**Geophysical Prediction of Water Migration along the Soil-Bedrock Interface at the Shale Hills Critical Zone Observatory**

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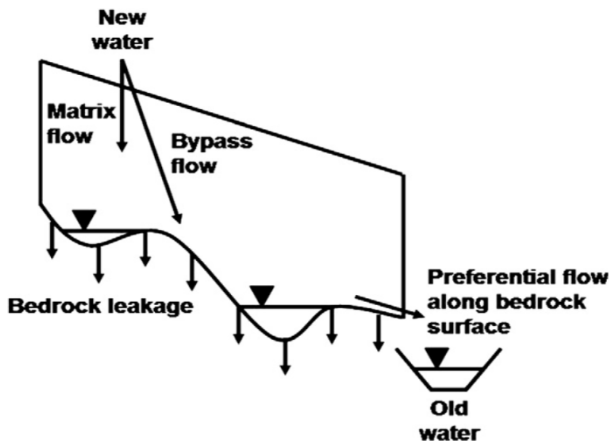


Figure 1: Conceptual model proposed to explain lateral subsurface flow on a hillslope (Graham, Woods, & McDonnell, 2010).

**Statement of Proposed Work**

Recent field studies suggest that the hillslope response to rainfall at some sites may be controlled by bedrock microtopography (Graham, Woods, & McDonnell, 2010; Graham & McDonnell, 2010). In what is referred to as "fill and spill" model, the proposed mechanism is rapid infiltration of precipitation through the soil layer down to the bedrock followed by lateral flow along the soil bedrock interface through macropores, with water filling each small bedrock depression and then overflowing down into the next (Figure 1).

This model was developed to explain the results of a dye tracer test performed at the Maimai Experimental Watershed in New Zealand. There a dye release and subsequent excavation clearly showed a rapid downward infiltration followed by migration along the soil-bedrock interface (Figure 2).

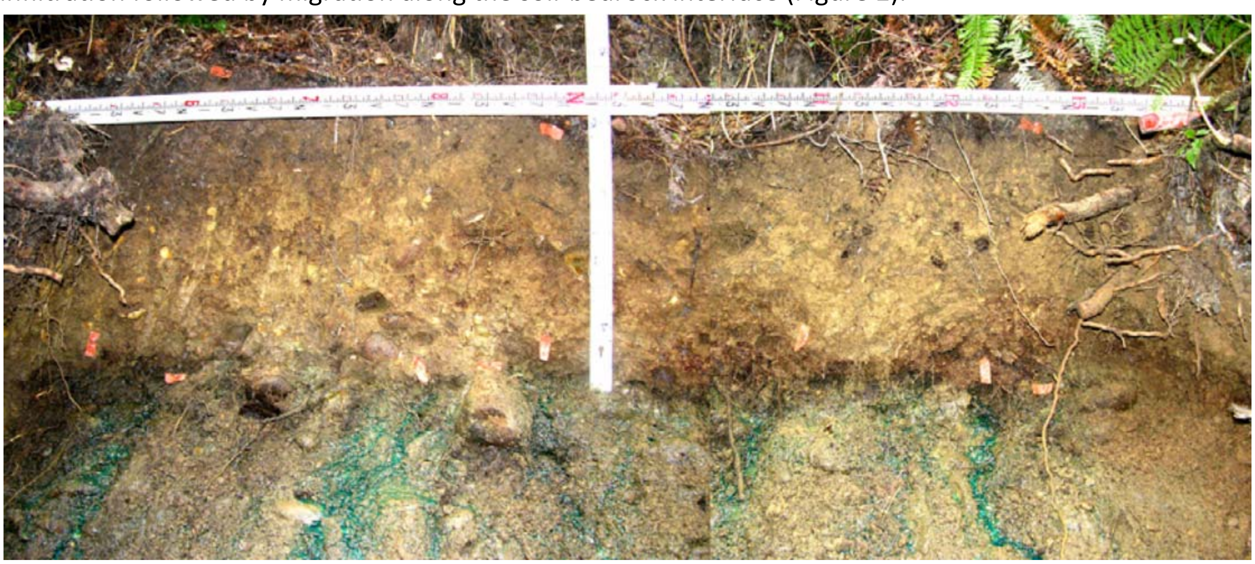

Figure 2: Evidence for preferential flow along the soil-bedrock interface at Maimai (Graham, Woods, & McDonnell, 2010).

