United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI – Geophysical Field Assistance **Date:** 6 April 2005

To: Robin Heard
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Purpose:
The 18th World Congress of Soil Science (WCSS) will be held in Philadelphia, Pennsylvania, on July 9-15, 2006. Mid-Congress tours and special activities are being planned. Three sites selected for the Mid-Congress tours were visited and geophysical investigations were conducted in preparation for the WCSS.

Participants:
John Chibirka, Soil Scientist, USDA-NRCS, Leesport, PA
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Vicki Meyers, Soil Scientist, USDA-NRCS, Leesport, PA

Activities:
All field activities were completed during on 21, 22 and 24 March 2005.

Results:

1. At Honey Hollow Farm, Bucks County, a deeper-sensing EM31 meter failed to provide any additional information concerning the transition from sandstone to limestone parent rocks. Resolution of two underground utility lines was poorer than previous recorded with the EM38DD meter. Ground-penetrating radar (GPR) is a more suitable geophysical tool to demonstrate at this site. However, the value of electromagnetic induction (EMI) for locating buried utility lines in advance of excavations can be vividly demonstrated at this site.

2. The fields at Cedar Meadow Farm, in Lancaster County, continue to be enigmatic to EMI. Spatial pattern, though seemingly natural, are unreasonable and conflicted with previous experiences. Negative values were recorded on lower-lying, more poorly drained and wetter areas of the field. Typically, because of increased soil moisture contents, these areas have higher apparent conductivity (EC_a). In addition, the highest EC_a was recorded on the higher-lying, more sloping and better drained portion of the landscape where the solum was thinner and the surface was very channery. Typically, these areas would have the lowest EC_a. Expanded EMI surveys at Cedar Meadow Farm are planned to clarify the nature of the enigmatic EC_a reading obtained with the EM38DD meter.

3. The soils that were surveyed in Berks County with EMI have low and comparatively invariable EC_a. Because of invariable EC_a and bland spatial patterns, these soils are considered poorly suited for a

demonstration of EMI. However, these soils are well suited to demonstrate GPR during the Mid-Congress Tours.

It was my pleasure to work in Pennsylvania and with members of your fine staff.

With kind regards,

James A. Doolittle
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cc:
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Equipment:
The EM31 and EM38DD meters were used in this study. Both meters are manufactured by Geonics Limited (Mississauga, Ontario).[1] These meters are portable and require only one person to operate. No ground contact is required with either meter. Lateral resolution is approximately equal to the intercoil spacing.

McNeill (1980) has described the 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 provides theoretical penetration depths of about 3 and 6 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1980).

Operating procedures for the EM38DD meter are described by Geonics Limited (2000). The EM38DD meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, the EM38DD meter provides theoretical penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively.

The Geonics DAS70 Data Acquisition System 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, and a Garmin Global Positioning System Map 76 receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack).[1] With the acquisition system, the EMI meter is keypad operated and measurements are automatically triggered.

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

Discussion:
<u>Honey Hollow Watershed, Bucks County:</u>
The Honey Hollow Watershed Conservation Area is the first upland watershed dedicated to conservation and flood prevention in the United States. The watershed was created in 1939 and consists of five farms totaling 650 acres. Honey Hollow Watershed is located just west of Solebury, Pennsylvania, along PA Highway 263. The watershed is used to demonstrate soil, water, and wildlife conservation and flood prevention through local cooperative planning and action.

An EMI survey was competed on a grassed field that contained a sampled pit of Penn soil (03PA017001). The area is underlain by colluvium derived from principally limestone. The underlying parent rock is limestone on higher-lying slopes (northwest) and sandstone on lower-lying slopes (southeast). The EM31 meter was operated in the vertical dipole orientation and continuous mode with measurements recorded at 1-sec intervals. The meter was held at hip-height with its long axis parallel to the direction of traverse. Walking at a fairly brisk and uniform pace, in a random back and forth pattern across the field, the EM31 meter recorded 981 geo-referenced measurements.

The area was very resistive and apparent conductivity measurements were exceeding low. Apparent conductivity averaged 10.9 mS/m with a range of -26.3 to 99.1 mS/m. The rather extreme range in EC_a reflects the presence of buried utility lines and other artifacts. Extreme values of EC_a were recorded near these buried cultural features. Across most of this site, EC_a was rather invariable. One half the observations had an EC_a between 7.4 and 10.9 mS/m.

Figure 1 is a choropleth map showing the spatial distribution of EC_a measured with the EM31 meter. In Figure 1, the color interval is 1 mS/m. The EMI traverse line and observation points are shown in Figure 1. Though spatial resolution is poor, the general tracks of two buried utility lines are evident in this plot. The presence of

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

these lines was unknown to soil scientists when a sample pit was excavated at this site. This site demonstrates the value of EMI to detect buried utility lines prior to digging.

