United States Department of Agriculture	**Natural Resources Conservation Service**	**207 W. Main Street Room 204 Wilkesboro, NC 28697**

Subject: SOI -- Geophysical Field Assistance

Date: 12 November 2002

To: Stephen K. Chick
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Purpose:
Site 1 (Monday 9-30-02) To evaluate the potential use of GPR and EMI as a tool to accurately and consistently determine depth to the argillic horizon (clay pan layer and aquitard) and if possible detect presence or absence of the E horizon. These are episaturated wetlands that are usually dry.
Site 2 (Tuesday 10-1-02) To determine and chart the depth of water table as well as the old historic river channels/swales that have been filled by depositional material on the Platte River flood plain. The site is located on a parcel of land that is owned and managed by The Nature Conservancy.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS, NSSC, Newtown Square, PA
Luis Hernandez, State Soil Scientist, USDA-NRCS, Lincoln, NE
Jerry Jasmer, Wildlife Biologist, USDA-NRCS, Lincoln, NE
Tyler Labenz, Resource Soil Scientist USDA-NRCS, Holdrege, NE
Casey Latta, Resource Soil Scientist, USDA-NRCS, York, NE
Wes Tuttle, Soil Scientist (Geophysical), USDA-NRCS, Wilkesboro, NC

Activities:
All field activities were completed on 30 September 2002 and 01 October 2002.

Equipment:
The GEM300 multifrequency sensor is manufactured by Geophysical Survey Systems, Inc. [1] Won and others (1996) describe the use and operation of this sensor. This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation. With the GEM300 sensor, the penetration depth is considered "skin depth limited" rather than "geometry limited." The skin-depth represents the maximum depth of penetration and is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signals. Theoretical penetration depths of the GEM300 sensor are dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequencies. Multifrequency sounding with the GEM300 theoretically allows multiple depths to be profiled with one pass of the sensor. The sensor is keypad operated and measurements can either be automatically or manually triggered.

Geonics Limited manufactures the EM38DD meter.[1] This meter is portable and requires only one person to operate. No ground contact is required with this meter. The EM38DD operates at a frequency of 14,600 Hz. It has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 2000). The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One unit acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one unit acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on).

The Geonics DAS70 Data Acquisition System was used to record and store both EMI and GPS data. [1] The acquisition system consists of an EM38DD meter, Allegro field computer, Trimble AG114 GPS receiver, backpack and frame for GPS, and associated cables. With the logging system, the EM38DD meter is keypad operated and measurements can either be automatically or manually triggered.

The ground-penetrating radar (GPR) unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974) and Doolittle (1987) have discussed the use and operation of GPR. The SIR System-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. The 200 and 400 MHz antennas were used in this study.

Fillmore, Scott, and Massie soils

Results:

GPR

The very deep, somewhat poorly drained Fillmore and the very deep, poorly and very poorly drained Scott and Massie soils formed in loess in depressions. These soils are members of the fine, smectitic, mesic Vertic Argialbolls family.

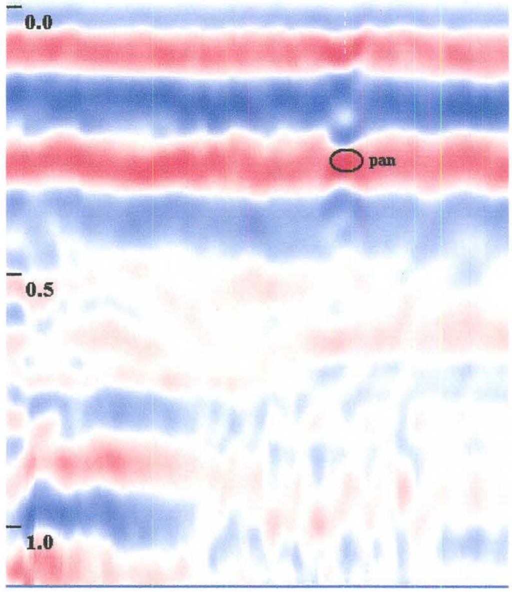

Figure 1 – Representative radar profile from an area of Fillmore soils.

Radar traverses were conducted with both the 200 and 400 MHz antennas. With both antennas, the depth of observation was less than 20 inches. The high clay content and prevalence of 2:1 expanding lattice clay minerals produced high attenuation rates that restricted the GPR's penetration depth. Compared with the 200 MHz antenna, the 400 MHz antenna provided similar observation depths and superior resolution of subsurface features. Because of high rates of signal attenuation, high levels of background noise and low amplitude, diffuse, parallel reflectors plagued radar profiles.

