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

Subject: SOI – Geophysical Field Assistance **Date:** 22 March 2006

To: Dr. Henry Lin
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Purpose:
Spatial and temporal variations in soil moisture contents and water movement are being investigated within highly instrumented fields at Pennsylvania State University's Kleper Farm in Centre County. The purpose of this investigation was to complete a high-intensity electromagnetic induction (EMI) survey of these fields. Spatial patterns of apparent conductivity, as measured with a Dualem-2 meter, will provide an additional layer of soil information for this hydropedological research project.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Shujiang Kang, Ph.D. student, Department of Crop and Soil Sciences, Pennsylvania State University, University Park, PA
Wes Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, Wilkesboro, NC
Bob Zhou, Postdoctoral Research Associate, Department of Crop and Soil Sciences, Pennsylvania State University, University Park, PA

Activities:
All field activities were completed on 15 March 2006.

Summary:

1. The National Soil Survey Center provided geophysical field assistance to the Department of Crop and Soil Sciences, Pennsylvania State University at the Kleper Research Farm in Centre County, Pennsylvania. A comprehensive, mechanized EMI survey was completed on a highly instrumented research site with a Dualem-2 meter.

2. Spatial patterns of apparent conductivity (EC_a) were principally related to differences in soil wetness, thickness of the residuum and depth to limestone. Areas with low EC_a are on higher-lying, more sloping, better drained summit and shoulder slopes. These areas are inferred to have thinner caps of residuum and shallower depths to limestone bedrock. Areas with high EC_a are on lower-lying, more imperfectly drained, plane and concave lower back slopes and foot slopes. These areas are often wetter and were inferred to have thicker caps of residuum and deeper depths to bedrock.

3. All EC_a data have been forwarded to Dr Lin for further analysis and interpretation.

It was our pleasure to participate in this hydropedological investigation and to be of assistance.

With kind regards,

James A. Doolittle	Wes Tuttle
Research Soil Scientist	Soil Scientist (Geophysical)
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cc:
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Background:
Spatial and temporal variations in soil moisture contents and water movement are being investigated within several highly instrumented fields at Pennsylvania State University's Kleper Farm. The research plan includes for the installation of 142 TDR tubes; 40 nested tensiometers, piezometers and wells; 5 automatic soil moisture monitoring systems; and 6 rain gauges. The specific objectives of this research are (i) to characterize spatial and temporal patterns of surface and subsurface soil moisture in both the non-cropping and cropping seasons, (ii) link observed spatial patterns of soil moisture to soil types, surface topography, bedrock topography, and crop yield, and the interactions of these parameters at the pedon, hillslope and landscape scales, (iii) link observed temporal patterns of soil moisture to rainfall intensity, soil types, surface topography, bedrock topography, water table depth, and crop type at daily, weekly and monthly scales, and (iv) predict dominant subsurface flow pathways based on spatial-temporal dynamics of soil moisture and crop yield responses. The results of this research will be used to develop conceptual models describing the dominant surface and subsurface water flow paths within this landscape.

In 1996 and 1997, the National Soil Survey Center conducted preliminary EMI surveys at the Rock Spring Agronomy Farm, Pennsylvania State University, Centre County, Pennsylvania. Electromagnetic induction surveys of the fields containing the present research area were completed during these periods. In these rather coarse surveys (30-m grid interval), measurements were obtained in the station-to-station mode with EM31 and EM38 meters in both the horizontal and vertical dipole orientations. In June 2005, a reconnaissance survey was conducted across this site with an EM31 meter. The survey consisted of 10, widely spaced traverse lines. Along each traverse line, apparent conductivity (EC_a) was recorded with the EM31 meter in the vertical dipole orientation and in the continuous mode of operation. These EMI surveys provided rather coarse resolution of EC_a within the research site. The purpose of this investigation was to complete a more comprehensive EMI survey of the research site using the National Soil Survey Center's mobile EMI cart.

