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

**Subject:** Soils – Geophysical Field Assistance **Date:** April 23, 2007

**To:** Dr Martin Rabenhorst
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**Purpose:**
Soils with high iron- and manganese-oxide contents have been reported by Blank and Rabenhorst (2006) in the Piedmont of Maryland. The purpose of this investigation was to use electromagnetic induction (EMI) to help characterize areas of these soils.

**Participants:**
Rebecca Blank, Graduate Student, College of Agriculture and Natural Resources, University of Maryland, College Park, MD
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Martin Rabenhorst, Professor, College of Agriculture and Natural Resources, University of Maryland, College Park, MD

**Activities:**
All activities were completed on 28 March 2007.

**Results:**
1. Initial plans were to use the newly designed EM38MK2 meter from Geonics Limited. This meter allows the simultaneous measurement of both inphase and quadrature (conductivity) phase data. However, the meter was unavailable at the time of this investigation and the EM38DD meter was used instead. The EM38DD meter provides for the simultaneous measurements of either inphase or quadrature data (but not both) in both the horizontal and vertical dipole orientation (therefore providing two depths of observation). When surveys were conducted with this meter over long periods, excessive drift was observed in some measurements, especially those obtained in the horizontal dipole orientation. While all surveys were affected to some extent, drift was especially noticeable in the data collected in the horizontal dipole orientation at Flickinger site. The observed instability is attributed to instrument drift, variations in magnetic susceptibility, and inadequate calibration.

2. Compare with the fall survey, which was supposedly conducted under generally drier soil conditions, $EC_a$ was generally higher. In the present survey, negative responses in areas of darker-colored, ferromanganiferous soils were more restricted and believed to have been suppressed by the higher soil moisture contents.

3. Results from the present surveys show that $EC_a$ was generally higher in the shallower-sensing (0 to 75 cm) horizontal than in the deeper-sensing (0 to 150 cm) vertical dipole orientation. This relationship was attributed to higher clay and moisture content of the upper solum and the occurrence of more electrically resistive parent rock in the lower portions of some profiles. However, the magnitude of difference between measurements made in the two dipole orientations was considered uncharacteristic for very deep soils formed in relatively homogenous residuum and colluvium. Differences between the two dipole measurements appear to be greater in the area where ferromanganiferous soils had been identified and sampled.

4. In the present surveys, measurements made with the EM38DD meter in the two dipole orientations lacked correlation. In areas of very deep soils that do not have strongly contrasting subsurface layers, the lack of correlation between the two dipole measurements is considered unusual and is uncommon. Correlation coefficients (r) of 0.068, -0.340, 0.055, -0.442, and 0.046 were obtained for $EC_a$ data collected in the horizontal and vertical dipole orientations at Dotter1, Dotter 2, Dotter 3, and Grossnickle sites, respectively.

5. To express the difference in $EC_a$ measured with the EM38DD meter in the two dipole orientation, a *vertical change index* was devised. It was presumed that ferromanganiferous soils would have a higher $EC_a$ in the shallower-sensing horizontal dipole orientation (because of low bulk density and high moisture retention?) and a very low or negative $EC_a$ in the deeper-sensing vertical dipole orientation (because of magnetic susceptibility?). Based on these premises, areas that have a large *vertical change index* are more likely to be dominated by ferromanganiferous soils.

I enjoyed this opportunity to work once again with Dr Rabenhorst and Rebecca Blank and to explore the use of EMI on soils suspected to display high levels of magnetic susceptibility.

With kind regards,

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cc:
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**Background:**
Soils with exceptionally high Mn and Fe oxide contents (greater than 170 g $kg^{-1}$ Fe and 100-150 g $kg^{-1}$ Mn) have been identified in Frederick County, Maryland (Black and Rabenhorst, 2006). The high levels of Fe and Mn impart distinctive black colors (moist Munsell value and chroma commonly < 2/1) and unique physical and chemical properties to these soils. Soils with high Mn and Fe oxide contents occur in areas underlain by complex metamorphic geology. These soils have been associated with residuum weathered principally from marble and other calcareous parent rocks (Black and Rabenhorst, 2006). Ferromanganiferous soils are being investigated by the University of Maryland using digital spatial data sets (including soil, geology, and topography surveys) that are supported by field reconnaissance assessments (Black and Rabenhorst, 2006).

High levels of Fe and Mn affect the magnetic susceptibility of soils and the performance of geophysical sensors. In recent years, the effects of magnetic susceptibility on geophysical sensors have been particularly evident and problematic in military and terrorism searches for buried landmines, unexploded ordnance, and other explosive devices. Current knowledge of the distribution and spatial variation of soil magnetic properties in natural soil environments is limited. Information provided by soil maps and surveys do not provide information on magnetic properties, as currently this is not part of any standard soil description procedures. While electromagnetic induction (EMI) is not designed to specifically measure magnetic susceptibility, its response is affected by variations in this property.

**Equipment:**
An EM38DD meter was used in this study. This meter is manufactured by Geonics limited (Mississauga, Ontario).[1] This meter requires no ground contact and needs only one person to operate. The EM38DD meter weigh about 2.8 kg (6.2 lbs) and is 1 m long. 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 orientation and having both transmitter and receiver activated) and one meter acts as a slave unit (meter that is positioned in the horizontal orientation with only the receiver switched on). When placed on the soil surface, the meter has effective penetration depths of about 0.75 m and 1.5 m in the horizontal and vertical dipole orientation, respectively (Geonics Limited, 2000).

