Evaluation of Field Hydraulic Conductivity Data: Comparing Spot Infiltrometer Test Data To Continuous Recession Data

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Introduction

Rain gardens are one type of stormwater control measures (SCMs) which are used to reduce the quantity and improve the quality of water through infiltration and evapotranspiration (ET). Rain garden soils maybe either native or engineered media. Hydraulic conductivity is typically used as a performance measure of rain gardens, and this is most commonly determined in the field using infiltration testing. The most common type of infiltration testing is the double-ring infiltrometer (ASTM D3385); however, these systems require a large amount of water, can be difficult to install, and are time consuming to perform. Smaller single-ring infiltrometer tests can be easier to install and require less water. Additionally, more tests could be performed in the same amount of time, which means more area of a site can be tested. Since the accuracy of these methods is not well-documented, this study compared single-ring infiltrometer data to historical recession rate data recorded in the pond of the SCM to determine the accuracy of this testing technique.

Figure 1: A single-ring infiltrometer test.

Figure 2: Single-ring infiltration testing.

Site Description

The Bioinfiltration Traffic Island (BTI) is a retrofit unlined rain garden that was constructed on Villanova University's campus in 2001 and has been monitored continuously since 2003. A conventional mounded traffic island was converted into a rain garden. The soils in the rain garden are classified as a Unified Soil Classification System (USCS) silty sand and a United States Department of Agriculture (USDA) loamy coarse sand. A surface organic layer was found to exist in varying depths across the SCM pond. This organic soil is classified as a USCS sandy silt and a USDA silt loam. The BTI is instrumented with various sensors to measure hydrologic performance.

Figure 3: The Bioinfiltration Traffic Island.

Methodology

In the Fall of 2014, seven single-ring infiltrometer tests were conducted at the BTI to determine the field hydraulic conductivity. The test method was designed to be simple and inexpensive while providing repeatability, rapid-testing times, test accuracy, and adequate precision. The single-ring infiltrometer test used a 15.2 cm diameter, 15.2 cm long steel ring with a beveled cutting edge. The ring was driven 7.6 cm into the soil, leaving 7.6 cm exposed above the soil surface. The soil in the ring was protected using a filter fabric, which prevents water from altering the soil surface. The time required for a 2.5 cm drop was measured and the test was run multiple times until the intake rate stabilized. The single-ring infiltrometer has a range of 7×10^{-5} cm/s to 7×10^{-3} cm/s. The seven tests were performed on 0.13 m^2 (<0.1%) of the entire SCM area, with areas encompassing various portions of the SCM.

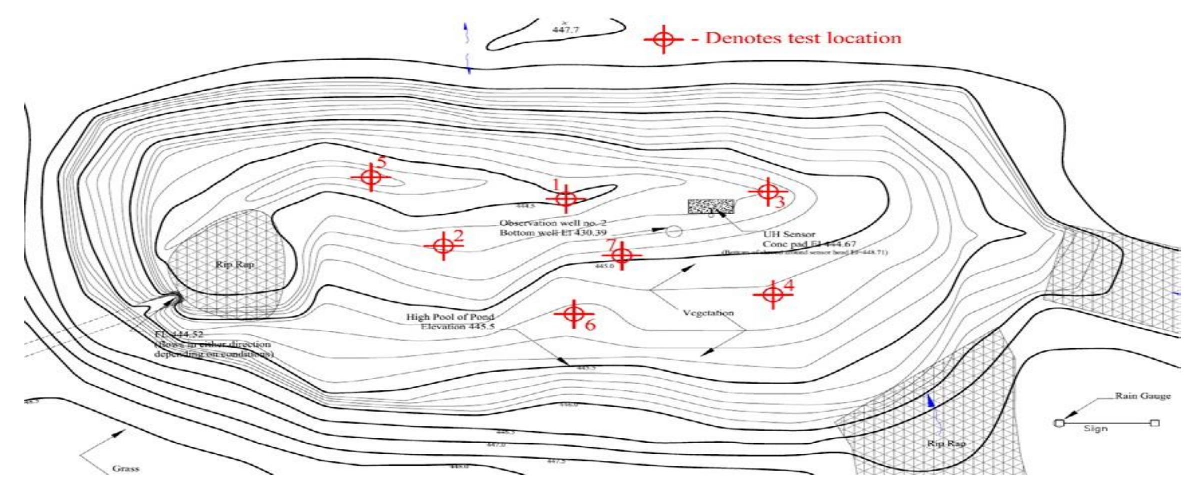

Figure 4: Single-ring infiltrometer test locations.

Intake rates are dictated by unsaturated flow conditions and three-dimensional flow characteristics, but the intake rate approaches a steady rate as water is added, and this rate is correlated to the field hydraulic conductivity. A variably saturated groundwater model was adapted to the specific and repeatable test conditions. The model inputs include boundary conditions and van Genuchten unsaturated soil properties; the model is run multiple times to develop a relationship between the observed intake rate and hydraulic conductivity.

