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

Subject: SOI – Geophysical Field Assistance **Date:** 17 May 2003

To: Patricia S. Leavenworth
State Conservationist
6515 Watts Road, Suite 200
Madison, Wisconsin 53719-2726

Purpose:
Training was provided to Jennifer Maziasz on the operation of ground-penetrating radar (GPR) and interpretation of radar records. In addition, training was provided to all participants on the use and operation electromagnetic induction (EMI) meters.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Terry Kroll, Soil Scientist, USDA-NRCS, Ashland, WI
John Lucassen, MLRA Project Leader, USDA-NRCS, Ashland, WI
Jennifer Maziasz, Soil Scientist, USDA-NRCS, Ashland, WI
Jesse Turk, Soil Scientist, USDA-NRCS, Ashland, WI

Activities:
All activities were completed during the period of 27 to 30 April 2004. April 27 and 28 were spent in the field operating the SIR System-2000 unit and collecting radar data. April 29 was spent in the survey office transferring, reviewing, and interpreting radar records. Electromagnetic induction surveys were conducted on 30 April. As part of the EMI survey, data collected with an EM38DD meter and a newly developed EM38-MK2 meter were compared.

Background:
This past winter, the National Soil Survey Center provided a Subsurface Interface Radar (SIR) Sytem-2000 unit to the Wisconsin Soil Staff. In December 2003, this unit was delivered to the soil staff in Ashland, Wisconsin. Your office had purchased two antennas (400 and 200 MHz) for use with this system. At the time of delivery, training was also provided on the operation of the SIR System-2000 control unit. During the ensuing winter months, the Ashland soil staff collected radar imagery of peat deposits, which was reviewed during this field visit. Jennifer Maziasz is the designated radar operator.

Summary:

1. Jennifer Maziasz is a highly competent soil scientist and a quick learner of GPR. I was impressed by her retention of information and aptitude for radar interpretations. Jennifer interpretations of the soil/bedrock interface were consistent with mine. Jennifer's knowledge of GIS will allow her to improve the presentation and use of radar data. She will make an excellent radar operator and it is a privilege to work with her.

2. To support field operations that are conducted with the backpack unit, a shorter transmission cable (cable that connects control unit with antenna) is needed. I highly recommend the purchase of a 15 ft transmission cable from Geophysical Survey Systems, Incorporated.

3. An Omega zip-drive was transferred to Jennifer Maziasz in order that radar records could be transferred into her computer and made into digital images for reports. As training, some radar records were transferred and processed in MS Paint.

4. Electromagnetic induction provides a fast, economical, and noninvasive tool for mapping soils. Plots of apparent conductivity (EC_a) can be used to improve the quality of soil surveys. Because of the increased sampling density afforded with EMI, EC_a maps often show the locations of both major and minor components within soil polygons.

5. Within NRCS, the integration of continuous GPS and EMI measurements has been accomplished. Geographical information systems (GIS) have become accessible to soil scientists and field offices. Integration of EMI, GPS, and GIS techniques provides a more expedient and cost-effective method for soil mapping and displaying multiple data sets.

Special thanks are extended to Jesse Turk for his preparation of the ArcGIS images shown in this report.

It was my pleasure to work with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
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GPR:

Equipment:

The radar unit is the Subsurface Interface Radar (SIR) System-2000, 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-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. A 12-volt battery powers the system. This unit is backpack portable and, with an antenna, requires two people to operate. The 200 and 400 MHz antennas were used during this training session. Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc, 2003). [1] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance and surface normalization, and range gain adjustments.

Background:

In many upland areas of northern Wisconsin is exceedingly difficult and impractical to determine bedrock depths with traditional soil survey tools. Numerous rock fragments severely limit the effectiveness of shovels and augers. Soil scientists spend unwarranted amount of time and energy attempting to determine the depth to bedrock only to be refused, in many instances, by rock fragments. In addition, doubts arise as to whether auger penetration was restricted by a large rock fragment or bedrock. Ground-penetrating radar is more efficient and effective than traditional soil survey tools for bedrock determinations. The use of GPR facilitates the documentation of bedrock depths and improves map unit design based on soil-depth criteria.

