United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI – Geophysical Field Assistance **Date:** 22 March 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. Several sites selected for the Mid-Congress tours were visited. The suitability of ground-penetrating radar (GPR) and electromagnetic induction (EMI) for agronomic, soil, and hydrologic investigation at these probable Mid-Congress tour sites was evaluated. In addition, a GPR survey was completed in an area of Chrome soil in Chester County.

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 22 to 24 March l 2004.

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2000, 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-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. The model 5106 (200 MHz) antenna was used in this study.

The RADAN NT (version 2.0) software program was used to process the radar records (Geophysical Survey Systems, Inc, 2001).[1] Processing included color transformation, marker editing, distance and surface normalization, and range gain adjustments. All radar records were converted into bitmap images using the Radan to Bitmap Conversion Utility (version 1.4) developed by Geophysical Survey Systems, Inc.[2]

The electromagnetic induction meter used in this study was the EM38DD, manufactured by Geonics Limited.[2] Geonics Limited (2000) describes the operating procedures of this meter. The EM38DD meter is portable and requires only one person to operate. No ground contact is required with this meter. The EM38DD 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 vertical dipole orientations, respectively. The EM38DD meter consists of two EM38 meters bolted together and

[1] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

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 was used to record and store both EMI and GPS (global positioning system) data.[2] The acquisition system consists of an EM38DD meter, Allegro field computer, and Trimble AG114 GPS receiver. With the logging system, the EM38DD meter is keypad operated and measurements can either be automatically or manually triggered.

To help summarize the results of this study, the SURFER for Windows (version 8) program, developed by Golden Software, Inc.,[2] was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search.

Results:

1. At Cedar Meadow Farm, a high-intensity apparent conductivity maps were prepared of a cultivated field using EMI. The field had been mapped as Glenelg soil. EMI responses were more variable and informative in the shallower-sensing horizontal dipole orientation than in the deeper-sensing vertical dipole orientation. The shallower-sensing, horizontal dipole measurements appear to respond principally to differences in the clay and moisture content of the A and Bt horizons. The highest EMI responses were measured in the more sloping areas of the field. In these portions of the field, it is possible that the depth to the argillic horizon is shallower, the argillic horizon contains slightly more clay, and/or the surface layers are heavier. Low readings in the horizontal dipole orientation are attributed to shallower depths to saprolite, thicker, lighter-textured surface layers, and/or deeper depths to the argillic horizon. Shallow measurements were lowest along a ridgeline that extends across the field and parallels the northeast field boundary. Here, soils are presumed to be shallower to more resistive bedrock.

2. At the Stroud Water Research Center GPR was used to map the thickness and distribution alluvium along White Clay Creek and to differentiate upland from floodplain soils.

3. In an area of Chrome soils, GPR provide a suitable means for determining the depth to saprolite materials where the C horizon occurs within depths of 1.2 m.

4. Bitmaps of the included radar records have been forwarded to Ed White and John Chibirka for distribution to the participants (Steve Groff, Stroud Water Research Center, and Honey Hollow Watershed Conservation Area).

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

With kind regards,

James A. Doolittle
Research Soil Scientist

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Discussion:

<u>Chrome Soil:</u>

The soil survey of Chester County, Pennsylvania, is being digitized and updated. Serpentine rock outcrops in portions of Chester County as well as in adjoining counties of southeastern Pennsylvania and north-central Maryland. Soils formed over serpentine are often low in essential nutrients and have high concentrations of metals (nickel and chromium) that are toxic to many plant species. Unique plant communities grow on these soils. These unique plant communities have almost no species common with the surrounding forest or fields. Known as *serpentine barrens,* prairie grasses and pitch pines form dominant communities.

The moderately deep, well-drained Chrome soil formed in residium weathered mostly from serpentine. In Chester County, Chrome soil has been mapped on the serpentine barrens (Kunkle, 1963). Chrome is a member of the fine, mixed, mesic Typic Hapludalfs family.

