United States Department of Agriculture

NRCS

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SUBJECT: MGT – Trip Report - Geophysical Assistance

May 9, 2011

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

Purpose:
At the request of the Dr. Henry Lin, geophysical field assistance was provided by the National Soil Survey Center (NSSC) to the Department of Crop and Soil Sciences at Pennsylvania State University. Electromagnetic induction (EMI) surveys were conducted within the Shale Hills *Critical Zone Observatory* (CZO) in Huntington County. Electromagnetic induction surveys were completed across four small grid sites in an attempt to capture the short-range variability in EC_a associated with temporal and spatial differences in soil moisture.

Participants:
Doug Baldwin, Graduate Student, Dept. of Crop & Soil Sciences, Pennsylvania State University, University Park, PA
James A. Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Lincoln, NE

Activities:
Field activities were completed on April 25, 2011.

Summary:

1. During this visit, a third set of time-lapsed EMI surveys was completed on four, small grid sites located within the Shale Hills Catchment. Results from this and the November 2010 and March 2011 surveys are briefly compared in this report. Temporal and spatial differences in apparent conductivity (EC_a) are used to infer variations in soil moisture caused by differences in soil structures and hydrologic processes within the four grid sites, which are located on contrasting soil-landscape components.

2. Time-lapsed EMI surveys suggest that variations in EC_a are associated with changes in the amount and distribution of soil water.

3. For the three time-lapsed EMI surveys, the two grids located on Weikert dominated, plane upper side slopes had slightly lower average EC_a than the two grids located on the Berks and Rushtown dominated swales. Differences in EC_a between the two major landscape components are more evident when soils are comparatively dry (late fall) that when the soils are wet (early spring).

4. Results reveal areas of slightly higher EC_a on steeper, western flanks of swales. This difference is attributed to lateral flow of water along and within the bedrock emerging along the western flanks of these north-south trending swales.

5. Variations in spatial EC_a patterns at these grid sites suggest that the distribution and flow of soil moisture is non-uniform, temporally variable, and dependent on existing soil moisture conditions. However, care must be exercised in evaluating these patterns as the accuracy of global positioning systems within this steeply-sloping, forested terrain was diminished by satellite shading and signal multi-pathing.

6. A copy of the worksheet file containing the geo-referenced EC_a data has been turned-over to the principal investigators, Doug Baldwin, for his analysis.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to contribute to the research that is being carried out within the Shale Hills *Critical Zone Observatory*.

/s/ Susan S. Andrews, Acting

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:
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Technical Report on Geophysical Investigations conducted at the Shale Hills *Critical Zone Observatory* (CZO) in Huntington County, Pennsylvania on April 25, 2011.

James A. Doolittle

Equipment:
An EM38-MK2 meter (Geonics Limited; Mississauga, Ontario) was 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 two nominal penetration depths of 1.5 and 0.75 m in the vertical dipole orientation (VDO), and 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 (χ_m) 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). All EC_a data were temperature corrected to a standard temperature of 75^o F.

A Trimble AG114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to georeferenced the EC_a data collected with the 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. [1] The RTM38MK2 program (Geomar Software, Inc., Mississauga, Ontario) was used with the EM38-MK2 meter to record and display 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:
Three time-lapsed EMI surveys have been completed at four small grid sites located in the Shale Hills Catchment. These surveys were completed in November 2011, March 2011, and April 2011 with an EM38-MK2 meter. At the time of the November 2011 surveys, soils were noticeably dry. Soils were very moist at the time of the March 2011 surveys, which immediately followed snow melt. Soils were considered moist at the time of the present survey (April 2011), but less moist than at the time of the March 2011 survey.

Each time-lapsed EMI survey was conducted across the four grid sites. Two grid sites are located on both north and south-facing slopes. On both north and south-facing slopes, one grid is located in a swale; the other is on a plain, upper side slope. The plain, upper side slope grid sites are dominated by Weikert (loamy-skeletal, mixed, active, mesic Lithic Dystrudepts) soils; the swale grid sites are dominated by Berks (loamy-skeletal, mixed, active, mesic Typic Dystrudepts) and Rushtown (loamy-skeletal over fragmental, mixed, active, mesic Typic Dystrudepts) soils.

