media above the water table. The Manual (Appendix C) calls for a minimum **2-foot** clearance above limiting zones (i.e., seasonal high water table or bedrock). Two feet is generally accepted as the absolute minimum for most infiltration BMPs, but two feet may not be sufficient in all cases. Some BMP designs may encounter conflicts with the 2-foot minimum clearance – especially larger infiltration BMPs (See Section on *Transmissivity*). Therefore, the designer is advised to consider a **3-foot** or greater clearance above limiting zones where tolerance limits of the permeable soil layer is encountered to avoid complications with long term performance. This stipulation is imperative for any design proposing exceedances to the recommended loading ratios and/or BMP designs having medium to large footprints.

A facility having a relatively thick (**>3 ft**.) and permeable (**>1.0 in/hr** measured rate) underlying soil layer may permit designing an infiltration facility using a loading ratio greater than the recommended values. However, justification should be provided by a qualified professional (e.g. soil scientist (PSSc), geologist (PG), or geotechnical engineer (PE)) and as deemed appropriate under their respective licensure. Runoff from the contributing drainage area (particularly an impervious area) would need to have sufficient pretreatment – especially for subsurface systems. (Also see *Pretreatment*).

Conversely, systems that have a shallow permeable layer (**< 3 ft.**) may need to have a *reduced loading* because there may not be adequate soil to assimilate seasonal loadings of water (also see *Large Drainage Areas*). It may also be difficult to meet other volume requirements with very shallow limiting zones and low permeability.

Special consideration may also be necessary when high infiltration rates are encountered. This may be of particular concern when these rates are disproportional with other adjacent testing. The Manual states (Append. C, pg. 14 of 21) that *soils with rates* (measured) *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*. Extensive variability for soil infiltration rates is not uncommon, however these anomalies should be properly evaluated by a qualified professional prior to seeking an increased loading ratio. The Manual goes on to say that *in carbonate soils, excessively rapid drainage may increase the risk of sinkhole formation, and some compaction or additional soil may be appropriate*.

Karst Geology

As stated in the BMP Manual (Section 7.4.2), a decision must be made on the incorporation of infiltration BMPs at a Karst site by the design professional. This decision must be based on a sound site assessment and consideration of potential contaminants that can be introduced by the proposed project. The worst scenario is to ignore Karst features entirely and thus significantly increase the potential for costly delays, repairs, catastrophes and legal proceedings. The loading ratio approach in Karst areas (3:1) should not be selected blindly without the proper site assessment (as previously mentioned). It is ultimately the responsibility of the design engineer (i.e. registered professional engineer) to properly design an infiltration BMP that suits the needs of a project, accounts for the limitations of a site, and abides by regulatory requirements/ engineering

standards. Designing a project without performing the necessary site investigation work[8] would be professionally irresponsible, particularly in a Karst area. Some small and shallow on-lot systems may be able to justify a reduced level of investigation, but this would be determined on a site-by-site basis.

For those projects electing to utilize infiltration BMPs within areas of Karst geology, the Manual specifies more stringent criteria for loading ratios for the following reasons:

- To avoid the concentration of stormwater flows and replicate natural loading ratios to the maximum extent practicable;
- To prevent new hydraulic stresses on the overburden soils and accelerated sinkhole development; and
- To contend with concerns with the potential for groundwater contamination.

In areas of Karst geology, increases to the BMP manual recommended loading ratios are strongly discouraged. If an applicant proposes greater loading ratios in these areas, they will need to thoroughly document that the risk of sinkhole formation and groundwater contamination are within the tolerance limits of the natural system and that a professional geologist has reviewed and concurred with this determination. Any deviation to the recommended loading ratio may be subject to additional evaluation during regulatory review (state, county or local) and must demonstrate their effectiveness through appropriate supporting analysis, calculations, test results or other documentation. (Also see *Maximum Thresholds*). Further discussion on Karst areas can be found in Chapter 7 of the Manual and Appendix B. Other notable authors on Karst are: Kochanov, 1993; Ralston et. al., 1999. (See *Technical References and Literature Review*)

Maximize Soil Mantle Thickness and Infiltration Rates in Karst

When using infiltration BMPs in areas of Karst geology, the soil mantle acts as a pollutant filter and hydraulic "buffer" that intercepts, slows, and distributes the infiltrated runoff before it reaches the underlying carbonate formations. In simple terms, the risk of sinkholes decreases as the thickness of the soil increases. Subsequently, in areas proposed for infiltration, the designer should seek the greatest amount of soil mantle thickness and minimize the amount of excavation (cut). Several feet of soil mantle is recommended in any area proposed for infiltration. The greater the footprint of the BMP, the greater the thickness should be to minimize risk. In areas of shallow carbonate bedrock or shallow carbonate bedrock pinnacles consideration should be given to increasing the soil thickness in the design. (check with Gary Kribbs on this)

Rapid infiltration rates may increase the risk of soil piping and sinkhole formation and/or groundwater contamination as water flows through the soil mantle with minimal lateral dispersion and slowing. Therefore, for those projects utilizing a loading ratio approach, the upper limit for a measured rate of infiltration in Karst areas is **6 inches/hour.** This is provided as a screening tool to help prevent subsidence and direct groundwater pollution through bedrock fractures and other direct connections. Variations to these rates of infiltration may be approvable on a case-by-case basis.

9.0 TRANSMISSIVITY:

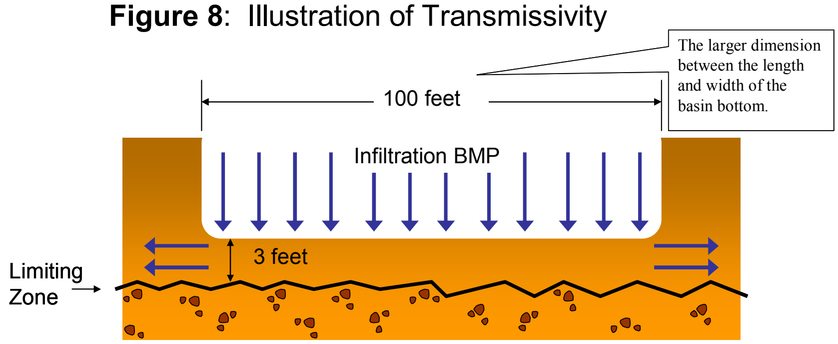
Transmissivity is a measure of the area of water moving past a specific zone in the soil over time. It is defined as the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It can be computed by multiplying the depth of saturated flow by the hydraulic conductivity, K, of the soil (Driscoll, 1986; Fetter, 1994).

Because of the relatively narrow permeable layers that are typically found in Pennsylvania, transmissivity can often be the limiting parameter for large infiltration BMPs, rather than hydraulic conductivity (K). Transmissivity is the most important parameter in mounding tests, which may be used to determine whether a particular area can adequately infiltrate the anticipated volume of water discharged to it without significantly affecting overlying or adjacent groundwater levels (Also see *Mounding Analysis*).

[8] For more information, the reader is advised to reference Appendix B, Recommendations for Proper Site Investigation/Design of Stormwater Infiltration BMPS. (PCPG)

The figure below illustrates an example of how transmissivity can dictate the rate at which water is assimilated by an infiltration BMP. Consider a moderately sized basin with a bottom width of 100 feet and hydraulic conductivity of the soil to be 10 ft/day. The initial (vertical) transmissivity for the BMP could be construed to be: 100 ft x 10 ft/day = 1,000 ft^2/day (per foot of length of the basin).

Figure 8: Illustration of Transmissivity



At some point in the soil column, water will reach a limiting zone (bedrock or water table) and the unsaturated zone will reach its storage capacity resulting in water traveling predominantly in the lateral direction. This depth can vary dramatically in Pennsylvania, but in many areas it can average 3 feet or less. Therefore, assuming a depth of 3 feet, the lateral transmissivity would be: 3 ft x 10 ft/day = 30 ft^2/day (per foot of length of the basin). As you can see in this example, transmissivity is greatly reduced and therefore the rate of water leaving the system is dictated by the depth of the permeable layer, *not* by the hydraulic conductivity (K). Note that for sake of simplicity, it is assumed that K in the vertical and horizontal directions are equal and transmissivity out of the sides of the BMP is not included.

