NRCS

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+SUBJECT: MGT- Trip Report – Geophysical Assistance

May 17, 2013

TO: Ivan Dozier
State Conservationist, NRCS
Champaign, Illinois

File Code: 330-20-7

Purpose:
The purpose of this study was to assist the Illinois NRCS Staff and MLRA 115C soil scientists characterize the variability of soil properties across several reclaimed surface-mined areas located in Fulton County, Illinois. In this study, spatial variations in soil properties were inferred and mapped using electromagnetic induction (EMI) and the concentration of heavy metals were analyzed from samples extracted from soil cores. The information obtained in this study will be used to improve soil data for the support of NRCS technical assistance.

Participants:
Jim Doolittle, Research Soil Scientist, NSSC, NRCS, Newtown Square, PA
Robert Nayden, Soil Conservation Technician, NRCS, Lewistown, IL
Kim Smail, District Conservationist, NRCS, Lewistown, IL
Roger Windhorn, Geologist, NRCS, Champaign, IL
Dan Withers, Cartographic Technician, NRCS, Champaign, IL

Activities:
All activities were completed during the period of April 9-11, 2013.

Summary:

1. The participants greatly appreciate the assistance provided by Edwin Muñiz (Assistant State Soil Scientist, NRCS, Somerset, New Jersey) in the analysis of soil samples collected at a study site with a portable X-ray fluorescence spectrometer.

2. At each reclaimed surface mine spoil area in Fulton County, the average apparent conductivity (EC_a) increased and the averaged in-phase (IP) response decreased with increasing soil depths. The vertical trend in EC_a is attributed principally to increasing moisture and clay contents with depth. The IP data reflects noticeable differences among the individual surveyed fields under different management schemes. The higher IP response in surface layers is attributed to differences in organic residue, surface moisture, soil compaction, and minerals related to differences in fertilization and management. Additional studies are warranted to better understand the role EMI can play in soil health.

3. In areas of Lenzburg soils, spatial EC_a patterns are complex and could not be associated with observed differences in soil drainage and landscape position.

4. At a representative Lenzburg site, based on the analysis of soil samples with a portable X-ray fluorescence spectrometer, the twelve most abundant metals present in surface layers are (in order of abundance): Fe, K, Ca, Ti, Zr, Mn, Ba, Co, Sr, Rb, Cr, and Zn. In these samples the average concentration of Fe (in mg/kg) was 163 % and 240 % higher than the average concentrations of K and Ca, respectively.

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

ACTING

DAVID R. HOOVER
Acting Director
National Soil Survey Center

Attachment (Technical Report)

cc:
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Technical Report on Geophysical Investigations conducted in Illinois on October 8-12, 2013

James A. Doolittle

It is estimated that about 10% of Fulton County is composed of reclaimed surface mined areas. Reclaimed surface-mine spoil areas are used as croplands, pastures, forest lands, fish and wildlife sanctuaries, and industrial, commercial and residential sites. The objectives of this study were to characterize spatial differences in soil properties and to improve interpretations for soil materials that have been excavated, replaced, and graded during surface mining operations. In this study, spatial variations in soil properties were inferred and mapped using electromagnetic induction (EMI) and the concentration of heavy metals in the samples extracted from soil cores were analyzed using X-ray fluorescence (XRF).

Figure 1. These images show areas of Lenzburg soils that are being used as cropland and a wildlife refuge. The field on the left has had its mine spoil overburden reshaped to the approximate pre-mined contours and restored to growing row crops according to topsoil and rooting medium depth requirements. The mine spoil area in the image on the right is used as a wildlife refuge and reflects practices that were allowed to occur before the passage of the Illinois Surface-Mined Land Conservation and Reclamation Act of 1971.

Equipment:
The EM31 and the EM38-MK2 meters (Geonics Limited; Mississauga, Ontario) were used in this study.[1] In either dipole orientation, these EMI meters provide simultaneous measurements of the quadrature component (apparent conductivity, EC_a) and the in-phase component (apparent magnetic susceptibility, IP). Apparent conductivity is expressed in milliSiemens/meter (mS/m). The IP response is expressed in parts per thousand (ppt) of the primary magnetic field generated by the transmitter. In this study, EC_a data were not corrected to a standard temperature of 75° F.

Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2009). The EM38-MK2 meter operates at a frequency of 14.5 kHz and weighs about 5.4 kg (11.9 lbs.). The meter has one transmitter coil and two receiver coils, which are separated from the transmitter coil at distances of 1.0 and 0.5 m. This configuration provides two nominal exploration depths of 1.5 and 0.75 m when the meter is held in the vertical dipole orientation (VDO), and 0.75 and 0.40 m when the meter is held in the

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

horizontal dipole orientation (HDO). However, these nominal depths of exploration are more restricted for IP measurements (Geonics Limited, 2009). When operated in the VDO and the in-phase mode, Dalan (2006) and Tabbagh (2009) reported that the EM38 meter has an effective penetration depth of only 40 to 50 cm.

McNeill (1980) has described the principles of operation for the EM31 meter. 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 ground surface, the EM31 meter measures the bulk apparent conductivity to nominal penetration depths of about 3.0 and 6.0 meters in the HDO and VDO, respectively (McNeill, 1980). This meter was used only at Study Site 1.

An Allegro CX field computer (Juniper Systems, Logan, Utah) and a Trimble AgGPS 114 L-band DGPS (differential global positioning system) receiver (Sunnyvale, CA) were used with the EMI meters.[2] With these components, the EMI meters are keypad operated and measurements are automatically triggered. The RTmap38MK2 and the RTmap31 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were respectively used with the EM38-MK2 and EM31 meters and the Allegro CX field computer, to record, store, and process EMI and GPS data.[2]

During the preceding fall, the Illinois State Soil Staff completed EMI surveys of Study Sites 1, 2, and 3 using a Veris system. The Veris system is a towed-array, multi-electrode resistivity unit manufactured by Veris Technologies (Salina, Kansas).[2] Operating procedures are described by Veris Technologies (1998). The Veris system measures apparent resistivity (expressed in ohm-m), but is programmed to convert these measurements into apparent conductivity (expressed in mS/m). 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, under suitable field conditions, can be pulled behind 4WD vehicle at speeds of about 5 to 10 m/hr. A Trimble 132 GPS receiver (Sunnyvale, CA) is used with the Veris system to geo-reference the collected EC_a data.[2]

To help summarize the results of the EMI surveys, SURFER for Windows (version 10.0), developed by Golden Software, Inc. (Golden, CO), was used to construct the simulations shown in this report.[2] Grids of EMI data were created using kriging methods with an octant search.

