United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI – Geophysical Field Assistance **Date:** 9 May 2008

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Purpose:
Ground-penetrating radar (GPR) and electromagnetic induction (EMI) were used to assist the identification of buried drainage tile and outlets at a proposed WRP wetland restoration area in Riverview Park, East Donegal Township, Lancaster County, Pennsylvania.

Participants:
John Chibirka, Soil Scientist, USDA-NRCS, Leesport, PA
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA

Activities:
All field activities were completed on 2 May 2008

Results:

1. Neither GPR nor EMI were ineffective in identifying a system of buried drainage tiles within the WRP wetland restoration area.

2. GPR records were plagued by high levels of background noise which made interpretations of buried drainage tiles ambiguous. Though a drainage tile was detected with GPR, this was the exception rather than the rule. Drainage tiles may exists in different states of structural integrity. Where broken or filled with water or debris, contrast with the enveloping soil materials is reduced and detection is more difficult.

3. Spatial EC_a patterns were associated with differences in soil moisture and clay contents. A sequence of spatial EC_a patterns, which were parallel the long axis of the terrace, were associated with differences in composition of the underlying alluvial materials. Areas of lower EC_a are suspected to be underlain by coarser-textured strata. Areas with higher EC_a are suspected to be underlain by finer-textured strata. No linear patterns which would suggest the presence of buried drainage tiles are evident in the plots of EMI data.

It was my pleasure to work in Pennsylvania and with John Chibirka.

With kind regards,

James A. Doolittle
Research Soil Scientist
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cc:
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Study Site:
The study site is located along the eastern edge of a cultivated field on a terrace to the Susquehanna River. The study site is bordered on the east by a drainage ditch and a railroad grade. Buried drainage tiles were observed in the sidewall of the drainage ditch. These tiles appear to drain the field. The site is located in an area mapped as Newark silt loam. The very deep, somewhat poorly drained Newark soils formed in mixed alluvium. Newark is a member of the fine-silty, mixed, active, nonacid, mesic Fluventic Endoaquepts family.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) discusses the use and operation of GPR. Antennas with center frequencies of 200 and 400 MHz were used in this study.

Radar records contained in this report were processed with the RADAN for Windows (version 6.6) software developed by GSSI.[1] Processing included: header editing, GPS positioning, setting the initial pulse to time zero, signal stacking, and range gain adjustments. The coordinates of each radar scan were recorded with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[1]

The SIR-3000 system provides a setup for the simultaneous use of a GPS receiver and serial data recorder (SDR). This setup allows the automatic integration of GPR and GPS data. With this setup, each scan on radar records is geo-referenced. Geo-referenced radar records are imaged using the *3D QuickDraw Module* of RADAN (version 6.6).

The EM38-MK2 meter, manufactured by Geonics limited (Mississauga, Ontario) was also used in this investigation.[1] This meter weighs about 5.4 kg (11.9 lbs) and requires only one person to operate. The EM38-MK2 meter operates at a frequency of 14,500 Hz. The meter has one transmitter coil and two receiver coils. The receiver coils are separated from the transmitter at distances of 1.0 and 0.5 m. This configuration provides effective depth ranges of 1.5 and 0.75 m in the vertical dipole orientation and 0.75 and 0.38 m in the horizontal dipole orientation. Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2007).

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

This meter measures the apparent conductivity (EC_a) and susceptibility of earthen materials, which are expressed in milliSiemens/meter (mS/m), and parts per thousand (ppt), respectively. The EM38-MK2 meter can provide simultaneous measurements of both quadrature-phase (conductivity) and in-phase (susceptibility) components within two depth ranges.

The coordinates of each EC_a measurement were recorded with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[1] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both EMI and position data.[1] The DAT38-MK2W software program developed by Geomar Software Inc. (Mississauga, Ontario) was used to record, store, and process EMI and GPS data.[1]

To help summarize the results of the EMI surveys, SURFER for Windows (version 8.0), developed by Golden Software, Inc. (Golden, CO), was used to construct the simulations shown in this report.[1] Grids of EMI data were created using kriging methods with an octant search.

Survey Procedures:
Traverses were conducted with the SIR-3000 and the 200 MHz antenna. While both 200and 400 MHz antennas were calibrated at this site, the 200 MHz antenna was preferred, as it provided the best balance of penetration depth and resolution. Four closely-spaced, parallel radar traverses were conducted across near the eastern field boundary and in an area known to contain a buried tile. Radar records were reviewed in the field and subsurface features identified. Based on radar interpretations a buried drainage tile was identified on one radar record and confirmed by soil coring.