Equipment:
A Dualem-2 meter, manufactured by Dualem Inc. (Milton, Ontario), was used in this survey[1]. Principles of operation for the Dualem-2 meter are described by Taylor (2000). The Dualem-2 meter operates at a fixed frequency (9,000 Hz) and consists of one transmitter and two receiver coils. One receiver and the transmitter provide a perpendicular geometry (PRP). The other receiver provides a horizontal co-planar geometry (HCP) with the transmitter. The dual-geometry array of the Dualem-2 meter allows the simultaneous measurement of apparent conductivity and magnetic susceptibility in two distinct orientations. This dual-geometry array permits two depths to be measured simultaneously without rotating the coils. The meter is keypad operated and has about 1 megabyte of memory. The depth of penetration is "geometry limited" and dependent on the instruments intercoil spacing, coil or receiver orientations and frequency. The Dualem-2 has a 2-m intercoil spacing between the transmitter and the two receivers. It has theoretical depths of penetration of 1.3 and 3.0 m in the PRP and HCP geometries, respectively. Lateral resolution is approximately equal to the intercoil spacing.

The DAS70 Data Acquisition System (Geonics Limited, Mississauga, Ontario) was used with the EMI meters to record and store both EC_a and GPS data.[1] The acquisition system consists of an EMI meter, an Allegro field computer (Juniper Systems, North Logan, UT), and a Trimble AG114 GPS receiver (Sunnyvale, CA).[1] With the acquisition system, the EMI meter is keypad operated and measurements are automatically triggered.

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

Field Methods:
A mechanized EMI survey of the study site was completed. The Dualem-2 meter was mounted in an EMI cart that was towed behind a John Deere "Gator" 6x4 ATV [1]. The Dualem-2 meter was positioned in the cart at a height of about 30-cm above the ground surface and operated in the continuous mode with geo-referenced EC_a measurements recorded at 1-sec intervals. Multiple traverses were completed with this system across the study site. Traverse lines were spaced about 10 m apart (see Figure 2, upper left-hand plot, for locations of traverse lines). Measurements obtained in the field were not corrected to a reference temperature of 25^o C.

Study Site:
The study site is located in Ferguson Township, about 3060-m west of the intersection of Pennsylvania Routes 26 and 45 in the town of Pine Grove Mills, Centre County. 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 study site is located in a valley and underlain by the Bellefonte formation (Early-Middle Ordovician age). The Bellefonte formation consists of a sequence of laminated dolostones and argillaceous dolostones. Bedded, nodular chert is common within this formation. A soil map of the site is shown in Figure 1. In Figure 1, red and gray lines define soil polygon and study site boundaries,

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

respectively. The names of the soil map units that were delineated within the study site are shown in Table 1 (Braker, 1981). The present taxonomic classifications of the soils mapped within the study site are listed in Table 2.

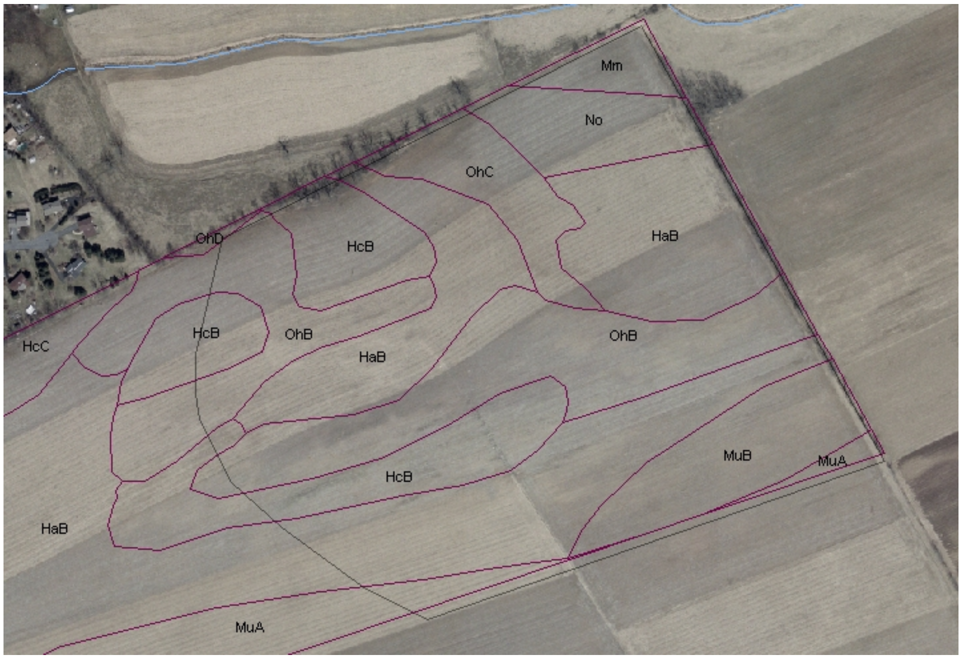

Figure 1. This aerial photograph of the study site shows the soil polygon lines and map unit symbols from the order-two soil survey (Braker, 1981). The boundary of the study site is defined by a gray line.

