United States Department of Agriculture	Natural Resources Conservation Service	11 Campus Boulevard, Suite 200 Newtown Square, PA 19073

Subject: SOI – Geophysical Field Assistance **Date:** 12 November 2003

To: Dr. Henry Lin
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Purpose:
Electromagnetic induction (EMI) methods are being used by the Pennsylvania State University's Hydropedology Team to map spatial variations in apparent conductivity within a small watershed. It is expected that these spatial patterns can be related to differences in soils and soil properties.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Henry Lin, Assistant Professor, Crop & Soil Sciences Department, Penn State University, University Park, PA
Brad Georgic, Senior Research Technologist, Crop & Soil Sciences Department, Penn State University, University Park, PA
Chip Kogelmann, PhD student, Crop & Soil Sciences Department, Penn State University, University Park, PA

Activities:
All field activities were completed on 16 October 2003.

Summary:

1. Apparent conductivity data were collected with three EMI instruments: the GEM300 sensor, EM31 meter, and EM38DD meter. With each instrument, data were collected in the station-to-station mode. Instruments were operated in both the horizontal and vertical dipole orientations. The GEM300 sensor malfunctioned during the survey. As a consequence data collected with this device were flawed and not discussed in this report. The GEM300 sensor will be returned to manufacturer for recalibration and repairs.

2. For the EM38DD and EM31 meters, spatial patterns varied with each meter and with each dipole orientation. The highest values of apparent conductivity occurred along the drainageway and in the southern portion of the watershed. Lower values of apparent conductivity dominated the higher-lying sideslopes and shoulder positions especially in the northern and eastern portions of the watershed. Some spatial patterns appear random and are assumed to reflect instrument errors and the sparse sampling.

3. Throughout most of the watershed, apparent conductivity was low and invariable reflecting the dominance of the Berks and Weikert soils and the influence of the underlying Rosehill shale. Higher values of apparent conductivity were measured along the lower course of the stream channel, especially where it departs the western

side of the watershed. Higher apparent conductivity values are attributed to deeper soil depths and/or higher moisture contents of the soils that are located in swales and along the stream channel.

4. The plots of apparent conductivity that are included in this report are unacceptable. More comprehensive EMI coverage of the site is required to elicit meaningful spatial patterns of apparent conductivity. In future surveys of the watershed, EMI data will be collected in the continuous mode rather than in the station-to-station mode. All data will be geo-referenced with a global positioning system (GPS). It is hoped that the relief and vegetative cover within the watershed will not impair the reception of GPS signals, and that steep slopes will not introduce errors into the EMI data set.

5. A second EMI survey of the watershed is planned for early January 2004.

6. A copy of the data has been forwarded to Brad Georgic under a separate cover letter.

It was my pleasure to participate in this study and to work in Pennsylvania and with the faculty and staff of Pennsylvania State University.

With kind regards,

James A. Doolittle
Research Soil Scientist
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cc:
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Equipment:
Geonics Limited manufacturers the EM38DD and EM31 meters.[1] These meters are portable and require only one person to operate. No ground contact is required with either meter. With each meter, the depth of penetration is “geometry limited” and is dependent upon the intercoil spacing, coil orientation, and frequency. Lateral resolution is approximately equal to the intercoil spacing. Geonics Limited (2000) describes the use and operation of the EM38DD meter. The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One unit acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one unit acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on). Each meter has a 1 m intercoil spacing and operates at a frequency of 14,600 Hz. The EM38DD meter has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 2000). McNeill (1980) has described principles of operation for the EM31 meter. The EM31 meter has a 3.66 m intercoil spacing and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM31 meter has effective

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

penetration depths of about 3.0 and 6.0 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1980).

The GEM300 multifrequency sensor is manufactured by Geophysical Survey Systems, Inc.[1] Won and others (1996) have described the use and operation of this sensor. This sensor is portable and requires only one person to operate. No ground contact is required with the GEM300 sensor. The GEM300 sensor is keypad operated and measurements can be either automatically or manually triggered. This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 19,950 Hz with a fixed coil separation (1.3 m). With the GEM300 sensor, the depth of penetration is considered "skin depth limited" rather than "geometry limited." The skin-depth represents the maximum depth of penetration and is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signal. The theoretical penetration depth of the GEM300 sensor is dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequency. Multifrequency sounding with the GEM300 allows multiple depths to be profiled with one pass of the sensor.

To help summarize the results of this study, SURFER for Windows (version 8.0) software developed by Golden Software, Inc.,[1] was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search.

