United States Department of Agriculture

NRCS

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SUBJECT: SOI – Geophysical Assistance

December 9, 2011

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

File Code: 330-7

Purpose:
Electromagnetic induction (EMI) surveys were completed at sites located in LaSalle, Livingston, Schuyler, and Montgomery Counties, Illinois. As part of *soil survey recorrelation* efforts in MLRA 108A, inconsistent joins in the soil survey data between the Livingston and LaSalle Counties were examined. Where data discrepancies have been identified, spatial apparent conductivity data, supported by core observations and tacit knowledge, will be used to improve the consistency, accuracy, and usefulness of soil survey information across this political boundary. In Schuyler County, working with MLRA 115C soil scientists and the University of Illinois in an area of reclaimed mined-spoil materials, EMI was used to assess spatial differences in soil compaction. In Montgomery County, EMI was used to evaluate the variability of soil physiochemical properties in an area of sodium-affected soils. Information will be used to improve soil data for support of NRCS technical assistance.

Participants:
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Jennifer Wollenweber, Soil Scientist, USDA-NRCS, Aurora, IL

Activities:
All activities were completed during the period of 14 to 17 November 2011.

Summary:

1. At sites located in LaSalle and Livingstone Counties, spatial EC_a patterns appear to reflect differences in soil drainage and landscape position. Higher EC_a values were recorded on lower-lying, more imperfectly drained areas. Lower EC_a values were recorded on higher-lying, more sloping, and better drained areas. Apparent conductivity values were consistent and spatial

patterns uninterrupted across the LaSalle / Livingston County boundary line. Based on the results of the EMI surveys, there is no justification for recognition of different soil on both sides of this political boundary.

2. At four of the five sites in LaSalle and Livingstone Counties, EC_a was inversely correlated with carbonates and not correlated with depth to till. This suggests that as the depth to carbonates decreases, the EC_a will increase. These findings support the use of EMI for depth to carbonate investigations on some soils.

3. At a reclaimed surface mine spoil area in Schuyler County, some of the areas with higher EC_a were associated with the former location of the haul road. However, the effective exploration depth of the EM31 meter, operated in the vertical dipole orientation (0 to 6 m), may have been inappropriate if the haul road occurred at relatively shallow soil depths. If so, the results from an EMI survey conducted with the EM31 meter operated in the shallower-sensing horizontal dipole orientation (0 to 3 m) would be more fitting.

4. At the Montgomery County site, based on the collected EC_a data, a response surface sampling design (RSSD) was used to identify optimal sampling points. Soil will be sampled at some of these optimal sampling sites to advance our understanding of sodium-affected soils, develop improved soil-landscape models, and improve interpretations.

5. At the Schuyler County site, the EM31 meter was damaged because of excessive vibrations as it was towed across very rough surfaces on its specially designed and padded cart. To avoid any future recurrences, surveys conducted with the EM31 meter and utility cart should be restricted to only those sites with smooth surfaces. Hard, clumpy, recently disked fields should be avoided.

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

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Technical Report on Geophysical Investigations conducted in Illinois on 14 to 17 November 2011

James A. Doolittle

Harmonization of soils along LaSalle/Livingston County Line:
Spurred by needs to improve the soil database, recent emphasis has been place on efforts to re-correlate soil map unit data joins (often referred to as *harmonization*) within each MLRA. The goal is a *seamless* soil survey. Soil scientists in Illinois are presently evaluating surveys and re-correlating soil data map units across political (soil survey) boundaries. A major issue along the LaSalle / Livingston County line is the join of Arrowsmith with Harco soils, and Hartsburg with Patton soils. All four soils have carbonates occurring within depths of 40 inches. Arrowsmith and Hartsburg formed in deep loess, whereas Harco and Patton formed in glaciolacustrine materials. This geophysical study supports this *harmonization* effort.

Development of soil-based reclamation success criteria:
In Schuyler County, EMI was used to map differences apparent conductivity (EC_a) across a reclaimed surface-mined area. The objectives of this research are to assess spatial differences in soil compaction along buried haul roads and to evaluate the use of soil-based reclamation *success criteria* for bond release on reclaimed surface-mined areas. This is a cooperative project among the NRCS, the Crop Science Department of the University of Illinois, and the Department of Mines and Minerals.

Soil Investigation in Montgomery County:
The objectives of this study are to determine the amount of sodium that is present in soils that were originally mapped as non-sodium affected, develop improved soil-landscape models, and associate the sodium content with periglacial features in MLRA 108B - *Illinois and Iowa Deep Loess and Drift, East-Central Part*

Equipment:
The EM31 and the EM38-MK2 meters (Geonics Limited; Mississauga, Ontario) were used in this study. [1] Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2007). 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 horizontal dipole orientation (HDO). This meter was used at sites located in LaSalle, Livingston, and Montgomery Counties.

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 has effective penetration depths of about 3.0 and 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 sites located in LaSalle, Livingston, and Schuyler Counties.

In either dipole orientation, these meters provides simultaneous measurements of the quadrature component (apparent conductivity (EC_a)) and the in-phase component (apparent magnetic susceptibility

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

(MS_a)) over two depth intervals. Apparent conductivity is expressed in milliSiemens/meter (mS/m). Apparent magnetic susceptibility is expressed in parts per million (ppm).

The Geonics DAS70 Data Acquisition System was used with the EM38-MK2 and EM31 meters to record and store both EC_a and GPS data. The acquisition system consists of the EMI meter, an Allegro CX field computer (Juniper Systems, Logan, Utah), and a Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[2] With the acquisition system, the meter is keypad operated and measurements are automatically triggered. The RTmap38MK2 and the RTmap31 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were correspondingly used with the EM38-MK2 and EM31 meters, and an Allegro CX field computer, to record, store, and process EC_a and GPS data.[2] The EC_a data were not corrected to a standard temperature of 75^o F.

To help summarize the results of the EMI survey, 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 EC_a data were created using kriging methods with an octant search.

Study Sites:

LaSalle/ Livingston Counties:

Sites 1 & 2:

Study sites 1 & 2 are located in cultivated fields on both side of 12th Road North in LaSalle (Site # 1) and Livingston (Site # 2) Counties. The LaSalle site is located in the SW ¼ of Section 31, T. 31 N., R. 3 E. The Livingston site is located in the NW ¼ of Section 6, T. 30 N., R. 3 E. Figure 1 is a soil map of the study sites from the Web Soil Survey.[3] A drainageway passes through the LaSalle site and another forms the southern boundary of the Livingston site. These sites were surveyed with both the EM38-MK2 and EM31 meters.

Table 1. Map Unit Symbols and Names for Study Sites 1 and 2

LaSalle County	
Symbol	**Map Unit Name**
152A	Drummer silty clay loams, 0 to 2 % slopes
154A	Flanagan silt loam, 0 to 2 % slopes
171C2	Catlin silt loam, 5 to 10 % slopes
244A	Hartsburg silty clay loam, 0 to 2 % slopes
614A	Chenoa silty clay, 2 to 5 % slopes
715A	Arrowsmith silt loam, 0 to 2 % slopes
818A	Flanagan-Catlin silt loams, 0 to 3 % slopes
Livingston County	
Symbol	**Map Unit Name**
142	Patton silty clay loam
443B	Barrington silt loam, 2 to 5 % slopes
484	Harco silty clay loam

Table 1 lists the map unit symbols and names for the soil delineations that are mapped in each study site. These very deep, very poorly drained to well drained soils have mollic epipedons and formed in loess or silty materials underlain by calcareous till, on till and glacial lake plains. However, exceptions to these common characteristics do occur. The Barrington and Drummer soils formed in silty material and the

[2] Manufacturer's names are provided for specific information; use does not constitute endorsement.
[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 [11/30/2011].

underlying stratified loamy outwash. The Patton soil formed in glaciolacustrine materials. The Hartsburg soils formed solely in loess or other silty materials. Table 2 lists the taxonomic classification of the named soil series. All are Mollisols and most have an argillic horizon.