The grids vary in size and range from about 0.24 to 0.32 ha for the Weikert dominated sites (Grids 1 and 3), and from 1.05 to 1.78 ha for the Berks and Rushtown dominated sites (Grids 2 and 4). Grids 1 and 2

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

are on south-facing slopes. Grids 3 and 4 are on north-facing slopes. The areas actually covered during each survey varied. This variation was caused by portions of the grid sites being shaded from satisfactory satellite reception due to slope and vegetation (buds and leafs had emerged at the time of the April 2011 survey). In addition, the number of satellites available and their geometry varied with the timing of each survey. Exceptionally poor reception was noticed at the time of the April 2011 survey.

Pedestrian surveys were completed with the EM38-MK2 meter across each grid site. Terrain conditions are unsuitable for the completion of systematic EMI surveys. Steep and slippery slopes, undergrowth, trees and hanging limbs interfered with the completion of orderly surveys.

The EM38-MK2 meter was operated in the deeper-sensing, vertical dipole orientation (VDO) with measurements recorded at a rate of 1/sec. The meter was orientated with its long axes parallel to the direction of traverse, and held, where possible, about 5 cm (about 2 inch) above the ground surface. While EC_a data were recorded for both the 50 and 100 cm intercoil spacings. Data recorded for the 50-cm (0 to 75 cm depth interval) displayed extremely low (often negative) and unstable values (suggesting the presence of background and equipment noise) and were not used. All EC_a data discussed in this report were temperature corrected.

Results:
The Shale Hills Catchment is characterized by exceedingly low (largely < 10 mS/m) and relatively invariable EC_a (Table 1). Within the catchment, the very low EC_a reflects the electrically resistive nature of soil and parent rock, and the low ionic concentration of the soil solution. Because of the resistive nature of the underlying earthen material, it was difficult to accurately calibrate measurements taken with the meter's shorter intercoil spacing (50 cm). As a rule, the smaller the meter's intercoil spacing, the more sensitive and difficult it is to calibrate.

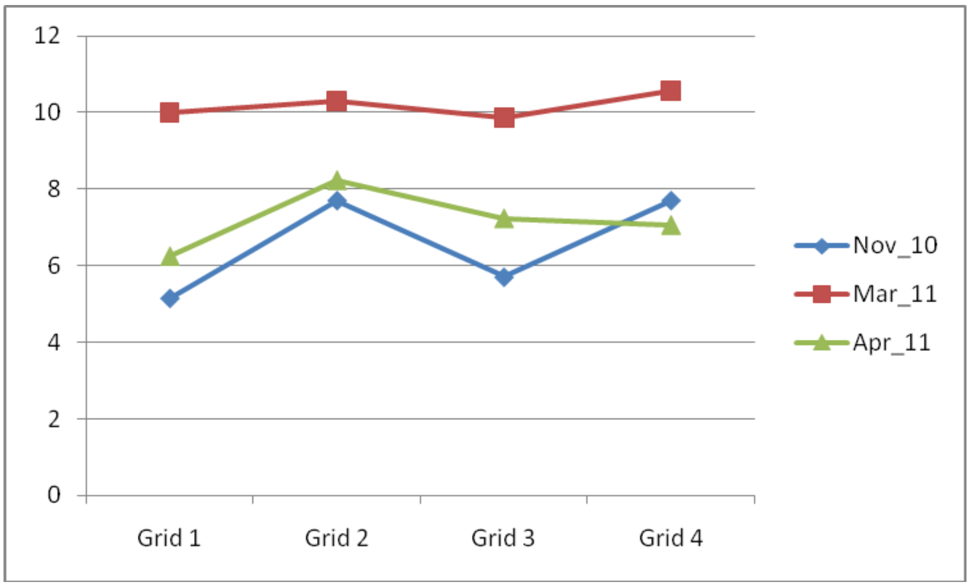
For the three EMI survey campaigns, EC_a ranged from about 0 to 24 mS/m. However, over most areas of each site, EC_a did not vary by more than 6 mS/m. Temporal variations in EC_a are noticeable in the data sets (Table 1) collected over a five month period. Compared with the November 2010 survey (colored red in Table 1), EC_a data collected in the March 2011 survey (colored green in Table 1) were higher. Compared with the March 2011 survey, lower EC_a is evident in the data collected in the April 2011 survey. By April 2011, the soils had dried out, but were moister than at the time of the November 2010 survey. These differences in average EC_a are associated with temporal differences in soil moisture content.