The EM38-MK2 meter was operated in the deeper-sensing, vertical dipole orientation and in the continuous (measurements recorded at 1-sec intervals) mode. EMI and GPS data were simultaneously recorded in the Allegro CX field computer. While surveying, the EM38-MK2 meter was held about 5 cm (about 2 inch) above the ground surface and orientated with its long axis parallel to the direction of traverse. Surveys were completed by walking at a uniform pace, in a back and forth pattern across an area adjacent to the eastern boundary of the field.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., bedrock, soil horizon, stratigraphic layer, buried drainage tile) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (v) are described in equation [1] (after Daniels, 2004):

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to equation [2] (after Daniels, 2004):

$$E_r = (C/\,v)^2 \qquad [2]$$

In equation [2], C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v.

Based on the measured depth (125 cm) and the two-way pulse travel time to a known subsurface reflector (buried drainage tile), the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profile were estimated using equations [1] and [2]. Soils were exceedingly moist at the time of this investigation. The estimated E_r was about 21.78 (v = 0.0638 m/ns)

Results:

GPR Survey:

Figure 1 is a portion of a radar record from the study site that shows a known buried drainage tile (A). While evident in this record, buried drainage tiles were difficult to detect with GPR in this area of Newark soils. If present, drainage tiles may have been partially filled with debris or water, or in different physical states (ruptured or broken). These conditions can reduce the dielectric contrast between the buried drainage tiles and the encircling soil materials and influence the discernment of tills with GPR.

The field was covered with corn stalks. The antenna would frequently lodge behind stalks. Dislodgement would jar the radar antenna and produce multiple echoes on radar records. These unwanted echoes are similar to the reflections produced by the buried drainage tile evident in Figure 1. This source of background noise plagued interpretations and lowered confidence in the ability of GPR to locate and identify buried drainage tiles.

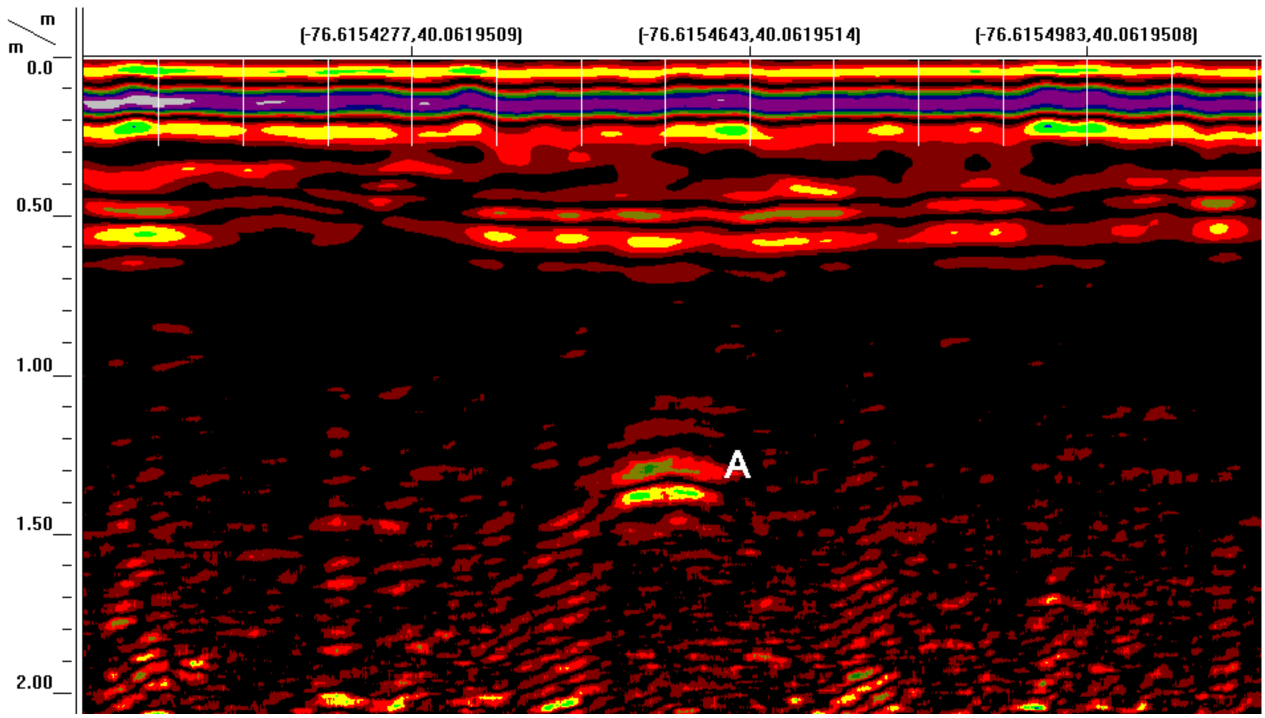

Figure 1. An identified, buried drainage tile (A) was profiled with the 200 MHz antenna in an area of Newark soils.