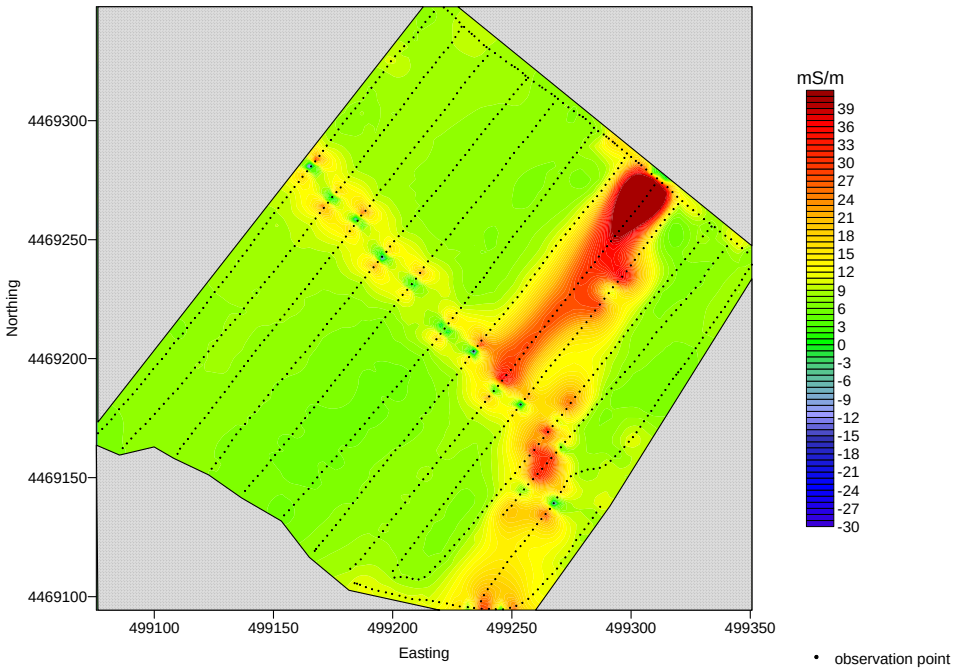

Figure 1. Map of EC_a obtained with the EM31 meter in an area of Penn-Lansdale complex, 8 to 15 percent slopes, (Tompkins, 1975) at the Honey Hollow Watershed, Bucks County.

With the exception of the two utility lines, spatial patterns of EC_a shown in Figure 1 are nondescript. Neither areas of Penn (fine-loamy, mixed, superactive, mesic Ultic Hapludalfs) nor Lansdale (coarse-loamy, mixed, mesic Typic Hapludults) soils were distinguishable with EMI. The change in parent rock (limestone to sandstone) either lacked sufficient contrast in electromagnetic properties or was masked by the overlying colluvium, and was therefore not identifiable with EMI.

Cedar Meadow Farm, Lancaster County:

Cedar Meadow is a 175-acres farm devoted to the production of vegetables. The farm is located in the township of Holtwood in southwest Lancaster County, Pennsylvania. In 1999, Steve Groff, owner/operator of Cedar Meadow Farm, received the No-Till Innovator award at the National No-Tillage Conference for his work in developing and implementing no-till crop production methods. Groff was the first vegetable grower in Pennsylvania to use a mechanized no-till planter on a large scale.

A field on the Cedar Meadow Farm was surveyed with an EM38DD meter. This field is mapped as Chester silt loam, 0 to 3 percent slopes (CbA), Glenelg silt loam, 3 to 8 percent slopes (GbB), and Glenelg silt loam, 8 to 15 percent slopes (GbC) (Custer, 1985). The very deep, well drained Chester and Glenelg soil formed in residuum weathered from micaceous schist. Chester and Glenelg are members of the fine-loamy, mixed, semiactive, mesic Typic Hapludults family. Glenelg soil typically has a thinner (< 30 inches) argillic horizon than Chester soil (25 to 45 inches). Depth to saprolite (C horizon) ranges from 18 to 35 inches and 31 to 51 inches for Glenelg and Chester soils, respectively. The C horizon has inherent laminar rock structure. A profile of Chester soil was described and sampled (SO3PA071002) in a pit located in this field (see approximate location in Figure 3). Included with Chester and Glenelg soils in mapping are areas of Elioak soil. Elioak is a member of the fine, kaolinitic, mesic Typic Hapludults family.

Figure 2. Soil polygons and the area (in yellow) surveyed with the EM38DD meter at the Cedar Meadow Farm, Lancaster County.