Studies:

Training was focused on the recognition of the soil/bedrock bedrock interface and estimation of the depth to bedrock on radar records. Multiple traverses were conducted across various soil map units and depth to bedrock analysis was successfully completed by Jennifer Maziasz. The results of the bedrock studies have been filed in the Ashland Soil Survey Office and will not be further discussed in this report. The results of a special study to discriminate till from outwash are discussed in the following paragraphs.

Subsurface reflections are evident on most radar records. Assemblages or groups of similar radar reflection types (high-angle clinoforms, parallel/planar, and hummocky/wavy, chaotic reflectors) identify *radar facies* and record discrete units of earthen materials. Terminations of *radar facies* identify bounding surfaces that generally indicate erosional unconformities. Radar records were collected near filled excavations of Stanberry and Spiderlake soils for the purpose of identifying and comparing reflective radar signatures of till and alluvial deposits.

The very deep, moderately well drained Stanberry soil forms in loamy alluvium underlain by dense sandy till. Stanberry soil is deep to a densic contact. The very deep, moderately well drained Spiderlake soils formed in silty and loamy alluvium or eolian deposits underlain by stratified sandy outwash. Spiderlake soil is moderately deep to stratified sandy outwash. Stanberry and Spiderlake soils are members of the coarse-loamy, mixed, superactive, frigid Alfic Oxyaquic Haplorthods.

Figure 1 is a representative radar record that was collected with a 200 MHz antenna near a filled pit of Stanberry soil. In this figure all scales are in meters. The depth scale is based on an assumed dielectric permittivity of 20. In till, radar facies typically appear as a chaotic collection of point reflectors of varying sizes and amplitudes. Although the upper part of this radar record does contain some low amplitude planar reflectors, the majority of the reflectors appear in a chaotic pattern that suggests till. The lower part (>1.0 m) of the Stanberry radar record is rather complex and contains high amplitude planar reflectors that suggest water flow and deposition. These high amplitude reflections, especially the initial, higher reflections, may represent layers of denser soil materials. Ground-truth observations were inadequate to confirm this interpretation. In places, these deeper reflectors are broken and appear as chaotic as the reflections in the overlying till.

