United States Department of Agriculture

NRCS

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SUBJECT: SOI – Geophysical Assistance

June 29, 2011

TO: William J. Gradle
State Conservationist
USDA-Natural Resources Conservation Service
2118 West Park Court
Champaign, IL 61821

File Code: 330-7

Purpose:
The purpose of this visit was to conduct comparative studies and provide field training using different electromagnetic induction (EMI) meters and a towed-array resistivity unit at sites located in Randolph, Montgomery, and Mclean Counties, Illinois.

Participants:
Mark Bramstedt, Resource Soil Scientist, USDA-NRCS, Watseka, IL
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Sam Indorante, MLRA Project Leader, USDA-NRCS, Carbondale MLRA, Carbondale, IL
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Roger Windhorn, Resource Soil Scientist, USDA-NRCS, Champaign, IL
Dan Withers, Cartographic Technician, USDA-NRCS, Champaign, IL

Activities:
All activities were completed during the period of 13 to 16 June 2011.

Summary:

1. Apparent conductivity (EC_a) data were used to assess variations in soil water and clay contents, soil types, and soil-landscape patterns.

2. At each site, based on the collected EC_a data, a response surface sampling design (RSSD) was used to identify six optimal sampling points. Soil will be sampled and water monitored at some of these optimal sampling sites to advance our understanding of soil-hydrologic processes and to improve interpretations.

3. At all sites where the EM38DD meter and the Veris system were used, EC_a increased with increasing depth (Veris *shallow* (0 to 30 cm) < EM38DD-HDO (0 to 75 cm) < Veris *deep* (0 to 90 cm)). However, the average value for the Veris *deep* (0 to 90 cm) was higher than the average value for the EM38DD-VDO (0 to 150 cm). Based on limited soil information, this relationship

cannot be presently explained. It is unclear whether these values represent existing soil heterogeneity and layering, or equipment and calibration errors.

4. Spatial relationships between EC_a and soil-landforms were contrary for the study sites located in Montgomery and Mclean Counties. At the Montgomery County site, swales had lower EC_a and summit areas of interfluves had higher EC_a. This relationship was associated with the infilling of swales with silts and the presence of a paleosol on more stable surfaces of interfluves. At the Mclean County site, swales had higher EC_a, which is attributed to higher moisture and clay contents. Summit areas of interfluves had intermediate EC_a. Also at the Mclean County site, areas of lowest EC_a are on lower-lying terrace positions. Soils on terraces are presumed to be coarser textured and better drained. Additional ground-truth auger observations are needed to verify these interpretations.

5. Ground-penetrating radar (GPR) calibration trials and traverses were completed in an area of Lenzburg soils. Low signal to noise ratios plagued radar records and necessitated the use of advance signal processing to improve the interpretability of radar records. Processed radar records were plagued by a large number of point reflectors, which obscured reflections from weakly expressed layers in the reclaimed mined materials. In Illinois, the effective use of GPR in areas of reclaimed mine spoil is limited.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to be of assistance to your staff.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL

Director

National Soil Survey Center

cc:
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Technical Report on Geophysical Investigations conducted in Illinois on 13 to 16 June 2011

James A. Doolittle

Equipment:
Several geophysical tools were used in this study. These geophysical tools are: the Veris 3100 soil EC mapping system (here after referred to as the Veris system), the EM31, EM38, and EM38DD soil conductivity meters, and the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (hereafter referred to as the SIR-3000).

The Veris system is a towed-array, multi-electrode resistivity unit manufactured by Veris Technologies (Salina, Kansas).[1] Operating procedures for the Veris system are described by Veris Technologies (1998). The Veris system converts measurements of apparent resistivity (ohm-m) into apparent conductivity (mS/m). The Veris system provides measurements of two soil depth intervals: the upper 0 to 30 cm (*shallow*) and the upper 0 to 90 cm (*deep*). The Veris system was used at the Randolph and Mclean County sites. This system was pulled behind a 4WD truck (Randolph County) or Polaris Ranger utility vehicle (Mclean County) at speeds ranging from about 3 to 10 m/hr. A Trimble 132 GPS receiver was used with the Veris system to geo-reference all EC_a measurements.[1]

The EM38, EM38DD, and the EM31 meters are manufactured by Geonics Limited (Mississauga, Ontario) [1]. These meters are portable, and require only one person to operate. No ground contact is required with these meters.

The EM38 meter weighs about 3 kg (6.6 lbs), and operates at a frequency of 14,600 Hz. The EM38 meter has effective penetration depths of about 0 to 0.75 and 0 to 1.5 m in the horizontal (HDO) and vertical dipole (VDO) orientations, respectively (McNeill, 1986). This meter was used at the Montgomery and Mclean County sites where it was pulled in a sled behind a Polaris Ranger utility vehicle at speeds of about 3 to 5 m/hr.

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 VDO and having both transmitter and receiver activated) and one meter acts as a slave unit (meter that is positioned in the HDO with only the receiver activated). The EM38DD meter weighs about 6 kg (13.2 lbs), and operates at a frequency of 14,600 Hz. It has effective penetration depths of about 0 to 0.75 and 0 to 1.5 m in the HDO and VDO, respectively. Geonics Limited (2000) describes the operating procedures of the EM38DD meter. This meter was used at the Randolph County sites where it was pulled in a sled behind a Polaris Ranger utility vehicle at speeds of about 3 to 5 m/hr.

The EM31 meter weighs about 12.4 kg (27.3 lbs), has a 3.66 m intercoil spacing, and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM31 meter has effective penetration depths of about 0 to 3.0 and 0 to 6.0 meters in the HDO and VDO, respectively (McNeill, 1980). McNeill (1980) has described the principles of operation for the EM31 meter. This meter was used at the Randolph and Mclean County sites. A pedestrian survey was completed at the Randolph County sites. At the McLean County site, the meter was pulled in a specially-designed cart behind a Polaris Ranger utility vehicle at speeds of about 3 to 5 m/hr

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

The Geonics DAS70 Data Acquisition System was used with the EMI meters to record and store both EC_a and GPS data.[2] The acquisition system consists of an EMI meter, an Allegro CX field computer (Juniper Systems, Logan, Utah).[2] The Trackmaker38DD, RTmap38MK2 and the RTmap31 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used with different EMI meters and an Allegro CX field computer to record, store, and process EC_a and GPS data.[2] All EC_a data were corrected to a standard temperature of 75^o F.

To help summarize the results of the EMI survey, SURFER for Windows (version 9.0), developed by Golden Software, Inc. (Golden, CO), was used to construct the simulations shown in this report.[2] Grids of EC_a data were created using kriging methods with an octant search.

The radar unit is the SIR-3000, manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[2] The SIR-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-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A 200 MHz antenna was used in this investigation.

The RADAN for Windows (version 6.6) software program (developed by GSSI) was used to process the radar records shown in this report.[2] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

Calibration of GPR:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, water table) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (*v*) are described in equation [1] (after Daniels, 2004):

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to equation [2] (after Daniels, 2004):

$$E_r = (C/\,v)^2 \qquad [2]$$

“C” is the speed of light in a vacuum, which is defined as exactly 299,792,458 m/s (about 0.3 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and *v*.

Ground-penetrating radar was only used at Site 2 in Randolph County. Based on the measured depth and the two-way pulse travel time to a known, buried subsurface reflector (metal plate buried at 50 cm), the *v* and the E_r through the upper part of a Lenzburg soil profiles was estimated using equations [1] and [2]. At the time of this study, soils were considered moist. In an area of Lenzburg gravelly silty clay loam, 1 to 7 % slopes (871B), the estimated E_r was 3. This E_r is very low for what are considered moist soils. This E_r results in an estimated *v* of 0.1732 m/ns.

[2] Trade names are used for specific references and do not constitute endorsement.

