United States Department of Agriculture

Natural Resources Conservation Service

11 Campus Boulevard
Suite 200
Newtown Square, PA 19073

Subject: -- Geophysical Assistance --

Date: April 17, 2001

To: William J. Gradle
State Conservationist
USDA - NRCS
1902 Fox Drive
Champaign, Illinois

Purpose:
The objectives of this investigation were to 1) further evaluate the potentials of using ground-penetrating radar (GPR) as a tool for golf green management and other urban initiatives, and 2) to conduct comparative studies in areas of sodium-affected soils using the EM38 and EM38-DD meters.

Participants:
Richard Boniak, Graduate Student, Department of Plant, Soils, and General Agriculture, Southern Illinois University, Carbondale, IL
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Sam Indorante, MLRA Project Leader, USDA-NRCS, Carbondale, IL
She-Kong Chong, Hydrologist-Soil Physicist, Department of Plant, Soils, and General Agriculture, Southern Illinois University, Carbondale, IL
Kathy Renfro, Golf Course Superintendent, Hickory Ridge Golf Course, Carbondale, IL

Activities:
All field activities were completed on 2 and 3 April 2001. On 2 April, intensive GPR grid surveys were conducted at two golf courses near Carbondale: Hickory Ridge and Stone Creek Golf Courses. Hickory Ridge is a public golf course that is owned and operated by the Carbondale Park District. Stone Creek Golf Course is a semi-public golf course. On 3 April comparative EMI surveys were completed at the State Fairgrounds in Du Quoin, Perry County, Illinois.

Results and Conclusions:

1. Advanced data processing techniques are needed to adequately chart the distribution of buried drainage lines beneath golf greens. Richard Boniak of Southern Illinois University will attend an "Advance Data Processing Course" at Geophysical Survey Systems Inc. GPR Data collected during this field assignment will be forwarded to this company and used to construct block diagrams and serve as instructional material for this course.

2. Comparative studies were completed with the EM38 and the newly developed EM38-DD meters. The EM38-DD meter is heavier and more awkward to operate than the EM38 meter. However, the dual dipole unit (EM38-DD) did significantly reduce survey time. Although spatial patterns were similar, absolute apparent conductivity values did differ. Measurements obtained in the vertical dipole orientation were consistent between the instruments. However, measurements obtained in the horizontal dipole orientation were not consistent between the instruments. Differences were attributed to greater system noise with the "slave unit" in the horizontal dipole orientation. Although more testing is required, I presently do not recommend the purchase of additional EM38-DD meters within NRCS.

3. The acquisition of a data logger by the Illinois Soil Staff is encouraged. A data logger will ease and expedite fieldwork, reduce recording errors, and facilitate the download of data into computers and software programs.

It was my pleasure to work again in Illinois and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
B. Ahrens, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
S. Indorante, MLRA Project Leader, USDA-NRCS, Room 245, 150 East Pleasant Hill Road, Carbondale, IL 62901
R. McLeese, State Soil Scientist, USDA-NRCS, 1902 Fox Drive, Champaign, IL 61820
T. Neely, State Soil Scientist/MO Leader, 6013 Lakeside Blvd., Indianapolis, Indiana 46278
C. Olson, National Leader for Soil Investigations, USDA-USDA, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
H. Smith, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250

1. GPR Study of Golf Greens:

Equipment:
The radar unit used in this study was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A model 3102 (500 MHz) antenna was used in this study. A 12-volt battery powered the system.

For intensive grid surveys of "green" surfaces, the SIR System-2 was calibrated using scanning times of either 24 or 20 ns. The samples/scan was 256, bits/sample was 16, and scans/sec was 32. One break point was used with a gain of 1. Horizontal low pass and high pass filters were set to 0.

