Testing to Determine Design Infiltration Rates for Post-Construction Infiltration BMPs

May 9, 2019

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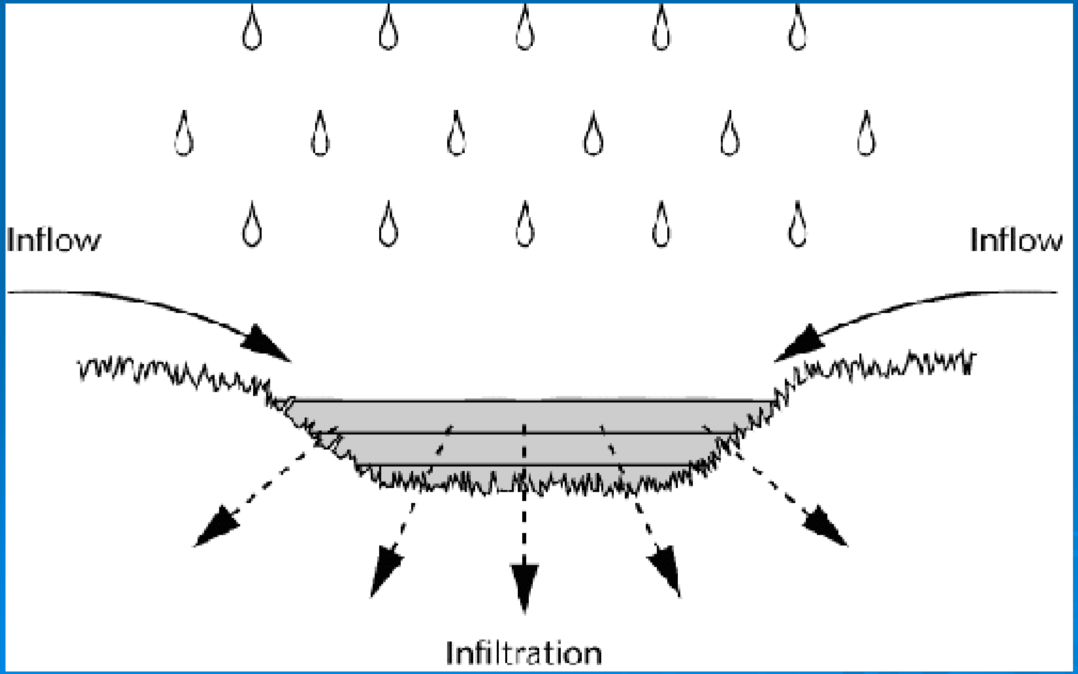
Overview of Presentation

- Quick infiltration overview
- Subsurface infiltration test considerations/options
- Measuring field infiltration rates for project design

Infiltration

- Infiltration is movement of water through a soil surface
  - Infiltration rate or capacity – rate of movement of water through a soil surface (length/time, e.g., in/hr)



For stormwater BMPs, “exfiltration” is infiltration from a BMP into the underlying and surrounding soil

Infiltration Rate vs Hydraulic Conductivity

Hydraulic conductivity ($K(h)$), saturated hydraulic conductivity (K_s), and field saturated hydraulic conductivity (K_{fs}) are measurable properties of the soil that have physical meaning

Relationship between Infiltration Rate and Hydraulic Conductivity

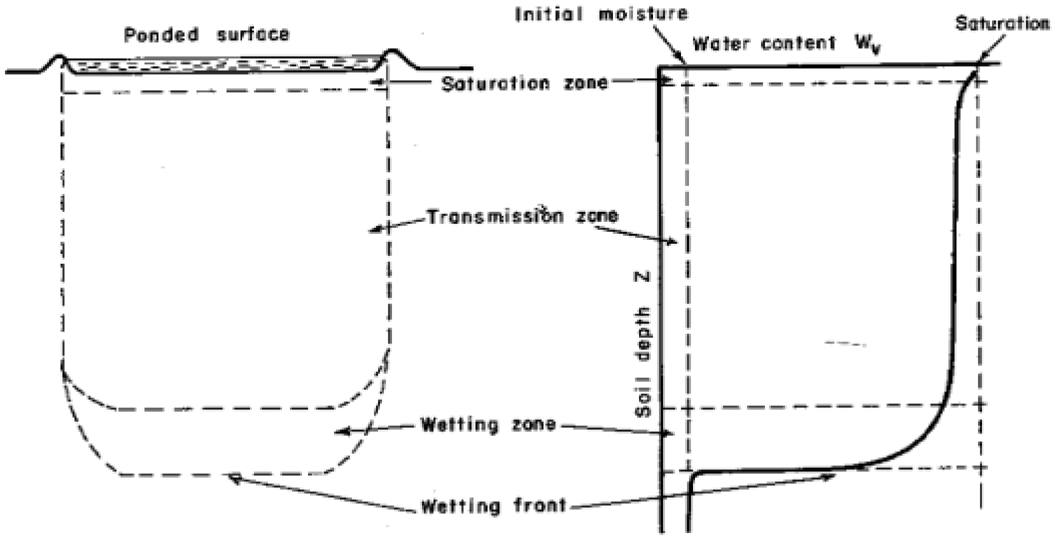


Fig. 12.3. The infiltration moisture profile. At left, a schematic section of the profile; at right, the water content versus depth curve. The common occurrence of a saturation zone as distinct from the transmission zone may result from the structural instability of the surface zone soil.