Study Sites:
<u>Sparta Army National Guard Training Area, Randolph County:</u>
Four study sites were selected within the Army National Guard Training Area near Sparta, Illinois (see Figure 1 for approximate locations of the sites). The study sites are located within a relatively large reclaimed surface mined area. All sites are on government-owned property that is presently in a state of disuse (overgrown with weeds, grasses, and undergrowth). Following mining operations, all sites were graded and covered with a layer of pre-mined soil materials. Sites are mapped as Swanwick silt loam, 5 to 10 % slopes (824C); and Lenzburg gravelly silty clay loam, 1 to 7 % slopes (871B). The very deep, moderately-well drained Swanwick and well drained Lenzburg soils formed in materials that have been excavated and reclaimed from surface mining operations. The regolith is dominantly fine earth materials that contain till pebbles and fragments of shale, siltstone, sandstone, or limestone. Lenzburg soils contain more rock fragments throughout than Swanwick soils. The taxonomic classifications of these soils are listed in Table 1. These soils are moderately-well drained and well drained, but soil scientists believe that the soil drainage classes of these soils do not represent the soils mapped. Based on the results of EMI surveys, six calibration points were identified at each of the study sites. Soil textural and moisture sampling (samples taken in 30-cm depth intervals to a depth of 90 or 120 cm) will be carried out at each of these twenty-four calibration points (6 points within each of 4 sites) to help substantiate the classifications of these soils.

Figure 1. This soil map of the Sparta National Guard Training Area shows the approximate locations of the four study sites. The soil map is from the Web Soil Survey.[3]

[3] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [June 23, 2011].

Table 1. Taxonomic classification of soils.

Soil Series	Taxonomic Classification
Drummer	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
Elpaso	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
Fishhook	Fine-silty, mixed, superactive, mesic Aquic Hapludalfs
Hennepin	Fine-loamy, mixed, active, mesic Typic Eutrudepts
Hickory	Fine-loamy, mixed, active, mesic Typic Hapludalfs
Kaneville	Fine-silty, mixed, superactive, mesic Mollic Oxyaquic Hapludalfs
Lenzburg	Fine-loamy, mixed, active, calcareous, mesic Haplic Udarents
Miami	Fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs
Mayville	Fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs
Oconee	Fine, smectitic, mesic Udollic Endoaqualfs
Raub	Fine-silty, mixed, superactive, mesic Aquic Argiudolls
Swanwick	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents

Montgomery County:

This study site is located on the *Scrubland Management Area* of the *Coffeen Lake State Fish & Wildlife Area* in the W ½ of Section 27, T. 8 N., R. 3 W. Soil map units delineated within this site include Fishhook silt loam, 5 to 10 percent slopes, eroded (6C2); Hickory silt loam, 10 to 18 percent slopes (8D); Hickory loam, 10 to 18 percent slopes, eroded (8D2); and Oconee silt loam, 2 to 5 percent slopes (113B). Figure 2 is the soil map for this study site. These very deep soils formed on till plains and are differentiated on the basis of soil drainage and thickness of loess mantle. The well drained Hickory soils formed in till with a loess cap that is less than 50 cm thick. The somewhat poorly drained Fishhook soils formed in 51 to 102 cm of loess and an underlying till, which contains a strongly developed paleosol. The somewhat poorly drained Oconee soils formed in loess, or in loess with an underlying silty pedisediment. The taxonomic classification of these soils is listed in Table 1.

McLean County Order 1 mapping exercise

This study site consists of units of CRP land in the W ½ of Section 5, T. 24 N., R. 5 W. Soil map units delineated within this site include Miami silt loam, 2 to 5 percent slopes, eroded (27B2); Mayville silt loam, 2 to 5 percent slopes, eroded (193B2); Raub silt loam, 0 to 2 percent slopes (481A); Kaneville silt loam, 0 to 2 percent slopes (667A); Drummer and Elpaso silty clay loams, 0 to 2 percent slopes (721A); and Miami and Hennepin soils, 18 to 35 percent slopes (964F). Figure 3 is a soil map of the study site. These very deep soils formed on till plains. The poorly drained Drummer and Elpaso, somewhat poorly drained Raub, and the moderately-well drained Kaneville, Mayville, and Miami soils formed in loess or other silty material and in the underlying loamy stratified outwash or till. The well drained Hennepin soils formed in calcareous glacial till on upland. Miami soils form in a thin (< 50 cm) layer of silty materials and are moderately deep to dense till. The taxonomic classification of these soils is listed in Table 1.

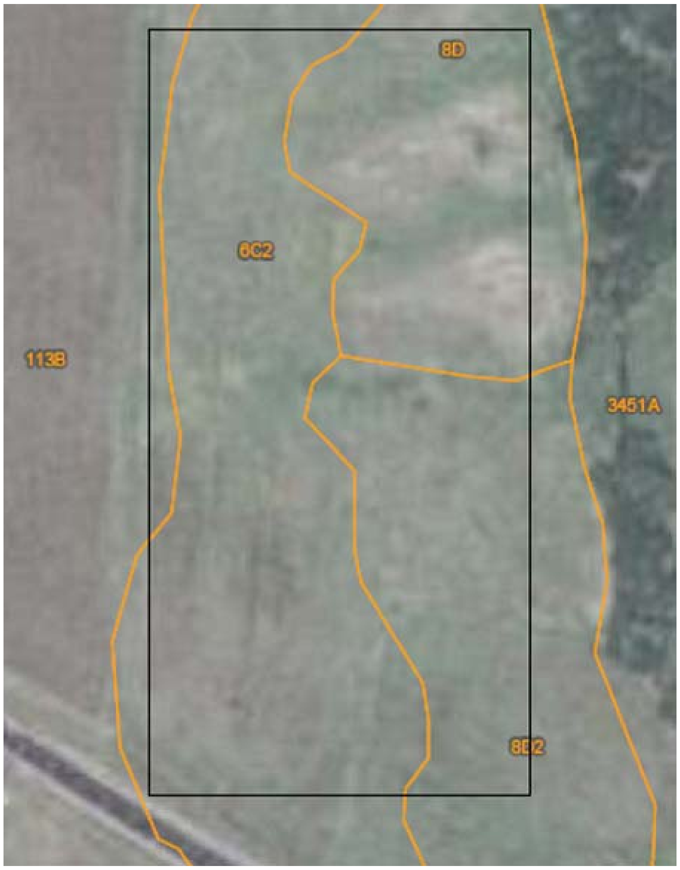

Figure 2. This soil map shows the location of the EMI grid area (enclosed by black, solid lines) within the Coffeen Lake State Fish & Wildlife Area in Montgomery County. Soil map is from the Web Soil Survey. [4]

Figure 3. This soil map shows the location of the EMI grid area (enclosed by black, solid lines) at the McLean County Site. Soil map is from the Web Soil Survey. [4]

[4] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [June 24, 2011].

Results:

<u>Sparta Army National Guard Training Area:</u>

Site 1:

This site is considered the wettest of the four sites study at the Army National Guard Training Area. The site is elongated and confined on either side by dense vegetation and wetter soil conditions. As a consequence the survey area is rather narrow and restricted. Mobile surveys were completed with both the EM38DD meter and the Veris system. As EC_a is known to increase with increasing soil moisture contents, this site was projected to have one of the highest EC_a. Paradoxically, of the four selected sites, this site had the lowest average and least variable EC_a recorded with both sensors. The lower EC_a at this site can be attributed to lower clay contents and/or greater concentrations of coarse fragments. If the lower EC_a is associated with a greater number of coarse fragments in the soils, the soil type at this site may need to be changed from Swanwick to Lenzburg. With both sensor, EC_a increases and became slightly more variable with increasing depth of penetration. This vertical trend in EC_a was repeated at each of the four sites. Table 2 lists these basic statistics for the EC_a data collected at this site.

Table 2. Basic EC_a statistics for Site 1 at the National Guard Training Area in Sparta, Illinois. With the exception of "Number", all values are in mS/m.

