United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI – Geophysical Field Assistance **Date:** 8 April 2004

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. Two 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
Kefeni Kejela, Soil Scientist, USDA-NRCS, Leesport, PA
Vicki Meyers, Soil Scientist, USDA-NRCS, Leesport, PA
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Activities:
All field activities were completed during on 22 to 24 March 2004.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR System-3000 is backpack portable. With an antenna, this system requires two people to operate. A 200 MHz antenna was used in the studies described in this report.

The RADAN for Windows (version 5.0) software program developed by Geophysical Survey Systems, Inc., was used to process the radar records. [1] Processing included setting the initial pulse to time zero, color table and transformation selection, marker editing, distance and surface normalization, and range gain adjustments. In addition all radar records were migrated to remove hyperbola diffractions and to correct the geometry of steeply dipping layers.

The electromagnetic induction meter used is the EM38DD, which is manufactured by Geonics Limited.[1] Operating procedures are described by Geonics Limited (2000). The EM38DD meter is portable and requires only one person to operate. No ground contact is required with this meter. The EM38DD meter operates at a frequency of 14,600 Hz. It has effective penetration depths of about 0.75 and 1.5 m in the horizontal and

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

vertical dipole orientations, respectively. The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One meter acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one meter acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on).

The Geonics DAS70 Data Acquisition System, developed by Geonics Limited, was used to record and store both EMI and GPS data. The acquisition system consists of the EM38DD meter, an Allegro field computer, and a Trimble AG114 GPS receiver.[2] With the logging system, the EM38DD meter is keypad operated and measurements are automatically triggered.

To help summarize the results of the EMI survey, the SURFER for Windows, version 8.0, developed by Golden Software, Inc., was used to construct a two-dimensional simulation.[2] The grids was created using kriging methods with an octant search.

Results:

1. At Honey Hollow Farm, GPR was used to characterize the depth and thickness of saprolite, provide a semi-quantitative assessment of the number of rock fragments in the soil, and a reasonable estimate of the depth and structure of the underlying bedrock.

2. The EMI survey at Honey Hollow farmed revealed the presence of two underground utility lines. Electromagnetic responses were noticeably lower and negative on a structural bench.

3. At Cedar Meadow Farm, a second high-intensity EMI survey was completed of a field. Temporal and spatial variations in EC_a between the two surveys were compared. Soils and underlying lithologies are considered electrical resistive. In both years, higher values of EC_a were recorded in the shallower sensing horizontal dipole orientation. This was attributed to the higher clay and moisture contents of the A and Bt horizons. However, soil descriptions taken from 20 sample points did not confirm this interpretation. For measurements obtained in the horizontal dipole orientation, the most strikingly dissimilar spatial pattern was a linear, northwest to southeast tending zone of lower EC_a that was only noticeable in the 2003 data. This zone was not repeated in the 2004 data and is suspected to be an artifact produced by equipment malfunctioning, noise, or field interference.

4. EMI surveys were completed at both Honey Hollow and Cedar Meadows Farms. At both sites, anomalous EMI measurements were attributed to magnetic susceptibility. Because of suspicious readings in the horizontal dipole orientation, additional surveys need to be conducted at Cedar Meadows Farms if EMI is to be demonstrated here for the 18th World Congress of Soil Science. Additional EMI surveys on other fields own by Steve Groff (either adjoining or distant) or one of his neighbor's fields may help to clarify the nature of the suspicious EC_a reading obtained with the EM38DD meter in the horizontal dipole orientation.

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

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:

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

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Discussion:

Honey Hollow Watershed:

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.

GPR:

Three sites within the watershed were examined with GPR. These sites are referred to as the Lansdale taxadjunct, Steinsburg (Lansdale taxadjunct, loamy-skeletal), and Penn taxadjunct.

The Lansdale taxadjunct site is located in a wooded area that had been mapped as Lansdale loam, 15 to 25 percent slopes (Tompkins, 1975). The deep and very deep, well drained Lansdale soil formed in residuum weathered from sandstone and/or conglomerate on uplands. Lansdale soil is moderately deep to sparolite (C horizon) and deep or very deep to sandstone bedrock (R). Lansdale is a member of the coarse-loamy, mixed, mesic Typic Hapludults family. Near the area traversed with GPR, a pit had been opened and the soil sampled (03PA017003) was classified as Lansdale taxadjunct (fine-loamy, mixed, mesic Typic Hapludults).

Figure 1 is a representative radar record from this area of Lansdale soil. In Figure 1, the depth scale is in meters and the white vertical marks at the top of the radar record are spaced about 5 m apart. The depth scale is based on the depth to a known reflector (see "A" in Figure 1) that was buried at a depth of 48 cm. Based on this depth, the velocity of propagation through the upper part of the soil was estimated to be about 0.12 m/ns and the dielectric permittivity (E_r) about 6. The vertical scale is exaggerated on this radar record. In Figure 1, horizon designations conform to those described in the sampled soil pit.

