United States Department of Agriculture

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SUBJECT: MGT – Trip Report - Geophysical Assistance — March 23, 2011

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, geophysical field assistance was provided by the National Soil Survey Center 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 caused by variations in soil and hydrologic properties.

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, MS 41, NRCS Lincoln, NE

Activities:
Field activities were completed on March 15, 2011.

Summary:

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

2. Time-lapsed EMI surveys suggest changes in the amount and distribution of soil water. Temporal variations in EC_a are noticeable in the data sets. Compared with the November 2010 survey, EC_a data collected in the March 2011 survey were higher, with differences linked to temporal differences in soil moisture.

3. For both 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. However, the differences between these two major landscape components were diminished at the time of the March surveys, when soils were wetter.

4. Observed variations in the 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.

5. Results revealed slightly higher EC_a on the western flanks than on the eastern flanks of swales. This difference is attributed to lateral flow of water within the bedrock emerging on the western flanks of these north-south trending swales.

6. A copy of the worksheet file containing the electromagnetic induction 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/ Jonathan W. Hempel

JONATHAN W. HEMPEL
Director
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cc:

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Technical Report on Geophysical Investigations conducted at the Shale Hills *Critical Zone Observatory* (CZO) in Huntington County, Pennsylvania, on March 15, 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).

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:
Two time-lapsed EMI surveys have been completed at four grid sites located in the Shale Hills Catchment. These surveys were completed in November 2011 and March 2011 with an EM38-MK2 meter. At the time of the November 2011 surveys, soils were noticeably dry. Soils were moister at the time of the March 2011 surveys, which immediately followed snow melt.

Each time-lapsed EMI survey was conducted across all 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 are variable 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 are on south-facing slopes. Grids 3 and 4 are on north-facing slopes. The purpose of these surveys was to capture short-range variability in EC_a caused by variations in soil and hydrologic properties.

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

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

undergrowth, trees and hanging limbs interfered with the completion of an orderly survey. As a consequence, the number, spacing, and locations of traverse lines and observation points within each grid site varied for each survey (November 2010 and March 2011). In addition, terrain obstructions, satellite shading, and multipath reception reduced the accuracy and reliability of GPS.

Pedestrian surveys were completed with the EM38-MK2 meter across each site. The EM38-MK2 meter was operated in the deeper-sensing, vertical dipole orientation (VDO). The meter was operated in the continuous mode 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:

This report summarizes the results of two EMI surveys. Each survey was conducted across four grid sites. This study attempts to characterize spatial and temporal heterogeneities in the subsurface on two prominent soil-landscape components: linear upper side slopes and swales.

The Shale Hills Catchment is characterized by exceedingly low 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. For the two 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). Compared with the November 2010 survey (colored red in Table 1), EC_a data collected in the March 2011 survey (colored blue in Table 1) were higher and slightly less variable. These differences are associated with temporal differences in soil moisture.

Table 1. Comparison of EC_a measurement collected on grid sites located on different soil-landscape components in November 2010 (dry, colored red) and March 2011 (wet, colored blue).

	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
Minimum	0.06	0.00	0.00	0.00		2.14	2.14	5.89	3.77
25%-tile	3.76	6.45	5.01	6.45		9.34	9.35	8.81	9.59
75%-tile	6.39	9.07	6.39	9.08		10.00	11.35	10.71	11.60
Maximum	14.56	13.43	9.42	13.43		17.11	15.30	23.33	21.53
Mean	5.16	7.71	5.71	7.71		10.00	10.30	9.87	10.56
Std. Dev.	2.02	2.12	1.22	2.12		1.66	1.66	1.68	1.63

For both 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). However, the differences between these two major landscape components (swale and upper side slopes) were diminished at the time of the March surveys, when soils were wetter. The data collected at Grids 1, 3 and 4 contain a cluster of anomalous EC_a measurements caused by the EM38-MK2 meter passing too close to installed instruments or passing over buried metallic objects. If these values are excluded, the grids located on plain, upper side slopes would have a lower average and less variable EC_a than recorded on the two grids located in the swales. The lower EC_a on

Weikert dominated plain, upper side slopes is attributed to shallower depth to bedrock, lower clay and/or moisture contents (especially in the soil column).

Table 2. Temporal Difference in EC_a at the four grid sites measured in November 2010 and March 2011. Positive values indicate a relative increase in EC_a from the November 2010 to the March 2011 surveys.

