United States Department of Agriculture

NRCS

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SUBJECT: SOI – Geophysical Assistance June 15, 2010

TO: Craig R. Derickson File Code: 330-7
State Conservationist
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Purpose:
Geophysical assistance was provided to Pennsylvania State University. At the request of Dr Kamini Singha of the Geoscience Department, a presentation and field demonstration on the uses of ground-penetrating radar (GPR) and electromagnetic induction (EMI) was provided at the "*Penn State Hydrogeophysics Field Experience*" field camp. This field camp is sponsored by Pennsylvania State University and the National Science Foundation. In addition, at the request of the Dr. Henry Lin, geophysical field assistance was provided to the Department of Crop and Soil Sciences. Detailed GPR grid surveys were completed within the *Shale Hills Critical Zone Observatory* (*CZO*) in Huntington County. The main purpose of these surveys was to obtain high resolution radar records of the subsurface, which would be used to help characterize the movement of water through soils and across landscape components in this steeply-sloping, forested watershed that developed over highly folded and fractured shale parent rock.

Participants:
Doug Baldwin, Graduate Student, Department of Crop & Soil Sciences, PSU, University Park, PA
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Henry Lin, Associate Professor of Hydropedology/Soil Hydrology, Department of Crop & Soil Sciences, PSU, University Park, PA
Kamini Singha, Assistant Professor, Geosciences Department, PSU, University Park, PA
Jun Zhang, PhD Student, Department of Crop & Soil Sciences, PSU, University Park, PA

Activities:
Field activities were completed on 25 to 27 2010.

Summary:

1. Detailed, ground-penetrating radar (GPR) surveys were conducted over three grid sites located in areas of Rushtown and Weikert soils. The Appendix to this report lists the radar file numbers associated with different traverses in these three grid sites.

2. Copies of the radar records that were collected over the three grid sites have been turned-over to the study's principal investigator, Jun Zhang, for analysis. As part of his research project, Jun is responsible for the analysis of the collected two-dimensional (2D) radar records, construction and interpretation of three-dimensional (3D) pseudo-images, and modeling. Data collected during this investigation will add to Jun's research on the infiltration of water in soils underlain by shale parent rock.

3. An EMI survey of the Shale Hill Watershed was attempted by Doug Baldwin. Although leafs cover was not complete, it was substantial enough to preclude the use of GPS within the watershed. Because the measured apparent conductivity (EC_a) could not be georeferenced, an EMI survey of the watershed was not feasible at this time.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL
Director
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cc: See attached list

cc:
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Technical Report on Geophysical Investigations conducted at the Shale Hills *Critical Zone Observatory* (CZO) in Huntington County on 26 and 27 May 2010.

James A. Doolittle

This study uses cutting-edge geophysical technologies to better understand and characterize how soil "architecture" and distributions on landscapes exert controls over hydrologic processes across different spatio-temporal scales (Lin, 2010).

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. The 400 and 900 MHz antennas were used in this investigation. The 900 MHz antenna was recently repaired at GSSI and performed remarkably well during this field investigation.

The RADAN for Windows (version 6.6) software program (GSSI; Salem, NH) was used to process the radar records shown in this report.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

Calibration of GPR:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., bedrock, soil horizon, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (*v*) are described in Equation [1] (after Daniels, 2004):

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to Equation [2] (after Daniels, 2004):

$$E_r = (C/ v)^2 \qquad [2]$$

In Equation [2], C is the velocity of propagation in a vacuum (0.299 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v.

Based on the measured depth and the two-way pulse travel time to a known, shallowly-buried, subsurface reflector (metal plate buried at 50 cm), the velocity of propagation and the relative dielectric permittivity through the upper part of a Rushtown (loamy-skeletal over fragmental, mixed, active, mesic Typic Dystrudepts) soil profile were estimated using Equations [1] and [2]. At the time of these studies,

[1] Trade names are used for specific references and do not constitute endorsement.

soils were moist. In the selected area of Rushtown soil, the estimated E_r was 12.3 and 11.9 for the 900 and 400 MHz antennas, respectively. These permittivity values resulted in estimated *v* of 0.0866 and 0.0869 m/ns for the 900 and 400 MHz antennas, respectively.