Table 1. Comparison of EC_a measurement collected on grid sites in November 2010 (dry, colored red), March 2011 (wet, colored green), and April 2011 (moist, colored blue).

	November 2010				March 2011				April 2011			
	Grid 1	Grid 2	Grid 3	Grid 4	Grid 1	Grid 2	Grid 3	Grid 4	Grid 1	Grid 2	Grid 3	Grid 4
Observations	214	857	335	857	277	981	175	459	241	637	187	359
Minimum	0.1	0.0	0.0	0.0	2.1	2.1	5.9	3.8	-6.7	-0.3	-1.1	-22.6
25%-tile	3.8	6.5	5.0	6.5	9.3	9.4	8.8	9.6	5.4	7.2	6.4	6.4
75%-tile	6.4	9.1	6.4	9.1	10.0	11.4	10.7	11.6	7.2	9.3	8.2	8.1
Maximum	14.6	13.4	9.4	13.4	17.1	15.3	23.3	21.5	12.0	17.9	11.0	11.5
Mean	5.2	7.7	5.7	7.7	10.0	10.3	9.9	10.6	6.3	8.1	7.2	7.1
Std. Dev.	2.0	2.1	1.2	2.1	1.7	1.7	1.7	1.6	1.6	1.9	1.4	2.4

For the three time-lapsed EMI surveys, the two grids located on Weikert dominated, plane upper side slopes (Grids 1 and 3) had slightly lower average EC_a than the two grids located on the Berks and Rushtown dominated swales (Grids 2 and 4) (see Graph 1). Differences between these two major landscape components (swale and upper side slopes) are more apparent under dry (November 2010) than under wet (March 2011) or moist (April 2011) conditions. Temporal differences in the averaged EC_a for each site reflect fluctuations in soil moisture content.

Graph 1. Temporal Difference in the averaged EC_a for the four grid sites, which were surveyed with an EM38-MK2 meter in November 2010, March 2011, and April 2011. Measurements are expressed in mS/m.



Figures 1 to 4 contain three-dimensional (3D) simulations showing the spatiotemporal variations of EC_a across each of the four grid sites for the three EMI surveys. In each 3D simulation, plots of EC_a data are superimposed on simulation of elevation data obtained from LIDAR (Light Detection and Ranging or Laser Imaging Detection and Ranging) imagery. The same color scale has been used in all simulations for comparative purposes.

In general, spatial EC_a patterns appear random and chaotic with slight variations in values within each site. In Figures 1, 2 and 4, however, localized anomalous values are evident. These anomalous EC_a values were recorded as the meter passed either too close to installed instruments or over buried metallic objects. These values occur as anomalously high or low conductivity measurements located in the northeast, west-central, and northeast corner of Grids 1, 2, and 4, respectively. The relative size and expression of each of these anomalies varies for each survey. These changes reflect differences in the number of observations and the relative positioning and orientation of the meter during each survey.

Within the Shale Hills Catchment, spatial variations in EC_a are presumed to reflect principally differences in the clay and moisture contents of soils. The contribution of absorbed ions on the soil particles, and the ionic strength and composition of the soil solution on EC_a, though unknown, is considered negligible within the catchment. Within the four grid sites, temporal variations in the magnitude and spatial patterns of EC_a data are attributed to differences in soil moisture contents. Figures 1 thru 4 clearly show the effects of temporal differences in soil moisture on absolute EC_a values and spatial patterns. These values and spatial patterns reflect temporal variations in soil moisture contents within the grid sites.

For the Weikert dominated plain, upper side slopes (Figures 1 and 2), EC_a is relatively low and, with the exception of the detected artifacts (anomalies), invariable across the grid sites. In humid regions, spatial EC_a patterns are presumed to remain fairly stable as they principally reflect variations in clay content. As evident in Figures 1 thru 4, at this scale of resolution, while temporal variations in the magnitude of EC_a are apparent, it is difficult to discern stable spatial patterns. Observed variations in the spatial EC_a patterns at these sites suggest that the distribution and flow of soil moisture is non-uniform, temporally variable, and dependent on existing soil moisture conditions. However, as the accuracy of GPS positioning is impaired within this steeply-sloping, forested catchment, some of spatial patterns are believed to reflect inaccuracies in GPS positioning.