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

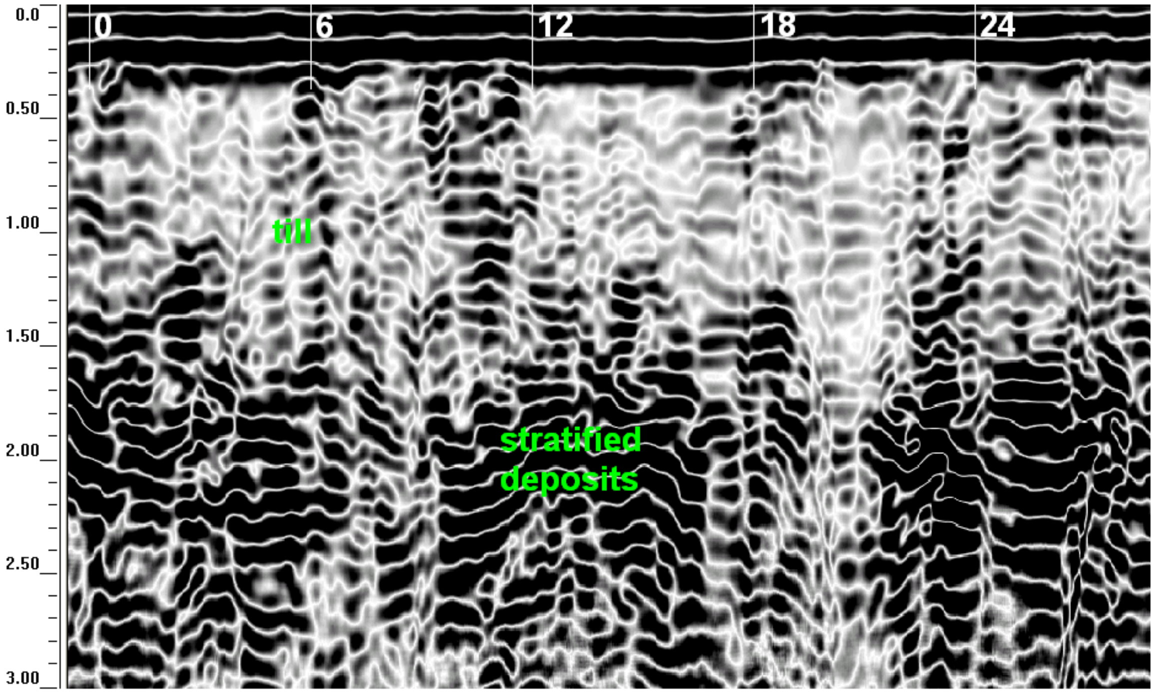

Figure 1. Representative radar record from an area of Stanberry soil.

Figure 2 is a representative radar record that was collected with a 200 MHz antenna near a filled pit of Spiderlake soil. In this figure all scales are in meters. The depth scale is based on an assumed dielectric permittivity of 14. In this radar record, the stratified, sandy outwash forms multiple, high-amplitude, plane to wavy reflections. These reflections represent distinct stratigraphic layers of different grain-size materials. Stratified sandy outwash deposits are characterized by these multiple, high-amplitude, plane to wavy reflections, which contrast with the more chaotic reflectors of till (see Figure 1).

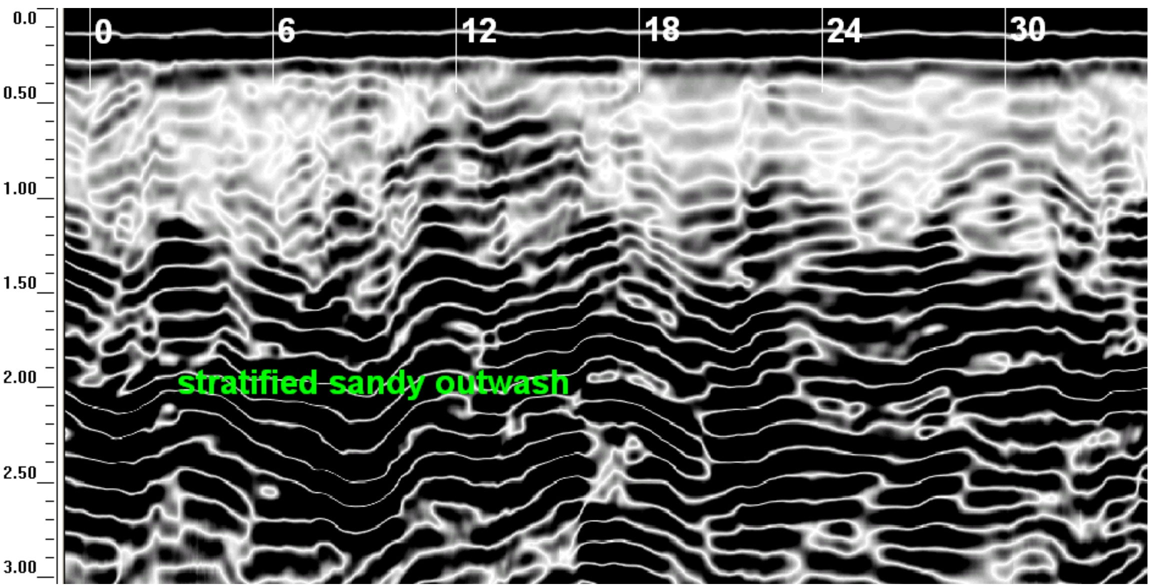

Figure 2. Representative radar record from an area of Spiderlake soil.