Source: Hillel (1982)

$$i(t) = K_{fs}\,\frac{\Delta H}{\Delta L} = K_{fs}\,\frac{H_{pond}(t)+L_f(t)-H_{suction}(t)}{L_f(t)}$$

Importance of Getting the Number Right (and Consequences of Getting It Wrong)

- Consequences of overestimating Kfs
  - System underdesign
  - Loss of hydrologic function (volume reduction, peak flow reduction, groundwater recharge, baseflow maintenance)
  - Flooding
  - Degraded water quality

Importance of Getting the Number Right (and Consequences of Getting It Wrong)

- Consequences of overestimating Kfs
- Consequences of underestimation
  - $$$$

Appropriate Use for Estimates

- Methods are available to provide rough estimates of infiltration (exfiltration) rates expected from infiltration BMPs. These methods are appropriate for **preliminary site planning**, i.e., to determine if an LID approach makes sense for a particular site or to develop a ballpark area allocated for infiltration BMPs.
- If moving forward with a design that incorporates infiltration BMPs field measured infiltration tests are necessary to determine accurate infiltration rate for sizing and design of BMPs.
  - Credit toward meeting WQv, runoff volume reduction or peak discharge requirements

Measuring Infiltration Rates

“When using infiltrometers to predict infiltration rates for a given system, one must be careful that the conditions of that system (water quality, temperature, soil conditions, surface conditions, lengths of inundation, infiltration flow system in the soil, etc.) are duplicated as much as possible with the infiltrometer so that the measurement is realistic.” H. Bouwer (1986)

Measuring Infiltration Rates

- Measuring the process of interest
  - Rainfall and runoff at the soil surface
  - Seepage in a leach bed
  - Exfiltration from a dry well
  - Exfiltration from an infiltrative BMP (pervious pavement, bioretention, underground detention/retention system)

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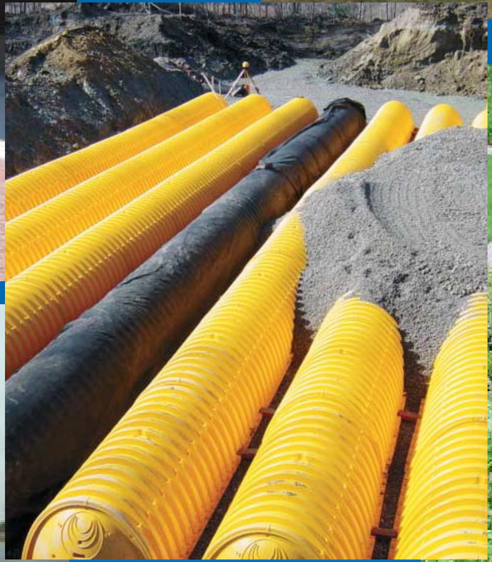
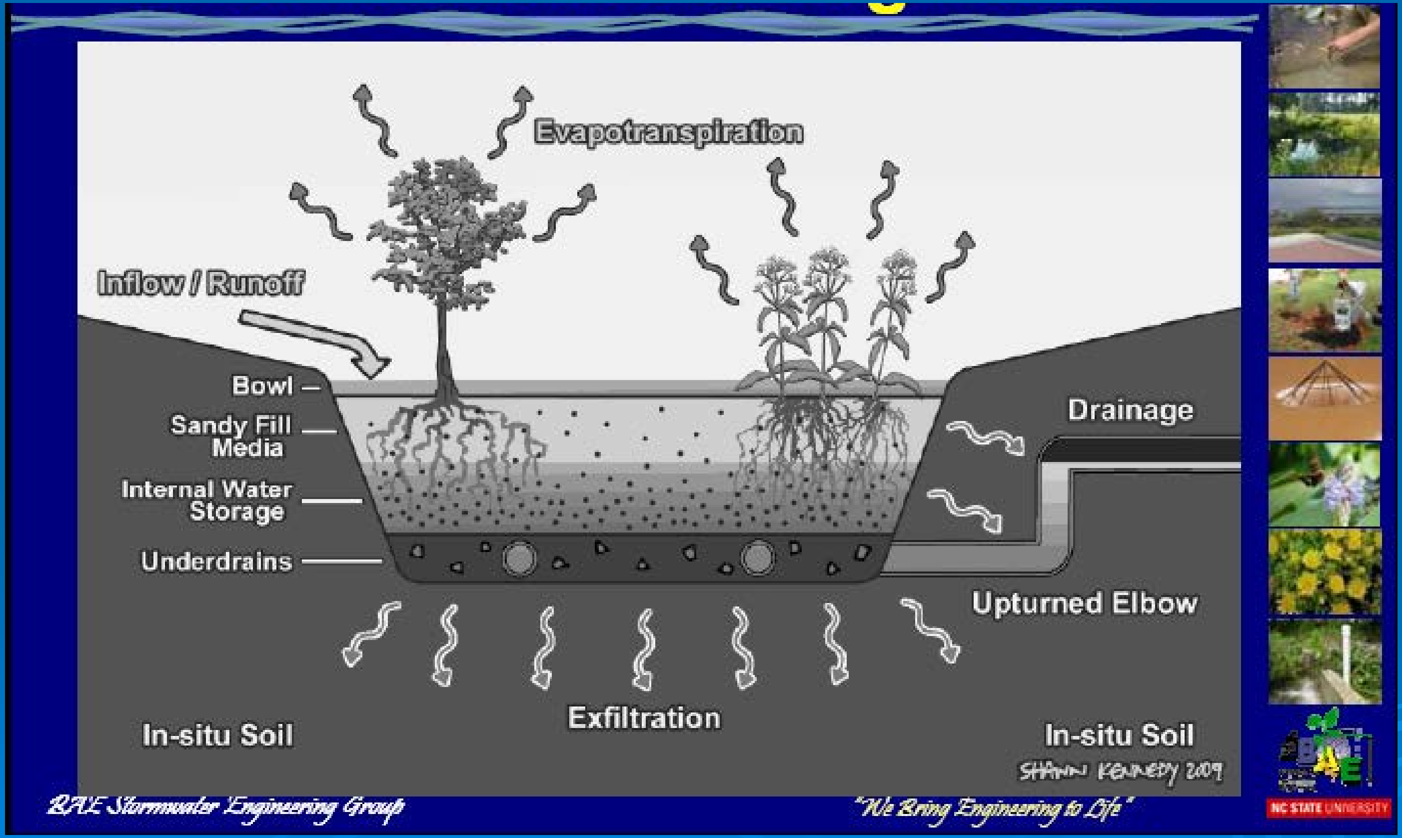
Infiltration BMPs