	Grid 1	Grid 2	Grid 3	Grid 4
Minimum	2.08	2.14	5.89	3.77
25%-tile	5.58	2.90	3.80	3.14
75%-tile	3.61	2.28	4.32	2.52
Maximum	2.55	1.87	13.91	8.10
Mean	4.84	2.59	4.16	2.85
Std. Dev.	-0.36	-0.46	0.46	-0.49

As shown in Table 2, most basic EC_a parameters increased from November 2010 to March 2011. This trend is a direct reflection of the impact of increased soil moisture on EC_a. At all grid sites, minimum, maximum, and averaged EC_a values increased from the time of the relatively drier November survey to the time of the wetter March survey. While most EC_a values increased, relative differences in EC_a within most sites declined (negative standard deviation values).

Figures 1 to 4 contain 3D simulations showing the spatiotemporal variations of EC_a across each of the four grid sites. In each of 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 Figures 1, 3 and 4, anomalous values were recorded as the meter passed too close to installed instruments or over buried metallic objects. These values occur as high-conductivity measurements located in the northeast, west-central, and northeast corner of Grids 1, 3, 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 for the two surveys.

For the Weikert dominated plain, upper side slopes (Figures 1 and 3), EC_a is relatively low and, with the exception of detected artifacts (anomalies), invariable across these grid sites. Within the Shale Hills Catchment, spatial variations in EC_a are presumed to reflect differences in clay, organic matter, 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. Temporal variations in the magnitude and spatial patterns of EC_a data are attributed to differences in soil water contents.

In a general context, spatial EC_a patterns appear dissimilar across Grid Sites 1 and 3 for the two sampling events. In humid regions, spatial EC_a patterns are presumed to principally reflect variations in clay content. In such textured-driven systems, spatial patterns remain relatively stable as variations in water contents are presumed to affect only the magnitude of the EC_a measurements (Johnson et al., 2003). 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.

Apparent conductivity is comparatively higher on Berks and Rushtown dominated swales (Figures 2 and 4), EC_a than on the Weikert dominated sites. During drier periods (November survey), swales have a greater variability in EC_a than upper side slopes. However, during wetter periods (March survey), variability is similar between the two slope components.

For both surveys (November and March), areas of very deep, *rapidly to very rapidly permeable* Rushtown soils, which dominate the two swale bottoms, 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 do not appear to be temporally stable, but emerge and migrate with presumed variations in soil moisture. The higher EC_a is attributed to lateral flow of moisture through and immediately above the shale bedrock column 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. For both sampling periods, EC_a is slightly higher on the slopes that form the western flanks to these swales. This can be attributed to the preferential flow of water within the bedrock structures.

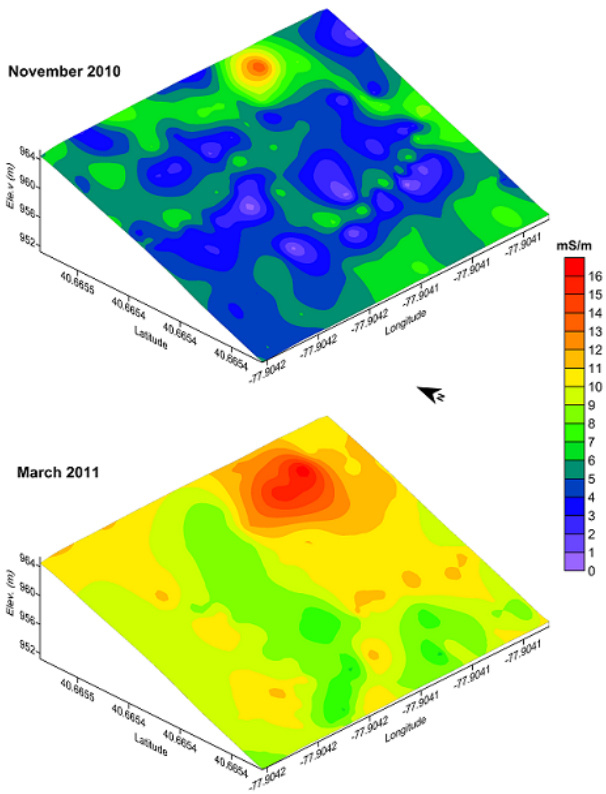

Figure 1. Spatiotemporal differences in EC_a between the November and March EMI surveys conducted across Grid Site 1; a south-facing, plain, upper side slope component.