The radar facies shown in figures 1 and 2 are noticeably different. Areas of till and outwash can be differentiated on the basis of radar facies appearing on radar records.

EMI:

An EM38-MK2 meter has been loaned to the National Soil Survey Center (NSSC) by Geonics Limited for field evaluations. An EMI survey was conducted in an area of hay land in Bayfield County, Wisconsin. The survey area is bounded on the east by a wooded, more steeply sloping area; on the north by a farm road; and on the west by a county road. A utility line crosses the northwest corner of the survey area. This line produced interference that partially masked soil patterns in this portion of the survey area.

Study Site:

The field is mapped as Porting-Herbster complex, 0 to 6 percent slopes (M.U. 480B); Cornucopia silt loam, 15 to 25 percent slopes (M.U. 481D); and Morganlake loamy sand, 0 to 6 percent slopes (M.U. 712C). Table 1 lists the taxonomic classifications of these soils. The very deep, well drained Cornucopia, moderately well drained Portwing, and somewhat poorly drained Herbster soils formed in clayey glacial till and/or clayey lacustrine deposits over stratified loamy and/or sandy lacustrine deposits. The thickness of the clayey till and depth to the stratified substratum ranges from 40 to 60 inches. The weighted average clay content of the particle-size control section ranges from 35 to 60 percent. Depth to free carbonates ranges from 20 to 40 inches. The very deep, moderately well drained Morganlake soils formed in sandy outwash and in the underlying loamy glacial till. The thickness of the sandy mantle and depth to till range from 20 to 40 inches. The till averages 15 to 50 percent fine sand or coarser and 18 to 35 percent clay in at least the upper 5 inches.

Table 1. Taxonomic composition of soils

Soil Series	Taxonomic Classification
Cornucopia	Fine, mixed, active, frigid Haplic Glossudalfs
Herbster	Fine, mixed, superactive, frigid Aeric Glossaqualfs
Morganlake	Sandy over loamy, mixed, active, frigid Alfic Oxyaquic Haplorthods
Portwing	Fine, mixed, superactive, frigid Oxyaquic Glossudalfs

Equipment:

Geonics Limited manufacturers the EM38DD and the EM38-MK2 meters.[2] Both meters are portable and require only one person to operate. No ground contact is required with either meter. Geonics Limited (2000) describes the use and operation of the EM38DD meter. The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One meter acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one meter acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on). Each meter has a 1 m intercoil spacing and operates at a frequency of 14,600 Hz. The EM38DD meter has effective penetration depths of about 75 and 150 cm in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 2000).

The EM38-MK2 meter consists of transmitter and two receiver coils that are horizontal coplanar. The transmitter coil is positioned at spacings of 0.5 and 1.0 meters from the receiver coils. It operates at a frequency of 40 KHz. The meter is operated in the vertical dipole orientation. In this orientation, the effective depth of penetration is 1.5 times the intercoil spacing. The meter provides depth-weight apparent conductivity (EC_a) measurements for the upper 75 and 150 cm of the soil profile.

The Geonics DAS70 Data Acquisition System was used to record and store both EMI and GPS data.[2] The acquisition system consists of an EM38DD or an EM38-MK2 meter, and an Allegro field computer and a Trimble AG114 GPS receiver. [2] With the acquisition system, the EMI meters are keypad operated and measurements are automatically triggered every second.

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

To help summarize the results of this study, SURFER for Windows (version 8.0) software developed by Golden Software, Inc.,[2] was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search. Jesse Turk kindly provided the ArcGIS presentations of the data shown in this report.

Survey Procedures:
EMI surveys were competed with both meters held about 2 to 3 inches above the ground surface with their long axes parallel to the direction of traverse. Walking at a fairly brisk and uniform pace, in a random back and forth pattern across the survey area, the EM38DD and EM38-MK2 meters recorded 1232 AND 1242 geo-referenced measurements, respectively. The operator of one meter followed the path of the other operator and meter at a distance of about 25 feet to avoid interference. Table 2 shows the basic statistics for these two EMI surveys.

