Cost Effective Tools for Assessment of Infiltration at Green Infrastructure Stormwater Management Sites

Figure 1. Installation of a temperature profiler into a cased borehole adjacent to the infiltration gallery.

Motivation:

Impermeable surfaces such as buildings and roads limit natural infiltration of precipitation into underlying soil. Reduced infiltration limits natural replenishment of groundwater, increases stormwater runoff and flooding, and can overload water-treatment systems. Green infrastructure (GI) is one potential method for offsetting reduced infiltration. GI encompasses a range of purpose-built landscape features that provide storage capacity for stormwater runoff and increase infiltration into the subsurface. Successful management of stormwater infiltration is achieved by optimizing the dimensions and characteristics of the GI system for compatibility with the infiltration capacity of the existing soil profile. The long-term performance of the GI system will be governed by changes to the water transmission characteristics of the GI system materials and the soil profile resulting from potential reductions in porosity and permeability over time, i.e., clogging. Direct measurements of water flux and the physical properties of subsurface materials during the lifetime of the GI system can be expensive and labor-intensive and therefore impractical. These limitations can be addressed using robust, low cost subsurface monitoring devices that track surrogate indicators of subsurface water movement.

Pilot Field Studies to Test GI-performance Monitoring Devices:

Two pilot studies were initiated to test the performance of subsurface monitoring devices and their ability to track movement of infiltrating stormwater into the subsurface. In the first study, EPA is collaborating with the U.S. Army as part of their Net Zero Initiative at a site in Kansas. This project studied an instrumented GI system that includes a section of permeable pavement coupled to a subsurface infiltration gallery to manage stormwater runoff and enhance recharge to groundwater. Soil temperature monitoring was demonstrated for tracking movement of captured stormwater runoff from the infiltration gallery into the soil profile. In the second study, EPA is collaborating with the U.S. Geological Survey to develop and evaluate performance of autonomous and remote geophysical sensing systems for monitoring infiltration. This project entails development of a sensing device and associated telemetry system to allow remote operation and data acquisition. Evaluations for remote monitoring of infiltration are being conducted for a permeable pavement test system and a natural soil control site in Connecticut.

Monitoring Soil Temperature in Kansas:

The use of soil temperature to monitor water flow is based on the principles of heat transfer that are in play when there is a contrast in the temperature of infiltrating stormwater and the ambient temperature of the soil profile. Heat transfer occurs through soil particles that are in contact with each other (conduction) and via flowing water as it moves through connected porosity in the soil (convection). The observed rate of temperature change can be used as a diagnostic to isolate the influence of flowing water on the overall heat transfer process. Research is being conducted to develop data analysis protocols for extracting information on water flow directly from the transient temperature signals. At the study site in Kansas, this exploratory work can be verified through comparison to independent measures of the movement of stormwater drainage through and out of the infiltration gallery. A view of the GI system and the physical locations of some of the monitoring devices are shown in Figure 1. Stormwater runoff is routed from the parking lot to the permeable pavers section, which is the entry point for flow into the infiltration gallery. Flow of stormwater through the infiltration gallery is monitored near the surface and near the gallery bottom.

One performance issue under investigation is the potential for infiltrated stormwater to exit the gallery through its sidewalls as well as its bottom. Evaluation of transient temperature signals following stormwater infiltration events has shown that there is lateral flow near the bottom of the southern sidewall of the infiltration gallery, but stormwater primarily exits through its bottom (Figure 2). Further evaluations are underway to optimize data acquisition and analysis protocols for using subsurface temperature to monitor stormwater infiltration.

Monitoring Resistivity in Connecticut:

The bulk electrical resistivity of earth materials is dependent on the resistivity of the fluid in the pore space. The open pore space in unsaturated or partially saturated soil is filled by a combination of air and water. Infiltrating water that flows through the connected pore space modifies the bulk resistivity of the

