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

**Subject:** -- Geophysical Assistance **Date:** 9 January 2004

**To:** Robert L. McLeese
State Soil Scientist
USDA-Natural Resources Conservation Service
2118 West Park Court
Champaign, IL 61821

Jonathan W. Hempel
State Soil Scientist
USDA-Natural Resources Conservation Service
Suite 200
6515 Watts Road
Madison, WI 53719-2726

Michael T. Sucik
State Soil Scientist
USDA-Natural Resources Conservation Service
Suite 693
210 Walnut Street
Des Moines, IA 50309-2180

**Purpose:**
The purpose of this investigation was to evaluate mapping and sampling protocol that can be used to conduct high intensity soils surveys with geophysical tools.

**Participants:**
Lee Clayton, Geologist, Wisconsin Geological Survey, Madison, WI
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Donna FerrenGuy, Soil Scientist, USDA-NRCS, Sparta, WI
Howard Gundlack, Soil Scientist, USDA-NRCS, Madison, WI
Eugene Hausner, Area Resource Conservationist, USDA-NRCS, Richland Center, WI
Frank Heisner, Soil Scientist, USDA-NRCS, Rock Falls, IL
Jonathan Hempel, State Soil Scientist, USDA-NRCS, Madison, WI
Tom Hunt, Manager, UW-Platteville Pioneer Farm, Platteville, WI
Randy Jerome, Technical Specialist, EarthIT, Madison, WI
Lester Johnson, Jo Davies County SWCD, Galena, IL
Robert McLeese, State Soil Scientist, USDA-NRCS, Champaign, IL
Phil Meyer, Soil Scientist, USDA-NRCS, Richland Center, WI
Duane Simonson, MLRA Project Leader, USDA-NRCS, Richland Center, WI
Cindy Stiles, Assistant Professor, Soil Science Department, U of Wisconsin, Madison, WI
Mike Sucik, State Soil Scientist, USDA-NRCS, Des Moines, IA
Elizabeth Swanberg, Soil Scientist, USDA-NRCS, Waverly, IA
Bob Vobora, Soil Scientist, USDA-NRCS, Waverly, IA
Chance Vogel, Soil Scientist, USDA-NRCS, Richland Center, WI
Woody Wallace, Geomorphologist, EarthIT, Madison, WI
Roger Windhorn, Resource Soil Scientist, USDA-NRCS, Champaign, IL
Dan Withers, Cartographic Technician, USDA-NRCS, Champaign, IL

**Activities:**
All field activities were completed during the period of 18 to 21 November 2003.

**Results:**

1. Electromagnetic induction (EMI) provides a fast, economical, and noninvasive tool for mapping soils. Plots of apparent conductivity ($EC_a$) have been used as a substitute for soil survey maps. Because of the increased sampling density afforded with EMI, $EC_a$ maps are assumed to be more accurate than soil maps. However, as soil scientists cluster observations into polygons that are determined by observed soil properties, supported by supplementary tactile information (such as plant response, topography, etc.), and delineated with the aid of remotely sensed data, it is unclear whether soil or $EC_a$ maps provides more meaningful and useful information.

2. Within the investigated sites in Illinois, Wisconsin, and Iowa, some patterns of $EC_a$ corresponded with mapped soil patterns, other patterns did not. As a number of soil factors (that include moisture content, clay content and mineralogy, soluble salt content and type, bulk density, and organic matter content) influence $EC_a$, it is not be surprising that agreement between soil and $EC_a$ polygons is not achieved. In this study, factors responsible for changes in $EC_a$ varied with sites and often within polygons. Relationships between soil properties, soils, map units, and $EC_a$ are often complex. As a consequence, relationships can be ambiguous and inexplicable without adequate ground truth observations.

3. Without some knowledge of variations of soils and soil properties across landscapes, $EC_a$ is a meaningless measure. In such situations, maps showing the spatial distribution of $EC_a$, though often very colorful and representing the cutting edge of modern technology are a poor substitute for soil maps. With knowledge of the variations and interplay of soils and soil properties on landscapes, $EC_a$ patterns can be more completely explained with a minimum sampling. With more intensive sampling, specific relationships within single polygons can be determined. In the absence of acceptable sampling, $EC_a$ alone appears to be a poor indicator of soil properties and soils.

4. In general, though absolute values varied with each instrument and configuration, spatial patterns of $EC_a$ were similar at each site. With greater number of samples a greater number of smaller polygons were recognized with EMI than on soil maps. However, the large number of samples and the greater number of smaller polygons did not seem to improve interpretations.

5. Results indicate that order-one soil surveys capture most of the small-scale variability in soils and soil properties and provide meaningful information and as recognizable polygons as shown on $EC_a$ plots. Most easily recognizable patterns are related to changes in topography (drainage). In humid regions, in the absence perceptible levels of soluble salts, $EC_a$ is highly dependent on changes in soil moisture and clay contents. As a result of the interplay of these two factors, soils formed on different landscape positions often have different $EC_a$. Because of the affects of topography on these factors, visual plots were prepared that drape $EC_a$ data over digital terrain model (DEM) data. Field soil scientists will determine whether these plots provide improved soil interpretations that can be used to improve order-one soil maps.

6. Because of greater sample size and increased sampling density, EMI and DEM data may be used to refine and improve soil maps prepared with conventional survey methods. In general, the greater sample size and sampling density of these technologies should enable the more accurate placement of soil boundaries and the delineations of some smaller soil polygons.

7. The collection of $EC_a$ data does not require knowledge of soils or soil survey techniques. Lesser-trained technicians can collect $EC_a$ data. However, as illustrated at the selected study sites, a thorough sampling scheme is often needed to unravel the various factors that are influencing the EMI response and produce meaningful soil polygons based on $EC_a$. A qualified soil scientist is essential for the proper interpretation and correlation of EMI data.

8. A soil scientist using the $EC_a$ and DEM data collected in this study will remap the Freeport site. His impressions as to how the $EC_a$ and DEM data have improved his work or affected his interpretations will be recorded. From these impressions, an assessment will be made as to whether the combined use of $EC_a$ and elevation data improves soil maps and interpretations. If the results are positive, protocol will be developed and modified for using geophysical and DEM data in high-intensity soil mapping.

9. At the Freeport site, in an area of Frankville soil, GPR provided good imagery and traced the soil/bedrock interface to a maximum depth of about 1.6 m. At the Platteville site, in an area of Tama soil, because of high clay contents and the dominance of 2:1 expanding lattice clays with high cation exchange capacities, GPR was more depth restricted and unsuitable for most soil investigations. Because of rapid signal attenuation, severe depth restrictions and the poor interpretative quality of radar records, the use of GPR is considered inappropriate for mapping most medium textured soils in the Midwest.

It was my pleasure to work in your states and with members of your fine staffs. Special thanks are extended to Dan Withers for his preparation of the ArcView GIS images shown in this report.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
J. McCloskey State Soil Scientist/MO Leader, USDA-NRCS, 375 Jackson Street, Suite 600, St. Paul, MN 55101-1854
T. Neely, State Soil Scientist/MO Leader, USDA-NRCS, 6013 Lakeside Blvd., Indianapolis, Indiana 46278
C. Olson, National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
D. Rooney, Earth Information Technologies, Corporation, 2453 Atwood Ave, Madison, WI 53704
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697

**Background:**
The availability of computers, global positioning systems (GPS), geographical information systems (GIS), and geophysical tools are changing the way we map soils. Over the last decade, these technologies have fostered the rapid expansion of site-specific management and the production of high-intensity soil maps. The preparation of high-intensity soil maps for site-specific management is, and will remain, principally a private sector pursuit (Mausbach, 1993). However, the Soil Survey Division of the USDA-NRCS should provide standards, models, guidance, and oversight for the development of high-intensity soil maps especially as new tools and methods are used to facilitate these surveys.

High-intensity or first-order soil surveys provide very detail information and describe the variability of soils and soil properties at scales of 1:15,840 or larger (Soil Survey Division Staff, 1993). Compared with standard soil surveys, soil maps for site-specific management are prepared at a higher intensity of field study and therefore contain more homogeneous map units that are delineated at higher level of resolutions. For site-specific management, map units need to be consociations and contain no dissimilar soils (Roberts, 1992).

The preparation of high-intensity soil maps is a novel and formidable task. Unless alternative field methods are developed, high intensity soil maps will be expensive, time-consuming, and labor-intensive to prepare. To facilitate the preparation of high intensity soil maps, alternative methods are needed to complement traditional soil survey techniques, provide more detailed information, and improve the assessment of soil properties. Alternative methods for mapping and examining soils are being used and evaluated by the USDA-NRCS. Continuous profiling, towed-array resistivity units and electromagnetic induction meters are two geophysical tools that are being used for high intensity soil surveys and site-specific management. For over twenty years, the Soil Survey Division has used ground-penetrating radar (GPR) as a quality control tool for soil surveys. These geophysical tools have great potential for identifying inclusions within soil delineations (Fenton and Lauterbach, 1999). Because of their speed and ease of use, these geophysical tools have significant advantages over conventional soil survey techniques. Using EMI, the number of observation is larger, sites can be more intensively covered in shorter periods of time, and often, more detailed maps can be prepared than is possible with conventional soil survey techniques.

Electromagnetic induction measures the spatial variability in apparent conductivity ($EC_a$). In non-saline areas, $EC_a$ is principally a function of clay and moisture contents and their distributions within soil profiles and variation across landscapes. Last year, a similar study was conducted in LaSalle County, Illinois. Across most of this 110-acre site, apparent conductivity was comparatively low and invariable. Some dissimilar soils had closely similar ranges of apparent conductivity. However, many $EC_a$ polygons did not conform to the order-one soil survey map of the site. Areas of high $EC_a$ were associated with soils having higher moisture and/or clay contents. However, the exact contributing factor(s) for the higher (or lower) $EC_a$ could not be discerned directly from the $EC_a$ maps without extensive ground-truth observations and knowledge of the soils. While the advantages of EMI are not disputed, the interpretative value of EMI data and the extent of required, supplementary, field verifications are questioned.

Although the EMI survey of the LaSalle site produced colorful maps with intricate patterns, the order-one soil survey of the site was more easily interpreted and appeared to provide more logical, meaningful, and useful information. The order-one survey was able to capture most of the small-scale variability in soils and soil properties that was related to changes in topography (drainage). Topography is one of the most obvious and unchangeable causes of variations in soils. In a given landscape, a set of soils occurs together in a predictable manner and soil scientists are trained to predict their occurrence. Knowledge of these relationships provides soil scientists with a distinct advantage over untrained technicians conducting EMI surveys. Topographic features such as slope gradient, complexity, length, and aspect are evident to the trained eye. Soil scientists use these topographic features to name and differentiate soil map units. At the LaSalle site, draping slope class data over plots of $EC_a$ was seen as the most logical method to improve interpretations.

Kitchen and others (2003) discussed the integration of topographic, $EC_a$, and yield data to improve interpretations. These researchers found a high correlation between $EC_a$ and slope. Apparent conductivity and elevation data can be collected simultaneously in the field on highly mobile, mechanized platforms, and digital elevation model (DEM) data are available at coarser scales for most areas of the United States. Combining $EC_a$ and topographic data is seen as a practical method to improve the assessment of delineated polygons. The objectives of this study were 1) to develop protocol for conducting high-intensity soil mapping with geophysical tools and 2) to determine whether the combined use of $EC_a$ and elevation data improved the interpretations of mapped polygons.