Table 2 Basic Statistics for EMI surveys conducted in Bayfield County, Wisconsin.

	EM38-MK2		**EM38DD**	
	Shallow	**Deep**	**Horizontal**	**Vertical**
Mean	14.0	18.8	21.8	23.2
Standard Dev.	7.1	9.7	13.5	13.1
Minimum	1.9	2.0	-2.4	-4.9
Maximum	45.9	72.5	184.1	104.6
25% tile	6.9	9.1	11.6	11.1
75% tile	19.3	26.1	28.6	32.9

Absolute EC_a values recorded with each meter were different. Higher and more variable EC_a were measured with the EM38DD meter than with the EM38-MK2 meter. Setup procedures were carefully followed, but the two meters did not provide identical EC_a at the same observation points or across the survey area. The EM38-MK2 meter is in a developmental phase and may not have been properly calibrated.

The EM38DD meter provided more variable measurements (standard deviation of about 13 mS/m in both dipole orientations) than the EM38-MK2 meter (standard deviation of about 7 and 10 mS/m for the 0.5 and 1.0 m intercoil spacings, respectively). The EM38-MK2 meter operates at a higher frequency (40 KHz) that is supposedly more stable to spherics (noise). As measurements collected with the EM38DD meter were the most variable, concerns are directed toward possible sources of interference (operator motions, eyelets on operators boots, and variations in the column of air between the bottom of the meter and the soil surface while surveying).

Plots of EC_a collected with the EM38DD and EM38-MK2 meters are shown in Figure 3. In each plot similar color ramps and isoline (6 mS/m) intervals have been used. In each plot, the likely location of the buried utility cable is shown as a blue-colored line in the northwest (upper left-hand) corner of the survey area. Regardless of device, orientation, or intercoil spacing, major spatial patterns are strikingly similar. In general areas mapped as the sandy Morganlake soils have lower EC_a (<12 mS/m) than areas mapped as the finer-textured Cornucopia, Porting, and Herbster soils (>18 mS/m). Though not verified, areas with intermediate EC_a are believed to represent transitional soils.

The EC_a maps closely approximate the soil map for these fields. However, a fairly large area of low (< 12 mS/m) EC_a soils shown in the west-central portion of the survey area had been missed by traditional Order-2 soil mapping.

With each meter, EC_a increases with increasing penetration depth. For the EM38DD meter, EC_a measured in the shallower sensing, horizontal dipole orientation was less than EC_a measured in the deeper-sensing, vertical dipole orientation. For the EM38-MK2 meter, EC_a measured with the shallower sensing, 0.5 m intercoil spacing was less than EC_a measured in the deeper-sensing, 1.0 m intercoil spacing. This trend reflects the general soil profile characteristic of increasing clay content with increasing soil depth.