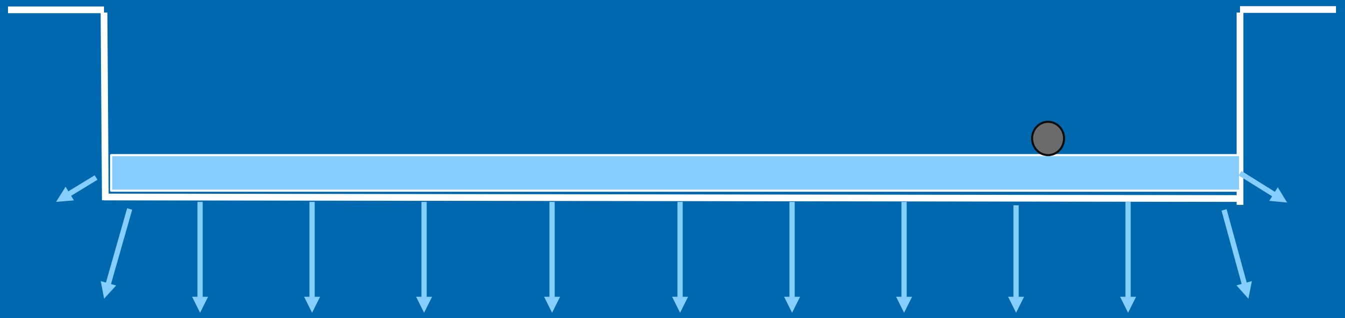


Exfiltration from an Infiltration BMP



Source: NC Extension (2009)

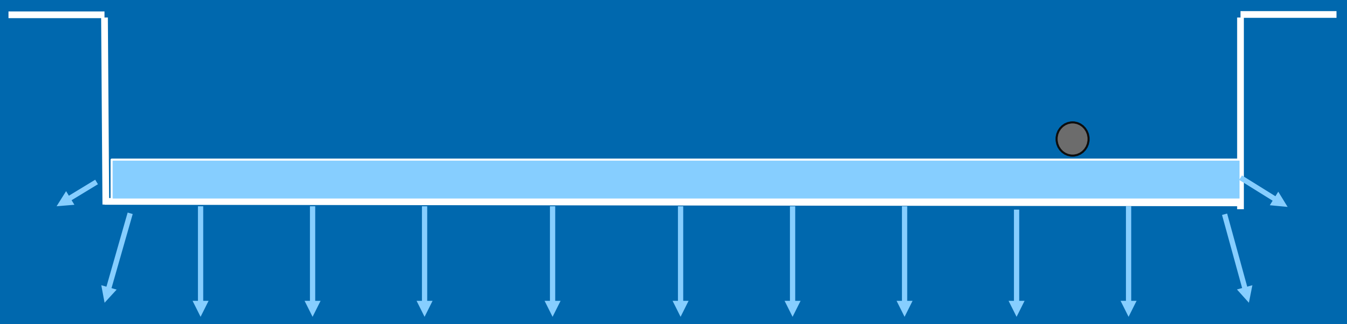
Infiltration Test for BMP Design?



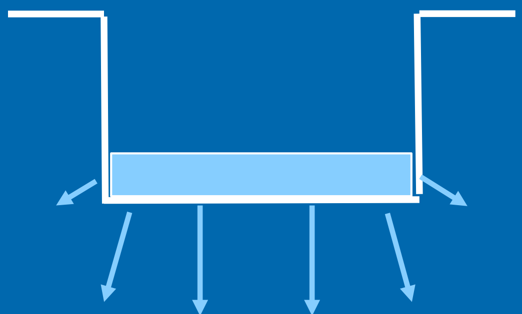
Infiltration Test Methods Considered

- Double-ring Infiltrometer Test
- Single-ring Infiltrometer Test – Constant Head
- Single-ring Infiltrometer Test - Falling-head
- Modified Phillip-Dunne Permeameter
- Pilot Infiltration Test (PIT Test)
- Bore Hole Infiltration Test

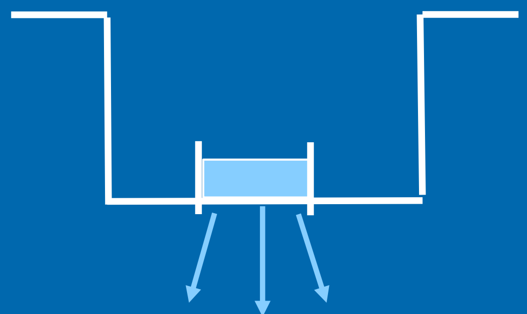
Infiltration with Shallow, Ponded One-dimensional Flow