Field Methods:

The Shale Hills Watershed is underlain by fractured rock. In this study, GPR was used to better understand and characterize soil structure and preferential flow paths over fractured bedrock, at scales of one to several meters. The three detailed grid sites are located on south facing slopes of the watershed. The Appendix to this report lists the radar file numbers associated with different traverses in these grid sites.

Two grid sites are located in areas of Rushtown soils. The very deep, excessively drained Rushtown soils formed in colluvium. Both Rushtown grid sites are located in the middle of concave swales that descend downwards to the major stream channel of the watershed. The dimensions of one Rushtown grid are 150 by 90 cm. This site is referred to as the "*infiltration grid*" site. Six sets of ten, 150-cm long traverses were completed across this grid area with both the 400 and 900 MHz antennas. The traverse lines were orientated essentially orthogonal to the slope. The interval between successive traverse lines was 10 cm. Different settings were used with each antenna. The number of samples was 256, the range was 40 ns, and the rate was 32 sans/sec for the 900 MHz antenna. For the 400 MHz antenna, the number of samples was 512, the range was 60 ns, and the rate was 32 sans/sec.

The second Rushtown grid site has overall dimensions of 12 by 15 ft. This site is referred to as the "*permanent grid*" site. Permanent plastic stakes have been inserted in the ground at the four grid corners. A rope grid-lattice has been fabricated and is attached to these stakes. In this process the grid area is completely overlain by the rope grid-lattice. The rope lines extend across the grid (parallel with X axis) and provide ground control. Each rope line is distance-graduated with distance marks affixed at intervals of 5 feet. The interval between successive traverse lines was 13 inches. A total of eleven, 15-ft long traverses were completed across this grid with both the 400 and 900 MHz antennas. Traverse lines were orientated essentially orthogonal to the slope.

The Weikert site is located along a plane, south-facing side slope. The shallow, well drained Weikert soils formed in materials weathered from interbedded acid shale, siltstone, and fine-grained sandstone. Weikert is a member of the loamy-skeletal, mixed, active, mesic Lithic Dystrudepts family. The dimensions of the Weikert grid are 200 by 100 cm. A total of eleven, 200-cm long traverses were completed across this grid with both the 400 and 900 MHz antennas. Along each traverse line, marks are affixed onto reference lines at an interval of 30 cm. Traverse lines were orientated essentially orthogonal to the slope. The interval between successive traverse lines is 10 cm.

Results:

<u>Subsurface flow:</u>

Many factors influence subsurface flow. Factors include soil, stratigraphic, and lithologic layering, complex macropore systems, and soil pipes caused by shrink-swell phenomena, animal borrows, and tree roots. In a research article that was submitted to *Hydrological Processes*, Zhang et al., (2010) noted that, within the Shale Hills Catchment, GPR data suggest that subsurface lateral flow dominates in areas of the shallow Weikert soils and subsurface vertical flow dominates areas of the very deep Rushtown soils. Using simulated radar images generated by four conceptual flow models and the GPR records, these researchers concluded that subsurface lateral macropore flow dominated areas of Weikert soils, while vertical macropore and lateral matrix flows dominated areas of Rushtown soils.

Ground-penetrating radar surveys were conducted with the 400 and 900 MHz antennas across the *infiltration grid* site to observe temporal differences in subsurface reflections associated with the flow of water through Rushtown soils. Figure 1 shows 2D radar records collected on *infiltration grid* site. These records were collected along first traverse line located immediately down slope of the infiltration hole. Traverses were completed with the 400 and 900 MHz antenna under dry field conditions (immediately before pouring water into the access hole), and under the wettest conditions (the last records obtained with each antenna near the conclusion of the study). In Figure 1, all measurements are expressed in meters.