Shale Hills Watershed:
The Pennsylvania State University's Hydropedology Team is studying spatial and temporal variations in soil properties that influence soil water and flow processes at different scales within the Shale Hills Watershed. The watershed is located near the Stone Valley Recreation Center in Huntingdon County (~15 miles from State College). This forested watershed is relatively small (19.2 acres) and well defined. Figure 1 shows the relative topography for most of the watershed. This map was prepared from GPS measurements collected at 72 observation points. Based on these measurements, elevations range from 232.5 to 275.8 m within the watershed. In Figure 1, a dotted line has been used to indicate the location of a small stream that drains the watershed.

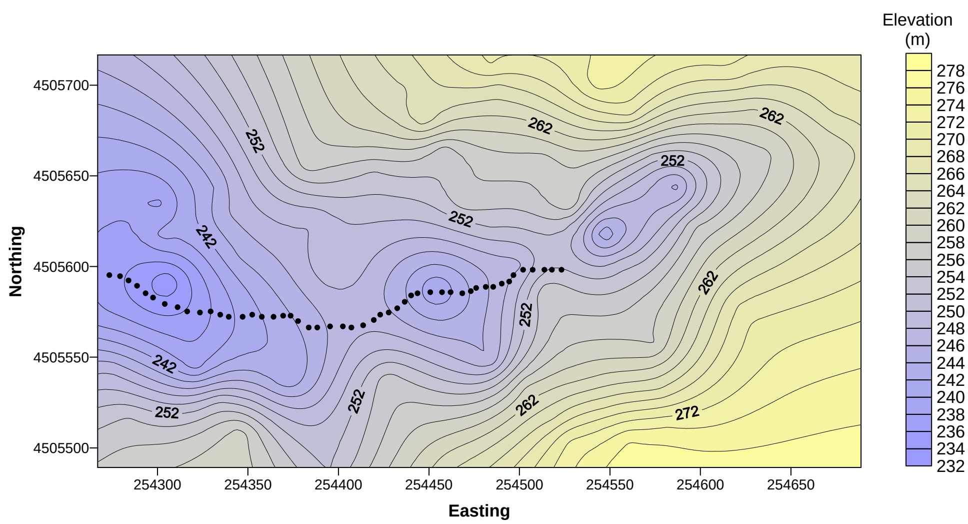

Figure 1. Relative topography of the Shale Hills Watershed (Based on GPS measurements).

The watershed has been mapped principally as Berks-Weikert association, steep, and Ernest silt loam, 3 to 8 percent slopes (Merkel, 1978). The watershed also includes small areas of Berks-Weikert shaly silt loam, 15 to 25 percent slopes, and Berks shaly silt loam, 8 to 15 percent slopes (Merkel, 1978). The Pennsylvania State University's Hydropedology Team has prepared an order one soil map of the watershed. Modifications to the USDA soil map include consociations of Berks, Blairton, Ernest, and Rushtown soils in swales and along the stream channel. Weikert soil dominates the remainder of the watershed. These soils contain large amounts of rock fragments and have varying depths to thinly bedded and highly fractured bedrock. Within the watershed, the underlying bedrock is Rosehill shale.

All soils formed in materials weathered from shale. The well drained, shallow Weikert and moderately deep Berks soils are on gently sloping to very steep upland areas. Weikert is a member of the loamy-skeletal, mixed, active, mesic Lithic Dystrudepts family. Depths to bedrock ranges from 25 to 50 cm (10 to 20 inches). The Berks soil is a member of the loamy-skeletal, mixed, active, mesic Typic Dystrudepts family. The moderately deep, somewhat poorly drained and moderately well drained Blairton soil is on upland flats and drainage heads. Blairton is a member of the fine-loamy, mixed, active, mesic Aquic Hapludults family. For Berks and Blairton soils, depths to bedrock range from 50 to 100 cm (20 to 40 inches).

The very deep, moderately well drained Ernest soil is on foot slopes and colluvial fans. Ernest is a member of the fine-loamy, mixed, superactive, mesic Aquic Fragiudults family. A fragipan is within depths of about 50 to 90 cm (20 to 36 inches). The very deep, excessively drained Rushtown soil is on swales. Rushtown is a member of the loamy-skeletal over fragmental, mixed, active, mesic Typic Dystrudepts family. For Ernest and Rushtown soils, depths to bedrock are greater than 152 cm (60 inches).

Results:

The EM31 meter has a 3.7 m intercoil spacing. This spacing makes the meter awkward to maneuver and difficult carry in this forested, steeply sloping watershed. The EM38DD meter, with a 1 m intercoil spacing, was more maneuverable, but if operated in the continuous mode must be held at a constant height and moved across ground litter. This may prove a challenge in future surveys. The GEM300 sensor has a 1.3 m intercoil spacing and is held at hip height. These features make this EMI instrument ideally suited to surveying this watershed.