Hence, if an infiltration BMP design includes one or more of the following attributes:

- a large footprint. (as defined in the previous section),
- a permeable soil layer depth at or near the 2-foot limit,
- a factor of safety of 2 or less (FOS<2 not recommended),

it will push the BMP design into a higher risk category and the BMP may encounter sustainability issues including retaining water and/or spill over of excess water without adequate volume control. As an infiltration BMP increases in footprint (i.e. bottom area) and becomes planar, the lateral movement of water from the BMP becomes negligible and it reaches its limit to transmit the design flow though the system. This is further exacerbated by the fact that in Pennsylvania, rainfall can commonly occur within 72 hours of the previous rainfall event.

This further emphasizes the need for a suitable factor of safety when designing infiltration BMPs. (Also see *Factors of Safety*). The designer should note that the safety factors in the Manual are minimum values and should be adjusted to suit the project.

Transmissivity is typically not as limiting for <u>small</u> infiltration systems, such as an infiltration trench. The width of the saturated zone through which water leaves the BMP is rarely larger than the depth of the permeable layer. Therefore, the hydraulic conductivity (K) is normally the limiting factor. In this situation, the recommended loading ratios from the BMP Manual (in non-karst areas) are generally conservative and may be more tolerant to increases, depending on hydraulic conductivity. This is consistent with the intent of the Manual, which is to promote distribution of stormwater to smaller BMPs across the entire project site.

10.0 MOUNDING ANALYSIS:

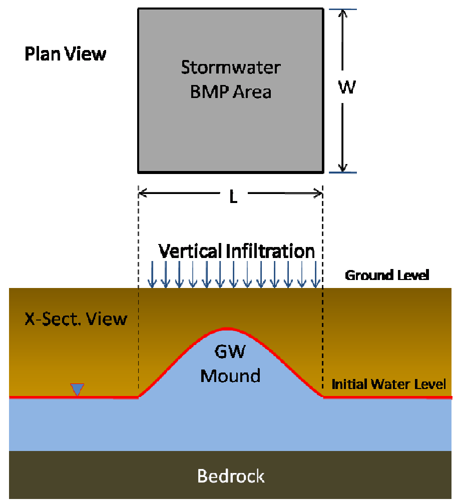
Ground water mounding, the process by which a mound of water forms on the water table as a result of recharge at the surface, can limit the effectiveness of an infiltration facility if it is not identified. As previously mentioned, the Manual specifies a minimum of **2 feet** of separation between the bottom of the infiltration facility and seasonally saturated soils (or from bedrock) to maintain the hydraulic capacity of the practice and provide adequate water quality treatment. As BMP increase in size, the respective separation distance should also

increase. In many cases, 3 feet or more is recommended. (Also see *Permeable Soil Layer* under Soils and Geology.)

A mounding analysis may be warranted in areas where infiltration is proposed with loading ratios exceeding the recommended values. As previously mentioned, this is of particular concern for infiltration BMP designs that have large footprints. A large infiltration BMP would be dependent on the lateral dimensions of the BMP with respect to the thickness of the underlying permeable soil layer, but could generally be considered:

- a subsurface BMP with length and width bottom dimensions both exceeding **100** feet (footprint area > 10,000 square feet).
- a vegetated surface BMP where the footprint area exceeds ½ **acre**.

Figure 9: Groundwater Mounding from a Stormwater Infiltration Facility



There is less concern for small on-lot systems and linear systems such as dry wells, rain gardens and infiltration trenches. Concerns about mounding effects could be mitigated if designs of the larger systems previously discussed conform to the following criteria:

1. Soil testing reveals very good infiltration rates (> 2 inches/hour measured rate);
2. Consistency with the recommended loading ratios;
3. Minimum Factor of Safety of 3;
4. Minimum 3-foot separation distance to limiting zones;
5. Maximum drawdown time is 48 hours or less (rather than 72 hours).

In some states, such as Minnesota, a mounding analysis is recommended for all stormwater infiltration BMPs. Though this is not a requirement in Pennsylvania, it is recommended that permit applicant's perform a mounding study or formulate conclusions based on acceptable surrogate parameters when proposals beyond the above-mentioned criteria are under consideration.

Besides concerns with BMP performance, mounding may also cause impacts to nearby structures. Though, the BMP Manual provides default setbacks from structures, in some cases, more detailed analysis may be necessary. For more information, the reader is advised to reference the *DRAFT Technical Guidelines for Evaluating Ground-Water-Recharge BMPs in New Jersey* (last rev. Mar. 2009).

When required, the maximum ground water mounding potential should be determined through the use of available analytical and numerical methods. Detailed ground water mounding analysis should be conducted by a qualified professional (e.g. Hydrogeologist (PG)) as part of the site design procedure. Further information on mounding studies can be found by the following authors: Glover and Hantush (recommended by Minnesota); Warner, Molden, Sunada, et.al., 1984 (New Jersey) and Kashef,1986; Driscoll, 1986; Todd, 1980.

Bear in mind that the common methods for prediction of mounding are often complex and difficult to apply. Simplified methods and computer models are available online. One example is the paper entitled *Simplified Solutions for Groundwater Mounding Under Stormwater Infiltration Facilities*, by Kaveh Zomorodi, from the AWRA 2005 Annual Water Resources Conference. Other notable literary sources are Kashef, 1986; Driscoll, 1986; Todd, 1980. (See *Technical References and Literature Review*)

Online computer models for mounding beneath circular and rectangular-shaped recharge areas can also be found at www.aquifertest.com/forum/methods.htm.

11.0 FACTORS OF SAFETY:

Reference is made to Appendix C of the BMP Manual (page 19 of 21) regarding factors of safety.

A factor of safety (FOS) is typically used due to uncertainty in the design process, the inexact nature of soil testing, and long-term variability. It is basically a countermeasure to mitigate concerns with risk. Values between 1 (no adjustment) and 10 have commonly been used in the design of stormwater infiltration systems, with a factor of 2 being the recommended minimum. A FOS should be applied to any measured infiltration rate, including double-ring infiltrometer testing. Based on the equation for computing infiltration volume found in the BMP Manual (e.g. Ch. 6, Pg. 16 of 257), the FOS is directly proportional to the infiltration period (i.e. drawdown time), and bed bottom area. It also affects the routing (how quickly the bed fills up during the storm.) Thus, it should be expected that one or all of these parameters would be affected by a FOS.

For those limited cases where the percolation test may be deemed appropriate (i.e. small and linear BMPs), a FOS would be applied in addition to a reduction factor. Reduction factors are further discussed in Appendix C of the Manual (pages 8 and 9). Therefore, an adjusted percolation rate of 0.5 inches per hour (after reduction factor) would be reduced to 0.25 inches per hour for design after applying a FOS of 2

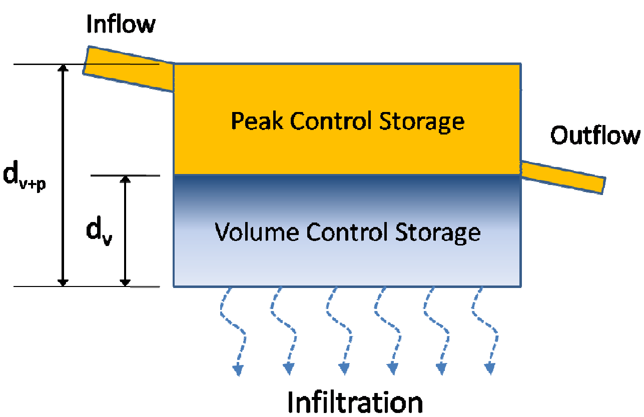
Design Rate (in/hr) **= measured (field) rate** (in/hr) **/ FOS)**.