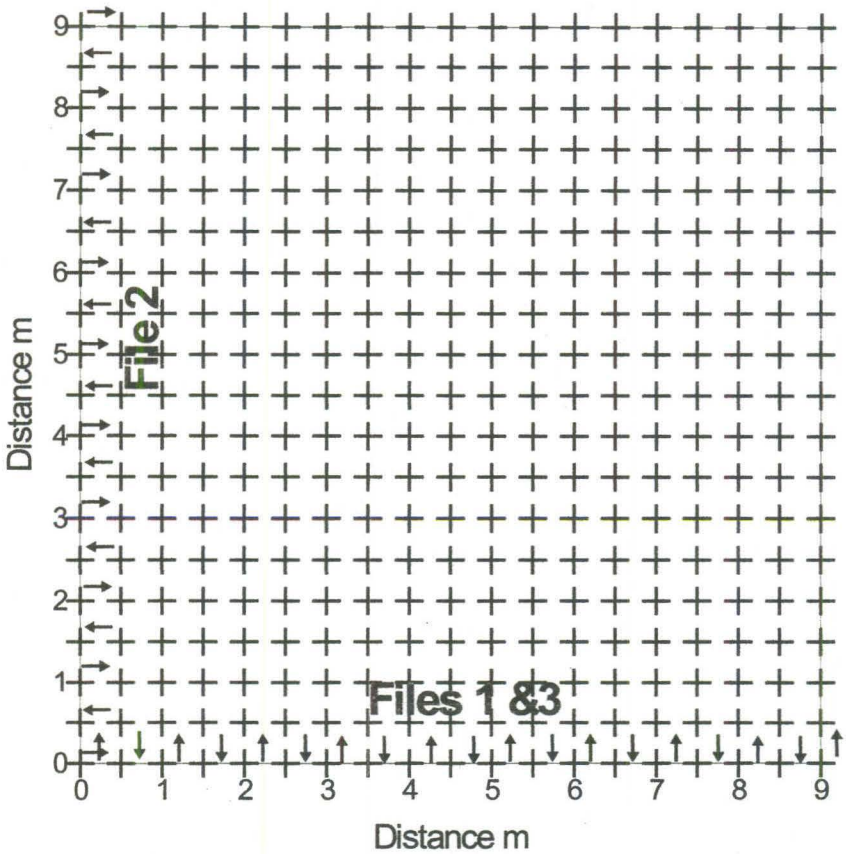
Background:
Following the successful results of a previous study (see my trip report of 23 November 1999), Dr. Chong and Southern Illinois University purchased a SIR-2000 radar system with a 900 MHz antenna for the investigation and characterization of golf greens. Graduate student Richard Boniak has become proficient with the operation of this system. In several studies, he has detected drainage tiles buried beneath greens, but has been unsuccessful at mapping compete drainage systems. The problem is the intensity of his grid sampling and the spacing of survey lines. I recommended more thorough GPR surveys coupled with the use of advanced data processing methods to create block diagrams of greens showing the distribution of buried drainage lines. Horizontal time slicing of block diagrams may provide the most useful mechanism for charting drainage systems beneath greens. I recommended that Richard Boniak attend the "Advance Data Processing Course" at Geophysical Survey Systems Inc., which is scheduled for 30 May to 1 June 2001. Dr Chong subsequently secured a spot for Richard in this course. The collected data will be forwarded to Dan Delea at Geophysical Survey Systems Inc., and used to construct block diagrams and serve as instructional material for this course.