	EM38DD-HDO	EM38DD-VDO	Veris-Shallow	Veris-Deep
Number	600	600	577	577
Minimum	18.98	35.20	6.80	29.63
25%-tile	25.65	44.40	13.40	43.97
75%-tile	31.28	49.47	18.85	54.23
Maximum	54.32	66.36	30.26	97.68
Mean	28.81	47.17	16.16	50.20
Std. Dev.	4.25	4.42	3.81	8.76

Figure 4 shows the spatial distribution of EC_a as measured with the EM38DD meter in the HDO (upper left-hand plot) and VDO (lower left-hand plot), and the Veris system *shallow* (upper right-hand plot) and *deep* (lower right-hand plot). These plots show that EC_a is comparatively low and, with the exception of the Veris *deep*, spatially invariable within Site 1. A comparison of these plots based on increasing effective penetration depths reveals that EC_a increases with depth (Veris *shallow* (0 to 30 cm) EM38DD-HDO (0 to 75 cm), Veris *deep* (0 to 90 cm)) until a depth of about the 75 to 90 cm, and then decreases to a depth of about 150 cm (EM38DD-VDO (0 to 150 cm)). A response surface sampling design model was applied to EC_a data collected with EM38DD meter and used to identify six optimal sampling or calibration points at Site 1. These calibration points are identified in the plots of EC_a data that were collected with the EM38DD meter (left-hand plots).

In Figure 4, spatial EC_a patterns shown in the four plots are vaguely similar. Comparative studies have mostly revealed close similarities between EC_a data collected with different instruments (Saey et al., 2008; Sudduth et al., 2003, 1999; Doolittle et al., 2002, 2001). However, differences in sensor calibration, depth sensitivity curves and volume of soil material measured do affect measurements and will result in slightly different EC_a values. Differences among EC_a data collected with different sensors have been attributed to differences in sensing depths and data collection modes (e.g., vertical vs. horizontal dipole orientations, or *deep* vs. *shallow* measurements (Veris)). Sudduth et al. (2003) noted that the most dissimilar EC_a values and maps will be produced over soils with highly contrasting layers. Within this area of reclaimed mine spoil, dissimilarities in the EC_a maps therefore suggest the presence of highly contrasting layers. The lack of consistent EC_a values and spatial patterns from different the EMI sensors may be a characteristic of reclaimed mined areas.

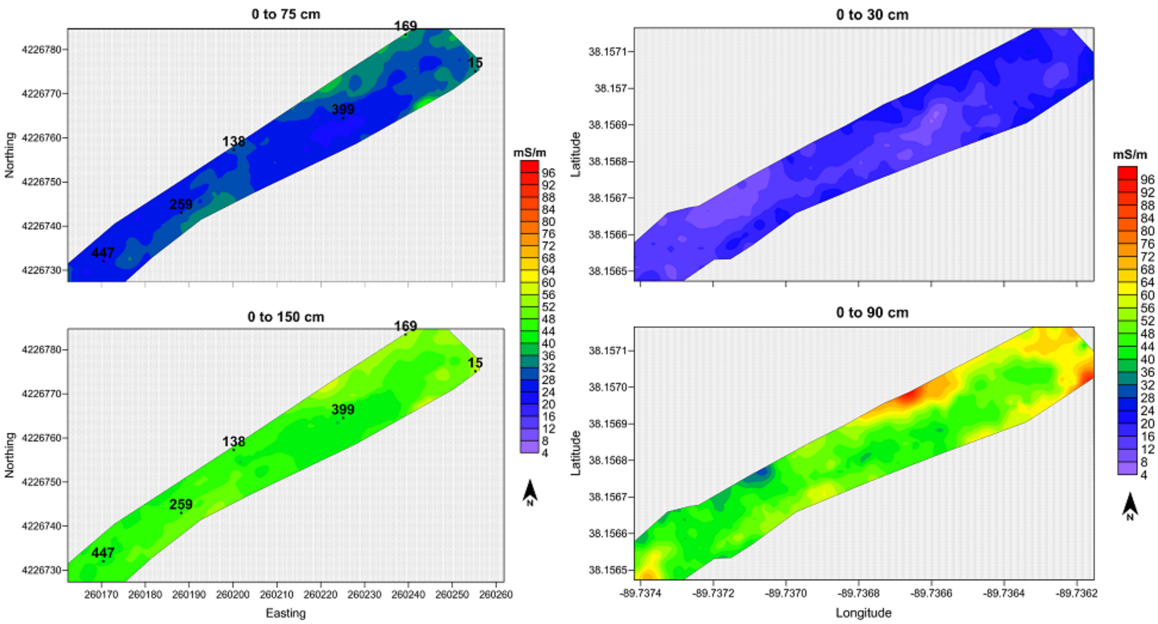

Figure 4. Plots of EC_a data collected at Site 1 with the EM38DD meter (left-hand plots) and Veris system (right-hand plots). The numbers above each plot represent the effective penetration depths. On the plots of data collected with the EM38DD meter, numbers identify the six optimal sampling points estimated from the RSSD program.

Site 2:
Mobile EMI surveys were completed across Site 2 with the EM38DD meter and the Veris system. A pedestrian survey was also completed with the EM31 meter. Like Site 1, Site 2 is mapped as Swanwick silt loam, 5 to 10 % slopes (824C). However, compared to Site 1, EC_a was noticeably higher and more variable at Site 2 (Compare Tables 2 and 3). This was counter to expectations as Site 1 has the appearance of being wetter and the soils at both sites are considered the same. Based on EC_a alone, Site 2 is more closely similar to Sites 3 and 4, which are mapped as Lenzburg soils. With each sensor, EC_a increased and became slightly more variable with increasing depth of penetration at Site 2. Table 3 lists these basic statistics for the EC_a data collected at this site.

Table 3. Basic EC_a statistics for Site 2 at the National Guard Training Area in Sparta, Illinois. With the exception of "Number", all values are in mS/m.

	EM38DD-HDO	EM38DD-VDO	Veris-Shallow	Veris-Deep
Number	1052	1052	902	902
Minimum	16.16	30.88	3.07	0.64
25%-tile	36.44	58.44	17.07	60.31
75%-tile	47.31	71.82	24.27	82.36
Maximum	159.67	185.37	116.18	321.82
Mean	46.35	70.20	21.87	75.05
Std. Dev.	20.95	24.11	10.09	34.73

Measurements recorded with the Veris *deep* were noticeably higher and more variable across this site than measurements obtained with the EM38DD meter.

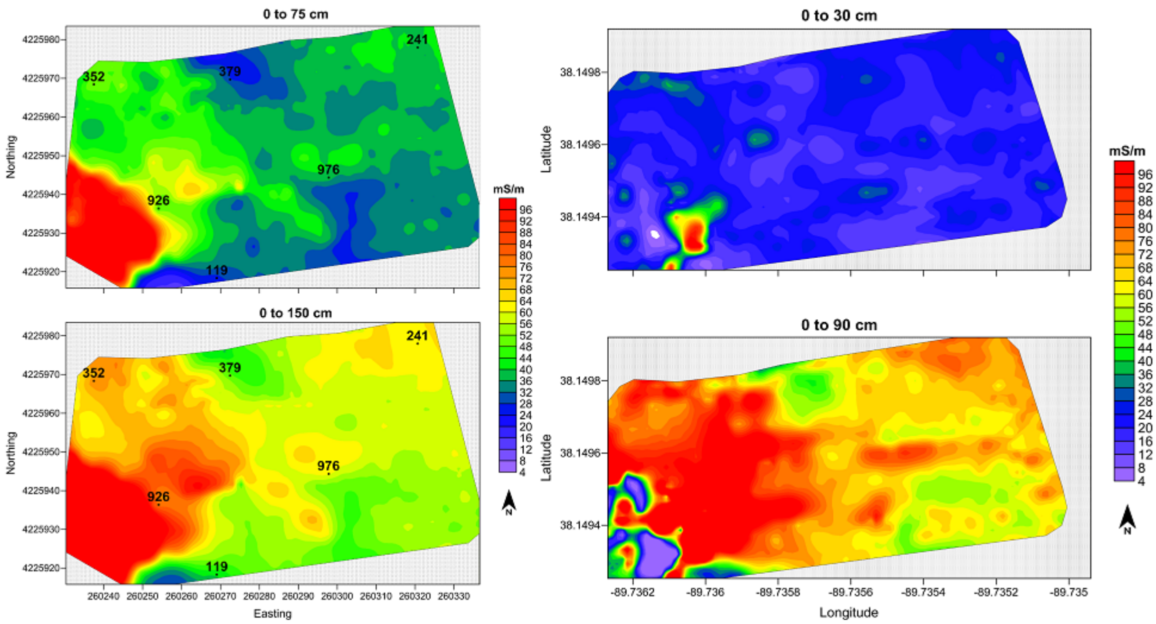

Figure 5. Plots of EC_a data collected at Site 2 with the EM38DD meter (left-hand plots) and Veris system (right-hand plots). The numbers above each plot represent the effective penetration depths. On the plots of data collected with the EM38DD meter, numbers identify the six optimal sampling points estimated from the RSSD program.