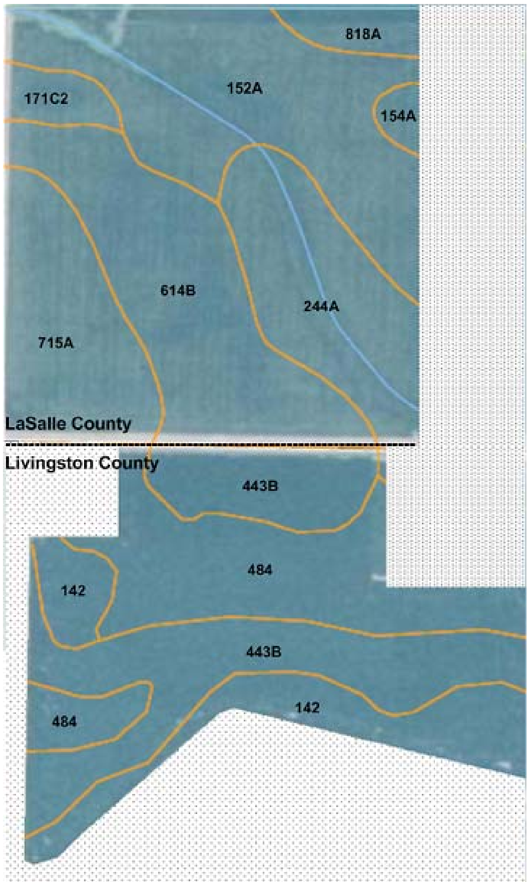

Figure 1. This soil map is from the Web Soil Survey and shows the soil delineations within LaSalle (upper field; Site 1) and Livingston (lower field; Site 2) sites.

Table 2. Taxonomic Classification of Soils at the LaSalle and Livingston Sites

Soil Series	***Taxonomic Classification***
Arrowsmith	Fine-silty, mixed, superactive, mesic Aquic Argiudolls
Barrington	Fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls
Buckhart	Fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls
Catlin	Fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls
Chenoa	Fine, illitic, mesic Aquic Argiudolls
Drummer	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
Flanagan	Fine, smectitic, mesic Aquic Argiudolls
Harco	Fine-silty, mixed, superactive, mesic Aquic Argiudolls
Hartsburg	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
Muscatune	Fine-silty, mixed, superactive, mesic Aquic Argiudolls
Patton	Fine-silty, mixed, superactive, mesic Typic Endoaquolls

Sites 4 & 5:
These study sites are located in cultivated fields on both side of 12th Road in LaSalle (Site # 5) and Livingston (Site # 4) Counties. The LaSalle site is located in the SE ¼ of Section 13, T. 30 N., R. 2 E.

The Livingston site is located in the SW ¼ of Section 18, T. 30 N., R. 3 E. Figure 2 is a soil map of the study sites from the Web Soil Survey.[4] In Figure 2, dark-colored segmented lines have been used to outline the areas that were surveyed with an EM38-MK2 meter.

Table 3 lists the soil map unit symbols and names for the soil delineations that are mapped within sites 4 and 5. In general, soils are very deep, very poorly drained to moderately well drained and formed in loess or silty materials on till, outwash and glacial lake plains. Some of the soils recognized at these sites have calcareous, stratified loamy outwash or calcareous till within depths of 2 m. Table 2 lists the taxonomic classification of the named soil series. All of these soil series are Mollisols and most have an argillic horizon. Typically, these soils have a silty mantle.

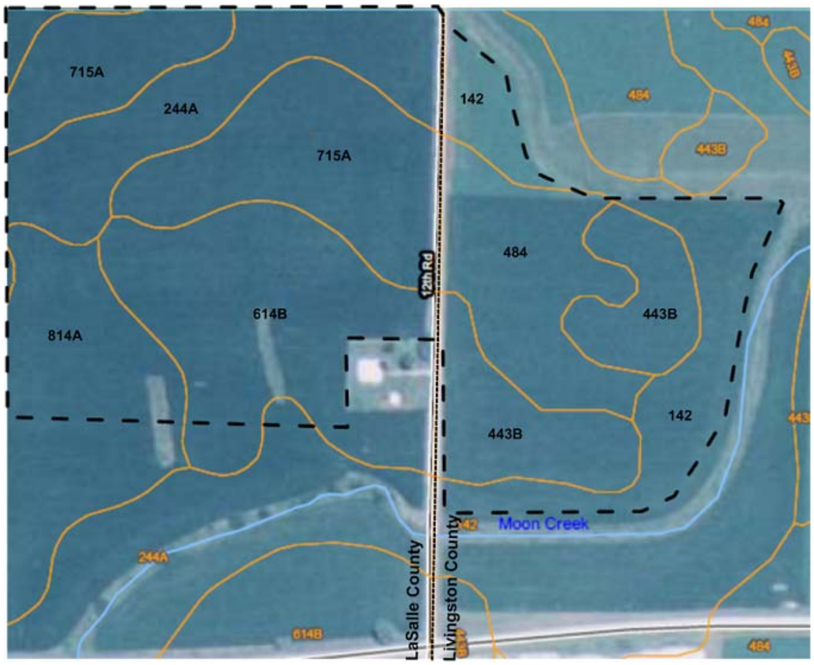

Figure 2. This soil map is from the Web Soil Survey and shows the soil delineations within LaSalle (left-hand field; Site 5) and Livingston (right-hand field; Site 4) sites.

Table 3. Map Unit Symbols and Names for Study Sites 4 and 5 in Livingston and LaSalle Counties

LaSalle County	
Symbol	**Map Unit Name**
244A	Hartsburg silty clay loam, 0 to 2 % slopes
614B	Chenoa silty clay, 2 to 5 % slopes
715A	Arrowsmith silt loam, 0 to 2 % slopes
814A	Muscatune-Buckhart silt loams, 0 to 3 % slopes
Livingston County	
Symbol	**Map Unit Name**
142	Patton silty clay loam
443B	Barrington silt loam, 2 to 5 % slopes
484	Harco silty clay loam

[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 [11/30/2011].

Sites 3:
This study site is located in a cultivated field in Livingston County. The site is located in the SE ¼ of Section 30, T. 30 N., R. 3 E. Figure 3 is a soil map of the study sites from the Web Soil Survey.[5] In Figure 3, dark-colored, segmented lines have been used to outline the area that was surveyed with an EM38-MK2 meter. Table 4 lists the map unit symbols and names for the soil delineations mapped at site 3. This site contains the Livingston County's type location for the Harco series. Table 2 lists the taxonomic classification of the named soil series. The two soils are Mollisols. Harco soils have an argillic horizon. Typically, these soils have a silty mantle.