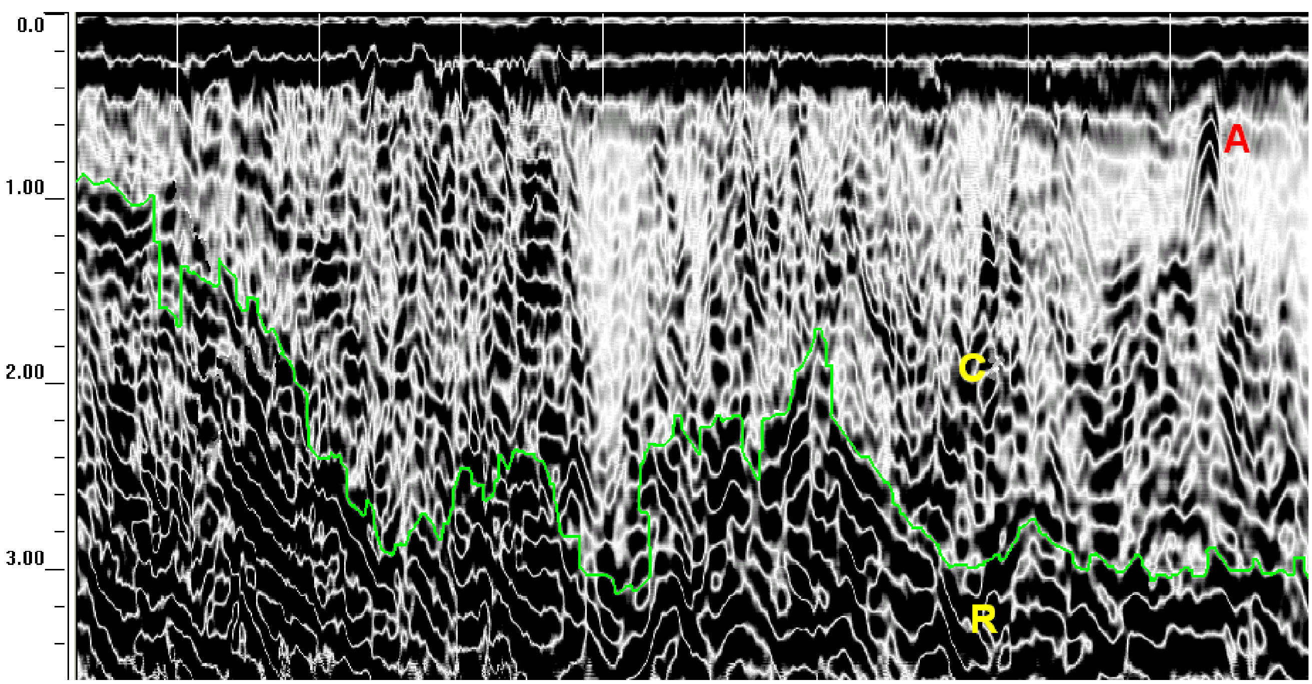

Figure 1. The depth to sandstone bedrock is highly interpretive in this radar record from a wooded area of Lansdale soil.

Although the 200 MHz antenna achieved satisfactory penetration depth and excellent resolution of subsurface features, the interface separating the C horizon from bedrock is indistinct (the C horizons grades into a Cr horizon with increasing depth in the sampled Lansdale soil). As evident on this radar record, the C horizon contains a large number of high-amplitude point reflectors that increase in number and grade into more continuous and inclined reflectors that area presumed to represent highly fractured sandstone bedrock with increasing depth. The contact separating the C and Cr horizons has not been interpreted, as it is transitional and too ambiguous to define. In Figure 1, a green line has been used to highlight the interpreted C/R interface. This interface is poorly expressed and also difficult to define. In Figure 1, the interpreted C/R interface varies in depth from about 90 to 310 cm. However, it is expected that interpretation errors as great as 50 cm can occur.

In similar areas of Lansdale soil, GPR can be used to characterize the depth and thickness of the C horizon, provide a semi-quantitative assessment of the number of rock fragments in the soil, and a reasonable estimate of the depth and structure of the underlying sandstone bedrock.

The Steinsburg site is located in a hay field and in an area that had been mapped as Penn-Lansdale complex, 8 to 15 percent (Tompkins, 1975). A radar traverse line was established across the crest and side slopes of an interfluve. Near the area traversed with GPR, a pit had been opened and the soil sampled (03PA017002) was classified as Lansdale taxadjunct (loamy-skeletal, mixed, mesic Typic Hapludults). The site has been named for the recognized dominance of Steinsburg soils within the mapped area. The moderately deep and well drained Steinsburg soil formed in residuum weathered from weakly cemented acid sandstone, arkosic sandstone, and conglomerate on uplands. Depth to sparolite ranges from about 25 to 75 cm. Steinsburg is a member of the coarse-loamy, mixed, active, mesic Typic Dystrudepts family.

