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

Subject: ENG -- Electromagnetic Induction (EMI) Assistance **Date:** 26 November 2002

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Purpose:
A high intensity electromagnetic induction (EMI) survey was conducted to provide ancillary information to soil maps and observations of a research field (Field K) at the Frey Farm in Centre County. The Frey Farm is owned and operated by Pennsylvania State University.

Participants:
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Sjoerd Duiker, Assistant Professor, Pennsylvania State University, University Park, PA
Jake Eckenrode, Resource Soil Scientist, USDA-NRCS, Lamar, PA
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Activities:
All field activities were completed on 14 November 2002.

Equipment:
The electromagnetic induction devices used in this survey were the EM31 and EM38DD meters, manufactured by Geonics Limited.* Each meter is portable and requires only one person to operate. No ground contact is required with these meters. The EM31 meter has a 3.66 m intercoil spacing and operates at a frequency of 9,810 Hz. It has effective penetration depths of about 3.0 and 6.0 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1980a). 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 (Geonics Limited, 2000). The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One unit acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one unit 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 data.* The acquisition system consists of an EMI meter, Allegro field computer, Trimble AG114 GPS receiver, backpack with extender arm for GPS, and associated cables. With the logging system, the EMI meters are keypad operated and measurements can either be automatically or manually triggered.

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

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

Survey Area:
The survey area is Field K of the Frey Farm. This research field is located about 2 miles southwest of the town of Fairbrook in Centre County, Pennsylvania. At the time of the survey the field was in corn stubble. The field contains a complex pattern of soils with areas of the following soil map units: Hagerstown silt loam, 0 to 3 percent slopes, Hagerstown silt loam, 3 to 8 percent slopes, Hublersburg silt loam, 3 to 8 percent slopes, and Nolin silt loam, local alluvium, 0 to 5 percent slopes (Braker, 1981). The deep, well-drained Hagerstown soil formed in residium weathered from limestone bedrock. Depth to bedrock ranges from 40 to more than 84 inches. Hagerstown is a member of the fine, mixed, semiactive, mesic Typic Hapludalfs family. The very deep, well drained Hublersburg soil formed in residium weathered from impure or cherty limestone. Hublersburg is a member of the clayey, illitic, mesic Typic Hapludults family. The very deep, well-drained Nolin soil formed in alluvium derived from limestone bedrock. Nolin is a member of the fine-silty, mixed, active, mesic, Dystric Fluventic Eutrudepts family. Included with areas of Hagerstown and Hublersburg soils in mapping are small areas of Opequon soil. The shallow, well-drained Opequon soil formed residium weathered from limestone. Opequon is a member of the clayey, mixed, active, mesic Lithic Hapludalfs family. In addition to varying depths to bedrock and clay contents, these soils are taxonomically discrete.

Field Procedures:
The survey area is about 22 acres. Survey procedures were simplified to expedite fieldwork. A set of parallel lines defined the east and west boundaries of the field. Along each of the two lines, twenty-six survey flags were inserted in the ground at intervals of 45 feet (13.2 m) and the defined not only the east and west boundaries of the field, but the centers of research plots. These flags served as grid line end points and provided some measure of ground control. With the exception of the southern most grid line, all lines were about 850 feet (260 m) long. The southern-most grid line was about 470 feet (143 m) long.

The EM31 and EM38DD meters were operated in the continuous mode with measurements recorded at 1-sec intervals. A surveys was completed with the EM38DD held about 3 inches above the ground surface with the long axis of the two meters parallel to the direction of traverse. Walking at a fairly uniform pace in a sequential, back and forth pattern between similarly numbered flags (spaced at 45 ft intervals) on the opposing two lines completed the survey with the EM38DD meter. A survey was completed with the EM31 meter held at hip height in the vertical dipole orientation with its long axis essentially parallel to the direction of traverse. Walking at a fairly uniform pace between every other (90 ft interval) similarly numbered flags on the opposing set of parallel lines in a sequential, back and forth pattern completed the survey with the EM31 meter.