The Geonics DAS70 Data Acquisition System was used with the EM38DD meter to record and store both $EC_a$ and position data.[1] The acquisition system consists of 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 EM38DD meter is keypad operated and measurements can be automatically triggered. The NAV38DD and Trackmaker38DD software developed by Geomar Software Inc. (Mississauga, Ontario) was used to record, store, and process $EC_a$ and GPS data.[1]

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

**Study Site:**
Study sites are located in cultivated fields in northeastern Frederick County, Maryland. Each site is identified by the name of its landowner. Most sites were located to the east and north of the village of Johnsville (see Figure 1, left-hand plot). These sites are located near Green Valley and Molasses roads. These sites include Dotter 1 (in soybean stubble), Dotter 2 (in corn stubble), Dotter 3 (in rye) and Grossnickle (in rye). Manure had been recently spread across the Dotter 2 site and would have an affect on EMI measurements. An additional site was located in extreme eastern Frederick County, just southwest of Union Bridge in Carroll County. The site is bordered on the east by Clemsonville Road and on the south by Marble Quarry Road. This site is referred to as the Flickinger Site (Figure 1, right-hand plot).

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

All sites are located in the Northern Piedmont Major Land Resource Area (MLRA 148). In this MLRA, the dominant soil orders are Alfisols, Inceptisols, and Ultisols (USDA-NRCS, 2006). Soils of this MLRA are best characterized as having a mesic soil temperature regime, udic soil moisture regime, and mixed, micaceous, or kaolinitic mineralogy (USDA-NRCS, 2006).

Table 1 is the legend for the soil map units that occur within the five study sites. The taxonomic classifications of the named soil series mapped within the study sites are listed in Table 2. The very deep, well drained Conestoga, Glenelg, and Letort soils form in residuum weathered principally from micaceous limestone, and calcareous and micaceous schist on uplands. The moderately deep, somewhat excessively drained Mt. Airy form in residuum weathered from similar parent rocks. The very deep, moderately well drained Wiltshire and Funkstown soils form in colluvium from micaceous schist over marble or limestone residuum. Though morphologically and taxonomically distinct these soils have a relatively low cation exchange capacity and similar clay contents (range of about 18 to 32 % clay); both of these factors will affect $EC_a$ measurements. With the exception of Mt. Airy, soils are very deep and formed in relatively homogenous materials. These properties affect the relative depth-response of the EM38DD meter in the two dipole orientations.

**Table 1. Soil Legend**

| *Symbol* | *Map Unit Name* |
|---|---|
| CoB | Conestoga and Letort silt loams, 3 to 8 percent slopes |
| CoC | Conestoga and Letort silt loams, 8 to 15 percent slopes |
| GmB | Glenelg-Mt. Airy channery loams, 3 to 8 percent slopes |
| MeC | Mt. Airy channery loams, 8 to 15 percent slopes |
| WtB | Wiltshire-Funkstown complex, 0 to 8 percent slopes |

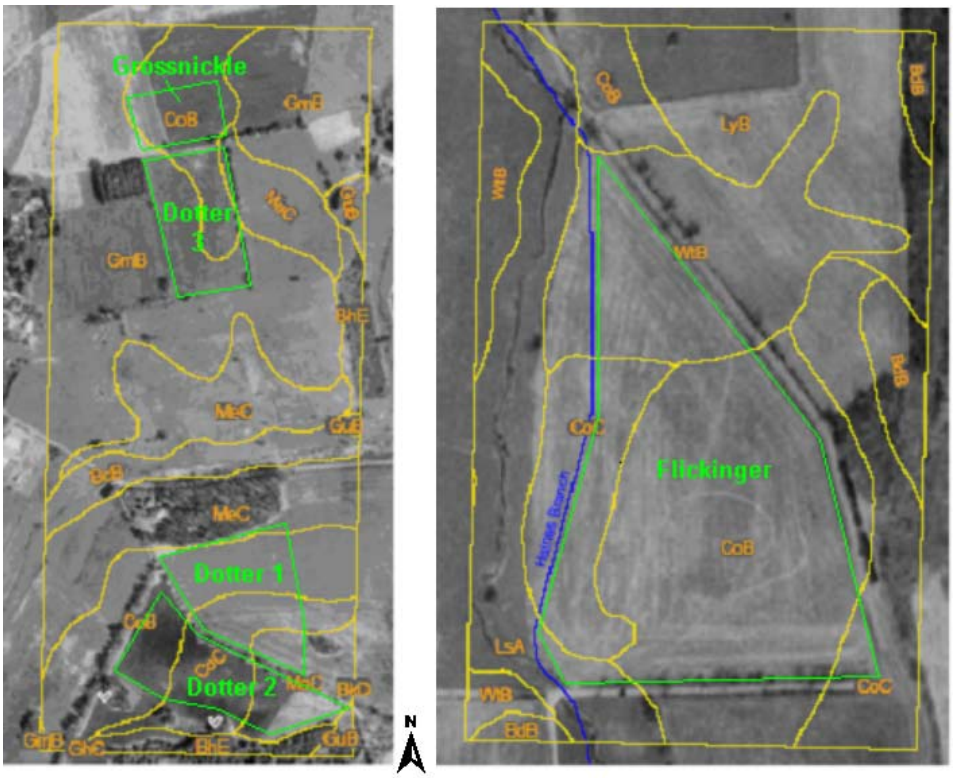


*Figure 1. These soil maps show the approximate locations of the study sites near Johnsville (left-hand image) and Union Bridge (right-hand image). Each study site is enclosed by green-colored lines and identified with the landowner's name.*