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

SURVEY DESIGN FOR GPR GRID SURVEYS

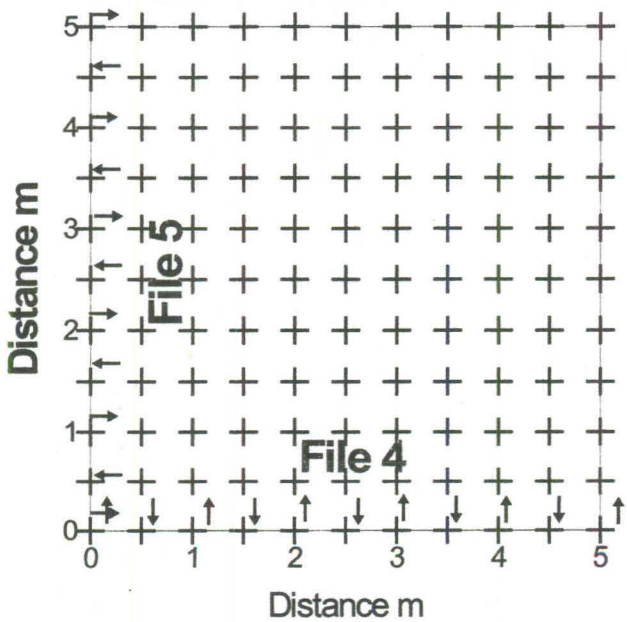
SHOWING FILE NUMBERS & SEQUENTIAL DIRECTIONS OF TRAVEL FROM ORIGIN

Hickory Ridge Golf Course



Green #4

Stone Creek Golf Course



Putting Green

Survey Procedures:
California style drains had been installed beneath the greens at the Hickory Ridge Golf Course. The drains are entrenched in the underlying soil materials an lack a gravel layer. *United State Golf Association* style drains underlie the putting green at the Stone Creek Golf Course. These drains are also entrenched into the underlying soil materials, but rest upon and are covered with a layer of gravel. The surveyed systems had a herringbone design.

A 9 by 9 m grid was established on green number 4 at the Hickory Ridge Golf Course and a 6 by 6 m grid was established putting area at the Stone Creek Golf Course (see Figure 1). For each survey, the grid interval was 50 cm. Surveys were completed in two, orthogonal directions (either 19 and 11 traverse lines in each direction). Double clicks marked the beginning and end of each traverse lines. These flagged position were spaced 50 cm from the grid area, but were not considered part of the survey area. Laying a tape between the flagged positions at opposing ends of the grid and pulling the 500 MHz along each of these lines completed surveys. Data were not reviewed or printed in the field. All data was stored on tape and will be sent to Geophysical Survey Systems, Inc., for processing.

2. Comparative EMI Study:

Background:
Nettleton and others (1994) used EMI to identify sodium-affected soils in south-central Illinois. Soils with natric horizons had apparent conductivities greater than 45 or 55 mS/m in the horizontal and vertical dipole orientations, respectively. Sodium-affect soils that lacked natric horizons had apparent conductivities of 20 to 45 mS/m or 30 to 55 mS/m in the horizontal and vertical dipole orientations, respectively.

Equipment:
Geonics Limited manufacturers the EM38 and the EM38-DD meters.[2] Both meters are portable and require only one person to operate. Geonics Limited (1998) describes the principles of operation for the EM38 meter. No ground contact is required with either meter. The depth of penetration is "geometry limited" and is dependent upon the intercoil spacing, coil orientation, and frequency. Lateral resolution is approximately equal to the intercoil spacing. These meters have a 1 m intercoil spacing and operate at a frequency of 14,600 Hz. These meters have effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 1998).

The positions of all observation points were obtained with Rockwell Precision Lightweight GPS receivers (PLGR).[1] The GPS receiver was operated in the continuous and the mixed satellite modes. The Universal Transverse Mercator (UTM) coordinate system was used. Horizontal datum was the North American 1983. Horizontal units were expressed in meters.

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

Study Area:
The study site was located principally in an area of Tamalco silt loam, 1 to 5 percent slopes, eroded, but included areas of Hoyleton-Darmstadt silt loams, 0 to 2 percent slopes (Grantham and Indorante, 1988). The moderately well drained Tamalco and the somewhat poorly drained Darmstadt and Hoyleton soils formed in loess and an underlying silty or loamy deposit that overlie a strongly weathered paleosol formed in the Illinoian till. Tamalco is a member of the fine, smectitic, mesic Typic Natrudalfs family. Darmstadt is a member of the fine-silty, mixed, superactive, mesic Albic Natraqualfs family. Hoyleton is a member of the fine, smectitic, mesic Aquertic Hapludalfs family.

Survey Procedures:
A 60 by 60 m grid was established at the study site. The grid interval was 15 m. Survey flags were inserted in the ground at each observation points. The UTM coordinates of each observation point were determined with GPS.

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

As measurements were obtained in both the horizontal and vertical dipole orientations and precise positioning of instruments was required, the EM38 and EM38-DD meters were operated in a station-to-station rather than a continuous mode. Measurements were taken with the EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations (see Figure 2). Measurements were taken with the EM38-DD meter placed on the ground surface with the master and the slave units in the vertical dipole and the horizontal dipole orientations, respectively. Later, a survey was completed with the EM38-DD meter operated in the continuous mode with a data logger (see Figure 3).

Figure 2 – Calibration of EM38 meter at an observation point. Meter is in the vertical dipole orientation.

Figure 3 – Operation of the EM38-DD meter with data logger. Master unit is in the vertical dipole orientation. Slave unit is in the horizontal dipole orientation.

Results:

Basic statistics for the EM38 and EM38-DD data are listed in Table 1. For the EM38 meter, apparent conductivity averaged 27.0 and 43.9 mS/m in the horizontal and vertical dipole orientations, respectively. In the horizontal dipole orientation, half of the observations had values of apparent conductivity between 22.0 and 33.0 mS/m. In the vertical dipole orientation, half of the observations had values of apparent conductivity between 37.0 and 51.0 mS/m. For the EM38-DD meter, apparent conductivity averaged 31.8 and 45.8 mS/m in the horizontal and vertical dipole orientations, respectively. In the horizontal dipole orientation, half of the observations had values of apparent conductivity between 27.0 and 37.9 mS/m. In the vertical dipole orientation, half of the observations had values of apparent conductivity between 39.0 and 51.5 mS/m. Measurements obtained with the two meters in the vertical dipole orientation were more similar than those obtained in the horizontal dipole orientation.

Table 1
Basic Statistics
EM31 Survey
Study Site #1
(All values are in mS/m)

	EM38-V	EM38-H	EM38-DD-V	EM38-DD-H
Average	43.9	27.0	45.8	31.8
Minimum	24.0	12.0	23.9	11.6
Maximum	62.0	41.0	67.2	52.6
First	37.0	22.0	39.0	27.0
Second	43.9	28.0	44.1	31.8
Third	51.0	33.0	51.5	37.9

Chart 1 shows the relationship between measurements obtained with the EM38 and the EM38-DD meters at the twenty-five observation points. When operated in the vertical dipole orientation, the correlation coefficient (r) between measurements obtained with the EM38 meter and measurements obtained with the EM38-DD was 0.95 (significant at 0.001 level). However, when operated in the horizontal dipole orientation, the correlation coefficient (r) between measurements obtained with the EM38 meter and measurements obtained with the EM38-DD meter decreased to 0.83 (significant at 0.001 level).

Because of its more extensive use and familiarity, greater confidence is placed in the measurements obtained with the EM38 meter. With the EM38-DD meter, only the transmitter coil of the master unit and the receiver coils of both the master and slave units are functional. If both transmitter coils were allowed to operate, severe signal interference would occur. The master unit is operated in the vertical dipole orientation and the slave unit is operated in the horizontal dipole orientation. Slight misalignment of coils in either unit can produce system noise. The poorer correlation of the horizontal dipole measurements (see Chart 1) is believed to be a manifestation of possible coil misalignment and system noise inherent in the slave unit. During survey operations, horizontal dipole measurements were observed to drift more widely than the relatively stable vertical dipole measurements with slight adjustments in the position of the EM38-DD meter on the ground surface.

Figure 4 shows the spatial distribution of apparent conductivity collected with the EM38 (upper plots) and the EM38-DD (lower plots) meters in the station-to-station mode. For each meter, the spatial distributions of apparent conductivity collected in the horizontal and vertical dipole orientations are shown in the left-hand and right-hand plots, respectively. In each plot, the isoline interval is 5 mS/m. The locations of the 25 observation points where measurements were made are shown in the upper left-hand plot. Though exceptions can be noted, spatial patterns are similar for each meter. However, spatial patterns are more closely identical for the measurements obtained with each meter in the vertical dipole orientation.