Infiltration BMP



Pit Test



Single-ring Infiltrometer

Infiltration Test Methods Considered

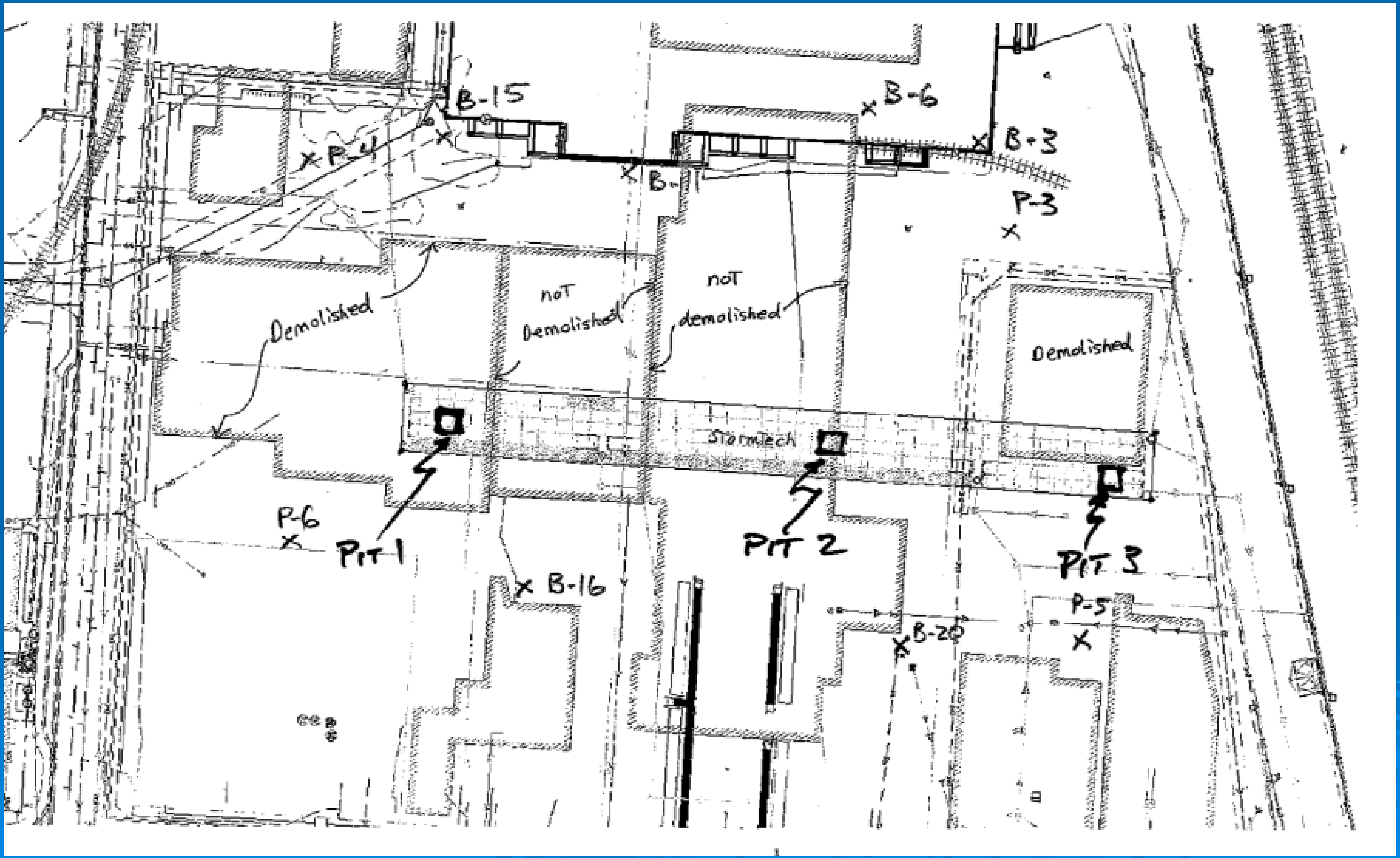
- ~~Double-ring Infiltrometer~~
- **Single-ring Infiltrometer – Constant Head**
- Single-ring Infiltrometer - Falling-head ???
- ~~Modified Phillip-Dunne Permeameter~~
- **Pilot Infiltration Test (PIT)**
- ~~Bore Hole Infiltration Test~~

Typically overestimates Kfs by 1000% or more

Minimum Sampling Density

Surface Area of Infiltration BMP (ft^2)	Number of Test Pits	Pit Tests	Single-ring Infiltrometer Tests (2 tests/pit)
<5000	2	2	4
5000-10000	3	3	6
>10000	4	4	8

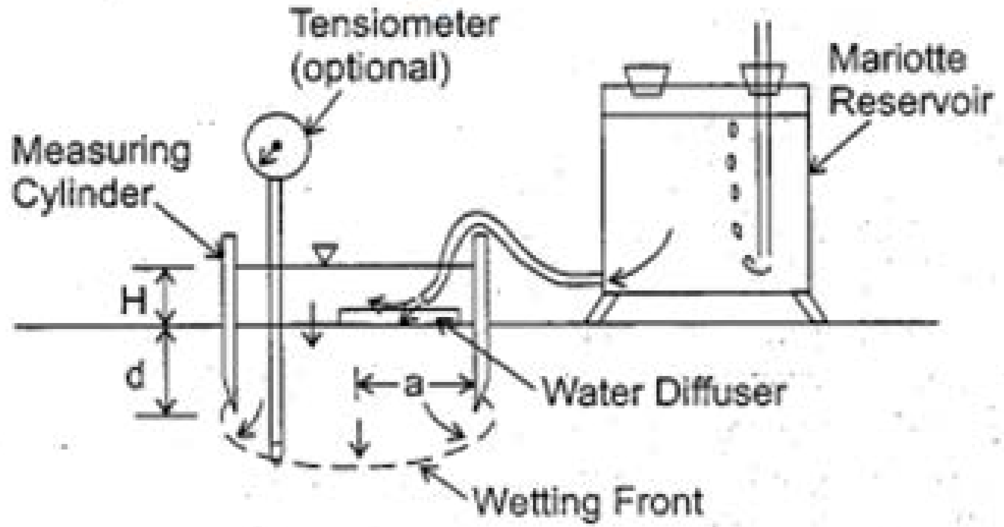
Choose Appropriate Test Locations



Excavate to Proposed BMP Depth

Describe Soil Profile from Surface to (at least) 3 Feet Below Proposed Depth

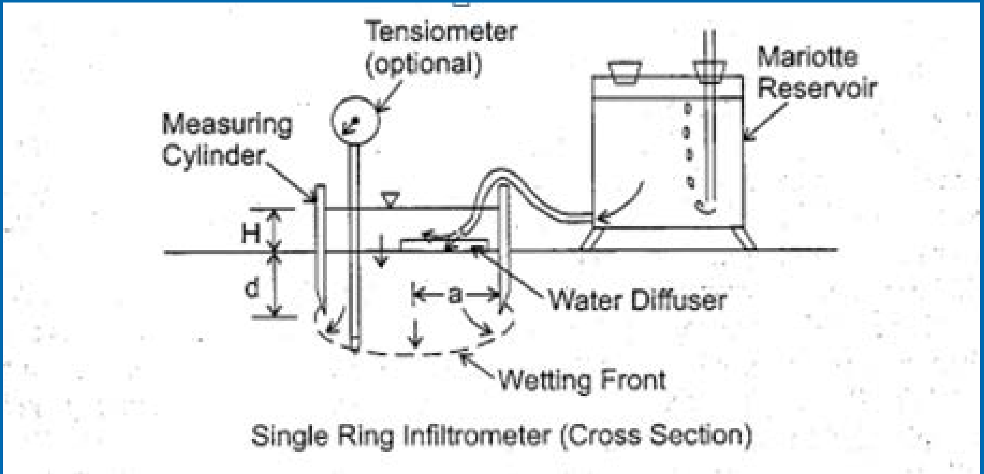
Single Ring Infiltrometer



Single Ring Infiltrometer (Cross Section)