**Table 2. Taxonomic Classification of Soils**

| Soil Series | Taxonomic Classification |
|---|---|
| **Conestoga** | fine-loamy, mixed, semiactive, mesic Typic Hapludalfs |
| **Funkstown** | Fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs |
| **Glenelg** | fine-loamy, mixed, semiactive, mesic Typic Hapludults |
| **Letort** | fine-loamy, mixed, superactive, mesic Typic Hapludalfs |
| **Mt. Airy** | loamy-skeletal, micaceous, mesic Typic Dystrudepts |
| **Wiltshire** | fine-loamy, mixed, semiactive, mesic Oxyaquic Fragiudualfs |

**Field Procedures:**
A mobile (using an ATV) EMI survey was conducted at each site. Compared with pedestrian surveys, mobile surveys are completed in a shorter period of time, with less effort, and often provide more comprehensive site coverage. In this survey, an EM38DD meter was towed behind an ATV in a plastic toboggan at speeds of 1 to 3 m/sec. Using the NAV38DD program, both GPS and $EC_a$ data were simultaneously recorded on an Allegro CX field computer.

At the time of this investigation, the soil temperature at a depth of 50 cm was $8^o$ C. All $EC_a$ data have been temperature corrected to a standard temperature of $25^o$ C by multiplying the $EC_a$ by a factor of 1.488.

**Interpretations:**
In an earlier study (see my trip report of 22 November 2006), it was observed that areas with negative $EC_a$ measurements coincided with areas of dark colored surface layers suspected to be enriched with Fe and Mn. Based on these preliminary results, areas with high levels of Fe and Mn oxides were associated with negative $EC_a$ values. However, to confirm this inference and to provide a greater understanding of spatial and temporal variability in the data set, additional, more extensive EMI surveys and sampling were recommended.

Basic statistics for the EMI surveys conducted this March at five sites are listed in Table 3. Within these sites, $EC_a$ ranged from about -61.0 to 70.0 mS/m. Exceptionally high, positive or negative $EC_a$ measurements are attributed to the presence of scattered artifacts and/or utility lines within some sites. These anomalous features appear as point or linear patterns on $EC_a$ plots and were easily identified. Though the range is considered large, the bulk of the $EC_a$ measurements were comparatively low and invariable within the sites. Within the five sites, for measurements obtained in either dipole orientation, $EC_a$ averaged less than 18 mS/m and the interquartile range was less than 6 mS/m.

**Table 3. Basic Statistics for the EMI surveys that were completed with an EM38DD meter in the horizontal and vertical dipole orientation at the five study sites. Excluding the number of observations, all measurements are for $EC_a$ and expressed in millSiemens/m.**

| *Field* | *Dipole Orientation* | *Minimum* | *25% tile* | *75% tile* | *Maximum* | *Mean* | *Standard Deviation* | *Number* |
|---|---|---|---|---|---|---|---|---|
| Dotter 1 | Vertical | -4.46 | 6.52 | 9.67 | 16.74 | 7.93 | 2.72 | 4706 |
| Dotter 1 | Horizontal | 4.84 | 10.42 | 14.51 | 25.12 | 12.62 | 2.95 | 4706 |
| Dotter 2 | Vertical | -61.01 | 5.40 | 11.90 | 69.76 | 8.70 | 7.17 | 1806 |
| Dotter 2 | Horizontal | 3.91 | 13.58 | 19.01 | 105.8 | 17.59 | 6.87 | 1806 |
| Dotter 3 | Vertical | -38.14 | 8.56 | 13.39 | 21.77 | 10.32 | 4.83 | 1135 |
| Dotter 3 | Horizontal | 1.86 | 11.53 | 15.25 | 24.92 | 13.52 | 3.03 | 1135 |
| Grossnickle | Vertical | -8.56 | 7.81 | 15.25 | 25.30 | 11.19 | 5.60 | 2116 |
| Grossnickle | Horizontal | -8.56 | 3.35 | 16.56 | 37.20 | 10.90 | 8.47 | 2116 |
| Flickinger | Vertical | -11.16 | 13.21 | 21.02 | 38.32 | 17.02 | 5.91 | 9454 |
| Flickinger | Horizontal | -1.31 | 16.37 | 24.18 | 43.72 | 20.60 | 6.09 | 9454 |

The EMI survey, which was conducted with an EM38 meter (operated in the vertical dipole orientation) across the Grossnickle site in November 2006, resulted in an average $EC_a$ of about 7.0 mS/m with a range of -32.5 to 33.5 mS/m. One-half of the $EC_a$ measurements were between about 4.1 and 10.5 mS/m. The present survey of the Grossnickle site revealed an average $EC_a$ of about 11.2 mS/m with a range of about -8.6 to 25.3 mS/m (measured with an EM38DD meter, vertical dipole orientation). One-half of the $EC_a$ measurements were between about 7.8 and 15.2 mS/m. For the March 2007 surveys, higher and less variable $EC_a$ is attributed to presumably higher and more uniform soil moisture contents across the Grossnickle site. The increased moisture content has increased the $EC_a$ of the soil. The conspicuous, negative $EC_a$ measurements, which were recorded at this site under presumably drier soil conditions last fall, are less extreme and noticeable under the seemingly moister soil conditions.