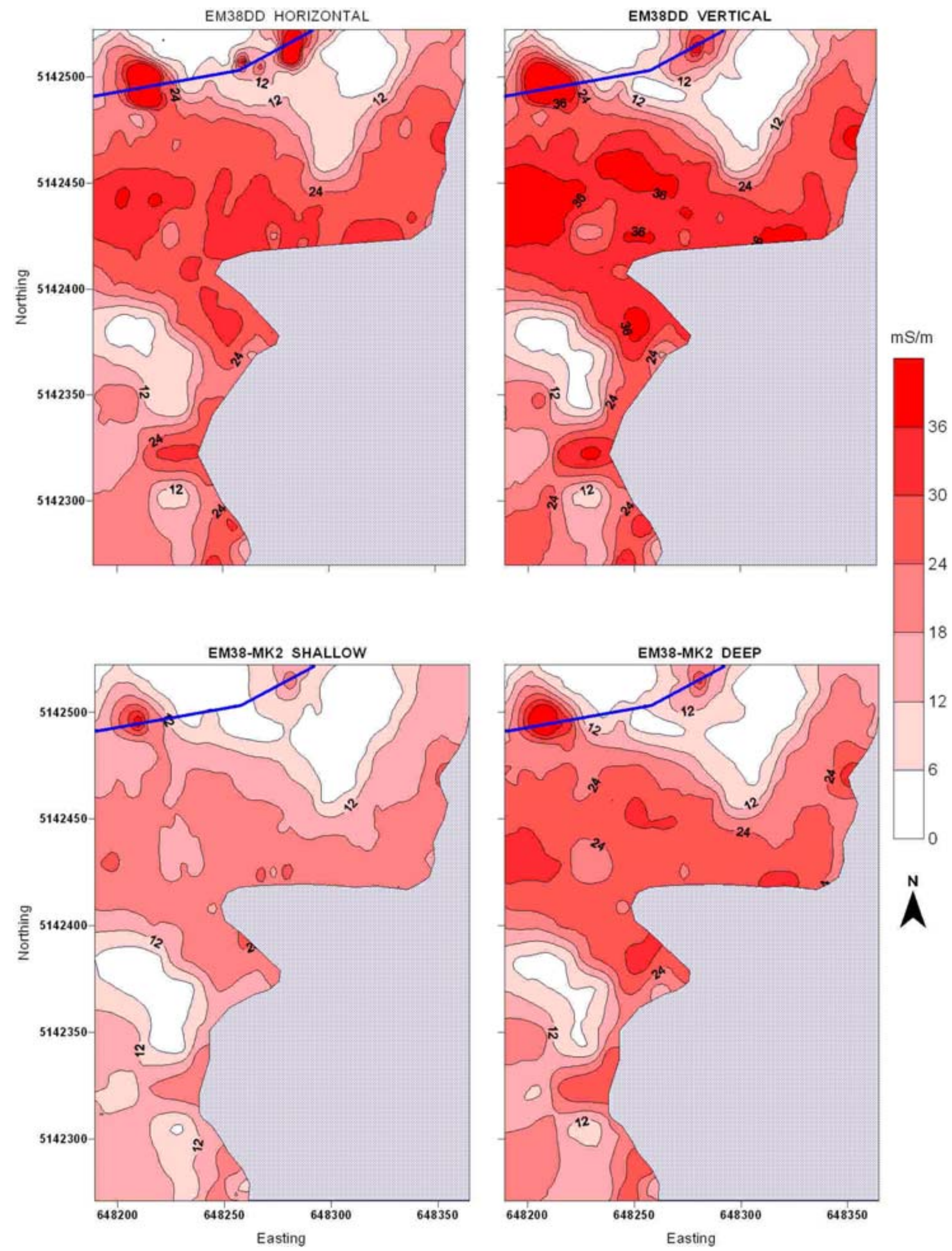

Figure 3. Plots of EC_a from the Bayfield County site.

Apparent conductivity data were imported into ArcGIS and processed into grids by Jesse Turk. Figure 4 provides a comparison of the data collected with both the EM38DD and EM38-MK2 meters at the Bayfield County site. Although the color ramps are similar, different scales and isoline intervals have been used in each plot. The dark lines in Figure 4 represent the boundary lines of soil polygons, which have been identified by their map unit symbols. The orthophography background and digitized soil boundary lines aid the recognition and interpretation of the EC_a patterns shown in these plots.

In the plots shown in Figure 4, EC_a patterns are more intricate than the mapped soil polygons. In general, higher values of EC_a can be associated with areas of the finer-textured Cornucopia, Porting, and Herbster soils. Areas of lower ECa conform to delineated areas of Morganlake loamy sand, 0 to 6 percent slopes, and included areas of Morganlake soil within the Porting-Herbster complex, 0 to 6 percent slopes.

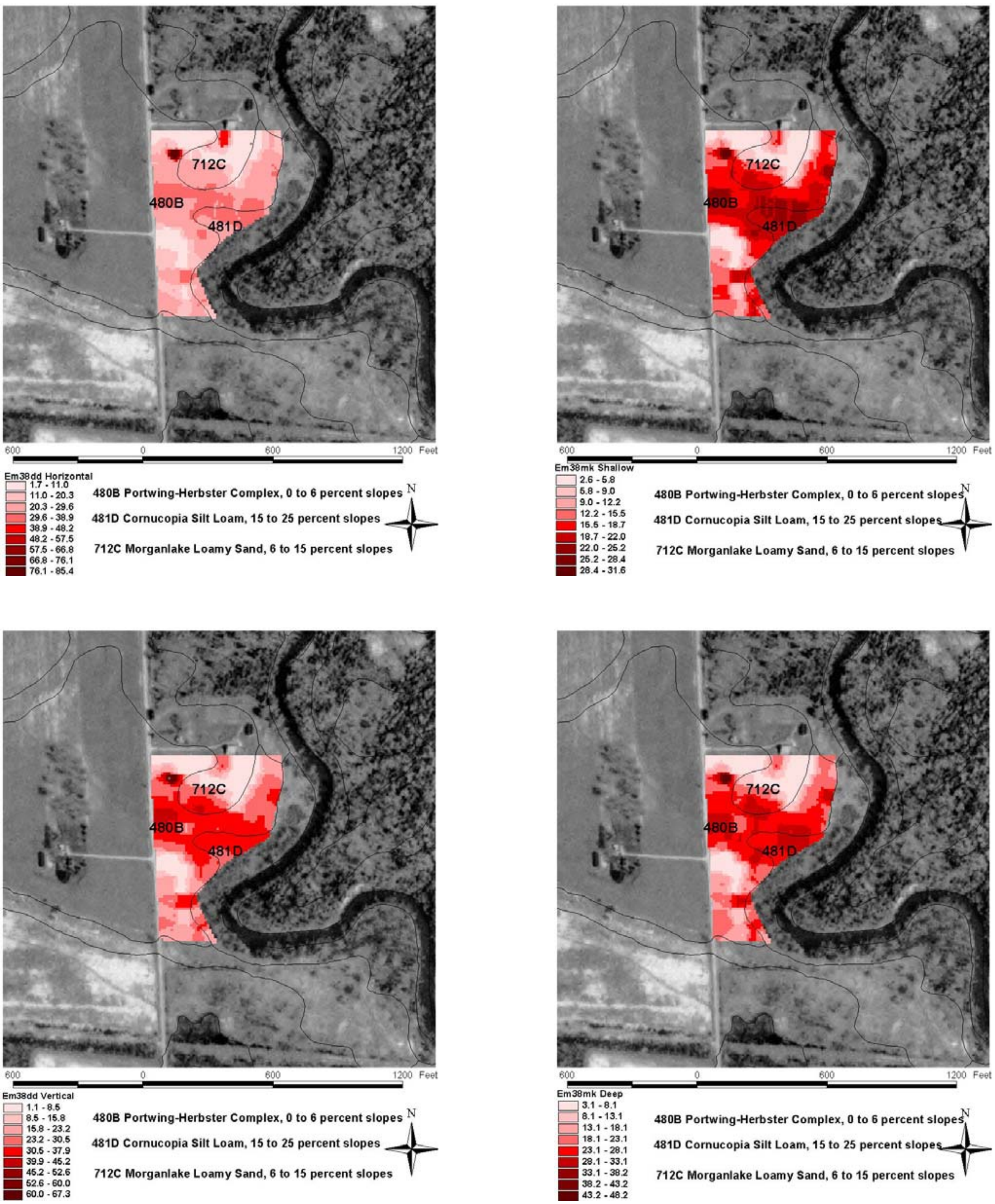

Figure 4. ArcView Presentations of the EC_a data collected with the EM38DD and EM38-MK2 meters.

Reference:

Daniels, D. J. 1996. Surface-Penetrating Radar. The Institute of Electrical Engineers, London, United Kingdom. 300 p.

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. 98 p.

Geonics Limited. 2000. EM38DD ground conductivity meter: Dual dipole version 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.

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. p. 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.