Figure 5 shows the spatial distribution of EC_a as measured with the EM38DD meter in the HDO (upper left-hand plot) and VDO (lower left-hand plot), and the Veris system *shallow* (upper right-hand plot) and *deep* (lower right-hand plot). Once again, a comparison of these plots based on increasing effective penetration depths reveals that EC_a increases with depth (Veris *shallow* (0 to 30 cm) < EM38DD-HDO (0 to 75 cm) < Veris *deep* (0 to 90 cm)) until a depth of about the 75 to 90 cm, and then EC_a decreases to a depth of about 150 cm (EM38DD-VDO (0 to 150 cm)). For both sensors and all penetration depths, the spatial patterns indicate that EC_a increases towards the west with highest values recorded near the southwest corner. For the Veris *deep* measurements, EC_a declines to very low values near the southwest corner of the study site. A random core observation in this portion of the site revealed the presences of coarse fragments from a former road bed. A response surface sampling design model was used to select six optimal sampling or calibration points based on EC_a measured with the EM38DD meter. These calibration points are identified in the plots of the EC_a data that were collected with the EM38DD meter (left-hand plots).

A pedestrian survey was completed with the EM31 meter operated in the deeper-sensing VDO across Site 2. Compared with the surveys completed with EM38DD meter and the Veris system, fewer traverse lines were completed and the site was less uniformly covered with the EM31 meter. However, a larger number of measurements were obtained with the EM31 meter than with the EM38DD or Veris system because of the slower speed of advance and higher density of measurement along each line. Table 4 lists the basic statistics for the EC_a data collected with the EM31 meter at this site. The average EC_a measured with the EM31 meter was higher than the average EC_a measured with either the EM38DD meter or the Veris system. This suggests that EC_a continues to increase below the maximum penetration depths of the EM38DD (150 cm) and the Veris system (90 cm).

Table 4. Basic EC_a statistics for data collected at Site 2 of the National Guard Training Area in Sparta, Illinois with the EM31 meter. With the exception of "Number", all values are in mS/m.

	EM31-VDO
Number	1171
Minimum	48.58
25%-tile	68.05
75%-tile	82.66
Maximum	122.01
Mean	77.28
Std. Dev.	13.52

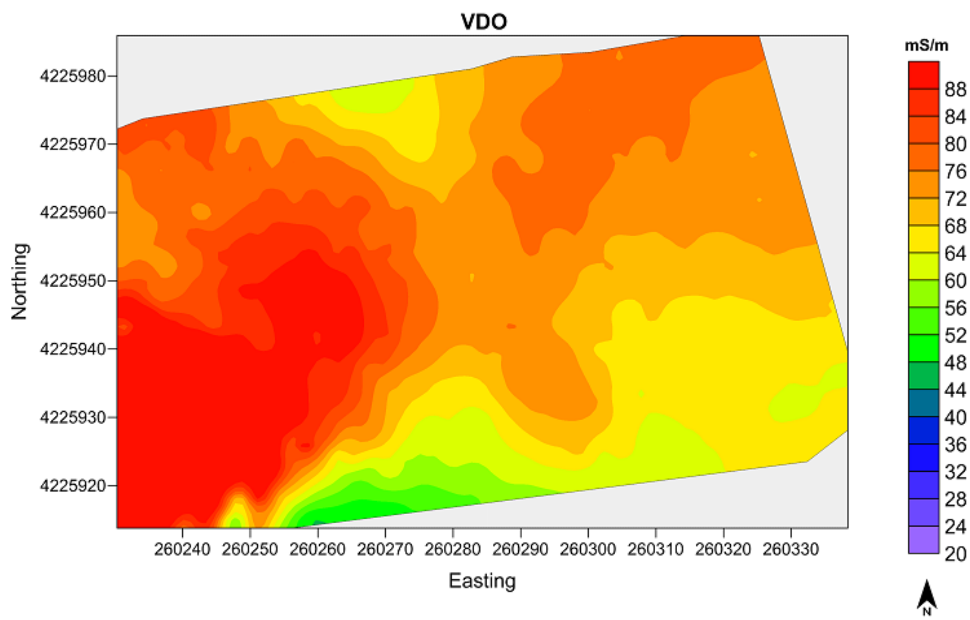

Figure 6. Plot of EC_a data collected at Site 2 with the EM31 meter, which was held at hip-height in the vertical dipole orientation (effective penetration depth of about 5 m).

Figure 6 is a plot of the EC_a data collected with the EM31 meter operated in the VDO at Site 2. Across the site, values recorded with the EM31 meter are higher than those recorded with the EM38DD meter or the Veris system. However, like the EM38DD meter and the Veris system, the highest EC_a is recorded in the southwest corner of the site with a visible extension stretching across the site and into the northeast corner.

Site 3:
Site 3 is located on a slight knoll and is mapped as Lenzburg gravelly silty clay loam, 1 to 7 % slopes (871B). Mobile EMI surveys were completed across Site 3 with the EM38DD meter and the Veris system. Once again, a comparison of data based on increasing effective penetration depths reveals that EC_a increases with depth (Veris *shallow* (0 to 30 cm) < EM38DD-HDO (0 to 75 cm) < Veris *deep* (0 to 90 cm)) until a depth of about the 75 to 90 cm, and then EC_a decreases to a depth of about 150 cm

(EM38DD-VDO (0 to 150 cm)). As with the other sites, measurements recorded with the Veris *deep* were the most variable across Site 3. The average EC_a measured at this site with the Veris *deep* was the highest of the four sites.

Table 5. Basic EC_a statistics for Site 3 at the National Guard Training Area in Sparta, Illinois. With the exception of "Number", all values are in mS/m.

	EM38DD-HDO	EM38DD-VDO	Veris-Shallow	Veris-Deep
Number	549	549	572	572
Minimum	26.70	47.64	4.50	43.14
25%-tile	35.21	58.77	12.25	73.92
75%-tile	41.49	66.22	20.21	92.66
Maximum	117.26	128.00	38.53	183.64
Mean	39.52	63.91	16.87	83.16
Std. Dev.	7.89	8.69	5.72	18.92