Walking at a fairly brisk and uniform pace, in a random back and forth pattern across the field, the EM38DD meter recorded 1830 geo-referenced measurements. Apparent conductivity averaged 8.6 mS/m and 9.1 mS/m for measurements obtained with the EM38DD meter in the horizontal and vertical dipole orientations, respectively. In the horizontal dipole orientation, EC_a ranged from -9.4 to 55.6 mS/m with a standard deviation of 9.5 mS/m. In the vertical dipole orientation, EC_a ranged from -9.1 to 19.0 mS/m with a standard deviation of 1.4 mS/m. In cropped areas, a small number of random, negative values are not uncommon and are attributed to noise and interference from discarded farm artifacts.

For the three surveys conducted at this farm, higher values of EC_a were recorded in the shallower-sensing horizontal dipole orientation. At first, this was attributed to the higher clay and moisture contents of the A and Bt horizons. However, soil observations did not confirm this interpretation. In Figure 3, in the plot of data collected in the horizontal dipole orientation (left-hand plot) a noticeable and seemingly natural pattern of negative EC_a is evident along a lower-lying swale in the southern portion of the field. Soils are wetter in this area and therefore would be expected to have a higher EC_a. Also in the left-hand plot, higher EC_a are recorded on the highest and most sloping portions of the landscape. Soils on these landscape components have very channery surface layers and are drier. These conditions should result in lower the EC_a. What is equally unusual is the fact that these patterns are neither repeated nor implied in the plot of EC_a data collected in the vertical dipole orientation (right-hand plot). Both dipole orientations are sensitive to the EC_a of surface layers. Because of this depth-weighted sensitivity, it is common for areas measured with a high EC_a in the horizontal dipole orientation to also have a high EC_a in the vertical dipole orientation. An opposite relationship has been repeatedly observed in the fields of this farm. This uncommon relationship may be attributable to management, magnetic susceptibility, or the weathering sequence of minerals in these soils. The spatial patterns of EC_a observed at this farm contradict all known models for EMI interpretation. Something is affecting the measurements collected in the horizontal dipole orientation. Steve Groff is using innovated methods to manage his fields and it is possible that some of his practices are affecting EC_a measurements. Because of suspicious readings in the horizontal dipole orientation and in preparation for the 18th World Congress of Soil Science, a more extensive EMI survey support by samples which will be analyzed at the National Soil Survey Laboratory is planned.

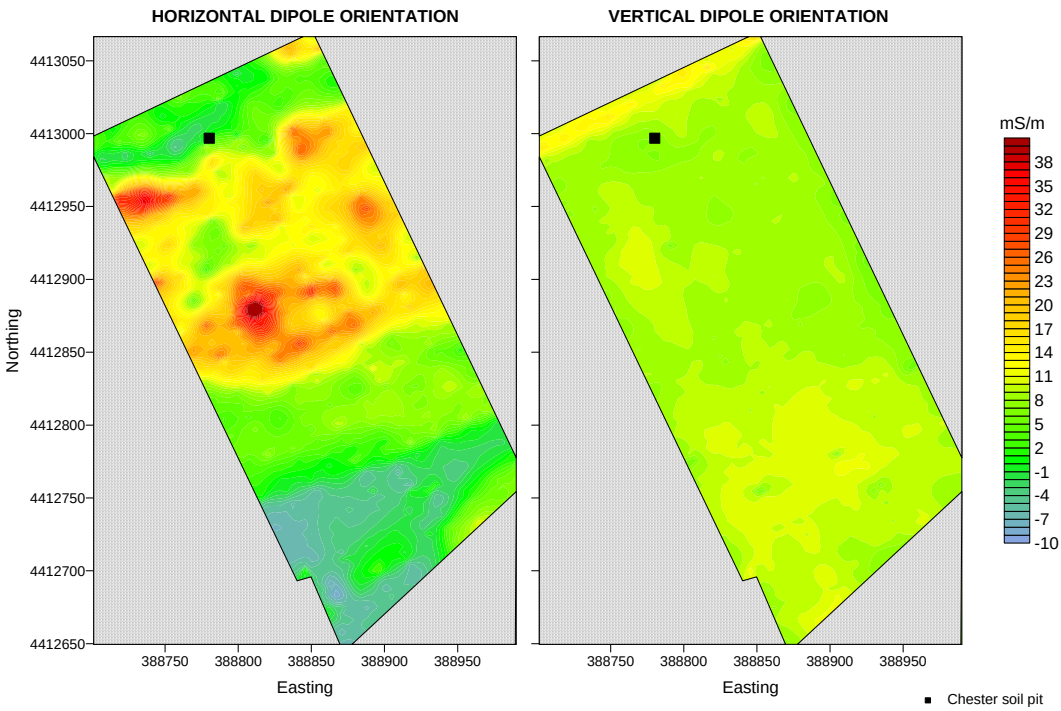

Figure 3. Maps of EC_a obtained with the EM38DD meter at Cedar Meadow Farm, Lancaster County.