Background:
Electromagnetic induction (EMI) is a noninvasive geophysical tool that can be used for detailed site assessments. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. This geophysical method can provide in a relatively short time the large number of observations that are needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions, planning further investigations, and locating sampling or monitoring sites.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are caused by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the type and concentration of ions in solution, the amount and type of clays in the soil matrix, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980b). The apparent conductivity of soils increases with increased soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Electromagnetic induction measures vertical and lateral variations in apparent electrical conductivity. Values of apparent conductivity are seldom diagnostic in themselves, but lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Interpretations are based on the identification of spatial patterns within data sets.

To assist interpretations, computer simulations are normally used.

Electromagnetic induction is not suitable for use in all soil investigations. Generally, the use of EMI has been most successful in areas where subsurface properties are reasonably homogeneous and one property (e.g. salt, clay, or water content) exerts an overriding influence over the soil in apparent conductivity. In these areas, variations in apparent conductivity can be directly related to changes in the dominant property (Cook et al., 1989). In the surveyed research field, differences in soil moisture and salt contents were assumed to be slight and to influence EMI response less than the spatial and vertical variations in clay content. Variations in clay content were attributed to differences in parent materials (fine textured residuum or fine-silty alluvium) and in depths to limestone bedrock. Compared with the underlying bedrock, the soils are considered a more conductive medium.

Results:

Table 1 summarizes basic statistics for the EMI survey. Data was recorded at three-second intervals. This resulted in 1384 measurements recorded with the EM38DD meter in the vertical and horizontal dipole orientations (see left-hand plot in Figure 1), and 708 measurements recorded with the EM31 meter in the vertical dipole orientation (see Figure 2). With the EM38DD meter, apparent conductivity increased with increasing depth of observation (shallow-sensing horizontal dipole orientation (0 to 0.75 m) measurements were lower than those measured with the deeper-sensing vertical dipole orientation (0 to 1.5 m)). This relationship is associated with the higher water and clay contents of soils. In the horizontal dipole orientation, the EMI response is sensitive to variations in soil properties within the surface layers. In the vertical dipole orientation, the EMI depth-weighted response is most sensitive to variations in soil properties occurring at a depth of 40 cm. In general the surface layers were lighter textured and less dense than the underlying, heavier textured subsoil.

Table 1

Basic Statistics
EMI Survey
(All values are in mS/m)

	EM38DD-H	EM38DD-V	EM31-V
Average	7.2	11.0	15.4
Standard Deviation	3.1	3.2	7.4
Minimum	-3.5	0.1	-19.1
Maximum	16.7	32.7	112.9
First Quartile	5.5	9.0	12.5
Second Quartile	9.3	12.6	16.6

Values of apparent conductivity were relatively low (less than 20 mS/m) across most of the research field. Anomalously high and low values were recorded with the EM38DD and EM31 meters in the vertical dipole orientation over a buried utility line. The location of this utility line had been in doubt. The utility line, based on field markers, was believed to cross the research field diagonally from near the southeast to northeast corners. The EMI survey revealed that the utility line does not cross the field diagonally, but is located near and parallels the western boundary of the field. Knowledge of the lines location is critical to many research projects involving the excavation of soil pits or deep soil core observations.

With the EM38DD meter, apparent conductivity averaged 7.16 mS/m and 10.98 mS/m in the horizontal and vertical dipole orientations, respectively. In the shallower-sensing, horizontal dipole orientation, one-half the observations had values of apparent conductivity between 5.5 and 9.3 mS/m. In the deeper-sensing, vertical dipole orientation, one-half the observations had values of apparent conductivity between 9.0 and 12.6 mS/m. With the EM31 meter, apparent conductivity averaged 15.4 mS/m in the vertical dipole orientation. One-half of the observations had values of apparent conductivity between 12.5 and 16.6 mS/m.