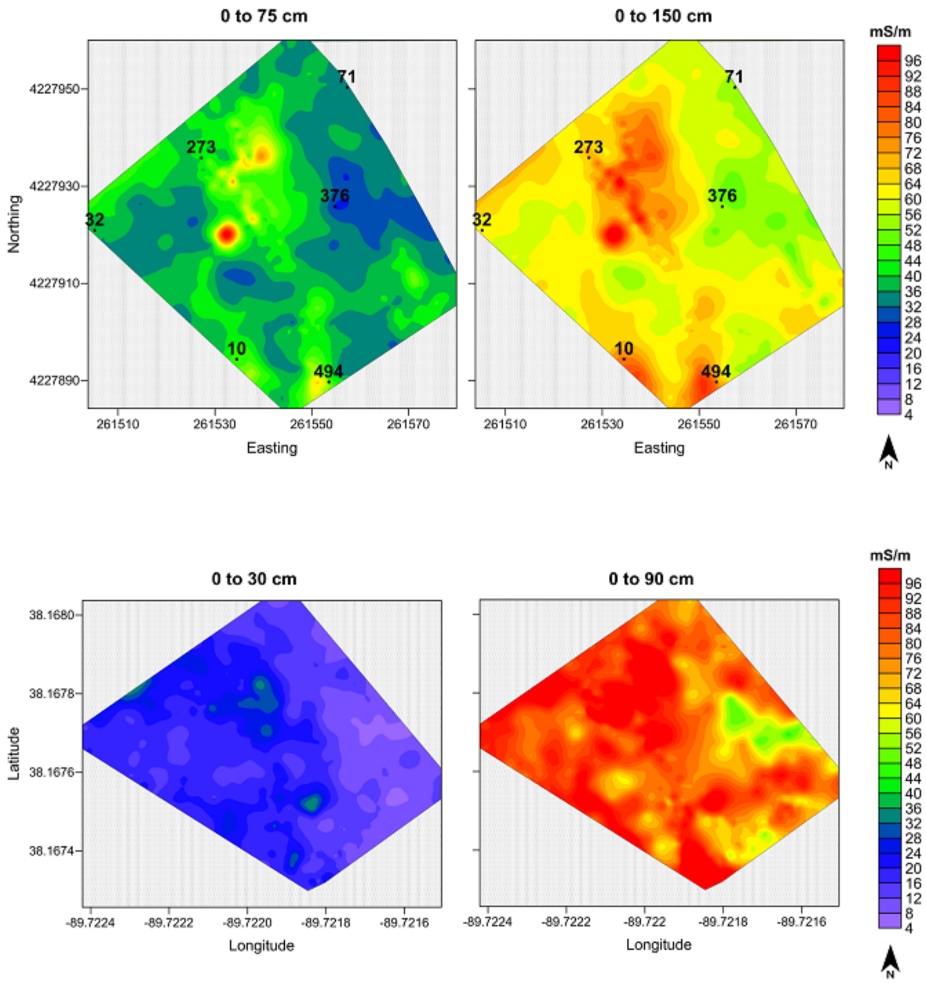

Figure 7. Plots of EC_a data collected at Site 3 with the EM38DD meter (upper plots) and Veris system (lower plots). The numbers above each plot represent the effective penetration depths. On the plots of data collected with the EM38DD meter, numbers identify the six optimal sampling points estimated from the RSSD program.

Figure 7 shows the spatial distribution of EC_a as measured with the EM38DD meter in the HDO (upper left-hand plot) and VDO (upper right-hand plot), and the Veris system *shallow* (lower left-hand plot) and *deep* (lower right-hand plot). Like Site 2, the complex spatial patterns at Site 3 suggest an underlying regolith with varying physiochemical properties. A response surface sampling design model was used to select six optimal sampling or calibration points based on the EC_a measured with the EM38DD meter. These calibration points are identified in the plots of the EC_a data that were collected with the EM38DD meter (upper plots).

Site 4:
Site 4 is located on a side slope that has been mapped as Lenzburg gravelly silty clay loam, 1 to 7 % slopes (871B). Mobile EMI surveys were completed across this site with the EM38DD meter and the Veris system. Table 6 lists these basic statistics for the EC_a data collected at Site 4. Compared with Site 3 (the other site mapped as Lenzburg soils), EC_a data collected with at Site 4 are similar (compare Tables 5 and 6).

Table 6. Basic EC_a statistics for Site 4 at the National Guard Training Area in Sparta, Illinois. With the exception of "Number", all values are in mS/m.

	EM38DD-HDO	**EM38DD-VDO**	**Veris-Shallow**	**Veris-Deep**
Number	856	856	862	862
Minimum	25.37	43.40	4.56	14.10
25%-tile	32.42	57.10	9.54	64.87
75%-tile	39.47	66.60	16.01	84.27
Maximum	53.85	79.34	40.07	118.19
Mean	36.18	62.04	13.45	74.40
Std. Dev.	5.03	6.26	5.32	15.45

Figure 8 shows the spatial distribution of EC_a as measured with the EM38DD meter in the HDO (upper left-hand plot) and VDO (upper right-hand plot), and the Veris system *shallow* (lower left-hand plot) and *deep* (lower right-hand plot). The same vertical trend in EC_a is observed at this site as at the other sites: EC_a increases with depth until a depth of about 75 to 90 cm, and then decreases to a depth of about 150 cm. Although the magnitude of EC_a response varies with depth, spatial EC_a patterns remain essentially stable with depth across Site 4 (Figure 8). In general, EC_a is lower in the northwest and northeast corners of the site. Apparent conductivity is higher in the eastern portion of the site. A response surface sampling design model was used to select six optimal sampling points at Site 4 based on the EC_a measured with the EM38DD meter. These optimal sampling points, which are identified in the plots of the EC_a data collected with the EM38DD meter (upper plots), can be used to verify the relationships of EC_a with specific physiochemical soil properties.

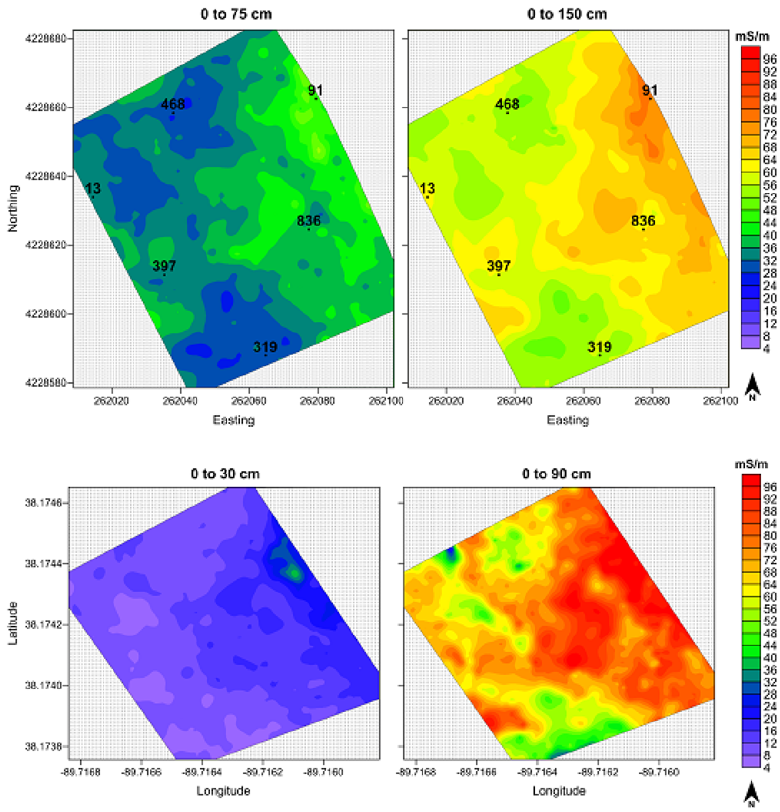

Figure 8. Plots of EC_a data collected at Site 4 with the EM38DD meter (upper plots) and Veris system (lower plots). The numbers above each plot represent the effective penetration depths. On the plots of data collected with the EM38DD meter, numbers identify the six optimal sampling points estimated from the RSSD program.

Montgomery County paleosol site:

Mobile surveys were completed with the EM38 and the EM31 meters operated in the VDO across this site. Basic statistics for these surveys are listed in Table 7. It is evident in reviewing this data that EC_a increases with increasing soil depth (EM38 (0-1.5m) < EM31 (0-6 m). This vertical trend can be associated with increases in soil moisture with increasing soil depth, and the denser and higher clay content of the underlying paleosol or pedisediment. However, as insufficient cores were collected from this site, it is unclear whether areas with high EC_a can be associated with an underlying, finer-textured paleosol or pedisediment. Negative EC_a values reflect the presence of metallic artifacts scattered across the site.

Table 7. Basic EC_a statistics for the EMI surveys that were completed at the Scrubland Management Area, Coffeen Lake State Fish & Wildlife Area, Montgomery County. With the exception of "Number", all values are in mS/m.