An Innov-X, Delta Standard portable X-ray fluorescence (P-XRF) spectrometer (manufactured by Olympus of Woburn, MA) was used by the New Jersey Soil Staff to assess the concentration of different metals in the soil samples collected at Study Site 1.[2] Samples were scanned with the P-XRF operated in a bench-top mode.

Study Sites:
Study sites are located in cultivated fields that are principally mapped as phases of Lenzburg soils. The Lenzburg series is a member of the fine-loamy, mixed, active, calcareous, mesic Haplic Udarents taxonomic family. The very deep, well drained Lenzburg soils formed in excavated materials from surface coal-mining operations. The Lenzburg regolith is calcareous, loamy till that contains a mixture of loess and residuum from excavated siltstone, sandstone, shale, and limestone. By law, the Lenzburg soil must be a minimum of 48 inches thick, including topsoil and subsoil. Some areas may contain refuse materials from coal processing, locally known as *gob* or *slurry*. *Gob* and *slurry* are, respectively, coarse and fine waste from the coal cleaning processes. These materials can be acid-forming and toxic to plants.

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

Study Sites 1 and 2 are located about 1.0 kilometer east-northeast of Cuba, Illinois. Figure 2 is a soil map of these study sites. This and all other soil maps shown in this report are from the Web Soil Survey.[3] Study Site 1 and 2 are located on the north and south sides of West Hickory Road, respectively. Study Site 1, though principally mapped as different phases of Lenzburg soils, includes small areas of relatively undisturbed Keomah (fine, smectitic, mesic Aeric Endoaqualfs), Sable (fine-silty, mixed, superactive, mesic Typic Endoaquolls), and Clarksburg (fine-loamy, mixed, superactive, mesic Oxyaquic Fragiudalfs) soils. The very deep, somewhat poorly drained Keomah and poorly drained Sable soils formed in loess on moraines and stream terraces. The very deep, moderately well drained Clarksburg soils formed in colluvium, glacial till, or residuum weathered from limestone, shale, and sandstone on uplands. Table 1 list the soil map units recorded at this and the other study sites.

Different slope phases of Lenzburg soils are mapped at Study Site 2. In addition, this study site contains a trench filled with water that is bordered by steep, wooded slopes (see Figure 2).

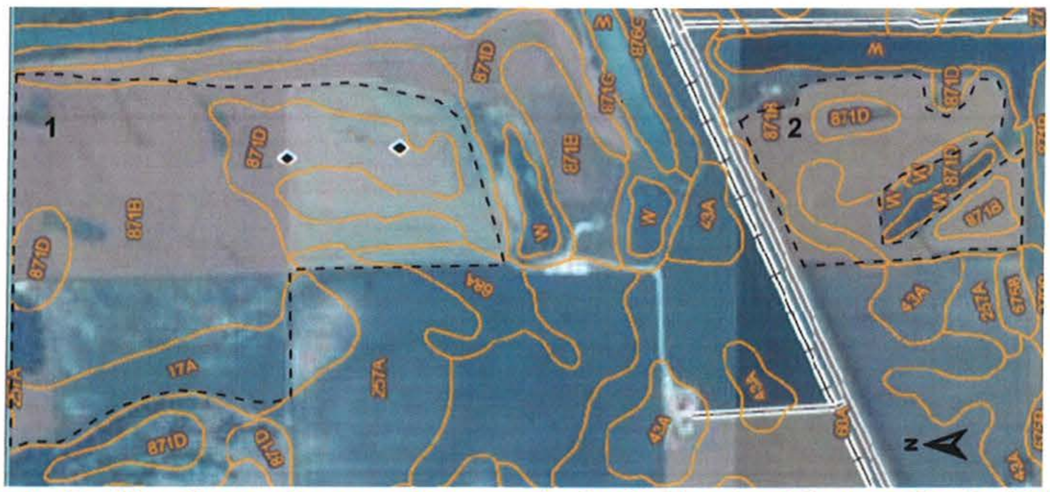

Figure 2. On this soil map, the areas that comprise Study Sites 1 and 2 are outlined with black segmented lines.

Table 1. Soil Map Units Delineated at the Study Sites in Fulton County

Symbol	Map Unit Name
17A	Keomah silt loam, 0 to 2 % slopes
68A	Sable silty clay loam, 0 to 2 % slopes
257A	Clarksburg silt loam, 0 to 2 % slopes
871B	Lenzburg silt loam, 1 to 7 % slopes
871D	Lenzburg silt clay loam, 7 to 20 % slopes
871G	Lenzburg silt clay loam, 20 to 60 % slopes

Study Site 3 is located off of North Hyatt Cemetery Road and north of West Hickory Road, about 7.3 kilometers northeast of Cuba, Illinois. Figure 3 is a soil map of Study Site 3. This site is mapped mostly as Lenzburg silty clay loam on 7 to 20 % slopes (871D), but includes areas of Lenzburg silt loam on 1 to 7 % slopes (871B) and Lenzburg silty clay loam on 20 to 60 % slopes (871G).

[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 [04/18/2013].

Study Site 4 is located off of East State Road 97, about 2.7 kilometers west of Fiatt, Illinois. Figure 4 is a soil map of this study site. This nearly level site is mapped as Lenzburg silt loam on 1 to 7 % slopes (871B), but includes a small, unmapped trench that is filled with water and encircled by steep slopes (enclosed by orange-colored, segmented line in Figure 4).

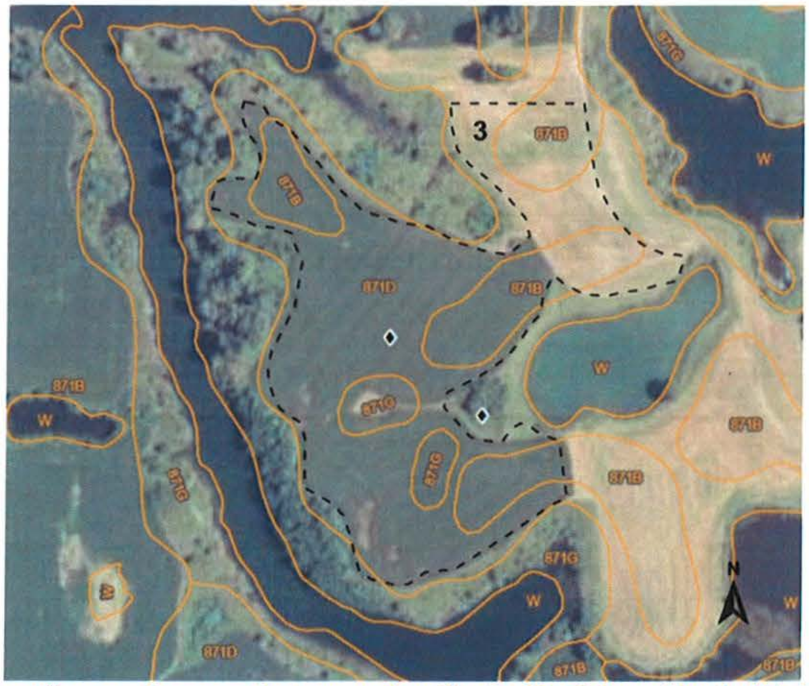

Figure 3. On this soil map, the area that comprises Study Site 3 is outlined with black segmented lines.