**Equipment:**
The Veris 3100 soil EC mapping system was used at several sites in this study. This system is a towed-array, multi-electrode resistivity unit manufactured by Veris Technologies.[1] Operating procedures are described by Veris Technologies (1998). The Veris 3100 soil EC mapping system converts measurements of apparent resistivity (ohm-m) into apparent conductivity (mS/m). The Veris 3100 implement provides two depths of penetration: one for the upper 0 to 30 cm (shallow) and one for the upper 0 to 90 cm (deep) of the soil. The depth of penetration is dependent upon the spacing and type of electrode array. The Veris 3100 implement, under suitable field conditions, can be pulled behind a 4WD pickup truck at speeds of about 5 to 10 m/hr. A Trimble 132 GPS receiver was used to geo-reference the measurements made with this system.[1]

Geonics Limited manufacturers the EM31 and EM38 meters.[1] These meters are portable and require only one person to operate. No ground contact is required with either meter. For each meter, lateral resolution is approximately equal to the intercoil spacing. McNeill (1980) has described the principles of operation for the EM31 meter. The EM31 meter 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 3.0 and 6.0 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1980). The Geonics DAS70 Data Acquisition System was used to record and store both EM31 and GPS data.[1] The acquisition system consists of an EM31meter, Allegro field computer, and Trimble AG114 GPS receiver. [1] With the logging system, the EM31 meter is keypad operated and measurements can either be automatically or manually triggered.

Geonics Limited (1998) has described the principles of operation for the EM38 meter. The EM38 meter operates at a frequency of 14,600 Hz. When placed on the soil surface, it has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 1998).

Earth Information Technology (Earth IT) Corporation used their *Field Measurement Device* (shown in Figure 1) to simultaneously collect geo-referenced apparent conductivity and elevation data. This system uses a Deere/Navcom Starfire GPS system with real-time kinematic differential correction (~ 2cm vertical and horizontal accuracy) to collect position and elevation data. [1] This system uses a radio link between a base station and a roving station to establish positions in real-time. Signals from the GPS and EM38 meter are combined on a tablet (see Figure 1) running Windows 2000 and the StarPal data collection software.[1] The roving GPS receiver is mounted on, and an EM38 meter (in Figure 1, meter is located in the covered sled that is on the ground) is towed behind an all-terrain vehicle (ATV) for fast, efficient, and simultaneous measurements.

To help summarize the results of this study, the SURFER for Windows, version 8.0 (developed by Golden Software, Inc.) was used to construct two-dimensional simulations.[1] Grids were created using kriging methods with an octant search.

Dan Withers prepared all ArcView presentations included in this report. Soil maps, which were prepared at smaller scales (1:20,000 or 1:15,840), were scanned and digitized using Arc/Info and imported into ArcView.[1] Using ArcView, soil lines and delineations, which were mapped at smaller scales, were overlain at a scale of 1:7,920 on a recent aerial photograph of each site.

The radar unit used in this study is the TerraSIRch SIR (Subsurface Interface Radar) System-3000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-3000 consists of a digital control unit (DC-3000) with keypad, color SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. This unit is backpack portable and, with an antenna, requires two people to operate. The antenna used in this study has a

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

center frequency of 200 MHz.

Figure 1. The Earth Information Technology (Earth IT) Corporation's *Field Measurement Device.*

The RADAN for Windows (version 5.0) software program was used to process the radar records (Geophysical Survey Systems, Inc, 2003).[3] Processing included surface adjustment, color transformation, marker editing, distance normalization, and range gain adjustments.

**Study Sites:**

Freeport, Illinois:

The site is located in the western half of Section 7, T. 27 N., and R. 8 E. The site is located just north of Freeport on Illinois Route 26 in Stephenson County. At the time of the survey, the site was in corn and soybean stubble. This site is located on a loess covered till plain. The site is topographically diverse with slopes ranging from 0 to 10 percent. The site is underlain by dolomite of the Galena formation. Two small intermittent drainages cross the western part of site from south to north. A larger and wetter intermittent drainage crosses the eastern part of site from south to north.

The soil survey of Stephenson County, Illinois, was completed in 1976 (Ray et al., 1976). At the time of the survey, soils were examined only to a depth of about 40 inches. Since then, new soil series have been introduced and series concepts, soil depth classes, and phases used to name soil map units have changed. Table 1 lists the names of the units that were mapped on the site in the 1976 survey. This soil survey identified six soil map units. The present taxonomic classification of these soils is listed in Table 2.

**Table 1. 1976 Soil Legend for Freeport Site**

| Map Unit | Name |
|---|---|
| **199A** | Plano silt loam, 0 to 2 percent slopes |
| **148B** | Proctor silt loam, 2 to 4 percent slopes |
| **406C** | Dodgeville silt loam, 4 to 7 percent slopes |
| **416B** | Durand silt loam, 2 to 4 percent slopes |
| **506B** | Hitt silt loam, 2 to 4 percent slopes |
| **506C2** | Hitt silt loam, 4 to 7 percent slopes |

**Table 2. Soil Taxonomic Legend for the Freeport Site**

| Series | Taxonomic family |
|---|---|
| **Ashdale** | fine-silty, mixed, superactive, mesic Typic Argiudolls. |
| **Blackberry** | fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls. |
| **Clare** | fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls. |
| **Dodgeville** | fine-silty over clayey, mixed, superactive, mesic Typic Argiudolls |
| **Durand** | fine-loamy, mixed, superactive, mesic Typic Argiudolls. |
| **Frankville** | fine-silty, mixed, superactive, mesic Mollic Hapludalfs |
| **Hitt** | fine-loamy, mixed, superactive, mesic Typic Argiudolls. |
| **Jasper** | fine-loamy, mixed, superactive, mesic Typic Argiudolls. |
| **Plano** | fine-silty, mixed, superactive, mesic Typic Argiudolls. |
| **Proctor** | fine-silty, mixed, superactive, mesic Typic Argiudolls |
| **Sawmill** | fine-silty, mixed, superactive, mesic Cumulic Endoaquolls. |

Figure 2 shows the 1976 soil map of the survey area. This map was prepared at a scale of 1:20,000. Soil lines and delineations from the soil map have been overlain on a recent aerial photograph at a scale of 1:7,920.

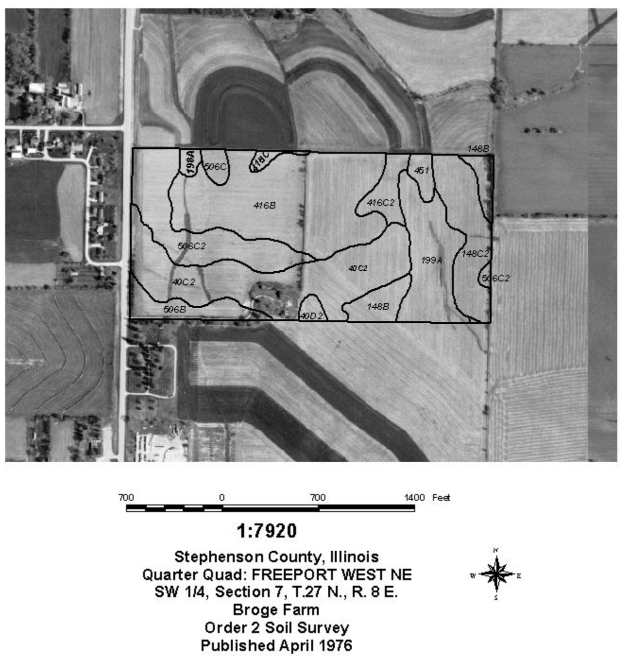


*Figure 2. The Freeport Study Site with the soil delineations that are shown in the soil survey report.*

The Illinois NRCS soil staff recently completed an order-one soil survey of this 80-acre site (see Figure 3). Figure 3 shows the results of the order-one soil survey. This high intensity soil survey identified nine soil map units (Table 3). The taxonomic classification of these soils is listed in Table 2.

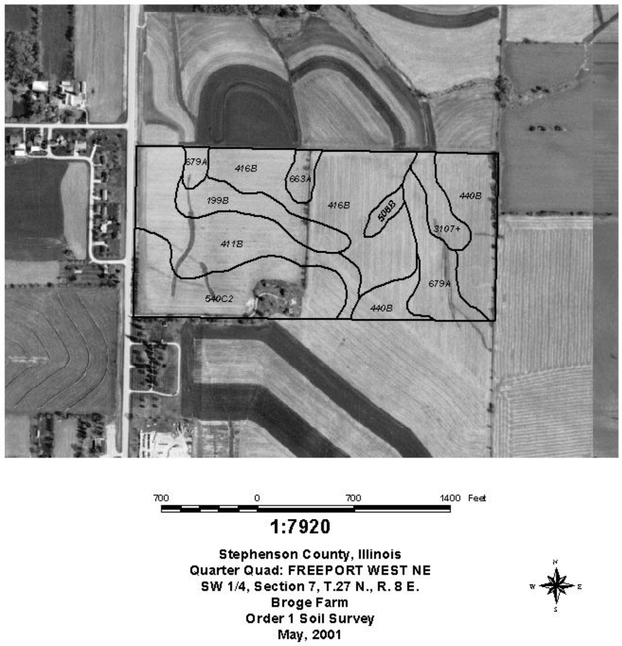


*Figure 3. The high-intensity, order-one soil map of the Freeport site.*

**Table 3. 2002 Soil Legend for Freeport Site**

| Map Unit | Name |
|---|---|
| **119B** | Plano silt loam, 0 to 5 percent slopes |
| **411B** | Ashdale silt loam, 2 to 5 percent slopes |
| **416B** | Durand silt loam, 2 to 5 percent slopes |
| **440B** | Jasper silt loam, 2 to 5 percent slopes |
| **506** | Hitt silt loam, 2 to 5 percent slopes |
| **540C2** | Frankville silt loam, 5 to 10 percent slopes |
| **663A** | Clare silt loam, 0 to 2 percent slopes |
| **679A** | Blackberry silt loam, 0 to 2 percent slopes |
| **3107+** | Sawmill silt loam, frequently flooded, overwash |

It is human nature to assume that an order-one is a better survey than an order-two soil survey. This assumption is simply based on the greater number and density of observations and the number and size of the polygons. Frequently, when an order-two soil survey is remapped as an order-one, a greater amount of information is gathered. As a consequence, the number of named soils will typically double and the number of polygons quadruples (Robert McLeese, personal communication). This trend was not realized at the Freeport site. The order-two survey of the site contained 6 different soil map units and 15 soil polygons. The more recently completed, order-one survey of the site contained 9 different soil map units, but only 11 soil polygons.

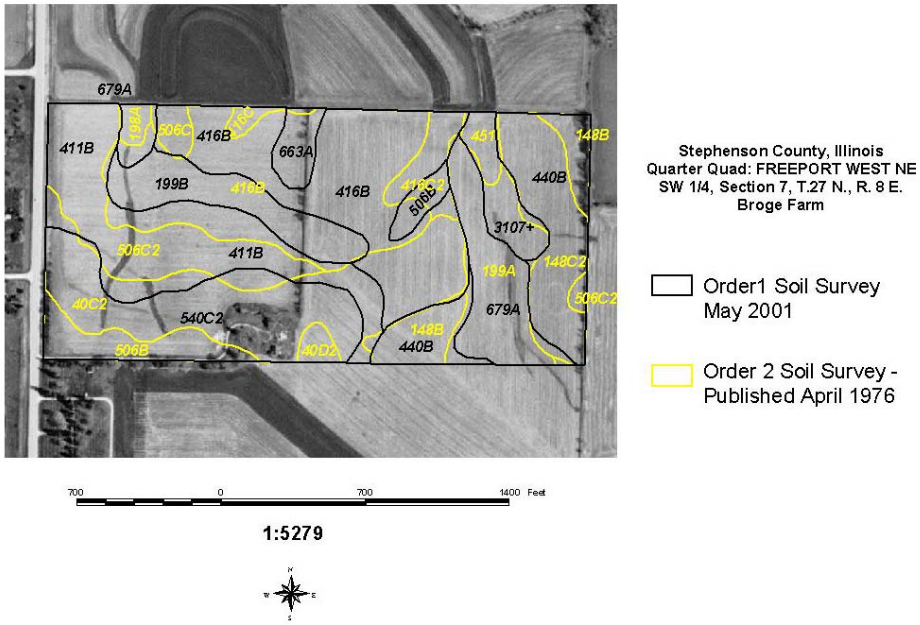


*Figure 4. Comparison of soil delineations and boundaries mapped in order-one and -two soil surveys of Freeport site.*

Comparing soil maps prepared at differing intensities of field observations is difficult. Field procedures for an order-one soil surveys are more rigorous and maps are prepared at smaller scales than for an order-two soil survey. Overlaying the maps at the same scale provides qualitative comparisons but does not allow for quantitative comparisons. Kitchen and others (1998) noted the difficulty in obtaining repeatable soil patterns when fields are resurveyed using traditional soil survey methods. Because of their subjectivity, soil boundaries drawn by soil scientists often lack repeatability (Fraisse et al., 2001). This was true for the Freeport site.