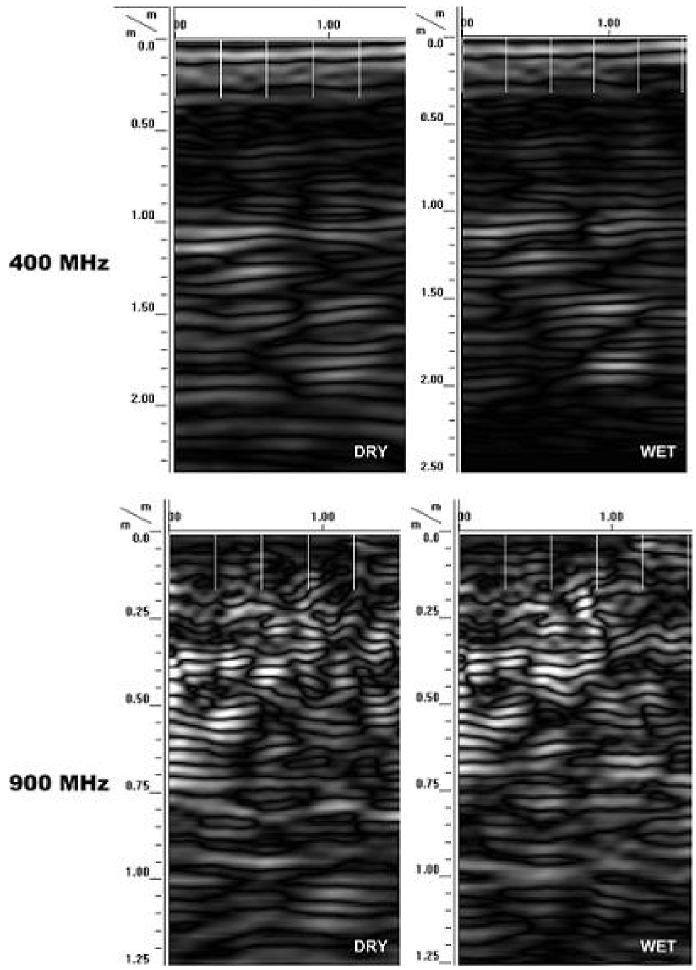

Figure 1. These 2D radar records are from the first traverse line down slope of the infiltration hole in the infiltration grid. Two examples are provided for the 400 and 900 MHz antenna: 1) a traverse conducted under dry field conditions, and 2) a traverse conducted under wet conditions. All measurements are expressed in meters.

It is immediately evident from the radar records show in Figure 1 that the depth of penetration is greater with the 400 MHz antenna (about 2.3 m compared with only about 1.25 m for the 900 MHz antenna), but resolution is greater with the 900 MHz antenna. Both antennas characterized the subsurface as being composed of multiple, closely-spaced, planar reflectors (Fig. 1). These reflectors, however, appear segmented. The higher resolution of the 900 MHz results in a greater number of gaps being detected. These gaps are believed to represent areas in which preferential flow is likely to occur. The large number of breaks in the planar reflectors supports the presence of inhomogeneities in the subsurface, and Zhang et al. (2010) findings that vertical macropore and lateral matrix flows dominate in areas of Rushtown soils.

Figure 2 contains 3D pseudo images of the *infiltration grid* site rendered from radar records collected with the 400 (upper images) and 900 (lower images) MHz antennas under relatively dry (left-hand images) and wet (right-hand images). These 3D pseudo-images provide no unambiguous evidence for increased water contents in these soils over time. The inability of 2D and 3D GPR to identify changes between different water injection stages and preferential flow pathways has been reported by Grasmueck and Viggiano (2006). What is noteworthy is that any increase in water contents in the shallow subsurface resulted in no apparent time-shifts (depth-shifts) in the upper part of the 2D GPR records and the 3D pseudo-images. However, noticeable changes in depths to interfaces and their amplitudes (becomes lower and more diffuse) can be observed on radar records and images especially those rendered with the 900 MHz antenna.