The BMP Manual (Appendix C, pg. 19 of 21) states that a FOS of 3 should be considered for infiltration areas with Maximum Impervious Loading Ratios greater than the recommended 5:1 (IDA:IA). Though not explicitly stated in the Manual for TDA:IA, a FOS of 3 should also be considered for Maximum Total Loading Ratios greater than 8:1.[Reconsider – OMIT?]

12.0 SITING OF INFILTRATION BMPs:

Infiltration BMPs may be constructed either **on-line** or **off-line**. On-line systems receive upstream runoff from all storms, providing runoff treatment for the maximum design storm and conveying the runoff from larger storms through an overflow. With the proper soil and drainage area conditions, an infiltration facility may also be combined with detention storage to provide runoff quantity control. In such systems, the invert of the lowest stormwater quantity control outlet is set at or above the pertinent water surface elevation. In these situations, care must be taken to limit the hydraulic depth above the infiltration surface at the bottom of the BMP. Figure 9 shows this as the *depth of volume control storage* ($\mathbf{d_v}$) and the *depth of the volume and peak control storage* ($\mathbf{d_{v+p}}$). If this type of design is sought, then ideally the $\mathbf{d_{v+p}}$ should be kept to 4 feet or less to avoid complications with compaction and clogging.

Figure 10: Sample BMP layout with both Peak and Volume Control Storage.



Concerns have been raised regarding the use of on-line infiltration systems for infiltration, particularly those having relatively large drainage areas (> 5 acres) due to the increased frequency of events requiring treatment. The designer should fully consider this concern when proposing an on-line system. Design alterations and an additional FOS may be appropriate.

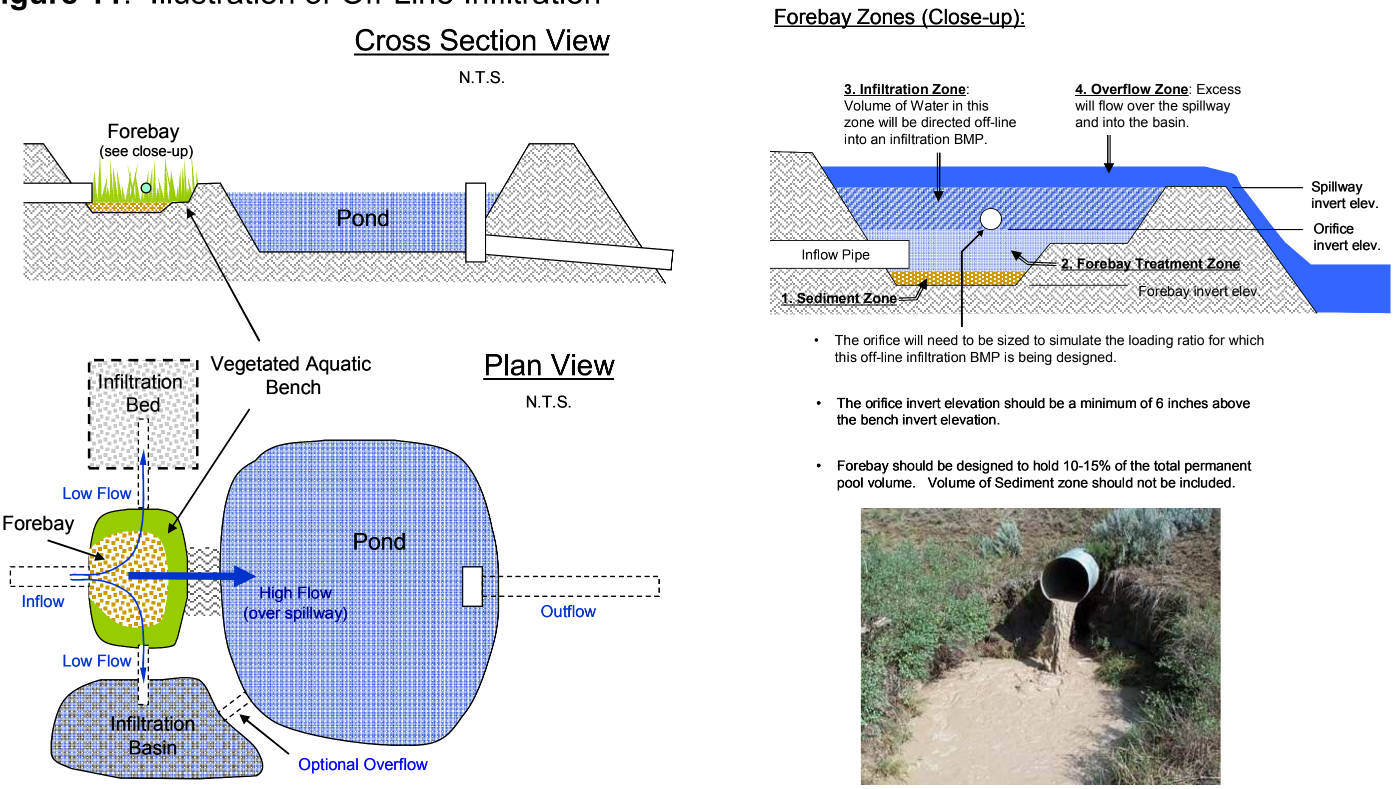
In off-line infiltration BMPs, most or all of the runoff from storms larger than the maximum design storm bypass the BMP through an upstream diversion. (Also see *Diverting Flows from Upslope Pervious Areas*) This not only reduces the size of the required BMP storage volume, but also reduces the BMP's long-term pollutant

loading and associated maintenance. (Source: NJ SWM BMP Manual, rev. 2004) The design for an off-line BMP will need to include inflow control in order to prevent hydraulic overloading. This can be done by:

(1) Setting an infiltration base area based on permit requirements and available space. Initial sizing should be based on impervious drainage from the "Delta" 2-year storm, though this target may become infeasible with larger drainage areas. For EV/HQ watersheds, the applicant will still need to have a stormwater plan which is protective of the uses of receiving stream which normally entails volume control for the entire "Delta" 2–year event. (also see "Special Protection Watersheds) In non-Special Protection watersheds, the designer may be able to utilize a tiered approach for sizing infiltration BMPs (such as noted in CCWRA Model Ordinance), provided that other BMPs are in place. In most cases, the **minimum** amount of infiltration volume should be **½ inch of runoff** from impervious surfaces.
(2) Sizing the inflow system. This is one of the most important steps and is normally done with a conduit or orifice. Also, routing computations should be performed to demonstrate that the amount of water required to manage in Step 1 is actually reaching the infiltration BMP.
(3) Ensuring drawdown of the system occurs within 72 hours or less as required for any other infiltration BMP.
(4) Include an optional overflow pipe or spillway from the infiltration BMP to the rate control BMP.

The diagram below shows an example of a rate control BMP with off-line infiltration. Pretreatment is provided through a sediment forebay and aquatic bench. Flow into the adjacent infiltration BMPs would occur at an elevation above the WQ volume[9] (with a set amount of freeboard to account for sediment accumulation). In this example, the forebay is designed to overflow into the wet pond during flows exceeding the design storm (say 1-inch storm) for the forebay and/or infiltration BMPs. [for impervious areas in the entire drainage area]

Figure 11: Illustration of Off-Line Infiltration



[9] WQ Volume in not fully described in the BMP Manual. This may be due to the fact that PA's Post-Construction Stormwater Program is focused on dealing with volume control (net difference in 2-year 24-hour storm), for which the WQ volume would be a fraction. In this situation, the designer may be best suited following the recommendations for forebay sizing, which recommends 10 to 15 of the total permanent basin volume for wet ponds.

Flow Equalization:

When off-line arrangements of these BMPs are not feasible, a variation that the designer may utilize is a peak rate control facility (e.g. tank or basin) upstream of an infiltration BMP providing flow equalization. This peak control BMP could regulate inflows so that established criteria (e.g. maximum hydraulic head (2 feet) and maximum dewatering time (72 hours) are sustained.) This arrangement may not work in all cases, therefore both state and local authorities would need to be agreeable to this setup prior to its use.