Figure 1 is a representative radar profile of the Fillmore soil. In Figure 1 a metal pan was buried at a depth of 30 cm. At 30 cm, the metallic pan is barely detectable. The location of this reflector has been highlighted with a circle. A depth scale (in meters) is located along the left-hand side of the radar profile. The estimated depth scale, pulse propagation velocity, and dielectric permittivity were based on the depth to the buried metallic reflector. For the upper part of the soil profile, with the 400 MHz antenna, the estimated velocity of propagation was 0.07 m/ns and the dielectric permittivity was 17.

Severely restricted penetration depths, and the poor quality and interpretability of radar profiles made the use of GPR inappropriate in areas of Fillmore, Scott, and Massie soils. Depths to finer textured argillic horizons or the thickness of albic horizons could not be calculated from the radar imagery. The use of GPR for soil investigations is considered inappropriate on these soils.

EMI

The entire field was surveyed with an EM38DD meter and the DAS70 data acquisition system. Data collected with these tools are shown in Figure 2. The locations of the 2263 EMI observation points and the survey lines are shown in the left-hand plot of Figure 2. In the horizontal dipole orientation, apparent conductivity averaged 9.77 mS/m and ranged from –5.5 to 31.0 mS/m. One-half of the observations had an apparent conductivity between 7.4 and 12.0 mS/m. In the vertical dipole orientation, apparent conductivity averaged 28.7 mS/m with a range of 10.5 to 55.3 mS/m. One-half of the observations had an apparent conductivity between 24.4 and 33.4 mS/m. Apparent conductivity increased and became more variable with increasing soil depth (vertical dipole measurements were

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

greater and more variable than horizontal dipole measurements). The higher apparent conductivity at greater soil depths was in agreement with the conceptual model for this site and was attributed to the increased clay and moisture contents of the argillic horizon.

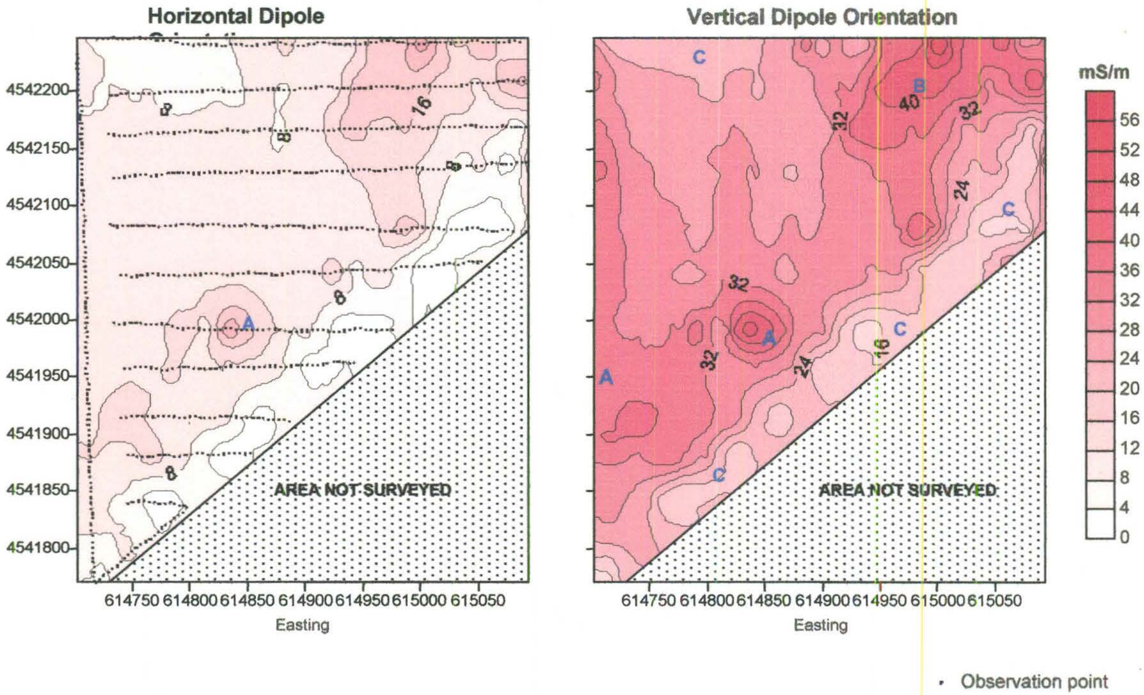

Figure 2 – Apparent conductivity measured with the EM38DD meter in an area of Fillmore, Scott, and Massie soils. Survey is shown with respective northing and easting coordinates.