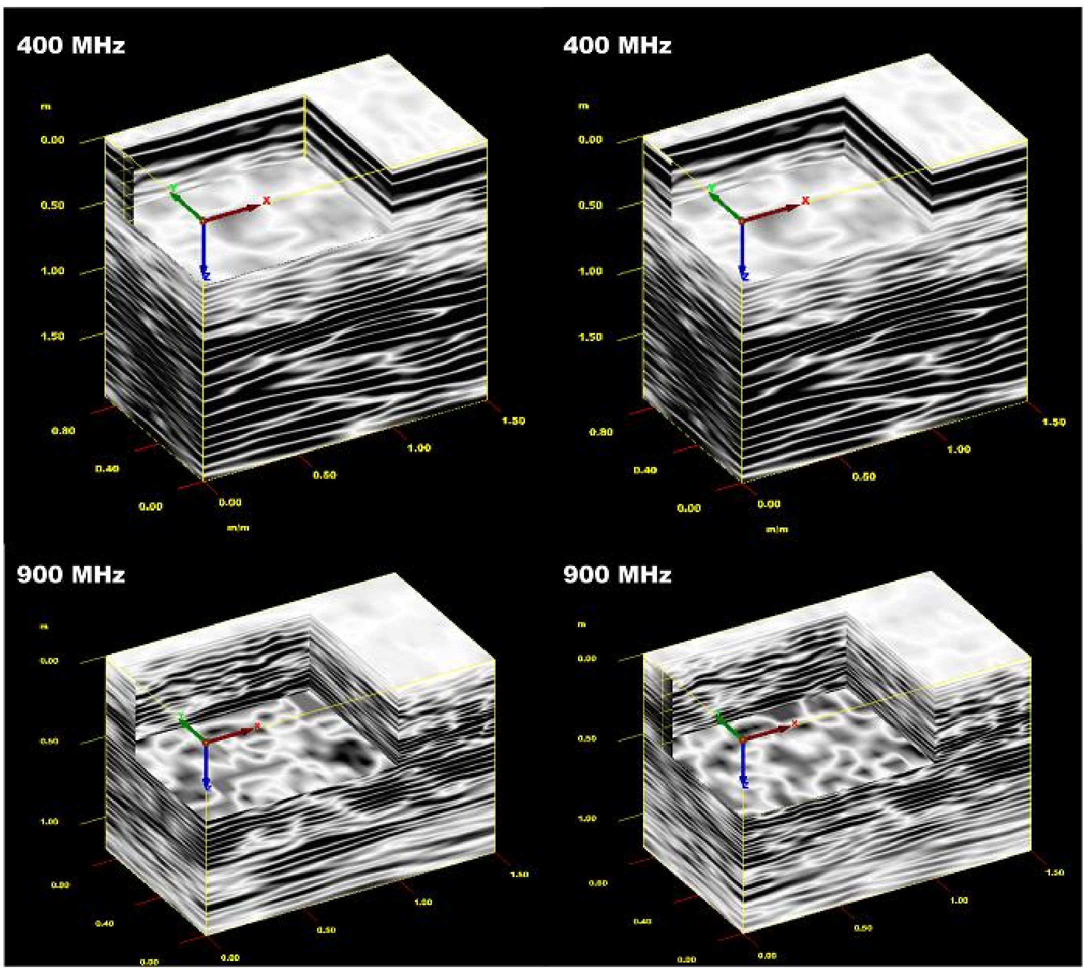

Figure 2. Three-dimensional pseudo images of the infiltration grid site rendered from radar records collected with the 400 (upper images) and 900 (lower images) under relatively dry (left-hand images) and wet (right-hand images) soil conditions.

Figure 3 is a time-sliced (depth sliced at 20 cm) pseudo-image from the 3D-cube rendered from data collected with the 900 MHz antenna at the Weikert Grid Site. At a depth of 20 cm, high-amplitude (colored white) segmented reflections are seemingly arranged into narrow, linear patterns which cross the grid site essential from top to bottom (the down slope direction). Though the source(s) of these reflections is unknown, their spatial patterns suggest a buried knotty tree-root system.

