

**Subject:** Electromagnetic induction (EM) field  
assistance at the Remington Farms Project;  
1 June 1995

**Date:** June 13 1995

**To:** Raymond Forney  
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**Purpose:**

To explore the potentials of using electromagnetic induction (EM) to map differences in soils and assess hydrologic properties of Coastal Plain deposits.

**Activities:**

An preliminary study was conducted in Field C-1 on 1 June 1995.

**Equipment:**

The electromagnetic induction meter was the EM31, manufactured by GEONICS Limited. The observation depth of an EM meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM31 meter has a fixed intercoil spacing of 3.66 m. It operates at a frequency of 9.8 kHz. The EM31 meter has effective observation depths of about 3 m and 6 m in the horizontal and vertical dipole orientations, respectively. Measurements of conductivity are expressed as milliSiemens per meter (mS/m).

**Study Site:**

The study site was located in a cultivated field and in an area of Mattapex variant silt loam, 0 to 2 percent slopes (White, 1982). The extreme northeastern portion of the study site contained a small area of Butlertown-Mattapex silt loams, 2 to 5 percent slopes, moderately eroded. The southwest corner of the study site contained a small area of Mattapex variant silt loam, 2 to 5 percent slopes. Mattapex variant is a member of the fine-loamy, mixed, mesic Aquic Hapludults. This soil varies from Mattapex soils by being underlain by buried, clayey, soil materials. Butlertown is a member of the fine-silty, mixed, mesic Typic Fragiudults family

**Field Methods:**

A 300 by 800 foot grid (5.5 acres) was established across the site. The grid interval was 100 feet. This interval provided 36 grid intersections or observation sites. Two additional measurements were

taken along a drainageway in the western portion of the study site. At each grid intersection, measurements were taken with the EM31 meter. Measurements were taken with the meter placed on the ground surface in both the horizontal and vertical dipole orientations.

To help summarize the results of this survey, the software program SURFER for Windows was used to construct two-dimensional simulations. The simulated grids of the study site were created using kriging methods with an octant search. The data were smoothed using cubic spline interpolation. In the accompanying computer simulations, to help emphasize the spatial distribution of apparent conductivity values, colors and filled contour lines were used. These plots represent the spatial distribution of apparent conductivity values over a specified observation depth. Other than showing trends in values of apparent conductivity (i.e. zones of higher or lower electrical conductivity), no significance should be attached to the colors themselves.

#### **Discussion:**

Electromagnetic induction techniques have been used to determine the depths to bedrock (Zalasiewicz et al., 1985) glacial deposits (Zalasiewicz and Mathers, 1985; Palacky and Stephens, 1990), and permafrost (Sartorelli and French, 1982; Kawasaki and Osterkamp, 1988); estimate thicknesses of clays (Palacky, 1987) and sand and gravel deposits (McNeill, 1988); measure soil water content (Kachanoski et al., 1988); and evaluate edaphic properties important to forest site productivity (McBride et al., 1990). This technology has been used in general groundwater studies (McNeill, 1991), assessments of recharge and discharge areas in various landscapes (Richardson and Williams, 1994; and Williams and Arunin, 1990), and the location of water-bearing fracture zones in bedrock (McNeill, 1991; Olayinka, 1990). These studies have documented that this noninvasive technique is relatively inexpensive and easy to use, can provide comprehensive coverage of sites and the large number of observations needed for site characterization and assessments, and is applicable over broad areas and soils. Maps prepared from correctly interpreted EM data provide the basis for assessing site conditions and planning further investigations.

Electromagnetic induction techniques are a noninvasive geophysical method in which electromagnetic energy is used to measure the apparent conductivity of earthen materials. Apparent conductivity is the weighted average conductivity measurement for a column of earthen materials to a specified investigation depth (Greenhouse and Slaine, 1983). The averages are weighted according to the depth response function of the meter (Slavich and Petterson, 1990).

Apparent conductivity values are seldom diagnostic in themselves. However, lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Electromagnetic responses are dependent on soil properties. Variations in electromagnetic responses are produced by changes in soil moisture, salt content, texture, and mineralogy (Cook and Walker, 1992). In nonsaline areas, soil texture, mineralogy, and moisture are the principal factors determining apparent conductivity (Kachanoski et al., 1988). Each of these factors will affect the apparent conductivity of soils.

Electromagnetic induction is an imperfect tool and is not equally suitable for use in all soil investigations. Generally, the use of EM

techniques has been most successful in areas where subsurface properties are reasonably homogeneous, the effects of one factor (clay, water, or salt content) dominates over the other factors, and variations in EM response can be related to changes in the dominant factor (Cook et al., 1992). In such areas, information is gathered on the dominant factor, and assumptions are made concerning the behavior of the other factors (Cook et al., 1989).