	EM38-VDO	EM31-VDO
Number	2378	2064
Minimum	-145.38	18.40
25%-tile	12.13	25.20
75%-tile	20.00	30.70
Maximum	45.25	65.88
Mean	16.53	28.49
Std. Dev.	6.76	4.83

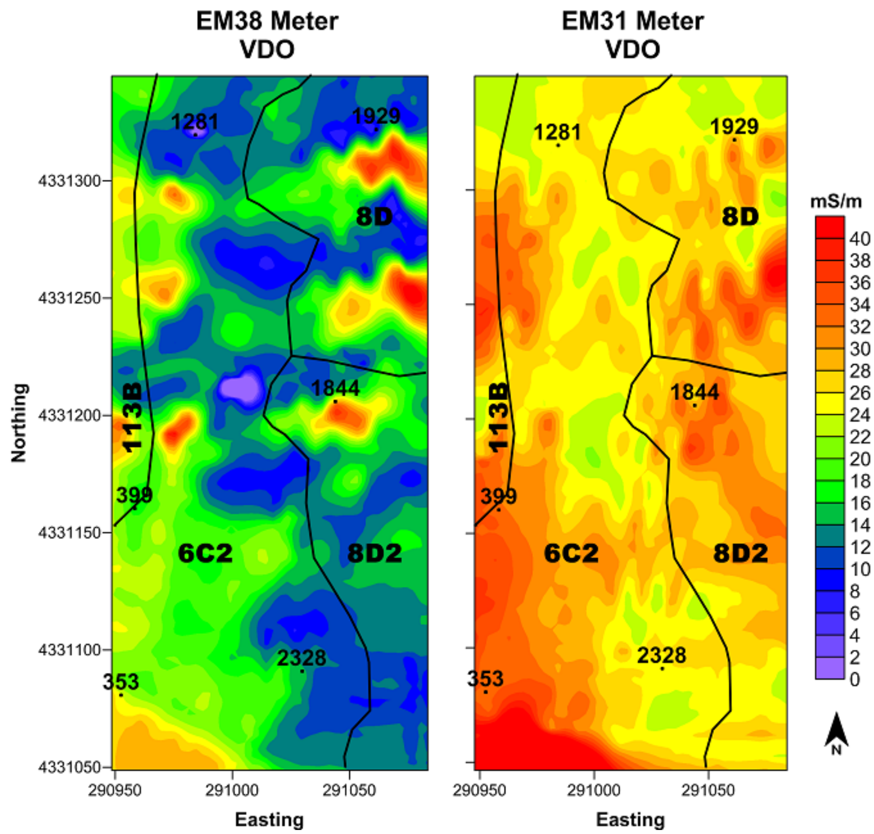

Figure 9. Plots of EC_a data collected at Montgomery County site with the EM38 meter (left-hand plot) and the EM31 meter (right-hand plot). Soil boundary lines have been digitized from the Web Soil Survey.[5] The numbers in each plot represent the map unit symbol (bolder and larger) and optimal sampling points (narrower).

Figure 9 shows the spatial distribution of EC_a as measured with the EM38 (left-hand plot) and the EM31 (right-hand plot) meters operated in the VDO. Soil boundary lines have been digitized and soil symbols (bolder and larger letters) identified from the Web Soil Survey. The narrower numbers in each plot represent the six optimal sampling points that were determined using a response surface sampling design and the EC_a data acquired with the EM38 meter. It can be observed in these plots that EC_a increases with increasing soil depth (measurements obtained with the EM38 meter (0 to 150 cm soil depth interval) are lower than measurements obtained with the deeper-sensing EM31 meter (about 0 to 600 cm soil depth interval). As evident in Figure 9, EC_a is higher along the western border of the site with fingers of higher conductivity extending eastward across the site. This higher-lying western portion of the site is dominated by Fishhook (6C2) and Oconee (113B) soils, which have an underlying Illinoian till that commonly contains a strongly developed paleosol. However, in the profiles examined in the field, the paleosol, though present, was not well expressed. Hopefully these plots can be used to guide soil scientists to areas of higher EC_a where the paleosol is projected to be shallower and/or better expressed.

[5] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [June 24, 2011].

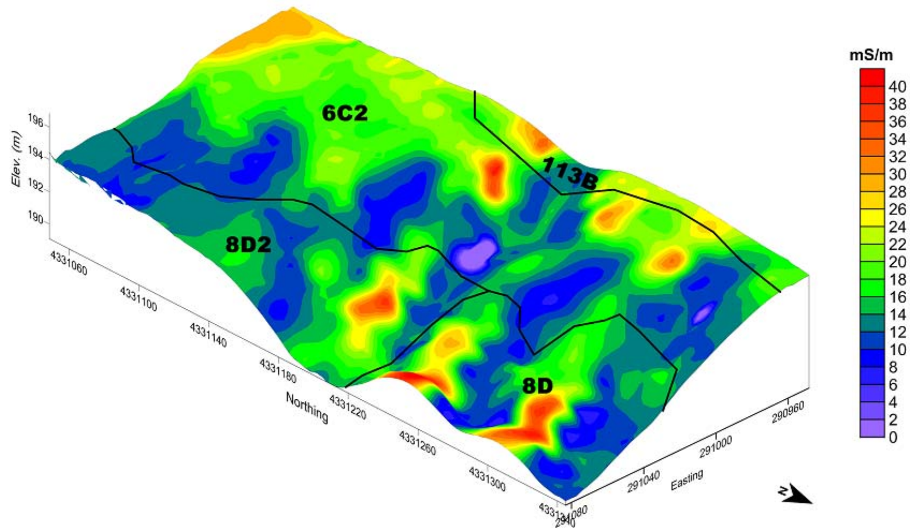

Figure 10. This three-dimensional representation of the Montgomery County site shows the spatial distribution of EC_a as measured with the EM38 meter. Soil boundary lines have been digitized from the Web Soil Survey.[6]

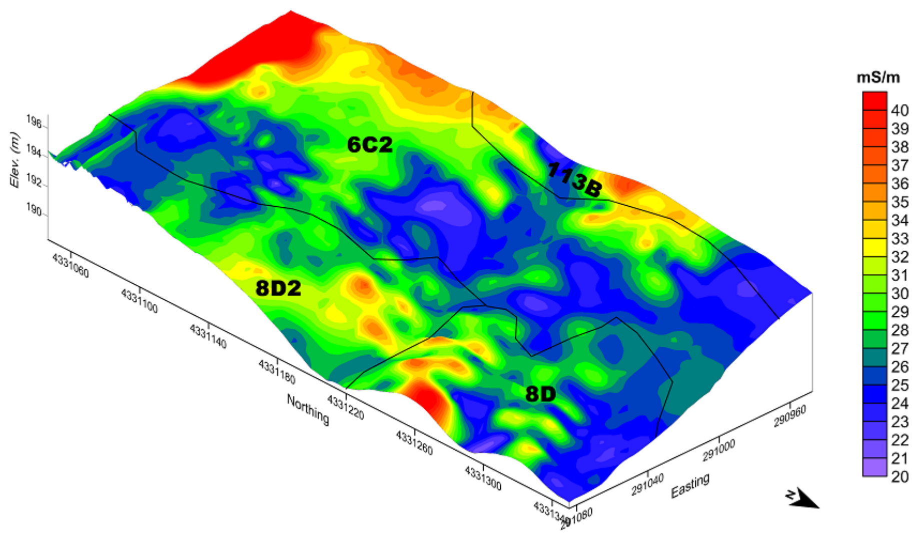

Figure 11. This three-dimensional representation of the Montgomery County site shows the spatial distribution of EC_a as measured with the EM31 meter. Soil boundary lines have been digitized from the Web Soil Survey.[6]

Figures 10 and 11 contain three-dimensional (3D) wireframe simulations of the elevations at the Montgomery County Site. Elevation data were acquired with the AG114 GPS receiver. Superimpose on

[6] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [June 24, 2011].

these 3D wireframe simulations are contour plot of the EC_a data measured with the EM38 (Figure 10) and the EM31 (Figure 11) meters. It is evident on these simulations that areas of higher EC_a are largely restricted to the higher-lying, more stable areas along the western margin of the study site and to convex summit area of interfluves that extend downwards towards a drainageway that border the study site to the east. In general, the lower side slopes and bottoms of swales, where soils are presumably wetter and have more organic matter, have lower EC_a than the convex summit and shoulder areas of the interfluves. Limited soil coring at this site confirmed the thicker silt deposits and the presence of E horizons within the swales,

Mclean County Site:
An earlier high-intensity EMI survey had been conducted on an adjoining area of land in 2007. In the 2007 survey, the locations of wetter or more imperfectly drained soils were identified by higher EC_a unit-areas. Polygons of somewhat poorly drained Raub (481A) soils and poorly drained Drummer and Elpaso soils (721A) occur on lower-lying concave surfaces along drainageways, which were characterized by higher EC_a. Polygons of moderately-well drained Miami (27B2) and Mayville (193B2) soils, which occur on higher-lying plane and convex surfaces, were characterized by lower EC_a.