Figure 4 compares the map units delineated by the order-one and –two soil surveys of the Freeport site. Within this and the other study sites in Iowa and Wisconsin, topography played a major role in defining the number and size of polygons and the placement of soil boundaries. Differences are evident in Figure 4. These maps differ in the number and names of map units and the placement of boundary line. Some of these differences can be attributed to changes in series and mapping concepts. Others are related to the differences in survey intensities and the judgments of the soil scientists.

<u>Platteville, Wisconsin:</u>
The site is located on the Pioneer Farm near Platteville, Wisconsin, in the northwest quarter of Section 20, T. 3 N., and R. 1 E. At the time of the survey, the site was in corn stubble and alfalfa. This site was mapped as different phases of Tama soil (Watson, 1966). The site is underlain by dolomite of the Galena formation. The published soil survey identified four soil map units (Table 4) on this site. The very deep, well and moderately well drained Tama soil formed in loess on upland. Tama is a member of the fine-silty, mixed, superactive, mesic Typic Argiudolls family. At the time of the order-two soil survey, soils were only examined to a depth of about 40 inches. Then, Tama soil was recognized as forming in 42 inches of loess and could be underlain by limestone bedrock or sandy outwash at depths as shallow as 4 feet. The very deep, well drained Worthen soils formed silty alluvium on alluvial fans and stream terraces. Worthen is a member of the fine-silty, mixed, superactive, mesic Cumulic Hapludolls family.

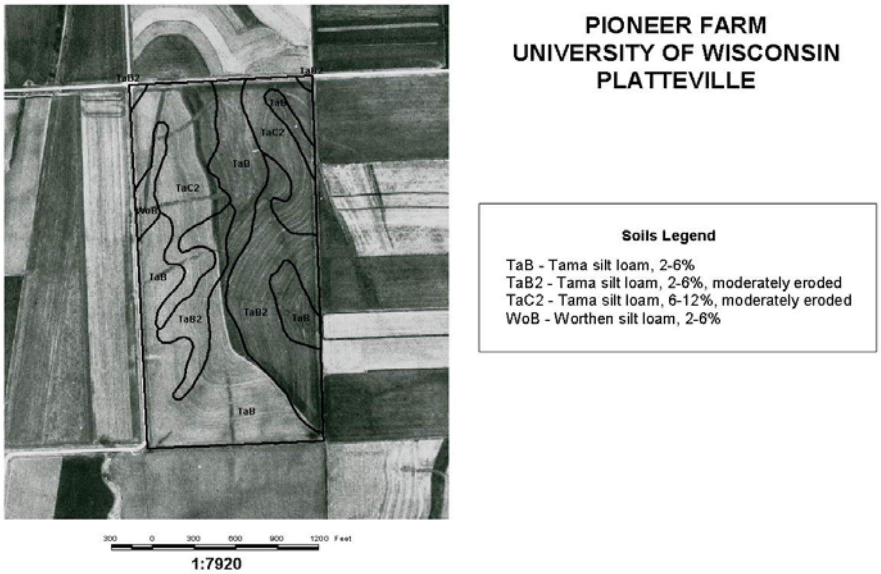


*Figure 5. The Platteville Study Site with the soil delineations that are shown in the soil survey report.*

Figure 5 shows the 1966 soil map of the survey area. This map was prepared at a scale of 1:15,840. In this figure, soil lines and delineations from the soil map have been overlain on a recent aerial photograph at a scale of 1:7,920.

**Table 4 Soil Legend for Platteville Site**

| Map Unit | Name |
|---|---|
| **TAB** | Tama silt loam, 2 to 6 percent slopes |
| **TAB2** | Tama silt loam, 2 to 6 percent slopes, moderately eroded |
| **TAC2** | Tama silt loam, 6 to 12 percent slopes, moderately eroded |
| **WoB** | Worthen silt loam, 2 to 6 percent slopes |

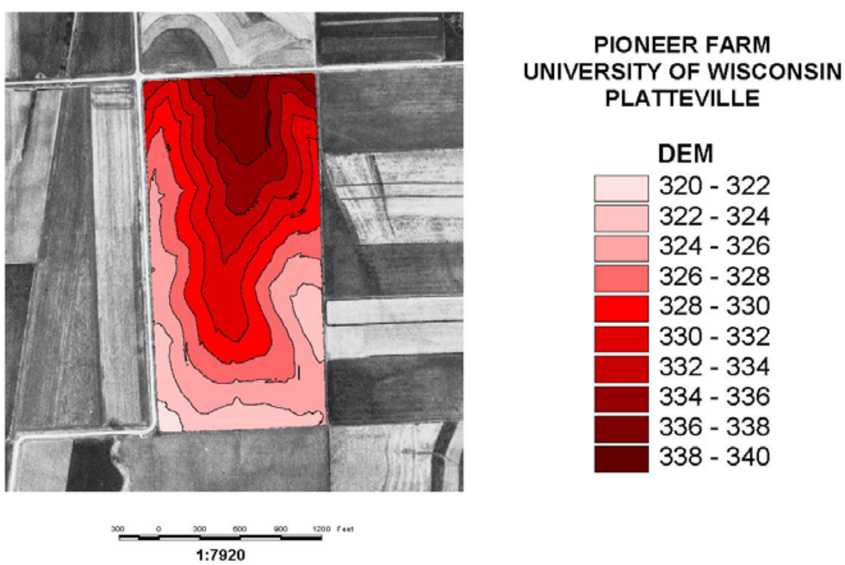


*Figure 6. Contour map of the Platteville site based on DEM data.*

Figure 6 is a contour map of the Platteville site based on DEM data. The contour interval is two meters. The nose slope of an interfluve descends southward across the central portion of the site. Side slopes are fairly uniform with the exception of several indentation filled with presumably alluvial materials. If all other contributing soil properties remain constant, ECa would be expected to increase towards the less sloping, lower-lying, and presumably moister southern, southwestern and southeastern portions of the site. The higher-lying, more sloping potions of the site are better drained and therefore were anticipated to have lower ECa.

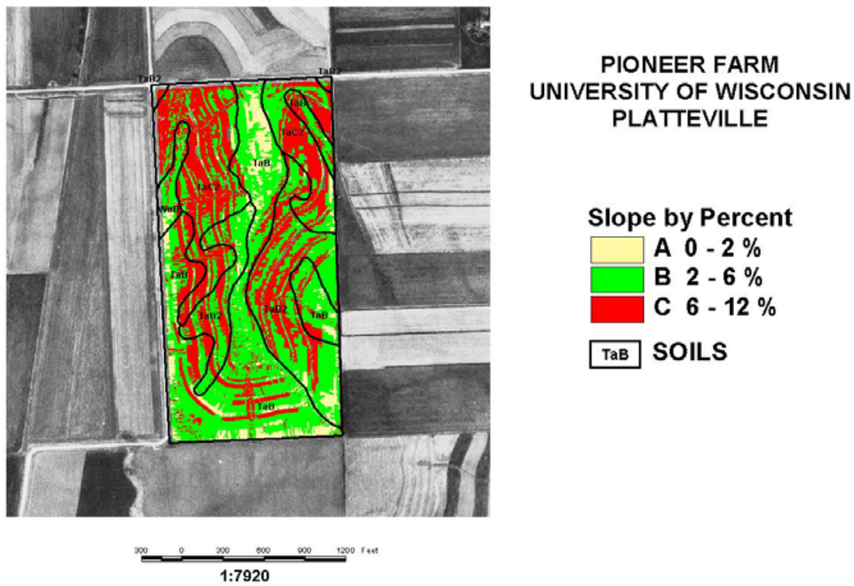


*Figure 7. Slope map draped over an order-two soil map of the Platteville site.*

In Figure 7, a rudimentary slope map has been draped over the soil map of the Platteville site. The slope map is based on elevation measurements made with EarthIt's *Field Measurement Device.* Areas of more strongly sloping soils are located on the east and west sides of the nose slope. These areas generally correspond with the more sloping and eroded areas on the soil map (map units TAB2 and TAC2). The western and southern portions of the site were recently plowed and the surface was very rough and uneven. This may have caused the Field *Measurement Device* to be jostled and more inclined in some areas resulting in the seemingly anomalous ribbon-like patterns of slope measurements. These seemingly anomalous measurements are considered artifacts and are based on the scale and spacing of measurements. Artifacts should be removed from the data set.

<u>Waverly, Iowa:</u>
The site is located southwest of Waverly, Iowa, in the northeast quarter of Section 30, T. 91 N., and R. 14 W. At the time of the survey, the site was in soybean stubble. This was the driest and most topographically diverse of the three sites. The soil survey identified ten soil map units within the site (Buckner, 1967). Table 5 lists the names of the soil map units mapped within the site. Major soils identified within this upland site are Aredale, Atkinson, Cresco, Dinsdale, Floyd, Kenyon, Ostrander, Sogn, and Terril. The taxonomic classification of these soils is listed in Table 6.

Figure 8 shows the 1967 soil map of the survey area. This map was prepared at a scale of 15,840. In this figure, soil lines and delineations from the soil map have been overlain on a recent aerial photograph at a scale of 1:7,920.

Figure 9 is a contour map of the Waverly site based on DEM data. The contour interval is two meters. Two areas within the site were not surveyed and are colored black in Figure 9. These areas include a cemetery that is located in the southeast corner and an area with multiple, open drainage ditches that were impassable to the ATV in the north-central portion of the site. Slopes are highly complex with a large number of slope elements and shapes. Lower-lying and presumably more imperfectly drained areas are located in the east and north-central portions of the site.  Once again, higher-lying, more sloping portions of the site were presumed to be better drained and have lower moisture contents and $EC_a$.

