Appendix B

Stormwater Infiltration/Recharge Requirements

[This page left intentionally blank]

Stormwater Infiltration/Recharge Requirements

1.1 General Requirements

The following requirements shall apply to the design of stormwater infiltration BMPs, in addition to the design requirements referenced in *Section 5.9* and *Appendix G* of this manual. Stormwater infiltration BMPs include dry wells, infiltration basins, infiltration chambers and galleys, infiltration trenches, leaching catch basins, and bioretention systems (including rain gardens, tree filters, stormwater planters, and curb extensions) when specifically designed for infiltration.

- Required Infiltration Rate: Native soils should have a minimum field infiltration rate of 0.5 inches per hour (Hydrologic Soil Group A and B soils) at the actual location and soil layer where infiltration is proposed. Stormwater infiltration may be proposed at locations having field infiltration rates of between 0.2 and 0.5 inches per hour (Hydrologic Soil Group C soils), provided that field infiltration rates are field-verified by saturated hydraulic conductivity testing[1]. Stormwater infiltration shall not be sited in soils with field infiltration rates lower than 0.2 inches/hour (Hydrologic Soil Group D soils) due to the potential for failure. For filtering practices such as bioretention, no minimum infiltration rate is required if the system is designed with an underdrain.

- Maximum Draining Time: Infiltration practices must be designed to completely drain the design volume (the largest of the groundwater recharge volume, water quality volume, or runoff reduction volume depending on the infiltration design objective) within 72 hours after the storm event.

- TSS Pretreatment: TSS pretreatment is recommended prior to discharge to most stormwater infiltration BMPs. For some LID practices in highly urbanized settings, pretreatment may be economically or physically impractical due to insufficient space, insufficient grades, or utility conflicts, thereby preventing the use of otherwise effective treatment techniques. In these instances, a larger LID BMP system or a more intensive maintenance schedule may be used in lieu of pretreatment, if allowed by the approving authority. This flexibility also applies to pretreatment requirements in other sections of this manual for LID practices at constrained sites.

1.2 Soil Evaluation

When designing infiltration BMPs, a soil evaluation must be performed to verify that the anticipated field infiltration rate meets or exceeds the minimum required infiltration rate and to identify the Hydrologic Soil Group (HSG) soils on-site using classification methodologies developed by the U.S. Natural Resources Conservation Service (NRCS). The Hydrologic Soil

[1] According to Rawls 1982, the lower end of soils assigned to Hydrologic Soil Group C have an average infiltration rate of 0.17 inches per hour. Hydrologic Soil Groups A and B are more conducive to stormwater infiltration than "C" soils, so care must be exercised when designing stormwater infiltration system in "C" soils.

Groups are used in conjunction with impervious areas on a site to calculate the required groundwater recharge volume.

A soil evaluation is conducted in two phases by a qualified professional[2]: (1) initial feasibility evaluation, and (2) concept design testing. An initial feasibility evaluation is conducted to determine whether infiltration is feasible and potential locations on the site for infiltration facilities. An initial feasibility evaluation is meant to screen unsuitable sites, reducing testing costs. If the results of the initial feasibility evaluation show that infiltration is feasible, then concept design testing must be performed to support the infiltration system design.

1.2.1 Initial Feasibility Evaluation

The following steps are required for the initial feasibility evaluation.

1. Review NRCS Soil Survey

NRCS soil surveys are to be used as the first step in identifying soils and Hydrologic Soil Goups present at the site. Locate the site using the electronic/Web Soil Survey or on plans included in a hard copy of the Soil Survey. Identify the NRCS soil type, Hydrologic Soil Group, and saturated hydraulic conductivity by consulting the Soil Survey for the site.

2. Site Visit and Review of Previous Testing Data

After reviewing the NRCS Soil Survey, the qualified professional shall perform the following tasks:

- Conduct site visit. Determine whether any noticeable deviations on site exist from the NRCS Soil Survey (i.e., bedrock outcrops, open gravel/sand areas, recent filling). Determine whether the on-site soils have been disturbed, filled, or altered in any way.

- Review any existing field test pit data and available boring logs and compare with NRCS information published in the Soil Survey. Boring logs and test pit data often indicate the soil textural class and varying soil strata (i.e., restrictive layers) and may assist in further refinements of soil delineations. If no soil test data is available one test pit or soil boring shall be completed per one acre with a minimum of four test pits or soil borings per site. The depth shall be four feet below the bottom (including stone) of any possible BMP's. One of the tests pits or an additional test pit shall be completed near the proposed buildings and the depth shall be to the deepest proposed footing depth.

- Review any existing USGS geologic maps for general rock types and bedrock depths. The presence of bedrock, including rock outcrops, is a significant factor in the potential for groundwater recharge. Knowledge of the bedrock and rock type at the site will be

[2] A qualified professional is an individual with demonstrated expertise in soil science, including, but not limited to, a Certified Soil Scientist, Connecticut Registered Professional Engineer, Engineer in Training (EIT certificate) with a concentration in civil, sanitary or environmental engineering, or Bachelor of Arts or Sciences degree or more advanced degree in Soil Science, Geology, or Groundwater Hydrology from an accredited college or university.

beneficial in further characterizing existing recharge conditions.

- Review available aerial photographs. If a detailed site map is not available at the time of the initial investigation, an aerial photograph may provide additional information for delineating impervious and pervious areas.

- Review other available field testing data such as a written geotechnical report for the site as prepared by a qualified geotechnical consultant, a wetland delineation soils report, and septic percolation testing on-site, within 200 feet of the proposed BMP location and on the same contour. Septic percolation testing can be used to support determination of Hydrologic Soil Groups, initial infiltration rates, and water table/depth to bedrock for the initial feasibility evaluation. However, septic percolation testing is not an acceptable test for estimating saturated hydraulic conductivity at specific locations where infiltration systems are proposed. Percolation tests overestimate the saturated hydraulic conductivity rate.

- When the NRCS Soil Survey identifies the Hydrologic Soil Group(s) at the site, and the site investigation indicates site conditions are consistent with the NRCS Soil Survey, the required groundwater recharge volume shall be calculated based on the Hydrologic Soil Group(s) on the site and the recharge factors listed in *Table B-3*. Then proceed to Concept Design Testing.

- When the Soil Survey does not identify the Hydrologic Soil Group(s) at the site (e.g., for sites located in urban areas or with significant fill or disturbed/non-native soils) or when the site conditions are not consistent with the NRCS Soil Survey, conduct a site-wide soil textural analysis.

    - A site-wide soil textural analysis is performed using test pits or soil borings. One test pit or boring should be completed per acre of the site, with a minimum of four test pits or borings per site. The soil textural analysis shall be completed using standard USDA soil physical analyses (Black, et. al., 1965), i.e., particle size analyses. Classification of soil texture shall be consistent with the USDA Textural Triangle (*Figure B-1*).

    - Soil texture represents the relative composition of sand, silt and clay in soil. Soil texture is determined using procedures described in the USDA, 2007, National Soil Survey Handbook, Section 618.67 (Texture Class, Texture Modifier, and Terms Used in Lieu of Texture). See http://soils.usda.gov/technical/handbook/contents/part618.html#67. Soils must not be composited from one test pit or bore hole with soils from another test pit or bore hole for purposes of the textural analysis. The NRCS also has online tools to assist in the soil texture analysis, once the relative proportions of sand, silt, and clay have been determined (see http://soils.usda.gov/technical/aids/investigations/texture/).

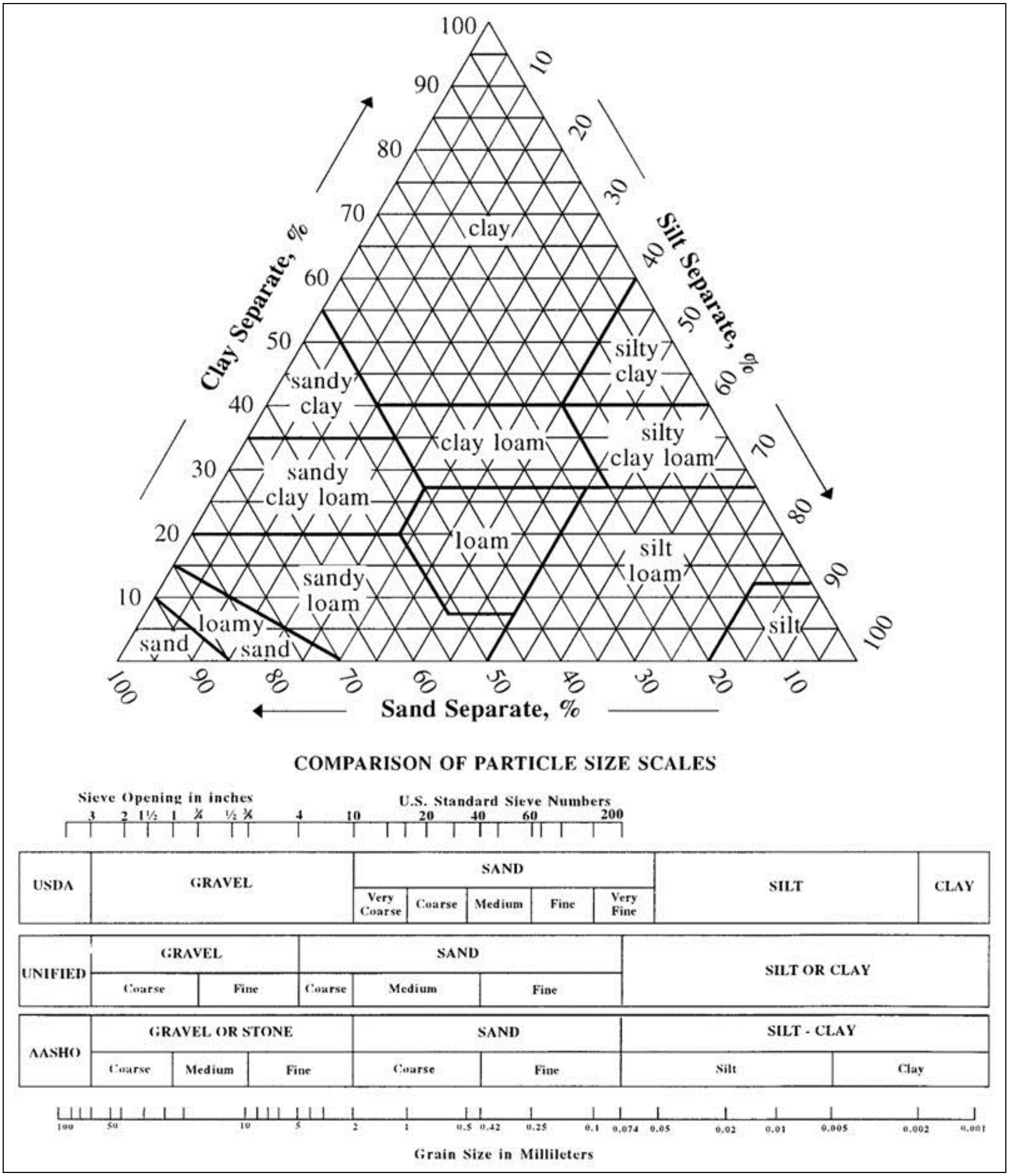

Figure B-1. USDA, NRCS, 2007 National Soil Survey Handbook, Part 618, Exhibit 8

http://soils.usda.gov/technical/handbook/contents/part618ex.html#ex8

- When fill materials are present or are added prior to construction of the system, a soil textural analysis must be conducted in both the fill material and the underlying native material below the fill layer, and the Hydrologic Soil Group of the more restrictive layer shall be used. Stormwater infiltration is not permitted through fill materials composed of asphalt, brick, concrete, construction debris, and materials classified as solid or hazardous waste. Alternatively, the debris or waste may be removed in accordance with applicable State solid waste regulations and replaced with clean material suitable for infiltration.

- Calculate the required groundwater recharge volume based on the Hydrologic Soil Group(s) determined from the site-wide soil textural analysis and the recharge factors listed in *Table B-3*.

1.2.2 Concept Design Testing

If the results of the initial feasibility evaluation indicate that infiltration is feasible, concept design testing shall be performed as described in this section, unless alternative methods are approved by the approving authority.

Concept design testing consists of test pits or soil borings, and saturated hydraulic conductivity testing in some instances, at the actual location(s) where infiltration is proposed. These field tests shall be conducted or supervised by a qualified professional.

<u>Test Pits/Borings</u>

- Perform test pits or soil borings to a minimum depth of 4 feet below the proposed bottom of the infiltration system.
- Excavate test pits or install encased soil borings at a frequency of 1 test pit or boring per 2,500 square feet of infiltration area. The proposed infiltration BMP's must be within the 2,500 square foot circular influence of the test pit or soil boring location. If only part of the infiltration BMP is within the circular influence of a test pit or soil boring the remaining area must be within another test pit or soil borings circular influence. Test pit/soil boring stakes are to be left in the field for inspection purposes and survey, and shall be clearly labeled as such.
- Test pits should be of adequate size, depth, and construction to allow a person to enter and exit the pit and complete a soil profile description.
- If borings are drilled, continuous soil borings should be taken using a bucket auger, probe, split-spoon sampler, or Shelby tube. Samples should have a minimum 2-inch diameter.
- Perform soil textural analysis using NRCS methods if a textural analysis.
- Determine depth to seasonal high groundwater (if within 4 feet of the proposed bottom of the infiltration system). Depth to seasonal high groundwater may be identified based on redoximorphic features in the soil. When redoximorphic features are not available, installation of temporary push point wells or piezometers should be considered. Ideally, such wells should be monitored in the spring when groundwater is highest and results compared to nearby groundwater wells monitored by the USGS to estimate whether regional groundwater is below normal, normal or above normal.

- Determine depth to bedrock (if within 4 feet of the proposed bottom of the infiltration system).

Saturated Hydraulic Conductivity Testing

- When infiltration is proposed within Hydrologic Soil Group C soils or when the "Dynamic Field" method is used to size the infiltration system, regardless of Hydrologic Soil Group, field infiltration rates must be determined by saturated hydraulic conductivity testing. Test methods to assess saturated hydraulic conductivity must simulate "field-saturated" condition. See ASTM D5126-90 (2004) Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone. The saturated hydraulic conductivity test must be conducted or supervised by a qualified professional. Acceptable tests include:
    - Borehole infiltration test (NHDES, 2008):
        i. Install casing (solid 4-6 inch diameter, 30" length to 12" below proposed bottom of the practice) (see *Figure B-2*)
        ii. Remove any smeared soil surfaces and provide a natural soil interface into which water may percolate. Remove all loose material from the casing. Upon the tester's discretion, a 2-inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring and sediment. Fill casing with clean water to a depth of 24" and allow to pre-soak for 24 hours.
        iii. 24 hours later, refill casing with another 24 inches of clean water and monitor water level (measured drop from the top of the casing) for 1 hour. Repeat this procedure (filling the casing each time) three additional times, for a total of 4 observations. The observations should be averaged. The average should be reduced by factor of 2 to determine the field infiltration rate for design purposes.
        iv. May be done through a boring or open excavation.
        v. Upon completion of the testing, the casings should be immediately pulled, and the test pit should be back-filled.
    - Guelph permeameter - ASTM D5126-90 Method
    - Falling head permeameter – ASTM D5126-90 Method
    - Double ring permeameter or infiltrometer - ASTM D3385-03[3], D5093-02[4], D5126-90 Methods
    - Amoozemeter or Amoozegar (constant head) permeameter – Amoozegar 1992

- Saturated hydraulic conductivity tests shall be performed at a frequency of 1 test per 500 square feet of infiltration area. The proposed infiltration BMP's must be within the 500 square foot circular influence of the hydraulic conductivity tests. The results shall be recorded on an infiltration test log approved by the Town.

---

[3] *ASTM D3385-03 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer*
[4] ASTM D5093-02 Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring.

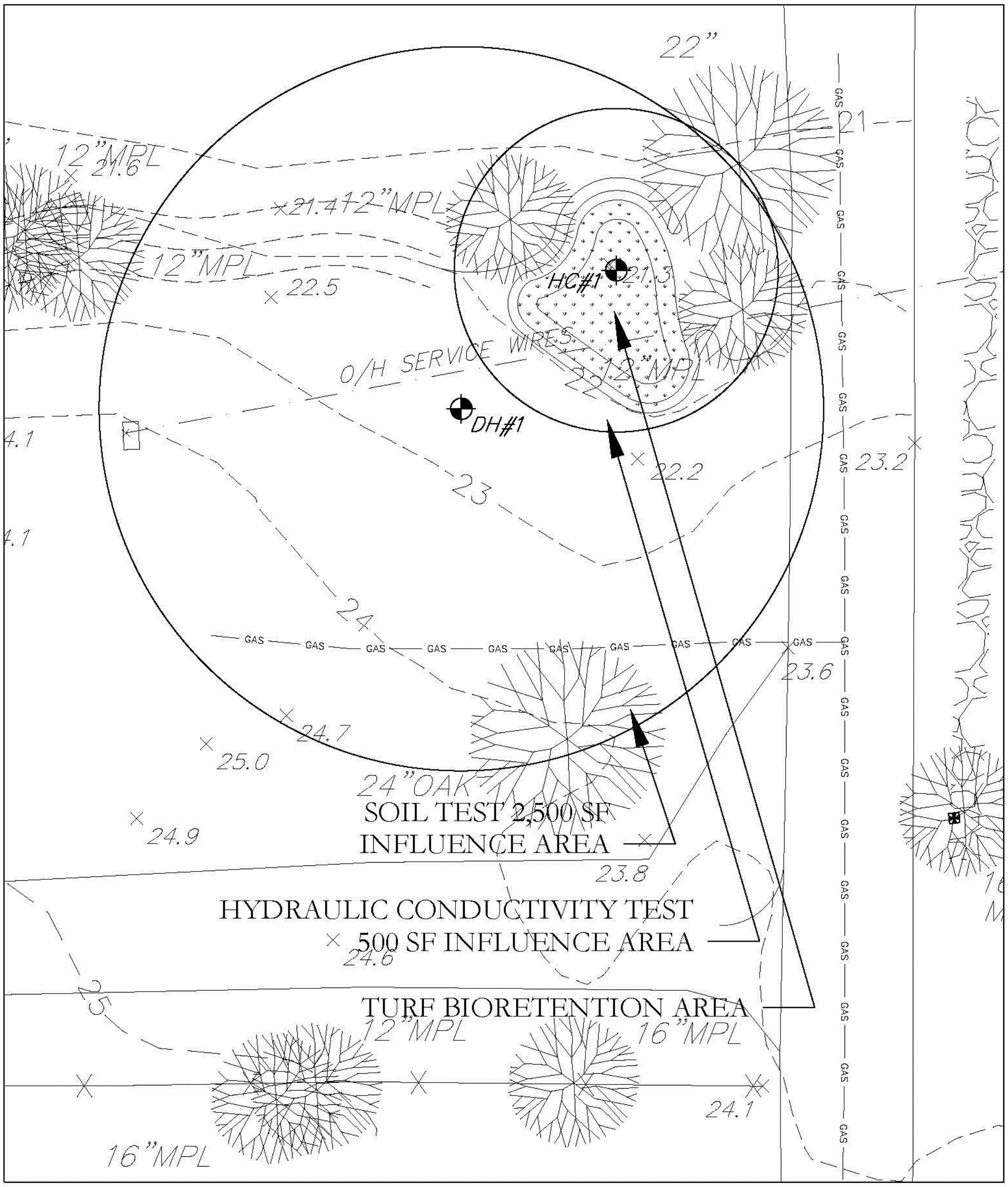

Figure B-1A. Soil Tests Influence Area Example

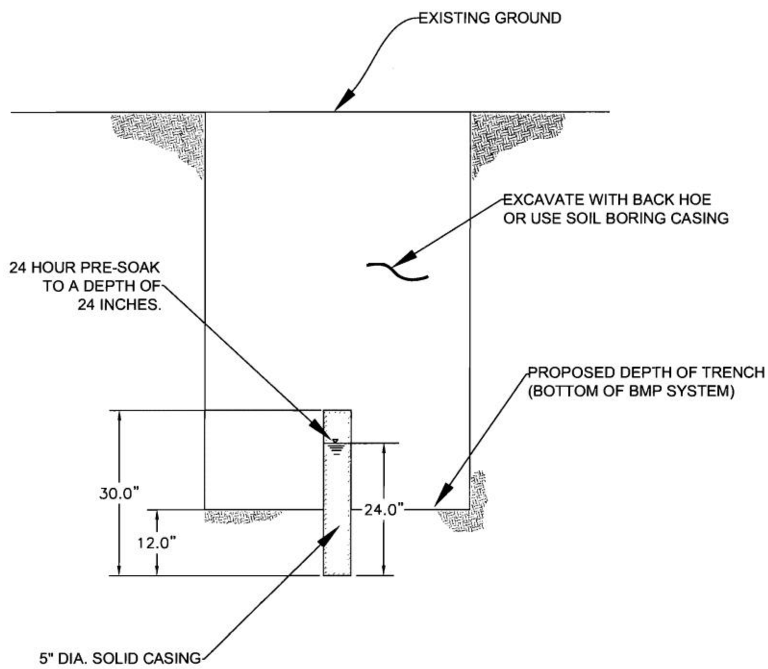

Figure B-2. Borehole Infiltration Test Detail

- A percolation test, performed in accordance with the guidelines of the Connecticut State Health Code or otherwise, is not an acceptable test for saturated hydraulic conductivity. Percolation tests overestimate the saturated hydraulic conductivity rate.

Field Infiltration Rates

- Field infiltration rates shall be determined from the results of NRCS soil textural analysis or saturated hydraulic conductivity testing, as described above. *Table B-1* summarizes the appropriate approach for determining field infiltration rates for designing infiltration systems depending on the infiltration design method and NRCS Hydrologic Soil Group.

- When the more conservative "Static" or "Simple Dynamic" Methods are used to size the infiltration system in Hydrologic Soil Group A or B soils, field infiltration rates are based upon NRCS soil textural classification and associated default infiltration rates (see *Table B-2*).

  Alternately, saturated hydraulic conductivities reported in the NRCS Soil Surveys may also be used to estimate field infiltration rates. NRCS Soil Surveys typically list multiple saturated hydraulic conductivities for the same soil, depending on the soil depth. The reported saturated hydraulic conductivity for a given layer also typically has a range of values. Select the limiting layer (slowest saturated hydraulic conductivity) reported beneath the proposed bottom of the infiltration system and the low end of the range for the default infiltration rate.

Table B-1. Requirements for Determining Field Infiltration Rates

Infiltration Design Method	NRCS Hydrologic Soil Groups			
	A	B	C	D
Static Method	Soil Textural Analysis	Soil Textural Analysis	Saturated Hydraulic Conductivity Testing	Infiltration Not Allowed
Simple Dynamic Method	Soil Textural Analysis	Soil Textural Analysis	Saturated Hydraulic Conductivity Testing	Infiltration Not Allowed
Dynamic Field Method	Saturated Hydraulic Conductivity Testing	Saturated Hydraulic Conductivity Testing	Saturated Hydraulic Conductivity Testing	Infiltration Not Allowed

Table B-2. Default (Rawls) Infiltration Rates

Texture Class	NRCS Hydrologic Soil Group (HSG)	Infiltration Rate Inches/Hour
Sand	A	8.27
Loamy Sand	A	2.41
Sandy Loam	B	1.02
Loam	B	0.52
Silt Loam	C	0.27
Sandy Clay Loam	C	0.17
Clay Loam	D	0.09
Silty Clay Loam	D	0.06
Sandy Clay	D	0.05
Silty Clay	D	0.04
Clay	D	0.02

Source: Rawls, Brakensiek and Saxton, 1982.

- The slowest of the Hydrologic Soil Groups determined to exist at the point where infiltration is proposed shall be used.
    - *Example:* Two samples are taken at a proposed infiltration bioretention system in the actual soil layer where recharge is proposed. One sample indicates sandy soils. The second sample indicates a sandy loam soil. The default infiltration rate used for the design analysis must use the sandy loam rate and not the sandy soil rate. Soils must not be composited for purposes of the soil textural analysis.

- When the "Dynamic Field" method is used to size the infiltration system (regardless of Hydrologic Soil Group) or infiltration is proposed within Hydrologic Soil Group C soils

(regardless of design method), saturated hydraulic conductivity testing must be performed to determine the field infiltration rate.
Soils may be amended to modify infiltration rates. Infiltration rates of amended soils should be subject to saturated hydraulic conductivity testing to confirm actual infiltration rates.

- If it is determined that the minimum required infiltration rate is not possible at the location of the proposed infiltration system, other potential on-site locations should be evaluated for infiltration feasibility.

Documenting Concept Design Testing Results

- Prepare a plan of the site clearly delineating the Hydrologic Soil Groups throughout the entire site and the specific point(s) where infiltration is proposed. Deviations from the NRCS Soil Surveys and special conditions discovered during additional investigations (relative to recharge potential) should be noted on the plan and described. The plan shall identify the locations of all borings, test pits, and hydraulic conductivity tests, including the location of any known prior tests. Test pit or boring logs shall be appended to the plan, identifying in cross section the soil types, seasonal high groundwater elevation, depth to bedrock and other confining layers, and other appropriate information. Hydraulic conductivity test logs shall also be appended to the plan.

1.3 Recharge Volume Calculations

1.3.1 Groundwater Recharge Volume

The required Groundwater Recharge Volume (GRV) equals a depth of runoff corresponding to the soil type times the impervious areas covering that soil type at the post-development site.

$$GRV = F \times I \tag{B.1}$$

where: GRV = required Groundwater Recharge Volume (cu ft or acre-feet)
F = target depth factor associated with each Hydrologic Soil Group (inches)
I = impervious area on the post-development site for new development projects or the net increase in impervious area for re-development projects

Attention must be given to ensure consistency in units. In particular, the target depth factors must be converted to feet.

Table B-3. Recharge Target Depth by Hydrologic Soil Group

NRCS Hydrologic Soil Group	Approximate Soil Texture	Target Depth Factor (F)
A	Gravels, sand, loamy sand or sandy loam	0.6 inch
B	Silty loam	0.35 inch

C	Sandy clay loam	0.25 inch
D	Clay, silty clay loam, sandy clay, silty clay	0.1 inch

When a site contains multiple Hydrologic Soil Groups, determine the required GRV for each impervious area by Hydrologic Soil Group and then add the volumes together.

- *Example:* Assume a ten (10) acre site. 5.0 acres are proposed to be developed for a retail use. Of the 5.0 acres proposed to be developed, 2 acres of impervious surfaces are proposed atop Hydrologic Soil Group (HSG) "A" soils, 1 acre of impervious surfaces atop HSG "B" soil, 1.5 acres of impervious surfaces atop HSG "C" soil, and 0.5 acres are proposed to be landscaped area. The remaining 5.0 acres, located on HSG "A" soil, are proposed to remain forested. Determine the required Groundwater Recharge Volume.

- *Solution:* The required Groundwater Recharge Volume is determined only for the impervious surfaces. The 5.0-acre forested area and the 0.5-acre landscaped area are not impervious areas. Although converted from forest, landscaped area is pervious area for purposes of the groundwater recharge standard. Use Equation B.1 to determine the required Groundwater Recharge Volume for each Hydrologic Soil Group covered by impervious area. Add together the required Groundwater Recharge Volumes determined for each HSG.

  $GRV = F \times \text{impervious area}$

  $GRV = [(F_{HSG\ \text{"A"}})(Area_1)] + [(F_{HSG\ \text{"B"}})(Area_2)] + [(F_{HSG\ \text{"C"}})(Area_3)] + [(F_{HSG\ \text{"D"}})(Area_4)]$

  $GRV = [(0.6\text{-in}/12)(2\ \text{acres})] + [(0.35\text{-in}/12)(1\ \text{acre})] + [(0.25\text{-in}/12)(1.5\ \text{acres})] + [(0.1\text{-in}/12)(0\ \text{acres})]$

  $GRV = 0.1605\ \text{acre-feet}$

  $GRV = 0.1605\ \text{acre-feet} \times 43560\ \text{square feet/acre-feet} = 6{,}991\ \text{cubic feet or}\ 258.9\ \text{cubic yards}$

The infiltration BMP must be evaluated to determine if the proposed recharge location will alter a surface water or wetland resource area by causing changes to the hydrologic regime. For example, if Watershed "A" contains a wetland fed by groundwater, and runoff from Watershed "A" is proposed to be directed to Watershed "B" for infiltration, an evaluation is necessary to determine if redirecting the runoff will cause an alteration to the wetland. In such instances, a water budget shall be calculated using the Thornthwaite or equivalent method. TR-20/TR-55 methods are not sufficient for water budgeting purposes. A water budget analysis is not required, if the recharge is directed to the same subwatershed where the impervious surfaces are proposed.

1.3.2 Sizing Storage Volume

Determine the storage volume of the basin, chamber, or voids that must be constructed in order to store the required design volume. Three methods may be used to determine the design volume:

- The "Static" Method;
- The "Simple Dynamic" Method; or the
- The "Dynamic Field" Method.

The "Static" Method assumes that there is no exfiltration until the entire infiltration system is filled to the elevation associated with the required design volume. The two "Dynamic" Methods assume stormwater exfiltrates into the groundwater as the storage chamber is filling. The "Simple Dynamic" Method assumes that the required design volume is discharged to the infiltration system over 2 hours and exfiltrates over the 2-hour period at the Rawls Rate. The "Dynamic Field" Method assumes that the required design volume discharges to the infiltration system over 12 hours and infiltrates at no more than 50% of the saturated hydraulic conductivity rate.[5] The "Static" Method produces a larger design volume than either Dynamic Method and produces the most conservative result.

When using the "Static" or "Simple Dynamic" Methods for designing infiltration systems in Hydrologic Soil Group A or B soils, only a soil textural analysis is required to determine the field infiltration rate. Saturated hydraulic conductivity testing must be performed to determine the field infiltration rate for infiltration systems designed in Hydrologic Soil Group C soils or when the "Dynamic Field" method is used to size the infiltration system, regardless of Hydrologic Soil Group.

Static Method

- Assume the entire required design volume is discharged to the infiltration system before infiltration begins.
- Size the volume of the infiltration system to hold the required design volume.
- Confirm that the bottom of the infiltration system is large enough to ensure that the system will completely drain in 72 hours or less.

Example: Assume a one (1) acre undeveloped site. Assume 75% of the site is proposed to be impervious area (0.75 acre). The soils are classified as Hydrologic Soil Group A. An infiltration structure is proposed to meet the groundwater recharge standard. Use the "Static" Method to determine the storage volume of the infiltration structure.

Solution: The required GRV is based on 0.60 inches (see *Table B-3*) of runoff. Using Equation B.1:

$$GRV = F \times \textit{impervious area}$$
$$GRV = (F_{\text{HSG "A"}}) \times (\textit{impervious area})$$

[5] 50% is used as a factor of safety to represent the anticipated long-term exfiltration rate due to clogging of the underlying media/soil that occurs over time.

GRV = [(0.6 inches/12 inches/foot)][(0.75 acre)(43,560 square feet/acre)]
GRV =1,633.5 cubic feet or 60.5 cubic yards

Assuming that the stored runoff will exfiltrate completely into the ground within 72 hours, the infiltration structure must have a storage volume of 1,633.5 cubic feet.[6]

Simple Dynamic and Dynamic Field Methods

Where a project proponent chooses to size an infiltration system to account for exfiltration of stormwater from the system at the same time that the storage chamber is filling, one of two methods can be used - the "Simple Dynamic" and "Dynamic Field" Methods. These methods result in smaller storage volumes than would otherwise be required by the "Static" Method. In Hydrologic Soil Group B and C soils, all three methods produce similar sized storage. However, in sandy soils (Hydrologic Soil Group A), the "Simple Dynamic" and "Dynamic Field" Methods can result in smaller storage requirements. Since the "Simple Dynamic" and "Dynamic Field" Methods are less conservative than the "Static" Method, maintenance over the life of the recharge practice is especially critical to ensure that the recharge practice will function as designed over the long-term.

Simple Dynamic Method - Of the two dynamic methods, the "Simple Dynamic" Method requires less time to complete. Field infiltration rates are based on a soil textural analysis[7] performed at the location and soil layer where the infiltration is proposed (for Hydrologic Soil Group A and B soils). The "Simple Dynamic" Method is more conservative than the "Dynamic Field" Method, because it limits the allowable infiltration time that is used to reduce the size of the infiltration BMP to the peak two hour period of a "typical storm." The "Simple Dynamic" Method can be performed by using the following equations:

$$V = A \times D$$

$$A = \frac{GRV}{(D + KT)} \qquad \text{(B.2)}$$

$$GRV = F \times I$$

---

[6] If the infiltration structure is a trench filled with stone, the excavated volume of the trench must be determined to account for the stone in the trench. The minimum excavated *infiltration trench* volume is determined as follows:

$$\text{Infiltration Trench Excavated Volume} = \frac{GRV}{n}$$

Where:
GRV = Required Groundwater Recharge Volume
n = porosity or percentage of void space between the stone

Assuming *n* = 0.35 (35% voids) between the stone, the minimum Infiltration Trench Excavated Volume for design purposes would be:

$$\text{Infiltration Trench Excavated Volume} = \frac{1633.5 \text{ cubic feet}}{0.35} = 4668 \text{ cubic feet}$$

[7] See Hydrologic Soil Group section above for information related to soil textural analysis.

where: *V* = required storage volume
A = minimum required surface area of the bottom of the infiltration structure
D = depth of the infiltration facility[8]
K = saturated hydraulic conductivity (use Rawls Rate, *Table B-2*),
T = the allowable drawdown during the peak of the storm (use 2 hours)
GRV = required Groundwater Recharge Volume (cu ft or acre-feet)
F = target depth factor associated with each Hydrologic Soil Group (inches)
I = impervious area on site

Example: Assume a one (1) acre undeveloped site. Assume 75% of the site is proposed to be impervious area (0.75 acre). The soils are classified as Hydrologic Soil Group "A." An infiltration structure that is 4 feet deep is proposed. Determine the storage volume of the infiltration structure, using the "Simple Dynamic" Method.

Solution:

$$GRV = F \times \text{impervious area}$$
$$GRV = [(0.6 \text{ inches}/12 \text{ inches/foot})][(0.75 \text{ acre})(43{,}560 \text{ square feet/acre})]$$
$$GRV = 1{,}633.5 \text{ cubic ft or } 60.5 \text{ cubic yards}$$
$$A = GRV/(D+KT)$$
$$A = 1633.5 \text{cubic ft} \div [4 \text{ ft} + (8.3''/\text{hr}/12''/\text{ft} \times 2\text{hr})]$$
$$A = 303.4 \text{ sq. ft.}$$
$$V = A \times D$$
$$V = 303.4 \text{ square ft} \times 4 \text{ ft}$$
$$V = 1203.6 \text{ cubic ft}$$

To size an infiltration BMP using the "Simple Dynamic" Method, proponents may also use a computer model based on TR-20 as described below. This computer model assumes that the required recharge volume enters the infiltration BMP during the peak two hours of the storm and that runoff is discharged from the BMP during the same two hour period at the Rawls Rate. This contemporaneous exfiltration allows a proponent to reduce the size of the infiltration BMP.

a. Use Equation B.1 to determine the required design volume.
b. Select a 24-hour rainfall event that generates the required design volume during the peak 2 hours. Use only the site's impervious drainage area and the default NRCS Initial Abstraction of 0.2S and Type III storm. Set the storm duration for 24 hours, but use a start time of 11 hours and an end time of 13 hours. This creates a truncated hydrograph where most of the rainfall typical of a 24-hour Type III Storm occurs in just 2 hours. Selecting the correct precipitation depth is an iterative process. Various precipitation depths must be tested to determine which depth generates the required design volume using TR-20. Each precipitation depth evaluated generates a runoff hydrograph. The area under the hydrograph is a volume. The correct result is achieved when the volume under the inflow hydrograph equals the required design volume.
c. Using the resulting inflow hydrograph, choose an appropriate infiltration system with an appropriate bottom area and storage volume.[9]

[8] If the infiltration facility is a practice that uses stone or another media such as a dry well, only the void spaces must be considered. In those circumstances, use nd instead of d, where n is the percent porosity of the stone or other media.

d. Use the infiltration system bottom as the maximum infiltrative surface area. Do not use sidewalls.[10]
e. Assume stormwater exfiltrates from the device over the peak 2-hour period of the rainfall event determined in step b above.
f. Set exfiltration rates no higher than the Rawls Rates for the corresponding soil at the specific location where infiltration is proposed (see *Table B-2*).
g. Assume exfiltration rate is constant.
h. Using the computer model, confirm adequate storage volume.
i. Confirm that the bottom of the proposed infiltration BMP is large enough to ensure that the practice will drain completely in 72 hours or less. For purposes of this evaluation, assume the exfiltration rates are no higher than the Rawls Rates.

Example: Assume a one (1) acre undeveloped site. Assume 75% of the site is proposed to be impervious area (0.75 acre). The soils are classified as Hydrologic Soil Group "A." An infiltration structure is proposed with a bottom that has a surface area of 303 square feet and a storage volume of 1212 cubic feet. Use the "Simple Dynamic" Method to confirm that this storage volume is adequate.

Solution using the computer model:

GRV = F x impervious area
GRV= [(0.6 inches/12 inches/foot)][(0.75 acre)(43,560 square feet/acre)]
GRV =1,633.5 cubic feet or 60.5 cubic yards

The amount of precipitation is determined iteratively by developing a hydrograph that generates the 1,633.5 cubic feet, the required GRV, during the peak two hours of the storm. A hydrograph is generated for a storm that produces 1.29" of precipitation and indicates the runoff is entering the infiltration structure at a maximum rate of 0.87 cfs during the most intense two hours of the storm. An exfiltration system is sized to store the difference between the inflow volume and the outflow volume using an infiltration rate of 8.3 inches/hour for HSG "A" soil (based on the Rawls Rates) over the 2-hour period. The outflow hydrograph reveals that runoff will leave the infiltration structure at a constant rate of 0.06 cfs during the peak two hours of the storm. The results yield an infiltration structure with a surface ponding depth of 4.0 feet and a storage volume of 1,212 cubic feet. [11]

Dynamic Field Method – For the "Dynamic Field" method, saturated hydraulic conductivity testing is required at the actual location where exfiltration is proposed.

a. Use Equation B.1 to determine the required GRV.
b. Select a 24-hour rainfall event that generates the required GRV over 12 hours. Use only the site's impervious drainage area and the default NRCS Initial Abstraction of 0.2S and Type III storm. Set the storm duration for 24 hours, but use a start time of 6 hours and an end time of 18 hours. This creates a truncated hydrograph where most

[9] An applicant may have to select several different size infiltration structures before s/he identifies a structure that is adequately sized.
[10] If the recharge system includes stone or other media, remember that the effective storage volume only includes the voids between the stone or other media.
[11] The storage volume calculated using software based on TR-20 is 1216 cubic feet, is nearly identical to the storage volume using the formula set forth herein.

of the rainfall typical of a 24-hour Type III storm occurs in just 12 hours. Selecting the correct rainfall depth is an iterative process. Various precipitation depths must be tested to determine which depth generates the required GRV, using TR-20. Each precipitation depth evaluated generates a runoff hydrograph. The area under the hydrograph is a volume. The correct result is achieved when the volume under the inflow hydrograph equals the required GRV.

c. Using the resulting inflow hydrograph, choose an appropriate infiltration structure with an appropriate bottom area and storage volume.[12]
d. Use recharge system bottom as maximum infiltrative surface area. Do not use sidewalls.
e. Assume that exfiltration begins immediately at 6 hours and continues for 12 hours. Infiltration of the required GRV may take more than 12 hours.
f. Set exfiltration rate used in the analysis to no higher than 50% of the saturated hydraulic conductivity rate in the soil layer where infiltration is proposed (e.g., if the field rate is 10 inches/hour, 50% x 10 in/hr = 5 inches/hour).
g. Assume exfiltration rate is constant
h. Using computer model, confirm adequate storage volume.
i. Confirm that the bottom of the infiltration BMP is large enough to ensure that the system will completely drain in 72 hours using 50% of the saturated hydraulic conductivity rate determined using field-testing.

Example: Assume a one (1) acre undeveloped site. Assume 75% of the site is proposed to be impervious area (0.75 acre). The soils are classified as Hydrologic Soil Group "A." A field evaluation reveals a saturated hydraulic conductivity rate of 20" per hour. An infiltration structure with a bottom surface area of 303 square feet is proposed. Use the "Dynamic Field" Method to determine the storage volume of the infiltration basin.

Solution:

GRV=F x impervious area
GRV= [(0.6 inches/12 inches/foot)][(0.75 acre)(43,560 square feet/acre)]
GRV =1,633.5 cubic feet or 60.5 cubic yards

The amount of precipitation is determined iteratively by developing a hydrograph that generates the required GRV over a 24-hour period. Based on this process, a hydrograph that generates 0.6 inches of runoff (this is the Target Depth Factor for HSG A soils in *Table B-3*) during the peak 12 hours of a storm. A hydrograph is generated for a storm that produces 0.87 inches of precipitation over 24 hours with runoff entering the infiltration structure at a maximum rate of 0.55 cfs during the most intense period of the storm. Assume the bottom has a surface area of 303 square feet and that runoff exfiltrates at 10 inches per hour (50% of the saturated hydraulic conductivity rate determined by field-testing). Based on the hydrograph, runoff leaves the infiltration structure at 0.07 cfs. The model calculates a storage capacity of 595 cubic feet. Note: the peak elevation calculated by the model is 1.96 feet, approximately half of the ponding depth produced by the "Simple Dynamic" Method. The smaller peak elevation arises, because infiltration is assumed to occur over a longer period in the "Dynamic Field" Method than the "Dynamic Simple" Method, i.e., 12 hours instead of two hours, and the infiltration rate for the

[12] An applicant may have to try different size infiltration structures before an infiltration structure that is adequately sized is identified.

"Dynamic Field" Method is 10 inches per hour instead of the 8.3 inches per hour (Rawls Rate) for the "Dynamic Simple" Method.

1.3.3 Drawdown Within 72 Hours

Use the same infiltration rate that is used for sizing the infiltration BMP to confirm that the infiltration BMP will drain completely within 72 hours. For the "Static" and "Simple Dynamic" Methods, the Rawls Rates associated with the slowest of the Hydrologic Soil Groups determined to exist at the point where recharge is actually proposed shall be used. For the "Dynamic Field" Method (and where infiltration is proposed within Hydrologic Soil Group C soils), 50% of the average value obtained from the test results for saturated hydraulic conductivity measured in the field at the actual location and soil layer where recharge is proposed shall be used.

- For infiltration BMPs sized using the "Static" Method or the "Simple Dynamic" Method, the drawdown analysis is based on the required design volume exfiltrating at the Rawls Rates based on the soil textural analysis conducted at the proposed infiltration location and soil layer. The slowest Rawls Rate (1982) at the actual location where the recharge is proposed is used for purposes of the drawdown analysis.
- For infiltration BMPs sized using the "Dynamic Field" Method or within Hydrologic Soil Group C soils, the drawdown analysis must be based on the required design volume infiltrating at 50% of the average saturated hydraulic conductivity rate at the location and specific soil layer where infiltration is proposed.
- The infiltration rate shall be assumed to be constant for purposes of the drawdown analysis. [13]
- Only the bottom surface shall be considered. No credit shall be afforded to sidewall exfiltration.
- If the drawdown analysis indicates the entire volume cannot be drawn down within 72 hours, the bottom area of the infiltration BMP must be increased or the required design volume must be reduced. The required design volume may be reduced by reducing the amount of impervious surfaces on the site or through the use of LID BMPs.

To determine whether an infiltration BMP will drain within 72 hours, the following formula shall be used[14]:

$$Time_{drawdown} = \frac{GRV}{(K)(Bottom\ Area)} \qquad \text{(B.3)}$$

where: GRV = required Groundwater Recharge Volume (cu ft or acre-feet) or equivalent design volume
K = Field infiltration rate

[13] The drawdown analysis also assumes that the water table does not fluctuate during the draw down period.

[14] In some cases, the infiltration structure may be designed to treat the required Water Quality Volume and/or to attenuate peak discharges in addition to infiltrating the required Groundwater Recharge Volume. In that event, the storage volume of the structure must be used in the formula for determining drawdown time in place of the required Groundwater Recharge Volume.

Bottom Area = Bottom Area of Recharge Structure[15]

Example ("Static" and "Simple Dynamic" Methods): Assume a one-acre site. An area that is 0.75 acre is proposed to be developed as impervious area. The soils are Hydrologic Soil Group "A" soils. The required GRV is determined to be 1633.5 cubic feet. The soil textural analysis determined the soil layer for the proposed infiltration basin bottom is "sand," which is classified by the NRCS as Hydrologic Soil Group "A". The bottom area of the proposed basin is 303 square feet. Determine whether the proposed infiltration structure will draw down the 1633.5 cubic feet of water within 72 hours.

$$Time_{drawdown} = \frac{1633.5\ cubic\ \ feet}{(8.3\ inches\ /\ hour)(1\ ft\ /12\ inches)(303\ square\ \ feet)}$$

$Time_{drawdown}$ = *7.8 hours*

7.8 hours < 72 hours so result is satisfactory for design purposes

The infiltration structure as designed is estimated to drawdown in 7.8 hours, well within the 72-hour requirement. If the analysis indicated that the recharge took longer than 72 hours, the bottom area of the infiltrative surface would need to be increased (e.g., instead of an infiltration structure with 303 square foot bottom area, evaluate a structure with a bottom area of 350 square feet, etc.) or the required GRV would have to be reduced. The required GRV could be reduced by reducing the amount of impervious surfaces or by using LID BMPs.

Example ("Dynamic Field" Method): Assume a one-acre site. 0.75 acres is proposed to be developed. The soils are classified in the NRCS County Soil Survey as Hydrologic Soil Group "A" soils. Although the required GRV is 1633.5 cubic feet, the storage volume of the infiltration basin was determined to be 595 cubic feet using the "Dynamic Field" Method. The saturated hydraulic conductivity tests in the actual soil horizon where infiltration is proposed indicates that the average rate is 20 inches/hour. The bottom area of the proposed basin is 303 square feet (sized approximately 30 long by 10 feet wide). Determine whether the proposed infiltration basin will draw down the required GRV for design purposes within 72 hours.

Solution: The exfiltration rate used for purposes of design is 50% of the field rate. Assuming the infiltration rate is constant, the time to drawdown the required GRV for design purposes would be:

$$Time_{drawdown} = \frac{GRV}{(K)(Bottom\ \ Area)}$$

---

[15] To account for the porosity of the stone, a different formula is required to determine whether the required Groundwater Recharge Volume drains within 72 hours if the infiltration structure is a trench filled with stone. In that event, the drawdown time would be calculated as follows with n = porosity of the stone:

$$Time_{drawdown} = \frac{GRV}{(K)(Trench\ \ Bottom\ \ Area)(n)}$$

Where
Rv= Required Recharge Volume
K = 50% of the field Saturated Hydraulic Conductivity
Bottom Area = Bottom Area of Recharge Structure

$$Time_{drawdown} = \frac{1633.5\ cubic\ feet}{(10\ inches/hour)(1\ ft/12\ inches(303\ square\ feet)}$$

$$Time_{drawdown} = 6.5\ hours$$

6.5 hours < 72 hours so result is satisfactory for design purposes.

1.3.4 Groundwater Mounding Analysis

A groundwater mounding analysis is required when the vertical separation from the bottom of an infiltration system to seasonal high groundwater is less than 2 feet (or 3 feet in high load areas), *and* the infiltration system is proposed to attenuate the peak discharge from a 10-year or higher 24-hour storm (e.g., 10-year, 25-year, 50-year, or 100-year 24-hour storm). In such cases, the mounding analysis must demonstrate that the r*equired design volume* is fully dewatered within 72 hours (so the next storm can be stored for exfiltration). The mounding analysis must also show that the groundwater mound that forms under the infiltration system will not break out above the land or water surface of a wetland.

The Hantush or other equivalent method may be used to conduct the mounding analysis. The Hantush method predicts the maximum height of the groundwater mound beneath a rectangular or circular recharge area. It assumes unconfined groundwater flow, and that a linear relation exists between the water table elevation and water table decline rate. It results in a water table recession hydrograph depicting exponential decline. The Hantush method is available in proprietary software and free on-line calculators on the Web in automated format. If the analysis indicates the mound will prevent the infiltration BMP from fully draining within the 72-hour period, an iterative process must be employed to determine an alternative design that drains within the 72-hour period.

1.3.5 When One Structural BMP is Sized to Meet Multiple Standards

A single structural BMP is often sized to meet more than one stormwater management standard such as runoff reduction/groundwater recharge and pollutant reduction. Unless 80% of the TSS load is proposed to be fully removed prior to discharge to the infiltration BMP, the infiltration BMP is being used to fulfill the requirements of both the pollutant reduction and runoff reduction/groundwater recharge standards. In such instances, the infiltration BMP must be sized to treat or hold the larger of the required Water Quality Volume and the required Runoff Reduction/Groundwater Recharge Volume. For example, if the required Water Quality Volume is 1 inch, the Required Recharge Volume is 0.6-inches, and the Runoff Reduction Volume is 2 inches, the infiltration system (if designed to meet all three standards alone) needs to be sized to handle the Runoff Reduction Volume, since it is larger than the Groundwater Recharge and Water Quality Volumes.

1.4 References

Akan, A.O., Sizing Stormwater Infiltration Structures, 2002, Journal of Hydraulic Engineering, Vol. 128, No. 5, pp. 534 – 537

American Society of Civil Engineers (ASCE), 1996, Hydrology Handbook, Second Edition, ASCE Manuals and Reports on engineering Practice No. 28, ASCE, New York, NY

ASTM D3385-03 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer

ASTM D5093-02 Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring

ASTM D5126-90, 2004, Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone.

Amoozegar, Aziz, 1992, Compact Constant Head Permeameter: A Convenient Device for Measuring Hydraulic Conductivity, Soil Science Society of America. Advances In Measurement of Soil Physical Properties: Bringing Theory into Practice.

Bagarello, V., and Provenzano, G., 1996, Factors Affecting Field and Laboratory Measurement of Saturated Hydraulic Conductivity, Transactions of the American Society of Agricultural Engineers, Vol. 39, No. 1, pp 153-159.

Black C. A. (Ed). 1965. Methods of Soil Analysis, Part I, Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling, American Society of Agronomy, Inc., Madison, WI

Black. C. A. (Ed.) 1965. Methods of Soil Analysis Part II, Chemical and Microbiological Properties, American Society of Agronomy, Inc. Madison, WI

Bouwer, Herman, 2002, Artificial Recharge of Groundwater: Hydrogeology and Engineering, Hydrogeology Journal, 10:121-142

Carter, Timothy L., Rasmussen Todd C., 2006, Hydrologic behavior of vegetated roofs, Journal of the American Water Resources Association, 42 (5): 1261-1274

Comprehensive Environmental Inc., 2002, Stormwater: Best Engineering Criteria No. 6.

Ferguson, B.K., 1994, Stormwater Infiltration, CRC Press, Boca Raton, Florida

Fletcher, P.C. and Veneman, P.L.M., Soil Morphology as an Indicator of Seasonal High Water Tables, http://nesoil.com/properties/eshwt.htm

Hantush, M. S. 1967. "Growth and Decay of Groundwater Mounds in Response to Uniform Percolation." *Water Resources Research*, Vol.3, 227–234.

Hantush, M.S. and Jacob, C.E. 1955. Nonsteady radial flow in an infinite leaky aquifer. *Trans. Amer. Geophys. Union*. 36. pp. 95-100.

Jabro, J.D. and Evans, R.G., 2006, Discrepancies Between Analytical Solutions of Two Borehole Permeameters for Estimating Field-Saturated Hydraulic Conductivity, Applied Engineering in Agriculture, Vol. 22(4): 549-554, http://www.sidney.ars.usda.gov/Site_Publisher_Site/pdfs/personnel/Discrepancies_Jay.pdf

Mohanty, B.P., Kanwar R.S., and Everts C.J., 1994, Comparision of Saturated Hydraulic Conductivity Measurement Methods for a Glacial Till Soil, Soil Science Society of America Journal, Vol. 58, No. 3.

New Hampshire Department of Environmental Services (NHDES), 2008. New Hampshire Stormwater Manual.

Nimmer, M.A., Thompson, A.M., Misra, D., 2007, Groundwater Mounding Beneath Stormwater Infiltration Basins, 2007 ASAE Annual Meeting

Nolan, Bernard T., Healy, Richard W., Taber, Patrick E., Perkins, Kimberlie, Hitt, Kerie J., Wolock, David M., 2007, Factors influencing ground-water recharge in the eastern United States, Journal of Hydrology, Volume 332, Issue 1-2, pp. 187-205.

Ostendorf, D.W., DeGroot D.J., and Hinlein E.S., 2007, Unconfined Aquifer Response to Infiltration Basins and Shallow Pump Tests, Journal of Hydrology, Vol. 338 No. 1-2, Pp. 132-144

Pitt, R., Clark, S., and Parmer, K., 1993, Potential Groundwater Contamination from Intentional and Nonintentional Stormwater Infiltration, Cooperative Agreement CR 819573, U.S. EPA, Cincinnati, Ohio

Pitt, R., Clark, S., Parmer, K., and Field, R., 1996, Groundwater Contamination from Stormwater Infiltration, Ann Arbor Press, Michigan.

Rawls, Brakensiek and Saxton, 1982, Estimation of Soil Water Properties, Transactions American Society of Agricultural Engineers 25(5): 1316 - 1320, 1328

Rawls, W.J., Gimenez, and Grossman, R., 1998. Use of Soil Texture, Bulk Density and Slope of Water Retention Curve to Predict Saturated Hydraulic Conductivity, Transactions American Society of Agricultural Engineers 41(4): 983-988.

Scanlon, B.R., Healy, R.W., Cook, P.G., 2002, Choosing appropriate techniques for quantifying groundwater recharge, *Hydrogeology Journal* 10 (2002), pp. 18–39.

S.J. Thien. 1979. *A flow diagram for teaching texture by feel analysis.* Journal of Agronomic Education. 8:54-55

U.S. Department of Agriculture, Natural Resources Conservation Service, 2007. National Soil Survey Handbook, title 430-VI, http://soils.usda.gov/technical/handbook/

United States Department of Agriculture, Natural Resource Conservation Service, 2007, Part 630 Hydrology National Engineering Handbook, Chapter 7, Hydrologic Soil Groups, http://policy.nrcs.usda.gov/media/pdf/H_210_630_7.pdf

Veneman, P.L.M. and P.C. Fletcher. 1997. Massachusetts soil evaluator program. In: M.S. Bedinger, A.I. Johnson and J.S. Fleming (eds.) Site characterization of onsite septic systems. ASTM STP 1324. Am. Soc. Testing Materials.

Warner, James W., Molden, David, Chehata, Mondher, and Sunada, Daniel K., 1989. Mathematical Analysis of Artificial Recharge from Basins, Journal of the American Water Resources Association 25 (2), 401–411.

Winkler, E, et al, 2000, Final Report Addendum: Assessment of the Relative Importance of Hydraulic Parameters On Infiltration Basin Performance, University of Massachusetts. (PDF File, April, 2001)

Winkler, E, Ahlfeld, D., Askar, G., Minihane, M., 2001, Final Report: Development of a Rational Basis for Designing Recharging Stormwater Control Structures and Flow and Volume Design Criteria. Prepared for Massachusetts Department of Environmental Protection Project 99-06/319. University of Massachusetts. (PDF File, April, 2001)

Wisconsin Department of Natural Resources, 2004, Conservation Practice Standards, Site Evaluation for Stormwater Infiltration, Practice 1002, http://dnr.wi.gov/runoff/pdf/stormwater/techstds/post/dnr1002-Infiltration.pdf

Wisconsin Department of Natural Resources, 2004, Conservation Practice Standards, Infiltration Basin Sizing, Practice 1003, http://dnr.wi.gov/runoff/pdf/stormwater/techstds/post/InfiltrationBasin_1003.zip

Wisconsin Department of Natural Resources, 2006, Conservation Practice Standards, Bioretention for Infiltration, Practice 1004, http://dnr.wi.gov/runoff/pdf/stormwater/techstds/post/Bioretention_1004a.zip

Wisconsin Department of Natural Resources, 2004, Compost, Specification S100, http://dnr.wi.gov/runoff/pdf/stormwater/techstds/post/SpecificationS100Compost.pdf

Kaveh Zomorodi, 2005, Simplified Solutions for Groundwater Mounding Under Stormwater Infiltration Facilities, AWRA 2005 Annual Water Resources Conferences, Seattle, WA, http://www.dewberry.com/uploadedFiles/SimplifiedSolutionsforGroundwaterMounding.pdf