Values of apparent conductivity were comparably low and invariable across most of the watershed, confirming the influence of electrically resistive, acid Rosehill shale and the pervasiveness of Weikert and Berks soils. Apparent conductivity was higher in lower-lying, wetter areas adjoining drains and in some swales.

Table 1 summarizes the results of the October EMI survey of the watershed. At the time of the survey, the soil temperature at a depth of about 18 inches was 50^{o} F. All values have been corrected to a temperature of 25^{o} C. Apparent conductivity ranged from about -1 to 33 mS/m. Negative values are attributed to calibration errors and/or surface or near-surface metallic artifacts. With the EM38DD meter, apparent conductivity generally decreased and became slightly more variable with increasing depth. In the shallower-sensing, horizontal dipole orientation (0 to 0.75 m), apparent conductivity averaged 7.6 mS/m with a standard deviation of about 3.1 mS/m. One-half the observations had values of apparent conductivity between 6.21 and 9.00 mS/m. In the deeper-sensing, vertical dipole orientation, apparent conductivity averaged about 5.8 mS/m with a standard deviation of about 4.1 mS/m. One-half the observations had values of apparent conductivity between 4.0 and 6.47 mS/m. The higher conductivity at shallow depths was attributed to the soil cover, which had greater moisture and clay contents than the underlying bedrock.

Table 1. Basic EMI Statistics for EMI Survey of Shale Hills Watershed
October 16, 2003

	EM31-VDO	EM31-HDO	EM38DD-VDO	EM38DD-HDO
Number	80	80	80	80
Minimum	6.49	4.66	-0.79	2.17
Maximum	20.32	17.28	33.21	26.53
25 % Percentile	7.48	5.64	4.00	6.21
75 % Percentile	9.38	7.06	6.47	9.00
Mean	8.81	6.66	5.79	7.60
SD	2.19	1.76	4.11	3.14

With the EM31 meter, apparent conductivity increased and became slightly more variable with increasing depth. The survey was completed with the EM31 meter held at hip-height. When held at hip-height and operated in the horizontal dipole orientation, this meter is more responsive to the column of air that exists between the meter and the ground surface than it is when operated in the vertical dipole orientation. This could explain the slight increase in apparent conductivity measured in the deeper-sensing vertical dipole orientation. Increased moisture at greater depths would also contribute to the increased conductivity measured with the EM31 meter in the vertical dipole orientation. In the horizontal dipole orientation, apparent conductivity averaged about 6.7 mS/m with a standard deviation of about 1.8 mS/m. One-half the observations had values of apparent conductivity between 5.64 and 7.06 mS/m. In the vertical dipole orientation, apparent conductivity averaged about 8.8 mS/m with a standard deviation of about 2.2 mS/m. One-half the observations had values of apparent conductivity between 7.48 and 9.38 mS/m.

Figure 2 contains contour plots of apparent conductivity measured with the EM31 meter that have been overlain on three-dimensional surface plots of the watershed. The contour plots are based on 80 EMI measurements and show the spatial distribution of apparent conductivity as measured with the EM31meter. The upper plot contains data measured in the shallower-sensing horizontal dipole orientation. The lower plot contains data measured in the deeper-sensing, vertical dipole orientation. Color variations have been used to show the distribution of apparent conductivity. In each plot, the color interval is 3 mS/m. Throughout most of the watershed, apparent conductivity is low and invariable reflecting the dominance of the Berks and Weikert soils and the control of the underlying Rosehill shale. In each plot, higher values of apparent conductivity can be observed along the lower course of the stream channel, especially where it departs the western side of the watershed.

Figure 3 contains contour plots of apparent conductivity measured with the EM38DD meter that have been overlain on three-dimensional surface plots of the watershed. The contour plots are based on 80 EMI measurements and show the spatial distribution of apparent conductivity as measured with the EM38DD meter. The upper plot contains data measured in the shallower-sensing horizontal dipole orientation. The lower plot contains data measured in the deeper-sensing, vertical dipole orientation. Color variations have been used to show the distribution of apparent conductivity. In each plot, the color interval is 3 mS/m. Once again, throughout most of the watershed, apparent conductivity is low and invariable reflecting the dominance of the Berks and Weikert soils and the control of the underlying Rosehill shale. In each plot, higher values of apparent conductivity can be observed along the lower course of the stream channel, especially where it departs the western side of the watershed.