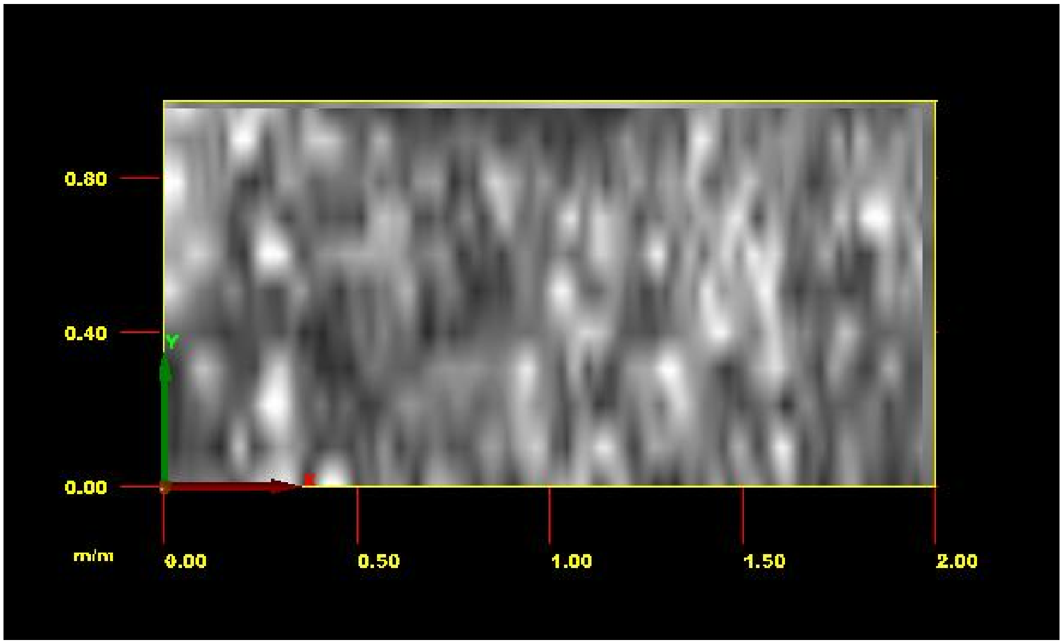

Figure 3. Narrow, linear patterns of high amplitude reflections in this time-sliced image from the Weikert Grid Site suggest possible tree roots. Data were collected with a 900 MHz antenna.

References:

Daniels, D.J., 2004. Ground Penetrating Radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.

Grasmueck, M. and D.A. Viggiano, 2006. 3d/4D GPR toolbox and data acquisition strategy for high-resolution imaging of field sites. *In:* Daniels, J. J., and C-C. Chen (Eds.) Proceedings of the 11th International Conference on Ground Penetrating Radar, Columbus, Ohio, June 19 – 22, 2006. 6p.

Jol, H., 2009. Ground Penetrating Radar: Theory and Applications. Elsevier Science, Amsterdam, The Netherlands.

Zhang, J., H. Lin, and J. Doolittle, 2010. Hillslope subsurface flow revealed by time-lapsed ground penetrating radar and real-time soil moisture monitoring. *Hydrological Processes* (paper submitted).

Appendix: GPR File Numbers associated with different radar traverses and study sites.

Detailed Grid Surveys - May 26 2010

File	Antenna	Description	Time (ns)
32	400 MHz	Plate at 1.68'	60
33	400 MHz	Plate at 1.68'	60
34-45	400 MHz	Permanent Grid	60
46	900 MHz	Plate at 1.68'	60
47	900 MHz	Plate at 1.68'	35
48	900 MHz	Plate at 1.68'	35
49-60	900 MHz	Permanent Grid	35
61	900 MHz	Plate at 50 cm	35
62	900 MHz	Plate at 50 cm	35
63	900 MHz	Plate at 50 cm	35
64	400 MHz	Plate at 50 cm	60
65	400 MHz	Plate at 50 cm	60
66-76	400 MHz	Weikert Grid	40
77-87	900 MHz	Weikert Grid	40
88-97	900 MHz	Rushtown Grid	40
98-107	400 MHz	Rushtown Grid	40

Infiltration Study – May 27, 2010

File	Antenna	Description
1 to 10	900 MHz	Dry Run
11	900 MHz	Cross hole in down slope direction
12 to 21	400 MHz	Dry Run
22-31	400 MHz	Wet 1
32-41	900 MHz	Wet 1
42-51	900 MHz	Wet 2
52-61	400 MHz	Wet 2
62-71	400 MHz	Wet 3
72-81	900 MHz	Wet 3
82-91	900 MHz	Wet 4
92-101	400 MHz	Wet 4
102-111	400 MHz	Wet 5
112-121	900 MHz	Wet 5