Spatial $EC_a$ patterns within the five sites are shown in Figures 2 thru 6. In each plot, the same scale, isoline interval, and color scheme have been used to aid comparisons. As the coordinates of the sample pits were not recorded, the locations of these sites are not shown on these plots.

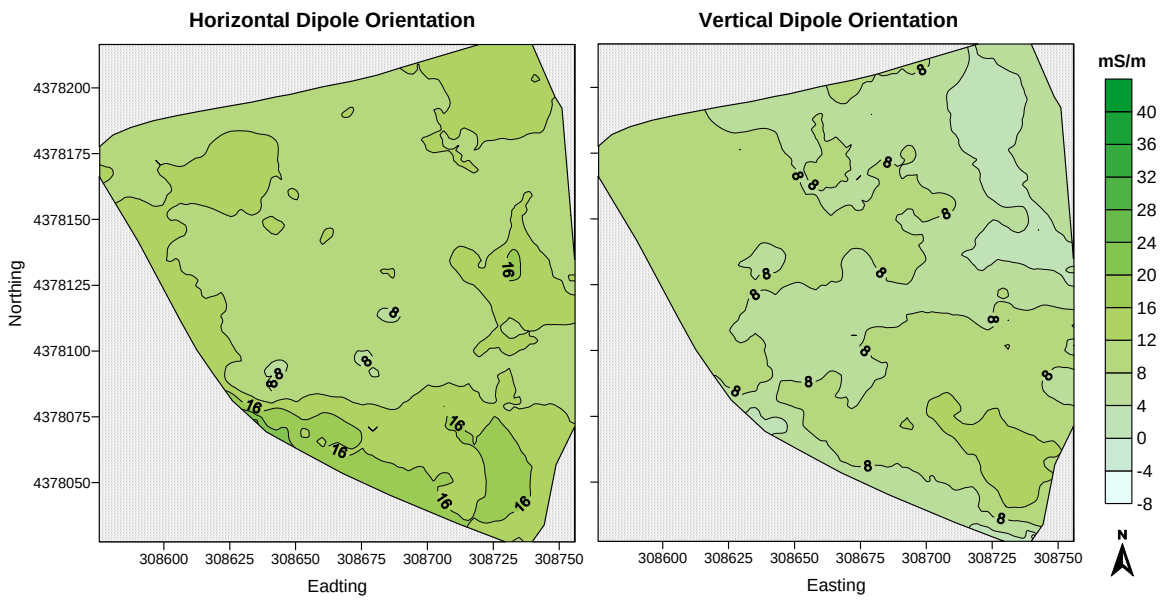


*Figure 2. Plots of $EC_a$ data collected on Dotter 1.*

Figure 2 contains plots of $EC_a$ data collected at the Dotter 1 site. This site is bordered on the west and south by a gravel access road (see left-hand plot in Figure 1). A refilled soil pit was observed near the field boundary with the gravel road in the southern portion of the survey area. In general, soils have low $EC_a$, but negative values are not common across this site. Across most of this site, noticeably higher $EC_a$ were recorded in the shallower-sensing horizontal dipole orientation than in the deeper-sensing vertical dipole orientation. This relationship was attributed to the higher clay and moisture content of the upper solum and the occurrence of more electrically resistive parent rock in the lower portions of some profiles (areas of Mt. Airy soils). Differences between the two dipole measurements were markedly greater in the area near the refilled soil pit.

Figure 3 contains plots of $EC_a$ data collected at the Dotter 2 site. This site is bordered on the north by a gravel access road (see left-hand plot in Figure 1). A refilled soil pit was observed near the gravel road in the northwestern portion of the survey area. Compared with the results from the survey of Dotter 1, soils in this field had higher and more variable $EC_a$. This field had been recently manured, and the higher $EC_a$ response in the horizontal dipole orientation can be, in part, attributed to higher amounts of organics and soluble salts in the surface layers. During the survey, a buried utility cable was crossed in the northern part of the site, in an area

adjacent to the gravel road. The location of this buried cultural feature is clearly expressed in the $EC_a$ data collected in the vertical dipole orientation (Figure 3, lower plot, see conspicuous linear zone of higher $EC_a$ adjacent to field boundary and road). In general, higher values of $EC_a$ were recorded in the shallower-sensing horizontal dipole orientation than in the deeper-sensing vertical dipole orientation. This relationship is attributed to the higher clay and moisture content of the upper solum and the occurrence of more electrically resistive parent rock in the lower portions of some profiles (areas of Mt. Airy soils). In some areas, most noticeably in the northwest portion of Dotter 2, differences between the two dipole measurements were exceptionally large and considered atypical for $EC_a$ measurements obtained over very deep soils (Conestoga and Letort) that are composed of relatively homogenous materials.