EMI Survey:

Table 1 summarizes the results of the EMI survey that was completed over a portion of the study site. All measurements were obtained with the EM38-MK2 meter operated in the vertical dipole orientation. For the shallower-sensing (0 to 75 cm), 50 cm coil separation, EC_a ranged from about 0.0 to 33.0 mS/m. For this coil separation, EC_a averaged 9.21 mS/m with a standard deviation of 4.63 mS/m. One-half the EC_a measurements were between 6.7 and 12.2 mS/m. For the deeper sensing (0 to 150 cm), 100 cm coil separation, EC_a ranged from about 7.8 to 27.6 mS/m. For this coil separation, EC_a averaged 19.64 mS/m with a standard deviation of 2.83 mS/m. One-half the EC_a measurements were between 17.7 and 21.7 mS/m.

Table 1

***Basic EMI Statistics for EMI survey of a portion of Riverview* Park, East Donegal Township.**

(Other than the number of observations, all values are in mS/m)

	0 to 150 cm	0 to 75 cm
Number	2628	2628
Minimum	7.85	0.00
25%-tile	17.73	6.72
75%-tile	21.68	12.19
Maximum	27.58	33.09
Average	19.64	9.21
Standard. Deviation	2.83	4.63

Figures 2 contain two-dimensional plots of the EC_a data measured with the EM38-MK2 meter operated in the vertical dipole orientation. The upper plot displays EC_a data recorded for the 50 cm coil spacing. The lower plot displays EC_a data recorded for the 100 cm coil spacing. In each plot, the isoline interval is 4 mS/m and the same color ramp is used.

Spatial EC_a patterns appearing in Figure 1 were presumed to be related to differences in soil moisture and clay contents. Areas with lower EC_a are suspected to be underlain by coarser-textured strata of alluvium. Areas with higher EC_a are suspected to be underlain by finer-textured strata of alluvium. In addition, areas with higher EC_a were suspected to have higher moisture contents. In Figure 2, linear band can be identified in the plots of EC_a data. These bands trend in a north-northwest to south-southeast direction with EC_a increasing towards the east and the tree-lined drainage ditch. Buried drainage tiles were suspected to traverse the study site from north to south. No linear patterns which would suggest the presence of buried drainage tiles are evident in these plots.

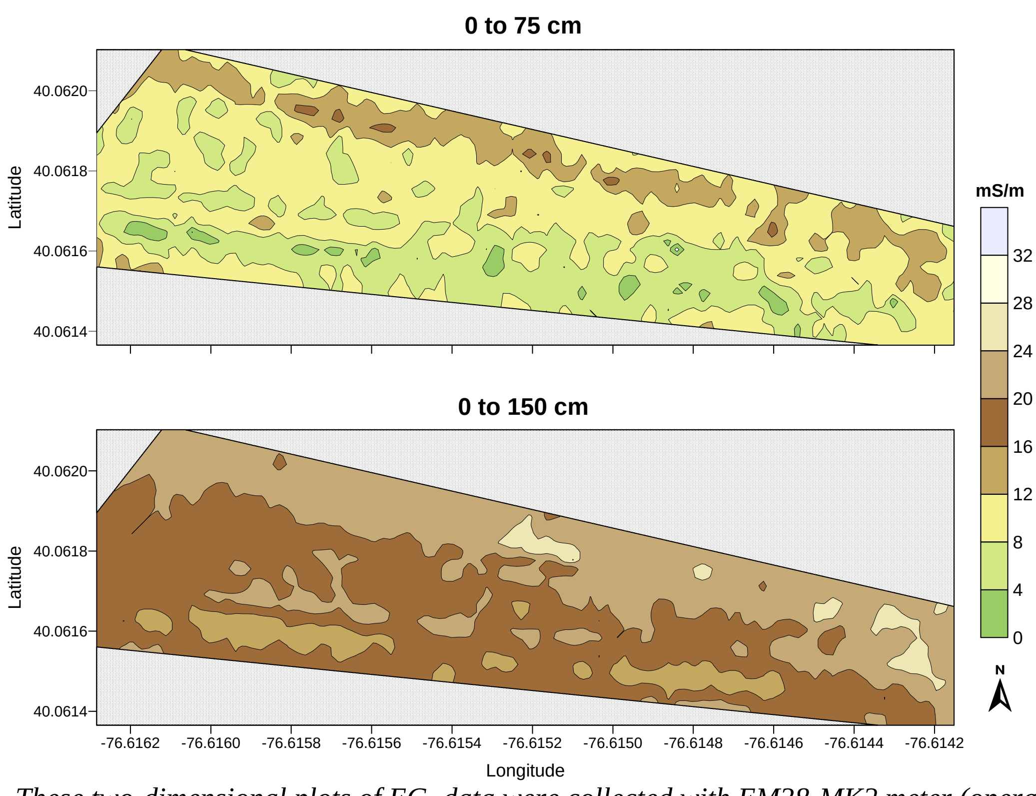

Figure 3. These two-dimensional plots of EC_a data were collected with EM38-MK2 meter (operated in the vertical dipole orientation). Each plot provides a depth-weighted average of EC_a over a different depth interval.

References:

Daniels, D. J., 2004. Ground Penetrating Radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.

Geonics Limited, 2007. EM38-MK2 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario.