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Purpose:

The purpose of this study was to evaluate the potential of using a global positioning system and electromagnetic induction techniques (EM) to map soil and geologic features within selected sites in Massac County. In addition, the study attempted to demonstrate the value of integrating contemporary geophysical and computer technologies with traditional soil survey techniques to characterize the spatial variability of soils and geologic materials over large areas. The successful integration of these techniques can increase the number of observations, confidence levels, spatial accuracy, and cost effectiveness of soil mapping and site characterization.

This study supports the Southern Seven GIS Project. Counties included in this project are Alexander, Johnson, Hardin, Massac, Pope, Pulaski, and Union.

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Activities:

All field activities were completed during the period of 15 to 19 April 1996. On the morning of 16 April, a short slide presentation covering the various uses of electromagnetic induction methods within NRCS was held in Vienna, Illinois. This presentation was presented to the Zone Seven Technology

Development Team. The remainder of the week was spent conducting field studies on two sites located on the Mermet Quadrangle (7.5 minute).

Equipment:

The electromagnetic induction meters used in this study were the EM38 and EM31. These meters are manufactured by Geonics Limited[*] (Mississauga, Ontario, Canada). Both meters are portable and require only one person to operate. Principles of operation have been described by McNeill (1980, 1986). No ground contact is required with these meters. Each meter provides limited vertical resolution and depth information. For each meter, lateral resolution is approximately equal to the intercoil spacing. The observation depth of these meters is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface.

The EM38 meter has a fixed intercoil spacing of about 40 inches. It operates at a frequency of 13.2 kHz. The EM38 meter has effective observation depths of about 30 and 60 inches in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). The EM31 meter has a fixed intercoil spacing of about 12 feet. It operates at a frequency of 9.8 kHz. The EM31 meter has effective observation depths of about 10 and 20 feet in the horizontal and vertical dipole orientations, respectively (McNeill, 1980). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

All field coordinates were obtained with a Rockwell Precision Lightweight GPS Receiver (PLGR) *. This receiver was operated using an external power source (portable 9 volt battery). The system was operated in the continuous mode. This mode uses the most power, but acquires and continues to track up to five satellites. Changes in position are continuously shown on the display. Positions were recorded using the Latitude and Longitude coordinates system. Positions were reported in degrees and minutes with a maximum position resolution of six feet. All recorded points had a *figure of magnitude* (FOM) of 1. The selected horizontal datum was the WGS 1984. The spheroid was WGS 84.

A digital elevation model (DEM) was used to simulate the landforms in this soil-landscape study. The DEM data consist of a sampled array of elevations for ground positions cast on a Universal Transverse Mercator (UTM) projection. Spacing between the data points was 30-meters. The reference datum for the Mermet Quadrangle (7.5 minute) is North American Datum of 1927. These data were compiled in a grid format using the Terrain Analysis Package (TAPPS) developed by Softwright (Golden, Colorado).*

To help summarize the results of this study, the SURFER for Windows program, developed by Golden Software, Inc. [*] (Golden, Colorado), was used to construct two- and three-dimensional simulations. Grids were created using kriging methods with an octant search. All grids were smoothed using a cubic spline interpolation. Colors and filled contour lines have been used to help emphasize spatial patterns. Other than showing trends and patterns in values of apparent conductivity (i.e., zones of higher or lower electrical conductivity) or estimated soil depths, no significance should be attached to the colors themselves.

Study Area:

Study sites were located on the Mermet Quadrangle, Illinois (7.5 minute series). Figure 1 shows the approximate location of this quadrangle in southern Illinois and its relationship to the encircling tri-county area. Figure 2 is a three-dimensional surface net of a portion of this quadrangle showing the

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locations of the study sites in relation to the major landforms and cultural features. This surface plot was prepared from a 30-meter spacing DEM. The red lines indicate the location of several major roadways. In Figure 2, the location of the Johnson County/ Massac County line has been shown.

Dr. Leon Fullmer has characterized, mapped, and discussed the surficial geology of the Mermet Quadrangle (Fullmer 1995). The following information was gleaned from his draft legend. The study area is located in the Cache Valley Region of southern Illinois. Major landforms include floodplains, terraces (Brownfield, Reevesville, and Mermet), bedrock uplands, and loess-covered uplands and terraces. The floodplain consists of Cahokia alluvium (post-glacial Holocene deposits) overlying stratified outwash and lacustrine deposits of Wisconsinan age. Terraces occur between distinct elevations and consist of stratified alluvial deposits. These deposits are variable in texture and age. The terraces are covered by either younger alluvium or loess deposits. The bedrock uplands contain exposed areas of Paleozoic sandstone, shale, or limestone. In most areas, the bedrock uplands are overlain by 0 to 5 feet of loess or residuum. The loess-covered uplands and terraces consist of 5 to 15 feet of weathered silt deposits. These deposits consist of three units: Peoria Silts (youngest), Roxana Silts, and Loveland Silts.

Several of the landforms described by Fullmer can be seen in Figure 2. These landforms include the floodplain and terraces, bedrock uplands, and loess-covered uplands. Floodplains and terraces form the broad, low-lying plain in the southern and southwestern portions of this simulation. In Figure 2, the steep escarpments and talus slopes of the bedrock uplands appear as risers. The loess-covered uplands comprise the less steeply sloping, higher-lying, step-like areas in the northern portion of this simulation.

Study Site #1 was located on the loess-covered upland in the eastern portion of the Mermet Quadrangle. Study Site #2 was located on floodplains and terraces in the south-central portion of the Quadrangle.

Field Procedures:

Each study site was about 160 acres. Random traverses were conducted across each site. As neither site was wooded, most traverses were conducted in straight lines across the quarter sections. However, on the upland site, lines were abbreviated and reoriented by several stream channels. At varying intervals along each traverse line, measurements were obtained with the EM meters and the coordinates of these observation points were obtained from the GPS receiver. The distance between observations and traverse lines were selected by the GPS operator to accommodate the steepness and breaks in topographic slopes. These intervals ranged from about 25 to 300 feet. A total of 146 and 86 observation points was recorded on the upland (site #1) and floodplain (site #2) sites, respectively. The locations of these points within each study site are shown in figures 3 and 4.

At each observation point, measurements were taken with the EM38 and EM31 meters in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. The coordinates of each observation point were recorded with a Rockwell Precision Lightweight GPS receiver.

Discussion:

Background:

Electromagnetic inductive methods measure vertical and lateral variations in the apparent electrical conductivity of earthen materials. In themselves, the measured values of apparent conductivity are seldom diagnostic. However, lateral and vertical variations in these measurements can be used to infer changes in soils and earthen materials. Interpretations of the EM data are based on the identification of spatial patterns within data sets.

Electromagnetic induction techniques are not suitable for use in all investigations. Generally, the use of EM techniques has been most successful where subsurface properties are reasonably homogeneous. These techniques have been successfully applied in areas where the effects of one property (e.g., clay, water, or salt content) dominate over the other properties, and variations in EM response can be related to changes in the dominant property (Cook et al., 1989).

Models constructed from EM data are more accurate in areas having a minimal sequence of dissimilar horizontal layers. The accuracy of models decreases with increasing numbers of layers. Within the Mermet Quadrangle, the upland site was conceptualized as consisting of two dissimilar layers: an overlying loess mantle and layer of residuum, and the underlying sandstone bedrock. The overlying loess mantle and residuum were presumed to be more electrically conductive than the underlying sandstone. The floodplain site was conceptualized as consisting of stratified layers of alluvium. Deposits dominated by finer-textured materials (Cahokia Alluvium and Equality Formation) were assumed to be more conductive than deposits dominated by sands (Henry Formation).

The meters must be sensitive to the differences existing between the layers. In other words, a meter must be able to detect differences in electromagnetic properties between the layers. Some subsurface layers have varying thicknesses and properties, but closely similar conductivity values. On loess-covered and bedrock uplands, the sandstone bedrock would have conductivity values similar to layers of fluvial sands and gravels. Where these dissimilar layers occur in the same landscape, they can produce equivalent solutions. Equivalent solutions can seriously reduce the accuracy and limit the effectiveness of bedrock models. In most alluvial settings, several undesirable parameters (heterogeneous materials, lateral variations in conductivity or conductivity-thickness products) fostered ambiguous EM interpretations and lessened the probability of attaining unique solutions. The inherent variability of alluvial settings reduces the appropriateness of geoelectric models.

Site 1 -- Upland Site

Site 1 was located in the northwest quarter of Section 9, T. 13 S., R. 4 E. Figure 5 is a three-dimensional surface diagram of the study site. This simulation shows the locations of the stream channels and the major divides. Also depicted in this figure is a sunken road. The road is believed to be expressed by the cleft that runs adjacent and parallel to the western border of the site. Within the site, relief was about 92 feet (28.2 m).

The site was in pasture. Soil delineations include several slope and erosional phases of Hosmer silt loam. Slopes ranged from 2 to 12 percent slopes (Parks, 1975). Hosmer soils are members of the fine-silty, mixed, mesic Typic Fragiaudalfs family. These very deep, moderately well drained soils formed in loess on uplands. The loess is underlain by sandstone bedrock. Map unit descriptions for Hosmer soils on slopes less than 12 percent do not describe the possible occurrence of bedrock within these delineations. The Illinois State Geological Survey has characterized the site as having 5 to 15 feet of loess over bedrock (Fullmer, 1995).

Basic statistics for the EM data collected within the upland site are displayed in Table 1. In general, values of apparent conductivity became more variable with increasing observation depths. For the shallower-sensing EM38 meter, one-half of the observations had values of apparent conductivity between 10.5 and 18.0 mS/m in the horizontal (0 to 30 inches), and between 9.2 and 16.7 mS/m in the vertical (0 to 60 inches) dipole orientation. For the deeper-sensing EM31 meter, one-half of the observations had values of apparent conductivity between 13.7 and 22.5 mS/m in the horizontal (0 to 10 feet), and between 12.2 and 22.8 mS/m in the vertical (0 to 20 feet) dipole orientations.

Figures 6 and 7 are two-dimensional plots of data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. Figures 8 and 9 are two-dimensional plots of data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 4 mS/m. Dashed lines indicate the approximate locations of the stream channels.

Table 1
Basic Statistics
EM Survey
Site 1 -- Upland
(all values are in mS/m)

				Quartiles			
Meter	Orientation	Minimum	Maximum	1st	Median	3rd	Average
EM38	Horizontal	3.8	25.2	10.5	13.9	18.0	14.0
EM38	Vertical	1.8	26.1	9.2	13.4	16.7	13.3
EM31	Horizontal	6.8	36.7	13.7	18.8	22.5	18.2
EM31	Vertical	6.1	36.4	12.2	18.5	22.8	18.1

The spatial patterns appearing in these figures are closely similar. Values of apparent conductivity appear to conform to a predictable spatial relationship and pattern. Lower values of apparent conductivity were recorded on lower-lying, more poorly drained areas along stream channels. Higher values of apparent conductivity were recorded on higher-lying and better drained summit, shoulder, and backslope positions.

Terrain influences soil moisture and the apparent conductivity of earthen materials. In similar materials, values of apparent conductivity increase with increasing soil moisture contents. Typically, in similar materials, values of apparent conductivity will be lower on higher-lying, better drained positions than on lower-lying, more poorly drained areas. This relationship does not occur within the study area. The discordant patterns evident in figures 6 to 9 prompt the assumption that the underlying materials are dissimilar between the lower-lying stream channels and the higher-lying summit positions.

The patterns appearing in these figures were believed to reflect the thickness of the loess cap or the depth to sandstone. Areas having low values of apparent conductivity were presumed to have thin loess caps and shallow depths to sandstone. Areas with high values of apparent conductivity were presumed to have thick loess caps or very deep depths to sandstone.

At three observation points, the depth to bedrock was measured with a hydraulic probe. At these observation points, the depth to bedrock averaged 79.6 inches and ranged from 26 to 120 inches. A comparison of soil probe and EM data collected at the three observation points revealed positive relationships between the observed depths to bedrock and the EM data.

The observed depths were compared with EM data and used to develop a regression equation to predict depths to bedrock from values of apparent conductivity. Data collected with the EM31 meter in the vertical dipole orientations had the strongest correlation with the depth to bedrock (r^2 = 0.99859) and were used to develop a predictive regression equation:

$$D = -0.63336 + (0.214843 * EM31V) \qquad [1]$$

Where "D" is depth to bedrock (m) and "EM31V" is the apparent conductivity (mS/m) measured with the EM31 meter in the vertical dipole orientation.

Equation [1] was used to estimate the depth to bedrock at each grid intersection. Based on 146, EM measurements and the predictive equation [1], the average depth to bedrock was estimated to be 128 inches with a range of 26.6 to 282.9 inches. One-half of the observations had depths to bedrock between 79 and 169 inches. Within the upland site, bedrock was moderately deep (20 to 40 in) at 5 percent, deep (40 to 60 in) at 11 percent, and very deep (>60 in) at 84 percent of the observation points. Fifty-six percent of the observations had depths to bedrock between 120 and 240 inches.

Areas of moderately deep and deep soil occurred along stream channels, footslopes, and lower-lying backslope positions. Because of differences in apparent conductivity values, soil drainage and depth, these soils (16 percent of the study site) are assumed to be dissimilar from the named Hosmer soils.

Figure 10 is a two-dimensional plot showing the distribution of depths to sandstone. These spatial patterns indicate that the depths to bedrock are greatest on summit, shoulder, and upper sideslopes components. Here the thickness of the loess deposits is greatest. Depths to bedrock are least along stream channels and on lower-lying backslope and footslope positions. Here, the loess deposits have been eroded away and the soils have formed in a thin mantle of alluvial deposits and residuum.

Site 2 -- Floodplain Site

Site 2 was located in the northern half of Section 30, T. 14 S., R. 4 E. Figure 11 is a three-dimensional surface diagram of the study site. Two conspicuous terraces appear in this plot. Within the site, relief is about 43 feet (13.2 m).

The site was in cropland. This site consists of soils formed on low terraces and bottomlands of the Cache River lowland. Soil delineations mapped in this area include: Alvin fine sandy loam, 2 to 4 percent slopes; Lamont fine sandy loam, 7 to 12 percent slopes, eroded; Cape silty clay loam; Ginat silt loam; Sciotoville silt loam, 0 to 2 percent slopes; Sciotoville silt loam, 2 to 4 percent slopes; and Wheeling silt loam, 2 to 4 percent slopes (Parks, 1975). Alvin and Lamont soils are members of the coarse-loamy, mixed, mesic Typic Hapludalfs family. Cape soils are members of the fine, montmorillonitic, acid, mesic Typic Fluvaquents family. Ginat soils are members of the fine-silty, mixed, mesic Typic Fragiaqualfs family. Sciotoville soils are members of the fine-loamy, mixed, mesic Aquic Fragiudalfs family. Wheeling soils are members of the fine-loamy, mixed, mesic Ultic Hapludalfs family.

Basic statistics for the EM data collected within this site are displayed in Table 2. Values of apparent conductivity increased and became more variable with increasing depths of observations. The increase in values of apparent conductivity with increasing observation depths is attributed to increased clay and moisture contents at lower soil depths. The greater variability with increasing observation depths is attributed to the presence of stratified deposits with varying particle size distributions. For the shallower-sensing EM38 meter, one-half of the observations had values of apparent conductivity between 17.4 and 31.3 mS/m in the horizontal (0 to 30 inches), and between 20.8 and 40.0 mS/m in the vertical (0 to 60 inches) dipole orientation. For the deeper-sensing EM31 meter, one-half of the observations had values of apparent conductivity between 29.6 and 57.5 mS/m in the horizontal (0 to 10 feet), and between 33.6 and 64.4 mS/m in the vertical (0 to 20 feet) dipole orientations.

Table 2
Basic Statistics
EM Survey
Site 1 -- Floodplain
(all values are in mS/m)

				Quartiles			
Meter	Orientation	Minimum	Maximum	1st	Median	3rd	Average
EM38	Horizontal	4.4	47.8	17.4	23.0	31.3	23.9
EM38	Vertical	3.2	57.8	20.8	28.5	40.0	30.4
EM31	Horizontal	6.9	82.4	29.6	46.6	57.5	44.0
EM31	Vertical	8.4	101.0	33.6	56.1	64.4	51.6

Figures 12 and 13 are two-dimensional plots of data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. Figures 14 and 15 are two-dimensional plots of data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 5 mS/m. Linear patterns or trends are apparent in each of these plots. These patterns conform with the orientation of the basic landforms (see Figure 11) within the quarter section. However, the isoline interval is too narrow for the small number of observations (86) and the range in apparent conductivity values measured among the observation sites.

Figures 16 and 17 represents the spatial distribution of apparent conductivity for the upper 30 inches and the upper 60 inches of the soil profile, respectively. Figures 18 and 19 represents the spatial distribution of apparent conductivity for the upper 118 inches and the upper 236 inches of the soil profile, respectively. In these plots the isoline interval is 20 mS/m. The spatial patterns appearing in each of these plots reflect lateral changes in depositional environments. Measurements obtained with the EM38 meter in the horizontal dipole orientation (see figures 12 and 16) were the least variable and reflect fairly uniform properties (clay, moisture, and soluble salt contents) in the surface layers. Measurements obtained with the EM31 meter in the vertical dipole orientation (see figures 15 and 19) were the most variable. These measurements reflect the increasing variability of properties (clay, moisture, and soluble salt contents) with increasing observation depths (0 to 236 inches).

Comparing the plots, vertical changes in values of apparent conductivity at a given observation point are believed to reflect the stratified nature of the underlying deposits. Horizontal changes in values of apparent conductivity were assumed to reflect changes in depositional environments and landforms. Two terraces are evident in Figure 11. Each terrace extends across the study site in an east - west direction. One terrace is located along the northern border of the site; the other terrace spans the central portion of the site. Judging from their respective EM responses, the two terraces are composed of dissimilar materials. For each meter and meter orientation, lower values of apparent conductivity were recorded on the northern-most terrace. Based on these low EM responses, this higher-lying terrace was presumed to be underlain by relatively coarse-textured materials.

The lower-lying terrace spanning the central portion of the site (see Figure 11) had intermediate EM responses. Compared with the other terrace, this terrace had higher EM responses and was assumed to be composed of finer-textured materials. In the accompanying plots, this terrace appears to be best expressed and differentiated in the measurements obtained with the EM31 meter. Between the two terraces is a lower-lying area or trough containing materials having high values of apparent conductivity. This area is believed to be an abandoned channel deposit that has been filled with finer-textured materials. In portions of this feature, apparent conductivity values in excess of 80 mS/m were recorded with the EM31 meter. Such high readings are often attributed to the accumulation of soluble salts. No deep, auger measurements were taken to confirm these interpretations.

Results:

1. This study demonstrated the feasibility of integrating global positioning systems, digital elevation models, electromagnetic induction, and computer graphic techniques to improve the characterization of soils and geologic materials over large areas.

2. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations do not substitute for direct observations, but rather reduce their number, direct their placement, and supplement their interpretations. Interpretations should be verified by ground-truth observations.

3. The site was mapped as consociations of Hosmer silt loam with differing slope and erosional phases. Map unit descriptions do not describe the possible occurrence of bedrock along stream channels (Parks, 1975). The MLRA Project leader is aware of these included areas and is reviewing the adequacy of mapping, map unit descriptions, and interpretations.

4. It was sincere pleasure to work in your state and with members of your fine staff.

With kind regards,

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