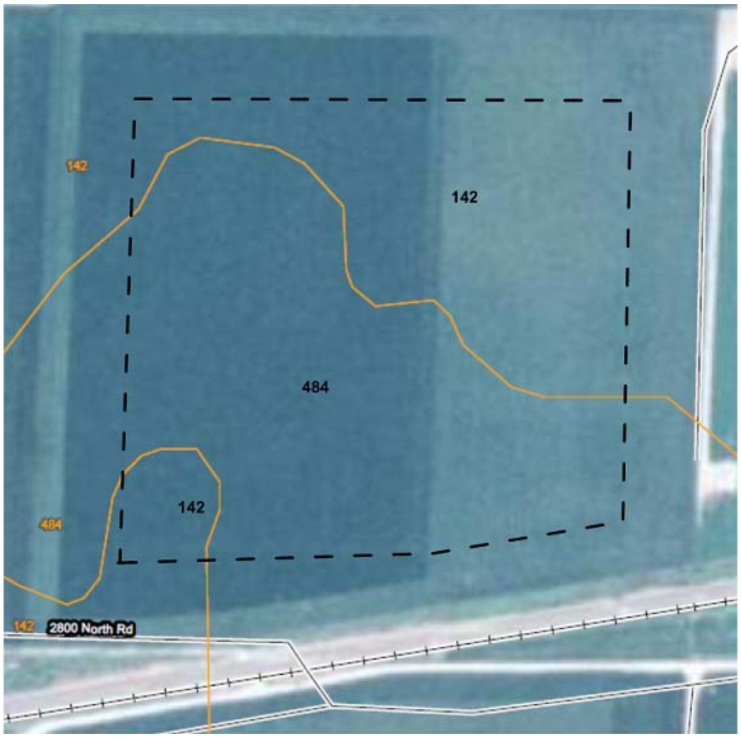

Figure 3. This soil map is from the Web Soil Survey and shows the soil delineations with Site 3, Livingston County.

Table 4. Map Unit Symbols and Names for Study Site 3 in Livingston County

Symbol	*Map Unit Name*
142	Patton silty clay loam
484	Harco silty clay loam

Schuyler County:
The Schuyler County site is located in recently disked fields. The site is located in the SE ¼ of Section 28, T. 2 N., R. 4 W. Figure 4 is a soil map of the study site from the Web Soil Survey.[5] In Figure 4, dark-colored segmented lines have been used to outline the areas that were surveyed with an EM31 meter.

[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 [11/30/2011].

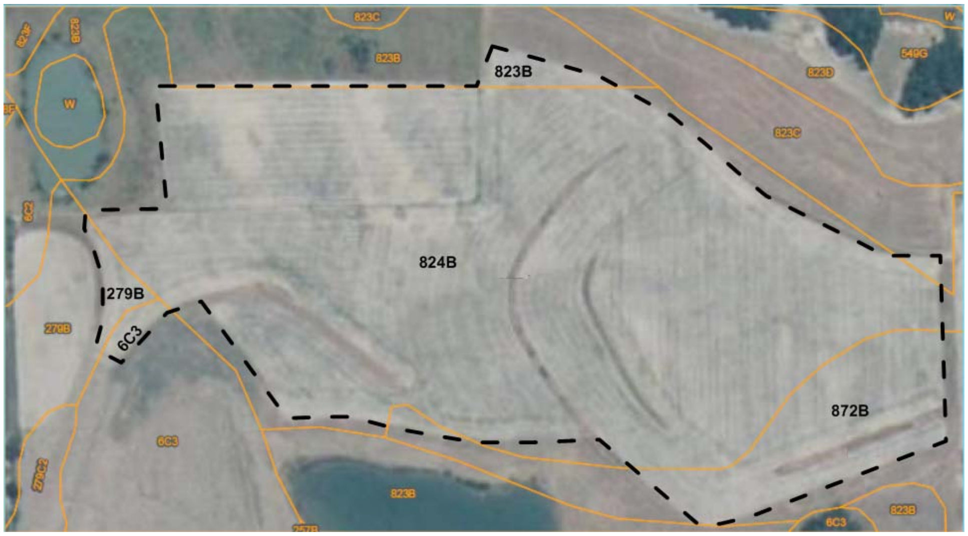

Figure 4. This soil map is from the Web Soil Survey and shows the soil delineations that are mapped on Schuyler County Site.

Table 5. Map Unit Symbols and Names for the Schuyler County Study Site.

Symbol	***Map Unit Name***
279B	Rozetta silt loam, 2 to 5 % slopes
823B	Schuline silty clay loam, 2 to 5% slopes
824B	Swanwick silt loam, 2 to 5 % slopes
872B	Rapatee silty clay loam, 2 to 5 % slopes

Table 6. Taxonomic Classification of Soils at the Schuyler County Site

Soil Series	***Taxonomic Classification***
Rapatee	Fine-silty, mixed, superactive, nonacid, mesic Mollic Udarents
Rozetta	Fine-silty, mixed, superactive, mesic Typic Hapludalfs
Schuline	Fine-loamy, mixed, superactive, calcareous, mesic Alfic Udarents
Swanwick	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents

Table 5 lists the map unit symbols and names for the soil delineations mapped at the Schuyler County site. The very deep, well drained Rapatee and Schuline soils and moderately well drained Swanwick soils are on surface-mined areas. These soils formed in fine-earth material or a mixture of fine-earth materials and fragments of bedrock that have been excavated and reclaimed during surface mining operations. Most areas have dark colored surface layers composed of pre-mined soil materials. All of these soil series are Entisols. The very deep, well drained Rozetta soils formed in loess on uplands. Table 6 lists the taxonomic classification of the named soil series.

<u>Montgomery County Site:</u>
The study site is located in a cultivated field bounded by County Line Road on the west and 13th Avenue on the north. The site is located in the NE ¼ of Section 31, T. 9 N., R. 5 W. Figure 5 is a soil map of the study site from the Web Soil Survey.[6] This study site was surveyed with an EM38-MK2 meter.

[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 [11/30/2011].

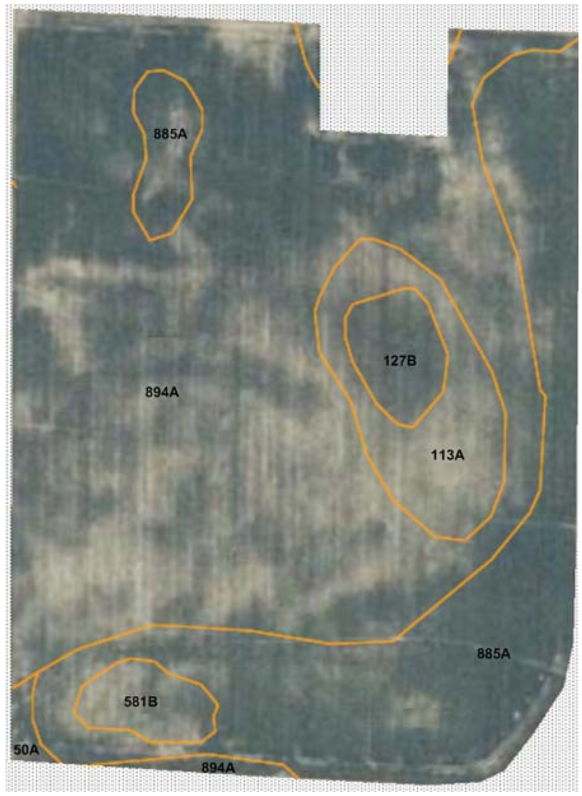

Figure 5. This soil map is from the Web Soil Survey and shows the soil delineations that are mapped on Montgomery County Site.

Table 7. Map Unit Symbols and Names for the Montgomery County Study Site.

Symbol	*Map Unit Name*
50A	Virden silty clay loam, 0 to 2 percent slopes
113A	Oconee silt loam, 0 to 2 percent slopes
127B	Harrison silt loam, 2 to 5 percent slopes
581B	Tamalco silt loam, 2 to 5 percent slopes
882A	Oconee-Darmstadt-Coulterville silt loams, 0 to 2percent slopes
885A	Virden-Fosterburg silt loams, 0 to 2 percent slopes
894A	Herrick-Biddle-Piasa silt loams, 0 to 2 percent slopes

Table 8. Taxonomic Classification of Soils at the Montgomery County Site

Soil Series	***Taxonomic Classification***
Biddle	Fine, smectitic, mesic Aquic Argiudolls
Coulterville	Fine-silty, mixed, superactive, mesic Aeric Epiaqualfs
Darmstadt	Fine-silty, mixed, superactive, mesic Aquic Natrudalfs
Fosterburg	Fine, smectitic, mesic Vertic Argiaquolls
Harrison	Fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls
Herrick	Fine, smectitic, mesic Aquic Argiudolls
Oconee	Fine, smectitic, mesic Udollic Endoaqualfs
Piasa	Fine, smectitic, mesic Mollic Natraqualfs
Tamalco	Fine, smectitic, mesic Aquic Natrudalfs
Virden	Fine, smectitic, mesic Vertic Argiaquolls

Table 7 lists the map unit symbols and names for the soil delineations mapped at the Montgomery County site. These very deep, poorly drained to moderately well drained soils formed in loess, or loess and underlying loamy or silty materials on till plains. The Darmstadt, Piasa, and Tamalco soils have natric horizons. Table 8 lists the taxonomic classification of the identified soil series at the Montgomery County site. These soils are Alfisols and Mollisols, and have either natric or argillic horizons.

Survey procedures:
The 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, vertical dipole orientation and orientated with their long axis parallel with the direction of travel. Data were recorded at a rate of one measurement per second.

The ground surface at the Schuyler County Site was exceedingly rough, which resulted in the EM31 meter suffering excessive vibrations on its specially designed and padded cart. During a second survey of the site, with the EM31 meter operated in the HDO, because of this excessive vibration, one end of the meter worked itself loose and fell off with the cables subsequently being frayed. At this point, measurements became anomalous and the operator noticed the problem. The meter is presently inoperable. The meter will be returned to Geonics Limited for repairs. However, to avoid any future recurrences, surveys with the EM31 meter towed on the utility cart should be restricted to only those sites with smooth surfaces. Hard, clumpy, recently disked fields should be avoided.

Results:
LaSalle-Livingston Counties:
Site 1 and 2:
Table 9 lists basic statistics for the EC_a data collected at this site with the EM38-MK2 and EM31 meters. For measurements recorded with the EM38-MK2 meter, the average EC_a increases with increasing depth of observation suggesting increases in clay and moisture contents with depth. For nominal exploration depths of 75 and 150-cm, EC_a averaged 23 and 36 mS/m, respectively. However, measurements ranged from about -240 to 1280 mS/m and 9.5 to 1280 mS/m for measurements recorded with the 50-cm and 100-cm intercoil spacings, respectively. Buried metallic artifacts (e.g., utility lines, farm implement parts) are suspected to be responsible for the extreme minimum and maximum values. Over one half of the data recorded with the EM38-MK2 meter were between about 19 and 26 mS/m and 33 and 38 mS/m for measurements recorded with the shallower-sensing ,50-cm and the deeper-sensing, 100-cm intercoil spacings, respectively. Variations in EC_a were attributed to variations in bulk moisture and clay contents.

Table 9. Basic EC_a statistics for Site 1 LaSalle County and Site 2 Livingston County, Illinois. With the exception of "Number", all values are in mS/m.

	EM38-MK2 0 to 75 cm	***EM38-MK2 0 to 150 cm***	***EM31VDO 0 to 6 m***
Number	13485	13485	12409
Minimum	-240.1	9.5	24.6
25%-tile	19.1	32.0	32.8
75%-tile	26.0	39.1	37.2
Maximum	1279.9	1279.9	53.6
Average	23.0	36.0	35.04
Std. Dev.	12.3	12.0	3.48

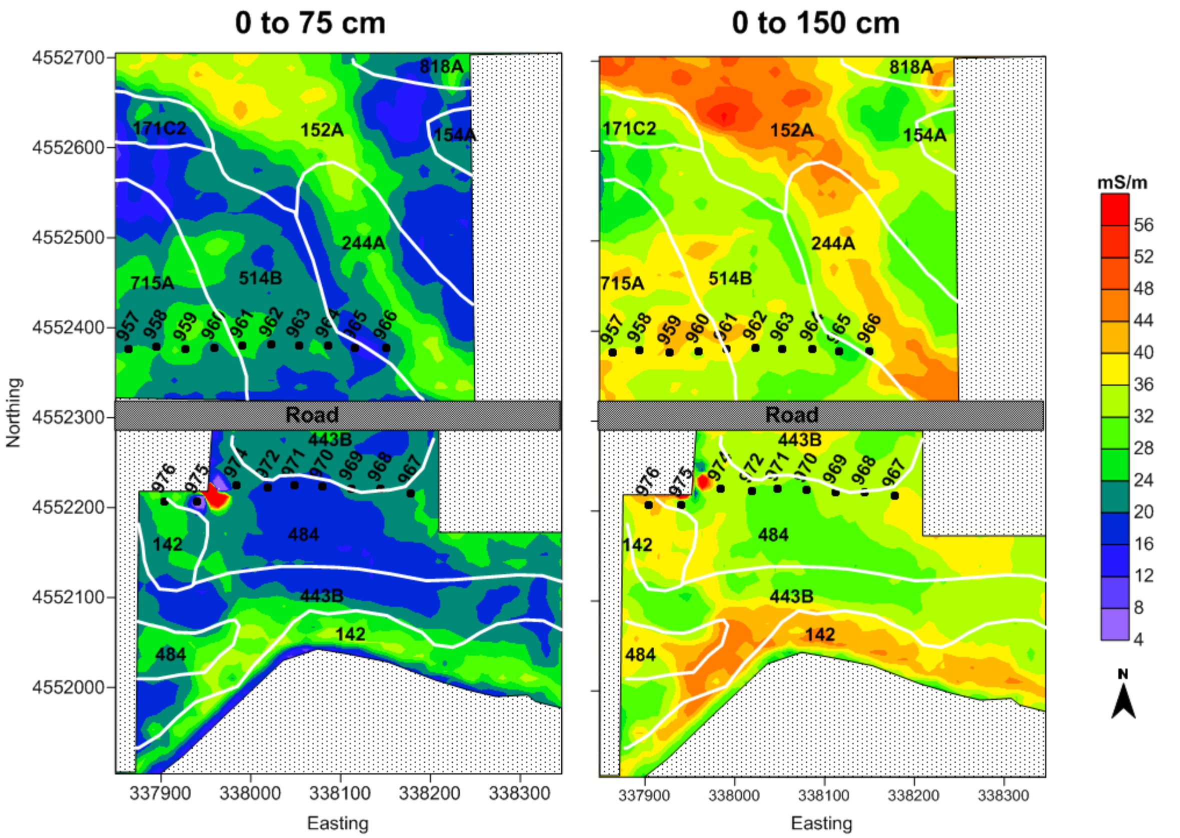

Figure 6. These plots of spatial EC_a patterns were obtained from data collected with an EM38-MK2 meter operated in the 50-cm (left-hand plot) and 100-cm (right-hand plot) intercoil spacings. Soil lines are from the Web Soil Survey. The locations of core sites have been identified.

Figure 6 contains plots of EC_a collected for the shallower sensing, 50-cm (left-hand plot) and deeper sensing, 100-cm (right-hand plot) intercoil spacings. The locations of cores extracted from these sites at the time of the EMI survey are also shown and labeled in each plot. The soil boundary lines have been digitized from Web Soil Survey data[7]. Spatial EC_a patterns appear to reflect differences in soil drainage and landscape position. At both sites, higher EC_a values were recorded in or adjacent to lower-lying drainageways. Lower EC_a values were recorded on higher-lying, more sloping, and better drained areas of each site. Apparent conductivity values were consistent and spatial patterns uninterrupted across the LaSalle / Livingston County boundary line. Based on EC_a measured with the EM38-MK2 meter, there is no justification for recognition of different soils on both sides of this political boundary.