Table 1.

Soil Map Units occurring within the Study Site

Symbol	Name
HaA	Hagerstown silt loam, 0 to 3 percent slopes
HaB	Hagerstown silt loam, 3 to 8 percent slopes
HcB	Hagerstown silty clay loam, 3 to 8 percent slopes
Mm	Melvin silt loam
MuA	Murrill channery silt loam, 0 to 3 percent slopes
MuB	Murrill channery silt loam, 3 to 8 percent slopes
No	Nolin silt loam, local alluvium, 0 to 5 percent slopes
OhB	Opequon-Hagerstown complex, 3 to 8 percent slopes
OhC	Opequon-Hagerstown complex, 8 to 15 percent slopes

Table 2
Taxonomic Classification of Soils

Series	Family
Hagerstown	Fine, mixed, mesic Typic Hapludalfs
Melvin	Fine-silty, mixed, nonacid, mesic Typic Fluvaquents
Murrill	Fine-loamy, mixed, mesic Typic Hapludults
Nolin	Fine-silty, mixed, mesic Dystric Fluventic Eutrochrepts
Opequon	Clayey, mixed, mesic Lithic Hapludalfs

Results:
Table 3 summarizes the results of the EMI survey. For the shallower-sensing (0 to 1.3 m), perpendicular geometry (PRP), EC_a ranged from -0.8 to 99.1 mS/m. In the PRP, EC_a averaged 5.4 mS/m with a standard deviation of 3.4 mS/m. One-half the EC_a measurements recorded in the PRP were between 4.2 and 6.3 mS/m. For the deeper sensing (0 to 3.0 m), horizontal co-planar geometry (HCP), EC_a

ranged from -87.9 to 79.5 mS/m. In the HCP, EC_a averaged 11.2 mS/m with a standard deviation of 7.8 mS/m. One-half the EC_a measurements recorded in the HCP were between 8.8 and 11.6 mS/m.

Table 3
Basic EMI Statistics for EMI survey of the Klepler Farm Research Site, Pine Grove Mills, Centre County.
(Other than the number of observations, all values are in mS/m)

	PRP	HCP
Number	5407	5407
Mean	5.4	11.2
Standard Deviation	3.4	7.8
Minimum	-0.8	-87.9
Maximum	99.1	79.5
25%-tile	4.2	8.8
75%-tile	6.3	11.6

In general, EC_a increases and became more variable with increasing depths of observations (EC_a measured in the deeper-sensing HCP were higher and more variable than EC_a measured in the shallower-sensing PRP). However, as the PRP is most sensitive to conditions immediately below the meter, the 30-cm air gap between the meter and the soil surface undoubtedly lowered the measured EMI response in this geometry. Measurements made in the deeper-sensing HCP were less affected by this air gap. The range of EC_a was noticeably affected by the presence of buried utility lines within the fields. With the exception of anomalous measurements obtained over buried utility lines, EC_a is relatively low and modestly variable across this site. The low EC_a areas dominated by fine-textured Hagerstown and moderately-fine textured Melvin and Merrill soils seems at first incongruous, as these soils have as much as 60, 35, and 35 % clay in their textural control sections, respectively. However, these soils are highly-weathered and do not contain relatively large amounts of high-CEC clay minerals.

