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

**Subject:** SOI – Geophysical Field Assistance **Date:** 23 March 2006

**To:** Dr. Henry Lin
Assistant Professor of Hydropedology/Soil Hydrology
Crop & Soil Sciences Department
415 Agricultural Sciences and Industries Building
Pennsylvania State University
University Park, PA 16802

Edward White
State Soil Scientist
USDA-NRCS
One Credit Union Place, Suite 340
Harrisburg, PA 17110-2993

**Purpose:**
Multiple electromagnetic induction (EMI) surveys have been completed of the Shale Hills Watershed in northern Huntingdon County, Pennsylvania. The purpose of these investigations is to assess spatial and temporal variations in apparent conductivity ($EC_a$) within a small, steeply-sloping, forested watershed in central Pennsylvania. This is a report on the latest investigation.

**Activities:**
All field activities were completed on 13 March 2006.

**Participants:**
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Wes Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, Wilkesboro, NC

**Summary:**
1. The Shale Hills Watershed is composed of electrically resistive materials. Soils contain large amounts of shale fragments and have electromagnetic properties that are closely similar to the underlying shale parent rock. These electrically resistive materials result in exceedingly low and invariable $EC_a$ across the watershed. Because of similar electromagnetic properties, the use of EMI to differentiate soil from parent rock or to determine the depth to bedrock is not considered practical in this and similar watersheds. Ground-penetrating radar (GPR) is more suitable for these uses in these soils and terrains.

2. Spatial $EC_a$ patterns within the watershed are attributed principally to variations in soil moisture. The highest $EC_a$ occurs along the stream channel. The lowest $EC_a$ occurs on upper back slopes and shoulder areas. Results from the EMI surveys indicate that while spatial patterns are indistinct, with increased soil moisture contents, swales have slightly higher $EC_a$ and are distinguishable from adjoining plane and convex back slopes. The higher $EC_a$ within swales is attributed to greater depths to bedrock and higher clay and moisture contents.

3. This watershed offers several challenges to EMI surveys, not the least of which is its steep, complex slopes and forested terrain. Because of the varied and complex topography of this watershed, in order to capture smaller scale variability in some soil properties, the intensity of EMI surveys needs to be greater than on the more level and simple slopes of agricultural lands located in valleys within the Northern Appalachian Ridge and Valley MLRA.

It was our pleasure to participate in this study.

With kind regards,

| | |
|---|---|
| James A. Doolittle | Wes Tuttle |
| Research Soil Scientist | Soil Scientist (Geophysical) |
| National Soil Survey Center | National Soil Survey Center |

cc:
B. Ahrens, Director, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
S. Carpenter, MLRA Office Leader, USDA-NRCS, 75 High Street, Room 301, Morgantown, WV 26505
M. Golden, Director, Soil Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
D. Hammer, National Leader, Soil Survey Investigations, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
W. Tuttle, Soil Scientist (Geophysical), National Soil Survey Center, USDA-NRCS, P.O. Box 60, 207 West Main Street, Rm. G-08, Federal Building, Wilkesboro, NC 28697

**Materials and Methods:**
An EM38 meter, manufactured by Geonics Limited (Mississauga, Ontario) was used in this study.[1] This meter weighs about 1.4 kg (3.1 lbs) and needs only one person to operate. No ground contact is required with this instrument. The EM38 meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, it has a theoretical penetration depth of about 1.5 m in the vertical dipole orientation (Geonics Limited, 1998). The size and light weight of this instrument makes it suited for use in steeply-sloping, forested terrains.

The DAS70 Data Acquisition System (Geonics Limited, Mississauga, Ontario) was used with the EM38 meter to record and store both $EC_a$ and position data.[1] The acquisition system consists of the EM38 meter, an Allegro CE field computer (Juniper Systems, North Logan, UT), and a Garmin Global Positioning System (GPS) Map 76 receiver (with CSI Radio Beacon receiver, antenna and accessories that are fitted into a backpack) (Garmin International, Inc., Olathe, KS) .[1] When attached to the acquisition system, the EM38 meter is keypad operated and measurements can be automatically triggered.

To help summarize the results of this survey, SURFER for Windows, version 8.0, (Golden Software, Inc., Golden, CO), was used to construct the simulations shown in this report.[1] Grids of $EC_a$ data were created using kriging methods with an octant search.