Presently, mobile surveys were completed with the EM38 and EM31 meters operated in the VDO and the Veris System. Basic statistics for these surveys are listed in Table 8. In reviewing this data, it is evident, that at shallow soil depths, EC_a is comparatively low, but increases and then remains fairly constant with increasing soil depth. This vertical trend can be associated with increases in soil moisture with increasing soil depth, and the presence of an argillic horizon and a denser and higher clay content underlying paleosol. However, data obtained with the EM38 meter (0 to 150 cm) and the Veris *deep* (0 to 90 cm) once again reverses this general trend and confounds interpretations. The average value for the Veris *deep* is higher than the average value for the EM38 meter operated in the VDO. It is unclear whether these values represent soil heterogeneity, depth to argillic horizon, and layering, or equipment and calibration errors.

Table 8. Basic EC_a statistics for the EMI surveys that were completed at the Mclean County Site. With the exception of "Number", all values are in mS/m.

	EM38-VDO	**EM31-VDO**	**Veris-Shallow**	**Veris-Deep**
Number	5364	2835	1502	1502
Minimum	0.50	14.30	-9	-9
25%-tile	25.63	27.18	10.4	22.32
75%-tile	33.13	31.63	17.9	41.8
Maximum	48.38	40.20	40.2	79.9
Mean	29.30	29.15	14.39	32.57
Std. Dev.	5.67	4.11	5.92	13.50

Figure 12 shows the spatial distribution of EC_a as measured with the EM38 (left-hand plot) and the EM31 (right-hand plot) meters operated in the VDO. Soil boundary lines have been digitized and soil symbols (bolder and larger letters) identified from the Web Soil Survey. The smaller numbers in each plot represent the six optimal sampling points that were determined using a response surface sampling design and EC_a data acquired with the EM38 meter. It can be observed in these two plots that EC_a increases with increasing soil depth (measurements acquired with the EM38 meter (0 to 150 cm soil depth interval) are less than measurements acquired with the deeper-sensing EM31 meter (0 to 600 cm soil depth interval). Spatially, EC_a is higher in the northeast corner and along the eastern margin of the site. Areas of Kaneville silt loam, 0 to 2 percent slopes (667A), and Miami and Hennepin soils, 18 to 35 percent slopes

(964F), have relatively low EC_a. These units are located on a lower-lying stream terrace. Areas of Miami silt loam, 2 to 5 percent slopes, eroded (27B2), and Mayville silt loam, 2 to 5 percent slopes, eroded (193B2), are characterized by intricate spatial patterns with variable levels of EC_a. Areas of Drummer and Elpaso silty clay loams, 0 to 2 percent slopes (721A), are characterized by high EC_a. The poorly drained Drummer and somewhat poorly drained Elpaso soils are expected to have higher moisture contents, more fines, and associated EC_a than other soils in this catena.

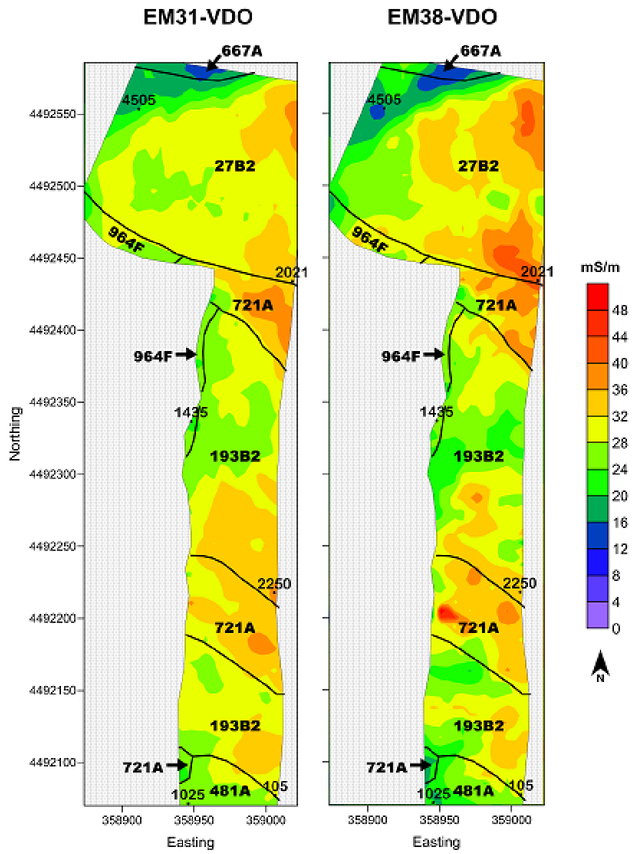

Figure 12. Plots of EC_a data collected at Mclean County site with the EM38 meter (left-hand plot) and the EM31 meter (right-hand plot). Soil boundary lines have been digitized from the Web Soil Survey.[7] The numbers in each plot represent the map unit symbol (bolder and larger) and optimal sampling points (smaller).

Figure 13 shows the spatial distribution of EC_a as measured with the Veris system in the *shallow* (left-hand plot) and *deep* (right-hand plot) configurations. Soil boundary lines have been omitted as coordinates for the Veris system are expressed in Geodetic (Latitude and Longitude), output for the Web Soil Survey data are expressed in UTM (Northing and Easting), and no conversion routine is readily available. Comparing the plots shown in Figure 13, it is apparent that EC_a increases with increasing soil depth. Similar, broad spatial patterns are evident in both of the plots shown in Figure 13. These patterns conform to observable soil-landscape relationships. The lowest EC_a is recorded on lower lying terrace

[7] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [June 24, 2011].

positions occupied by Kaneville, Miami and Hennepin soils. The highest EC_a is recoded in swales that drain the uplands. Drummer and Elpaso soils have been mapped on these landforms. Extensive areas of Miami and Mayville on sloping uplands have intermediate and more variable EC_a.

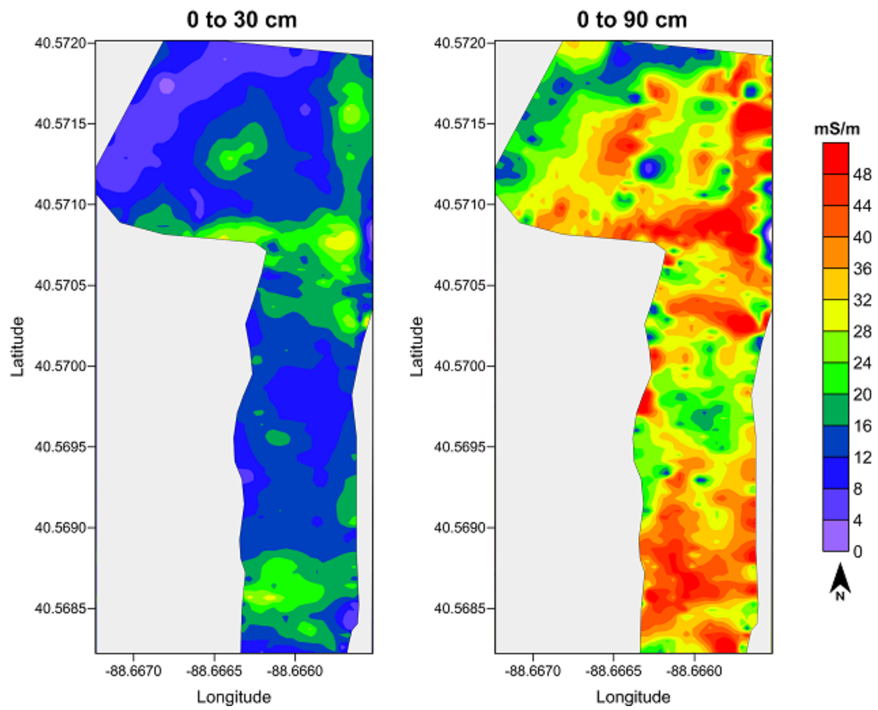

Figure 13. Plots of EC_a data collected at Mclean County site with the Veris system shallow (left-hand plot) and the Veris system deep (right-hand plot).