Figure 2 contains a soil profile and a representative radar record from this area of Steinsburg soil. On the soil profile, the depth scale is about 190 cm with increments labeled at 20 cm intervals along the measuring tape. Highly weathered and soft bedrock extends from a depth of about 60 to 80 cm to the bottom of the exposed soil profile.

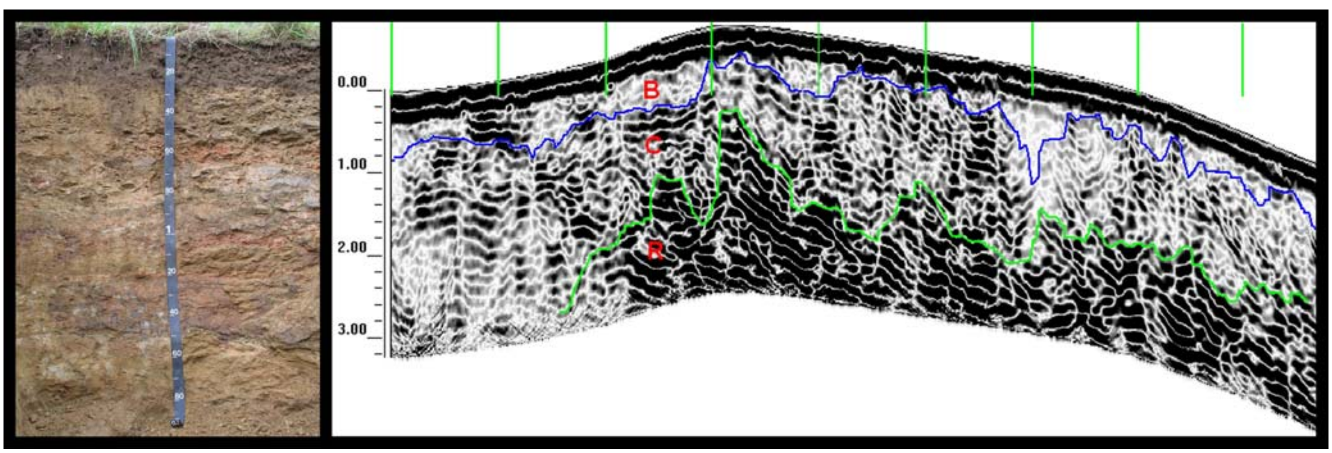

Figure 2. The depth to shale bedrock is shown in these soil and "surface-normalized" radar profiles of Steinsburg soil. The soil profile is courtesy of John Chibirka.

On the radar record, the depth scale is in meters and the white vertical marks at the top of the radar record are spaced about 5 m apart. Based on hyperbola-matching processing techniques (the shape of a hyperbole is dependent on signal velocity), the velocity of propagation decreased with depth, but over the scanned depth averaged about 0.10 m/ns (E_r of 8). This velocity of propagation was used to scale the radar record. On the radar record the maximum depth is about 3.2 m. In Figure 2, the radar record has been terrain corrected to improve the visual presentation. Through a process known as "surface normalization" elevations are assigned to each reference point and the radar record is corrected for changes in elevation. Surface normalization adjusts the vertical scale to conform to changes in topography. Through surface normalization, a more accurate depiction of soil depth and bedrock structure with landform position is provided.

Once again, the 200 MHz antenna provided satisfactory penetration depth and resolution of subsurface features. The B and C horizons (a Cr horizon was described in the sampled soil pit but not in the official series description for the Steinsburg series) as well as the underlying sandstone bedrock (R) have been labeled on the radar record. On the radar record in Figure 2, blue and green lines have been used to highlight the interpreted B/C and C/R interfaces, respectively. The interpreted depths to the C horizon range from about 35 to 145 cm. The interpreted depths to the R horizon range from 105 to more than 300 cm. As evident on this radar record, the B horizon is relatively free of coarse fragments. The C horizon contains a large number of high-amplitude reflections that appear to increase with increasing depth. Some of these reflectors are similarly aligned, inclined, and appear to represent fractured bedding planes that extend upwards from the underlying bedrock. The C/R interface has been defined as the closest point at which high-amplitude, well-defined, continuous, inclined reflectors approach the soil surface. This interface is poorly expressed and difficult to define. As shown in the radar record, depths to C horizon and bedrock appear shallowest on the crest of the interfluve and are deeper on side slopes. Within the bedrock, bedding planes slope to the right (southeast). The inclination of the bedding planes will influence ground water flow and soil development.