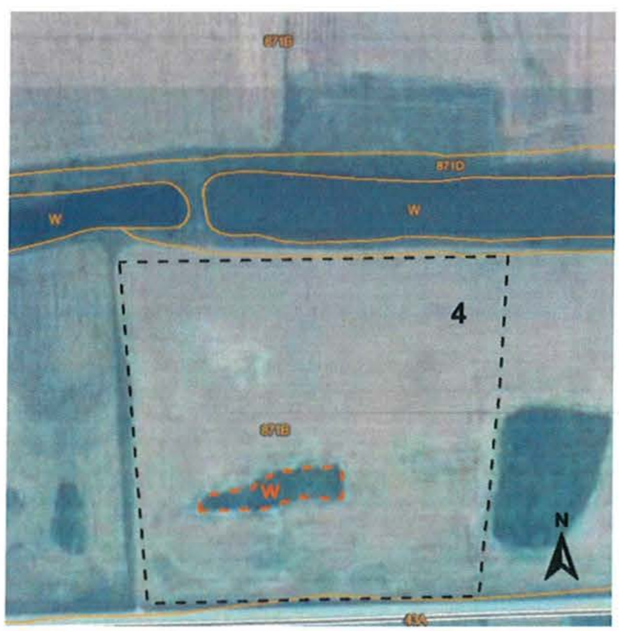

Figure 4. On this soil map, the area that comprises Study Site 4 is outlined with black segmented lines.

Survey procedures:
The EMI meters were pulled behind a Polaris Ranger utility vehicle on either a specially-designed cart (EM31 meter) or *jet sled* (EM38-MK2 meter) at speeds of about 3 to 5 m/hr. Both meters were operated in the deeper-sensing VDO with their long axis orientated parallel with the direction of travel. Data were recorded at a rate of two measurements per second.

Results:
Study Site 1:
Table 2 lists basic statistics for the EMI data collected with the EM38-MK2 and EM31 meters, and the Veris system at Study Site 1. In this and all subsequent tables of EM38-MK2 data, EC_a recorded at nominal penetration depths of 0 to 150 and 0 to 75 cm are listed as 100-EC_a and 50 EC_a, respectively. Also for the EM38-MK2 meter, in-phase measurements recorded with intercoil spacings of 100 and 50 cm are listed in the tables as IP-100 and IP-50, respectively. With the Veris system, EC_a measurements recorded for nominal depths of 0 to 90 and 0 to 30 cm are listed as *Deep* and *Shallow*, respectively.

At Study Site 1, with both the EM38-MK2 meter and the Veris system, the EC_a increased with increasing depth (measurements obtained with the deeper sensing 100-EC_a and *Deep* arrangements were higher than those obtained with the shallower-sensing 50-EC_a and *Shallow* arrangements). For these EMI sensors, the two shallower measurements were closely similar. However, the *Deep* measurements obtained with the Veris system were higher and more variable than the 100-EC_a measurements of the EM38-MK2 meter. Although these two deeper measurements are for slightly different depths, it was anticipated that the EC_a data would be lower at the time of the Veris survey (fall of 2012) than the EM38-MK2 survey (spring of 2013). Typically, soils are moister in the spring and drier in the fall. Apparent conductivity is directly related to soil moisture content. Neither data set was corrected to a standard temperature. Without some available soil temperature and moisture measurements for these two surveys, no further interpretation can be made on the vertical and temporal relationships at this time.

Table 2. Basic EMI statistics for Study Site 1 in Fulton County, Illinois.
With the exception of "Number", EC_a values are in mS/m and IP values are in ppt.

	100-EC_a	50-EC_a	100-IP	50-IP	Deep	Shallow	EM31-EC_a	EM31-IP
Number	10580	10580	10580	10580	3581	3581	1264	1264
Minimum	25.0	-12.2	5.1	10.8	19.6	9.0	32.8	-0.36
25%-tile	38.6	27.3	10.9	39.9	45.3	28.4	41.2	-0.07
75%-tile	45.7	33.1	15.9	56.5	56.4	33.7	46.3	0.09
Maximum	63.1	45.9	87.7	94.5	72.0	45.4	51.8	0.44
Mean	42.3	30.3	13.5	48.7	50.9	30.9	43.8	0.004
Std. Dev.	4.8	4.2	3.6	10.3	7.5	4.4	2.28	0.12

With the EM38-MK2 meter, for nominal exploration depths of 0 to 75 and 0 to 150 cm, EC_a averaged 30 and 42 mS/m, respectively. One half of the EC_a data were between 27 and 33 mS/m and 39 and 46 mS/m for measurements recorded with the shallower-sensing (50-EC_a) and the deeper-sensing (100-EC_a) intercoil spacings, respectively. With the Veris system, EC_a averaged 31 and 51 mS/m for the *Shallow* and *Deep* measurements, respectively. One half of the EC_a data were between 28 and 34 mS/m and 45 and 56 mS/m for measurements recorded with the *Shallow* and *Deep* electrode spacing, respectively. The vertical differences in EC_a recorded with the two sensors were attributed principally to increasing moisture and clay contents within increasing soil depths.

The averaged IP response of the EM38-MK2 meter decreased with increasing depth. The IP measurements were noticeably higher and more variable for the 50-IP than the 100-IP measurements (average values of 49 versus 14 ppt). However, the range in IP measurements was closely similar (11 to

94 ppt and 5 to 88 mS/m) for the two sets of measurements. Differences in field management and the application of different waste products and/or chemicals to surface layers are believed to be responsible for these values and depth relationships.

Figure 5 contains plots of EMI data collected at Study Site 1 with the EM38-MK2 meter in the shallower sensing 50-cm (right-hand plots) and deeper sensing 100-cm (left-hand plots) intercoil spacing. The upper and lower plots show spatial EC_a and IP data, respectively. To facilitate comparison, the same color scale and color ramp have been used for each similar data set (EC_a and IP). At this site, soil samples were collected from the 0 to 30 cm depth interval at four locations for analysis with a P-XRF spectrometer (analysis was completed by Edwin Muniz, Assistant State Soil Scientist, USDA-NRCS, Somerset, New Jersey). The location and identity of each of these sampling points are shown in these plots. The soil boundary lines on this and other Surfer plots shown in this report have been digitized from Web Soil Survey data[4].