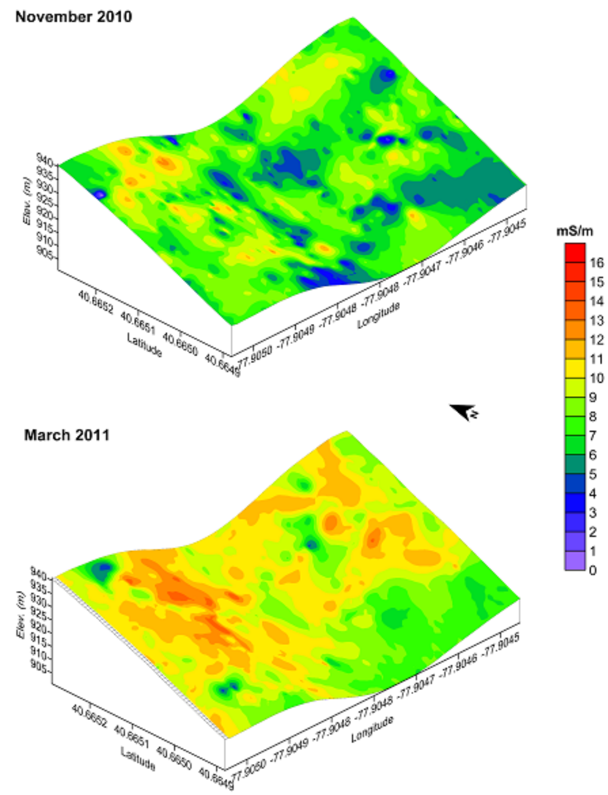

Figure 2. Spatiotemporal differences in EC_a between the November and March EMI surveys conducted across Grid Site 2; a south-facing, swale component.

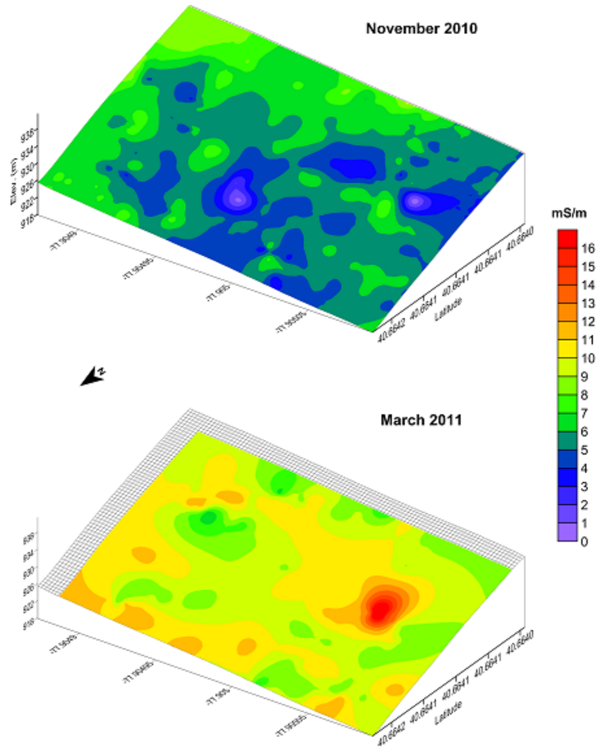

Figure 3. Spatiotemporal differences in EC_a between the November and March EMI surveys conducted across Grid Site 3; a north-facing, plain, upper side slope component.

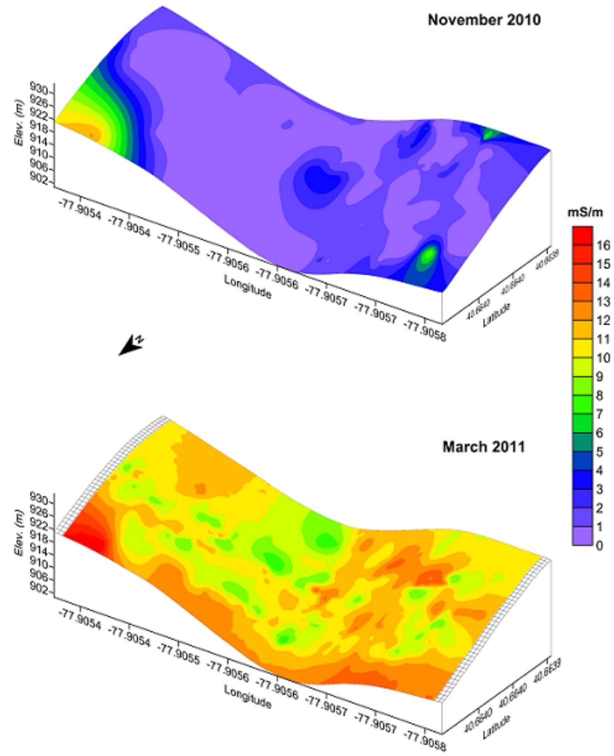

Figure 4. Spatiotemporal differences in EC_a between the November and March EMI surveys conducted across Grid Site 4; a north-facing, swale component.

References:

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

Johnson, C.K., J.W. Doran, B. Eghball, R.A. Eigenberger, B.J. Wienhold, and B.L. Woodbury, 2003. Status of soil electrical conductivity studies in central state researchers. ASAE Paper No. 032339, ASAE Annual International Meeting, 27-30 July 2003, Las Vegas, Nevada, ASAE, St Josephs, MI.