Figure 12. Sample Diagram for Flow Equalization

13.0 SPECIAL PROTECTION WATERSHEDS:

Exceptional Value and High Quality Waters have inherent value that is worthy of protection and preservation. Antidegradation requirements in Chapter 93 are designed to provide this protection. Design criteria for NPDES Permit applications for construction projects is more stringent in Special Protection Waters than it is for other waters. These criteria carry over to loading ratios and site-specific approaches to sizing infiltration BMPs. Therefore, infiltration BMPs in special protection waters should abide by the following criteria:

- Minimum FOS of 3 for those projects following the recommended loading ratios.
- Minimum FOS of 4 for those projects exceeding the recommended loading ratios.
- Loading Ratio Approach: Maximum threshold – 8:1 IDA:IA (non-karst). (Also see *Maximum Thresholds*)

14.0 EROSION CONTROL CONSIDERATIONS:

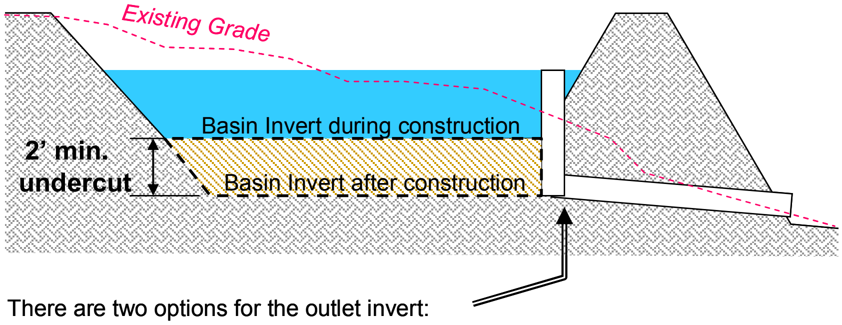
The placement of infiltration BMPs in the same location as sediment basins and/or traps induces a higher risk; may bring about future problems; and is discouraged. The construction of these temporary erosion control devices can cause compaction of the underlying soils and/or clogging of the soil pores. Where site conditions predicate mandate overlapping of these facilities, the following preventative measures should be taken:

(1) The sediment basin/trap should be undercut by a minimum of 2 feet from the bottom elevation of the infiltration BMP. Although undercutting the invert of the sediment basin/trap may reduce the clogging potential in certain instances, the recommended loading ratios should still be followed.
(2) The area should be protected from heavy equipment. This will require vigilant oversight during maintenance activities. (i.e. restoring sediment volume in the basin.)
(3) Stabilization of the basin should be conducted using a seed mix with deep rooted perennials and basin mowing should be kept to a minimum.
(4) Additional infiltration soil testing should be conducted after the basin is converted to verify soil properties haven't been compromised.

Further information on erosion control considerations can be found in the Department's Erosion and Sediment Pollution Control Program Manual (2000)[10].

[10] During the drafting of this document, the Department was in the final stages of releasing an update to the E&S Manual.

Figure 13. Converted Sediment Basin / Trap



There are two options for the outlet invert:
- If proposing a Dry ED Basin, then install outlet at proper elevations at the onset (as shown) or reinstall another permanent outlet works at the proper elevation when the basin is ready to be converted.
- If proposing a wet pond, then outlet works may remain unchanged to accommodate a 2-foot minimum pond depth.

15.0 MAXIMUM THRESHOLDS:

As previously mentioned, designing infiltration BMPs is often an iterative process with loading ratios being one mere element. The design adjustments discussed in this document may not be suitable in all case but are provided to "responsibly" assist plan preparers attempting to justify loading ratios greater than those recommended in the Manual. However, setting upper limits are often necessary to prevent designs from grossly exceeding their intended purpose and surpassing acceptable risk levels. The topic of loading ratios has been included in the Manual to address concerns with infiltration system failure due to substantial volumes of water being directed to relatively small areas. Taking all this under consideration, the table of adjusted maximum loading ratios has been provided below for those BMPs that meet the aforementioned criteria.

Maximum allowable loading ratios:

	Non-Karst	
	BMP Manual Recommended	Maximum Adjusted
TDA:IA	8:1	**N/A**[11]
IDA:IA	5:1	**10**:1[12]

Much of the information in this document has been provided as an incentive for improving the overall design and sustainability of these practices. However, until the BMP Manual is revised, there is no guarantee that any of these recommendations will be acceptable and all attempts should be made to follow the recommended loading ratios, where practicable, particularly those projects having sufficient space and soil properties.

All of these adjustments need to be looked at comprehensively by knowledgeable professionals in such matters and it is highly recommended that project proponent's follow a site-specific approach with professionals from diverse professional backgrounds as discussed in various parts of this document.

[11] One of the lessons learned while developing this document is that the Maximum Impervious Loading Ratio is a much more important consideration than Maximum Total Loading Ratio for designing infiltration BMPs. Therefore, this document no longer includes a maximum adjusted TDA:IA , as this value may not factor significantly in the design process.

[12] This number was selected as a conservative estimate for those designers following a loading ratio approach to infiltration BMP design. Greater loading ratios can be justified, within reason, when proper soil and geologic investigations are conducted. See other recommendations in this document and Appendices A and B.

For those following a loading ratio approach, it should be noted that this document was not intended for the designer to unilaterally select one type of adjustment to justify a loading ratio at the maximum threshold. For this reason, the designer should utilize a minimum of three factors (i.e. thick permeable soil layer, small DA, low risk, land use, water quality/pretreatment, factor of safety, siting, etc.) prior to requesting justification for a loading ratio at the maximum threshold. This document does not include any recommendations to exceed the recommended loading ratios in Karst areas.

16.0 CONCLUSIONS:

After considering all the variation that can be found on virtually any project, it is apparent that a *site-specific approach* to sizing infiltration BMPs is superior. A *loading ratio approach* has been provided in the BMP Manual as a conservative default and it will always have its utility. One of the problems that will continue to exist is the fact that the engineering and scientific communities do not fully understand the long term stresses that are frequently placed on our natural soil and geologic systems to handle excess stormwater runoff. DEP's post-construction stormwater management policies have received much criticism that they require excessive stormwater to be infiltrated (i.e. CG-1). Closer review of DEP's policies and watershed management goals will show that this criteria is for volume control, of which infiltration is one component. Infiltration is the preferred method for volume control due to its relative ease of design and it will continue along this path until more recognized and acceptable methods are developed for other volume control alternatives such as capture and reuse and vegetated systems with evapotranspiration. The future of stormwater management is to find acceptable methods of incorporating all volume control alternatives into a stormwater plan which truly mimics the natural hydrology of a site.

17.0 TECHNICAL REFERENCES AND LITERATURE REVIEW:

Pennsylvania SWM BMP Manual 12/26/2006 [check PACD Manual]

Little Lehigh Creek Watershed Act 167 Plan – Water Quality Update April 2006

Little Lehigh Creek Watershed Stormwater Management Ordinance – April 2006

New Jersey SWM BMP Manual, April 2004, Pgs. 9.5-10

Development of Appropriate Stormwater Infiltration BMPs: Part I - Potential Water Quality Impacts, Monitoring and Efficacy Evaluation - G. Fred Lee, PhD, PE, DEE, Anne Jones-Lee, PhD and Scott Taylor, PE, Ground Water Protection Council 98 Annual Forum, September, 1998

EPA "Stormwater Technology Fact Sheet" Bioretention, EPA 832-F-99 012, Sept. 1999.