COMPARATIVE STUDY
EM38 & EM38-DD METERS

AREA OF HOYLETON, DARMSTADT, & TAMALCO SOILS
PERRY COUNTY, ILLINOIS

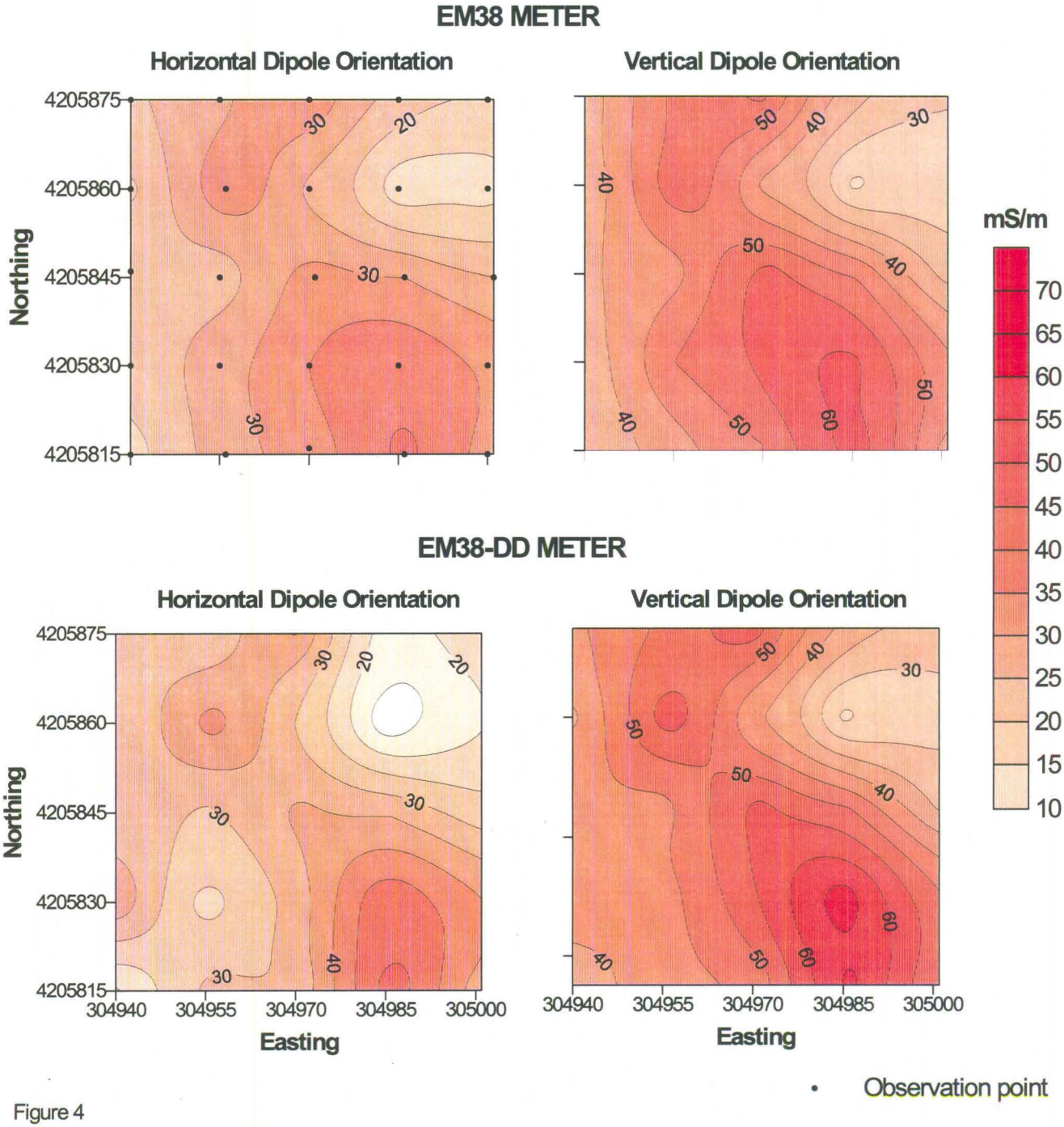

Figure 4

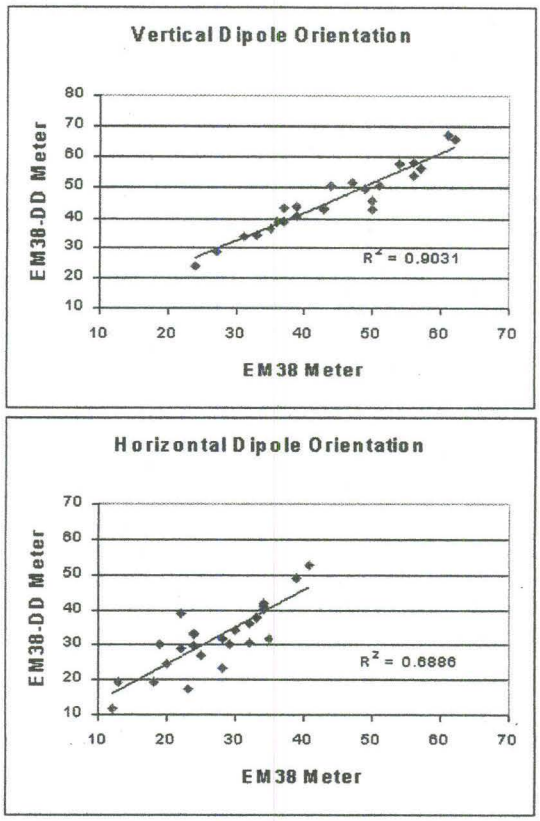

Chart 1. Comparison of measurements obtained with the EM38 and the EM38-DD meters at the same observation points.

Both meters can be operated in either the station to station or the continuous modes. A major drawback of the EM38 meter is the device's inability to simultaneously record measurements of apparent conductivity in both dipole orientations. Surveys can be completed with the EM38 meter operated in the station-to-station mode in both dipole orientations or in the continuous mode in only one dipole orientation. In the station-to-station mode, at each observation point measurements are made in one dipole orientation then the meter is rotated and re-nulled prior to obtaining measurements in the other dipole orientation. This tedious operation slows survey speeds. When operated in the continuous mode, a data logger is required and separate surveys must be completed with the EM38 meter in each dipole orientation. For surveys conducted in the continuous mode, the EM38 meter cannot be rotated to the different dipole positions. The EM38-DD meter simultaneously records both dipole measurements. It can be operated in either the station-to-station or the continuous mode without the necessity of re-nulling the unit before each measurement.

In this study, the times required to complete the survey were 18 and 8 minutes with the EM38 and EM38-DD meters, respectively. Simultaneous measurements and the lack of the requirement to repeatedly re-nulling the EM38-DD meter decrease survey time by 56 percent.

The EM38-DD meter provides simultaneous measurements of both dipole orientations and, with a data logger, can be operated in the continuous mode and thus provide more data and comprehensive coverage of sites. Figure 5 shows the results from a survey conducted with the EM38-DD meter in the continuous mode. This survey was completed in 4.6 minutes and provided 205 observations. While similar, differences in spatial patterns can be observed in the data collected with the EM38-DD meter in the station-to-station (see Figure 4) and the continuous (see Figure 5) modes. Differences are attributed to the differences in the number of observations, placement and height (for the station-to-station survey, the unit was placed on the ground; for the continuous survey, the unit was about 2 inches above ground surface) of the meter.

Illinois owns and operates seven EM38 meter and should explore the use of a data logger. The use of a data logger eases and expedites fieldwork, reduces recording errors, and facilitates the download of data into computers and