Source: Reynolds et al (2002)

Single Ring Infiltrometer Equipment



Source: Reynolds et al (2002)

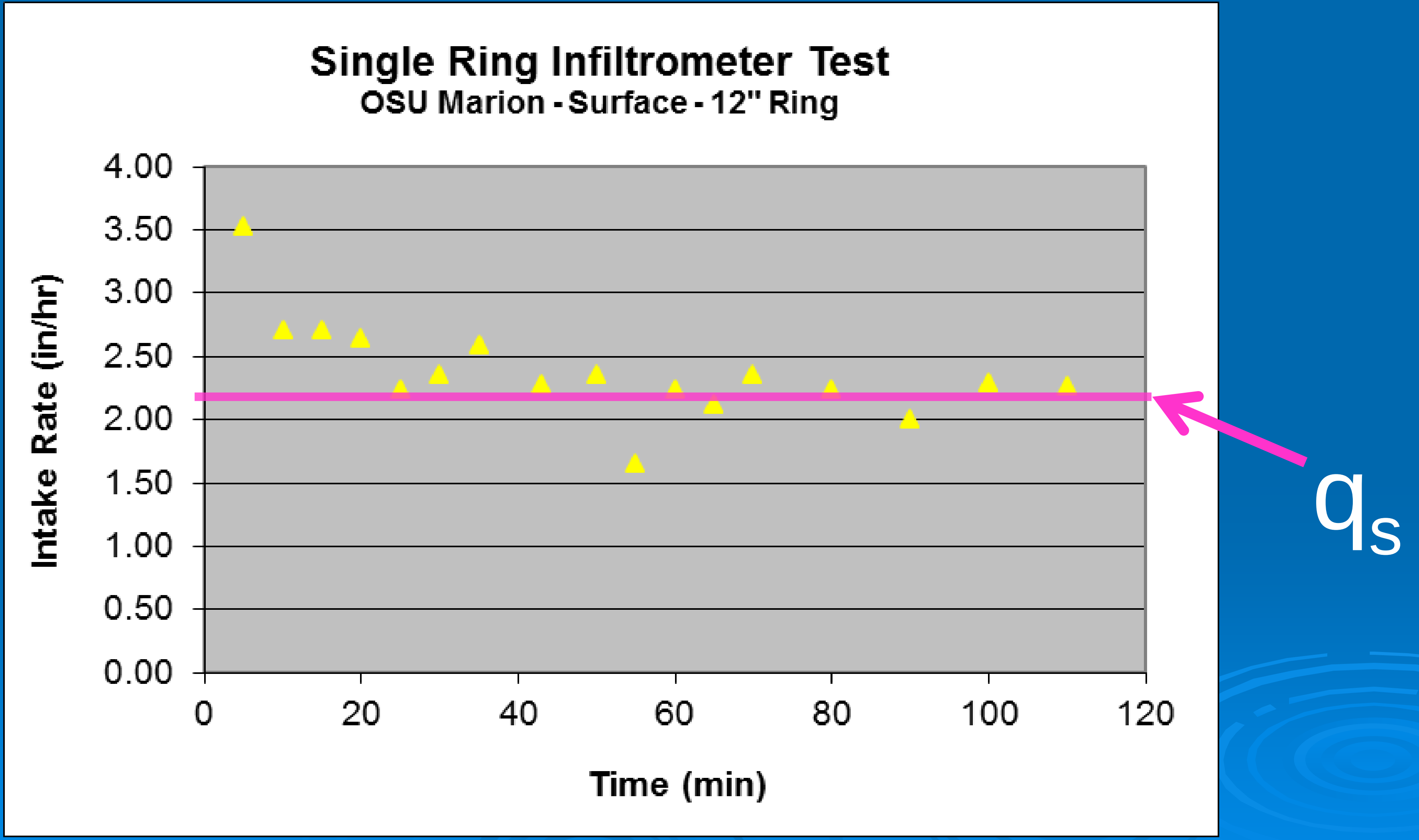
1. Rings (measuring cylinders)
2. Depth gages or rules
3. Graduated water supply reservoir (Mariotte bottle)
4. Stop watch
5. Field sheet/clipboard
6. Screen or cloth for initial wetting
7. Shovel, garden hoe, soil auger

Install Infiltration Rings

Wet Surface and Bring to Ponding Depth

Record Volume Infiltrated While Maintaining Constant Depth

Post-Processing - Determine Final Field Measured Intake Rate (q_s)



Ponded Ring Infiltrometer Test Accounting for Flow Divergence

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Ponded Infiltration From a Single Ring: I. Analysis of Steady Flow

W. D. Reynolds,* and D. E. Elrick

ABSTRACT

A new analysis of steady, ponded infiltration from within a single ring takes soil hydraulic properties, ring radius, depth of ring insertion, and depth of ponding into account. It also provides a means for determining the field-saturated hydraulic conductivity (K_{fs}) and the matric flux potential (ϕ_m). The analysis employs numerically determined shape factors (G) that are found to depend significantly on ring radius (a) and depth of ring insertion (d), but only slightly on depth of ponding (H) and soil hydraulic properties. As a consequence, averaged G values (G_a) can be developed for specified d and a that apply to a wide range of ponded heads and soil types. Procedures for calculating K_{fs} and ϕ_m are based on G or G_a, and on the ponding of one, two, or multiple H levels in the ring. Test calculations based on G_a suggest that K_{fs} can be obtained with an accuracy of about ±20% for H = 0.05 to 0.25 m and α = 1 to 36 m^{-1}, where α is the soil parameter of the exponential hydraulic conductivity–pressure head relationship. A similar level of accuracy (using G_a) is obtained for ϕ_m when α is small ($\alpha \leq 4$ m^{-1}), and when both α and H are large ($\alpha > 4$ m^{-1}, $H \geq 0.20$ m). Significant errors in ϕ_m can occur, however, when α is large but H is small. Potentially important features of this single ring method include low sensitivity of the K_{fs} calculation to errors in G_a, reduced measurement errors resulting from small-scale soil variability, and the ability to pond large heads in order to increase flow rates in low-permeability materials.