Technical Best Management Practices Manual and Infiltration Feasibility Report: *Infiltration of Stormwater in Areas Underlain by Carbonate Bedrock within the Little Lehigh Creek Watershed*, Lehigh Valley Planning Commission, 2003

Minnesota Stormwater Manual –Jan. 2008, http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html

Simplified Solutions for Groundwater Mounding Under Stormwater Infiltration Facilities - Kaveh Zomorodi, Dewberry, AWRA 2005 Annual Water Resources Conference www.dewberry.com/uploadedFiles/SimplifiedSolutionsforGroundwaterMounding.pdf

[DATE] New York State SWM Design Manual – Ch. 9 – Alternate SWM Practices

Wisconsin Department of Natural Resources – Conservation Practice Standards – 02/04

[DATE] SWM Controls for Western Australia, Structural Controls

North Central Texas – Residential/Commercial BMP Manual 7/1993

[DATE] Maine –BMPs Technical Design Manual Vol. III Chap. 6 Infiltration BMPs

[DATE] Iowa Stormwater Management Manual

National Management Measures to Control Nonpoint Source Pollution from Urban Areas
Management Measure 5: New Development Runoff Treatment - November 2005

Driscoll, F. G., Ph.D. (1986). Groundwater and Wells, 2nd ed., Published by Johnson Filtration Systems Inc., St. Paul, Minnesota 55112.

Fetter, C. W., Jr. (1994). Applied Hydrogeology, 3rd. ed. Published by Prentice-Hall Inc., Simon & Schuster Co. Upper Saddle River, New Jersey 07458

Kashef, A. I., (1986), Groundwater Engineering, McGraw Hill Book Co. New York, New York.

Todd, D. K. (1980). Groundwater Hydrology, 2nd ed. John Wiley & Sons, New York, New York, pp. 520.

Kochanov, W. E. 1993. Sinkholes and Karst-Related Features of Montgomery County, Pennsylvania. Open File Report OF 93-02. PA Department of Environmental Resources

Mark R. Ralston, M.R. Issa S. Oweis, I.S., 1999, Geotechnical Engineering Considerations for Stormwater Management in Karst Terrain, Pennsylvania Stormwater Management Symposium, Villanova University, Villanova, Pennsylvania. October 20-21, 1999

18.0 AUTHORS:

Domenic Rocco, P.E., CPESC, CPSWQ; Chief, Stormwater Section; PA DEP, Southeast Regional Office, Watershed Management Program

Christopher Smith, P.E., CPESC; Project Manager; PA DEP, Southeast Regional Office, Watershed Management Program

Frank Payer, Soil Scientist; PA DEP, Central Office, Bureau of Watershed Management, Division of Waterways, Wetlands and Stormwater Management.

19.0 ACKNOWLEDGEMENTS:

The authors would like to thank and acknowledge the following peer reviewers and commenters for their time and helpful feedback, including:

Jeffrey MacKay, P.E. – NTM Engineering, Inc.
Robert Traver, P.E., PhD – Villanova University
Frank Browne, P.E., PhD, - FX Browne Inc.
Clay Emerson, PhD – Villanova University/Princeton-Hydro
Mark Bowen, P.E. – CMX Engineers/Kleinschmidt

Theodore Koven, P.E. - Castle Valley Consultants, Inc.
Melissa Stevens, E.I.T., Taylor, Wiseman and Taylor
Andrew Potts, P.E., Cahill Associates/CH2MHill.
Jeremy Maderas, P.E., Horizon Engineers/Wilkinson Associates

Pennsylvania Association of Professional Soil Scientists (PAPSS)

Russell Losco, C.P.S.S. – Lanchester Soil Consultants, Inc.
Michael Lane, C.P.S.S. – Brickhouse Environmental
Steve Dadio, C.P.S.S. – CMX Engineering Inc.
William Davis, C.P.S.S. – PADEP
Tom Benusa, C.P.S.S. – Benusa Environmental
Mike Sowers, C.P.S.S. – Del Val Soil & Environmental Consulting
Bruce Willman C.P.S.S.- Skelly & Loy

Pennsylvania Council of Professional Geologists (PCPG)

Paul White, P.G. - Brickhouse Environmental
Gary Kribbs, P.G. - AEON Geoscience, Inc.
Bruce Haigh, P.E. - Wittemore and Haigh Engineering, Inc.
Konrad Crist, P.G. - Geo-Technology Associates, Inc.
Louis Vittorio, P.G. - Earth RES Group
Patrick Considine, - P.G. Considine Associates
David Farrington, P.G. -Brickhouse Environmental

20.0 INTRODUCTION TO APPENDICES

Soils and Geologic Considerations

This section has been created by collaboration between Soil Scientists, Geologists and Engineers. It is intended to be a guide for those projects that are too complicated to take advantage of the straight forward loading approach. The concept is to assemble a team of professionals in the soils; geology/hydrogeology and storm water engineering disciplines that will result in a proper evaluation of the site and recommend designs that will not only work properly, but establish the maintenance plans for sustainability. Historically the investigation of storm water management has been driven by other project needs. This is intended to begin the discussion and investigation at the very beginning of the design process. The following package is a summary of the scientific criteria that should be considered, investigated and evaluated, by the appropriate professional, early in the process to ensure that the most viable designs are considered by the project originator.

Appendix A
PA Association of Professional Soil Scientists (PAPSS) Recommendations for Soil Characterization for Infiltration of Stormwater

Pennsylvania has an incredible diversity of soils. From the deep crystalline soils of the Piedmont to the shallow, skeletal soils of the Glaciated Plateaus and shallow soils of the Allegheny Mountains we see a range of diversity rarely encountered in such a short distance. For this reason, no one set of simple rules and procedures for design of stormwater infiltration Best Management Practices (BMP) can be expected to apply successfully throughout the state without including detailed investigation of the soils. Though review of published data may be sufficient to rule out many sites in some of the more difficult areas, detailed site specific testing will be needed in order to site BMP's successfully. In order for a BMP to function as designed requires detailed, high quality investigation and testing of the soil.

The initial part of any soil investigation is a review of the existing published soils information. While this information is invaluable in land development planning, it must only be viewed as a first step in the investigation.

Soil surveys that are published or available on-line provide a reasonable approximation for the soil properties that one can expect on a given property. These soil surveys were made for farmers and foresters to manage the land so that the natural resources may be harvested in a sustainable fashion. The information in these soil surveys has also been useful for the practice of civil engineering and general land use planning in identifying areas with poor drainage, steep slopes, rock outcrops, and erosional features, but is insufficient to characterize a site to accommodate BMP's.

In Pennsylvania, there are published and on-line soil surveys for every county in the Commonwealth. [insert web link here] The scale for these surveys range from 1:12,000 to 1:31,680 (classified as Order 2 surveys). This equates to a range of scales on the aerial photograph maps of 1" = 1/5 to 1"= ½ mile. The minimum soil map unit size for these Surveys is 1.5 to 10 acres. The Web Soil Survey, published on-line by the USDA NRCS provides updated information in a readily user-friendly format, but still lacks sufficient detail for design and is intended to be a reconnaissance tool.

For any type of land development, this level of investigation is insufficient to determine the site-specific properties of the soil and their relationship to stormwater management BMPs. A site-specific investigation, or Order 1 soil survey, should be advanced to more accurately identify the pre-development existing soil characteristics of the site. Additionally, further investigations will need to be advanced in the areas specifically proposed for a stormwater management BMP.

It should also be noted that the soil series referenced in each published or on-line soil survey is appropriate for the scale of the investigation of that particular soil survey and was created with the county-level soil surveys in mind. For the purposes of agriculture and forestry and general land-use planning, the information in the soil survey is accurate. While the soil survey may show one soil type the site-specific investigation may find an entirely different soil series on the site.

It is likely that the soils encountered during a site-specific investigation do not match any one particular soil series perfectly and would likely be considered a taxadjunct (variant) to a soil series. While soil classification is important relative to pre-existing conditions and in establishing soil hydrologic groups, the soil morphological properties as they relate to stormwater BMPs are the critical portion of this investigation.

Appendix C of the BMP Manual, *Site Evaluation and Soil Testing*, states, "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." Because of the complexities of soil characterization, any soil investigation should be conducted

by or under the direct supervision of a SSSA (formerly ARCPACS) Certified Professional Soil Scientist or Soil Classifier (CPSS or CPSC) or professional member of the Pennsylvania Association of Professional Soil Scientists (PAPSS). Additionally, investigations conducted in areas of Karst geology must also be reviewed by a Professional Geologist (PG).