**Table 5 Soil Legend for the Waverly Site**

| Map Unit | Name |
|---|---|
| **ArC** | Aredale loam, 5 to 9 percent slopes |
| **AtC** | Atkinson loam, 5 to 9 percent slopes |
| **CrC** | Cresco loam, 5 to 9 percent slopes |
| **DsB** | Dinsdale silty clay loam, 2 to 5 percent slopes |
| **DsC** | Dinsdale silty clay loam, 5 to 9 percent slopes |
| **FoB** | Floyd loam, 1 to 4 percent slopes |
| **KeC** | Kenyon loam, 5 to 9 percent slopes |
| **OsC** | Ostrander loam, 5 to 9 percent slopes |
| **SoD** | Sogn soils, 5 to 14 percent slopes |
| **TxB** | Terril loam, 2 to 5 percent slopes |

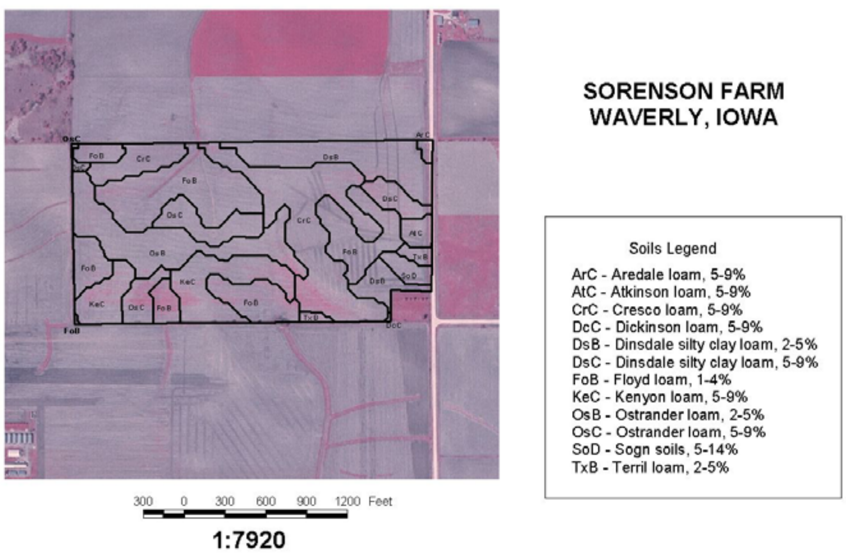


*Figure 8.  The Platteville Study Site with the soil delineations that are shown in the soil survey report.*

**Table 6 Soil Taxonomic Legend for the Waverly Site**

| Series | Taxonomic family |
|---|---|
| **Aredale** | fine-loamy, mixed, superactive, mesic Typic Hapludolls |
| **Atkinson** | fine-loamy, mixed, superactive, mesic Typic Argiudolls |
| **Cresco** | fine-loamy, mixed, superactive, mesic Typic Argiudolls |
| **Dinsdale** | fine-silty, mixed, superactive, mesic Typic Argiudolls |
| **Floyd** | fine-loamy, mixed, superactive, mesic Aquic Hapludolls |
| **Kenyon** | fine-loamy, mixed, superactive, mesic Typic Hapludolls |
| **Ostrander** | fine-loamy, mixed, superactive, mesic Typic Hapludolls |
| **Sogn** | loamy, mixed, superactive, mesic Lithic Haplustolls |
| **Terril** | fine-loamy, mixed, superactive, mesic Cumulic Hapludolls |

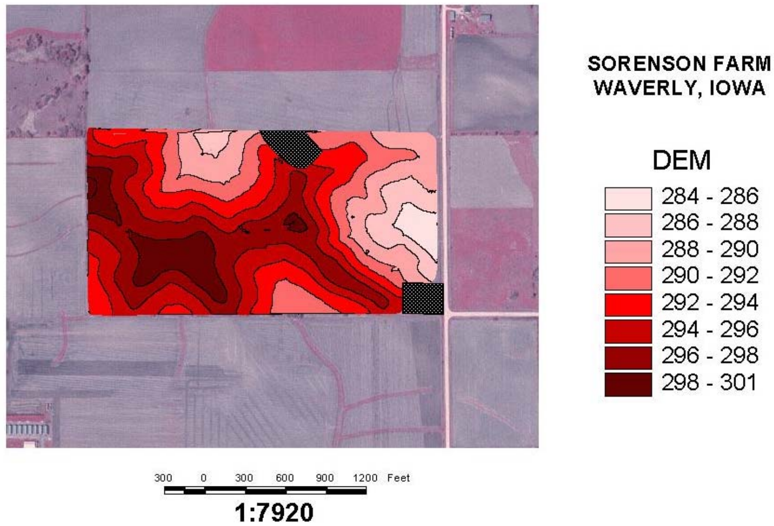


*Figure 9. Contour map of the Waverly site based on DEM data.*

Figure 10 shows a rudimentary slope map that has been draped over the soil map of the Waverly site. The slope map is based on elevation measurements made with EarthIt's *Field Measurement Device*. The displayed soil map units are expected to include inclusions of various slope phases as well as soils. In some portions of the site, slope phases on the soil survey map and the DEM data correspond fairly well. However, in other portions of the site, there is a general lack of agreement between the soil survey map units and the DEM slope phases. It is apparent in Figure 10 that the placement of some soil boundary lines and the recognition of soil map unit phases can be improved using DEM data. However, once again, some seemingly anomalous slope measurements do appear in the DEM data. These inconsistent measurements can be edited out of the data.

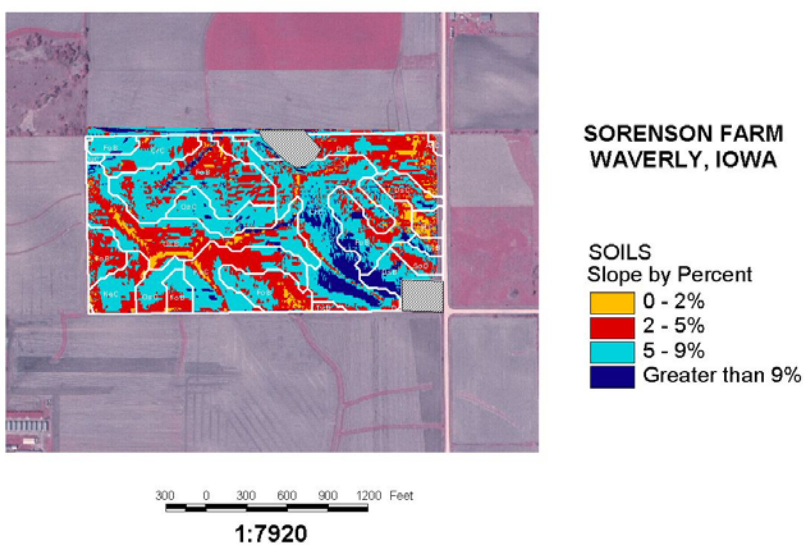


*Figure 10. Slope map draped over an order-two soil map of the Waverly site.*

**Field Procedures:**
All sites were located in cultivated fields. Because of varying speed of advance over different portions of each surveyed field, the number and density of observation points varied with each instrument. At the Freeport site, the

Earth IT Corporation's *Field Measurement Device* was driven along parallel row spaced about 10 m apart and at speeds between 12 and 17 mph. At the other sites, the *Device* followed the tracks of the Veris 3100 soil EC mapping system. However, additional traverses were added with the *Device* between the row made with the Veris system and around the perimeter of the fields. Because of chisel-plowed sections within the Platteville site, the *Field Measurement Device* needed to be operated at slower speeds (about 5 mph).

All data collected with the *Field Measurement Device* were reviewed in ArcView for consistency and culled for potentially bad or extraneous points. The data were processed through ArcView in a special script that is designed to remove the offset between GPS receiver and EM38 meter, and to correct the elevation data for the height of the GPS receiver. Point data were interpolated using Delauney triangulation, masked, and converted into a grid using ArcView. Once the data were in a grid format, a low pass filter was applied to smooth the DEM data (Woody Wallace personal communication).

The Veris 3100 soil EC mapping system was towed behind a 4WD vehicle. Measurements were continuously recorded and geo-referenced with a GPS receiver. An observation (two apparent conductivity measurements (shallow and deep) with coordinates) was recorded every second. At the time of this investigation, fields at the Freeport site and a large portion of the Platteville site were too wet for the Veris to be used.

The EM1 meter was operated in the vertical dipole orientation and in the continuous mode with measurements recorded at 1-sec intervals. The EM31 was held at hip height with its long axis parallel to the direction of traverse. Traverse lines were essentially parallel and spaced about 33 m apart.

**Results:**
**EM31 Meter:**
Freeport, IL:
Table 7 summarizes the results of the EMI surveys that were conducted with the EM31 meter (operated in the vertical dipole orientation) at the three sites. At the Freeport site, $EC_a$ ranged from about –0.5 to 34.5 mS/m. Negative values are attributed to calibration errors and/or surface or near-surface metallic artifacts. Apparent conductivity averaged about 14.9 mS/m with a standard deviation of about 5.0 mS/m. One-half the observations had $EC_a$ values between 11.1 and 18.2 mS/m.

**Table 7. Basic EMI Statistics for EM31Surveys at the three study sites.**
(Other than the number of observations, all values are in mS/m.)

| | Freeport | Platteville | Waverly |
|---|---|---|---|
| **Number** | 5690 | 5835 | 6133 |
| **Minimum** | -0.5 | 8.2 | 12.9 |
| **Maximum** | 34.5 | 40.3 | 61.9 |
| **25%-tile** | 11.1 | 16.6 | 36.4 |
| **75%-tile** | 18.2 | 22.5 | 46.2 |
| **Mean** | 14.9 | 19.8 | 40.3 |
| **Standard Deviation** | 5.0 | 4.8 | 9.4 |

With the EM31 meter, based on landscape position, $EC_a$ was generally higher on lower-lying, more imperfectly drained positions and lower on higher-lying, better-drained positions. This inverse relationship with elevation principally reflects variations in soil moisture contents with landscape position. However, based on field observations, within higher-lying areas, the thickness of the soil column, clay content, and depth to bedrock all appear to be inter-related factors that control $EC_a$. The depth to bedrock was observed to range from about 36 to 117 cm at ten observation points that were drilled on these higher-lying upland areas. The correlation coefficient (r) between $EC_a$ and bedrock depth was 0.666 and 0.854 for measurements made with the EM31 meter in the vertical and horizontal dipole orientations, respectively. Figure 11 shows the relationship between $EC_a$ (measured with the EM31 meter held at hip-height and operated in the horizontal dipole orientation) and depth to bedrock. On upland areas, $EC_a$ varies directly with bedrock depth and is generally higher in areas that are deeper to bedrock and have thicker columns of clay enriched soil materials overlying the relatively resistive dolomite bedrock.

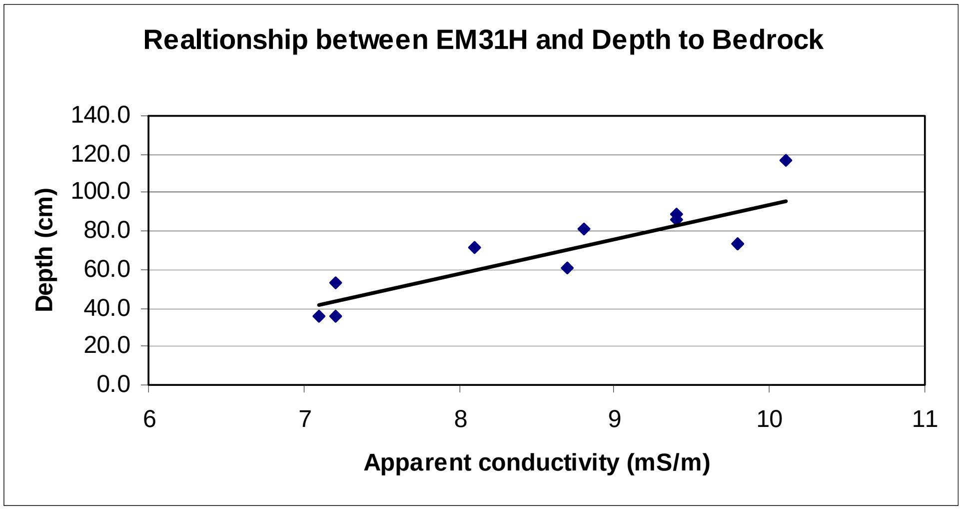


*Figure 11. Relationship between* $EC_a$ *measured with the EM31 meter in the horizontal dipole orientation and depth to bedrock on upland areas of the Freeport site.*

Figure 12 is a plot of $EC_a$ measured with the EM31 meter in the vertical dipole orientation at the Freeport site. The isoline interval in Figure 12 is 5 mS/m. The locations of traverse lines and observations are shown in Figure 12. Also shown in this figure is the location of a GPR traverse line (see Figure 22).

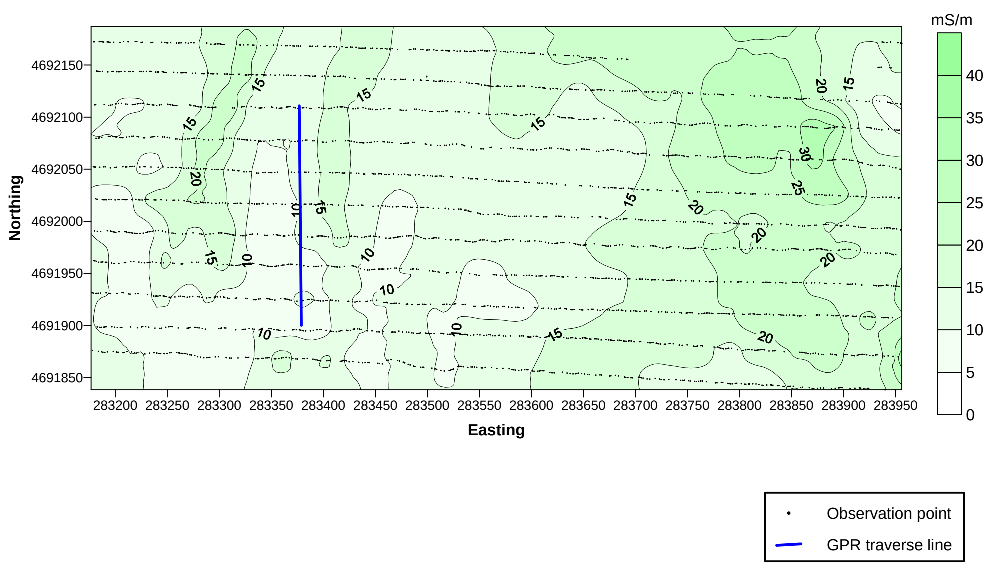


*Figure 12. Map of Apparent conductivity obtained with the EM31 meter at the Freeport site.*

The size of the site shown in Figure 12 is reduced, as $EC_a$ data from the last two traverses in the northern portion of the site were lost. Spatial patterns, while intricate, are continuous and explainable as they correspond with recognizable landscape and soil components. The three major linear zones of higher $EC_a$, which have south to north orientations, correspond with lower-lying, more imperfectly drained intermittent drainage areas. A higher-lying area that is shallower to bedrock dominates the southwest portion of the site. This area is bisected by several south to north trending zones of higher $EC_a$ that are presumed to represent deeper to bedrock and possibly, more imperfectly drained areas. In the western part of the site, $EC_a$ patterns suggest basically south to north trending, relatively narrow and linear polygons. This is inconsistent with the comparatively broad, more east to west trending soil patterns that are evident in figures 2 and 3. Soil and $EC_a$ patterns are more similar in the eastern portion of the site that is occupied by the larger and more obvious intermittent drainage area.

In general, $EC_a$ measurements were not random, but varied systematically with landscape position and drainage. High values were measured in lower-lying, more imperfectly drained drainageways. Lower $EC_a$ values were measured on higher-lying convex summits and back slopes that are presumably better drained and shallower to bedrock.

<u>Platteville, WI:</u>
Table 7 summarizes the results of the EMI survey that was conducted with the EM31 meter at the Platteville site. Apparent conductivity ranged from about 8.2 to 40.3 mS/m. Apparent conductivity averaged about 19.8 mS/m with a standard deviation of about 4.8 mS/m. One-half the observations had $EC_a$ values between 16.6 and 22.5 mS/m. Compared with the Freeport site, $EC_a$ was slightly higher, but equally variable at the Platteville site.

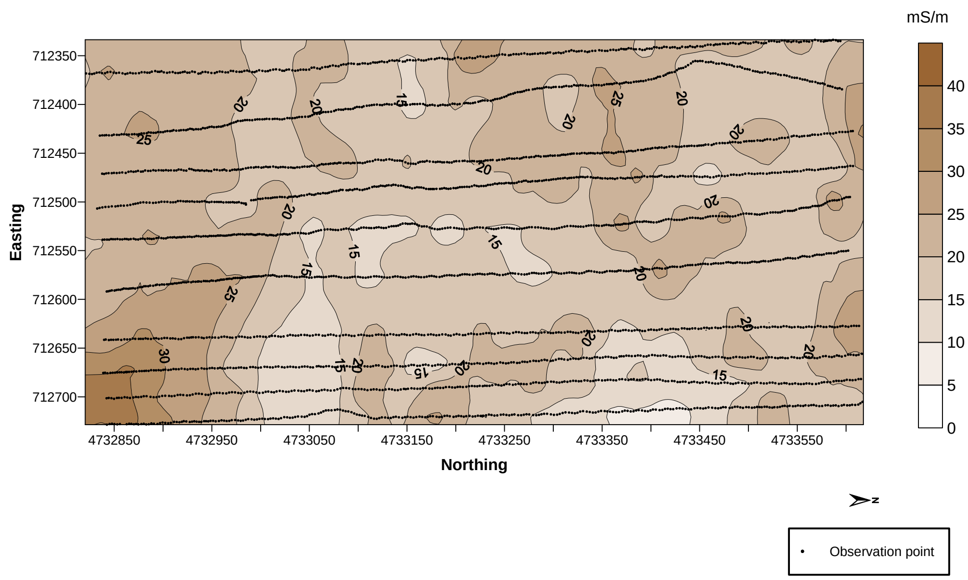


*Figure 13. Map of Apparent conductivity obtained with the EM31 meter at the Platteville site.*

Figure 13 is a plot of $EC_a$ measured with the EM31 meter in the vertical dipole orientation at the Platteville site. In Figure 13, the isoline interval is 5 mS/m. The locations of traverse lines and observations are shown in Figure 13. In the absences of ground-truth data, $EC_a$ patterns are more difficult to explain at the Platteville than the Freeport site. In general, these patterns do not conform to the topography of the site (see Figure 6). In the eastern part of the Platteville site, areas of lower $EC_a$ were visually correlated with lower-lying, slightly elongated, plane to slightly concave foot slopes and toe slopes areas. These areas are in elongated swales and are suspected of having layers of coarser-textured, over-washed deposits. Across much of the remainder of the site, $EC_a$ was higher, but relatively invariable. One-half the measurements had $EC_a$ between 16 and 22 mS/m. Areas of higher (>25 mS/m) $EC_a$ were widely scattered across the site and occurred on several landscape components. Areas of higher $EC_a$ could represent areas of Tama soils that are finer textured, moister, and/or more erode (and therefore shallower to a finer-textured Bt horizon). However, supplementary data and extensive ground-truth observations are needed to satisfactorily explain these spatial patterns.

As seen in Figure 13, the spacing between traverse lines is fairly wide and is non-uniform. However, it is not felt that additional traverse lines or more uniform spacing would significantly improve the spatial patterns shown in Figure 13.

Waverly, IA:
Table 7 also summarizes the results of the EMI survey with the EM31 meter at the Waverly site. Apparent conductivity ranged from 12.9 to 61.9 mS/m. Apparent conductivity averaged about 40.3 mS/m with a standard deviation of about 9.4 mS/m. One-half the observations had $EC_a$ values between 36.4 and 46.2 mS/m. Apparent conductivity was conspicuously higher and more variable at this site than at the other two sites.

Figure 14 is a plot of $EC_a$ measured with the EM31 meter in the vertical dipole orientation at the Platteville site. In Figure 14, the isoline interval is 5 mS/m. The locations of traverse lines and observations are shown in Figure 14. Broad spatial patterns of $EC_a$ within the Waverly site appear to conform to major topographic and some soil patterns (see figures 8 and 9). In general, areas of higher $EC_a$ correspond with higher-lying and more sloping areas of Cresco, Floyd, Kenyon, and Ostrander soils. Areas of lower $EC_a$ correspond with lower-lying or less sloping areas of Dinsdale, Atkinson, Sogn, and Terril soils.

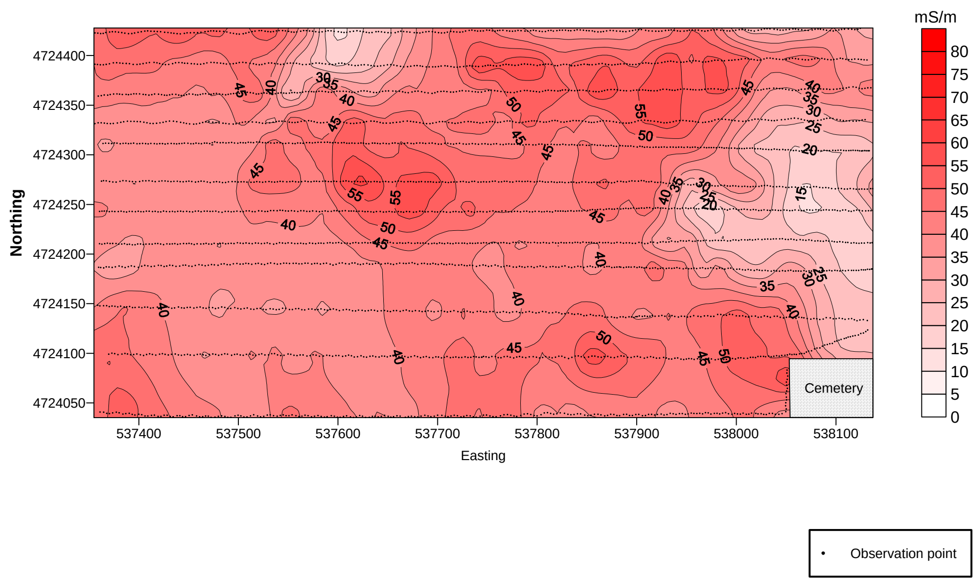


*Figure 14. Map of Apparent conductivity obtained with the EM31 meter at the Waverly site.*

In non-saline soils, $EC_a$ is frequently observed to increase in lower slope positions. This "terrain effect" is largely caused by increases in soil moisture contents in lower-lying slope positions. However, in the Midwest, $EC_a$ has been frequently observed to increase with increased elevation and slope. This relationship is attributed to changes in stratigraphy and the effects of soil erosion (shallower depths to finer-textured Bt horizons or changes in glacial drift). Within the Waverly site, $EC_a$ greater than 35 mS/m can be associated with higher-lying, more sloping areas of Cresco, Floyd, Kenyon, and Ostrander soils. These soils form in loamy sediments overlying firm till. For these soils, variations in depth to firm till, clay and/or soil moisture contents appear to be principal factors responsible for differences in $EC_a$. However, within these broadly defined polygons, individual areas of Cresco, Floyd, Kenyon, and Ostrander soils can not be identify by EMI data alone.

Areas of lower (< 25 mS/m) $EC_a$ correspond with lower-lying areas in the eastern and north central part of the site. At the Platteville site, areas of lower $EC_a$ also occurred in lower-lying areas and were associated with coarser-textured, overwash materials. Within the Waverly site, areas of lower $EC_a$ corresponded with areas that had been principally mapped as Dinsdale soil with smaller included areas of Atkinson, Sogn, and Terril soils. The presence of coarser-textured overwash deposits and variations in depths to finer-textured materials or firm till appear reasonable to explain the lower $EC_a$ in areas of Dinsdale and Terril soils. Lower $EC_a$ in areas of Atkinson and Sogn soils can be explained by the shallower depth to more electrically resistive bedrock and lower clay contents in the lower part of the soil profile.

Without some knowledge of soils and landscapes, $EC_a$ becomes a meaningless measure and maps showing the spatial distribution of $EC_a$ are a poor substitute for soil maps. With knowledge of the interplay of landscape position and variations in soil properties and soils, broad patterns of $EC_a$ can be explained with minimum sampling. With more intensive sampling, specific relationships within single polygons may be determined. In the absence of acceptable sampling, $EC_a$ alone appears to be a poor indicator of soil properties and soils.

**EM38 Meter:**

The mobile EM38 survey recorded a greater number and density of observations and therefore produced a more thorough survey at each site.

Freeport, IL:

Table 8 summarizes the results of the EMI surveys that were conducted at the three sites with an EM38 meter operated in the vertical dipole orientation. At each site, compared with the pedestrian survey that was conducted with the EM31meter, a greater number of observations were obtained with the more mobile, mechanized EMI mapping system. In open fields, mobile surveys results in larger data sets, greater acquisition efficiency, and less operator fatigue. At the Freeport and Platteville sites, the averaged $EC_a$ measured with the shallower-sensing (0 to 1.5 m) EM38 meter was higher than the averaged $EC_a$ measured with the deeper-sensing (0 to 5 m) EM31 meter. As the EM31 meter is more sensitive than the EM38 meter to factor influencing $EC_a$ at deeper soil depths, the relationships observed at the Freeport and Platteville sites can be explained by the presence of more electrically resistive materials in the lower part of the soil profiles. At the Waverly site, the averaged $EC_a$ measured with the EM38 meter was lower and less variable than the averaged $EC_a$ measured with the EM31 meter. This relationship was attributed to the higher bulk density and clay content of the underlying firm till. As these explanations are unconfirmed, they should be viewed as assumptions.

At the Freeport site, $EC_a$ measured with the EM38 meter ranged from 2.8 to 47.8 mS/m. Apparent conductivity averaged about 22.9 mS/m with a standard deviation of about 4.2 mS/m. One-half the observations had $EC_a$ values between about 20.6 and 25.4 mS/m.

Figure 15 is the plot of $EC_a$ collected with the EM38 meter that was towed behind the EarthIt's *Field Measurement Device*. The location of every other observation point is shown in this figure. In Figure 15, the interval used for the EM38 data is the same that was used for the EM31 data shown in Figure 12. In general, patterns of $EC_a$ produced with the EM38 meter measurements are more intricate and complex than those obtained with the EM31 meter. The greater number of observations measured with the EM38 meter resulted in a greater number of smaller polygons. However, the number of polygons or the complexity of spatial patterns did not necessarily produce more meaningful information or insight into how $EC_a$ varied with soil, landscape position, and/or drainage.

**Table 8. Basic EMI Statistics for EM38Surveys at the three study sites.**
(Other than the number of observations, all values are in mS/m.)

| | Freeport | Platteville | Waverly |
|---|---|---|---|
| Number | 11147 | 15155 | 10834 |
| Minimum | 2.8 | 4.0 | 9.5 |
| Maximum | 47.8 | 80.9 | 60.6 |
| 25%-tile | 20.6 | 22.1 | 28.6 |
| 75%-tile | 25.4 | 28.2 | 38.9 |
| Mean | 22.9 | 25.0 | 33.7 |
| Standard Deviation | 4.2 | 4.9 | 7.9 |

Two of the three linear, north-south trending zones of higher $EC_a$ detected with the EM31 meter were also detected with the EM38 meter. These zones of higher $EC_a$ were visually correlated with lower-lying, slightly more imperfectly drained swales. The lower $EC_a$ in these lower-lying swales were associated with moister soil conditions.

Spatial patterns for $EC_a$ data collected with the EM31 and EM38 meters are more similar in the eastern portion of the site. This portion of the site contains the large, lower-lying, and more noticeable intermittent drainageway. The EM38 meter identified the higher-lying, shallower to bedrock area in the southwest portion of the site. Here, $EC_a$ was low. However, the larger data set measured with the shallower-sensing EM38 meter portrayed this area of low $EC_a$ as less extensive and more segmented than did the sparser data set collected with the deeper-sensing EM31 meter.

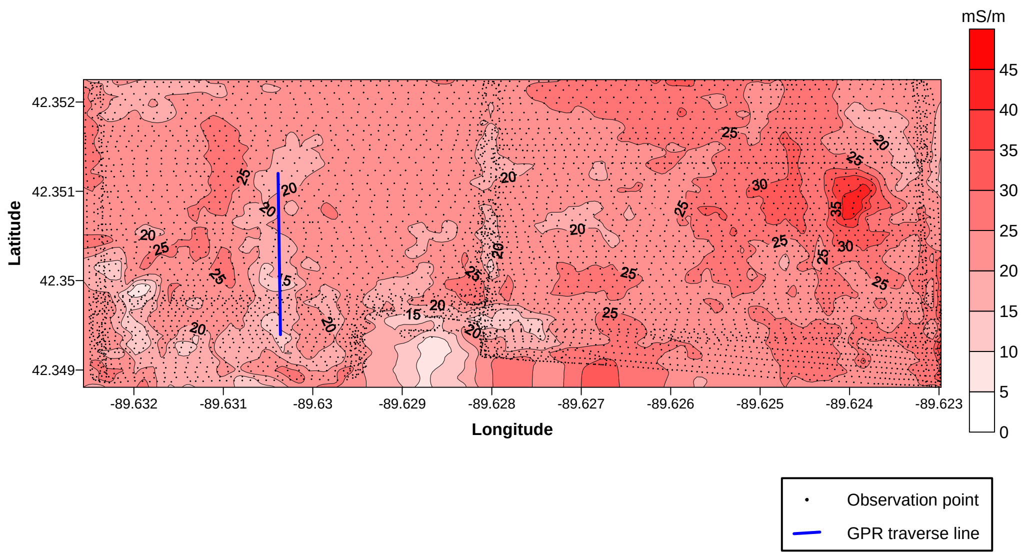


*Figure. 15. Map of Apparent conductivity obtained with the EM38 meter at the Freeport site.*

The Freeport site was not uniformly sampled by the EarthIt's *Field Measurement Device.* The device must reduce speeds in turns at the end of the fields. However, during these turns, the sampling rate remains constant. As a consequence a greater number of observations are recorded in turn areas. This device appears to have been turned and driven up and down a north-south trending, field boundary road in the central part of the site. This has resulted in a denser sampling of the road. Because of soil compaction, $EC_a$ was noticeably lower along this road.

Apparent conductivity data from the Freeport site were imported into ArcView GIS and processed into grids using ArcView's Spatial Analyst extension. Figure 16 provides a comparison of the data collected with both the EM38 and EM31meters at the Freeport site. The dark lines in Figure 16 represent slope phase boundary line. These lines are based on the DEM data collected at this site. Map symbols are A (0 to 2 % slopes), B (2 to 5 % slopes), and C (5 to 10 % slopes). Soil properties and the use and management of soils are closely related to slope gradient (Soil Survey Division Staff, 1993). In the plots shown in Figure 16, $EC_a$ patterns are not confined to, but cross the boundaries of slope polygons. In general, higher values of $EC_a$ can be associated with polygons having lower slope gradients; and lower values of $EC_a$ can be associated with polygons having higher slope gradients. In the plots shown in Figure 16, the draped $EC_a$ patterns provide a means to further partition each slope polygon into a greater number of smaller supposedly more homogeneous polygons.

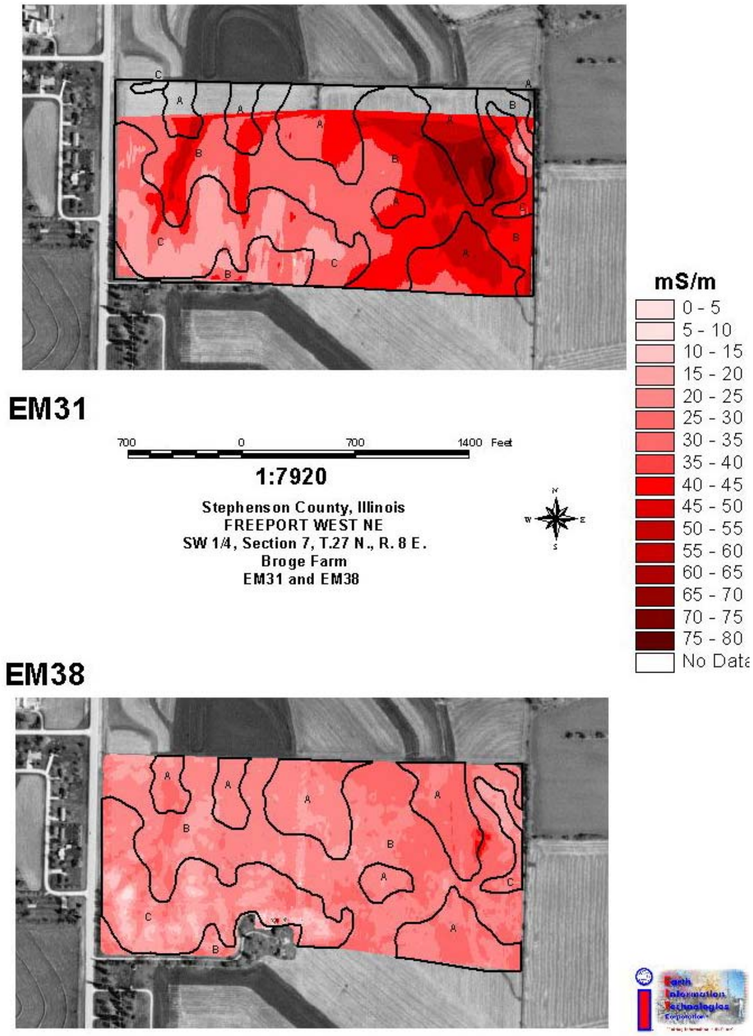


*Figure. 16. Comparison of the apparent conductivity data measured with the EM31 and EM38 meters at the Freeport site.*

<u>Platteville, WI:</u>
Table 8 summarizes the results of the EMI survey completed with the EM38 meter at the Platteville site. Apparent conductivity measured with the EM38 meter ranged from 4.0 to 80.9 mS/m. Apparent conductivity averaged about 25.0 mS/m with a standard deviation of about 4.9 mS/m. One-half the observations had $EC_a$ values $EC_a$ between 22.1 and 28.2 mS/m.

Figure 17 is a plot of $EC_a$ collected with an EM38 meter towed behind the EarthIt's *Field Measurement Device* at the Platteville site. The location of every other observation point is shown in this figure. A 5 mS/m isoline interval has been used for the EM38 data; the same interval that was used in the plot of EM31 data shown in Figure 13. If a line were extended from the northwest to southeast corner of the site, it would closely approximate the boundary separating the portions of the field that were in soybean stubble and chisel plowed. The chisel-plowed portion of the field is to the south and west of this line. The effects of the very rough and uneven, chisel plowed surface on the $EC_a$ measurements obtained with the mechanized EarthIt's *Field Measurement Device* are evident in this figure. In the chiseled plowed section of this site, linear patterns of apparent conductivity with often-noticeable differences from one line to the next are evident. These distinct linear patterns follow the course of the device (which followed the course of the chisel plow) and are artifacts. The plot of EM38 data from the Platteville site also appears to contain higher levels of random noise and clutter. This could be a result of the rough surface and excessive instrument vibrations. Along the eastern portion of the southern boundary, interference from overhead power transmission lines is responsible for the anomalously high $EC_a$.

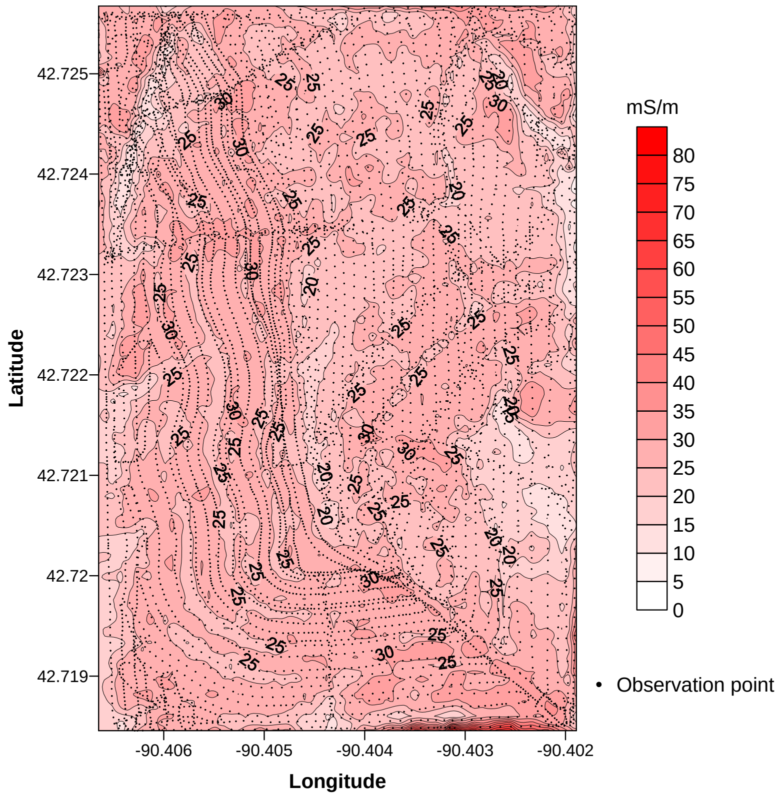


*Figure. 17. Map of Apparent conductivity obtained with the EM38 meter at the Platteville site.*

Polygons of $EC_a$ measured with the EM38 meter were generally smaller and more intricate than those measured with the EM31meter. System noise, the shallower measuring depths, and/or the greater number of observations measured with the EM38 meter may have been responsible for the greater number of smaller polygons. The greater number of polygons and the complexity of spatial patterns did not produce more meaningful interpretations of the variations of $EC_a$ with soil, landscape position, and/or drainage than those obtained with the EM31 meter. In the eastern part of the Platteville site, areas of lower $EC_a$ were associated with lower-lying, slightly elongated, plane to slightly concave areas. These areas are in swales and are suspected of being blanketed by layers of coarser textured overwash deposits. These deposits have lower $EC_a$ than the higher-lying deposits. Areas of higher $EC_a$ were widely scattered across the site and occurred on or crossed several landscape components. Though more difficult to explain, areas of higher $EC_a$ could represent soils that are finer textured, moister, and/or more eroded and shallower to finer-textured materials (Bt horizon). Extensive ground-truth observations would be needed to satisfactorily assess the causes of these spatial patterns.

EMI data from the Platteville site were imported into ArcView GIS and processed into grids using ArcView's Spatial Analyst extension. Figure 18 provides an alternative presentation of the Platteville site. In this map, color variations have been used to show the distribution of $EC_a$. The isoline interval is 5 mS/m. While color variations have been used in this map, the isoline boundary lines and observation points have not been shown. This provides a less cluttered and more appealing presentation. Measurement errors caused by difference in tillage and the vibration of the EM38 meter are evident in Figure 18. In general, with the exception of the lower-lying areas that are presumed to contain overwash deposits and the effects of background noise and clutter, $EC_a$ is essentially invariable across this site. This is not surprising, as a soil scientist had mapped the site as principally different phases of Tama soil.

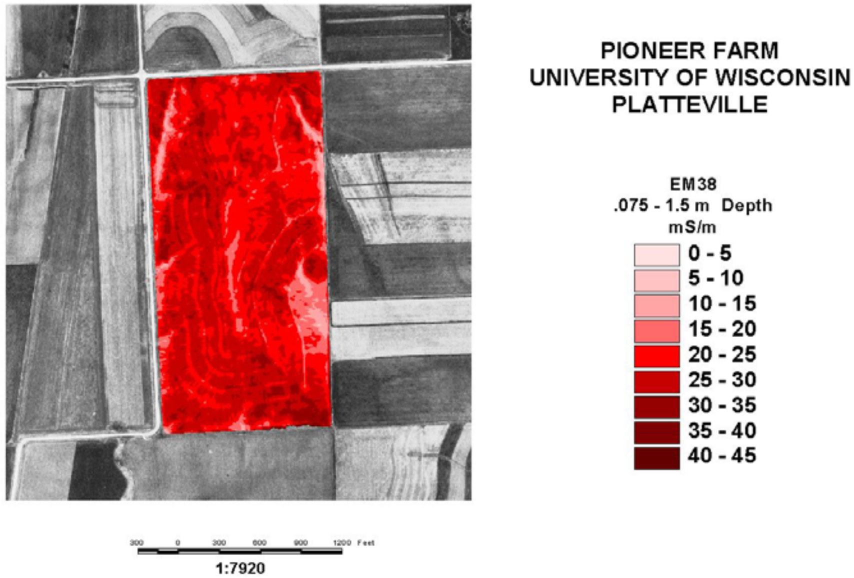


*Figure. 18. An ArcView map of apparent conductivity measured with the EM38 meter at the Platteville site.*

Waverly, IA:

Table 8 summarizes the results of the EMI survey completed with the EM38 meter at the Waverly site. Apparent conductivity measured with the EM38 meter ranged from 9.5 to 60.6 mS/m. Apparent conductivity averaged about 33.7 mS/m with a standard deviation of about 7.9 mS/m. One-half the observations had values of apparent conductivity between about 28.6 and 38.9 mS/m.

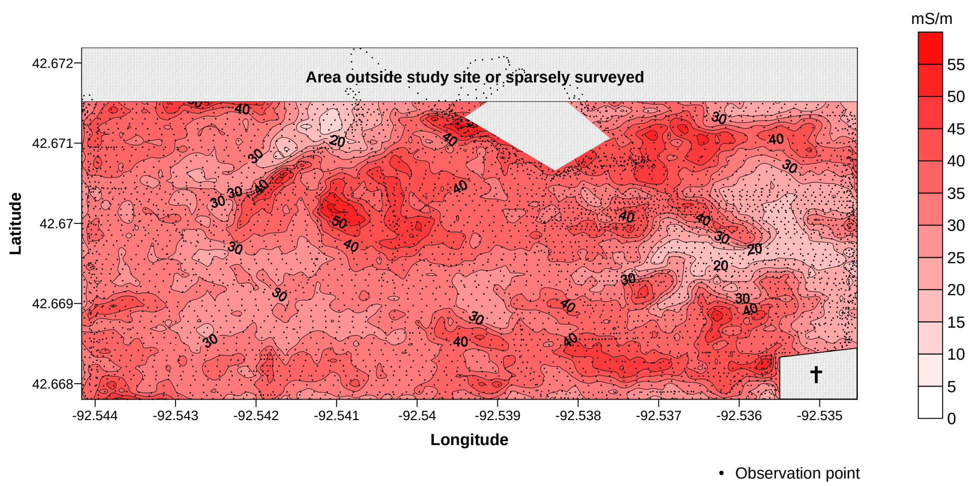


*Figure. 19. Map of Apparent conductivity obtained with the EM38 meter at the Waverly site.*

Figure 19 is a plot of $EC_a$ collected with an EM38 meter towed behind the EarthIt's *Field Measurement Device* at the Waverly site. The location of every other observation point is shown in this figure. In Figure 19, a 5 mS/m isoline interval was used for the EM38 data; the same interval that was used for the plot of EM31 data shown in Figure 14. Measurements were recorded outside the northern boundary of the site when the *Device* was maneuvered around an area of open ditches. This broad, rectangular area was sparsely sampled and therefore excluded from interpretations. Two areas within the site were not surveyed. These areas include a cemetery that is located in the southeast corner and an area in the north-central portion of the site that had multiple, open drainage ditches that were impassable to the ATV.

Spatial patterns of $EC_a$ measured with the EM31 (Figure 14) and EM38 (figure 19) meters are similar. With both meters, broad patterns of $EC_a$ within the Waverly site appear to conform to major topographic and some soil patterns. With the greater number of measurements collected with the EM38 meter, areas of higher (>35 mS/m) $EC_a$ appear to principally coincide with higher-lying and more sloping areas of Cresco soil. Areas of lower (<25 mS/m) $EC_a$ correspond with lower-lying or less sloping areas of Dinsdale, Atkinson, Sogn, and Terril soils.

The higher $EC_a$ in areas of Cresco soil is attributed to changes in stratigraphy and the effects of soil erosion (shallower depths to the finer-textured Bt horizon or firm till). Variations in depth to firm till, clay and/or soil moisture contents are presumed to be the principal factors responsible for differences in $EC_a$ within delineations of Cresco soils.

Similar to measurements obtained with the EM31meter, areas of low $EC_a$ measured with the EM38 meter correspond with lower-lying areas in the eastern and north central part of the site. Compared with the data collected with the EM31 meter (pedestrian survey; see Figure 14), the larger number of measurements obtained with the EM38 meter (mechanized) resulted in an improved definition of these areas. Though not confirmed, the lower $EC_a$ in these areas was associated with coarser-textured overwash deposits (based on Platteville model), shallower depth to more electrically resistive bedrock, and/or lower clay contents in the lower part of the soil profile (based on information supplied by soil survey). The greater number of $EC_a$ measurements obtained with the mechanized *Field Measurement Device* provided a greater sampling density, which portrayed the areas of lower apparent conductivity as elongated, linear features. These spatial patterns suggest overwash deposits, but do not eliminate the possibility of shallower depths to bedrock and/or a decrease in clay contents at greater depths in the soil profiles. Because these factors collectively vary across the site and within spatially contiguous and/or single polygons shown in Figure 19, interpretations are limited and ambiguous. Extensive, field-specific calibrations are required to better define the properties responsible for the within-field variations in $EC_a$ and delineate the distribution of these properties within the site. However, because of the use of EMI, the number of auger observations should be substantially less than the number that would be required using traditional soil survey methods.

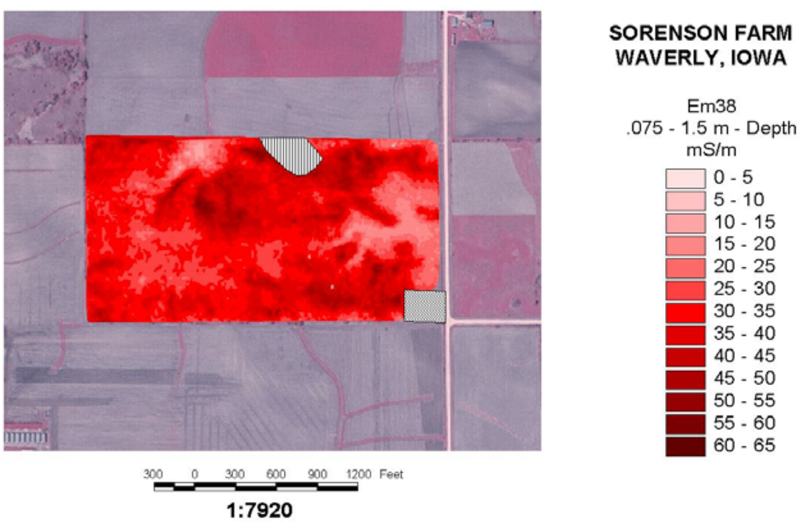


*Figure. 20. An ArcView map of apparent conductivity measured with the EM38 meter at the Waverly site.*

Apparent conductivity data from the Waverly site were imported into ArcView GIS and processed into grids using ArcView's Spatial Analyst extension. Figure 20 provides an alternative presentation of the Waverly site. In this map, color variations have been used to show the distribution of $EC_a$. In Figure 20, the isoline interval is 5 mS/m.

***Veris 3100 soil EC mapping system*:**
Soils were too wet to permit the operation of the Veris tow-array resistivity unit within the Freeport and Platteville sites. Field conditions were suitable only within the Waverly site.

At the Waverly site, with the Veris 3100 soil EC mapping system, $EC_a$ averaged about 11.3 mS/m with a range of 1.9 to 40.9 mS/m for the shallow (0 to 30 cm) measurement. For the shallow measurements, one-half the observations had $EC_a$ values between 11.1 and 13.2 mS/m. Apparent conductivity averaged 20.6 mS/m with a range of 2.7 to 57.9 mS/m for the deep (0 to 90 cm) measurements obtained with the Veris system. For the deep measurements, one-half the observations had $EC_a$ values between 20.1 and 25.1 mS/m.

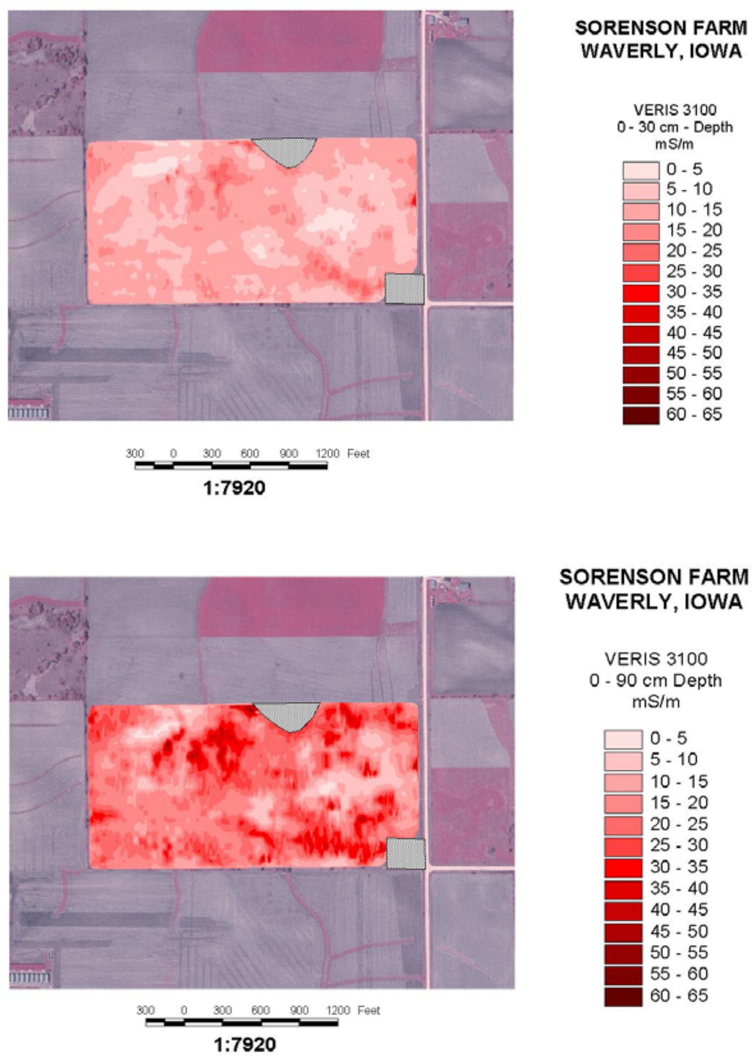


*Figure 21 ArcView maps of apparent conductivity measured with the Veris 3100 soil EC mapping system at Waverly site.*

Figure 21 contains ArcView GIS images of $EC_a$ maps (Veris 3100 soil EC mapping system; shallow (upper plot) and deep (lower plot)) that have been overlain on an orthophoto of the Waverly site. The isoline interval is 5 mS/m. In general, though absolute values varied with instrument and configuration, spatial patterns of $EC_a$ are similar to those obtained with the EM31 (Figure 14) and EM38 (Figure 19) meters.

**Ground-Penetrating Radar (GPR):**
A traverse was completed with GPR at the Freeport and Platteville sites. At the Freeport site, in an area of Frankville soil, GPR provided good imagery and traced the soil/bedrock interface to a maximum depth of about 1.6 m. At the Platteville site, in an area of Tama soil, because of high clay contents and the dominance of 2:1 expanding lattice clays with high cation exchange capacities, GPR was more depth restricted and unsuitable for most soil investigations.

Figure 22 is a representative radar profile from an area of Frankville silt loam, 5 to 10 percent slopes. The location of this traverse line is shown in figures 12 and 15. A scale (in meters) is located along the left-hand side of the radar profile. This scale represents the two-way travel time of the radar pulse. For the upper part of the soil profile, with the 200 MHz antenna, the velocity of propagation was estimated to be about 0.10 m/ns (based on tabled values). Based on this velocity of propagation, a two-way travel time of 50 ns provides a maximum penetration depth of about 2.5-m. The segmented vertical lines at the top of the radar profile represent equally spaced (about 3 m) reference marks.

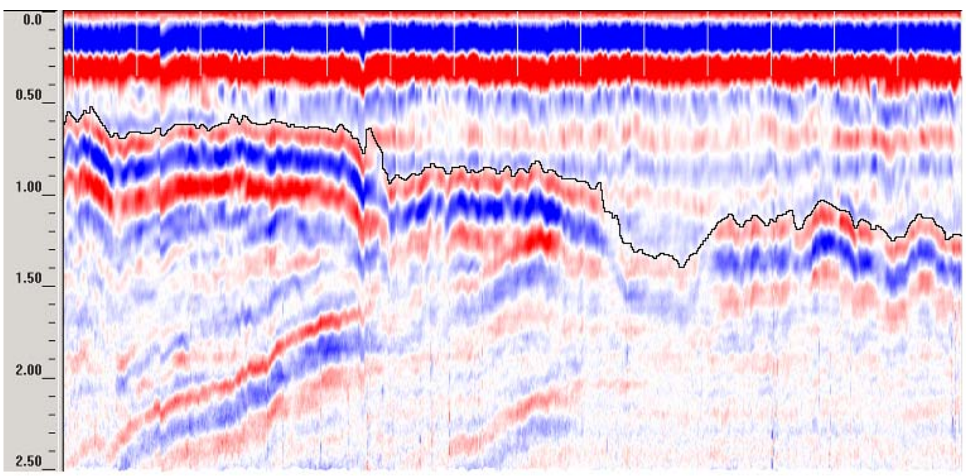


Figure 22. Representative radar profile from an area of Frankville silt loam, 5 to 10 percent slopes

The bedrock surface has been highlighted with a dark line in Figure 22. This interface varies in depth from about 0.5 to 1.4 m on this radar record. Within this area of Frankville soil, the deepest depth to which the soil/bedrock interface could be traced was about 1.65 m. In light of the soils texture and cation exchange activity class, this depth is considered exceptional. In Figure 22, the inclined lines below the soil/bedrock interface represent major strata within the bedrock.

Figure 23 is a representative radar profile from an area of Tama silt loam, 2 to 6 percent slopes, moderately eroded. A scale (in meters) is located along the left-hand side of the radar profile. This scale represents the two-way travel time of the radar pulse. For the upper part of the soil profile, with the 200 MHz antenna, the velocity of propagation was estimated to be about 0.094 m/ns (based on tabled values). Based on this velocity of propagation, a two-way travel time of 50 ns provides a maximum penetration depth of about 2.3-m. The segmented vertical lines at the top of the radar profile represent equally spaced (about 3 m) reference marks.

The radar record from this area of Tama soil is depth restricted and of poor interpretative quality. The radar record is basically nondescript. Because of the high clay content and the amount of 2:1 expanding lattice clay minerals, Tama soil is highly attenuating to GPR. Although an artifact is evident at a depth of about 80 cm in the extreme left-hand portion of Figure 23, soil information is principally restricted to the upper boundary of the argillic horizon (depths of about 30 to 40 cm). Below this interface, other than reverberated signals from higher-lying surface and near surface interfaces and low frequency background noise, no meaningful information is available. Because of severe depth restrictions and poor image quality, the use of GPR in areas of Tama soils is inappropriate for most soil investigations.

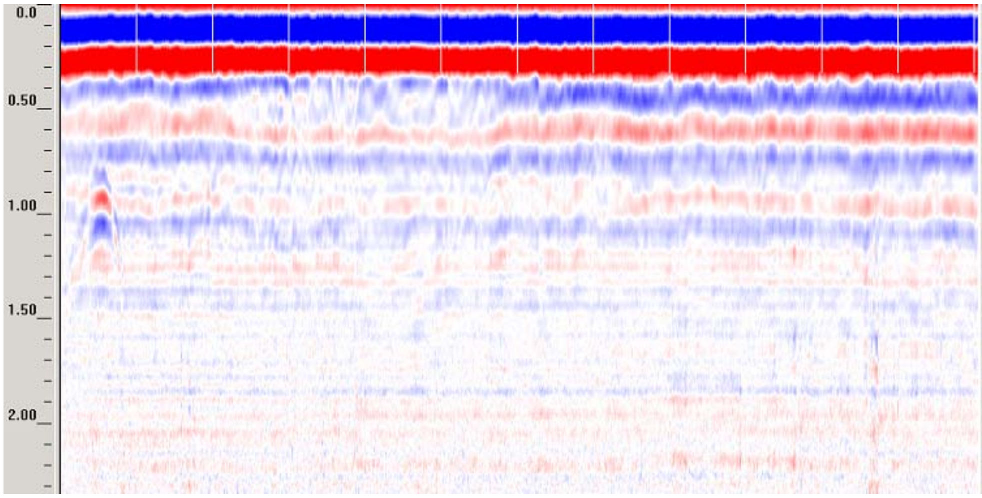


Figure 23. Representative profile from an area of Tama silt loam, percent slopes.

**References:**

Buckner, R. L. 1967. Soil Survey of Bremer County, Iowa. USDA-Soil Conservation Service in co-operation with the Iowa Agricultural Experiment Station. U.S. Government Printing Office, Washington D.C.

Daniels, D. J. 1996. Surface-Penetrating Radar. The Institute of Electrical Engineers, London, United Kingdom.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. 11-32 pp. IN: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20.

Fenton, T. E. and M. A. Lauterbach. 1999. Soil map unit composition and scale of mapping related to interpretations for precision soil and crop management in Iowa. 239-251 pp. IN: Robert, P. C., R. H. Rust, and W. E. Larson (Eds.) Proceeding of the 4$^{th}$ International Conference if Site-specific management. St Paul, MN, July 19-22, 1998. American Society of Agronomy. Madison, WI.

Fraisse, C. W., K. A. Sudduth, and N. R. Kitchen. 2001. Delineation of site-specific management zones by unsupervised classification of topographic attributes and soil electrical conductivity. Transaction of the ASAE 44(1): 155-166.

Geonics Limited. 1998. EM38 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario.

Geophysical Survey Systems, Inc, 2003. RADAN for Windows; Version 5.0 User's Manual. Manual MN43-162 Rev A. Geophysical Survey Systems, Inc., North Salem, New Hampshire.

Kitchen, N. R., T. S. Drummond, E. D. Lund, K. A. Sudduth, and G. W. Buchleiter. 2003. Soil electrical conductivity and topography related yield for three contrasting soil-crop systems. Agronomy Journal 95: 483-495.

Kitchen, N. R., K. A. Sudduth, and T. S. Drummond. 1998. An evaluation of methods for determining site-specific management zones. 133-139 pp. IN: Proc. North Central Extension-Industry Soil Fertility

Conference. Brookings, South Dakota. Potash and Phosphate Institute.

Mausbach, M. J., D. J. Lytle, and L. D. Spivey. 1993. Application of soil survey information to site specific farming. 57-68 pp. IN: Soil Specific Crop Management. Robert, P. C., R. H. Rust, and W. E. Larson (Eds.) ASA, CSSA, and SSSA. Madison, WI.

McNeill, J. D. 1980. Electrical Conductivity of soils and rocks. Technical Note TN-5. Geonics Ltd., Mississauga, Ontario.

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. 212-232 pp. *IN:* Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction, held at Henniker, New Hampshire. Aug. 11-16, 1974.

Ray, B. W., J. B. Fehrenbacher, R. Rehner, and L.L. Acken, 1976. Soil Survey of Stephenson County, Illinois. University of Illinois Agricultural Experiment Station in co-operation with USDA-Soil Conservation Service. Urbana, Illinois.

Roberts, P. 1992. Characterization of soil conditions at the field level for soil specific management. Geoderma 60: 57-72.

Soil Survey Division Staff. 1993. Soil Survey Manual. US Department of Agriculture - Soil Conservation Service, Handbook No. 18, US Government Printing Office. Washington, DC, USA.

Veris Technologies. 1998. 3100 Soil EC Mapping System Operations Manual. Publication No. AN 1CM02-02. Veris Technologies, Salina, KS.

Watson, B. G. 1966. Soil Survey of Lafayette County, Wisconsin. USDA-Soil Conservation Service in co-operation with the Wisconsin Geological and Natural History Survey, Soil Survey Division, and the Wisconsin Agricultural Experiment Station. U.S. Government Printing Office, Washington D.C.