The Penn taxadjunct site was located in a grassed field in an area that had been mapped as Penn-Lansdale complex, 8 to 15 percent slopes (Tompkins, 1975). The moderately deep, well drained Penn soil formed in materials weathered from Triassic age noncalcareous reddish shale, siltstone, and fine-grained sandstone on uplands. Penn is a member of the fine-loamy, mixed, superactive, mesic Ultic Hapludalfs family. A radar traverse line was established across what appears to be a structural bench. The traverse line was orthogonal to the long axis of the bench and crossed portions of the adjoining risers. Near the area traversed with GPR, a pit had been opened and the soil sampled (03PA017001) as Penn deep (fine-loamy, mixed, mesic Ultic Hapludalfs).

Figure 3 contains a soil profile and a representative radar record from this area of Penn soil. On the soil profile, the depth scale is about 200 cm with increments labeled at 20 cm intervals along the measuring tape. Near the tape, the reddish brown to strong brown Bt horizon extends from a depth of about 25 to 60 cm. Bedrock (Stockton formation) is evident at a depth of about 150 cm in the lower part of the exposed soil profile.

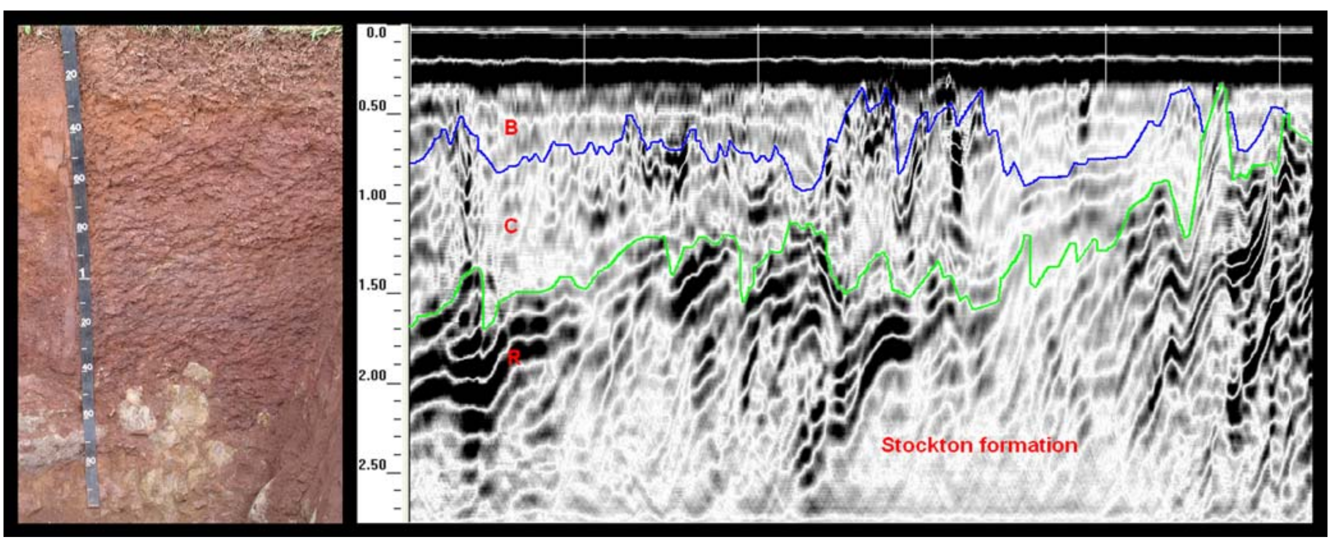

Figure 3. The depth to bedrock as showed in these soil and radar profiles of Penn soil. The soil profile is courtesy of John Chibirka.

On the radar record, the depth scale is in meters and the white vertical marks at the top of the radar record are spaced about 10 m apart. Based on hyperbola-matching processing techniques, the velocity of propagation averaged about 0.08 m/ns (E_r of 14). This velocity of propagation was used to scale the radar record. In the radar record the maximum depth is about 2.8 m.

On the radar record in Figure 3, blue and green lines have been used to highlight the interpreted B/C and C/R interfaces, respectively. Both interfaces are highly irregular in depth and variable in expression. Higher amplitude reflections represent more abrupt and contrasting changes in dielectric properties. The B horizon is relatively free of high-amplitude reflectors, which in this record are inferred to represent coarse fragments. The C horizon consists of medium-amplitude inclined parallel reflectors that contain areas of higher-amplitude reflectors. The C horizon is saprolite that contains a large number of less weathered or more resistant rock materials. The interpreted depths to the C horizon range from about 40 to 100 cm. The C/R interface has been defined as the closest point at which high-amplitude, continuous, inclined reflectors approach the soil surface. In places, this interface is poorly expressed and difficult to define. The interpreted depths to the R horizon range from about 40 to more than 170 cm.