Table 10 summarizes the core data that were extracted from these sites at the time of the survey. Soil series recognized at these sites are differentiated based on soil drainage, parent materials, depth to carbonates, and depth to till. After averaging the EC_a for the two nearest points closest to each of these core sites (Table 10); EC_a data set for both the 50-cm and 100-cm intercoil spacings were compared with both the depth to carbonates and depth to till. None or very weak correlations were estimated between the depth to carbonates and EC_a measured with the 50-cm ($r = 0.2219$) and 100-cm ($r= 0.0992$) intercoil spacings. Stronger correlations were estimated between depth to till and EC_a measured with the 50-cm ($r = 0.4472$) and 100-cm ($r= 0.5505$) intercoil spacings. Considering the manifest difference in soil drainage

[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 [11/7/2011].

and observed difference in texture across these sites, the moderate positive correlation with depth to till was unexpected and perplexing. As average EC_a is known to increase with depth (Table 9), the positive relationships with depth to till suggest that the deeper the depth to till the greater the EC_a. This inference seems to be inaccurate and improbable. It is suspected that other unaccounted factors are exerting a strong influence on EC_a at these sites.

Table 10. Abbreviated Field Notes on Cores Extracted from Sites 1 and 2.

ID	*Easting*	*Northing*	*CARBS*	*TILL*	*DRAINAGE*
955	338529.4	4543971.1	31"	78"	SWP
956	338064.7	4544313.9	13"	66"	PD
957	337864.1	4552376.1	38"	77"	SWP
958	337894.3	4552378.6	32"	74"	SWP
959	337927.5	4552376.0	37"	60"	SWP
960	337959.1	4552377.6	53"	64"	SWP
961	337990.4	4552379.5	36"	60"	SWP
962	338022.9	4552380.9	39"	59"	SWP
963	338053.3	4552379.8	37"	37"	SWP
964	338086.1	4552379.9	32"	32"	SWP
965	338116.4	4552377.0	54"	54"	SWP
966	338150.2	4552377.7	58"	55"	PD
967	338177.9	4552216.3	40"	90"	SWP
968	338144.2	4552220.2	67"	67"	SWP
969	338112.2	4552221.4	50"	50"	SWP
970	338079.4	4552223.0	43"	59"	SWP
971	338048.1	4552224.4	55"	52"	SWP
972	338019.0	4552222.3	47"	63"	SWP
974	337983.7	4552224.4	62"	67"	SWP
975	337940.3	4552206.4	31"	74"	SWP
976	337903.5	4552207.1	66"	37"	SWP

Table 9 lists the basic statistics for the EC_a data collected at this site with the EM31 meter. Assuming a nominal exploration depth of 6 m, the average EC_a was 35 mS/m with a range of about 25 to 54 mS/m. Variations in EC_a are attributed to variations in bulk moisture and clay contents. Compared with the measurements obtained with the EM38-MK2, the average EC_a is similar, but the spatial variability of EC_a is significantly less for the EM31 meter.

Figure 7 contains plots of EC_a and apparent magnetic susceptibility data measured with the EM31 meter operated in the VDO. The locations of cores extracted from the sites at the time of the EMI survey are shown and labeled in each plot. The soil boundary lines have been digitized from Web Soil Survey data[8]. Spatial EC_a patterns are believed to principally reflect differences in soil drainage and landscape position. At both sites, higher EC_a values were recorded in or adjacent to the drainageways. However this relationship with the soil landscape is less obvious than the one displayed with the EC_a data collected with the EM38-MK2 meter (Figure 6). Lower EC_a values were recorded on higher-lying, more sloping, and better drained areas of each site. Again, EC_a is consistent and spatial patterns appear uninterrupted across the LaSalle / Livingston County boundary line. Based on EC_a measured with the EM31 meter, there is no justification for recognition of different soils on both sides of this political boundary.

[8] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [11/7/2011].

Apparent magnetic susceptibility (Figure 7; right-hand plot) is comparatively low and invariable across these sites. Differences in magnetic susceptibility are attributed to buried cultural artifacts, land management (tillage), surface roughness, and vegetation.

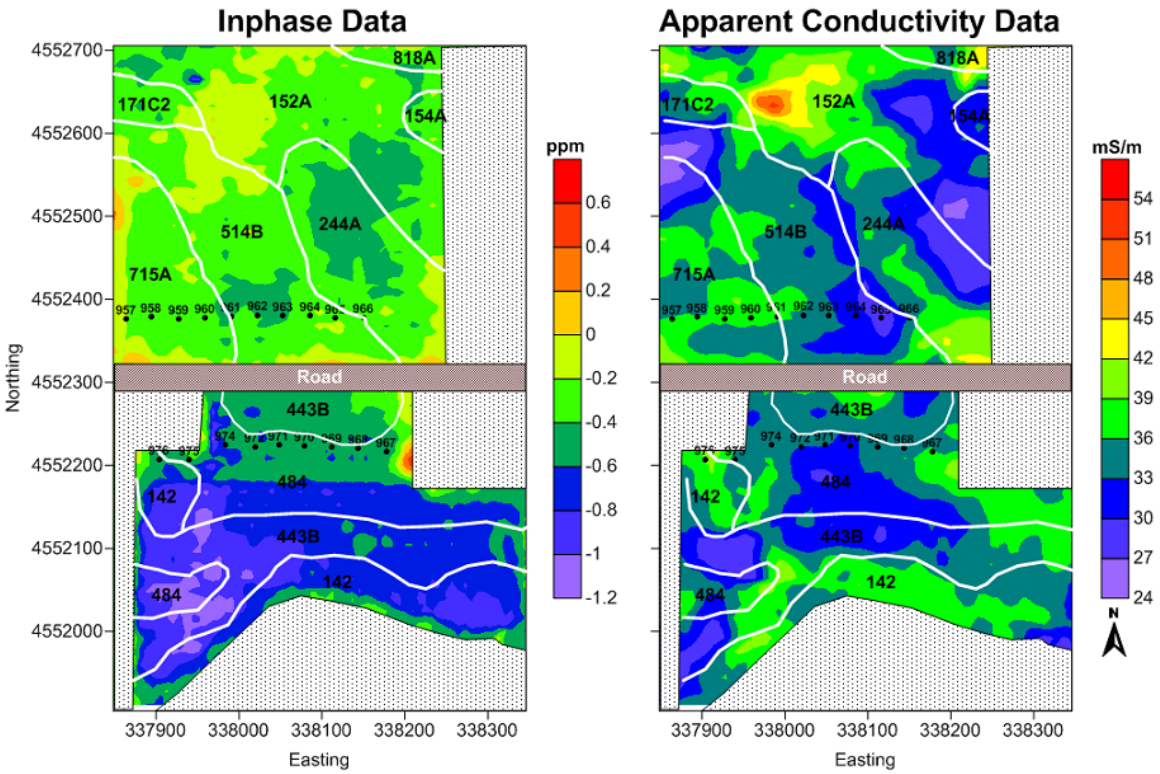

Figure 7. These plots of spatial EC_a (right-hand plot) and magnetic susceptibility (left-hand plot) were obtained from data collected with an EM31 meter operated in the VDO. Soil lines are from the Web Soil Survey. The locations of core sites have been identified.

Site 3-Livingston County (Site 3):

Table 11 lists basic statistics for the EC_a data collected at this site with the EM38-MK2 meter. Average EC_a increases with increasing depth of observation. For the nominal exploration depths of 75-cm and 150-cm, EC_a averaged about 29 and 39 mS/m, respectively. Over one half of the data recorded with the EM38-MK2 meter were between about 24 and 33 mS/m, and 34 and 43 mS/m for measurements recorded with the 50-cm and 100-cm intercoil spacings, respectively. Variations in EC_a were attributed to variations in bulk moisture and clay contents.

Table 11. Basic EC_a statistics for Site 3 in Livingston County, Illinois. With the exception of "Number", all values are in mS/m.

	EM38-MK2 0 to 75 cm	*EM38-MK2 0 to 150 cm*
Number	3927	3927
Minimum	-1.64	20.90
25%-tile	24.02	34.00
75%-tile	33.28	42.80
Maximum	85.43	97.11
Average	28.97	38.96
Std. Dev.	6.35	6.98

Table 12. Abbreviated Field Notes on Cores Extracted from Site 3

Easting	*Northing*	*ID*	*CARBS*	*TILL*	*DRAINAGE*
338557.556	4543975.085	977	69"	69"	PD
338581.5586	4543997.413	978	63"	99"	PD
338596.546	4544014.995	979	34"	66"	PD
338627.9193	4544047.057	980	47"	75"	SWP
338692.2887	4544102.711	981	39"	83"	SWP

Table 12 summarizes the core data that were extracted from this site at the time of the survey. Soil series recognized at this site (Harco and Patton) are principally differentiated based on soil drainage and depth to carbonates. Averaging the EC_a measured at the two nearest points to each of these core sites, the averaged EC_a data for both the 50-cm and 100-cm intercoil spacings were compared with both the depth to carbonates and depth to till. In contrast to Sites 1 and 2, at Site 3, EC_a was strongly and inversely correlated with carbonates and not correlated with depth to till. The depth to till is expected to be very deep at this site. None or very weak correlations were estimated between depth to till and EC_a measured with the 50-cm (r = -0.0552) and 100-cm (r= -0.01382) intercoil spacings. Stronger negative correlations were estimated between depth to carbonates and EC_a measured with the 50-cm (r = -0.6799) and 100-cm (r= -0.8692) intercoil spacings. This suggests that as the depth to carbonates decreases, the EC_a will increase.

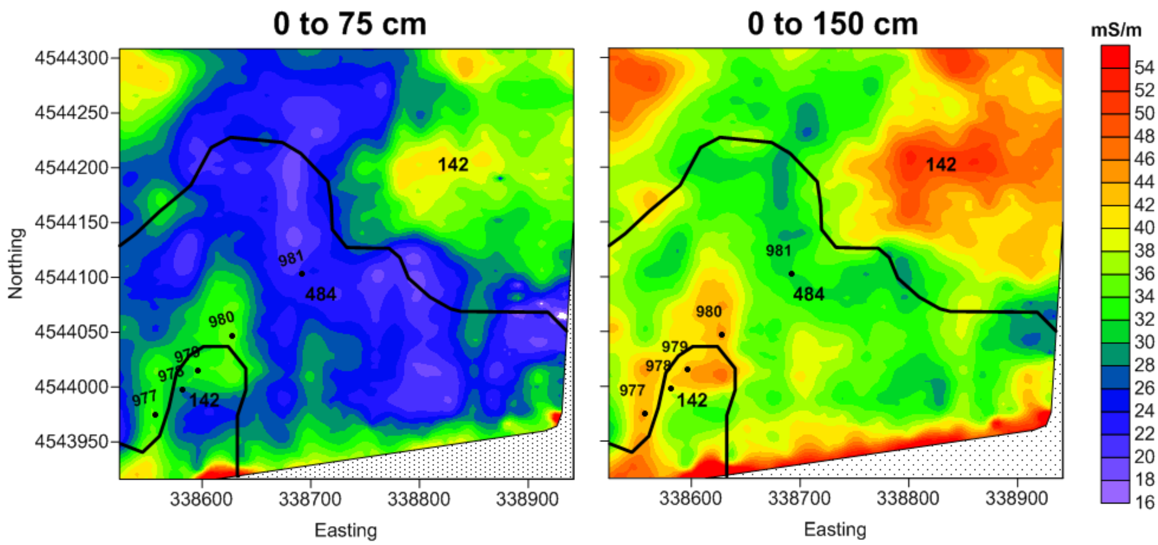

Figure 8. These plots of spatial EC_a patterns were obtained from data collected with an EM38-MK2 meter for the 50-cm (left-hand plot) and 100-cm (right-hand plot) intercoil spacing. Soil lines are from the Web Soil Survey. The locations of core sites have been identified.

Figure 8 contains plots of EC_a collected for the shallower sensing, 50-cm (left-hand plot) and deeper sensing, 100-cm (right-hand plot) intercoil spacings. The locations of cores extracted from the sites at the time of the EMI survey are shown and labeled in each plot. The soil boundary lines have been digitized from Web Soil Survey data[9]. Spatial EC_a patterns appear to reflect differences in soil drainage and landscape position. Higher EC_a values were recorded on slightly lower-lying depressional areas where glaciolacustrine deposits are more likely to be identified. Lower EC_a values were recorded on slightly

[9] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [11/7/2011].

higher-lying, more sloping, and better drained knolls or swells. Higher EC_a were also recorded along the southern boundary of the site where a road and utility corridor parallels a railroad line (see Figure 3).

LaSalle-Livingston Counties (Sites 4 & 5):

Site 4- Intermediate fields:

Table 13 lists basic statistics for the EC_a data collected at these sites with the EM38-MK2 meter. The average EC_a increases with increasing depth of observation. For the nominal exploration depths of 75-cm and 150-cm, EC_a averaged about 24 and 36 mS/m, respectively. Variations in EC_a were attributed to variations in bulk moisture and clay contents.

Table 13. Basic EC_a statistics for Sites 4 & 5 in Livingston and LaSalle Counties, Illinois. With the exception of "Number", all values are in mS/m.

	EM38-MK2 0 to 75 cm	*EM38-MK2 0 to 150 cm*
Number	7161	7161
Minimum	-9.73	-61.52
25%-tile	21.99	33.48
75%-tile	26.45	38.13
Maximum	91.72	64.18
Average	24.50	35.97
Std. Dev.	3.81	4.05

Table 14 summarizes the core data that were extracted from these sites. The recognized soils at these sites are principally differentiated by soil drainage, parent materials and depth to till and carbonates. Averaging the EC_a measured at the two nearest points to each of these core sites, the averaged EC_a data for both the 50-cm and 100-cm intercoil spacings were compared with both the depth to carbonates and depth to till. Apparent conductivity was inversely correlated with carbonates and not correlated with depth to till (depth to till is expected to be very deep in these soils). None or very weak correlations were estimated between depth to till and EC_a measured with the 50-cm (r = -0.0104) and 100-cm (r= -0.0203) intercoil spacings. Stronger negative correlations were estimated between depth to carbonates and EC_a measured with the 50-cm (r = -0.5448) and 100-cm (r= -0.4855) intercoil spacings. The inverse relationship suggests that as the depth to carbonates decreases, EC_a will increase.

Table 14. Abbreviated Field Notes on Cores Extracted from Sites 4 & 5.

Easting	*Northing*	*ID*	*CARBS*	*TILL*	*DRAINAGE*	*NOTES*
337834.9	4547552.6	982	41"	62"	SWP	silty material @43"
337826.2	4547511.4	983	45"	45"	SWP	silty material @37"
337827.8	4547485.5	984	40"	56""	SWP	silty material @40"
337832.1	4547464.6	985	40"	64"	SWP	silty material @40"
337828.8	4547420.5	986	40"	73"	SWP	silty material @39""
337827.3	4547383.4	987	40"	67"	SWP	silty material @36"
337827.4	4547351.1	988	42"	47"	SWP	silty material @41"
337828.5	4547317.6	989	38"	35"	SWP	silty material @30"
337751.4	4547499.4	990	39"	41"	SWP	
337725.1	4547531.1	991	40""	47"	SWP	silty material @30"
337721.9	4547567.0	992	40"	47"	SWP	silty material @37"
376872.2	4547604.8	993	52"	62"	SWP	no silty zone