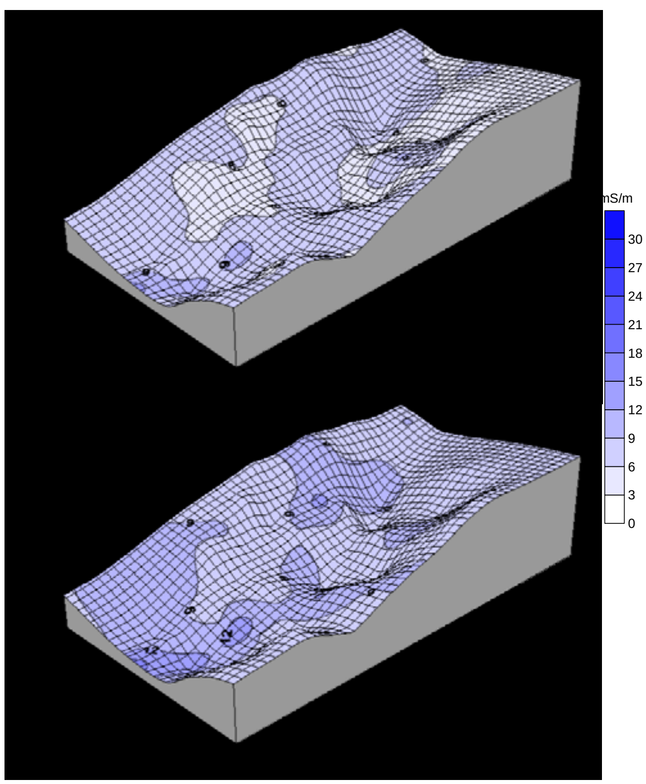

Figure 2. Plots of apparent conductivity data collected with the EM31 meter overlain on three-dimensional surface maps of the Shale Hills Watershed.

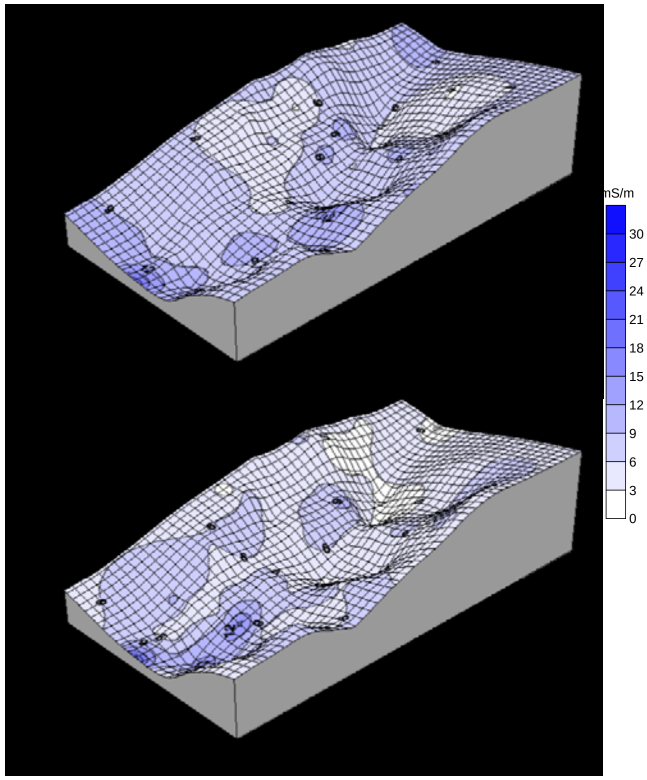

Figure 3. Plots of apparent conductivity data collected with the EM38DD meter overlain on three-dimensional surface maps of in the Shale Hills Watershed.

Apparent conductivity was comparatively low and invariable within the watershed. Spatial patterns vary with each meter and with each dipole orientation. However, higher values of apparent conductivity are more common along the drainageway and in the southern portion of the watershed. Lower values of apparent conductivity dominate the higher-lying sideslopes and shoulder positions especially in the northern and eastern portions of the watershed. Some spatial patterns appear random and reflect instrument errors and sparse sampling. If is anticipated that more continuous EMI sampling will increase the size of the data set, and provide more comprehensive coverage and reasonable spatial patterns that conform to the order-one soil patterns.

References:

Geonics Limited. 2000. EM38DD ground conductivity meter: Dual dipole version operating manual. Geonics Ltd., Mississauga, Ontario.

Merkel, E. 1978. Soil Survey of Huntingdon County, Pennsylvania. USDA-Soil Conservation Service in cooperation with Pennsylvania State University College of Agriculture and the Pennsylvania Department of Environmental Resources and State Conservation Commission. Government Printing Office, Washington DC.

McNeill, J. D. 1980. Electromagnetic terrain conductivity measurement at low induction numbers. Technical Note TN-6. Geonics Limited, Mississauga, Ontario.

Won, I. J., Dean A. Keiswetter, George R. A. Fields, and Lynn C. Sutton. 1996. GEM-2: A new multifrequency electromagnetic sensor. Journal of Environmental & Engineering Geophysics 1:129-137.