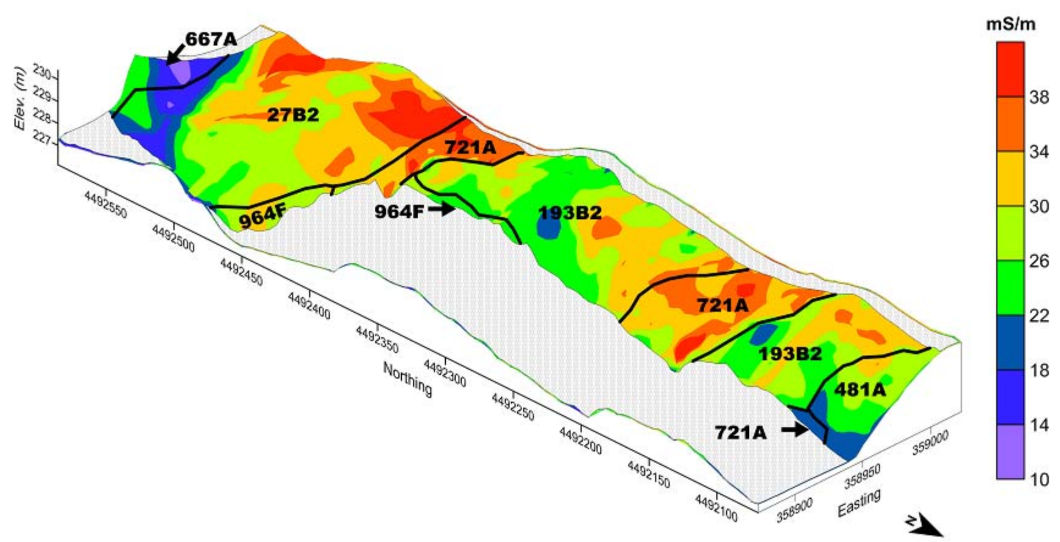

Figure 14. This three-dimensional representation of the McLean County site, shows the spatial distribution of EC_a across the survey area as measured with the EM38 meter

Figures 14 and 15 contain three-dimensional (3D) wireframe simulations of the elevations at the Mclean County Site. Elevation data were acquired with the AG114 GPS receiver. Superimpose on the 3D wireframe simulations are contour plot of the EC_a data measured with the EM38 (Figure 14) and the EM31 (Figure 15) meters. It is evident on these simulations that areas of higher EC_a are largely restricted to swales that extend down slope towards a drainageway. This is the opposite of the spatial relationships that were observed between EC_a and soil-landforms at the Montgomery County site where swales had lower EC_a and summit areas of interfluves had higher EC_a. At the Mclean County site, the higher EC_a in the swales is attributed to higher moisture and clay contents. At the Mclean County site, areas of lowest EC_a are on lower-lying terrace positions. Soils on terraces are presumed to be coarser textured and better drained.

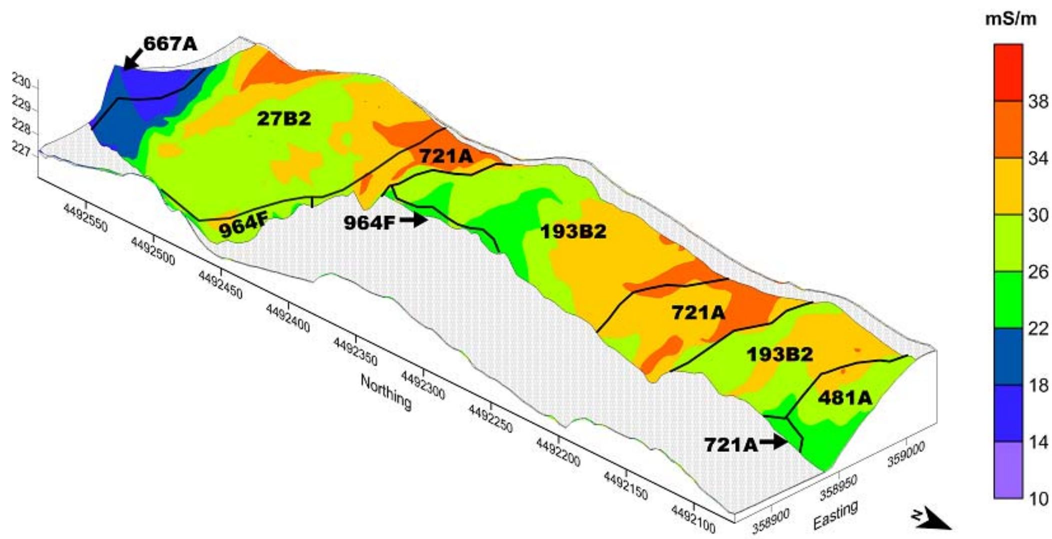

Figure 15. This three-dimensional representation of the McLean County site, shows the spatial distribution of EC_a across the survey area as measured with the EM31 meter

GPR:

At a Randolph County site, calibration trials and two traverses were completed with the SIR-3000 system and a 200 MHz antenna in an area of Lenzburg soils (Site 2). The Lenzburg soil is considered to have low potential for many GPR applications because of its moderate clay content (generally between about 24 to 35% clay) and presence of calcium carbonate and other compounds (http://soils.usda.gov/survey/geography/maps/GPR/methodology.html). As a consequence, penetration depths are restricted and radar records are plagued by low signal to noise ratios. Advance signal processing procedures are needed to improve the interpretability of radar records collected in areas of Lenzburg soils.

Figure 16 is a representative radar record form Site 2. Signal stacking, range gain adjustments, horizontal high pass filtration and migration were used to process this radar record. In Figure 16, the horizontal and vertical scales are in meters. While an estimated depth of about 3.2 m was attained in this area of Lenzburg soils, the radar record is of low interpretive quality. The radar record is plagued by a large number of point reflectors, which are believed to represent larger rock fragments. There is a slight suggestion of layering on this radar record. However, the layers that can be seen are weakly expressed, high segmented, and have limited horizontal extent.

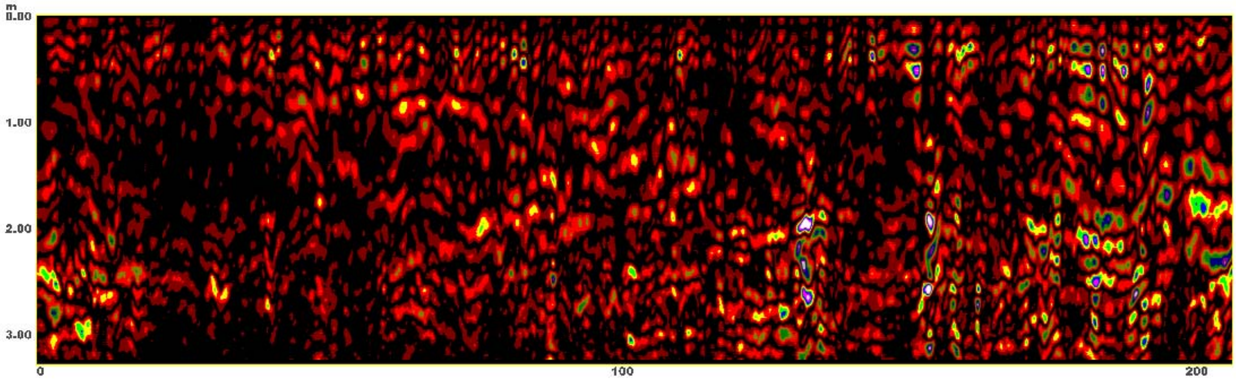

Figure 16. A representative radar record from an area of Lenzburg soil in a reclaimed mined area in Randolph County. All scales are in meters.

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