Levels of Investigation

Preliminary

For sites below a level of 10,000 ft^2 of earth disturbance or additional impervious surfaces, no investigation would be required. For sites of less than 10 acres in size but with over 10,000 ft^2 of disturbance or impervious surface, an investigation must have a minimum of 1 test pit/acre. For sites between 10 and 40 acres in size, an investigation must have a minimum of 1 test pit/ 2 acres. For sites greater than 40 acres in size, an investigation must have a minimum of 1 test pit/4 acres. This minimum density does not preclude advancing additional test pits. If there are abrupt changes in soil texture, depth to bedrock, drainage class, rock fragment content, or slope, additional observations can and should be required.
A grid is not an acceptable method in which to advance these test pit investigations. Because soils are predictable across landscapes, an accurate investigation involves mapping landscapes as much as mapping soils. Observations through test pits should be advanced within each geomorphic landscape position, based upon the experience of the individual soil scientist conducting the investigation.

Detailed

For a particular stormwater infiltration BMP, additional testing may be required. It is proposed that one test pit be advanced within each BMP of 10,000 ft^2 or less.

- BMP between 10,000 and 20,000 ft^2 = 2 test pits
- BMP between 20,000 and 30,000 ft^2 = 3 test pits
- BMP between 30,000 and 1 acre = 4 test pits
- BMP greater than 1 acres in size = 1 test pit/ additional 10,000 ft^2 beyond 1 acre . It should be stressed that several small BMP's will function more efficiently than one large one. Additional testing may be required if differences in soil morphological or physical properties are observed between test locations.

Soil Profile Description

Perhaps one of the most important aspects of a soil assessment is the soil profile description. Although there are a number of methods for describing soils, the USDA/NRCS methodology, consistent with the National Cooperative Soil Survey is the most detailed and is the method that should be required for describing soils for stormwater management and infiltration. Other methods, such as the AASHTO, Unified Soil Classification System and Modified Burmeister are useful for engineering purposes but exclude much valuable information that is vital to the purposes of stormwater infiltration. Soil descriptions made using the USDA/NRCS methodology can readily be translated or converted into these other systems, where the reverse is not true.

A soil profile description is only as good as the individual making the description, therefore, in order to be accurate, descriptions must be made by an experienced, qualified soil scientist familiar with the USDA/NRCS methodology and readily conversant in soil taxonomy.

The soil profile description should summarize all relevant information regarding the soil being examined. Minimum details that should be accepted include, but are not limited to the following:

- Soil master horizon and subordinate distinctions.
- Soil color using the Munsell soil color system.

- Soil texture. Hand textures are sufficient in most cases however laboratory particle size analysis may be required in some cases.
- Soil structure.
- Consistence.
- Horizon boundaries including distinctness and topography.
- Redoximorphic feature (formerly known as mottling) abundance, size, and contrast.
- Coarse fragments.
- Observed depth to bedrock limiting zones.
- Observed depth to seasonal or perched water tables limiting zones.
- Taxonomic classification.
- Observed soil series.

In addition, the soil scientist may need to report other relevant information that may be observed, such as:

- Roots, pores and krotovina or other significant macropores.
- Mineralogy.
- Apparent parent material.
- Moisture regime.
- Drainage classification. [Estimate of Hydrologic Soil Group (HSG) for modeling purposes]
- Identification or epi-saturation versus endo-saturation, if present.
- Restrictive horizons.
- Total porosity.
- Bulk density.

The soil profile description, and/or the narrative that accompanies it should also describe landscape position and morphometry, slope gradient and shape, hillslope position and geomorphic component. Physical location of all testing should be given either by location on a map or plan or by supplying Universal Transverse Mercator System (UTM) or latitude and longitude as derived by a Global Positioning System with sufficient accuracy for the project.

Every soil profile description should bear the signature and seal or proof of qualifications of the individual making the description.

Seasonal High Water Table

Seasonal High Water Table shall be determined by meeting (1) one of the following criteria:

1. Depth to observed water table (static level)

    a) if redoximorphic features are encountered **directly** above observed water table (endo-saturation), the shallowest observed redoximorphic feature shall be used to determine the depth.

2. Depth to gleyed horizon

    a) A gleyed horizon shall be determined by a soil horizon with a **reduced** matrix color less than or equal to 2 chroma. Soils with lithic chromic colors of 2 chroma or less are not considered "gleyed"

    b) if redoximorphic features are encountered **directly** above the gleyed horizon, the shallowest observed redoximorphic feature shall be used to determine the depth.

Redoximorphic features formed as a result of perched saturation from a hydraulically restrictive horizon, a slowly permeable horizon, or from a textural discontinuity shall not be used to determine the depth to the seasonal high water table. Relict redoximorphic features shall not be interpreted to indicate a seasonal high water table. Lithochromic colors resulting from the color of the parent material, mimicking redoximorphic depletions shall not be interpreted to indicate a seasonal high water table. It may be necessary in some cases to install shallow monitoring wells or piezometers to determine is questionable redoximorphic features are relict or not.

Infiltration Testing

Infiltration testing for stormwater control and disposal determination is probably the easiest test to complete but the most difficult to quantify as to determine the appropriate infiltration rate to apply to the site. The difficulty in determining the appropriate infiltration rate comes as a result of the numerous models, equations and variations of statistical analysis. The purpose of the infiltration testing is to provide the design engineer with a Saturated Hydraulic Conductivity (Ksat or Kfs) factor to utilize in the stormwater control design calculation. This testing should be completed PRIOR to the design engineer finalizing the infiltration system.

Hydraulic conductivity is a measure of the ability of soil to transmit water. Hydraulic conductivity is also the proportionality factor in Darcy's law relating flux density or flux to the hydraulic gradient. **Please note that infiltration rate and hydraulic conductivity are not synonymous**. The measurement of any volume of water flow into soil needs to utilize the Darcy' Law equation or other related solution. The basic Darcy's Law equation is given as

$$\mathbf{Q = K_{fs}Ai}$$

Or

$$\mathbf{K_{fs} = Q/Ai}$$

Where **Q** = volume of water flow through the soil
Ksat or Kfs = saturated hydraulic conductivity
A = cross-sectional area
I = dimensionless hydraulic gradient (H1-H2/L).

The hydraulic conductivity of saturated soil is one of the most important soil properties controlling water infiltration and surface runoff. Saturated hydraulic conductivity depends strongly on soil texture and structure, and therefore can vary widely in space.

Since hydraulic conductivity is determined essentially at points on a field scale, a large number of determinations are required to assess the magnitude and structure of the variation within the selected area. For structured or heterogeneous, stratified soils in particular, as opposed to structureless sands such as beach sand, saturated hydraulic conductivity has to be measured directly in the field to minimize disturbance of the sampled soil volume and to maintain its functional connection with the surrounding soil. The ideal testing method would use small volumes of water, consist of easily transportable equipment, and be conducted as a short-duration experiment. This would therefore allow an individual to obtain hydraulic conductivity data at a great number of locations over a large area and with the realistic use of resources in terms of time and costs.

The determination of field hydraulic conductivity and the proposed testing methods is very site specific and depends on the soil texture, structure and moisture content, as well as the coarse fragment content and size. The intention of this section of the site testing guidance is not to limit the assessors testing methods by prescribing a single testing method, nor is it capable of listing every type of infiltration methodology, but does mention several practical testing methodologies. Whatever testing method is used, it should be based on sound science and provide a statistically definable measurement of the soils hydraulic conductivity.

Different testing methods are better suited for some sites than others. The testing method utilized would determine which statistical analysis/equations should be used. Following are some of the testing methods commonly used. This is not an exclusive or complete list but only a list of examples of commonly acceptable methods.

Testing Methods:

Double ring infiltrometer – Follow ASTM Methodology or approved other
Single Ring Infiltrometer - [1]
Constant-head well permeameter method

Amoozemeter – Ksat Corp procedures.
American Manufacturing Permeameter
Cased-borehole

- **Falling Head Test**
- **Constant Head Test**

Basin Flooding Test - This testing method can be used in areas of the state where coarse fragment content is too great to properly set rings or tubes.

[1] Wu, L., L. Pan, J. Mitchell, and B. Sanden. 1999. "Measuring Saturated Hydraulic Conductivity using a Generalized Solution for Single-Ring Infiltrometers". Soil Sci. Soc. Am. J. 63:788-792; Reynolds, W.D., and Elrick, D.E. 1990. "Ponded infiltration from a single ring: I. Analysis of steady state flow." Soil Sci. Soc. Am. J. 54:1233-1241; Wu, L., L. Pan. 1997. "A generalized solution to infiltration from single-infiltrometers by scaling." Soil Sci. Soc. Am. J. 61:1318-1322.

Conspicuous by its absence from this list is *"percolation" testing*. It must be noted that percolation tests are one of the least accurate methods of measuring soil permeability. Percolation testing is an antiquated method where it is impossible to isolate vertical from horizontal movement of water and can not be utilized to find Ksat. For these reasons it should be avoided for testing for stormwater infiltration.

The numbers of test to run must be dependent on the size of the testing area and the differences in soil structure and texture. A minimum of three infiltration borings/rings should be run at each single house location. Basins and large infiltration galleries (>2000 sq feet) - 1 boring/ring for every 250 sq feet

Basin flood test – 1 every 150 sq. feet

Equations and Results – Since January 2000, over 8000 articles pertaining to infiltration testing equations have been written in the Tri-societies (ASA, CSSA, SSSA) Soils and Vadoze Zone scientific manuals. It is not correct to simply take rates of drop and convert them directly to infiltration rates, as these rates of drop are dependent upon head pressure and will vary depending upon the water level. It is important that the values be related to Darcy's Law and corrected for head pressure. The infiltration testing method will dictate which equation/statistical analysis is proper. The final result of the infiltration testing MUST be verifiable and justifiable.

APPENDIX B
PA COUNCIL OF PROFESSIONAL GEOLOGISTS RECOMMENDATIONS FOR PROPER SITE INVESTIGATION/DESIGN OF STORMWATER INFILTRATION BMPS

TABLE OF CONTENTS

Proper Site Investigation/Design of Stormwater Infiltration BMPs

1.0 BACKGROUND

The following information has been prepared by the Pennsylvania Department of Environmental Protection (DEP) as supplemental guidance to the recommended criteria for loading ratios for infiltration BMPs in the PA Storm water Best Management Practices (BMP) Manual (Dec. 26, 2006). It is intended primarily for projects facing site constraints and associated challenges in meeting the volume control guidelines described in Chapter 3 of the BMP Manual.

The intent of the practices in the DEP manual is to have the Post Development hydrological regime mimic the Pre-Development hydrological regime for the site, receiving waters and groundwater beneath the site. Users of the Manual and this document are strongly encouraged to follow the progression of prevention first, local sitting at source second and mitigation third. Conflicts with design criteria can commonly occur when designers push the threshold and tolerance limits of infiltration BMPs. The success of infiltration BMPs requires thinking outside of the box and setting aside conventional storm water practices of detention/retention ponds , which have focused on addressing flood control through limiting peak flow rates. The prior DEP storm water management policy did not consider storm water volume control, velocity discharge or groundwater recharge. Water quality degradation has occurred throughout the Commonwealth to receiving streams, wetlands and riparian buffers due to increased

volume of storm water discharges and increased pollutant loading. The resulting reduction in groundwater recharge has affected stream side wetlands and stream base flow as well as aquifer recharge.

Failure to consider the Pre-Development natural hydrologic regime may significantly increase the risk of conflict arising with many of the recommended BMPs and associated technical criteria in the Manual, including the use of **loading ratios. A through discussion of this situation, which is very common, at the Pre Application meeting and the development of the "Site Conceptual Model" may reduce the difficulties at the application review phase.**

The Department strongly supports the professional community in that the proper approach to design of infiltration BMP lies in a "Site Conceptual Model"; adequate site investigation and the application of sound scientific principles and models. The Department states this as the preferred design approach for infiltration BMPS. The Department however recognizes that there are some limited low risk situations where a full site investigation and computer modeling may not be cost effective. Under these limited circumstances the Department is willing to allow the applicant to use a more conservative "loading ratio" concept for sizing of infiltration BMPs. The Department recognizes that the use of concept of loading ratios for infiltration BMPs is a unique concept within the Commonwealth of Pennsylvania, that while based in theory upon sound basic scientific principals it lacks the full documented performance evaluations that are necessary to validate the design loading ratios. The Department has chosen to allow the loading ratio design approach within the regulated community in order to obtain an adequate number of sites in the data base to validate the loading ratio design assumptions.

The "loading ratio" design approach is based in part on experiences in Prince George's County Maryland, 1993. This historical research document is "Storm water Technology Fact Sheet-Bioretention, EPA 832-F-99-012, September 1999. The Department has modified this EPA document for use in designing infiltration BMPs in Pennsylvania. The "loading ratio" design approach also draws upon the Little Lehigh Creek Watershed Act 167 Storm water Management Plan.

The debate on increasing loading ratios alone is a conservative approach that does not have (sufficient) adequate scientific and empirical support. However, volume control for some measure of flood control should be the target all the professionals on both sides should keep it mind. If infiltration is greatly desired and the "loading ratio" design approach does not appear to fit the proposed project because of site conditions, geology, soils, wetlands, or streams etc., then the outlined approach in Appendix A and Appendix B, Section 8 may be employed. The approach is an outline of the scientific items that should be considered. This method is intended to raise the level of investigation involved in the project in order to make scientific decisions about the project. The outline methodology is not a guarantee of a solution, but the best that science can offer at this stage in development.

2.0 EXEMPTIONS FOR SMALL PROJECTS

An exemption from the requirement of infiltration BMPs is provided for new developments which are expected to have an insignificant impact on the watershed. The exemption applies to the following type projects.

a. Developments creating <10,000 square feet of added impervious area are exempt from the requirements of the BMP Manual except for infiltration of storm water from roof downspouts.

b. Township and county requirements remain in effect
c. Cumulative increases in impervious area are measured from the date of the BMP Manual (December 30, 2006), the date of the Watershed Act 167 Storm water Management Plan or Ordnance or the date of the Municipal Storm water management Ordinance; which ever is earliest

DOES NOT INCLUDE projects listed in Section 4.0.

3.0 PROJECTS ELECTING TO FOLLOW GUIDANCE IN BMP MANUAL

a. Project must meet the loading ratios specified by Chapter 6 and Appendix C
b. Testing protocol must be conducted in accordance with Appendix C
DOES NOT INCLUDE projects listed in Section 4.0.

4.0 PROJECTS REQUIRED TO FOLLOW DETAILED SITE-SPECIFIC CHARACTERIZATION PROCESS

a. Projects that do not comply with loading ratios in Chapter 6 and Appendix C
b. Hot-spot" land uses as specified in Section 5.0
c. Projects in high quality or exceptional value watersheds for reasons specified in Section 6.0
d. Projects underlain by Karstic carbonate bedrock

5.0 HOT SPOT LAND USE

Hot Spot land uses are land uses or activities that generate higher concentrations of hydrocarbons, trace metals or other toxic substances than typically found in storm water runoff. Infiltration BMPS alone are typically not designed to treat these higher levels of pollutants. Storm water runoff from Hot Spot land uses, because of the higher pollutant loads, need to be pre-treated with suitable BMPs before being discharged to surface waters of the commonwealth. Infiltration BMPs may not be used for Hot Spot land uses.

