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SUBJECT: MGT – Trip Report - Geophysical Assistance — December 7, 2010

TO: Denise C. Coleman
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File Code: 330-20-7

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Purpose:
At the request of the Dr. Henry Lin, Associate Professor of Hydropedology, geophysical field assistance was provided by the National Soil Survey Center to the Department of Crop and Soil Sciences at Pennsylvania State University. Geophysical investigations were conducted within the Shale Hills *Critical Zone Observatory* (CZO) in Huntington County. Jim Doolittle also provided field demonstrations on ground-penetrating radar (GPR) and electromagnetic induction (EMI) to two classes: one taught by Dr. Henry Lin and the other by Dr. Patrick Drohan.

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

Activities:
Field activities were completed during the period of November 17 to 19, 2010.

Summary:

1. High-intensity EMI surveys were completed on four, small grid sites that typify two major soil-landscape components within the Shale Hills Catchment. These detailed EMI surveys revealed slightly lower EC_a on Weikert dominated linear side-slopes than on Rushtown and Berks dominated swales. These surveys also revealed slightly higher EC_a on western than on eastern flanks of the swales. These differences are attributed to lateral flow within the bedrock emerging on the western flanks of these north-south tending swales.

2. The synergy of GPR and global positioning systems (GPS) were further explored in the Shale Hills Catchment. Once again, problems were encountered with satellite reception due to satellite shading and multipath distortion caused by the steep terrain and vegetation. However, based on 50,481 interpreted, georeferenced depth to bedrock measurements made along seven GPR

traverse lines, the average depth to bedrock is about 105 cm, with a range of about 11 to 281 cm. Over one-half of these measurements were between the depths of 39 and 165 cm. Along the seven traverse lines, the depth to bedrock is shallow at 38%, moderately deep at 13%, deep at 23%, and very deep at 26% of the measurement points.

3. A copy of the worksheet file containing the electromagnetic induction and radar data, which were collected at the Shale Hills Catchment, were turned-over to the principal investigators, Jun Zhang and Doug Baldwin, for analysis.

4. Hands-on field demonstrations of both GPR and EMI were provided to classes taught by Dr. Henry Lin and Dr. Patrick Drohan. On the afternoon of November 17 demonstrations were provided at Pennsylvania State University's Klepler Farm to Dr. Lin's Hydropedology class. On the afternoon of November 18 demonstrations were provided outside the Agricultural Sciences and Industries Building on the campus of Pennsylvania State University to Dr. Patrick Drohan's Introductory Environmental Studies class.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL
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Technical Report on Geophysical Investigations conducted at the Shale Hills *Critical Zone Observatory* (CZO) in Huntington County, Pennsylvania, on November 17-19, 2010.

James A. Doolittle

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-3000 (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 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) and Jol (2008) discuss the use and operation of GPR. A 200 MHz antenna was were used in this investigation. A Trimble AgGPS 114 L-band DGPS (differential GPS) receiver (Trimble, Sunnyvale, CA) was used to georeferenced GPR data.[1]

An EM38-MK2 meter (Geonics Limited; Mississauga, Ontario) was also used in this study.[1] Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2007). The EM38-MK2 meter operates at a frequency of 14,500 Hz and weighs about 5.4 kg (11.9 lbs). The meter has one transmitter coil and two receiver coils, which are separated from the transmitter coil at distances of 1.0 and 0.5 m. This configuration provides nominal penetration depths of about 1.5 and 0.75 m in the vertical dipole orientation (VDO), and about 0.75 and 0.40 m in the horizontal dipole orientation (HDO). In either dipole orientation, the EM38-MK2 meter provides simultaneous measurements of both apparent conductivity (EC_a) and magnetic susceptibility over two depth intervals. Apparent conductivity is typically expressed in milliSiemens/meter (mS/m). Susceptibility is the ratio of the secondary to primary magnetic fields and is expressed in parts per thousand (ppt).

A Trimble AG114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to georeferenced EC_a data collected with the SIR-3000 and EM38-MK2 meter. [1] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both GPS and EC_a data[2]. The RTM38MK2 program (Geomar Software, Inc., Mississauga, Ontario) was used with the EM38-MK2 meter to display and record both GPS and EC_a data on the Allegro CX field computer. [1]

To help summarize the results of the EMI surveys, the SURFER for Windows (version 9.0) software (Golden Software, Inc., Golden, CO) was used to construct the simulations shown in this report. [1] Grids were created using kriging methods with an octant search.