CONTINUOUS EMI SURVEY
EM38-DD METER

AREA OF HOYLETON, DARMSTADT, & TAMALCO SOILS
PERRY COUNTY, ILLINOIS

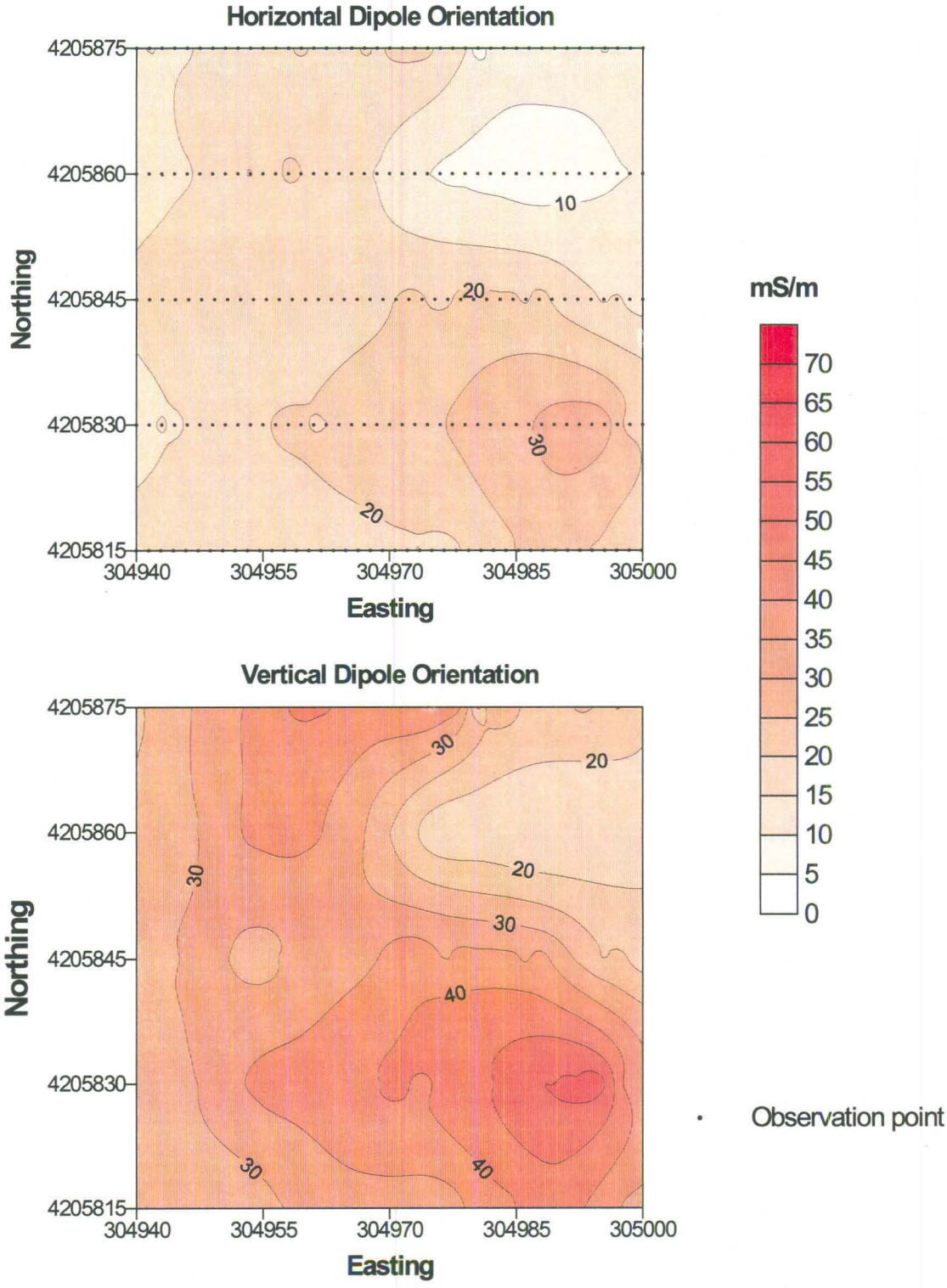

Figure 5

computer programs. The meters owned by NRCS in Illinois provide an analog rather than digital output. These meters can be used with a DL720 data logger that accepts analog outputs. The cost of this logger is $3775. The EM38 meters can be modified to provide a digital output ($1300) and used with either a DL600 data logger ($2500) or Pro400 computer ($2800). The hand held (lightweight) and waterproof Pro400 computer can be used to record both EMI and GPS data.

References

Geonics Limited. 1998. EM38 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario. 33 p.

Grantham, D. R. and S. J. Indorante. 1988. Soil Survey of Perry County, Illinois. USDA-Soil Conservation Service and the Illinois Agricultural Experiment Station. US Government Printing Office, Washington DC. 172. p.

Nettleton, W. D., L. Bushue, J. A. Doolittle, T. J. Endres, and S. J. Indorante. 1994. Sodium-affected soil identification in South-Central Illinois by electromagnetic induction. Soil Sci. Soc. Am. J. 58:1190-1193.Nettleton