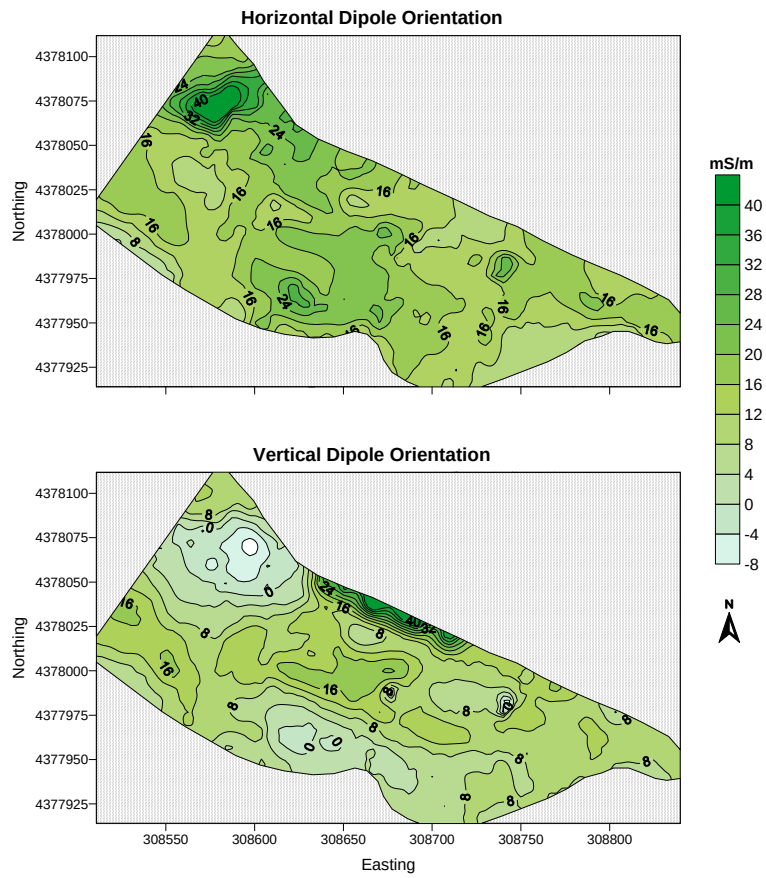


*Figure 3 Plots of $EC_a$ data collected on Dotter 2*

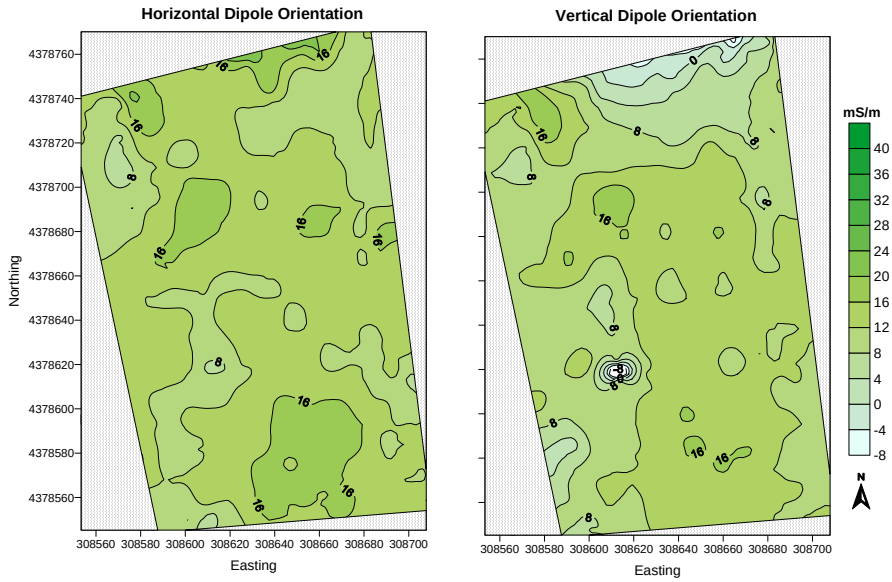


*Figure 4. Plots of $EC_a$ data collected on Dotter 3*

Figure 4 contains plots of $EC_a$ data collected at the Dotter 3 site. In the plot of $EC_a$ data collected in the deeper-sensing vertical dipole orientation (see right-hand plot), a large point anomaly believed to represent a buried cultural feature is evident near 308613 E., 4378620 N. Otherwise, spatial $EC_a$ patterns are generally unremarkable across this site. However, a large area of low and negative $EC_a$ is evident along the northern boundary of the site. Across this field boundary, an area of ferromanganiferous soils had been identified and mapped at the Grossnickle site.

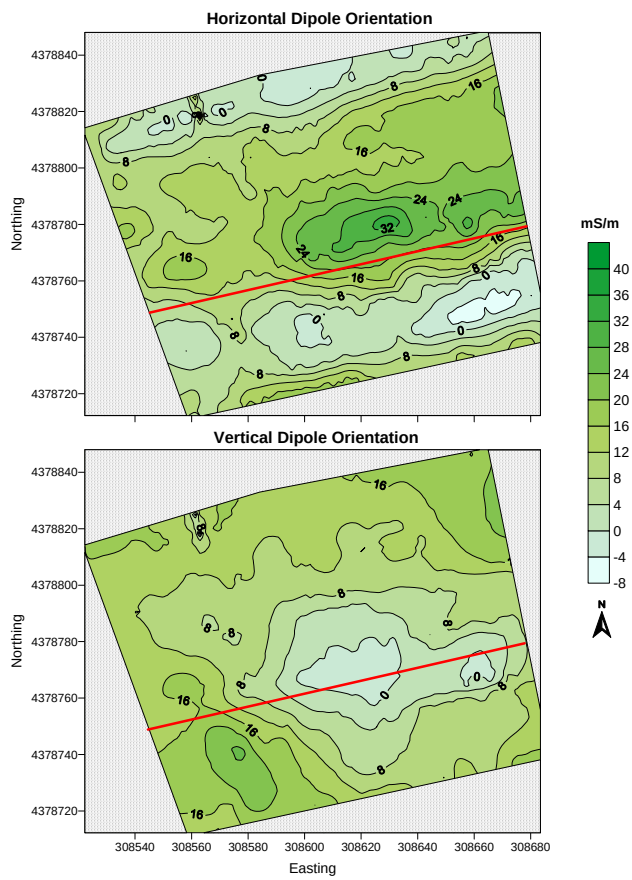


*Figure 5 Plots of $EC_a$ data collected on Grossnickle's Field.*

Figure 5 contains plots of $EC_a$ data collected at the Grossnickle site. In each plot, a red-colored line marks the approximate location of a field boundary that separates the Grossnickle site from the Dotter 3 site. The present survey of the Grossnickle site extends several tens of meters into the Dotter 3 site. Across some portions of the Grossnickle site, higher $EC_a$ were recorded in the shallower-sensing horizontal dipole orientation than in the deeper-sensing vertical dipole orientation. Once again, this relationship can be attributed to higher clay and moisture content of the upper solum and the occurrence of more electrically resistive parent rock in the lower portions of some profiles. However, the magnitude of difference between measurements made in the two dipole orientations was considered most uncharacteristic for EMI in areas of undisturbed, very deep soils formed in relatively uniform residuum. Differences between the two dipole measurements were markedly greater in the area where ferromanganiferous soils had been identified and sampled.

Figure 6 contains a plot of $EC_a$ data collected in the vertical dipole orientation at the Flickinger site. Data collected in the horizontal dipole orientation showed marked drift, were considered unreliable, and were not used. Spatial $EC_a$ patterns are highly complex and variable across the Flickinger site. This site had the highest averaged $EC_a$ (vertical dipole orientation) and the largest inter-quartile range.

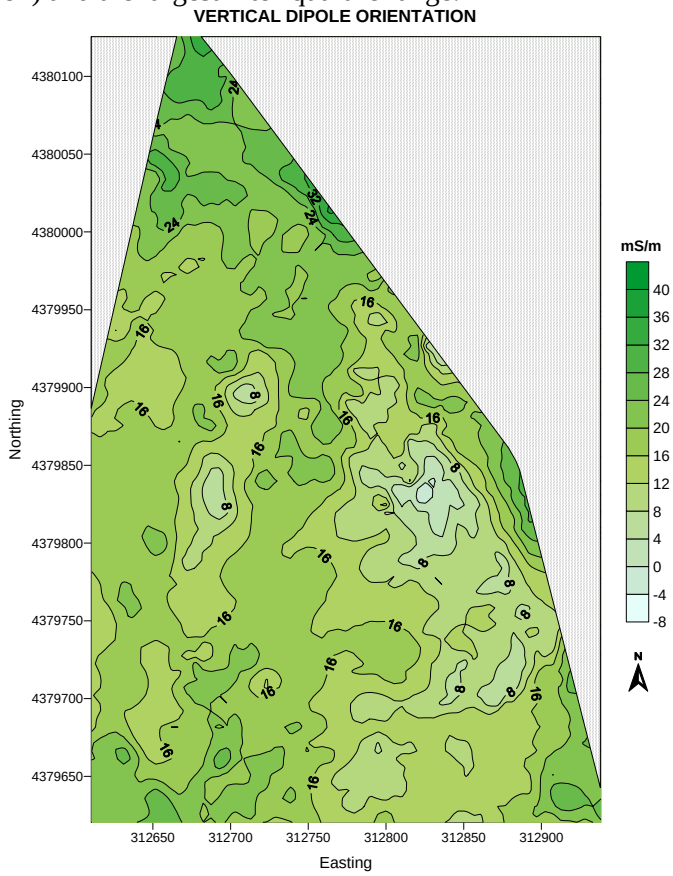


*Figure 6. Plot of $EC_a$ data collected on Flickinger's Field.*

Compare with the fall survey, which was supposedly conducted under generally drier soil conditions, $EC_a$ was generally higher in the present surveys. Temporal changes in $EC_a$ caused by differences in soil moisture contents are commonly observed in EMI surveys that are conducted over the same parcels of land at different times. In the present survey, negative responses in areas of darker-colored, ferromanganiferous soils appeared more restricted and suppressed by higher moisture contents. Results from the present surveys show that $EC_a$ was often higher in the shallower-sensing horizontal dipole orientation than in the deeper-sensing vertical dipole orientation. This relationship was attributed to higher clay and moisture content of the upper solum and the occurrence of more

electrically resistive parent rock in the lower portions of some profiles. However, the magnitude of difference between measurements made in the two dipole orientations was considered uncharacteristic for measurements obtained with the EM38DD meter in areas of very deep soils formed over relatively uniform columns of residuum or colluvium. In addition, differences between the two dipole measurements appeared markedly greater in the area where ferromanganiferous soils had been identified and sampled.