Field Methods:
For the high-intensity EMI surveys of the four grid sites, the EM38-MK2-2 meter was operated in the deeper-sensing, vertical dipole orientation (VDO). While EC_a data were recorded for both the 50 and 100 cm intercoil spacings in the VDO, the 50-cm (0 to 75 cm depth interval) data displayed extremely low (often negative) and unstable values (suggesting the presence of background and equipment noise) and was not used. The EM38-MK2-2 meter was operated in the continuous (measurements recorded at a rate of 1/sec) mode.

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

While surveying, where possible, the EM38-MK2-2 meter was held about 5 cm (about 2 inch) above the ground surface. The meter was orientated with its long axes parallel to the direction of traverse. Multiple traverses were conducted in a back-and-forth manner across each grid site. Terrain obstructions, satellite shading and multipath reception reduced the accuracy and reliability of GPS. The EC_a data discussed in this report were not temperature corrected.

Radar traverses were conducted along the ridge line perimeter and upper side slopes of the catchment. These areas are mapped as Berks-Weikert shaly silt loams, 15 to 25 percent slopes (BiD) and Berks-Weikert association, steep (BmF). The well drained, shallow Weikert and moderately deep Berks soils form in materials weathered from acid shales on uplands. Berks and Weikert soils are members of the loamy-skeletal, mixed, active, mesic Typic and Lithic Dystrudepts taxonomic families, respectively. All of these soils are considered to have moderately potential for GPR (http://soils.usda.gov/survey/geography/maps/GPR/index.html).

Results:

EMI:

Four, high-intensity EMI surveys were conducted across two distinct soil-landscape components within the Shale Hills Catchment. These soil landscape components are: plain side slopes dominated by Weikert soils, and concave swales composed of the Berks-Rushtown catena. The purpose of these surveys was to capture short-range variability in EC_a caused by variations in soil and hydrologic properties. Four small grids were established across these two soil-landscape components, one for each soil-landscape component on both north- and south-facing slopes of the catchment. The grids were variable in size and ranged from about 0.24 to 0.32 ha for the Weikert dominated plain side slopes (Grids 1 and 3), and from 1.05 to 1.78 ha for the Berks-Rushtown catena in swales (Grids 2 and 4). Each grid was surveyed uniformly with the EM38-MK2 meter along closely-spaced traverse lines.

Table 1. Comparison of EC_a measurement collected on grid sites located on different soil-landscape components.

	Grid 1	Grid 2	Grid 3	Grid 4
Observations	214	857	335	489
Minimum	0	0	0	0
25%-tile	2.3	4.2	3.3	3.7
75%-tile	4.1	5.9	4.2	5.1
Maximum	9.5	8.8	6.2	12.7
Mean	3.1	5.1	3.7	4.4
Std. Dev.	1.6	1.4	0.8	1.3

Though recently wetted by a rainfall event, soils were relatively dry at the time of the EMI surveys. Table 1 lists the basic statistic for EC_a data that were collected within the grid sites. As expected, the seasonally low soil moisture contents resulted in low and relatively invariable EC_a. The two grids located on Weikert dominated plane side slopes (Grids 1 and 3) had slight lower average EC_a than the two grids located on the Berks-Rushtown catena in swales (Grids 2 and 4). The data collected at Grid 1 contain a cluster of anomalous EC_a measurements caused by the EM38 meter passing too close to installed instruments. If these values are excluded, the grids located on plain side slopes would have a lower range in EC_a than recorded on the two grids located in the concave swales. The lower EC_a on Weikert dominated plain side slopes was attributed to shallower depth to bedrock, lower clay and/or moisture contents.

Figure 1 contains four 3D simulations showing the distribution of EC_a across the four grid sites. The two left-hand (Grids 1 and 3) and right-hand (Grids 2 and 4) simulations show the spatial distribution of EC_a on Weikert dominated plain side slopes, and Berks-Rushtown dominated swales, respectively. In these simulations, plots of EC_a data are superimposed on three-dimensional simulation of elevation data obtained from Lidar imagery. The same color scale has been used in all simulations for comparative purposes.

In Figure 1, the anomaly in the northeast corner of Grid 1 was caused by the meter passing too close to a cluster of installed instruments. For the Berks-Rushtown dominated swale, areas of very deep, rapidly to very rapidly permeable *Rushtown soils in the two swale bottom have slightly lower EC_a than adjoining, higher-lying areas of moderately deep, moderate to moderately rapid permeable Berks soils. However, areas of higher EC_a are evident on some higher-lying areas of Berks soils. The higher EC_a is attributed to* lateral flow through and immediately above the highly fractured and folded shale bedrock column from higher-lying slope positions emerging into the Berks soils. This lateral flow could contribute to higher soil water content in the Berks soils. For both of these grid sites, EC_a is slightly, but still noticeably higher on the slopes that form the western flanks to the swales. This can be attributed to the preferential flow of water within the bedrock structures.

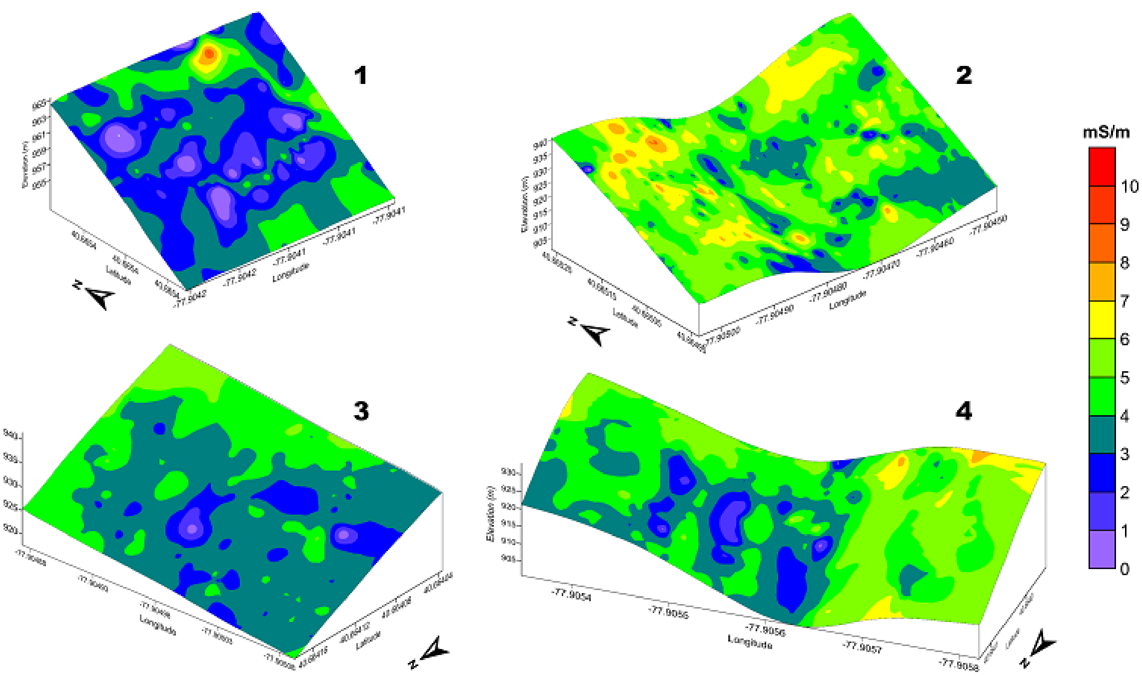

Figure 1. These 3D simulations show the distribution of EC_a across two soil-landscape components with the Shale Hill Catchment. Grids 1 and 3 are located on plain side slopes dominated by Weikert soils. Grids 2 and 4 are located in swales dominated by the Berks-Rushtown catena. Grids 1 and 2 and Grids 3 and 4 are located on south- and north-facing slopes, respectively.

GPR:

The SIR-3000 system provides a setup for the simultaneous use of a GPS receiver with a serial data recorder (SDR). This setup georeferences GPR data for display and analysis in imaging software such as Google Earth and geographic information systems (GIS). With this setup, each scan on a radar record is essentially georeferenced (position/time matched). GPR readings (scans) are not continuous, but are taken at set time intervals. In this study, the scanning rate was 40 scans/sec. Position data were recorded at a rate of one measurement/sec with the Trimble AG114 L-band DGPS antenna. In the RADAN for Windows (version 6.6) software program (GSSI), the position of each radar scan is proportionally adjusted according to the time stamp of the two nearest positions recorded with the GPS receiver. As each scan of the radar is georeferenced, the integration of GPS with GPR results in incredibly large data sets.

Using the *Interactive 3D Module* of RADAN, depths to a subsurface reflector, which was interpreted to be soil-bedrock contact, were quickly picked and recorded in a layer file. This layer file was exported into an Excel worksheet for analysis. Based on 50,481 interpreted measurements made along seven traverse lines, the average depth to bedrock is about 105 cm, with a range of about 11 to 281 cm. Over one-half of these measurements were between depths of 39 and 165 cm. Along the seven traverse lines, the depth to bedrock is shallow at 38 %, moderately deep at 13 %, deep at 23 %, and very deep at 26 % of the measurement points.

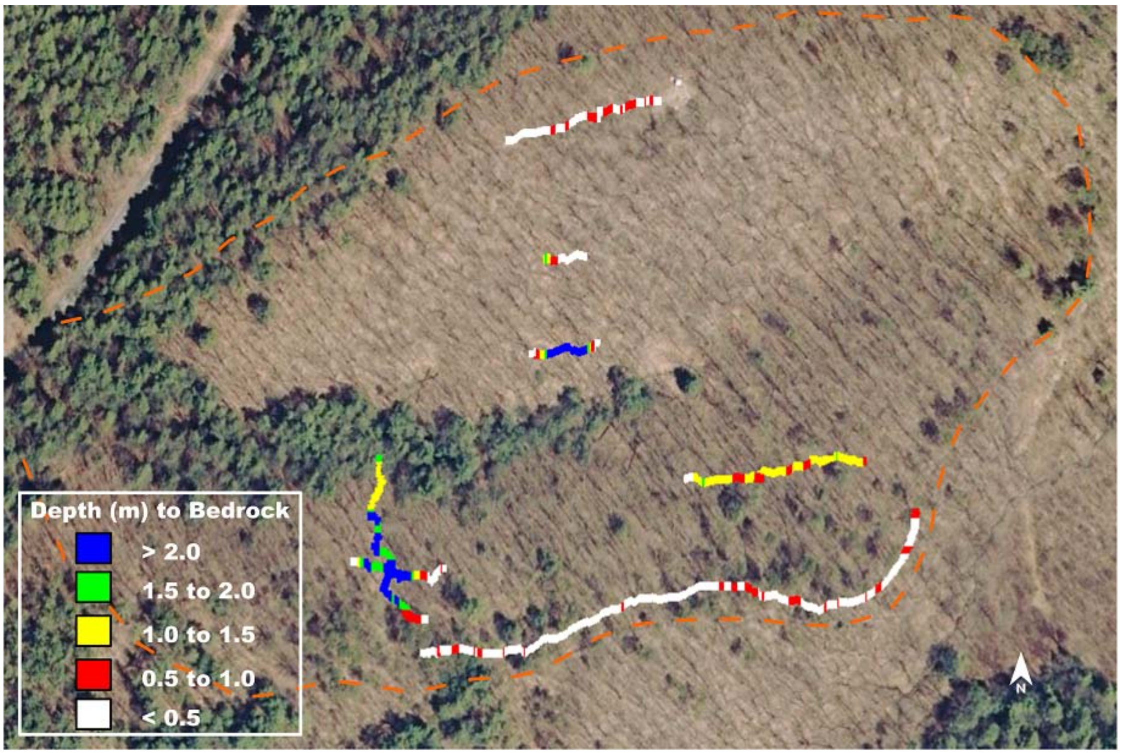

Figure 2. In this Google Earth image of the Shale Hills Catchment, the locations of georeferenced GPR traverse lines are shown. Colors indicate the interpreted depths to bedrock along each traverse line.

Figure 2 contains a Google Earth image of the Shale Hills Catchment. The approximate boundary of this catchment has been indicated with a segmented orange-colored line. The locations of seven radar traverse lines are shown. The seven radar traverses were conducted along summit areas and north- and south-facing upper side slopes where satellite reception was favorable. Colors are used to represent the depth to bedrock interpreted from the radar records. Four of the seven traverse lines are located within swales. Soils are principally very deep (colored green and blue) along most of traverse lines that cross swales. On plain upper side slopes and convex summit areas, soils are typically shallow (colored white) to moderately deep (colored red). The synergism of GPS and GPR allows the expedient mapping of bedrock depths at intermediate scales.

References:

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

Geonics Limited, 2007. EM38-MK2 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario.

Jol, H., 2008. Ground Penetrating Radar: Theory and Applications. Elsevier Science, Amsterdam, The Netherlands.