The study site was located in serpentine barrens off of Barren Road, in the town of Oxford near the Maryland line.   Nearby, a representative pedon of Chrome soil had been sampled. Based on laboratory analysis at the National Soil Survey Laboratory, Lincoln, Nebraska, this pedon was classified as a member of the fine, magnesic, active, mesic Typic Hapludalfs family. At the sample site, the depth to the argillic horizon is 18 cm (7 inches). The clay content of the Bt2 horizon is about 35 percent (36 percent silt and 29 percent sand). Depth bedrock is 56 cm (22 inches). Clay mineralogy X-ray analysis of several samples revealed relative peak sizes of medium for vermiculite and talc, and very small for mica, goethite, and quartz.

The velocity of propagation and the dielectric permittivity is moisture dependent and varies with antenna frequency.   Soils were moist in the upper part. For the upper part of the Chrome soil profile, with the 200 MHz antenna, the estimated velocity of propagation was about 0.066 m/ns and the dielectric permittivity was 20. This estimate was based on the depth (25 to 72 cm) to the C horizon in three soil cores and the depth (46 cm) to a buried metallic reflector.

Figure 1 is the radar record from this area of Chrome soil. The short, vertical lines at the top of the radar record represent equally spaced (7.6-m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record.   The broad line approximates the depth to the C horizon (saprolite). Compared with the overlying Bt horizon, the C horizon had inherent highly weathered rock structure, less fines, and was noticeably drier. The C horizon is typically thin and is immediately underlain by serpentine bedrock. The Bt/C interface is distinct to depths of about 1.2 m. Below this depth, high rates of signal attenuation weaken the reflected signals and the interface is less clear and interpretations are ambiguous.

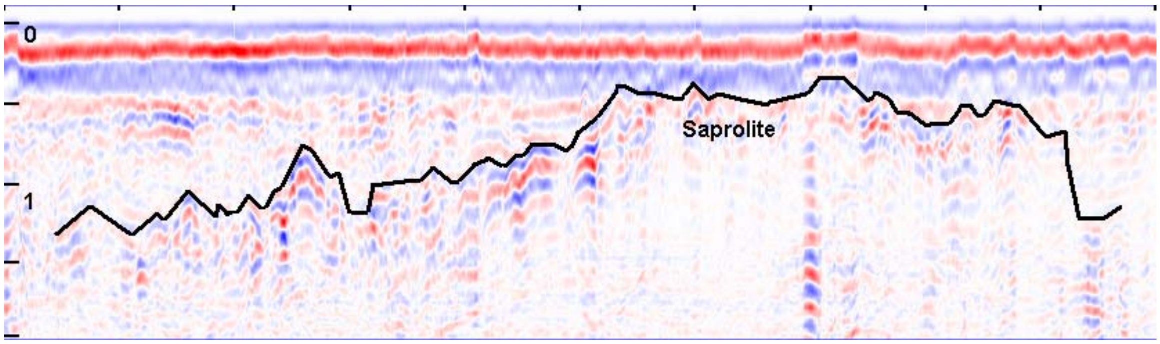

Figure 1. Radar record showing the depth to the C horizon in an area of Chrome soil.

Cedar Meadow Farm, Holtwood, Pennsylvania:

Cedar Meadow is a 175-acres farm devoted to the production of corn, soybeans, alfalfa, tomatoes, pumpkins, and small grains. 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 vegetable transplanter on a large scale. Each summer, Steve Groff, in cooperation with the Pennsylvania Association for Sustainable Agriculture, the Keystone Chapter of the Soil and Water Conservation Society and local agric-businesses and equipment dealers, hosts an educational field day at Cedar Meadow Farm.

A field on the Cedar Meadow Farm was selected for a high-intensity electromagnetic induction (EMI) survey. The availability of information technologies (i.e. computers, GPS, and geographical information systems (GIS)) is changing the way we identify, evaluate, and map spatial and temporal variations in soils. Over the last decade, information technologies have fostered the rapid expansion of site-specific management (also know as precision agriculture, prescription farming, or site-specific farming). Site-specific management attempts to quantify and manage the spatial and temporal variability of soils. The integration of information technologies has spurred the use of yield maps that show patterns of crop response and the effects of variable rate applications. While yield maps show the effects of site-specific management, they do not explain the actual sources of within-field variability. In order to better understand the factors that influence yields, more detailed and accurate soil maps are needed that show the "cause and effect" relationship between soil physical and chemical properties and crop yields.