In Figure 2, variations in apparent conductivity are principally attributed to differences in clay and/or moisture contents. Slightly lower-lying, moister areas of Massie soils are believed to be responsible for the higher apparent conductivities (>32 mS/m) near *A* in the right hand plot of Figure 2. Also in the right-hand plot, higher apparent conductivities near *B*, were attributed to higher clay contents. Slightly higher-lying, better-drained areas of Fillmore soils border the field. In both plots, areas of somewhat poorly drained Fillmore soil have lower apparent conductivities. In the right hand plot, areas of Fillmore soil have been labeled *C*.

An additional survey was completed using a predetermined rectangular grid. The grid was 60 meters by 50 meters. The GEM300 sensor was used with comparable results to the survey completed with the 38DD meter. Again areas of Massie soil have higher apparent conductivity values due to possible increases in clay and/or moisture content. With adequate soil core verifications, the resulting values may provide a reliable indicator to predict the depth to the clayey argillic horizon. The EMI survey mirrored the soil survey soils map, with increasing values in the area where Massie soil (**A**) occurs within the grid area. Massie soil would normally be the wetter of the three soils especially in drier times of the year. Refer to figure 3.

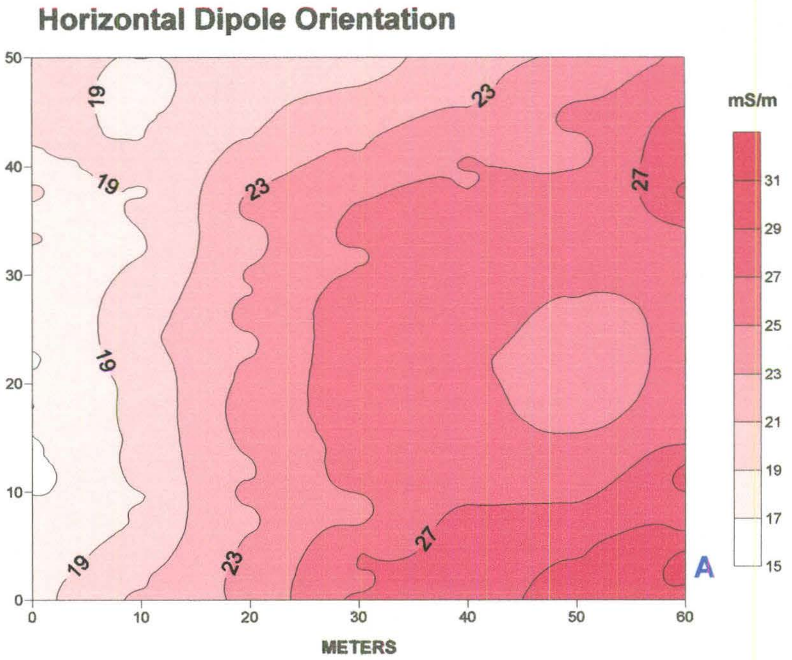

Figure 3 – Apparent conductivity measured with the multifrequency GEM300 sensor in an area of Fillmore, Scott, and Massie soils. The frequency selected was 9810Hz; the dipole orientation was horizontal.

Data collected with the GEM300 sensor is shown in Figure 3. For this plot, 258 data points were collected. In the horizontal dipole orientation, apparent conductivity averaged 23.4 mS/m and ranged from 15.4 to 31.9 mS/m. One-half of the observations had an apparent conductivity between 20.0 and 26.1 mS/m. The higher apparent conductivity was in agreement with the conceptual model for this site and was attributed to the increased clay and/or moisture contents of the argillic horizon.

While the use of GPR was inappropriate in these soils, the use of EMI provided information on the distribution of soils and variations in soil properties within this unit of management. Variations in EMI responses were related to variations in the clay and/or moisture contents. The moisture content did noticeably increase with increasing apparent conductivity values (at point A), as observed during ground truthing.

Area of Platte and Wann soils in Hall County, Nebraska

Areas of Platte loam and Wann fine sandy loam (Yost, 1962) were surveyed in Hall County, Nebraska. The study site was located in the SW1/4 of Section 20, T. 9 N., R. 11 W. The somewhat poorly drained Platte soil is shallow over coarse sand to gravelly coarse sand. Platte soil is a member of the sandy, mixed, mesic Aeric Fluvaquents family. The very deep, somewhat poorly drained Wann soil is a member of the coarse-loamy, mixed, superactive, mesic Fluvaquentic Haplustolls family. These soils formed in stratified, calcareous alluvium on flood plains.