In Figure 4, a portion of the radar record that is shown in Figure 3 has been terrain corrected to improve the visual presentation. Compare with the radar record in Figure 3, the terrain corrected image shows bedding planes that are less inclined and more horizontal. Surface normalization has also improved the depiction of bedrock depths with landscape position. Depths to bedrock are noticeably shallower on the tread and on the upper part of the risers slope to the structural bench. The bedrock interface plunges to deeper depths on the lower riser slope component. Here deep layers of colluvium attenuate the radar signal and make the soil/bedrock interface less distinct.

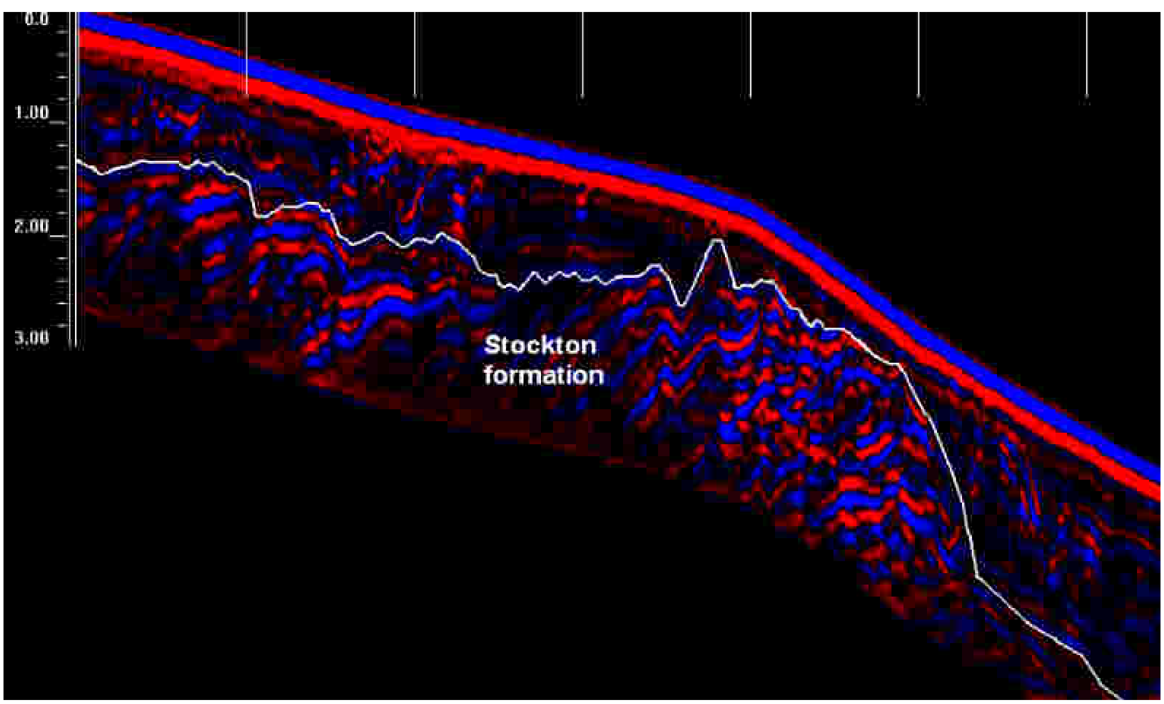

Figure 4. The interpreted depth to the Stockton formation is shown with a white line in this "surface-normalized" radar record of Penn soil on a structural bench. .

<u>EMI:</u>
An EMI survey was competed in the grassed field that contained the pit sampled (03PA017001) as Penn deep. The EM38DD meter was operated in the continuous mode with measurements recorded at 1-sec intervals. The EM38DD was held about 3 inches above the ground surface 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 EM38DD meter recorded 1807 geo-referenced measurements.

Basic statistic for apparent conductivity (EC_a) measured with the EM38DD meter is listed in Table 1. The area was very resistive and apparent conductivity measurements were exceeding low. Apparent conductivity averaged about 7.4 and 1.8 mS/m for measurements obtained in the shallower-sensing, horizontal and in the deeper-sensing, vertical dipole orientations, respectively. Apparent conductivity ranged from about -8.5 to 43.6 mS/m with a standard deviation of about 3.8 mS/m in the vertical dipole orientation. Apparent conductivity ranged from about -1.1 to 25.9 mS/m with a standard deviation of about 3.7 mS/m in the horizontal dipole orientation.

Table 1. Apparent Conductivity Data collected with the EM38DD meter.
(All values are in mS/m)

	Horizontal Dipole	Vertical Dipole
Average	7.39	1.79
Standard Deviation	3.69	3.75
Minimum	-1.1	-8.4
Maximum	25.9	43.6
25% Quartile	5.25	0.25
75% Quartile	8.15	2.92

The values obtained at this site were not only low, but also suspected of interference from *magnetic susceptibility*. Many soils and rocks are either weakly magnetic or are susceptible to induced magnetization in the presence of an ambient field. Induced magnetization is directly proportional to the intensity of the ambient field and the soils ability to enhance this locally induced field. A soils ability to enhance the local field of an EMI meter and cause anomalous responses is called *magnetic susceptibility*. The magnetic properties of soils are principally determined by the presence of iron. While the magnetic properties of soils is principally determine by the presence of maghemite and magnetite, hydrated iron oxides such as muscovite, dolomite, lepidocrocite, and geothite also contribute to the magnetic susceptibility of soils. At Honey Hollow and Cedar Meadows Farm, anomalous EMI measurements were attributed to magnetic susceptibility. Both of these sites are located on the Piedmont, an area that I have repeatedly observed what I consider to be problems associated with magnetic susceptibility when conducting EMI surveys.

Figure 5 contains choropleth maps showing the spatial distribution of apparent conductivity collected with the EM38DD meter. In each map, color variations have been used to show the distribution of apparent conductivity. In each plot the color interval is 2 mS/m. Two buried utility lines are evident in these plots. Though information was properly submitted, the locations of these lines were unknown to soil scientists when a sample pit was excavated at this site. The left-hand plot show data collected in the shallower sensing, horizontal dipole orientation. The north-northeasterly trending utility line is best expressed in this plot and therefore is assumed to be more shallowly buried. The west-northwesterly trending utility line, though evident in the left-hand plot, is best expressed in the right-hand plot, which contains the data collected in the deeper-sensing, vertical dipole orientation. Therefore, this line is assumed to be more deeply buried.

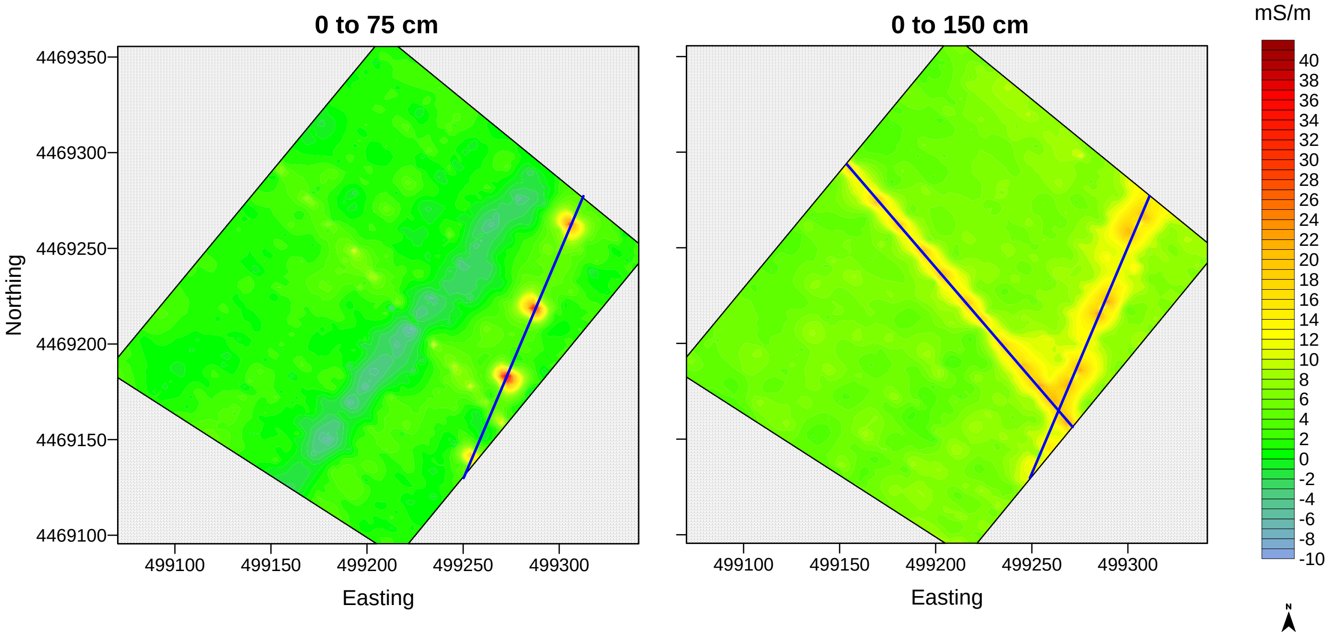

Figure 5. Maps of apparent conductivity obtained with the EM38DD meter in an area that had been mapped as Penn-Lansdale complex, 8 to 15 percent slopes at the Honey Hollow Watershed.

With the exception of the two utility lines, the spatial patterns of apparent conductivity shown in these plots are generally nondescript. The location of the structural bench is well defined by negative values in the left-hand plot of Figure 5. However, no other noteworthy features or spatial patterns are evident in these plots.

Cedar Meadow Farm:

Cedar Meadow is a 175-acres farm devoted to the production of corn, soybeans, alfalfa, tomatoes, pumpkins, and small grains. 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 on his farm. Groff was the first vegetable grower in Pennsylvania to experiment with using a mechanized no-till planter on a large scale.

Electromagnetic induction is being extensively used in precision agriculture. Electromagnetic induction provides a fast, economical, and noninvasive method for mapping soils. Because of its speed and ease of use, EMI has significant advantages over conventional soil survey techniques. Maps of apparent conductivity (EC_a) have been used as a substitute for soil survey maps. Because of the larger number of observations, EC_a maps can provide higher levels of resolution and are assumed to be more accurate than soil maps prepared with conventional methods (Jaynes, 1995). However, as soil scientists cluster observations into polygons that are determined by observed soil properties, supported by supplementary tactile information (such as plant response, topography, etc.), and delineated with the aid of remotely sensed data, it is unclear whether soil or EC_a maps provide more meaningful and useful information.

A field on the Cedar Meadow Farm was resurveyed with an EM38DD meter. This field had been mapped as Glenelg silt loam, 3 to 8 percent slopes (Custer, 1985). The very deep, well drained Glenelg soil formed in residuum weathered from micaceous schist. Glenelg is a member of the fine-loamy, mixed, semiactive, mesic Typic Hapludults family. The particle-size control section is 20 to 35 percent clay. Depth to sparolite (C horizon) ranges from 18 to 35 inches. The C horizon has inherent laminar rock structure.

Table 2. Basic statistics for EC_a data collected with the EM38DD meter at the Cedar Meadow Farm in April 2003 and March 2004.
(All values are in mS/m.)

	2003		2004	
	HDO	**VDO**	**HDO**	**VDO**
Average	20.7	6.9	18.8	6.8
Standard Deviation	7.7	1.8	6.6	1.8
Minimum	0.7	2.2	-11.8	-2.1
Maximum	37.6	15.3	31.7	17.4
25% Quartile	14.5	5.5	13.7	5.6
75% Quartile	27.2	8.2	24.3	7.9

Basic statistics for the data collected with the EM38DD meter in 2003 and 2004 are shown in Table 2. In each year, the EMI survey was completed in the spring, soil temperatures were similar (about 46^o F at 50 cm), and EC_a data were not corrected to a standard temperature (75^o F). The basic statistics for the EC_a data collected during these two surveys are remarkably similar. Data collected in the vertical dipole orientation are nearly identical; larger variations occurred in the data sets collected in the horizontal dipole orientation, but were considered within normal observation errors. In each survey, EC_a decreased and became less variable with increasing observation depths.

In the 2004 survey, EC_a averaged 18.8 mS/m and 6.8 mS/m for measurements obtained in the horizontal and vertical dipole orientations, respectively. In the horizontal dipole orientation, apparent conductivity ranged from about -12 to 32 mS/m with a standard deviation of 6.6 mS/m. In the vertical dipole orientation, apparent conductivity ranged from about -2 to 17 mS/m with a standard deviation of 1.8 mS/m.

Figure 6 compares the temporal and spatial variations in EC_a between the two surveys. In general, the soils and underlying lithologies are considered electrical resistive. In both years, higher values of EC_a were recorded in the shallower-sensing horizontal dipole orientation (upper plots in Figure 6). This can be attributed to the higher clay and moisture content of the A and Bt horizons. In both of the upper plots of Figure 6, higher values of EC_a were measured in the more sloping areas of the field. It was initially presumed that the depth to the argillic horizon was shallower, the argillic horizon contains slightly more clay, and/or the surface layers are heavier in these portions of the field. However, soil descriptions taken from twenty sample points (shown in Figure 6) did not confirm these interpretations. For measurements obtained in the horizontal dipole orientation, the most striking difference in spatial patterns between the two years is the linear, northwest to southeast tending zone of lower EC_a that is apparent in the 2003 data. This zone parallels the northern field boundary. This zone is not repeated in the 2004 data and is suspected to be an artifact produced by equipment malfunctioning, cultural noise, or field interference.

In the lower plots of Figure 6, values of EC_a measured in the vertical dipole orientation are very low and invariable across the field. These characteristics are attributed to the lower clay and moisture contents of the saprolite and the suspected uniformity of underlying lithologies.

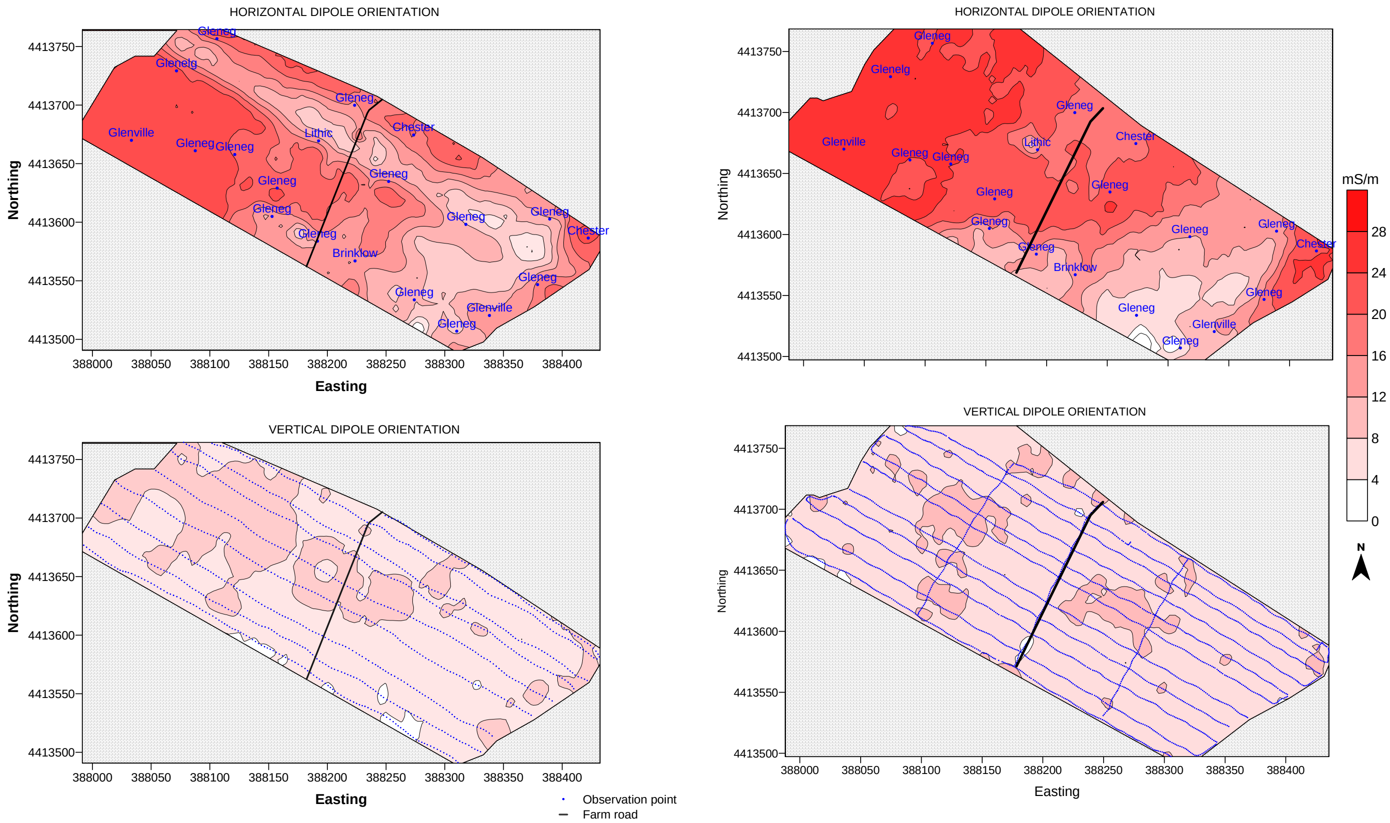

Figure 6. Maps of apparent conductivity obtained with the EM38DD meter in 2003 and 2004 from an area that had been mapped as Glenelg silt loam, 3 to 8 percent slopes.

For both surveys, the EM38DD meter was difficult to calibrate at this site. Calibrations conducted in the western portion of the field resulted in negative horizontal dipole measurements in the eastern portion of the field. Calibrations conducted in the eastern portion of the field resulted in inflated horizontal dipole measurements in the western portion of the field. Differences in the site of calibration did not appear to affect measurements taken with the EM38DD and EM31 meters in the vertical dipole orientation.

Something is affecting the measurements collected in the horizontal dipole orientation. As no differences were detected in the measurements collected in the vertical dipole orientation, the meter seemingly is being affected by conditions or properties above or in the upper part of the soil. At a different site, the EM38DD meter was compare with an EM38 meter; results were similar and no problems were observed during calibration. Cedar Meadow Farm is located to the east of Three Mile Island and soil contamination may be a factor. Steve Groff is using innovated methods to manage his fields and it is possible that some of his practices or measures are affecting EC_a measurements. As discussed earlier in this report, EC_a measurements may be influenced by *magnetic susceptibility*. The magnetic susceptibility of soils is principally determined by the presence of iron.

Because of suspicious readings in the horizontal dipole orientation, additional surveys need to be conducted at this site if EMI is to be demonstrated here for the 18th World Congress of Soil Science. An EMI survey of other fields own by Steve Groff (either adjoining or distant) or one of his neighbor's fields may help to clarify the nature of the distrusted reading obtained with the EM38DD meter in the horizontal dipole orientation.

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