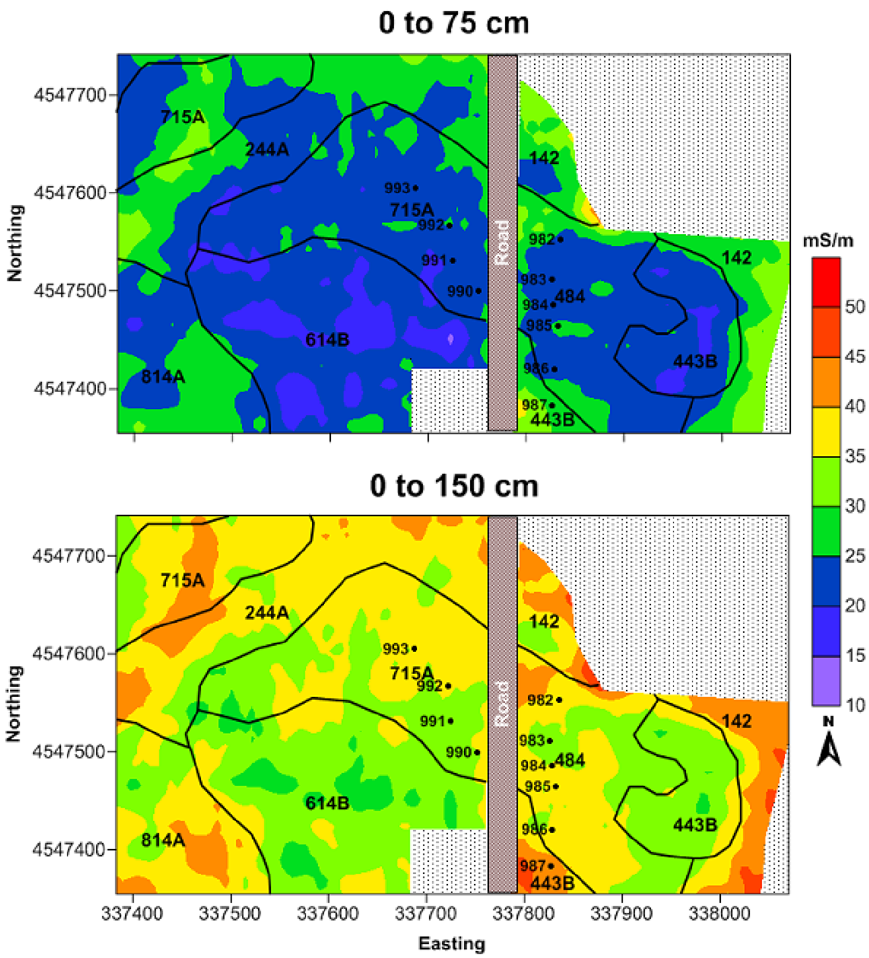

Figure 9. These plots of spatial EC_a patterns were obtained from data collected with an EM38-MK2 meter for the 50-cm (upper plot) and 100-cm (lower plot) intercoil spacing at Sites 4 & 5. Soil lines are from the Web Soil Survey. The locations of core sites have been identified.

Figure 9 contains plots of EC_a data collected with the shallower sensing, 50-cm (upper plot) and deeper sensing, 100-cm (lower plot) intercoil spacings. The locations of cores extracted from the sites at the time of the EMI survey are shown and labeled in each plot. The soil boundary lines have been digitized from Web Soil Survey data[10]. Spatial EC_a patterns are complex with higher values generally occurring in lower-lying, more imperfectly drained portions of these sites. Patterns do appear to correspond to some extent with the soil delineations.

Schyuler County:
Electromagnetic induction has been used to assess soil compaction occurring at relatively shallow depths. Islam et al. (2011) used an EM38 meter to evaluate soil and crop variability within flooded rice fields. These researchers found that variation in EC_a could be attributed to differences in subsoil bulk density, with the lowest EC_a values representing the lowest bulk density. This effect was attributed to differences in compaction of the plough pan due to differential puddling. Hedley et al. (2004) also observed elevated EC_a in areas of soil compaction in a pastoral-cropping farming system.

[10] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [11/7/2011].

This study attempted to evaluate difference in soil compaction caused by a haul road. It is my understanding that this road predated reclamation and that it is presently deeply buried beneath reclaimed mine spoil materials. For this reason an EM31 meter was used.

Table 15 lists basic statistics for the EC_a data collected at the Schuyler County Site with an EM31 meter. The EM31 meter was operated in the VDO with a nominal exploration depth of about 6 meters. Apparent conductivity averaged 50.9 mS/m, with a range of 35.2 to 77.4 mS/m. Variations in EC_a were attributed to variations in bulk moisture and clay contents. In these reclaimed mined-spoil materials, magnetic susceptibility, which was inferred from the in-phase data, is very low and spatially invariable.

Table 15. Basic EC_a statistics for the Schuyler County Site. With the exception of "Number", all values are in mS/m.

	EM31VDO EC_a	***EM31VDO In-phase***
Number	10890	10890
Minimum	35.23	-11.34
25%-tile	46.58	-2.41
75%-tile	54.90	-0.86
Maximum	77.40	3.83
Average	50.90	-1.65
Std. Dev.	6.26	1.17

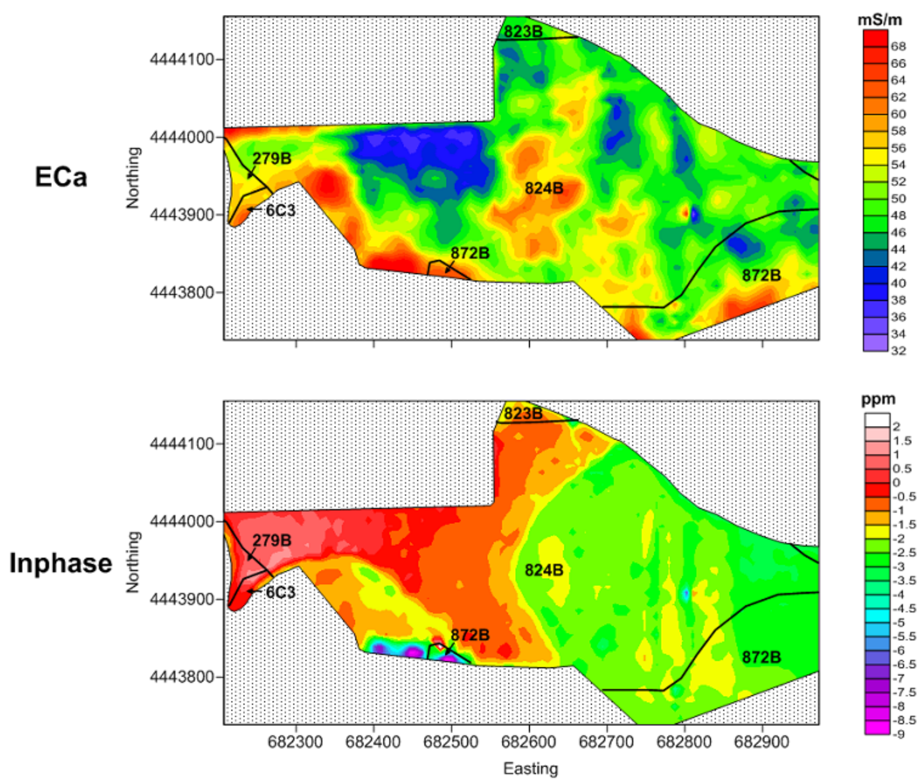

Figure 10. These plots of spatial EC_a (upper plot) and apparent magnetic susceptibility (lower plot) were obtained from data collected with an EM31 meter operated in the VDO. Soil lines are from the Web Soil Survey.

Figure10 contains plots of EC_a and apparent magnetic susceptibility (in-phase data expressed in ppm) data measured with the EM31 meter operated in the VDO. The soil boundary lines have been digitized from Web Soil Survey data.[9] Spatial EC_a patterns are believed to principally reflect differences in water and clay contents and possibly soil compaction. Based on recollections of a photo showing the former haul road, some of the areas with higher EC_a (> 54 mS/m) in the central and western portions of the site, appear to conform to the location of the haul road. The in-phase data are relatively invariable across the site. Spatially, the in-phase data appears to distinguish different units of management (separated by terraces or field boundaries). Differences in apparent magnetic susceptibility are attributed to differences in land management (tillage) and surface roughness.