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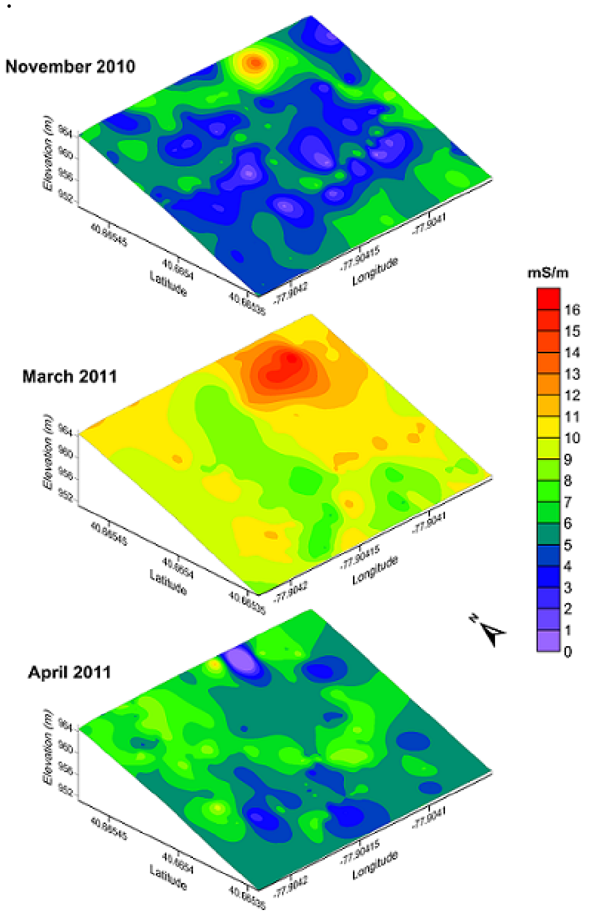

Figure 1. Spatiotemporal differences in EC_a for the EMI surveys conducted across Grid Site 1; a south-facing, plain, upper side slope component.

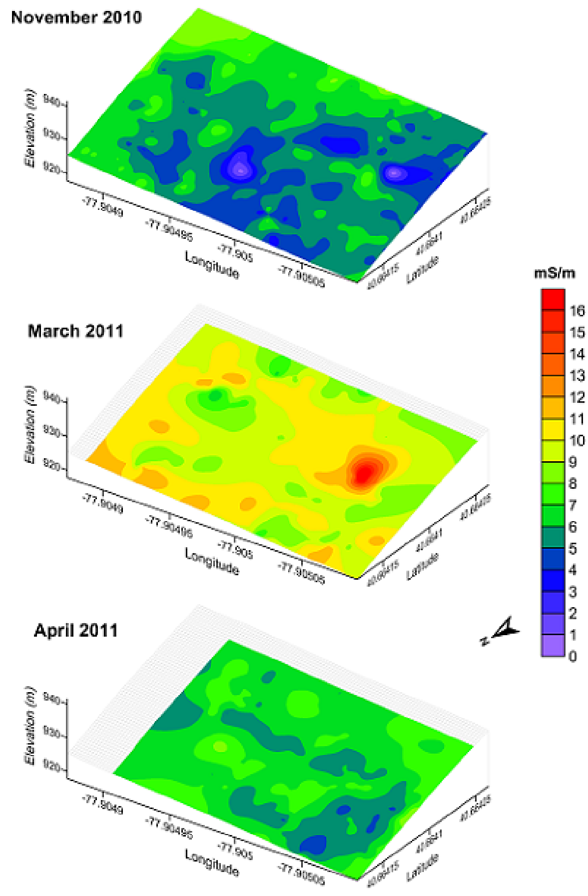

Figure 2. Spatiotemporal differences in EC_a for the EMI surveys conducted across Grid Site 3; a south-facing, swale component.