Each soil will have a characteristic EM response. For a particular soil, the EM response will constitute a range of values which will be influenced by temporal variations in soil moisture and temperature. Furthermore, cultural and natural features can be expected to influence these ranges. Similar soils will have a similar range in EM responses. Within a given geographic area, the conductivities of some soils will overlap. Soil properties and types can be inferred with EM techniques provided one is cognizant of changes in parent materials, drainage, topography, and vegetation.

Soils can be differentiated by characteristic ranges of apparent conductivity (Hoekstra et al., 1992). As EM measurements integrate several soil properties, responses can be correlated within geographic areas to soil types. Generally, in geophysical research, the term "soil type" has been used to refer to the particle-size class of unconsolidated sediments. Zalasiewicz and Mathers (1985) used EM techniques to map glacial sediments and distinguish areas of bouldery clays from arenaceous deposits. Sartorelli and French (1982) charted the identity of grouping of the Unified Soil Classification System with characteristic apparent conductivity values. Kingston (1985) used EM techniques to distinguish and map soil and geologic deposits and strata. In these studies different "soil types" and lithologies induced distinct and characteristic EM responses.

Results:

Interpretations of the EM data are based on the identification of spatial patterns within the data set. Figure 1 contains two-dimensional plots of the EM data collected with the EM31 meters in the horizontal and vertical dipole orientations. These plots are based on measurements collected from 36 observation points. In each plot, the interval is 2 mS/m.

Comparing the plots appearing in Figure 1, values of apparent conductivity, as a rule, increase with increasing observation depth (responses in the horizontal dipole orientation were typically less than those in vertical dipole orientation). The lower EM responses at shallower observation depths were attributed to the lower clay and moisture contents of the silty surface layers. The higher EM responses with increased observation depths were attributed to the greater moisture and clay contents of the underlying buried, clayey, soil materials (Mattapex variant).

Within Field C-1, subsurface properties were considered relatively homogeneous. The site was characterized as consisting of a relatively thin mantle of silty loess overlying clayey soil materials. The underlying clayey materials were assumed to be more conductive than the surficial silty deposits. These materials were of variable thickness.

At this site, two factors (clay and moisture contents) varied both laterally and with increasing soil depth. With some ground truth verification, it should be possible to attribute variation in the EM response to the depth to clay.

Within the site, the range of EM responses was low (11.0 to 30.0 mS/m). A fairly broad zone of noticeably higher EM responses was evident in the south-central (left-hand portion of plots) portion of the study site. This portion of the field was located in an area of Mattapex variant silt loam, 0 to 5 percent slopes. It was inferred from these higher responses that the silty surface layers were thinner (possibly removed by erosion), the depths to the more conductive buried, clayey soil materials were shallower, and/or the soil moisture contents were greater in this portions of the study site. Electromagnetic responses were generally lower in the northern portion of the study site. These lower responses were believed to reflect changes in soil type (Butlertown and Mattapex) and the absence or greater depths to the buried, clayey soil materials.

Basic statistics for the EM measurements collected at 38 observation points within the study site are displayed in Table 1. The depth response of the EM meters conformed with the basic conceptual model for the site. This model predicted that EM responses should increase with increasing depths of observation.

**Table 1**  
**Field C-1**  
(all values are in mS/m)

Meter	Orientation	Minimum	Maximum	Quartiles			Average
				1st	Median	3rd	
EM31	Horizontal	11.0	30.0	14.0	15.0	17.5	16.6
EM31	Vertical	14.0	26.0	16.5	17.5	19.5	18.3

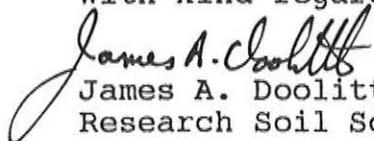
Figure 2 is a "highly interpretative" plot showing patterns of "EM slope" (Williams and Arunin, 1990). At each observation point, an EM slope was obtained by dividing the EM measurement obtained in the vertical dipole orientation by the measurement obtained in the horizontal dipole orientation. Though this technique has been found to be applicable in areas of salt-affected soils, the concept was applied to Field C-1. Generally areas where the EM measurements decrease with depth (values less than one) are assumed to reflect discharge areas. Areas where the EM measurements increase with depth (values greater than one) are assumed to reflect recharge areas. In Figure 2, the discharge area is restricted to a lower-lying portion of the field. This portion of the field is near a drainageway and appeared to be subject to periodic flooding by surface waters. The higher EM responses in the horizontal dipole orientation suggests higher moisture and/or clay contents in layers nearer the soil surface.

I hope that these plots will be of assistance to you in your research. Based on our work with both ground-penetrating radar and electromagnetic induction techniques at Remington Farms, I feel that the use of EM techniques is more appropriate. Hopefully, the simulated plots will provide insight into the hydrogeology of your research field.

It was my pleasure to assist you and your staff in this endeavor.

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With kind regards.

  
James A. Doolittle  
Research Soil Scientist

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