The recession rate is used as an estimate of an area-averaged hydraulic conductivity of the surface soils. The recession infiltration process is assumed to follow steady ponded infiltration which is characterized by gravimetric forces and saturated hydraulic conductivity of the soil. The recession rate is measured using ponding information collected from a bubbler within the pond. This information can be check with a pressure transducer in the pond. Previously, an ultrasonic sensor was used to determine ponding levels.

Data Analyses

Hydraulic conductivities were corrected to 20° C to account for the viscosity of water being dependent on its temperature. The hydraulic conductivity values ranged from $<7.7\times10^{-6}$ cm/s to 2.1×10^{-3} cm/s with the geometric mean found to be 2.9×10^{-4} cm/s. The depth of the organic silt loam layer was recorded at each test location as well.

Test No.	Temperature of Water (°C)	Depth of Organic Silt Loam (cm)	Hydraulic Conductivity (cm/s)	Temperature Corrected Hydraulic Conductivity (cm/s)
1	16.5	7.6	$<7.1\times10^{-6}$	$<7.7\times10^{-6}$
2	16.5	6.4	1.4×10^{-4}	1.5×10^{-4}
3	16.3	2.5	1.7×10^{-3}	1.9×10^{-3}
4	16.9	2.5	1.9×10^{-3}	2.1×10^{-3}
5	15.9	5.1	2.1×10^{-4}	2.4×10^{-4}
6	16.9	3.8	1.4×10^{-4}	1.5×10^{-4}
7	15.7	6.4	8.5×10^{-4}	9.4×10^{-4}

Figure 5: Single-ring infiltrometer data.

An analysis of the recession rate for all of monitored storms dating back to 2003 results in an average rate of 1.9×10^{-4} cm/s with seasonal variations on the order of a factor of two. The primary source of seasonal variation is related to the temperature-dependency of the viscosity of water and its direct influence on the hydraulic conductivity of the near-surface soils in the SCM.

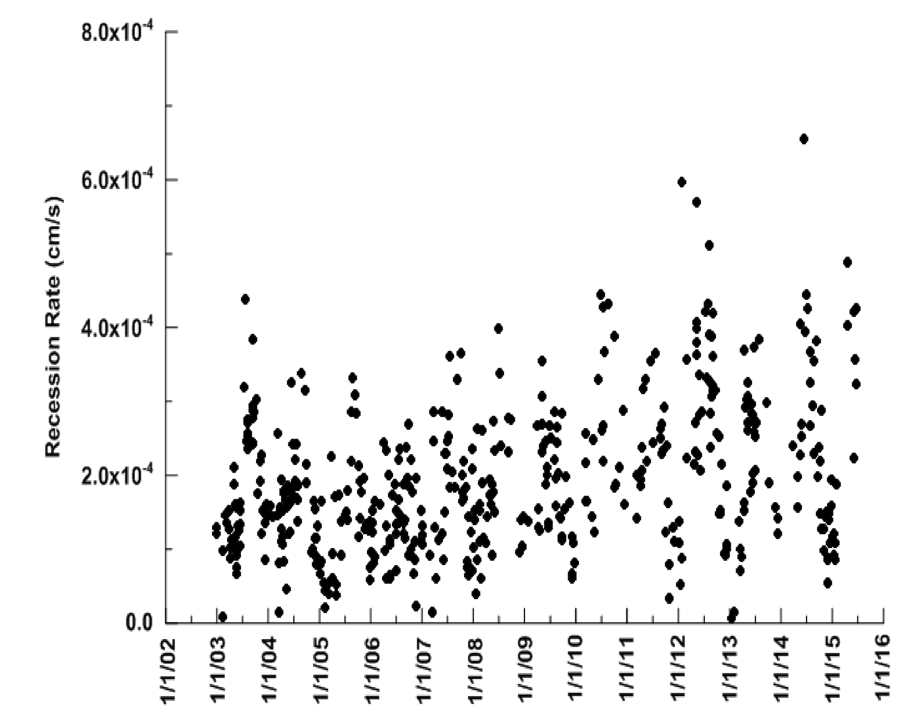

Figure 6: Recession rate data recorded at the BTI.

Comparison

The recession rate and single-ring infiltrometer test data both provide hydraulic conductivities within the same order of magnitude indicating that the single-ring infiltrometer testing method provides representative performance estimates for SCMs. The geometric average is the value that most accurately predicts the hydraulic conductivity of the surface soil at the SCM indicating that a certain quantity of tests is required to reflect SCM performance and account for heterogeneity of surficial soils. Conducting multiple tests is very difficult with the double-ring infiltrometer, given the amount of water and time required for such a testing procedure, and supports the use of the simpler, single-ring method. Additional research is required on two topics: the formation and role of near surface soil layers and a determination of the appropriate number of infiltration tests required to accurately predict the field behavior of a rain garden.

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