Soil surveys prepared by the USDA are intended for multipurpose land uses. These surveys describe the variability of soils at scales of 1:12,000 to 1:31,680 (Soil Survey Division Staff, 1993). Soil surveys are not prepared at an appropriate scale to show the variability of soils that are needed for more site-specific interpretations (Fenton and Lauterbach, 1999). Soil surveys use soil map units that contain similar and contrasting inclusions. The amount, size, and location of these inclusions vary within each delineation. Because of scale limitations, areas of similar and contrasting soils are not specifically located nor shown on soil maps (Robert, 1992). While not intended for site-specific management, soil surveys are readily available, and do provide useful spatial and interpretive information on soils for soil-specific management (Robert, 1992).

Electromagnetic induction is a geophysical tool that is being used in precision agriculture. Because of its speed and ease of use, EMI has significant advantages over conventional soil survey techniques. The efficiency of EMI fosters the collection of larger data sets than is possible with conventional soil survey techniques. Because of the larger number of observations, maps based on electromagnetic induction data can provide higher levels of resolution than soil maps prepared with conventional methods (Jaynes, 1995).

The field selected for the EMI demonstration was 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 C horizon ranges from 18 to 35 inches. The C horizon has inherent laminar rock structure.

Figure 2 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 5 mS/m. EMI responses were more variable and informative in the shallower-sensing (0 to 0.75 m), horizontal dipole orientation (upper map) than in the deeper-sensing (0 to 1.5 m), vertical dipole orientation (lower map). The deeper EMI measurements were relatively invariable across the field. This lack of variability is assumed to reflect greater consistency in soil physical and chemical properties with increasing depth. Shallow measurements of apparent conductivity were higher in the more sloping northwest portion of the field. Shallow measurements of apparent conductivity were lowest along a ridgeline that extends across the field and parallels the northeast field boundary. The soils are presumably shallower to more resistive bedrock along this ridgeline.