**Study Site:**
The Shale Hills Watershed is located near the Stone Valley Recreation Center in Huntingdon County (~15 miles south-southwest of State College). This forested watershed is relatively small (7.8 ha) and well defined. The study site is located in the Northern Appalachian Ridges and Valleys Major Land Resource Area (MLRA 147). This MLRA is typified by parallel sandstone and shale ridges that are separated by limestone and shale valleys. The Shale Hills Watershed is incised into a shale ridge composed of the Rose Hill formation, Clinton Group of middle Silurian age. The Rose Hill formation consists of a sequence of thinly bedded, highly fractured, folded and faulted, olive and purplish shale with thin beds of hematite sandstone and fossiliferous limestone.

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 completed an order-one soil survey of the watershed. On the high intensity soil map, the shallow to bedrock, well drained Weikert soil dominates the higher-lying and more sloping, plane and convex back slopes of the watershed. The very deep, moderately well drained Earnest and somewhat poorly drained Blairton soils are restricted to lower-lying foot slopes near the stream channel. The moderately deep, well drained Berks and the very deep, excessively drained Rushtown soils are in swales that extend upslope from the stream channel. The swales are micro-features in this landscape, but are too small to be delineated on an order-two soil survey. No defined drainageways can be observed in the swales. All soils contain large amounts of rock fragments and have varying depths to thinly bedded and highly fractured bedrock.

**Table 1**
**Taxonomic Classification of Soil**

| Series | Classification |
|---|---|
| Berks | Loamy-skeletal, mixed, active, mesic Typic Dystrudepts |
| Blairton | Fine-loamy, mixed, active, mesic Aquic Hapludults |
| Ernst | Fine-loamy, mixed, superactive, mesic Aquic Fragiudults |
| Rushtown | Loamy-skeletal over fragmental, mixed, active, mesic Typic Dystrudepts |
| Weikert | Loamy-skeletal, mixed, active, mesic Lithic Dystrudepts |

**Survey Procedures:**
The EM38 meter was operated in the vertical dipole orientation and continuous mode with measurements recorded at 1-sec intervals. The meter was generally orientated with its long axis parallel to the direction of traverse. Where possible, the meter was held about 5 cm (2 inches) above the ground surface. However, steep slopes, tree limbs and fallen forest

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

debris made walking difficult and caused the meter to vary in height. Where possible, traverses were conducted parallel with the slope contours. Multiple traverses were conducted across and along the center-line of each swale. Terrain obstructions, satellite shading and multipath reception reduced the accuracy and reliability of GPS positioning on lower slopes especially beneath the evergreen canopy along the lower reach of the stream.

**Results:**
Basic statistics for October 2005 and the March 2006 surveys are listed in Table 2. Both surveys were completed with the EM38 meter in the vertical dipole orientation. All data have been temperature corrected to a standard temperature of 75$^{o}$ F, and data points with negative values have been omitted (negative values are attributed to passing close to or over metallic objects, survey and calibration errors).

Compared with the October 2005 survey, $EC_a$ data collected in March 2006 were noticeably higher and more variable. These differences reflect the moister soil conditions in March 2006 than in October 2005. At the time of the October 2005 survey, soils were noticeably droughty and stream flow was restricted to only the lowest portion of the channel within the watershed. In addition, $EC_a$ was slightly more variable in March than in October (standard deviations of 2.25 and 1.38 mS/m, respectively). For the October 2005 survey, $EC_a$ averaged only 2.2 mS/m and ranged from 0.0 to 23.8 mS/m. One half the observations had values of $EC_a$ between 1.2 and 3.0 mS/m. For the March 2006 survey, $EC_a$ averaged 5.2 mS/m and ranged from 0.2 to 17.4 mS/m. One half the observations had values of $EC_a$ between 3.6 and 6.2 mS/m.

