United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOILS -- Geophysical Assistance **Date:** January 30, 2007

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Purpose:
Ground-penetrating radar (GPR) and electromagnetic induction (EMI) were used to help characterize soils and infer spatial variations in surface and groundwater flow patterns at a concentrated animal feeding operation (CAFO) located on the Maryland Eastern Shore. This site is being monitored by Dr Hilpert as part of his research on the transport of tetracycline and tetracycline resistance genes through poultry farm soils and aquifer materials.

Participants:
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Activities:
Geophysical field investigations were completed on 19 January 2007.

Observations:

1. Traditional sampling techniques are slow and expensive. As a consequence, data are limited for site characterizations. The synergistic use of densely sampled, moderate to high resolution geophysical data with traditional sampling methods increases the amount of information that is available for detailed site assessments. Within the study area, geophysical data provided additional layers of soil information and helped to reduce the ambiguity that is related to the site's hydropedological heterogeneity.

2. Plots of EC_a data may be used to assist the placement and reduce the number of sampling sites. Interpretations provided in this report may be useful in determining groundwater flow patterns. Radar records helped to characterized soil horizons and contrasting strata that influence the flow of

groundwater.

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

It was my pleasure to work in with you and your PhD candidates on the Eastern Shore of Maryland. A special thanks is given to Susan Demas for her assistance and in-depth knowledge of the soils.

With kind regards,

James A. Doolittle
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Background:
Geophysical methods are being increasingly used to help characterize the near-subsurface and provide estimates of hydropedologic properties. In this preliminary study, the uses of electromagnetic induction (EMI) and ground-penetrating radar (GPR) to provide dense, moderate to high resolution, subsurface data sets are assessed at a poultry operation on the Maryland Eastern Shore.

Electromagnetic induction is a noninvasive geophysical tool that has been used to assess spatial and temporal variations in soil nutrient contents at different depths and levels of resolution. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. Electromagnetic induction can provide a large number of measurements in a relatively short time.

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

Values of EC_a are seldom diagnostic in themselves. However, lateral and vertical variations in EC_a can be used to infer changes in soils and hydropedologic properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used. Maps prepared from properly interpreted EMI data provide the basis for assessing site conditions and locating sampling or monitoring sites.

Electromagnetic induction has been used to infer the relative concentrations, extent, and movement of contaminants from animal waste-holding facilities (Eigenberg et al., 1998; Bowling et al., 1997; Drommerhausen, et al., 1995; Ranjan and Karthigesu, 1995; Radcliffe et al., 1994; and Brune and Doolittle, 1990; Siegrist and Hargett, 1989; Stierman and Ruedisili, 1988). Typically, soils affected by animal wastes have higher EC_a than unaffected soils. Differences in EC_a are primarily dependent on the ionic content of the soil. These ions can be either cations (Ca^{++}, Mg^{++}, K^+, Na^+, and H^+) or anions (NO_3^-, SO_4^-, HCO_3^-, CO_3^-, and OH^-). Stevens et al. (1995) used EC_a as an indirect measure for NH_4 and K in animal-waste slurries. While EMI does not provide a direct measurement of specific ions or compounds, EC_a has been correlated with concentrations of chloride, ammonia, and nitrate nitrogen in soils (Eigenberg et al., 1998; Ranjan and Karthigesu, 1995; Brune and Doolittle, 1990). Cockx et al. (2005) used spatial EC_a patterns to delineate zones with different risks of NO_3 loss. Hubbard et al. (2001) used geophysical data to guide field operations and constrain field-scale numerical bacterial transport models. Eigenberg and Nienaber (1998) used plots of EC_a data to delineate soils with high nutrient buildup resulting from the application of animal wastes. Within composting sites, temporal variations in EC_a have been related to nutrient leaching, diffusion, and plant uptake (Eigenberg and Nienaber, 2003). However, at low ion concentrations, differences in clay and moisture contents will often mask changes in nutrient levels (Heiniger et al., 2003). Under these conditions, the use EMI is ineffective for the detection of spatial variations in soil nutrient contents.

Ground-penetrating radar has been used in hydropedological investigations to understand the soil parameters that control groundwater flow and transport. Hubbard et al. (1997, 2005) and Hubbard and Rubin (2006) summarize some of the uses of GPR to estimate such hydropedologic parameters as water content, hydraulic conductivity, geochemistry and lithofacies zonation. Brune and Doolittle (1990) used GPR to help identify contaminant plumes emanating from animal waste storage facilities.

Equipment:

The EM38 meter is manufactured by Geonics limited (Mississauga, Ontario).[1] This meter weighs about 1.4 kg (3.1 lbs) and needs only one person to operate. No ground contact is required with this instrument. The EM38 meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, it has effective penetration depths of about 0.75 m and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 1998).

The Geonics DAS70 Data Acquisition System was used with the EM38 meter to record and store both EC_a and position data.[1] The acquisition system consists of the EM38 meter, an Allegro CX field computer (Juniper Systems, North Logan, UT), and a Garmin Global Positioning System (GPS) Map 76 receiver (with CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack)(Olathe, KS).[1] When attached to the acquisition system, the EM38 meter is keypad operated and measurements can be automatically triggered. The NAV38 and Trackmaker38 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EC_a and GPS data.

To help summarize the results of the EMI surveys, SURFER for Windows, version 8.0 (Golden Software, Inc., Golden, CO), was used to construct a simulation of the EC_a data.[1] The grid of EC_a data shown in this report was created using kriging methods with an octant search.

The radar unit used is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[1] 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 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. Daniels (2004) discusses the use and operation of GPR. The 200 and 400 MHz antennas were used in this field investigation.

The radar record contained in this report was processed with the RADAN for Windows (version 5.0) software program developed by GSSI.[2] Processing included setting the initial pulse to time zero, header and marker editing, distance normalization, color transformation, and range gain adjustments.

Survey Area:

The survey area is located on Maryland's Eastern Shore Peninsula. The area is located off of Byrd Road in Pocomoke City, Maryland. Figure 1 is the soil map of the survey area from the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/). The locations of the three soil cores obtained by Susan Demas are shown in this figure. The core sites surround a large shed used to store poultry wastes. The four other structures shown in Figure 1 house the poultry.

Three soil polygons occur in the study area (see Figure 1). Table 1 lists the names and symbols of these soil map units. The taxonomic classifications of the named soils are listed in Table 2. These soils are very deep and have formed in fluviomarine Coastal Plain sediments. The slightly lower-lying, very poorly drained Berryland and Mullica soils formed in sandy sediments and in sandy and loamy siliceous sediments, respectively. The poorly drained Fallsington soil formed in loamy sediments. The slightly higher-lying, somewhat poorly drained Klej soil formed in sandy sediments. At the time of this investigation, within the study area, the water table was located 50 to 60 cm below the ground surface. This study focuses on the upper 1.5 to 2 m of the soils.

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

Figure 1. This soil map of the study area shows the soil symbols, polygon boundaries (green colored lines) and locations of three soil cores.

Table 1

Soil Map Units delineated within the survey area.

Map Symbol	Map Unit Name
Fa	Fallsington sandy loam
KsA	Klej loamy sand, 0 to 2 % slopes
Mu	Mullica-Berryland complex

Table 2
Taxonomic classification of soils

Soil Series	Taxonomic Classification
Berryland	Sandy, siliceous, mesic Typic Alaquods
Fallsington	Fine-loamy, mixed, active, mesic Typic Endoaquults
Klej	Mesic, coated Aquic Quartzipsamments
Mullica	Coarse-loamy, siliceous, semiactive, acid, mesic Typic Humaquepts

Field Procedures:
The EM38 meter was operated in the deeper-sensing (0 to 1.5 m), vertical dipole orientation and continuous mode with measurements recorded at 1-sec intervals. The EM38 meter was orientated with its long axis parallel to the direction of traverse and held about 5-cm above the ground surface. The EMI survey was completed by walking in a random back and forth pattern across the study area. At the time of this study, the soil

temperature at a depth of 50 cm was 46^o F. All EC_a data have been temperature corrected to a standard temperature of 25^o C.

A radar transect was completed by pulling the antenna by hand along a traverse line that was located on the western side of the waste-storage shed. The transect line was confine to an area of Fallsington sandy loam (Fa). Reference points were spaced at one-meter intervals along the traverse line. At each reference point, the radar operator impressed an identifying mark on the radar record.

Results:
Basic statistics for the EC_a measurements obtained with the EM38 meter are listed in Table 3. Based on 2,364 measurements, EC_a averaged 28.25 mS/m with a standard deviation of 41.14 mS/m and a range of –776.36 to 217.62 mS/m. Extreme negative and positive values represent interference from farm equipment, structures, and other metallic artifacts. At one-half of the observation points, EC_a was between 21.20 and 27.16 mS/m.

Figure 2 is a plot of EC_a data collected with the EM38 meter in the vertical dipole orientation. The isoline interval is 4 mS/m. Areas with anomalously high (> 60 mS/m) and low (< 0 mS/m) EC_a are shown in purple and yellow, respectively. In general, these areas contain metallic objects, equipment, and/or structures that interfered with the electromagnetic fields and produced anomalous EMI responses. These areas are evident adjacent to the two identified poultry barns and the south entrance to the waste-storage shed. Concrete pads with iron rebar are suspected to have caused the negative responses near the eastern end of the two poultry sheds. The anomalously high responses that form linear patterns along the immediate north and south sides of the two poultry barns represent interference from the structures themselves. However, the areas of anomalously high EC_a (>60 mS/m) that extend outwards from the eastern ends of the poultry barns and the southern end of the waste-storage shed may represent higher levels of soil contamination from poultry wastes.

Table 3
Basic Statistics for EMI Survey
(EC_a measurements are expressed in mS/m)

Number	2364
Minimum	-776.36
Maximum	217.62
25%-tile	21.20
75%-tile	27.16
Mean	28.25
Standard Deviation	41.14

In Figure 2, a rather extensive area of comparatively high EC_a (>24 mS/m) extends northward from the waste-storage shed and across the drainage ditch into a cultivated field. The comparatively high EC_a in this field could be the result of higher levels of nutrients from the poultry wastes. Soils in this northern field are similar to those in the cultivated field that lies to the south of the southern drainage ditch shown in Figure 2. In the southern field, EC_a is generally lower (16 to 22 mS/m). Though differences in EC_a between the two fields are considered slight and may be the result of varying natural soil properties, the relative values and spatial patterns suggest the possibility of contamination of the northern field by wastes emanating from the waste-storage shed. If so, runoff and groundwater flow are factors contributing to the development of this rather broad affected area. Surprisingly, the plot of EC_a data shows that the three soil cores were appropriately sited.

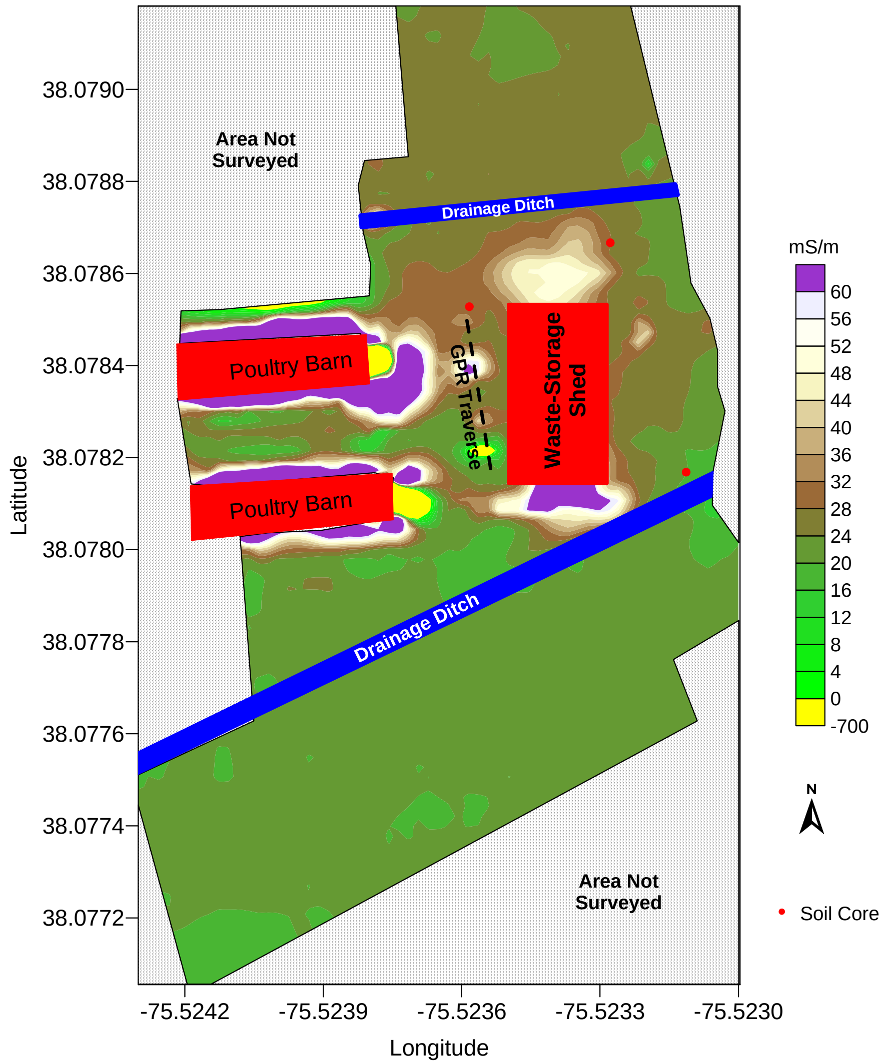

Figure 2. Plot of EC_a data collected with the EM38meter in the vertical dipole orientation.

Figure 3 is a portion of the radar record that was collected with the 400 MHz antenna along the GPR traverse line shown in Figure 2. Two buried cultural features (see “A” in Figure 3), which contrast in dielectric properties with the enveloping soil matrix, produce high amplitude (colored yellow, green and blue) reflections in the upper part of the radar record. A metallic plate was buried at a known depth of about 47 cm at the 1-m distance mark. At the 11-m distance mark, the high amplitude, point reflection at a depth of about 60 cm is also believed to represent a buried metallic artifact. A water table was observed at a depth of 33 cm near the 1-m mark. The strong reflection form the soil/air interface masks reflections occurring within the upper 30 to 35 cm of the soil profile. As a consequence, reflections from the shallow water table are obscured.

On the radar record shown in Figure 3, the interface separating the sandy subsurface layer (E horizon) from the loamy subsoil (Btg) produces the weak to moderate amplitude (shades of red), planar reflection evident at “B.” This interface is difficult to trace laterally across the radar record. Saturated soil conditions weaken the contrast in dielectric properties between these two soil horizons and have obscured this interface across most of the radar record. The subsoil is underlain by sandy strata (see “C” in Figure 3). Because of their moderate to high signal amplitudes, these strata are inferred to have contrasting grain-size distributions. Though vertically exaggerated on this radar record, these strata appear inclined and dip towards the north (towards the left-hand margin of Figure 3). The presence of these contrasting strata will influence the flow of groundwater.

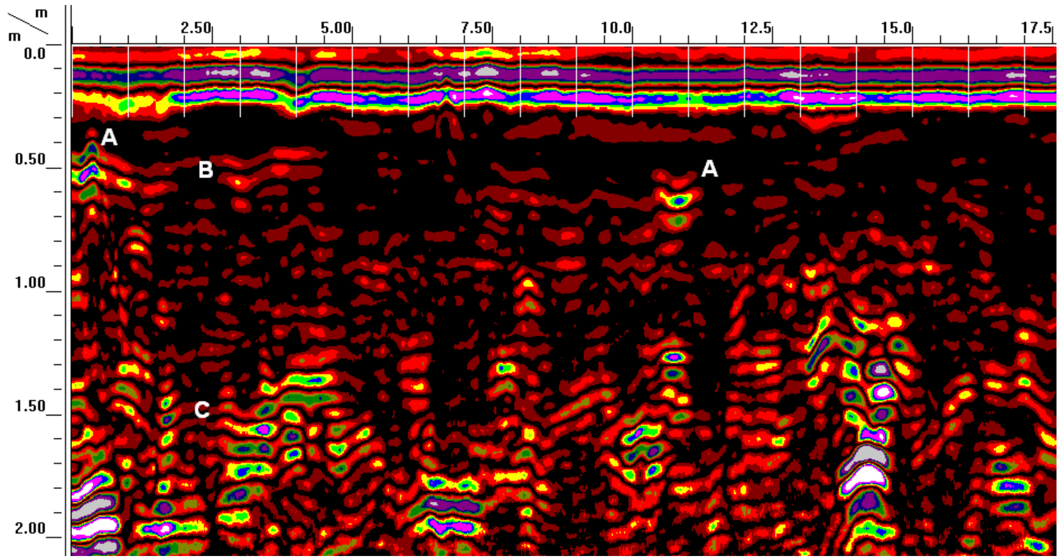

Figure 3. This radar record, which was collected with the 400 MHz antenna, helps to characterize the soils and subsurface stratigraphy within the study area.

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