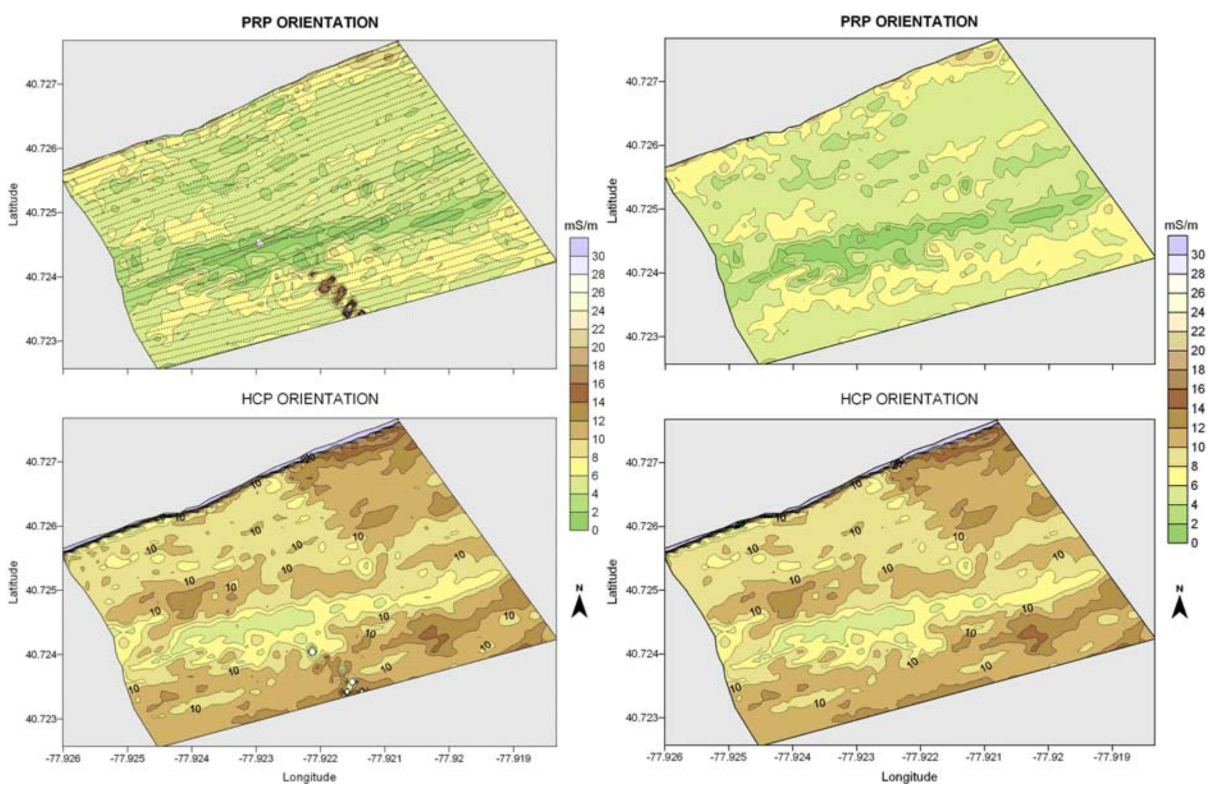

Figure 2. Plots of EC_a collected with the Dualem-2 m in the perpendicular geometry *(PRP) and horizontal co-planar* geometry *(HCP). The plots on the left represent unedited data. Plots on the right have been edited to remove noise caused by buried utility lines and some spurious EMI responses.*

Figures 2 contain two-dimensional plots of EC_a measured with the Dualem-2 meter in the PRP and HCP. In each plot, the isoline interval is 2 mS/m and the same color scale is used. The locations of the traverse lines and the EC_a measurement points are shown in the upper-left hand plot.

Buried utility lines parallel the northern boundary and buried power lines entered the south-central portion of the study site along a farm road. These utilities produced electromagnetic interference resulting in some negative, but all anomalously high EMI responses. In addition, some anomalous EC_a values are attributed to metallic artifacts that were discarded or buried in the field and crossed or closely approached with the EMI meter during the survey. In the left-hand plots of Figure 2, the approximate locations of the buried utility lines can be identified by anomalous EC_a values plotted along the northern boundary (mostly masked by blanking files) and in the extreme south central portion (most evident in the upper left-hand plot) of the research site. In the right-hand plots of Figure 2, anomalous values caused by these utility lines have been removed and slight adjustments to some EC_a values at individual grid nodes have been made to smooth the contours and remove some clutter.

In Figure 2, linear west-southwest to east-northeast bands can be identified in the plots of EC_a data. These spatial patterns closely conform to the strike of the underlying bedrock and are therefore inferred to represent changes in lithology and/or depth to parent rock. These patterns are more continuous in the plots of the EC_a data collected in the shallower-sensing, PRP. These patterns are less obvious in the plots of the EC_a data collected in the deeper-sensing, HCP.

Figures 3 contain two-dimensional plots of edited EC_a data that were measured with the Dualem-2 meter in the PRP and HCP. In each plot, a two-dimensional map of EC_a has been draped over a three-dimensional wireframe map of the site. In each plot, the isoline interval is 2 mS/m and the same color scale is used. The spatial patterns of EC_a appearing in Figure 3 are principally related to differences in soil wetness, thickness of the residuum, and depth to limestone. Areas with low EC_a are on higher-lying, more sloping, better drained landscape positions. These areas are inferred to have thinner caps of residuum and shallower depths to limestone bedrock. Areas with higher EC_a are on lower-lying, more imperfectly drained plane and concave slopes. These areas are wetter and were inferred to have thicker caps of residuum or deeper depths to bedrock.