In figure 5, a 100 meter by 100 meter grid was laid out and data was collected using the GEM300 sensor. The results of this survey are shown in Figure 5. For this plot, 747 data points were collected. In the vertical dipole orientation, apparent conductivity averaged 15.9 mS/m and ranged from 6.8 to 30.9 mS/m. One-half of the observations had an apparent conductivity between 13.0 and 18.2 mS/m. The higher apparent conductivity within the ancient river channels was in agreement with the conceptual model for this site and was attributed to the deposition of finer textured soil material back into these ancient river channels.

Figure 5 shows the possible courses of two ancient riverbeds, as represented by the higher apparent conductivitiy values measured in mS/m (milliseimens/meter). Two possible pathways show the meandering course of the river: A-B-D and A-C-D. Depressions on the landscape show evidence of this theory. Over the years, the ancient river channels were scoured out and over time the river changed its course, leaving the ancient riverbeds dry. Alluvial material was then deposited back into the river channels during flooding. Higher apparent conductivity values are associated with the back-fill of finer-textured material into these scoured out channels. Faint, sinuous patterns are also evident in this plot. These may represent former channels that have been back-filled with more coarser-textured materials. Casey Latta, Resource Soil Scientist, noted that the channels were irregular and were cut and filled with finer and coarser textured material.

During the process of conducting this survey the GEM300 malfunctioned. The operators heard banging noises within the instrument. There were noticeable "spikes" in the data prior to post processing. These "spikes" are known as "point anomalies" along the traverse lines and are represented by very high or very low values. These conspicuously anomalous values do not represent true readings. These "spikes" were removed in the post processing of the information. The unit was subsequently returned to the manufacturing company (GSSI) and the malfunction was verified and corrected .

Results:

1. The high clay content and prevalence of 2:1 expanding lattice clay minerals in Massie, Scott and Fillmore soils, produced high attenuation rates that restricted the GPR's penetration depth. Interpretative depths to the top of the argillic horizon were marginal at best. The thickness of the E horizon was indeterminate with the GPR.

2. EMI appeared to be a better choice of geophysical methods for soil survey and wetland applications in these 2:1 expanding lattice clay mineral soils. Although the depth to the top of the clayey argillic horizon or the thickness of the E horizon was indeterminent, the resulting spatial distributions did show an increase in moisture and/or clay content. The higher apparent conductivity with increasing soil depth was in agreement with the conceptual model for this site and was attributed to the increased clay and/or moisture contents of the argillic horizon. Soil auger observations revealed a definite increase in soil moisture that conformed to these spatial patterns. Comparable lab data is needed to confirm possible increase in clay content in the argillic horizon.

3. The successful amalgamation of EMI and GPS technologies to effectively and efficiently complete this survey appears to be the direction many of these surveys will be conducted in the future, especially on larger surveys. The simultaneous interface between these tools allows a greater coverage of an area in a shorter amount of time. Georeferencing of data allows greater accuracy as well as larger data sets.

4. GPR suitability was limited at the Platte River site. Because of the modest clay and carbonate contents of this soil, signal attenuation rates were high and observation depths were generally less than 1 m.

5. EMI appeared to be the more suitable tool at the Platte River site. The EMI survey did reveal indications of ancient river channels on the Platte River flood plain. Spatial patterns of apparent conductivity appear to reflect differences in depositional material in the ancient stream/river channels. These patterns are an indication of irregular stream channels that were once cut and then later filled with finer and coarser textured material. The local staff noted that these channels are characteristic of the area.

6. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil borings and pits). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations.

It was our pleasure to work in Nebraska and with members of your fine staff.

Sincerely,

Wes Tuttle

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Soil Scientist (Geophysical)

cc:
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References:

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. pp. 11-32. In: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20. p. 98

Geonics Limited. 2000. EM38DD ground conductivity meter: Dual dipole version operating manual. Geonics Ltd., Mississauga, Ontario.

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

Won, I. J., Dean A. Keiswetter, George R. A. Fields, and Lynn C. Sutton. 1996. GEM-2: A new multifrequency electromagnetic sensor. Journal of Environmental & Engineering Geophysics 1:129-137.

Yost, D. A. 1962. Soil Survey of Hall County, Nebraska. United States Agriculture Department Soil Conservation Service and the University of Nebraska Conservation and Survey Division. US Government Printing Office, Washington DC