**Table 2**
**Comparison of Basic Statistics for the Two EMI Surveys of the Shale Hills Watershed.**

| | March-2006 | October-2005 |
|---|---|---|
| **Number Observations** | 5760 | 5931 |
| **Minimum** | 0.19 | 0.00 |
| **Maximum** | 17.38 | 23.75 |
| **25% Quartile** | 3.62 | 1.25 |
| **75% Quartile** | 6.15 | 3.00 |
| **Mean** | 5.16 | 2.22 |
| **Standard Deviation** | 2.25 | 1.38 |

Figure 1 contains two-dimensional plots of the $EC_a$ data that were collected during the October 2005 (lower plot) and March 2006 (upper plot) surveys. Each plot shows the spatial distribution of $EC_a$ measured with an EM38 meter in the vertical dipole orientation. The same color scale and isoline interval (1 mS/m) have been used in each plot. In each plot, dotted blue lines represent the locations of the stream channel and the center lines of swales that extend upslope from this channel.

Spatiotemporal differences in $EC_a$ are evident in the plots shown in Figure 1. The Shale Hills Watershed is characterized by exceedingly low and relatively invariable $EC_a$. The electrical conductivity of soils is essentially an electrolytic process that takes place through soil pores (McNeill, 1980). Because of the low $EC_a$ evident in these plots, it is inferred that the concentration and mobility of dissolved ions in the soil solution are exceedingly low. Apparent conductivity is also related to the number of ions absorbed on clays and the type and amount of clays in the soils (McNeill, 1980). The low $EC_a$ suggests relatively shallow depths to electrically resistive parent rock and low clay contents and cation-exchange capacity of the soils within the watershed. These soils contain large amounts of shale fragments, which further reduces soil $EC_a$ and weaken the electromagnetic gradient between soil and parent rock.

In both plots, lower $EC_a$ are recorded on higher-lying plane and convex back slopes. These landscape components are dominated by the shallow Weikert soil. Areas of lower $EC_a$ appear to be more extensive on north-facing slopes than on south-facing slopes. This may reflect differences in slope length, gradient and/or form; and/or depth, topography and structure (joints, fractures, and sedimentary layering) of the parent rock. Linear patterns that parallel slope contours are evident on back slope areas. These may reflect differences in lithology, soil depths, and/or moisture contents. Areas of higher $EC_a$ are evident along the stream channel. Ernest and Blairton soils occur on this portion of the landscape.

Compared with other soils recognized within this basin, these soils have higher moisture contents and shallower depths to water table.

Temporal changes in absolute values and spatial patterns of $EC_a$ are also evident in these plots. Temporal changes reflect variations in soil moisture. The influence of water on $EC_a$ is greater in areas of low than in areas of high $EC_a$ (Kachanoski, 1988). Though low, the averaged $EC_a$ within the watershed was twice as high in March as it was in October (5.16 mS/m and 2.22 mS/m, respectively). Compared with the results of the October survey, $EC_a$ had increases in all areas by March survey. Perhaps what is most noticeably is the expansion of the zone of higher $EC_a$ along the stream channel from October to March. This zone expands not only linearly along the stream channel, but broadens in width and extends upslope into the swales. In addition, areas of higher $EC_a$, and presumably higher moisture contents, appear more interconnected and integrated into one anatomical system in March.

Berks and Rushtown soils occur in swales. During drier times of the year (see plot of October data), these deeper soils are indistinguishable and appear to have similar $EC_a$ as the shallower Weikert soils. However, during wetter times of the year (see plot of March data), swales and areas of Berks and Rushtown soils appear to have higher $EC_a$ and are distinguishable from adjoining plane and convex back slope areas of Weikert soils. The higher $EC_a$ is attributable to higher moisture contents.

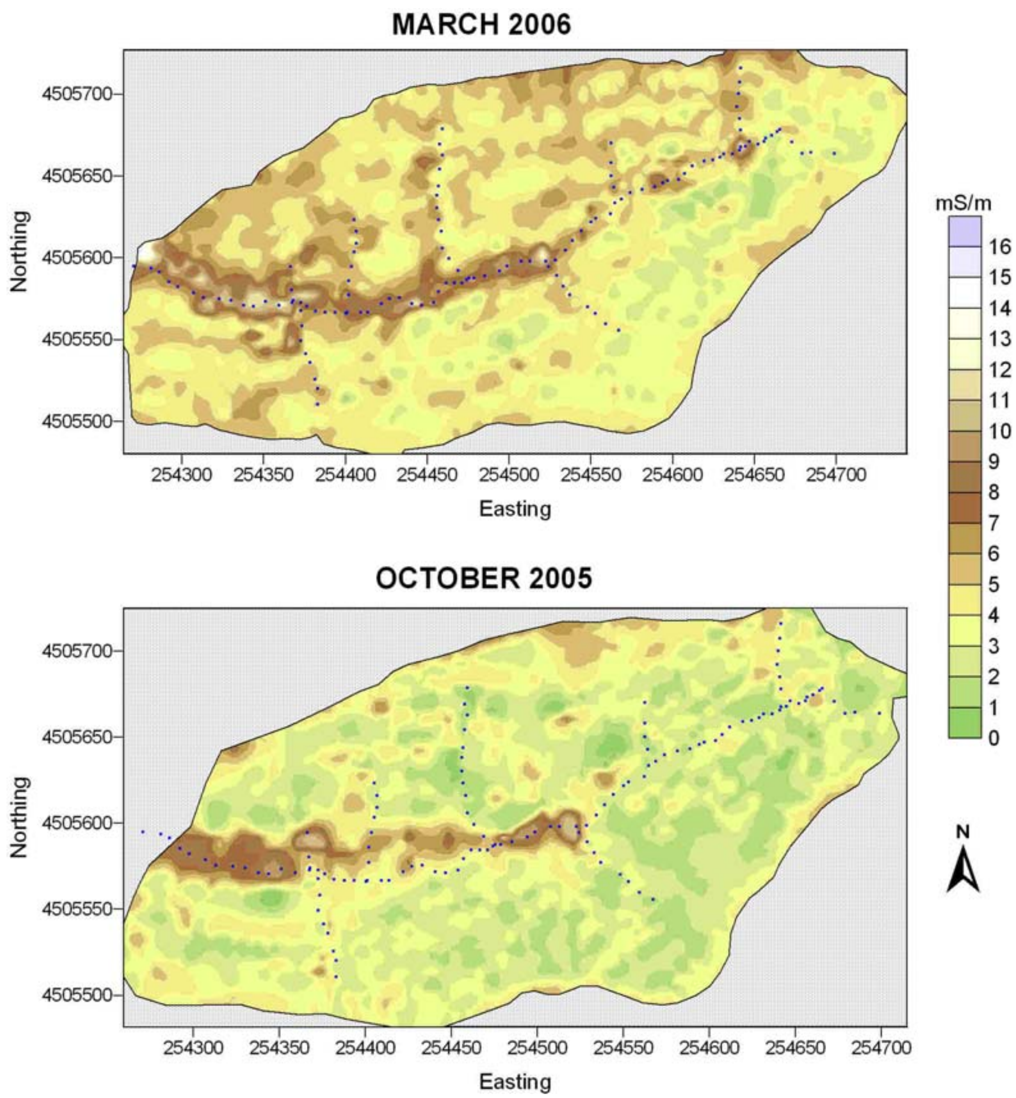


*Figure 1. This map shows spatiotemporal differences in $EC_a$ between the October 2005 and the March 2006 surveys.*

Figure 2 contains contour plots of $EC_a$ that have been overlain on a three-dimensional topographic plot of the watershed. Color variations have been used to show the distribution of $EC_a$. In each plot, the color interval is 1 mS/m. These three-dimensional plots enable a greater appreciation of the variations in $EC_a$ with landscape components.

Within the Shale Hills Watershed, $EC_a$ is relatively low and invariable reflecting the dominance of the Berks and Weikert soils and the control of the underlying electrically resistive Rosehill shale Patterns of $EC_a$ within the watershed are attributed principally to spatiotemporal variations in soil moisture. The highest $EC_a$ occurs along the stream channel. The lowest $EC_a$ occurs on upper back slopes and shoulder areas. Results from the EMI surveys indicate that while spatial patterns are indistinct, with increased soil moisture contents, swales appear to have slightly higher $EC_a$ and are distinguishable from adjoining plane and convex back slopes. The higher $EC_a$ is attributed to greater depths to bedrock and higher clay and moisture contents of soils within the swales.

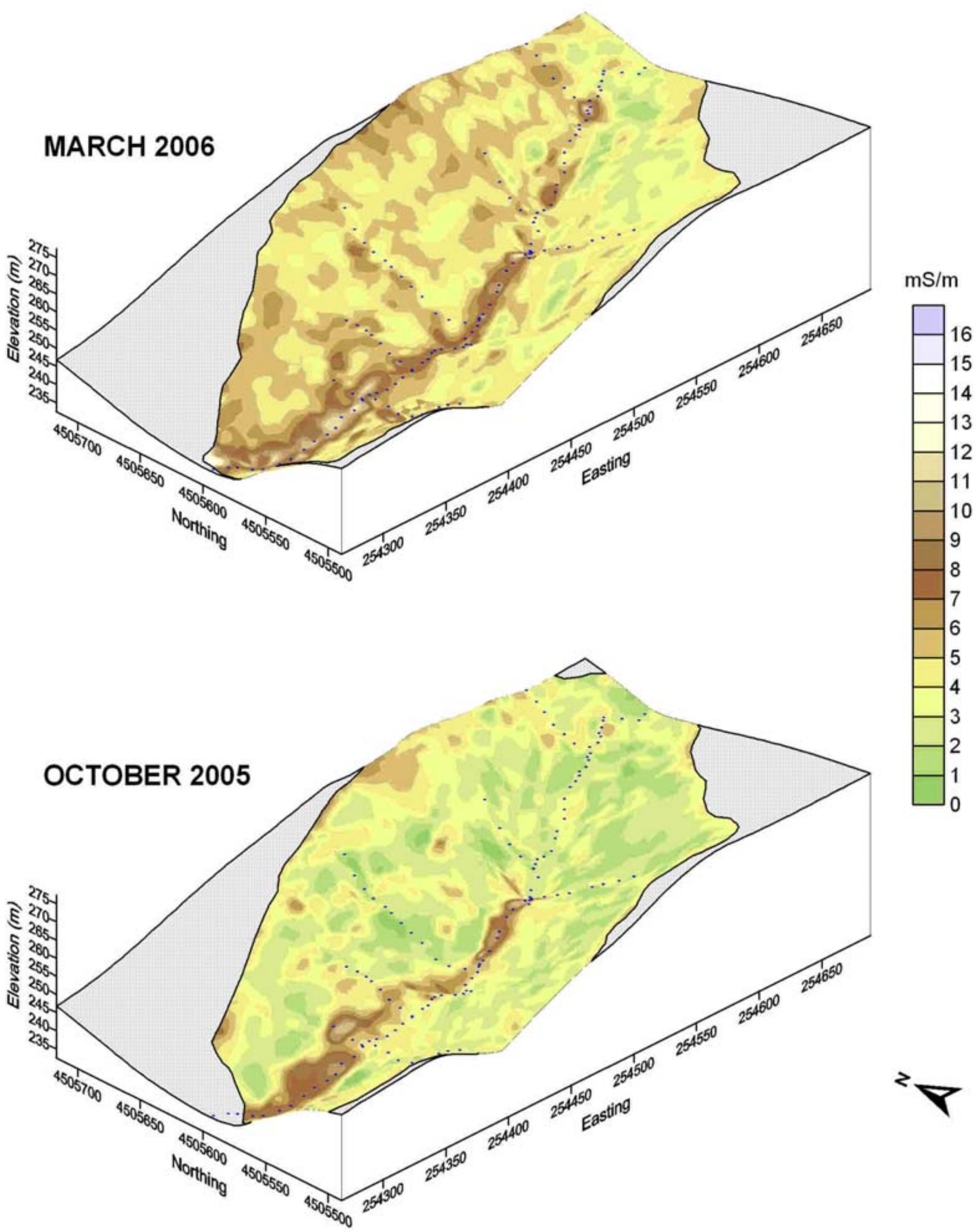


*Figure 2. This map shows spatiotemporal differences in $EC_a$ between the October 2005 and the March 2006 surveys.*

**References:**

Geonics Limited. 1998. EM38 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario.

Kachanoski, R.G. E.G. Gregorich, and I.J. Van Wesenbeeck. 1988. Estimating spatial variations of soil water content using nocontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

McNeill, J.D. 1980. Electrical conductivity of soils and rocks. Tech. Note TN-5. Geonics Ltd., Mississauga, ON.

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.