Berks County:

The site is located in a small cultivated field in North Heidelberg Township near Mt Pleasant. At the time of the survey the field was fallow and the soils were moist throughout. Soil patterns within the field are intricate with small polygons of Berks-Weikert complex, 25 to 60 percent slopes (BkF); Duffield silt loam, 3 to 8 percent slopes (DbB); Duffield-Ryder silt loams, 8 to 15 percent slopes (DfC); and Duffield-Ryder silt loams, 15 to 25 percent slopes (DfD) (Ackerman, 1970). The moderately deep, well drained Berks and shallow, well drained Weikert soils form in residuum weathered from shale and siltstone. The very deep, well drained Duffield and moderately deep, well drained Ryder soils form in residuum weathered from limestone and calcareous siltstone. The taxonomic classification of these soils is listed in Table 1.

Walking at a fairly brisk and uniform pace, in a random back and forth pattern across the field, the EM38DD meter recorded 924 geo-referenced measurements. Apparent conductivity was comparatively low and invariable across this site. Apparent conductivity averaged 10.2 mS/m and 7.1 mS/m for measurements obtained in the horizontal and vertical dipole orientations, respectively. In the horizontal dipole orientation, EC_a ranged from 2.5 to 19.9 mS/m with a standard deviation of 3.1 mS/m. In the vertical dipole orientation, EC_a ranged from 2.6 to 11.5 mS/m with a standard deviation of 1.4 mS/m. The higher and more variable EC_a in the horizontal dipole orientation was attributed to recent heavy rains and higher soil moisture contents in the surface layers.

Figure 4. Soil polygons and area (bounded by green line) surveyed with the EM38DD meter in Berks County.

Figure 5 is the EC_a maps resulting from this survey. These maps are unremarkable. The field's periphery was noticeable drier than the field's interior. This could account for the slightly higher EC_a measured in the horizontal dipole orientation across the field's interior. The low and invariable EC_a makes this site poorly suited for a demonstration of EMI at the 18th World Congress of Soil Science. The low conductivity of this and similar sites in Berks County would be more suitable for a demonstration of ground-penetrating radar.

Table 1. Taxonomic classifications of soils surveyed with EMI in Berks County.

Series	Taxonomic classification
Berks	Loamy-skeletal, mixed, mesic Typic Dystrochrepts
Duffield	Fine-loamy, mixed, mesic Ultic Hapludalfs
Ryder	Fine-loamy, mixed, mesic Ultic Hapludalfs
Weikert	Loamy-skeletal, mixed, mesic Lithic Dystrochrepts

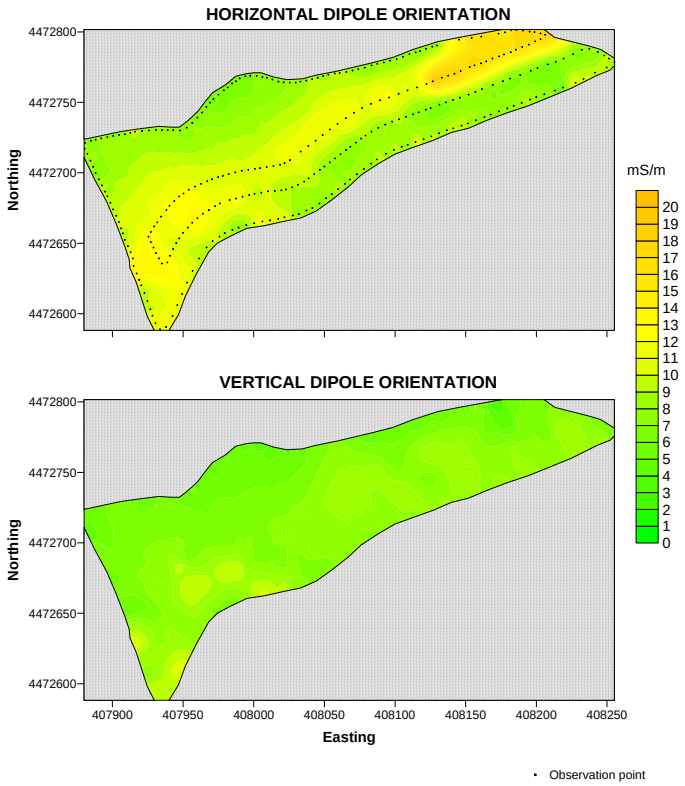

Figure 5. Maps of EC_a obtained with the EM38DD meter in Berks County.

References:

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