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

Subject: Soils – Electromagnetic Induction (EMI) training

Date: 21 November 2007

To: William J. Gradle
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USDA-Natural Resources Conservation Service
2118 West Park Court
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Purpose:
Training was provided to soil scientists from central Illinois on the use and operation of the EM38 meter, Allegro CE field computer, and related software programs. Field exercises were conducted with the Veris system and the EM38 meter on two topographically diverse sites, which contained several landforms, contrasting parent materials and soils.

Participants:
Kristine Ashpole, Soil Scientist, USDA-NRCS, Aurora, IL
Chris Cochran, Soil Scientist, USDA-NRCS, Charleston, IL
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Alison Steglich, Soil Scientist, USDA-NRCS, Aurora, IL
Roger Windhorn, Resource Soil Scientist, USDA-NRCS, Champaign, IL
Dan Withers, Cartographic Technician, USDA-NRCS, Champaign, IL

Activities:
All activities were completed on 5 thru 7 November 2007.

Summary:

1. Increasingly, NRCS staffs are using mobile platforms to conduct electromagnetic induction (EMI) surveys. The speed and ease with which data are recorded on these platforms greatly reduces survey time and makes practical the surveying of large areas. The Soil Staff in Illinois recently purchased a specially designed cart, which will facilitate mobile EMI surveys. This cart is amendable to the EM31 and EM38 meters presently operated in Illinois.

2. Mobile surveys are commonly conducted with a field computer, which simultaneously records EC_a (apparent conductivity) and GPS (global positioning system) data. The Illinois Soil Staff has two Omnidata polycorder, which can be used with the EM31 and EM38 meters to record EC_a data in both the manual and continuous modes of operation. Unfortunately, these recorders do not permit the simultaneous recording of EC_a and GPS data. To be effective, mobile EMI surveys require the collection of both sets of data.

3. Illinois recently upgraded (RT conversion) one of its EM38 meters to provide a digital output; and has the necessary software for collecting, storing, and processing both EC_a and GPS data. These technologies will support an advanced data collection system that can be used by various staffs throughout the state.

4. Because of Summary points 2 and 3, an Allegro CE field PC (serial # 7093) will be transferred from the National Soil Survey Center to the Illinois Soil Staff. This will allow your staff to conduct mobile EMI surveys with either

the EM31 or EM38 meters and simultaneously record both EC_a and GPS data. However, the Illinois Soil Staff will need to purchase two 7.5 meter cables (one for EM31 and EM38 meters). These longer cables are required in order for the EMI meters to be towed behind an ATV on the cart.

5. In addition to the Allegro CE field computer, two Omnidata polycorder, which were previously loaned to the Illinois Soil Staff, will be officially transferred. The serial numbers for the polycorders are: for the Model PC-722B - SN P72-0400, AG0002711487; for the Model PC600-44801 – SN 018-9179, AG0002942860.

6. Field training was provided on the operation of the EM38 meter, DAS70 Data Acquisition System, and supporting software. At each field site, an EMI survey was completed and the resulting EC_a data were transferred, processed, and displayed (as two-dimensional plots) using different software programs. Participants interpreted the spatial EC_a patterns that appeared on EC_a plots of each study site. At the field sites selected for this training, major spatial EC_a patterns were related principally to differences in the clay and moisture contents.

7. The information overload during this brief training period was acute. A training DVD covering the fundamentals of the EM38 and the DAS70 acquisition system has been provided by the National Soil Survey Center, to help users refresh their memory on the procedures covered.

8. The figures shown in this report were developed by Dan Withers. His assistance in these projects is greatly appreciated by all.

It was my pleasure to work in Illinois and to be of assistance to your staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
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Equipment:
The Veris system is a towed-array, multi-electrode resistivity unit manufactured by Veris Technologies (Salina, Kansas).[1] Operating procedures are described by Veris Technologies (1998). The Veris system provides two soil measurement depths: one for the upper 0 to 30 cm (shallow) and one for the upper 0 to 90 cm (deep). The Veris system was pulled behind a 4WD vehicle. A Trimble 132 GPS (Global Positioning System) receiver (Sunnyvale, CA) is used with the Veris system to geo-reference the collected EC_a data.[1]

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 orientation, respectively (Geonics Limited, 1998).