The sorptivity, S (m s$^{-1/2}$), may be estimated using (Philip, 1969; White and Sully, 1987)

$$S = [(\theta_{fs} - \theta_i)\phi_m/b]^{1/2}, \qquad [1]$$

where θ_{fs} (m^3 m^{-3}) is the field-saturated volumetric water content, θ_i (m^3 m^{-3}) is the background volumetric water content (assumed constant), b (dimensionless) is an empirical constant (defined below), and ϕ_m is defined by Gardner (1958) as

$$\phi_m = \int_{\psi_i}^{0} K(\psi)\mathrm{d}\psi; \qquad -\infty \leq \psi_i \leq 0, \qquad [2]$$

where ψ (m) is the pore-water pressure head, ψ_i (m) is the background pore-water pressure head (corresponds to θ_i), and $K(\psi)$ is the hydraulic conductivity–pressure head relationship. Philip (1969) has shown that b = 0.5 exactly for soils exhibiting a step-function (Green-Ampt) infiltration front. For general field soils, White and Sully (1987) suggested $b \approx 0.55$ to account for the fact that actual infiltration fronts tend not to be as sharp as a step function. Broadbridge and White (1988) calculated b using

$$b = [4(C - 1) + 2.923]/[\pi(C - 1) + 1.4615], \qquad [3]$$

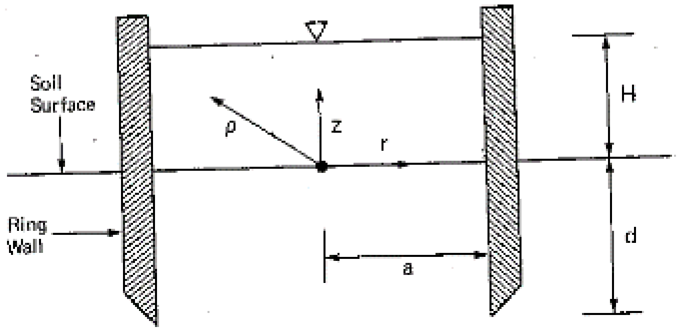


Fig. 1. Schematic of ponded flow from within a ring (r,z = cylindrical coordinate directions, ρ = spherical coordinate direction, a = ring radius, d = depth of ring insertion, H = steady depth of water ponding in the ring).

Source: Reynolds et al (2002)

$$q_s/K_{fs} = Q/(\pi a^2 K_{fs}) = [H/(C_1 d + C_2 a)] + \{1/[\alpha^*(C_1 d + C_2 a)]\} + 1 \qquad [3.4–11]$$

Post-Processing – Make Correction for Flow Divergence

Field Saturated Hydraulic Conductivity Measurement with Single Ring Infiltrometer

References: Reynolds, W.D. 2008b. Saturated Hydraulic Properties: Ring Infiltrometer.

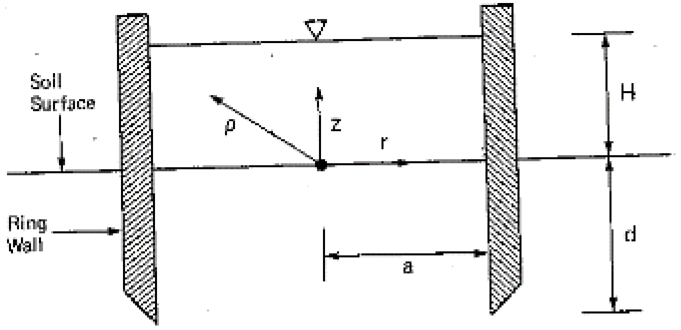
Kfs = qs / [(H/RF) + (1/(alpha-star*RF)) + 1]

Kfs =	field saturated hydraullic conductivity (in/hr)
qs =	Qs / pi*r^2
	quasisteady infiltration rate (in/hr)
H =	head - i.e., steady ponded depth of water in the cylinder (in)
alpha-star =	sorptive number of porous medium (in^-1; see Table 76.1 or determine through multiple constant head test)
RF =	C1*d + C2*r
	ring shape & installation factor based on depth of insertion (d, in) and cylinder radius (r, in)
C1 =	0.316*pi = 0.9927
	quasiempirical constant
C2 =	0.184*pi = 0.5781
	quasiempirical constant

Soil Type	Fine	
Ring Diameter, D =	12.0	inches
Depth of Insertion, d	3.0	inches
Depth of Ponding, h	6.0	inches
Field Measured Infiltration Rate, qs =	0.20	in/hr

Soil Type	Cylinder Diameter D in	Depth of Cylinder Insertion d in	Ring Factor RF in	Depth of Ponding H in	Sorptive Number alpha-star in^-1	Steady Field Measurec Infiltratior Rate qs in/hr	Corrected Field Saturated Conductivity Kfs in/hr	Overestimation Factor
Compacted	12.0	3.0	6.4	6.0	0.033333	0.20	0.03	6.6
Fine	12.0	3.0	6.4	6.0	0.1	0.20	**0.06**	3.5
Loamy	12.0	3.0	6.4	6.0	0.3	0.20	0.08	2.4