HOT SPOT LAND USES

LAND USE	PRE-TREATMENT METHODS
Vehicle Maintenance and Repair Facilities including Auto Parts Stores	• Oil /Water Separator • Use of Drip Pans and/or Dry sweep Materials Under Vehicle/Equipment • Use of Absorbent Devices to Reduce Liquid Release • Spill Prevention and Response Plan when Required
Vehicle Fueling Stations	• Oil Water Separator • Spill Prevention and Response Plan when Required
Storage Areas for Public Works	• Spill Prevention and Response Plan when Required • Provide cover or shelter for any materials posing a threat to water quality. (i.e. road salt)
Vehicle Cleaning Facilities	•
Outdoor Storage of Liquids	• Spill Prevention and Response Plan when

	Required • Perimeter containment for above ground storage tanks.
Facilities that generate, store, or dispose of regulated substances	•
Commercial Nursery Operations	• Vegetated swales/filter strips • Constructed wetland • Storm water Collection and Reuse.
Landfills, Salvage Yards and Recycling Facilities	BMPs that are part of a Storm water Pollution Prevention Plan under a NPDES Permit
Fleet Storage Yards and Vehicle Cleaning Facilities	BMPs that are part of a Storm water Pollution Prevention Plan under a NPDES Permit
Facilities that Store or Generate Regulated Substances	BMPs that are part of a Storm water Pollution Prevention Plan under a NPDES Permit
Marinas	BMPs that are part of a Storm water Pollution Prevention Plan under a NPDES Permit
Certain Industrial Uses (listed under NPDES)*	BMPs that are part of a Storm water Pollution Prevention Plan under a NPDES Permit

* Regulated under the NPDES Storm Water Program

6.0 SPECIAL PROTECTION WATERSHEDS

Exceptional Value and High Quality Waters have inherent value that is worthy of protection and preservation. Antidegradation requirements in Chapter 93 are designed to provide this protection. Design criteria for NPDES Permit applications for construction projects is more stringent in Special Protection Waters than it is for other waters. These criteria carry over to loading ratios. Therefore, infiltration BMPs in special protection waters must be designed utilizing the Tier II approach.

7.0 CONCEPTUAL MODEL/PRE LAND DEVELOPMENT PLANNING

Initial Site Planning Meeting (Pre-Application Meeting) : This is the initial step in any project development and should follow the recommendations contained in Appendix C of the Preliminary Site investigation/Characterization as outlined in the December 2006 BMP Manual and Chapter 4 – Integrating Site Design and Storm water Management. The preplanning meeting should be convened by the lead project manager. Attendees should include design engineers, geologists, soil scientists and others who may be involved in planning the project. This is an interdisciplinary exercise prior to starting actual field data collection.

As noted in the Manual, file reviews, use of available maps and documents about the environmental conditions at the site and the surrounding watershed should be reviewed and discussed by the team. Identification of any special protection waters, soil maps, geologic conditions (e. g. fracture trace analysis or seasonal high water tables) and other environmental concerns should also be discussed by the design team. Discuss the potential fatal flaws (such as the Natural Pre-Development Conditions) of the project and explore how to resolve them with all parties. Site development requirements should be

included in the review meeting. This may include reviewing municipal zoning, subdivision and land development ordinances, county watershed studies and other similar plans or regulatory requirements.

The initial assessment will help identify design constraints that may impact the location or size of the proposed construction footprint. The assessment will also enable site development phasing including access roads, plans for clearing and grubbing, sample collection and methods for obtaining the field data (access routes to limit potential compaction of the site or potential infiltration areas). A plan for accessing the site should be developed and be included as part of any bid or construction documents.

Gaps in the knowledge base should be identified during the meeting and data collection plans should be developed prior to initiation of the project. These plans will assist in collecting needed field data and guide decisions regarding the selection of BMP's and project phasing. QA/QC plans should also be prepared and reviewed to ensure that future data collection can be replicated if required by the regulatory agencies.

8.0 OUTLINE FOR SITE INVESTIGATION CONSIDERATIONS/CONCEPTUAL PLAN

I. Preliminary Considerations/Conceptual Plan
   a. Local Zoning and Land Use Restrictions
   b. Soil Characteristics*
   c. Geologic and Hydrogeologic Characteristics*
   d. Hydrologic Characteristics*
   e. Climatic Characteristics*
   f. Vegetation/Land Cover Characteristics*
   * (each of these is expanded below.)

II. Soils [ALSO SEE APPENDIX A – PAPSS]
   a. Land Surface and Soil Characterization/Geomorphology
   b. Topography
   c. Soil Profile Description
   d. Soil Morphologic Interpretations
   e. Permeability/Infiltration Estimates
   f. Surface Runoff
   g. Chemical/Biological Characteristics
   h. Preliminary Soils Suitability Determination

III. Geology and Hydrogeology
   a. Non Karstic formations proceed to c.
   b. Karst geology considerations
      i. Conduct a preliminary study
      ii. Risk based evaluation (Qualified PG).
         - Assess the project area
            a. Assess published data first
            b. Photo evaluation (CIR preferred)
               i. Current conditions
               ii. Historical records
            c. Ground Truthing (essential)
         - If the areas needed for infiltration show active karst or cannot not be economically mitigated then avoid infiltrating in the area.

- If the area is low risk for karst activity
- Proceed to the next component.

c. Depth to the water table (maximize where ever possible 5 to 10 feet) minimum and season ranges.
   i. Summarize how was this gathered (wells, drilling etc. and how reliable)

d. Bedrock/Aquifer Permeability/Transmissivity
   i. How is the aquifer handling the water?
   iii. Single fractures
   iv. Bedding partings
   v. Multiple fractures and joint systems
   vi. Interstitial voids
   vii. All of the above.
      - This should aid in the overall evaluation of the system (obviously, the more the anisotropy the greater the flow potential, but not a guarantee).

   viii. Average, wet, drought and range of infiltration/recharge for this geological/site setting. (cross reference with soil moisture conditions)

e. Groundwater Flow Estimates – Direction, gradient and Rate and range or values.
   i. Any surrounding conditions that may modify the flow direction or gradient?

f. Groundwater Mounding (relating to recharge and discharge areas both regional and local)(Conducted by a Qualified PG or PE)
   i. This analysis should be the controlling factor on the infiltrating loading rate. Either the soils infiltration capacity or the aquifer's mounding capacity.

g. Dispersion characteristics

IV. Hydrology

a. Perennial Streams (gaining and losing aspects)
   i. Where is the proposed site relative to recharge and discharge areas?

b. Intermittent Streams

c. Lakes and Impoundments

d. Springs and Seeps

e. Wetlands (what type and amount of saturation required to sustain)

f. Floodplains and Floodways

V. Climate

a. Water Budget components
   i. Precipitation (Average year, wet year and drought year)
   ii. NOAA source preferred.
   iii. Temperature ranges
   iv. Evaporation and/or Evapotranspiration

b. Storm water Volumes

c. Storage Requirements

VI. Vegetation

a. Pollutant Uptake/Removal (what happens to the parameter now in the plant?)

b. Erosion and Sediment Control

c. Growing Season vs. Winter Conditions

d. Management Considerations

VII. Site Characterization/Findings

a. Soil Characteristics (how were they tested – test pits/drilling/Geoprobe)
   Soil profile
   Soil permeability/infiltration (what tests were conducted to determine)
   Double ring infiltrometer is recommended over perc testing, other tests would be considered if proposed and explained why the test is more appropriate than double ring infiltrometer.
b. Land vegetation – what types of plants are there and how will they be impacted by construction
c. Geology (how was rock determined – outcrops, geologic map, drilling)
d. Karst evaluation and findings – should be more than just looking at the karst maps by Kochanov, strongly recommend geophysics. (See above)
e. Surface Water Conditions
   Water quality analysis (any suspected problems w/water quality)
f. Groundwater Conditions – flow and direction calculations
   Mounding calculations
   Dispersion
   Water quality analysis (any unknown problems w/water quality)
g. Hydrology
   Streams
   Lakes/impoundments
   Springs/seeps
   Wetlands
   Floodplains/floodways
h. Storm water volumes/storage requirement calculations

VIII. Storm water Quality
   a. Design considerations
   b. Estimate of Pollutant/Sediment Loading
   c. Ease of Removal/Reductions
   d. Treatment Considerations

IX. Construction and Maintenance
   a. Construction Oversight by Qualified Professionals
      i. PE Role
      ii. SS Role
      iii. PG Role
   b. Monitoring
   c. Specific roles should established in the design and assigned to the owner or representative. (should also specify who gets this task, i.e.: municipality, residential development, homeowner)