In areas of very deep soils formed over relatively uniform parent materials, a high, positive correlation is generally found between the measurements made in the two dipole orientations with the EM38DD. This is to be expected as measurements reflect similar segments of the same soil column. In additions, $EC_a$ measurements are based on depth-weighted averages and are more responsive to soil properties that are nearer to the surface. As a consequence, correlations coefficients between the measurements made in the two dipole orientations are typically greater than 0.80 and frequently greater than 0.90. In the present surveys the data sets displayed a lack of correlation. This is considered uncommon. Correlation coefficients (r) of 0.068, -0.340, 0.055, -0.442, and 0.046 were obtained for the $EC_a$ data collected in the horizontal and vertical dipole orientations with the EM38DD meter at Dotter1, Dotter 2, Dotter 3, and Grossnickle sites, respectively.

To express the difference in $EC_a$ measured with the EM38DD meter in the two dipole orientation, a *vertical change index* was devised. The *vertical change index* is simply the difference in $EC_a$ measured with the EM38DD meter in the horizontal and vertical dipole orientations (horizontal dipole measurement – vertical dipole measurement). The spatial distribution of these measurements within the Dotter and Grossnickle sites are shown in Figures 7 thru 10. It is inferred that areas with negative indices are characterized by very deep soils with $EC_a$ increasing with increasing soil depths (measurement in the vertical dipole orientation are greater than measurements in the horizontal dipole orientation). This increase in $EC_a$ with soil depth is attributed to increasing clay and moisture contents with depth. Areas with positive indices are characterized by shallower soils with $EC_a$ decreasing with increasing soil depths (measurement in the vertical dipole orientation are less than measurements in the horizontal dipole orientation). This decrease in $EC_a$ with soil depth is attributed to the presence of electrically resistive parent rock and possibly higher levels of magnetic susceptibility.

It is presumed that magnetic susceptibility affects all $EC_a$ measurements made at the sites in Frederick County. It is inferred from the spatial patterns shown in Figures 7 thru 10 that ferromanganiferous soils will have a higher $EC_a$ in the shallower-sensing horizontal dipole orientation (because of low bulk density and high moisture retention?) and a very low or negative $EC_a$ in the deeper-sensing vertical dipole orientation (because of magnetic susceptibility?). Areas that have a large positive *vertical change index* should best exemplify ferromanganiferous soils.