References:
Braker, W. L. 1981. Soil Survey of Centre County, Pennsylvania. USDA-Soil Conservation Service, Washington DC.

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

Taylor, R. S. 2000. Development and applications of geometric-sounding electromagnetic systems. Dualem Inc., Milton Ontario.

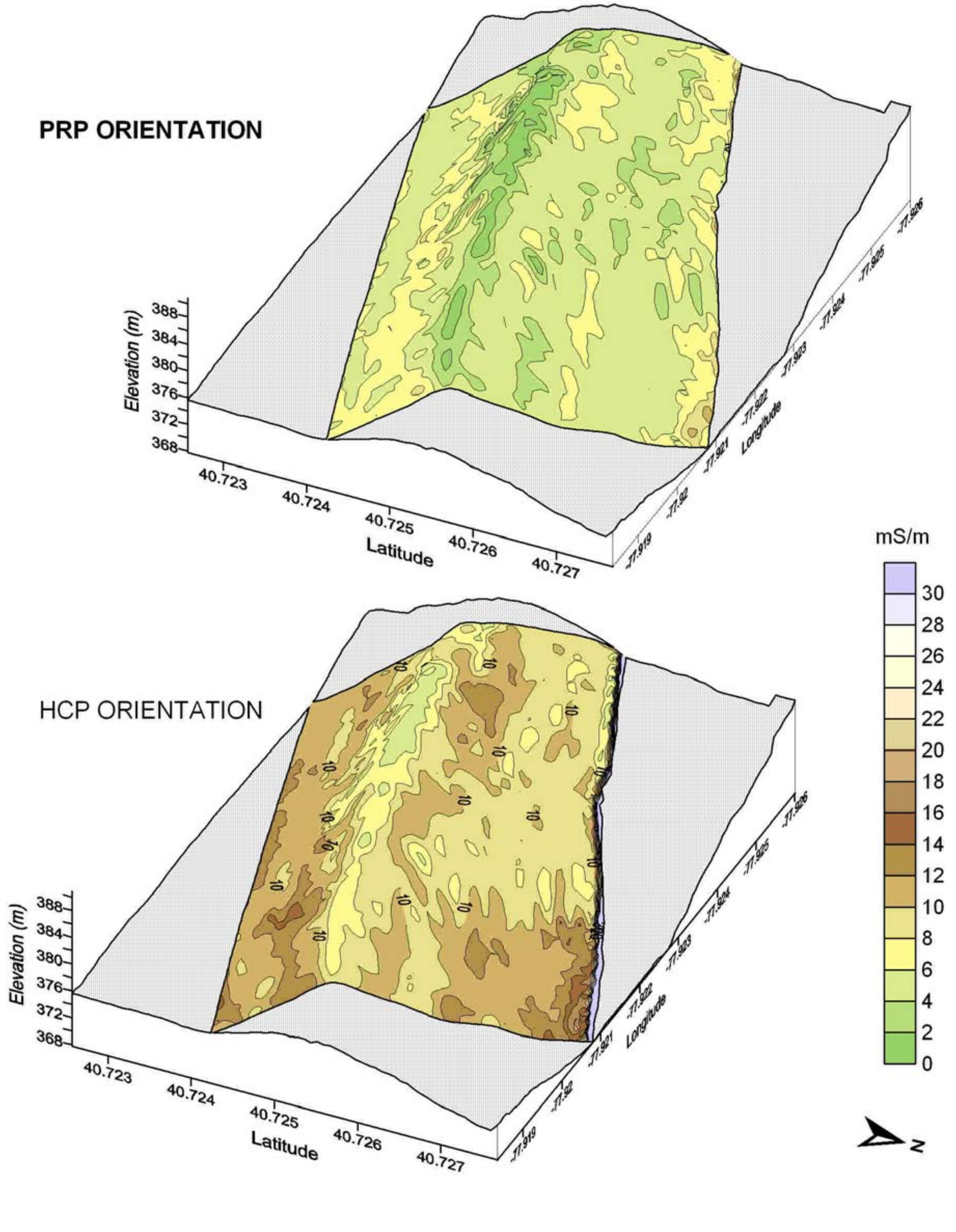

Figure 3. Contour plots of ECa measurements overlain on three-dimensional wireframe map of relative elevations