Geonics' DAS70 Data Acquisition System is used with EMI meters to record and store both EC_a and position data.[1] In this study, the acquisition system consisted of an EM38 meter, an Allegro CE field computer (Juniper Systems, North Logan, UT), and a Garmin 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, EC_a and GPS measurements are automatically recorded in the field computer. The NAV38, DAT38W, and Trackmaker38 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EC_a and GPS data.[1]

All soil maps shown in this report were scanned and digitized by Dan Withers using commercial software (ESRI Arc/Info (version 8.3).[2] All spatial data were imported into ESRI ArcView (version 3.3).[1] A triangular irregular network (TIN) was used to interpolate and convert the EMI data into a GRID/raster file.

Field Methods:
The Veris system was towed behind a 4WD vehicle. Measurements (consisting of two EC_a measurements (shallow and deep)) were recorded at one second intervals and geo-referenced with the GPS receiver. Surveys were completed by driving the 4WD vehicle at a uniform pace, in a random or back and forth pattern across each site.

The EM38 meter was towed behind an ATV in a plastic sled at speeds of 1 to 3 m/sec. The EM38 meter was operated only in the deeper-sensing (0 to 1.5 m) vertical dipole orientation and in the continuous (measurements recorded at 1-sec intervals) mode. While surveying, the EM38 meter was orientated with its long axis parallel to the direction of traverse. Surveys were completed by driving the ATV at a uniform pace, in a random or back and forth pattern across each site.

All data are expressed as values of EC_a in milliSiemens/meter (mS/m). EC_a measurements were not temperature corrected.

Study Sites:
Both study sites are located in McLean County, Illinois. Both sites were partially in CRP and in hay land. The first site is located off of County Road 3075 E in the S 1/2 of Section 31, T. 25 N., R. 5 E. The names of the soil map units delineated at this site by the 2nd order soil survey are listed in Table 1. The second site is located off of County Road 3100 E in the S 1/2 of Section 5, T. 24 N., R. 5 E. The names of the soil map units delineated in this site by the 2nd order soil survey are listed in Table 2. The taxonomic classifications of all soils recognized in the study sites are listed in Table 3.

The very deep, somewhat poorly drained Brenton and Elburn soils and well drained Camden soils formed in loess or other silty material overlying loamy stratified outwash on stream terraces. The very deep, well drained Fox soils formed in thin mantle of loess and/or loamy alluvium overlying stratified, calcareous, sandy outwash on stream terraces. Fox soils are moderately deep to stratified calcareous sandy outwash. The very deep, somewhat poorly drained Flanagan and Raub soils, and moderately well drained Miami, Mayville, and Saybrook soils formed in loess or other silty materials overlying loamy till on till plains. Miami soils are moderately deep to dense till. The very deep, well drained Strawn and Wyanet soils formed principally in calcareous, loamy till on till plains.

The very deep, poorly drained Drummer soils formed in loess or other silty material and in the underlying loamy stratified outwash on stream terraces. The very deep, poorly drained Elpaso soils formed in loess and glacial till on till plains. The

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

very deep, somewhat poorly drained Lawson soils formed in silty alluvium on upland drainageways. The very deep, poorly drained Sawmill soils formed in alluvium on flood plains.

Table 1. The soil symbols and map unit names for the polygons found at the first study site.

Map Unit Symbol	Map Unit Name
27B2	Miami silt loam, 2 to 5 % slopes, eroded
145B2	Saybrook silt loam, 2 to 5 % slopes, eroded
154A	Flanagan silt loam, 0 to 2 % slopes
193B2	Mayville silt loam, 2 to 5 % slopes, eroded
224C2	Strawn loam, 5 to 10 % slopes, eroded
481A	Raub silt loam, 0 to 2 % slopes
622B2	Wyanet silt loam, 2 to 5 % slopes, eroded
721A	Drummer and Elpaso silty clay loams, 0 to 2 % slopes
8107A	Sawmill silty clay loam, 0 to 2 % slopes, occasionally flooded

Table 2. The soil symbols and map unit names for the polygons found at the second study site.