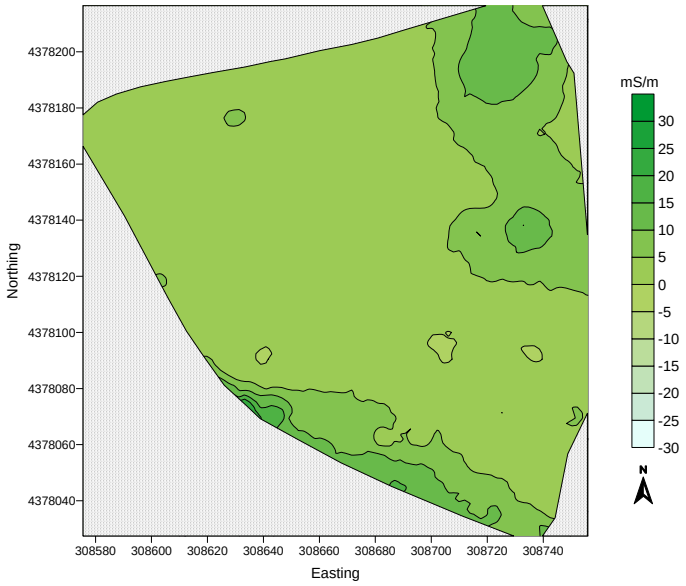


*Figure 7. Vertical Change Indices for Dotter 1*

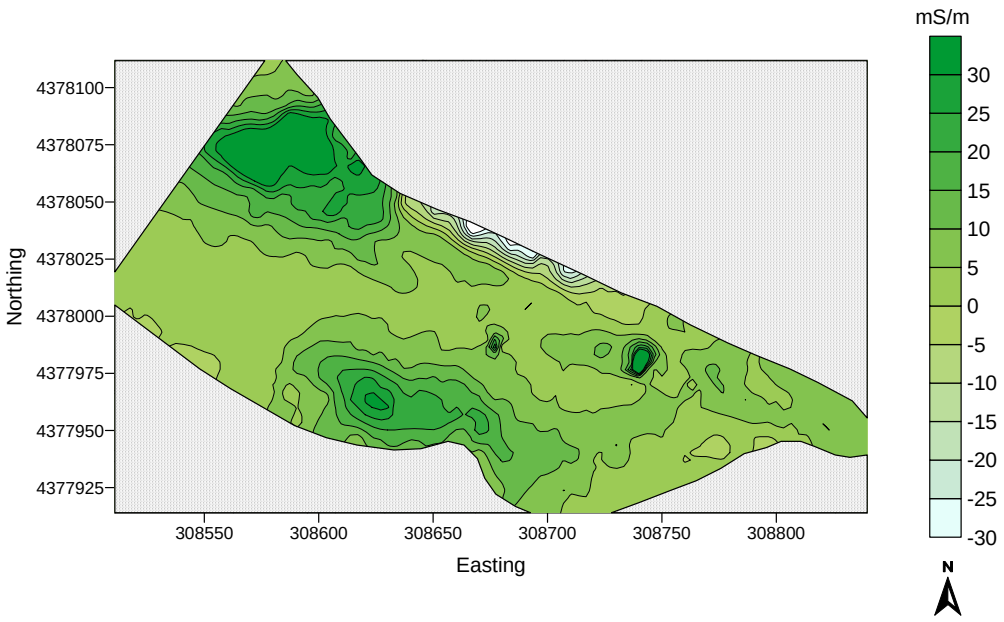


*Figure 8. Vertical Change Indices for Dotter 2*

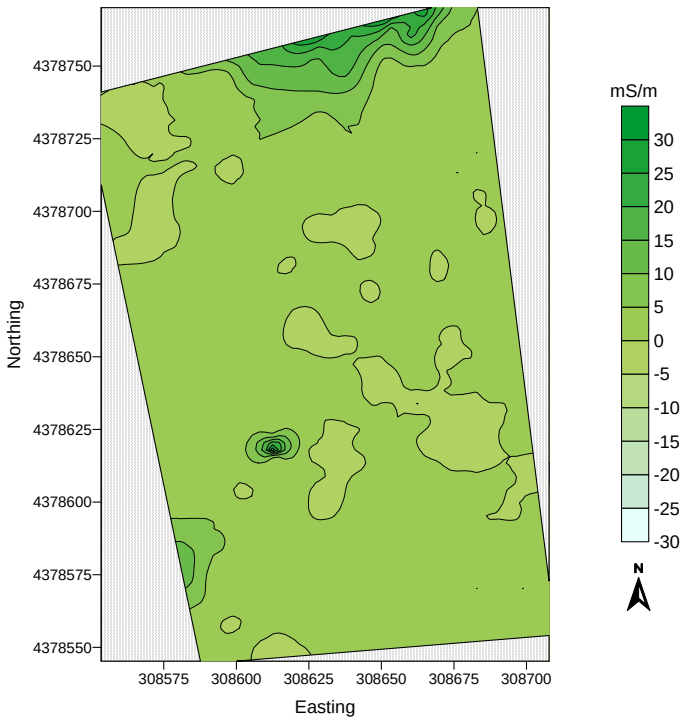


*Figure 9. Vertical Change Indices for Dotter 3*

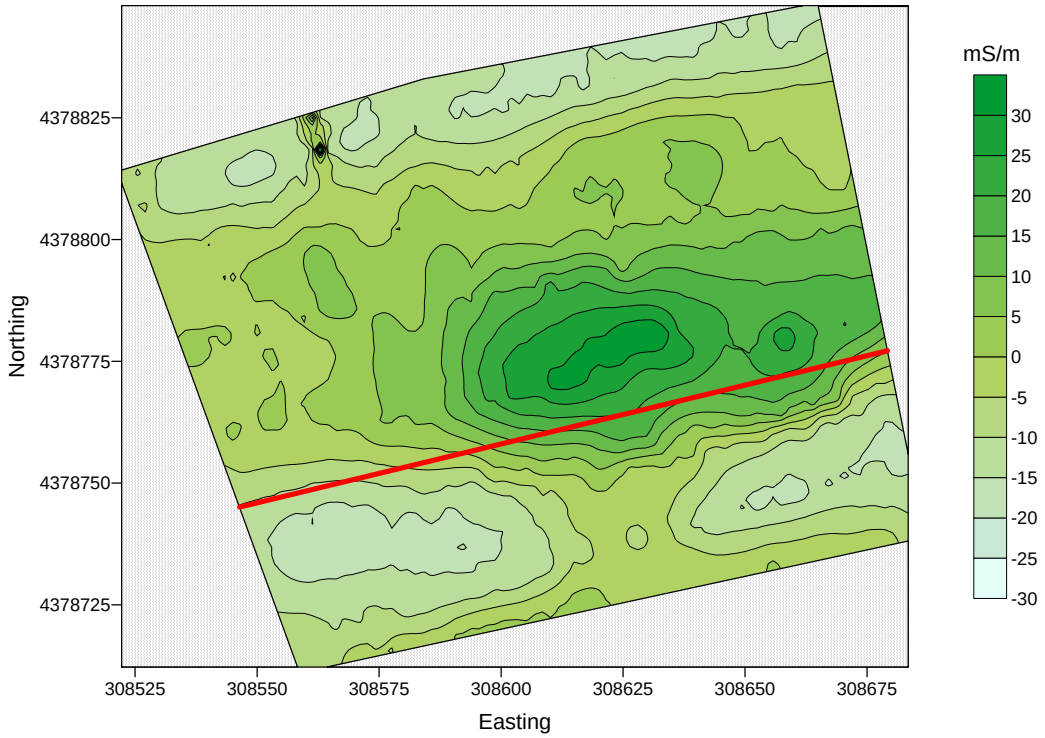


*Figure 10. Vertical Change Indices for Grossnickle*

**References**:

Blank, R. R. and M. Rabenhorst, 2006. Pedogenesis of highly ferromanganiferous soils in the Maryland Piedmont. Paper 101-11. Agronomy Abstracts. Soil Science Society of America Annual Meeting, November 12-16, 2006, Indianapolis, IN

Geonics Limited, 2000. EM38-DD Ground Conductivity Meter, Dual Dipole Version, Operating Manual. Geonics Ltd., Mississauga, Ontario.

Maryland Geologic Survey, 1968. Geologic Maps of Maryland; Frederick County. (http://www.mgs.md.gov/esic/geo/fre.html).

USDA-NRCS, 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. USDA Handbook 296, US Government Printing Office, Washington, District of Columbia.