Figure 1 shows the spatial distribution of apparent conductivity collected with the EM38DD meter in the horizontal and vertical dipole orientation. In each plot, the isoline interval is 4 mS/m. Spatial patterns in these plots are believed to principally reflect differences in soils and clay contents. However, spatial patterns of apparent conductivity do not conform to mapped soil delineations found in the published soil survey report (Braker, 1981). At the time of the EMI survey, soils were observed in each delineation and at nine observation points. Apparent conductivity measured in the shallower sensing horizontal dipole orientation are presumed to reflect the clay content of the surface layers and/or the depth to finer textured soil materials. In the left-hand plot of Figure 1, areas with lower conductivity are presumed to represent soils with lighter textured surface layers and/or deeper depths to finer textured subsoil. The conspicuous area of low conductivity (< 4 mS/m) occurs generally on concave and planar surfaces in the lower part of the landscape. Soils in these areas are Nolin or perhaps overwashed phases of Hagerstown. The location and name of the soil identified at each of the nine observation points are shown in the right-hand plot. The right-hand plot is believed to reflect the depth and clay content of the subsoil as well as the depth to bedrock, provided the depth is moderately deep (50 to 100 cm) or shallow (< 50 cm). The identified Opaquon soil, which is shallow to bedrock, is in an area of low conductivity.

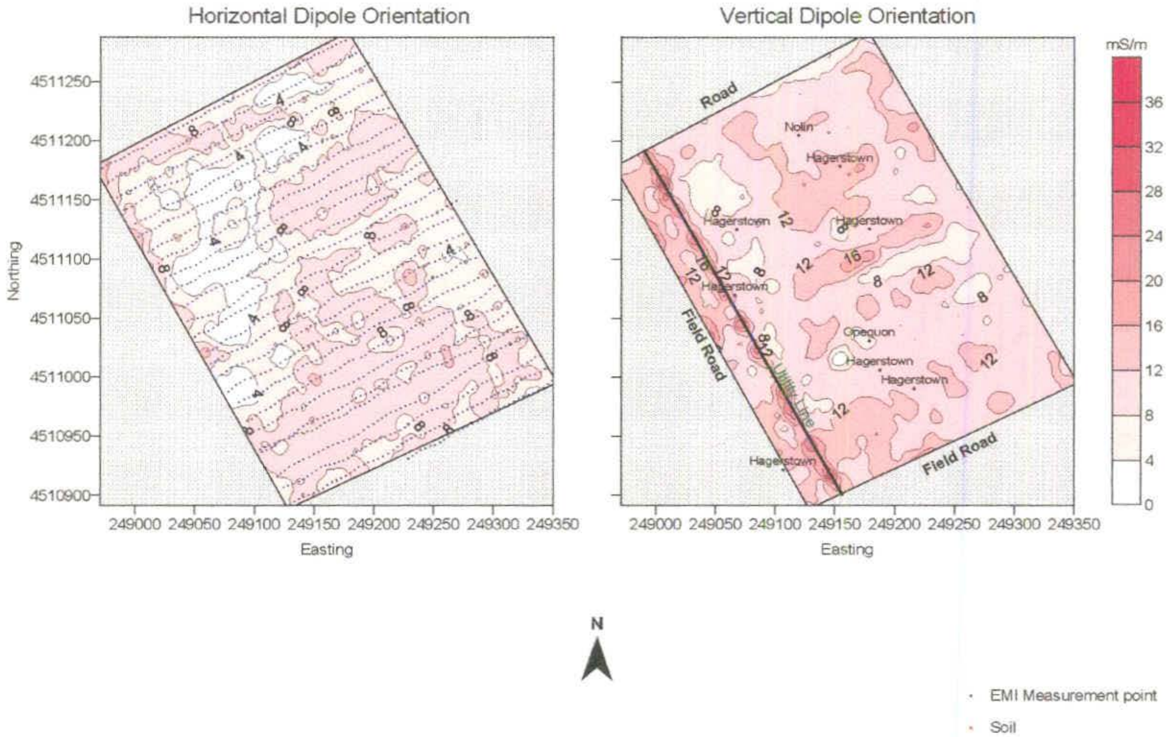

Figure 1. Plots of apparent conductivity measured with the EM38DD meter in the horizontal and vertical dipole orientations.