Map Unit Symbol	Map Unit Name
134B2	Camden silt loam, 2 to 5 % slopes, eroded
149A	Brenton silt loam, 0 to 2 % slopes
193B2	Mayville silt loam, 2 to 5 % slopes, eroded
198A	Elburn silt loam, 0 to 2 % slopes
327B2	Fox silt loam, 2 to 5 % slopes, eroded
8451A	Lawson silty clay loam, 0 to 2 % slopes, occasionally flooded

Table 3. Taxonomic classification of the named soils at the two study sites.

Soil Series	Taxonomic Classification
Brenton	Fine-silty, mixed, superactive, mesic Aquic Argiudolls
Camden	Fine-silty, mixed, superactive, mesic Typic Hapludalfs
Drummer	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
Elburn	Fine-silty, mixed, superactive, mesic Aquic Argiudolls
Elpaso	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
Flanagan	Fine, smectitic, mesic Aquic Argiudolls
Fox	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludalfs
Lawson	Fine-silty, mixed, superactive, mesic Aquic Cumulic Hapludolls
Mayville	Fine-loamy, mixed, active, mesic Typic Argiudolls
Miami	Fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs
Raub	Fine-silty, mixed, superactive, mesic Aquic Argiudolls
Sawmill	Fine-silty, mixed, superactive, mesic Cumulic Endoaquolls
Saybrook	Fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls
Strawn	Fine-loamy, mixed, active, mesic Typic Hapludalfs
Wyanet	Fine-loamy, mixed, active, mesic Typic Argiudolls

Results:

<u>Site One:</u>

Table 4 provides basic statistics for the EMI surveys that were completed with the Veris system and the EM38 meter at the first study site. In this table, the sensors have been arranged so that the depth of penetration increases with each row (0 to 30, 0 to 90, and 0 to 150 cm, respectively). Within this site, EC_a is relatively low and slightly variable. In general, EC_a

increased then decreased with increasing depth. The lowest averaged and least variable EC_a were measured for the 0 to 30 cm depth interval with the Veris system (shallow). The highest averaged and most variable EC_a were measured for the 0 to 90 cm depth interval with the Veris system (deep). This trend in EC_a may reflect the clay bulge in the argillic horizons of Hapludalfs and Argiudolls.

Table 4. Basic statistics for the EMI surveys that were conducted at Site 1.

Sensor	Number	Minimum	25%-tile	75%-tile	Maximum	Mean	St. Dev.
Veris-Shallow	1670	0.40	8.90	13.20	23.70	11.30	3.37
Veris-Deep	1670	0.60	12.60	20.90	41.30	16.99	6.78
EM38-VDO	1823	-12.75	10.63	15.38	51.25	13.43	4.22

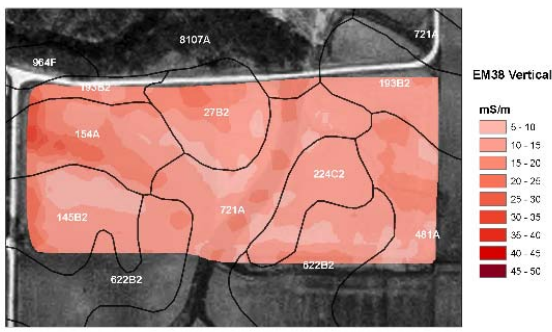

Figure 1. Spatial EC_a patterns derived from data collected with the EM38 operated in the vertical dipole orientation at Site 1 reveals higher values in wetter swales, drainageways, and on some higher-lying slopes.

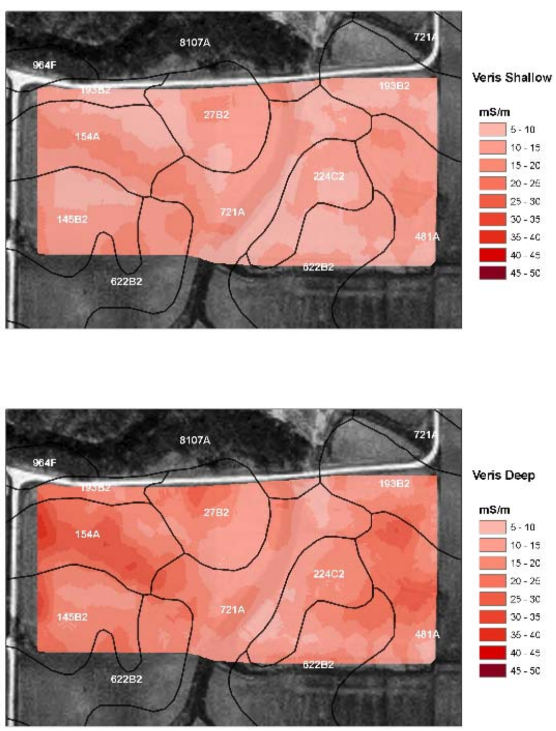

Figure 2. Spatial EC_a patterns from data collected with the Veris System in the shallow (upper plot) and deep (lower plot) sensing modes. Data sets provide similar spatial patterns that vary mostly in amplitude.

Plots of spatial EC_a patterns within Site 1 for the EM38 meter and the Veris system are displayed in Figures 1 and 2, respectively. For the purpose of comparison, all plots shown in this report used the same color ramp and scale. The spatial patterns appearing in Figures 1 and 2 are remarkable similar. Spatial patterns conform to variations in drainage classes, expected soil moisture contents, and depth to water table. In a study that was conducted in Ohio, Allred et al. (2005) observed that EC_a is most strongly affected by near-surface volumetric moisture contents (r = 0.73) followed by water table depth (r = -0.42). On all plots of this site, the locations of wetter or more imperfectly drained soils are identified by higher EC_a unit-areas. A major drainageway, which crosses the central portion of the study site from south to north, is well expressed in these plots. A minor intermittent drainageway, which trends from northwest to southeast into the major drainageway, is also evident in the western part of the site. A third, broad and intermittent drainageway, which drains the eastern portion of the site, was ill-defined with EMI. The poor definition of this third drainageway probably reflects the interaction of both variable clay and moisture contents. Anomalously high (>32 mS/m) or negative EMI responses are presumed to reflect buried cultural features or debris.

In general, polygons of well drained Strawn (224C2) and Wyanet (622B2) soils and moderately well drained Miami (27B2), Mayville (193B2), and Saybrook (145B2) soils occur on higher-lying plane and convex surfaces, which are characterized by lower EC_a. Polygons of somewhat poorly drained Flanagan (154A) and Raub (481A) soils and poorly drained Drummer and Elpaso soils (721A) occur on lower-lying concave surfaces along drainageways, which are characterized by higher EC_a. These soil polygons are constrained by uniform attribute values and do not capture the within map unit variability that is expressed in the EC_a plots. Plots of EC_a data suggest that the 2nd order soil survey of this site may not be adequate to map and interpret the variability in soils and soil properties that occur within this site. Spatial patterns evident in Figures 1 and 2 will vary in magnitude with changes in soil moisture contents (increasing EC_a with increasing moisture contents). However, spatial patterns and EC_a unit-areas should remain consistent as they are influenced by stable soil properties and unique soil/water/landscape relationships.

Table 5. Basic statistics for the EMI surveys that were conducted at Site 2.

Sensor	Number	Minimum	25%-tile	75%-tile	Maximum	Mean	St. Dev.
Veris-Shallow	1444	2.40	8.60	15.20	26.60	12.20	4.72
Veris-Deep	1444	2.20	15.30	27.50	49.40	21.77	8.73
EM38-VDO	1729	6.00	14.00	21.13	33.50	17.86	5.13

Table 5 provides the basic statistics for the EMI surveys that were completed with the Veris system and the EM38 meter at the second study site. Once again, the sensors are arranged so that the depth of penetration increases with each row (0 to 30, 0 to 90, and 0 to 150 cm, respectively). Compare with the first study site, EC_a is slightly higher and more variable for all measured depth intervals at this site. The same vertical trend (EC_a increasing then decreasing with increasing penetration depths) occurs at this site. The lowest average EC_a and least variable EC_a were once again measured for the 0 to 30 cm depth interval with the Veris system (shallow). The highest average EC_a and most variable EC_a were measured for the 0 to 90 cm depth interval with the Veris system (deep).