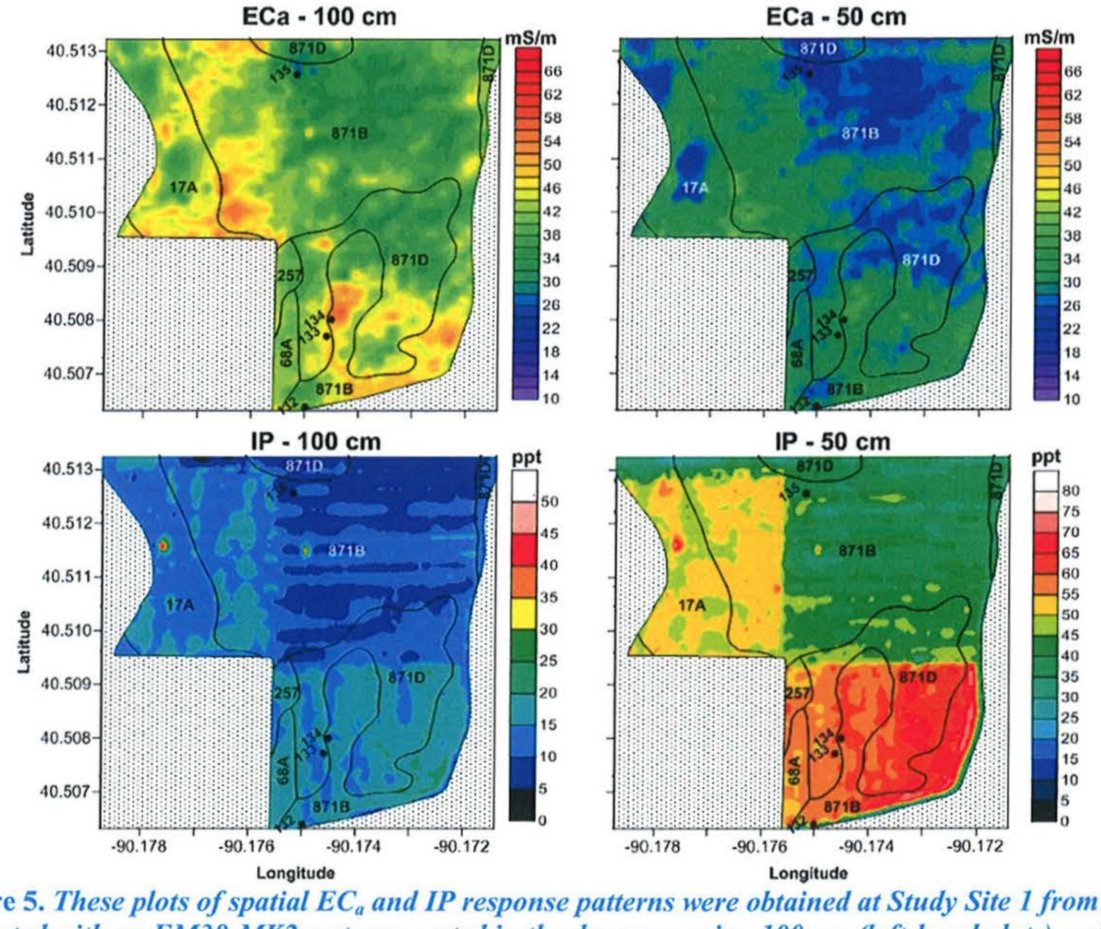

Figure 5. ***These plots of spatial EC_a and IP response patterns were obtained at Study Site 1 from data collected with an EM38-MK2 meter operated in the deeper-sensing 100-cm (left-hand plots) and the shallower-sensing 50-cm (right-hand plots) intercoil spacing. Soil lines are from the Web Soil Survey. The locations of sample sites have been identified in each plot.***

As evident in Figure 5, EC_a is lower in the northeast portion of Study Site 1. The lower EC_a in this field is associated with use and management. On all plots shown in Figure 5, a noticeable change in EMI response is evident along the north-south boundary that separates the two northern fields. Apparent

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[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 [04/18/2013].

conductivity is higher on the western and southern portions of the study site. The western portion of the study site contains areas that are supposedly not affected by mining operations. Here, spatial EC_a patterns between the reclaimed Lenzburg delineations and delineations of Keomah, Sable and Clarksburg soils are similar and indistinguishable. This suggests that the area of significant reclamation is located more to the east and northeast.

In areas of Lenzburg soils (871), spatial EC_a patterns are complex and could not be associated with observed differences in soil drainage and landscape position. As a general rule, EC_a will tend to increase in lower-lying, more poorly drained landscape positions. However, at this site, no correlation was observed between elevation and EC_a ($r = 0.01$ and -0.02 for the 100 and 50 cm intercoil spacings, respectively).

The spatial IP patterns shown in Figure 5 vary noticeably among the three fields and are, therefore, assumed to reflect differences in management. In addition, the relative magnitude of the IP response varies among the three fields. Within each of the three fields, spatial IP-response patterns appear to be orientated in either a north-south or east-west direction. These orientations are believed to reflect the direction of cultivation. Bevan (1994) observed that plowing can have a subtle effect on EMI responses, with values changing with the direction of plowing due to the alignment of soil particles. The magnitude of the IP-response varies with depth with higher values recorded in the IP-50 cm than the IP-100 cm response. Compared with the subsoil, surface layers often have greater magnetic susceptibility due to higher organic contents (Bevan, 1994). Each of the three fields is under different rotations and, therefore; organic residue, surface moisture, soil compaction, and minerals (due to differences in fertilization and management) are expected to differ.

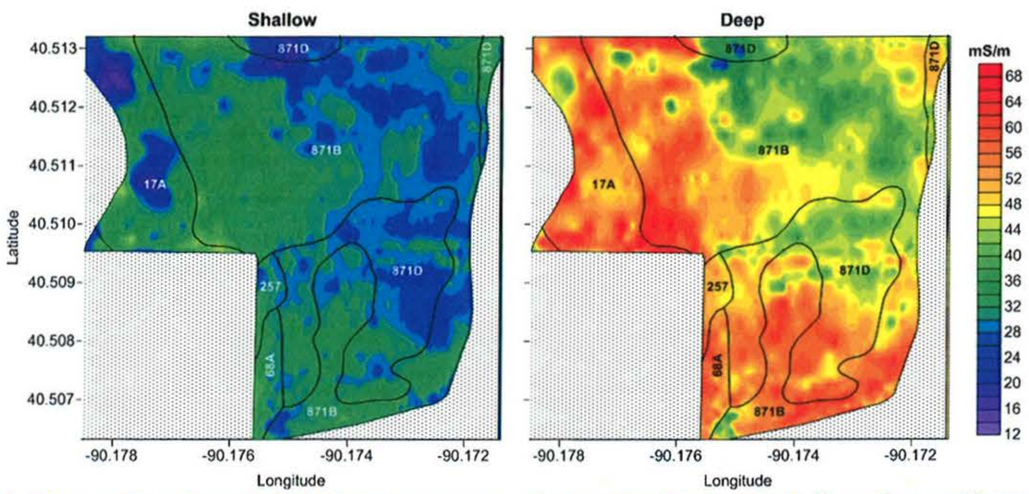

Figure 6. ***These plots of spatial EC_a patterns were obtained at Study Site 1 from data collected in the shallow (0 to 30 cm) and deep (0 to 90 cm) electrode spacing of the Veris system. Soil lines are from the Web Soil Survey.***

Figure 6 contains plots of EMI data collected at Study Site 1 with the Veris system with the *Shallow* (left-hand plot) and *Deep* (right-hand plot) electrode spacings. To facilitate comparison, the same color scale and color ramp have been used in both plots. Spatial EC_a patterns evident in Figure 6 are complex. For similar exploration depths, spatial EC_a patterns obtained with the Veris system (Figure 6) closely mimic the patterns obtained with the EM38-MK2 meter (Figure 5). This confirms that both sensors will produce comparable EC_a patterns and measurements. However, as noted earlier, EC_a values recorded with the Veris system are slightly higher and more variable than those measured with the EM38-MK2 meter. As these two set of EC_a data are spatially similar, the observed differences in relative magnitude must be principally associated with soil properties that vary temporally (e.g., moisture, temperature).

Study Site 2:
Table 3 lists basic statistics for the EMI data collected at Study Site 2 with the EM38-MK2 and the Veris system. As was the case at Study Site 1, with both sensors, EC_a increased and became more variable with increasing depth. The IP-response of the EM38-MK2 meter decreased and became less variable with increasing depth.

With the EM38-MK2 meter, for nominal exploration depths of 0 to 75 and 0 to 150 cm, EC_a averaged 31 and 48 mS/m, respectively. One half of the recorded EC_a data were between 27 and 34 mS/m and 44 and 53 mS/m for measurements recorded with the shallower-sensing 50-cm and the deeper-sensing 100-cm intercoil spacings, respectively. With the Veris system, for the *Shallow* and *Deep* measurements, EC_a averaged 28 and 51 mS/m, respectively. One half of the EC_a data were between 25 and 30 mS/m and 45 and 55 mS/m for measurements recorded with the *Shallow* and *Deep* electrode spacing, respectively. These vertical differences in EC_a measured with the two EMI sensors are considered substantial and attributed principally to variations in moisture and clay contents within soil profiles.

For the EM38-MK2 meter, IP measurements were noticeably higher and more variable for the 50-IP than the 100-IP measurements (average values of 65 versus 20 ppt). In addition, the range in IP measurements was noticeably different for the two intercoil spacings (about 15 to 171 ppt and 14 to 94 ppt recorded for the 50-IP and the 100-IP measurements, respectively). These differences are believed to reflect vertical differences soil magnetic properties caused by management, near-surface metallic objects scattered across the site, and the presence of electromagnetic interference from wire fencing and overhanging power lines in the northern part of the site.

Table 3. Basic EMI statistics for Study Site 2 in Fulton County, Illinois.
With the exception of "Number", EC_a values are in mS/m and IP values are in ppt.

	100-EC_a	50-EC_a	100-IP	50-IP	Deep	Shallow
Number	4168	4168	4168	4168	1821	1821
Minimum	-16.2	-70.7	14.1	15.0	24.4	17.3
25%-tile	43.8	27.0	17.9	60.9	44.9	25.4
75%-tile	52.8	34.2	20.6	67.3	54.9	30.0
Maximum	71.8	63.9	94.1	171.3	93.4	50.3
Mean	48.3	30.8	19.6	64.8	50.6	28.0
Std. Dev.	6.4	5.9	2.8	6.2	9.0	3.9

Figure 7 contains plots of EMI data collected at Study Site 2 with the EM38-MK2 meter for the shallower-sensing 50-cm (right-hand plots) and deeper-sensing 100-cm (left-hand plots) intercoil spacings. The upper and lower plots show spatial EC_a and IP data, respectively. To facilitate comparison, the same color scale and color ramp have been used for each similar data set (EC_a and IP).

In each plot shown in Figure 7, higher EMI responses were recorded along the northern border of the study site. As this border closely follows wire fencing and overhead power line, electromagnetic interference is suspected to have triggered the higher EMI responses. Spatial EC_a patterns do not appear to correspond with mapped soil delineations and soil landforms, but appear to vary randomly across these units. Several points of higher EC_a recorded in the shallower-sensing 50-cm intercoil spacing (Figure 7, upper right plot) suggest metallic cultural debris scattered across the site. Alternating lineations of higher and lower IP responses (Figure 7, lower plots) are artificial, products of land management, and may be related to reclamation. Very weak correlations were observed between elevation and EC_a (r = -0.26 and -0.28 for the 100 and 50 cm intercoil spacings, respectively).

Figure 8 contains plots of EC_a data collected with the Veris system in the *Shallow* (left-hand plot) and *Deep* (right-hand plot) electrode spacings at Study Site 2. To facilitate comparison, the same color scale and color ramp have been used in both plots. Spatial EC_a patterns derived from data collected with the EM38-MK2 meter and the Veris system (Figures 7 and 8) are remarkably similar in arrangement, but dissimilar in magnitude.