Montgomery County:
Table 16 lists the basic statistics for the EC_a data collected at the Montgomery County site with the EM38-MK2 meter. Average EC_a increases with increasing depth of observation suggesting increases in clay, moisture, and/or soluble salts with depth. For nominal exploration depths of 75-cm and 150-cm, EC_a averaged about 16 and 36 mS/m, respectively. Apparent conductivity ranged from about -241 to 56 mS/m, and from about -13 to 79 mS/m, for data recorded with the 50-cm and 100-cm intercoil spacings, respectively. Buried metallic artifacts (e.g., utility lines, farm implement parts) are suspected to be responsible for the extreme values. Over one half of the recorded data were between about 10 and 21 mS/m, and 29 and 43 mS/m for measurements recorded with the shallower-sensing, 50-cm and the deeper-sensing, 100-cm intercoil spacings, respectively. Variations in EC_a were attributed to variations in soluble salt, moisture and clay contents.

Table 16. Basic EC_a statistics for the Montgomery County Site. With the exception of "Number", all values are in mS/m.

	0 to 75 cm	***0 to 150 cm***
Number	11585	11585
Minimum	-241.1	-12.8
25%-tile	9.6	29.1
75%-tile	20.7	42.9
Maximum	55.6	79.1
Average	15.7	36.4
Std. Dev.	8.7	10.2

Figure 11 contains plots of the EC_a data collected with the shallower sensing, 50-cm (left-hand plot) and deeper sensing, 100-cm (right-hand plot) intercoil spacings. The soil boundary lines have been digitized from Web Soil Survey data[11]. Spatial EC_a patterns appear to reflect differences in soil drainage and landscape position. Lower EC_a values were recorded on a broad, slightly higher-lying, better drained knoll that has been partially mapped as Oconee silt loam, 0 to 2 percent slopes (113A) and Harrison silt loam, 2 to 5 percent slopes (127B). These units supposedly are non-sodium-affected. The more expansive, level areas that surround this knoll have higher EC_a. On these more level areas, spatial patterns are very complex, having a pock-marked appearance that is often associated with sodicity.

[11] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [11/7/2011].

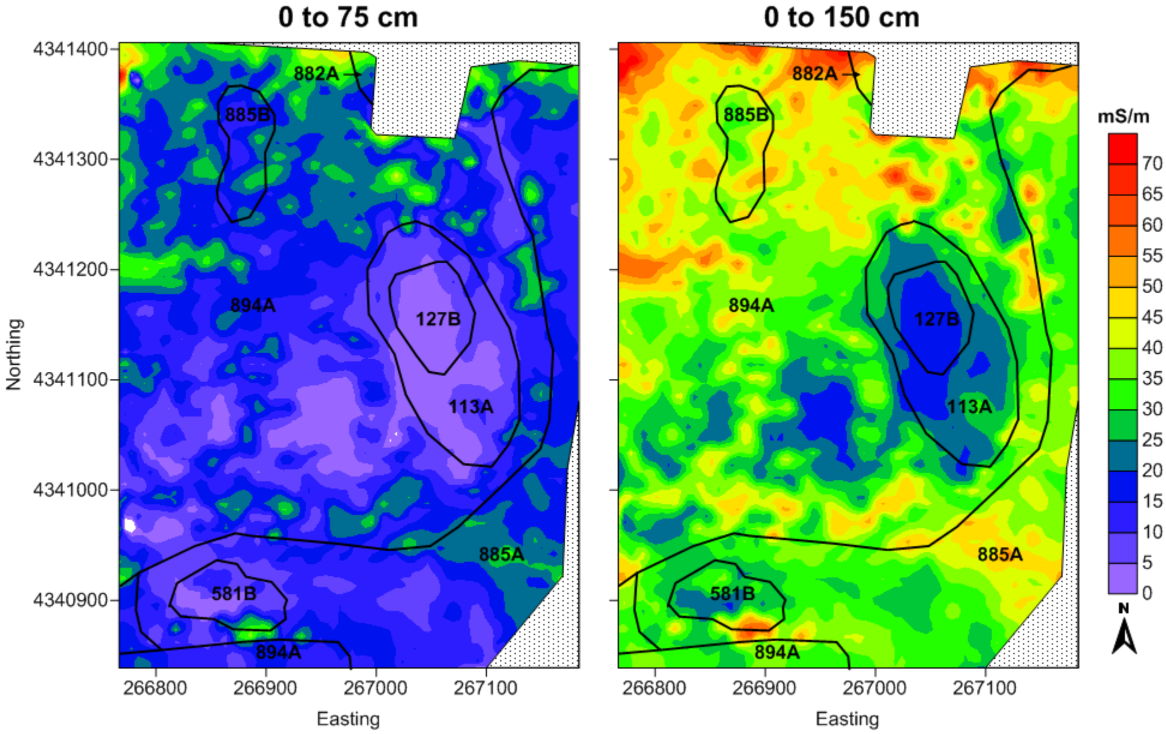

Figure 11. These plots of spatial EC_a patterns were obtained from data collected with an EM38-MK2 meter for the 50-cm (left-hand plot) and 100-cm (right-hand plot) intercoil spacing at the Montgomery County Site. Soil lines are from the Web Soil Survey.

A response surface sampling design model was applied to EC_a data collected at the Montgomery County site. This model was used to identify two sets of optimal sampling or calibration points for future sampling. The sampling points were identified using the *ESAP* (EC_e Sampling, Assessment, and Prediction) software's "*Respond Surface Sampling Design*" (RSSD) Program. The ESAP-RSSD program is a prediction-based sampling approach that is designed to reduce the number and optimize the location of calibration sampling points (either 6, 12, or 20 points) based on the observed magnitudes and spatial locations of the raw EC_a data. The sets contained 6 and 12 calibration points. Table 17 provides the georeferenced EC_a data for the six points, optimal sampling plan, which are identified by their observation number (OBS). Table 18 provides the georeferenced EC_a data for the 12 points, optimal sampling plan.

Table 17. Six Point Optimal Sample Scheme for the Montgomery County Site. The EC_a for the 0 to 150 cm and 0 to 75 cm sampling depths are shown

OBS	*EASTING*	*NORTHING*	*0-150CM*	*0-75CM*
1238	267171.762	4341287.563	36.13	15.51
2765	267153.37	4340915.029	38.16	16.88
6314	266890.259	4341384.722	51.91	30.51
6557	266969.897	4341061.374	17.38	3.05
9421	266780.126	4341357.188	54.96	28.13
10887	266844.488	4340887.649	20.82	1.02

Table 18. Twelve Point Optimal Sample Scheme for the Montgomery County Site. The EC_a for the 0 to 150 cm and 0 to 75 cm sampling depths are shown.

OBS	*EASTING*	*NORTHING*	*0-150CM*	*0-75CM*
7	267129.902	4341387.338	62.07	36.17
874	266902.464	4341399.457	51.48	30.39
1308	267157.212	4341261.609	34.41	13.91
1616	267172.944	4341120.694	34.18	17.58
2750	267162.727	4340912.003	43.67	21.56
4362	267034.878	4341153.258	17.15	2.85
5893	267029.25	4340885.107	28.67	9.57
6192	266936.526	4341256.621	37.81	16.6
6542	266965.363	4341080.492	18.71	1.48
10043	266805.165	4341201.829	54.57	27.5
10888	266844.715	4340886.426	21.05	1.29
11012	266798.085	4341006.603	38.63	13.87

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