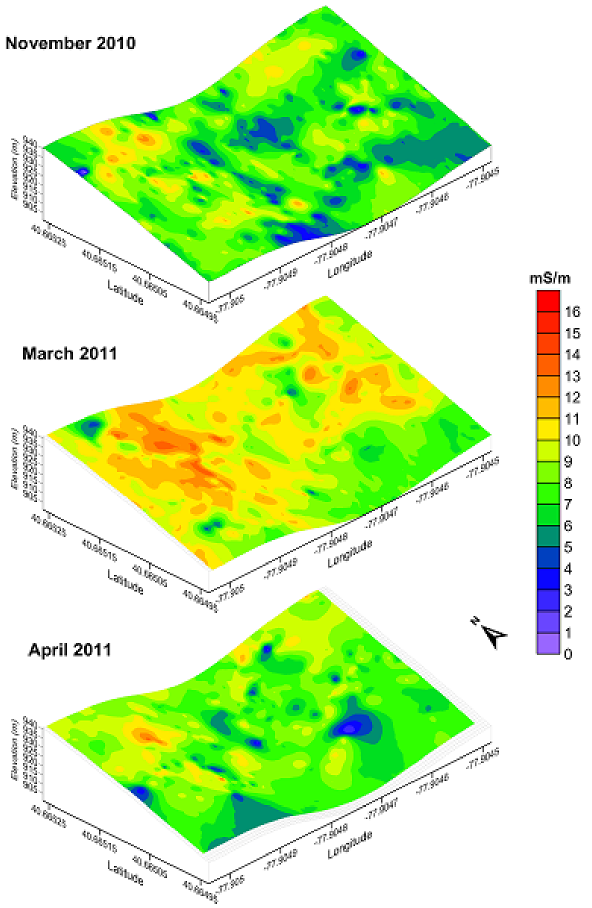

Figure 3. Spatiotemporal differences in EC_a for the EMI surveys conducted across Grid Site 2; a north-facing, plain, upper side slope component.

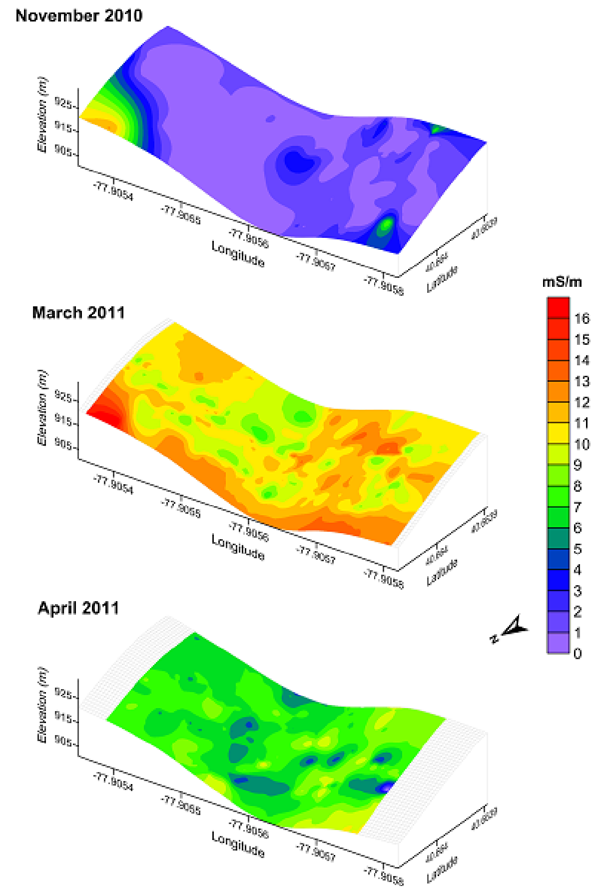

Figure 4. Spatiotemporal differences in EC_a for the EMI surveys conducted across Grid Site 4; a north-facing, swale component.

Apparent conductivity is comparatively higher on Berks and Rushtown dominated swales (Figures 3 and 4; Table 1), than on the Weikert dominated sites. In general, during drier periods (November survey), swales have slightly higher average EC_a than upper side slopes (Table 1, Graph 1). However, during wetter periods (March survey), differences in average EC_a between these two slope components are negligible.

For the three surveys, areas of very deep, *rapidly to very rapidly permeable* Rushtown soils, which dominate the two swale bottoms (see Figures 3 and 4), appear to have slightly lower EC_a than adjoining, higher-lying areas of moderately deep, *moderate to moderately rapid permeable* Berks soils. Zones of higher EC_a are evident on some higher-lying areas of Berks soils within these swales. These zones are most apparent on the steeper, western flanks of swales. These zones do not appear to be temporally stable, but emerge, diminish, and migrate with assumed variations in soil moisture. The higher EC_a on these portions of swales is attributed to lateral flow of moisture through and immediately above the shale bedrock from higher-lying slope positions, and its emergence on side slopes dominated by Berks soils. This lateral flow would contribute to higher soil water content in Berks soils on these slope components.

References:

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