*We hypothesize that the same mechanism may be in effect for portions of the Shale Hills Critical Zone Observatory, mainly along planer hillslopes and near ridgetop areas where the bedrock is shallow. This is supported by previous studies that have shown that at least for some storm events water arrives more quickly at depth than near the surface*(Lin & Zhou, 2008; *Graham & Lin, 2011). We further hypothesize that 3-D Ground*

*Penetrating Radar (GPR) can be used to map the shallow bedrock microtopography in sufficient detail to estimate fill-and-spill pathways.*

**What work is proposed?** For this proof-of-principal experiment we propose to test this hypothesis by conducting a detailed 3D GPR survey on a very small-scale (roughly an area of 2m x 3m) at a test site on the Weikert series soil where the bedrock in known to be only about 20 cm deep to develop a detailed map of the bedrock topography to predict the fill-and-spill pathway. Subsequently, we would conduct a series of infiltration tests monitored using time-lapse geophysics using a variety of methods. Finally, a dye infiltration test (we will use food coloring – nontoxic and geochemically unimportant) would conducted, monitored using time-lapse GPR, with temperature and moisture probes, and possibly using electrical resistance tomography. We would then excavate (again, only this small area) and photograph the site to ground truth flow predictions based on the geophysical data. The pit would then be back-filled with the excavated material.

**Why is this important?** To the best of our knowledge, this would represent the first time geophysical data has been used to in conjunction with this new fill-and-spill conceptual flow model. Preferential flow in hydrologic processes at all spatial and temporal scales is of critical importance to understanding the transport of water, nutrients, dissolved minerals, organic carbon and contaminants. If we can demonstrate that geophysics has the potential to help unravel the complexities of lateral preferential flow along the soil-bedrock interface it would create a strong case for follow-on proposals to NSF.

**When would the work be completed?** Field work would be conducted in May and June of 2013. The exact dates will depend on the schedules of all involved and on weather conditions.

**Where will the work be completed?** We propose to use a site where we collaborated with Dr. Henry Lin in the past, a small 2m x 3m test plot on the Weikert soils located on the northern, south-facing slope of the catchment. If disturbance of this small area is deemed unacceptable, we would move the experiment to the catchment adjacent to the Shale Hills similar characteristics.

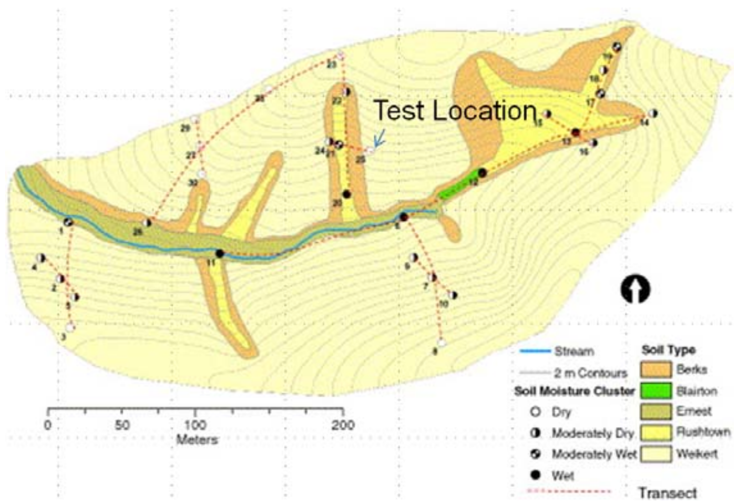


**Figure 3: Proposed project location**

**Who will do the work?** The experiment would form the basis of Temple graduate student Lacey Pittman's masters thesis under the supervision of Drs. Jonathan Nyquist (geophysicist) and Laura Toran (hydrogeologist) in collaboration with Dr. Henry Lin (PSU) and his graduate students.

**Bibliography**

Graham, C. B., & Lin, H. S. (2011). Controls and Frequency of Preferential Flow Occurrence: A 175-Event Analysis. *Vadose Zone Journal*, *10*(3), 816. doi:10.2136/vzj2010.0119

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## Proposed SSHO Interactions

**How will the proposed research or education or outreach activity fit into ongoing activities at SSHO?**

This activity will directly complement the long-standing hydropedology investigations at the SSHO conducted by Dr. Lin's research group. We will be building on the results of previous infiltration studies, but this will be the first used of dye-tracing and excavation for ground truth. Because the method disturbs the soil layer (on a very small scale) it makes sense to perform this work now, after extensive non-destructive characterization is complete.