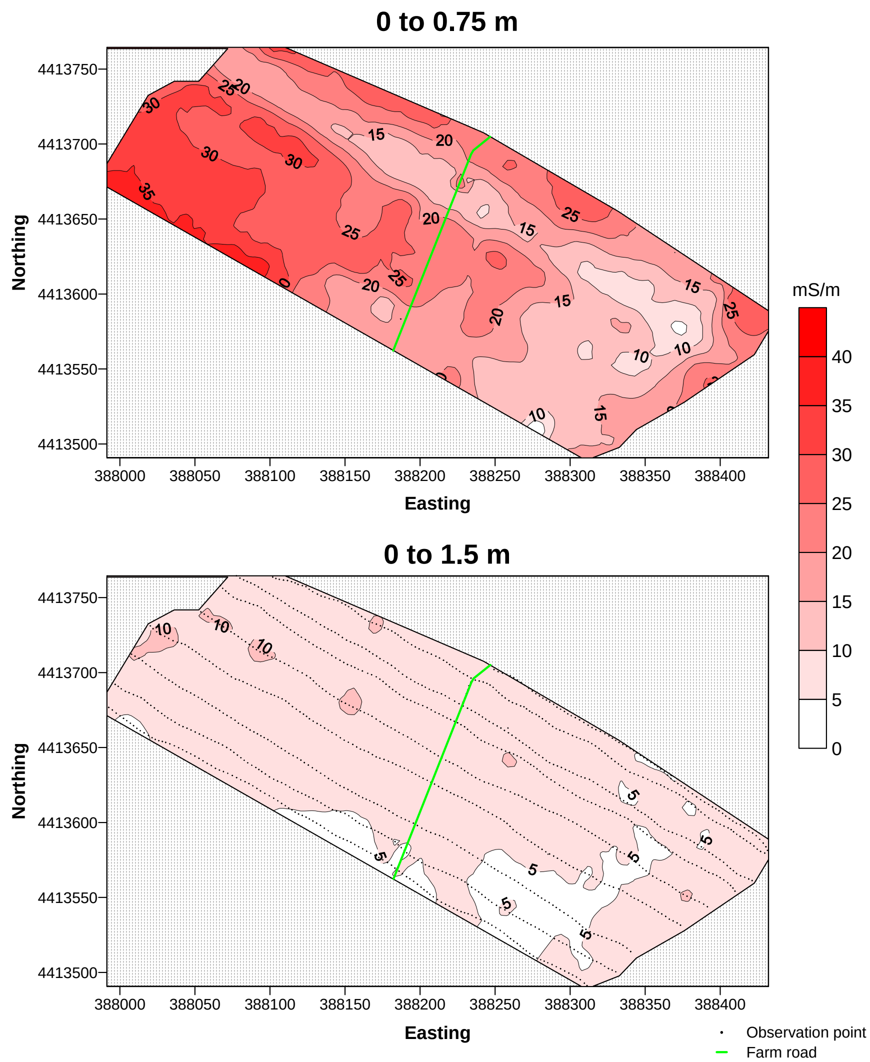

Figure 2. Maps of apparent conductivity obtained with the EM38DD meter in a cultivated area of Glenelg soil at the Cedar Meadow Farm.

In this area of Glenelg soil, the shallow measurements were higher and more variable than the deep measurements. Measurements obtained in the deeper-sensing, vertical dipole orientation are more responsive to the C horizon, which is drier and has a lower clay content than the Bt horizon. The shallower-sensing, horizontal dipole measurements are responding principally to differences in the clay and moisture content of the A and Bt horizons. The highest EMI responses were measured in the more sloping areas of the field. It is possible that the depth to the argillic horizon is shallower, the argillic horizon contains slightly more clay, and/or the surface layers are heavier in this portion of the field. Low readings in the horizontal dipole orientation are attributed to shallower depths to saprolite, thicker, lighter-textured surface layers, and/or deeper depths to the argillic horizon. Patterns look very good in the horizontal dipole orientation and may be associated with crop response. However these interpretations need to be confirmed.

Basic statistics for the data collected with the EM38DD meter are shown in Table 1. Apparent conductivity decreased and became less variable with increasing observation depths. Apparent conductivity averaged 20.7 mS/m and 6.9 mS/m for measurements obtained in the horizontal and vertical dipole orientations, respectively. In the horizontal dipole orientation, apparent conductivity ranged from about 1 to 38 mS/m with a standard deviation of 7.7 mS/m. In the vertical dipole orientation, apparent conductivity ranged from about 2 to 15 mS/m with a standard deviation of 1.8 mS/m.

Table 1. Apparent Conductivity Data collected with the EM38DD Meter in an area of Glenelg soil.
(All values are in mS/m.)

	Horizontal Dipole	Vertical Dipole
Average	20.7	6.9
Standard Deviation	7.7	1.8
Minimum	0.7	2.2
Maximum	37.6	5.3
25% Quartile	14.5	5.5
75% Quartile	27.2	8.2

<u>Stroud Water Research Center, Avondale, Pennsylvania:</u>
The mission of the Stroud Water Research Center (SWRC) is to advance the knowledge of stream and river ecosystems through interdisciplinary research, develop new ecological ideas, solve water resource problems, and promote the understanding of freshwater ecology. On 9 April, the Center was visited, but inclement weather precluded field work. The Mid-Congress tour of the 18th World Congress of Soil Science and possible projects involving the use of geophysical methods were discussed with the SWRC staff. On 28 April, GPR surveys were conducted within the White Clay Creek watershed. The purpose of these surveys were to evaluate the suitability of GPR to map the thickness and distribution of alluvium along White Clay Creek and to differentiate upland soils that have formed over marble and schists within the Stroud Preserve.

Two GPR traverse lines were established across White Clay Creek. The lower traverse, Line A, was established in an open, grassy area adjacent to the Center. This traverse was about 85-m long. Along Line A, relief was about 2.7 m. The upper traverse, Line B, was established in a wooded area. This traverse was about 171-m long. Along Line B, relief was about 14.8 m. Along each traverse line, survey flags were inserted in the ground at intervals of about 6.1-m (20 feet). The survey flags served as reference points. Pulling the 200 MHz antenna along each traverse line completed a radar survey file. As the radar antenna was pulled passed each flagged reference point, the operator impressed a vertical reference mark on the radar record to identify the reference point.

Figure 3 is the radar record from Line A. The short, vertical lines at the top of the radar record represent equally spaced (3.05 m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. Using measured elevation data, the radar record has been terrain corrected using the RADAN NT (version 2.0) software program. The green rectangle approximates the location of White Clay Creek.

To confirm the depth scale and verify radar interpretations, soils were examined at three locations along this traverse lines. Soil identified included Glenville soil on the colluvial side slopes, and Hatboro soil on the flood plain. The very deep, moderately well drained or somewhat poorly drained Glenville soil formed in residuum weathered from mica acid schist and crystalline rock containing mica on uplands. Depth to fragipan is 15 to 30 inches. Glenville is a member of the fine-loamy, mixed, active, mesic Aquic Fragiudults family. The very deep, poorly drained Hatboro soil formed in alluvium on flood plains. Organic carbon decreases irregularly with depth. Typically, the depth to strongly contrasting sand and gravel is more than 40 inches. Hatboro is a member of the fine-loamy, mixed, active, nonacid, mesic Fluvaquentic Endoaquepts family.

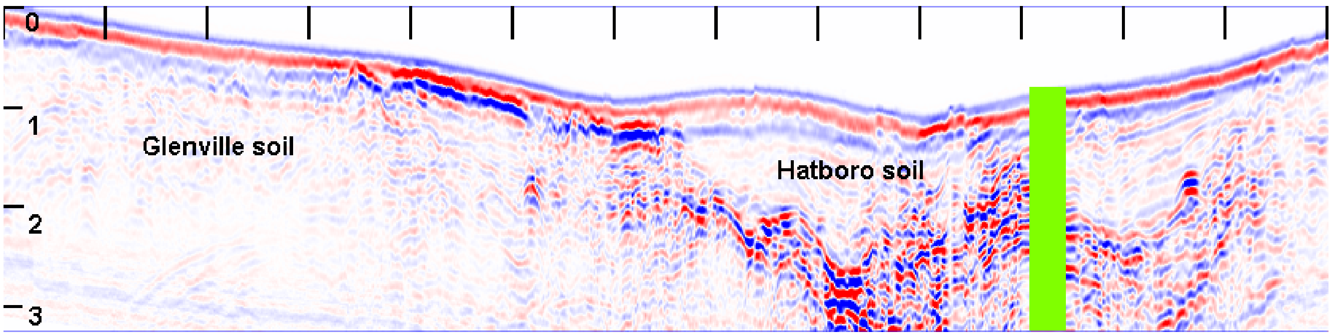

Figure 3. Terrain corrected radar record of Traverse Line A across White Clay Creek at the Stroud Water Research Center.

In Figure 3, the width of the floodplain and the thickness and distribution alluvium along White Clay Creek is apparent. Within the flood plain, the lower-most, high amplitude reflector is believed to represents the lower boundary of the coarser-textured channel fill deposits. Within these deposits, the multiple, segmented, and inclined reflectors represent strata. As these reflectors do not appear to restrict the radar 's observation depth, they are assumed to have low clay contents and to represent layers of coarser-textured soil materials that differ in grain size. In addition, variations in *graphic signatures* can be used to differentiate upland from floodplain soils. Though unconfirmed, faint reflectors that are near and parallel to the soil surface in areas of the Glenville soil may represent the fragipan.

Figure 4 is the radar record from Line B. Because of the length of this traverse line, the radar record has unfortunately been critically reduced in size to fit on this page. Because of this reduction in scale, details within the radar record are illegible. The short, vertical lines at the top of the radar record represent equally spaced (6.1 m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. Using measured elevation data, the radar record has been terrain corrected using the RADAN NT (version 2.0) software program. The green rectangle approximates the location of White Clay Creek.

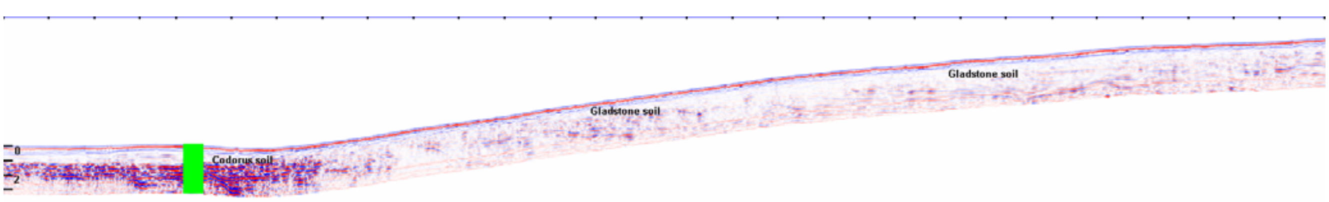

Figure 4. Terrain corrected radar record of Traverse Line B across White Clay Creek at the Stroud Water Research Center.

To confirm the depth scale and to verify radar interpretations, soils were examined at four locations along this traverse line. Soils identified include Codorus soil on the flood plain and Gladstone soil on the uplands. The very deep, moderately well drained and somewhat poorly drained Codorus soil formed in recently deposited alluvial materials on floodplains. Codorus is a member of the fine-loamy, mixed, active, mesic Fluvaquentic Dystrudepts family. The very deep, well drained Gladstone soil formed in residuum and colluvium weathered from granitic gneiss on uplands. Gladstone is a member of the fine-loamy, mixed, active, mesic Typic Hapludults family.

In Figure 4, high-amplitude reflections from stratified and segment alluvial deposits are evident on either side of White Clay Creek in the lower-lying left-hand portion of the radar record. Once again, *graphic signatures* vary with changes in soil type and landscape position. On the higher-lying upland positions, depth to bedrock is typically greater than 60 inches. Gladstone soil has solum that ranges from 30 to 50 inches and is underlain by highly weathered materials that retains original rock structure. In areas Gladstone soil, numerous planar reflections are evident on the radar record. These reflectors are believed to represent foliation (mineral layering) and cleavage planes and are remnants of the original rock structure. The higher amplitude reflections within the saprolite are believed to represent more resistant boudins of quartz. Weaker amplitude reflections are believed to represent fracture or cleavage planes. These planes influence the movement of water and solutes through these uplands.

Honey Hollow Watershed:

The Honey Hollow Watershed Conservation Area is the first small upland watershed in the United States that was in agricultural use to be developed to demonstrate soil, water, and wildlife conservation and flood prevention through local cooperative planning and action. The watershed was created in 1939 and consists of five farms totaling 650 acres. On 10 April, NRCS and Honey Hollow Watershed staffs discussed the 18th World Congress of Soil Science and took a cursory review of the soils within the Conservation Area. At the request of the Executive Director of the Honey Hollow Watershed Conservation Area a reconnaissance archaeological survey was completed using geophysical methods. The GPR unit had malfunctioned and could not be operated. As a consequence, the survey was completed with the EM38DD meter. Electromagnetic induction was not the tool of choice, as it does not provide the resolution of ground-penetrating radar. However, EMI is useful for detecting areas of soil disturbance and some buried cultural features.

The survey site is about 0.04 acre. A 30 by 60 foot grid was established across the site. Survey procedures were simplified to expedite fieldwork. A set of parallel lines defined the east and west boundaries of the survey site. Each line was 60-ft long. The lines were spaced 30-ft apart. Along each line, survey flags were inserted in the ground at intervals of 5 ft. These flags served as traverse line end points and provided some measure of ground control.

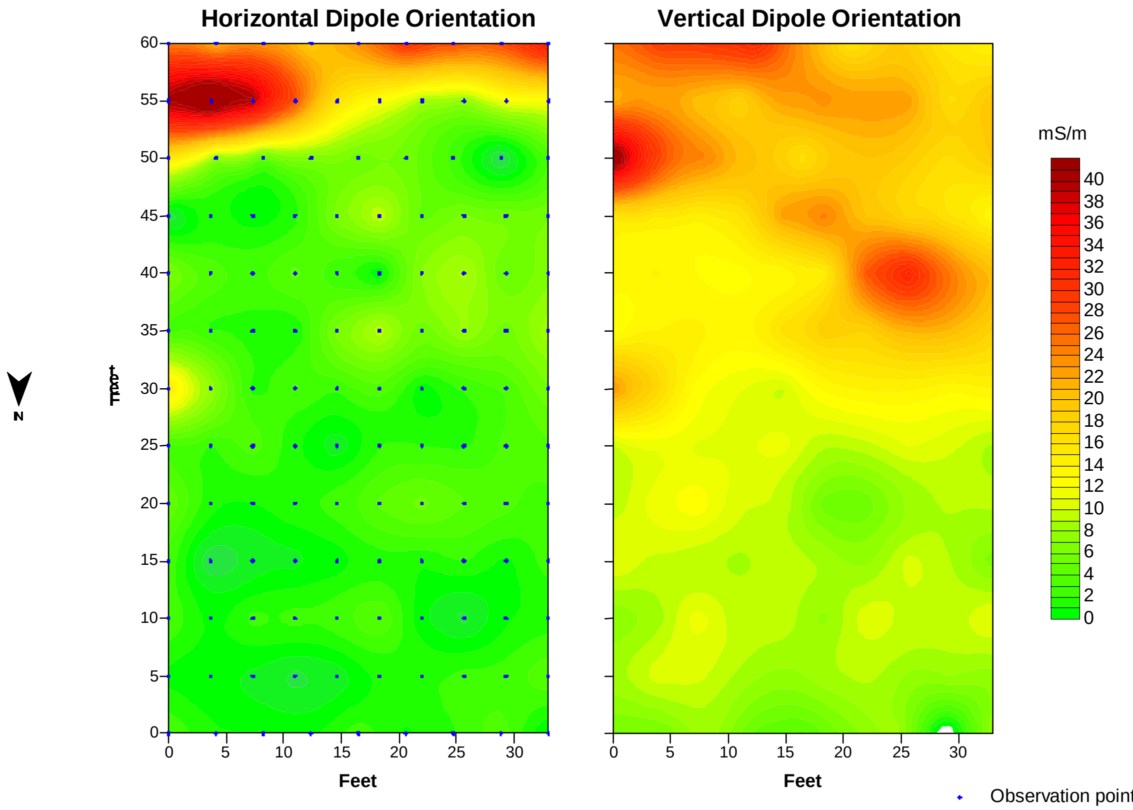

Figure 5. Apparent conductivity maps for the former building site at the Honey Hollow Watershed Conservation Area.

The site was surveyed with an EM38DD meter and the DAS70 data acquisition system. The origin (0, 0 m) of the grid was located in the northeast corner. Walking at a fairly uniform pace between similarly numbered flags on the two opposing parallel lines in a back and forth pattern across the grid area completed the EMI survey. For each traverse line, software was used to adjust the location of each measurement to provide a uniform interval between the observation points.

Data collected with these tools are shown in Figure 5. As zero and negative responses were few number and slight (0 to –2.3 mS/m), they have been suppressed in these maps. In Figure 5, the color scale interval is 1 mS/m. The locations of the 127 EMI observation points and the survey lines are shown in the left-hand plot of Figure 5. Within the grid area, apparent conductivity averaged 6.21 mS/m and ranged from about –2.3 to 45.8 mS/m in the horizontal dipole orientation. In the vertical dipole orientation, apparent conductivity averaged 14.26 mS/m with a range of about –2.2 to 45.0 mS/m. Apparent conductivity increased and became more variable with increasing soil depth (vertical dipole measurements were greater and more variable than horizontal dipole measurements).

An anomalous zone of higher apparent conductivity is evident in the southern (upper) portion of each map. Within this zone, high and variable values of apparent conductivity were recorded. Abrupt and contrasting patterns are not normal for undisturbed soils and suggest the occurrence of cultural disturbances and buried artifacts. These features may be related to a former structure(s), which is believed to have occupied this site.

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