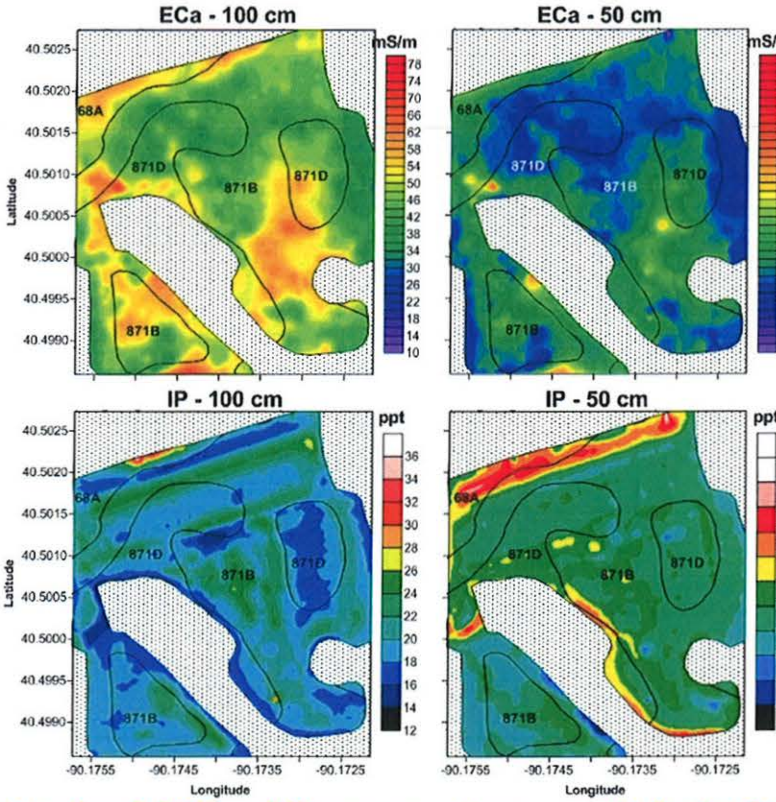

Figure 7. ***These plots of spatial EC_a and IP response patterns were obtained at Study Site 2 from data collected with an EM38-MK2 meter operated in the 100-cm (left-hand plots) and the 50-cm (right-hand plots) intercoil spacing. Soil lines are from the Web Soil Survey.***

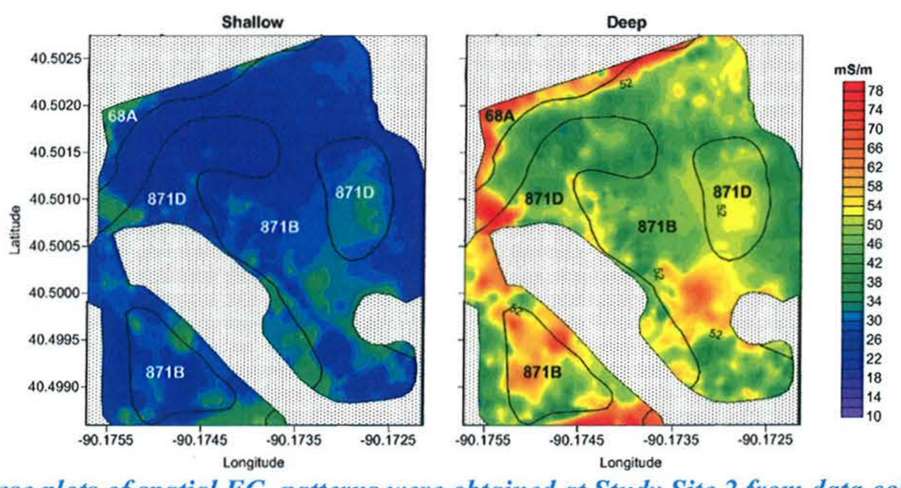

Figure 8. ***These plots of spatial EC_a patterns were obtained at Study Site 2 from data collected in the shallow (0 to 30 cm) and deep (0 to 90 cm) electrode spacing of the Veris system. Soil lines are from the Web Soil Survey.***

Study Site 3:
Table 4 lists the basic statistics for the EMI data collected at Study Site 3. With both the EM38-MK2 meter and the Veris system, EC_a increased and became more variable with increasing depth. With the EM38-MK2 meter, the IP-response decreased and became less variable with increasing depth. For corresponding exploration depths, EC_a measurements recorded with these sensors were similar. Vertical and spatial differences in EC_a were attributed principally to variations in moisture and clay contents within the soil profiles.

Table 4. Basic EMI statistics for Study Site 3 in Fulton County, Illinois.
With the exception of "Number", EC_a values are in mS/m and IP values are in ppt.

	100-EC_a	50-EC_a	100-IP	50-IP	Deep	Shallow
Number	5431	5431	5431	5431	1964	1964
Minimum	27.5	-0.4	-4.0	33.3	18.2	15.8
25%-tile	35.1	17.5	1.1	65.5	3.8	24.1
75%-tile	44.0	25.4	3.3	72.8	48.4	30.6
Maximum	67.8	47.2	17.0	87.8	71.9	50.6
Mean	40.1	21.9	2.2	69.2	43.4	27.4
Std. Dev.	6.2	5.5	1.5	5.5	7.3	4.4

With the EM38-MK2 meter, for the shallower 50-EC_a and the deeper 100-EC_a measurements, EC_a averaged 22 and 40 mS/m, respectively. One-half of the recorded EC_a were between 18 and 25 mS/m and 35 and 44 mS/m with the shallower 50-EC_a and the deeper 100-EC_a measurements, respectively. For the *Shallow* and *Deep* measurements recorded with the Veris system, EC_a averaged 27 and 43 mS/m, respectively. One-half of the recorded EC_a data were between 24 and 31 mS/m and 4 and 48 mS/m with the *Shallow* and *Deep* measurements, respectively.

For the EM38-MK2 meter, the shallower (50-IP) IP measurements were noticeably higher and more variable than the deeper (100-IP) IP measurements. These differences are believed to principally reflect differences in field management and metallic objects scattered across the site, but may also reveal differences in soil magnetic properties.

Figure 9 contains plots of the EMI data collected at Study Site 3 with the EM38-MK2 meter for the shallower sensing 50-cm (right-hand plots) and deeper sensing 100-cm (left-hand plots) intercoil spacing. The upper and lower plots show spatial EC_a and IP data, respectively. To facilitate comparison, the same color scale and color ramp have been used for each similar data set (EC_a and IP).

Figure 10 contains plots of EC_a data collected with the Veris system in the *Shallow* (upper plot) and *Deep* (lower plot) electrode spacings at Study Site 3. To facilitate comparison, the same color scale and color ramp have been used in both plots. The soil boundary lines have been digitized from Web Soil Survey data.

The EMI data shown in Figures 9 and 10 vary both spatially and vertically. In these plots, EC_a increases and becomes more variable with increasing exploration depths. Surveys completed with both EMI sensors resulted in similar spatial EC_a patterns. Though attributed to variations in moisture and clay contents, spatial patterns do not correspond to observed soil-landscape relations and their significance cannot be associated with any soil property at this time.

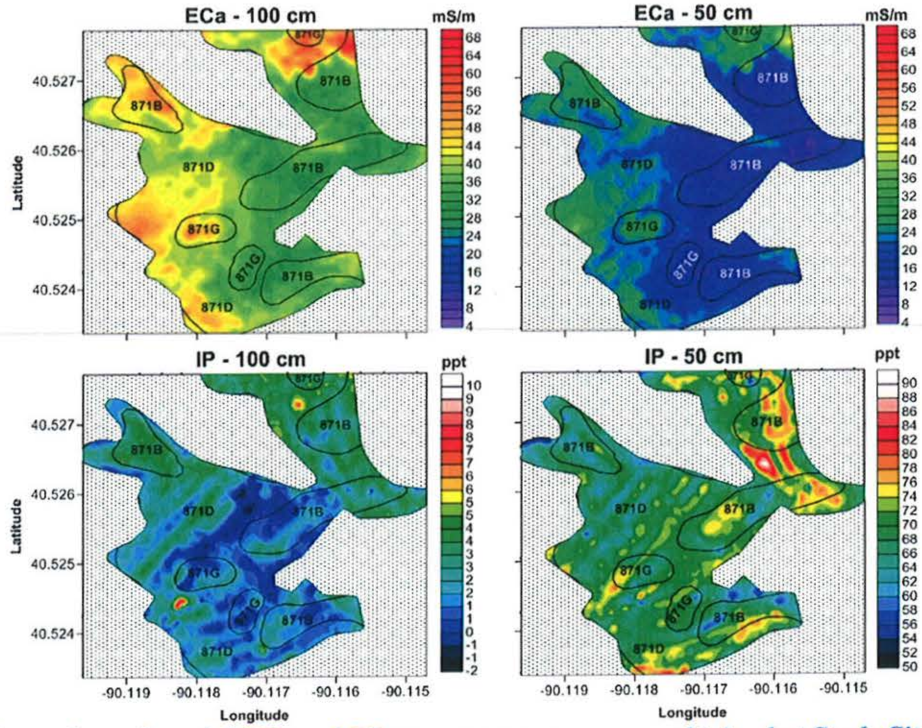

Figure 9. ***These plots of spatial*** EC_a ***and IP response patterns were obtained at Study Site 3 from data collected with an EM38-MK2 meter operated in the 100-cm (left-hand plots) and the 50-cm (right-hand plots) intercoil spacing. Soil lines are from the Web Soil Survey.***

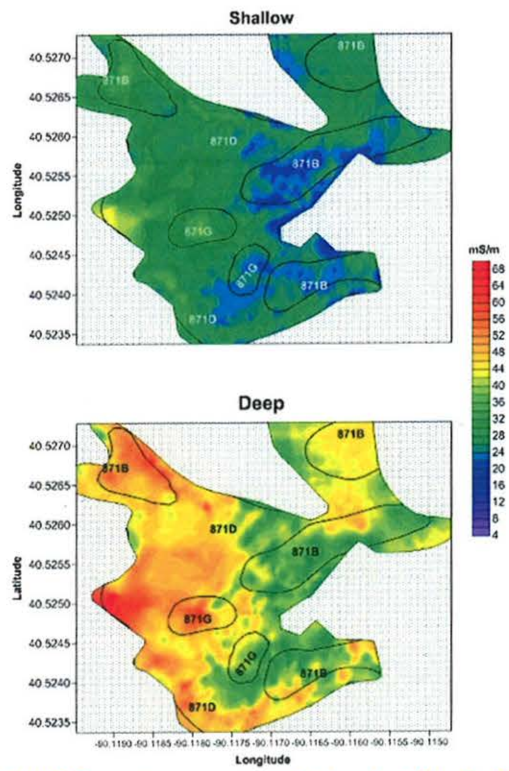

Figure 10. ***These plots of spatial*** EC_a ***patterns were obtained at Study Site 3 from data collected in the shallow (0 to 30 cm) and deep (0 to 90 cm) electrode spacing of the Veris system. Soil lines are from the Web Soil Survey.***

Study Site 4:

Table 5 lists the basic statistics for the EMI data collected at Study Site 4 with the EM38-MK2 meter. Once again, EC_a increased and the IP-response decreased with increasing depth.

Table 5. Basic EMI statistics for Study Site 4 in Fulton County, Illinois.
With the exception of "Number", EC_a values are in mS/m and IP values are in ppt.

	100-EC_a	50-EC_a	100-IP	50-IP
Number	2954	2954	2954	2954
Minimum	28.3	2.8	1.7	19.6
25%-tile	38.2	14.5	4.1	44.0
75%-tile	55.7	32.7	7.6	48.7
Maximum	77.2	62.2	31.6	126.1
Mean	47.0	23.5	5.9	46.7
Std. Dev.	10.1	10.8	2.5	5.3

With the EM38-MK2 meter, for nominal exploration depths of 0 to 75 (50-EC_a) and 0 to 150 (100-EC_a) cm, EC_a averaged 23 and 47 mS/m, respectively. One-half of the EC_a data were between 14 and 33 mS/m and 38 and 56 mS/m for the shallower 50-EC_a and the deeper 100-EC_a measurements, respectively.

As evident in Table 5, IP measurements were noticeably higher and more variable for the 50 cm (50-IP) than the 100 cm (100-IP) intercoil measurements. These differences are believed to principally reflect the effects of soil management and metallic objects scattered across the site.

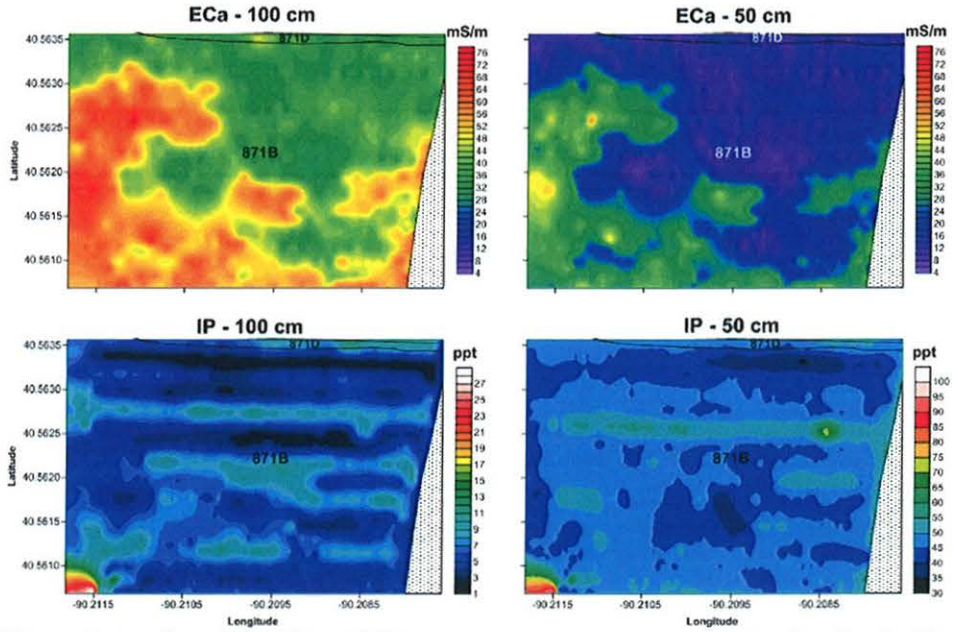

Figure 11. ***These plots of spatial EC_a and IP response patterns were obtained at Study Site 4 from data collected with an EM38-MK2 meter operated in the 100-cm (left-hand plots) and the 50-cm (right-hand plots) intercoil spacing. Soil lines are from the Web Soil Survey.***