The estimate of field saturated hydraulic conductivity is: 0.06 in/hr



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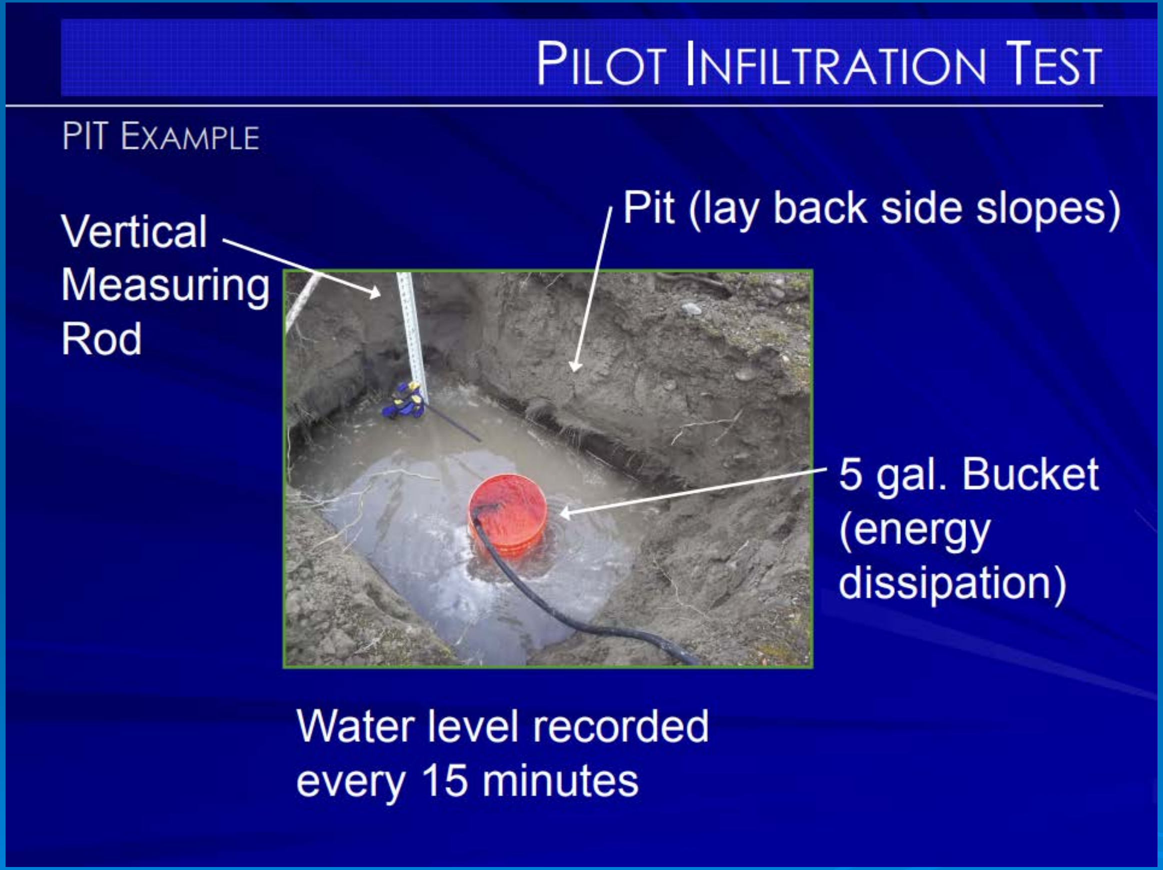
Pit Test Equipment



Source: Alice Lancaster, Herrera Environmental Consultants

1. Water level loggers
2. Measuring rod or ruler with readings in mm or 0.01 ft
3. Large water tank or nearby water supply
4. Hoses and fittings
5. Stop watch
6. Field sheet/clipboard
7. Bucket or splash pad for initial wetting
8. Backhoe
9. Shovel & auger

Pit Test Pre-soak

Excavate pit to desired dimensions

Place water level loggers

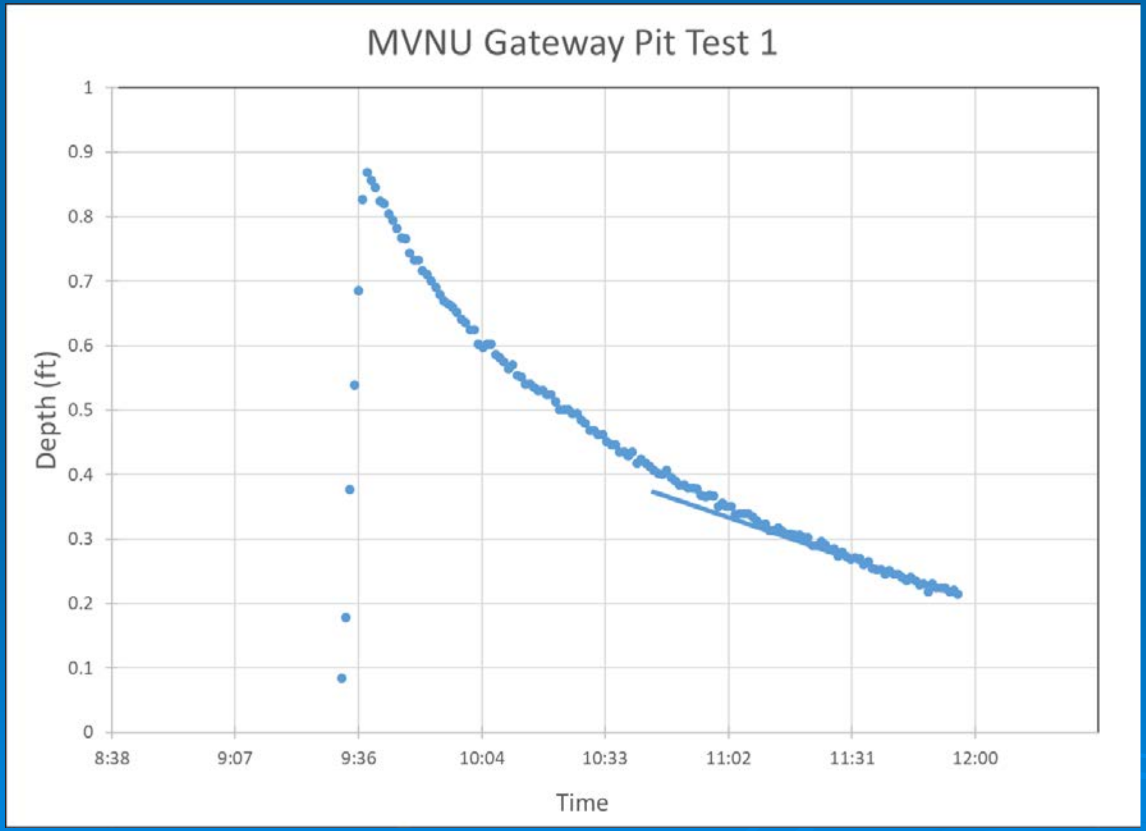
Fill test pit for initial pre-soak of underlying soils: (1) fill bottom of pit to 12” depth; (2) let soak for 3 hours or until water fully saturates