Figure 2 shows the spatial distribution of apparent conductivity collected with the EM31 meter in the vertical dipole orientation. In this plot, the isoline interval is 4 mS/m. Spatial patterns in these plots are believed to principally reflect differences in soils and clay contents. As with the EM38DD meter, spatial patterns of measured apparent conductivity do not conform to mapped soil patterns. The underlying limestone bedrock is more resistive (less conductive) than the overlying soil materials.

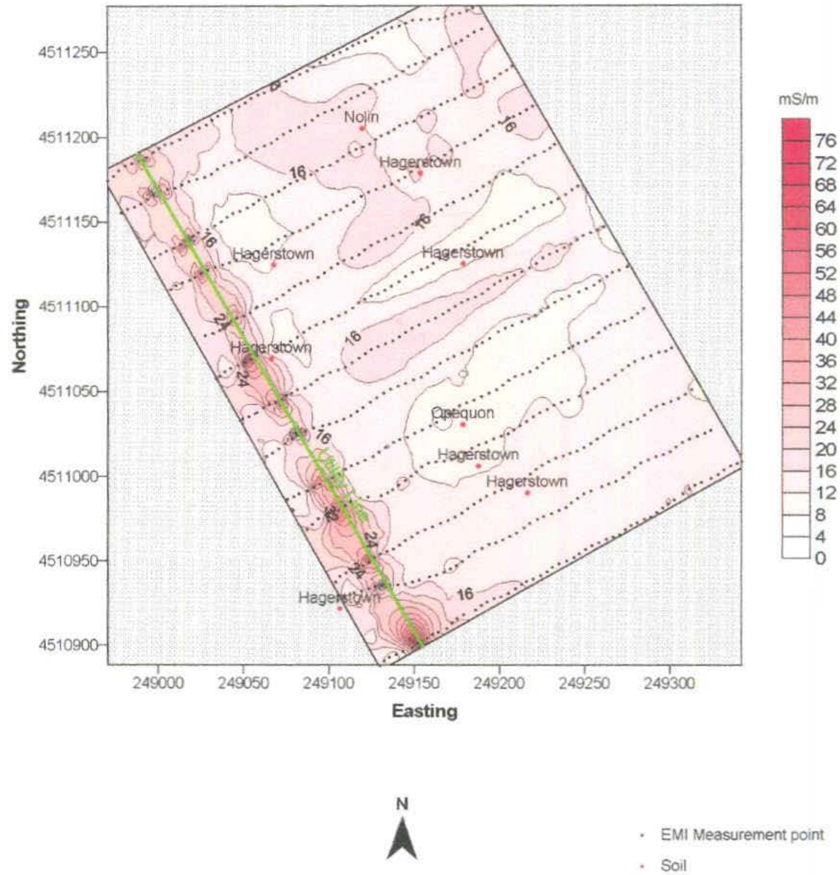

Figure 2. Spatial distribution of apparent conductivity measured with the EM31 meter in the vertical dipole orientations.

Conclusions:

1. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil borings and pits). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations.

2. Previous studies in areas of Hagerstown soil indicate a moderate ($r = 0.721$) and significant (0.001 level) correlation between the measured depth to bedrock and measurements obtained with the EM31 meter. Interpreted patterns suggest comparatively shallow (< 1.5 m) and uniform depths to bedrock (see Figure 4). Isolated patterns of shallower or deeper depths to bedrock patterns suggest the possible occurrence of minor solution feature and pinnacles within the fields that adjoin the proposed site of the composting-pad.

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

With kind regards,

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