Plots of spatial EC_a patterns within Site 2 for the EM38 meter and the Veris system are displayed in Figures 3 and 4, respectively. Spatial patterns appearing in these plots are remarkable similar. In all plots the transition from upland soils to Lawson soils (8451A) on the flood plain of the Mackinaw River is clearly expressed. On upland areas, alternating bands of higher and lower EC_a suggests varying soil and soil properties on surfaces that mimic terrace levels. These band trend in a general northwest to southeast direction and approximate some soil polygons (notably 134B2, 198A, and 327B2). Once again, soil polygons are constrained by uniform attribute value and do not capture the variability that is expressed in the EC_a plots. At Site 2, plots of EC_a data suggest that the 2nd order soil survey of this site may not be adequate to map and interpret the variability in soils and soil properties that occur within this site.

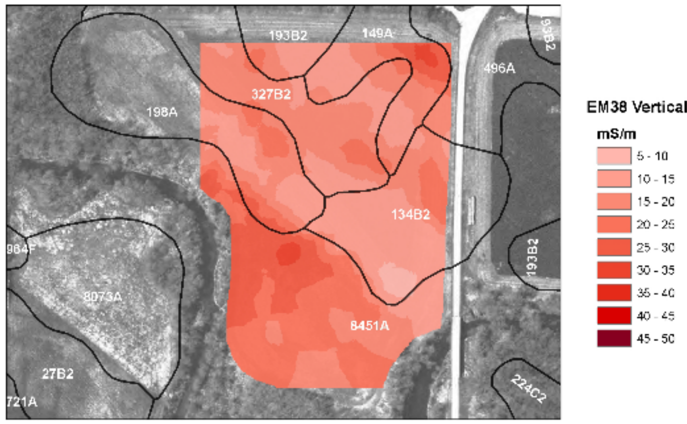

Figure 3. Spatial EC_a patterns derived from data collected with the EM38 operated in the vertical dipole orientation at Site 2 reveals alternating bands of higher and lower values, which reflect differences in landforms and soils

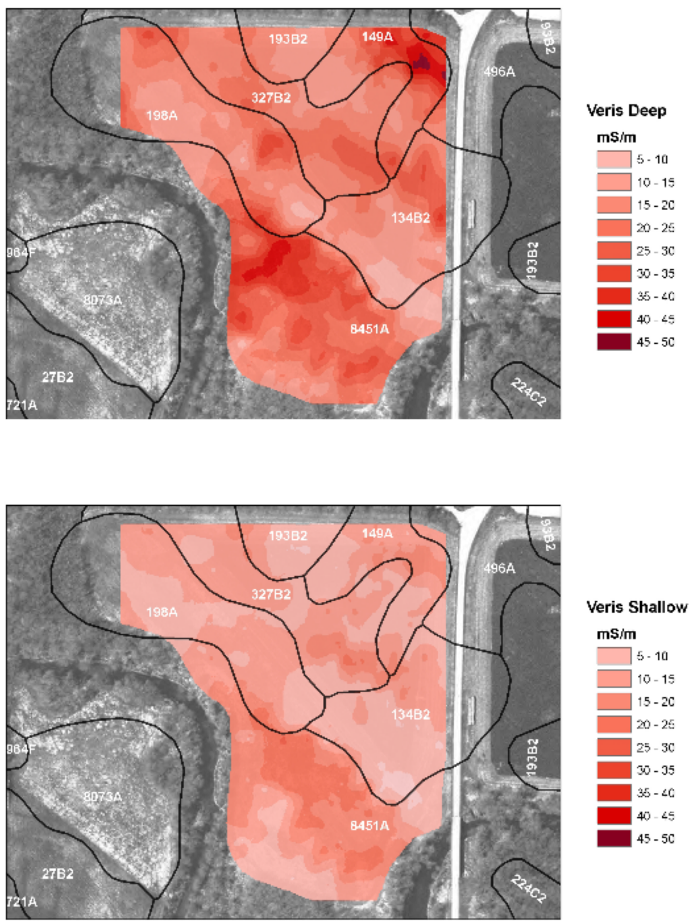

Figure 4. Spatial EC_a patterns from data collected with the Veris System in the shallow (upper plot) and deep (lower plot) sensing modes. Data sets provide similar spatial patterns that vary mostly in amplitude.

References:

Allred, B. J., M. R. Ehsani, and D. Saraswat, 2005. The impact of temperature and shallow hydrologic conditions on the magnitude and spatial pattern consistency of electromagnetic induction measured soil electrical conductivity. Transaction of the American Society of Agricultural Engineers 48(6): 2123-2135.

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