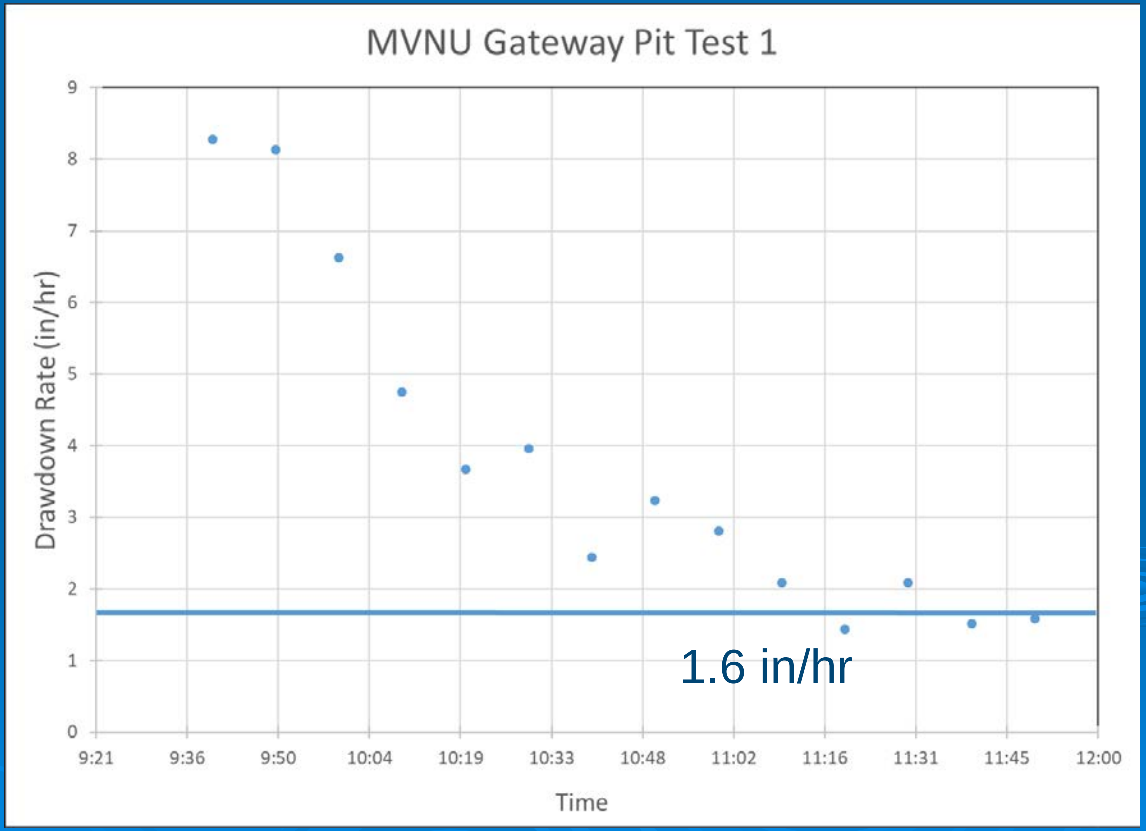
Complete Falling Head Tests

Refill pit to 12” ponded depth

Record surface elevation every 30 minutes until pit fully drains, or minimum 6 hours if pit does not fully drain

Post-Processing - Determine Final Field Measured Intake Rate





Infiltration Testing Costs

Single Ring Infiltrometer

1. Rings (measuring cylinders) - $100 - $500/12” ring
2. Driving cap and fence post driver - $200
3. Depth gages or rules
4. Graduated water supply reservoir
   - 5-gal bucket with spigot, tape - $30 - $40
   - Mariotte Bottle - $250 ea (small); $750 ea (large)
5. Stop watch - $20
6. Field sheet/clipboard
7. Screen or cloth for initial wetting
8. Backhoe - $400 - $2000/day

1. Water level loggers $500/logger
2. Measuring rod or rulers
3. Large water supply tank, hoses and fittings - $400
4. Stop watch - $20
5. Field sheet/clipboard
6. Bucket or splash pad for initial wetting
7. Backhoe - $400 - $2000/day

Equipment needed to conduct 6 tests/day $5000-6000
(6 rings, 6 Mariotte bottles, etc. or 7 water level loggers, etc.)

Hire – 3-6 tests/day $2500 - $6000/day
(two techs, backhoe rental, etc.)

Summary

- Field measurements necessary to determine infiltration rates for infiltration BMP design
- Two methods are acceptable:
  - Single-ring infiltrometer
  - Pit test
- The pit test requires less equipment and is simpler to perform – this method is recommended

RAINWATER AND LAND DEVELOPMENT PROVISIONAL APPENDIX A-#

INFILTRATION TESTING FOR STORMWATER PRACTICE DESIGN

DATE: 12/20/18

https://epa.ohio.gov/Portals/35/storm/technical_assistance/ProPractices.pdf

Questions:

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THE OHIO STATE UNIVERSITY
Stormwater Management Program