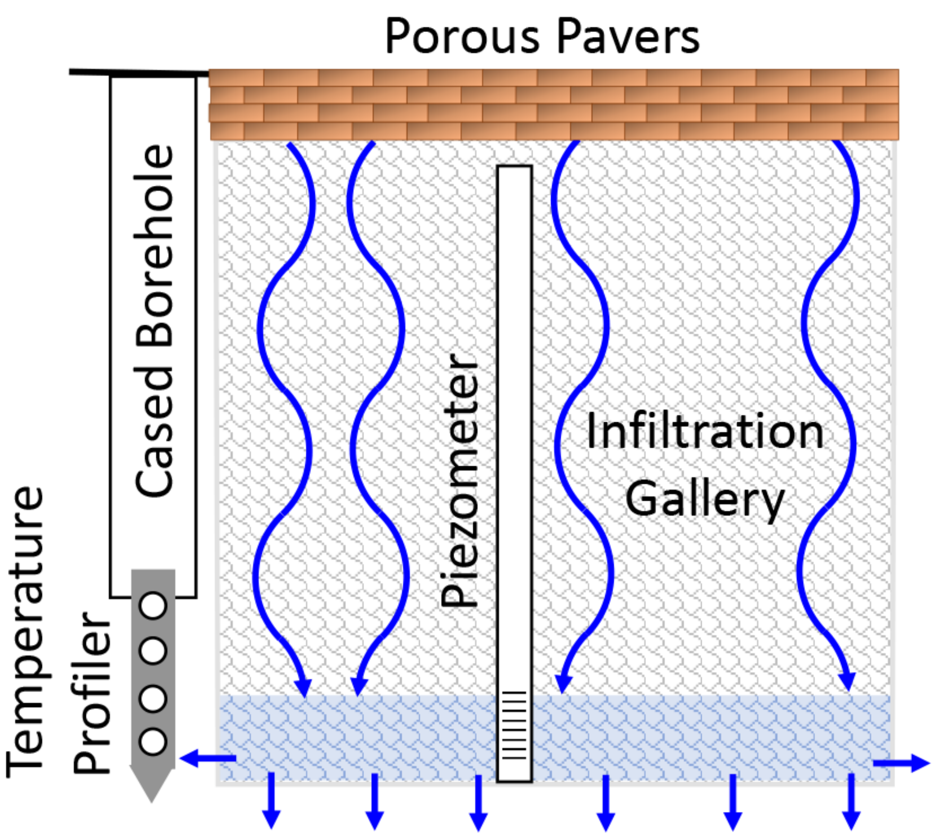

Figure 2. *Vertical illustration of the position of the temperature profiler relative to the infiltration gallery sidewall and bottom (not to scale).*

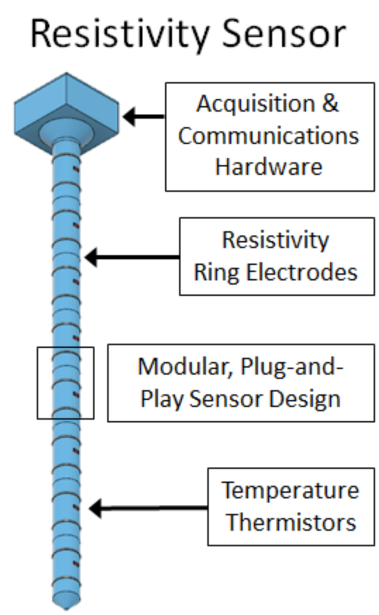

Figure 3. *Sensor with resistivity ring electrodes and temperature thermistors. Modular design allows customizable depth and sensor geometry. Top of sensor houses data acquisition and telemetry system for remote operation and acquisition control.*

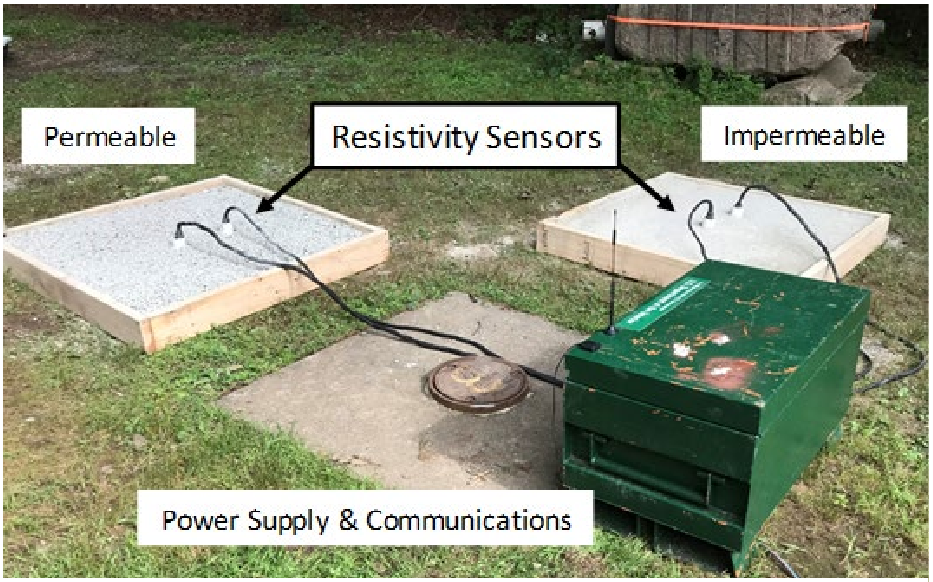

Figure 4. *Connecticut study site showing sensors (Fig. 3) installed in permeable and impermeable pavement pads. Undisturbed reference soil (not shown) plot instrumented with soil moisture probe and resistivity sensor.*

soil profile. This provides the basis for the measurement of resistivity to track the flow of stormwater infiltration through porous material. By conducting time-lapse resistivity measurements, it then becomes possible to track water movement through a soil profile. A dedicated, in-situ and low-cost instrument for continuous logging of resistivity and temperature profiles is being developed and tested for this study (Figure 3).

In addition, a telemetry system is being evaluated for remote monitoring of the performance of GI systems to allow data collection via an automated acquisition, processing, modeling, and visualization framework. At the Connecticut study site, three resistivity sensors, a soil moisture probe, and weather station will be deployed to conduct a year-long recharge monitoring experiment (Figure 4). Initial testing has shown that resistivity decreases in response to simulated recharge events and corresponding increases in water content.

The next stage of the research will include long-term monitoring with an updated version of the resistivity sensors to demonstrate remote control of data acquisition, use of an on-line data viewing platform, and model testing for interpreting results. Observations from this study will help to validate the use of resistivity to monitor recharge events and demonstrate remote application of the technology for monitoring performance of GI systems.

This document has been reviewed by the U.S. Environmental Protection Agency, Office of Research and Development and approved for publication.

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