**What will the proposer need from the SSHO team?**

The team will work predominately with Dr. Lin, but will coordinate all activities and report all results through the SSHO management structure.

**How does the proposer expect to publish their work?**

Expected publication results are: (1) a masters thesis, 1-2 conference presentations, and at least one journal publication. Dr. Lin and his students would be coauthors as appropriate.

**How will the proposer comply with the NSF mandate to archive all samples?**

We intend to archive all data and photographs online at the CZO website.

## Results of Prior Work on SSHO

Previous work at the SSHO as part of the hydrogeophysics team involved field and lab tracer tests to examine the role of fracture flow in solute transport. A masters student from Temple University (in progress) is following up on the work of Penn State MS student Brad Kuntz (2010). The current work involves using fracture flow models to better characterize the transport breakthrough. The fracture spacing in the calibrated model is similar to that in borehole logs, and the model is being tested for sensitivity to porosity variations. Results were presented at the all hands CZO meeting in Tuscon Arizon (2011) and at the national GSA meeting in Minneapolis (2011).

In the summer of 2012, Derek Lichtner, a Temple University undergraduate student working under the supervision Dr. Jonathan Nyquist (Temple geophysicist) and in collaboration with Dr. Henry Lin and his PSU graduate students conducted proof-of-principal experiments for three new approaches to monitoring water infiltration and migration in the shallow subsurface. The three methods tested involved monitoring changes in: (1) the radar surface reflection coefficient, (2) the velocity of the radar ground wave, and (3) the soil's electrical conductivity using Electrical Resistivity Tomography (ERT). All three methods showed promise. This work was reported at the 2012 annual meeting of the Geological Society of America (see abstract below). It was also presented to NSF program managers in DC at the invitation of Tom Torgersen, Division of Earth Sciences, as part of a presentation on student-led geophysical work at CZOs (see November 5$^{th}$ news entry on the Susquehanna Shale Hills CZO website (http://www.czo.psu.edu/about%20us/news.html).

## GSA Abstract

MONITORING TIME-LAPSE CHANGES IN SOIL MOISTURE DURING ARTIFICIAL INFILTRATION WITH GEOPHYSICAL METHODS

LICHTNER, Derek1, NYQUIST, Jonathan1, TORAN, Laura1, GUO, Li2, and LIN, Henry2, (1) Earth and Environmental Science, Temple University, Philadelphia, PA 19122, derek.lichtner@temple.edu, (2) Crop and Soil Sciences, Penn State University, 116 ASI Building, University Park, PA 16802Knowledge of the vadose zone and hydrological processes in near-surface soils is crucial for making agricultural decisions, understanding contaminant propagation, and describing infiltration and recharge. In July 2012, artificial infiltration experiments were conducted at the Shale Hills Critical Zone Observatory in central PA and monitored using time-lapse electrical resistivity tomography (ERT) and ground-penetrating radar (GPR). In addition to acquiring standard 2D radargrams, two GPR techniques known to respond directly to water content were tested: mapping changes in the direct transmitter to receiver ground wave velocity, and changes amplitude of the reflection off of the surface measured by elevating the antennae. These methods were assessed for their ability to observe changes in soil moisture content during infiltration at a small, 1 m by 3 m survey plot on a forested hillslope in Weikert series soil. Artificial infiltration events consisted of the addition of 26.5 or 53 L (7 or 14 gal) of water at constant head to a 1 m long, ~10 cm deep trench situated 20 cm upslope of the survey plot, promoting subsurface flow. Hilbert-transformed time lapse GPR images revealed significant increases in signal amplitude due to increased water content. In addition, small-scale heterogeneity of moisture distribution showed consistent patterns in pre-infiltration radargrams, surface reflection amplitude maps, and ERT profiles. The calculation of volumetric water contents from the GPR data was problematic owing to difficulty calibrating measurements. Qualitatively, the time-lapse images showed rapid infiltration, with moisture increases observed immediately after infiltration as far as 80 cm downslope. Within 15 minutes the geophysical signatures of infiltration decreased, with a majority of measurements within 20-40% of pre-infiltration values after 1 hour. Additionally, the infiltration of a second pulse of water suggested interflow pathways corresponding to already wetted flow paths and microtopography. Conductivity (ERT), ground wave velocity, and surface reflection amplitude all indicated changes in soil moisture that were useful in characterizing the soil's heterogeneity, infiltration rate, and flow path variability.