Figure 11 contains plots of EMI data collected at Study Site 4 with the EM38-MK2 meter for the shallower sensing 50-cm (right-hand plots) and deeper sensing 100-cm (left-hand plots) intercoil spacing. The upper and lower plots show spatial EC_a and IP data, respectively. To facilitate comparison, the same color scale and color ramp have been used for each similar data set (EC_a and IP).

Despite being the most level of the four study sites, Study Site 4 displayed the most variable EC_a. The spatial IP patterns evident in Figure 11 are associated with use and management, and the presence of metallic artifacts (especially in the southwest corner of the site).

EM31 Meter:
The Illinois State office's EM31 meter was used at Study Site 1. The meter was properly calibrated and used to survey the northeast field in this study area. The meter operated properly with no observed malfunctions.

With the EM31 meter, EC_a averaged 44 mS/m, with a range of 33 to 52 mS/m (see Table 2). Compared with the responses of the shallower-sensing EM38-MK2 meter and Veris system, with the deeper-sensing EM31 meter, EC_a was less variable in magnitude across this site with one-half of the recorded EC_a measurements between about 41 and 46 mS/m. Compared with the data collected with the other EMI sensors, the less variable EC_a measured with the EM31 meter suggests greater uniformity in soil properties with increasing soil depth.

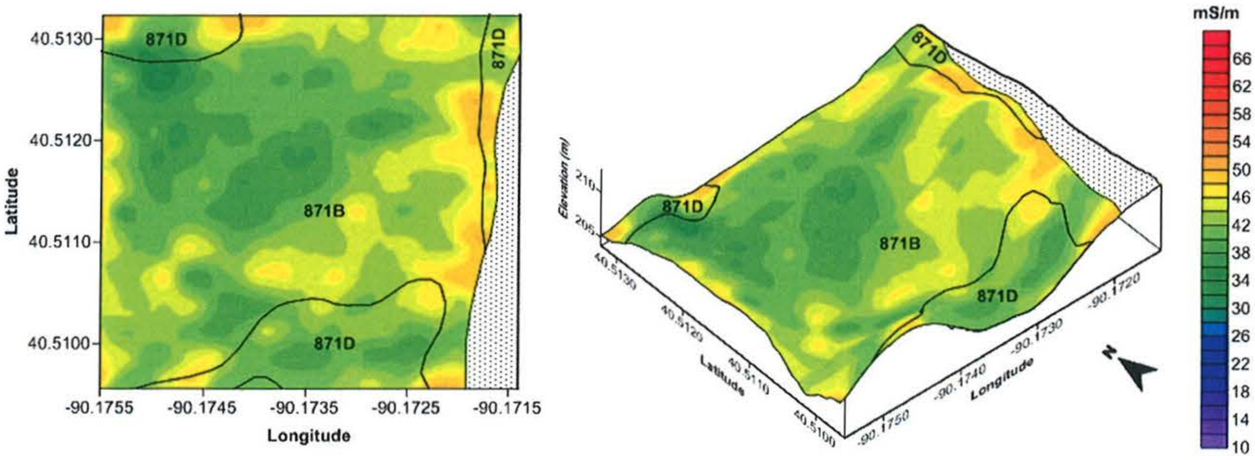

Figure 12. ***These plots of spatial EC_a and IP response patterns were obtained at Study Site 1 from data collected with an EM31 meter operated in the deeper-sensing VDO. Soil lines are from the Web Soil Survey.***

Figure 12 contains a 2D and 3D simulation of the EC_a data collected with the EM31 meter at Study Site 1. To facilitate comparison with the EM38-MK2 meter (Figure 5) and Veris system (Figure 6) data, the same color scale and color ramp used in the plots of data collected with these sensors have been used in the plots shown in Figure 12. Spatial EC_a patterns obtained with the three EMI sensors are similar with absolute values decreasing with increasing exploration depths (Veris Deep > EM38-MK2 100-cm intercoil spacing > EM31 VDO).

P-XRF:
Portable X-ray fluorescence spectrometers use high energy (incident X-ray photon) to forcibly eject electrons from the inner shell of atoms. The resulting electron holes cause instability that result in outer shell electrons being dropped into the inner shell to fill the voids. This process results in the emission of energy, which is referred to as *X-ray fluorescence*. The energy emitted as fluorescence is element specific, hence allowing the identification and quantification of different metals (Weindorf et al., 2012). A comprehensive discussion of P-XRF is provided by Kalnicky and Singhvi (2001).

At Study Site 1, soil samples were collected from the 0 to 30 cm depth interval at 4 sampling points (see Figure 5 for locations) for analysis with a P-XRF spectrometer. The twelve most abundant metals measured in these samples are listed in Table 6. These metals are (in order of abundance): Fe, K, Ca, Ti, Zr, Mn, Ba, Co, Sr, Rb, Cr, and Zn. In Table 6, it can be seen that the concentrations of these metals varied over several orders of magnitude. This data documents the average concentration of twelve different metals within a portion of the study site and in a representative area of Lenzburg soils.

Because of the small number of samples collected at this site, non-parametric statistics were used to evaluate the associations among the measured heavy metals and the EMI responses. However, the number of samples was too small to derive a satisfactory T-value.

Table 6. Concentration of elements in soil samples collected at Study Site 1.
Data is expressed in parts per million (mg/kg).

Sample	Fe	K	Ca	Ti	Zr	Mn	Ba	Co	Sr	Rb	Cr	Zn
132	22286	13773	11149	3847	504	411	279	226	115	72	62	66
133	21829	13752	8535	3951	509	306	273	234	118	76	64	54
134	21054	13789	17839	3790	513	378	279	243	123	70	60	52
135	31537	17800	2841	4868	496	710	330	332	101	97	75	67
Average	**24176**	**14779**	**10091**	**4114**	**506**	**451**	**291**	**259**	**115**	**79**	**65**	**60**

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