United States Department of Agriculture

NRCS

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SUBJECT: MGT – Trip Report – Geophysical Assistance April 11, 2011

TO: Kevin Wickey File Code: 330-20-7
State Conservationist, NRCS
Morgantown, West Virginia

Purpose:
The purpose of this visit was to deliver geophysical equipment to MLRA Soil Survey Office 13-2 in Huntington, West Virginia. In addition, introductory training on the operation of the SIR-3000 ground-penetrating radar (GPR) unit and basic radar data processing procedures was provided to Richard Jones.

Participants:
Carlos P. Cole, Soil Scientist, NRCS, Ripley, WV
Debra D. Cunningham, Soil Scientist, NRCS, Huntington, WV
Charles Delp, Acting State Soil Scientist/MO Leader, NRCS, Summersville, WV
James A. Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Lincoln, NE
Earl A. Johnson, Soil Conservationist, NRCS, Grayson, KY
Richard D. Jones, Soil Scientist, NRCS, Huntington, WV
David H. Kingsbury, Soil Scientist, NRCS, Morgantown, WV

Activities:
Activities were completed on March 21-24, 2011.

Summary:

1. A TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000) control unit (Geophysical Survey Systems, Inc. (GSSI) serial number 2318) with a 200 MHz (GSSI serial number 2479) and 400 MHz (GSSI serial number 57) antennas, a signal data recorder (GSSI serial number 134), two 7.5 m transmission cables, two-lithium-ion batteries and battery charger, and an EM31 meter (AG002518477; Geonics Limited serial number 9315002) have been loaned by the National Soil Survey Center to Richard Jones, the designated soil scientist responsible for geophysical investigations in the Appalachian and Interior Plateaus Soil Survey Region (MO 13) and the Appalachian and Interior Plateaus Soil Survey Region (MO 18).

2. Introductory training was provided to Richard Jones on the operation and use of the SIR-3000 GPR unit. Richard is an enthusiastic and quick learner and enjoyable to work with. Jim Doolittle is very impressed by his interest and enthusiasm for GPR.

3. Training was provided to Richard Jones on some of the basic processing procedures contained in the RADAN for Windows (version 6.6) software program. These processing procedures can be used to prepare, edit, display, and print radar data. During training, proper file management and storage were stressed. Procedures covered included: color table and transformation options, range gain adjustments, header and marker editing, time zero adjustments, horizontal distance normalization, and signal stacking. The RADAN for Windows program includes the *Interactive Interpretation module*. This module can be used to semi-automatically pick and scale depths to

subsurface interfaces (e.g., soil horizons, stratigraphic or lithologic layers, subsurface features). The "picked" depths are automatically entered into the data files, which can be read in Notepad or Excel. Using this module, soil depth information can be quickly and accurately compiled and exported for analysis and summary.

4. Field studies were conducted in Mason County, West Virginia, and Carter County, Kentucky, to assess the effectiveness of GPR for the identification of subsurface drainage tiles. Drainage tiles were successfully imaged in medium textured soils (Melvin, Stendal, and Stokly soils) with GPR. The use of GPR with a suitable global positioning system (GPS) receiver should provide an effective means to identify and georeference the locations of drainage tiles buried in moderately coarse and medium textured soils within the greater Ohio River Basin.

5. In an area of Monongahela soils, GPR was used to map the depth and characterize the spatial variability of the fragipan and a stratigraphic layer.

6. In Greenup County, Kentucky, electromagnetic induction (EMI) was used to identify potential seepage areas from two stock-watering ponds.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work with and be of assistance to your fine staff.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:
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Technical report on the initial ground-penetrating radar training conducted in West Virginia and Kentucky (March 21-24, 2011).

Jim Doolittle

Equipment:
The National Soil Survey Center has provided a complete TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000) unit with 200 and 400 MHz antennas for use in MO 13 and 18. The radar unit is manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH). [1] The SIR-3000 consists of a DC-3000 digital control unit with keypad, SVGA video screen, and connector panel. The system is powered by a 10.8-volt lithium-ion rechargeable battery. 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 (see Figure 1). Daniels (2004) and Jol (2008) discuss the use and operation of GPR.

Figure 1. Rick Jones uses GPR over an area of Stendal and Stokly soils to locate buried drainage tiles. All radar records shown in this report were collected by Rick Jones.

The RADAN for Windows (version 6.6) and the *Interactive 3D Module* software programs (GSSI) were also provide with the radar unit. [1] The RADAN software is used to process collected radar data. Recent technical developments allow the integration of GPR and GPS data (Doolittle et al., 2009). This integration effectively geo-references each scan on a radar record. Using the *Interactive 3D Module* of the RADAN for Windows (version 6.6) software program, depths to subsurface interfaces can be quickly interpreted, automatically picked and outputted to a layer file (X, Y, Z format; containing latitude, longitude, and depth). The synergism of these technologies permits the rapid collection of large, georeferenced GPR data sets, which can be stored, manipulated, analyzed, and displayed in GIS. These collection, analysis, and display formats should greatly improve the utility of GPR in MO 13 and 18.

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

GPR Basics:

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, bedrock, stratigraphic layer) 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 the following equation (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 the equation:

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

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is typically 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 and the two-way pulse travel time to known subsurface reflectors, and equations [1] and [2], the velocity of propagation and the relative dielectric permittivity through the profiled soils were estimated at field sites. At the Carter County site, based on the depth to a buried metal plate (0.48 m), the estimated v and E_r through the upper part of the soil profile were 0.0759 m/ns and 15.4, respectively. At the Mason County site, based on the depth to a buried drainage tile (0.76 m), the estimated v and E_r through the upper part of the soil profile were 0.0632 m/ns and 22.2, respectively

Ground-Penetrating Radar – Field Studies:

Drainage Tile Detection:

Subsurface drainage tiles are used to lower the water table. The most common drainage tile is 10 cm in diameter and constructed of either clay tile (prior to the 1960s) or more recently, corrugated plastic tubing (Allred et al., 2004a and 2004b). Installed subsurface drainage tiles are often in varying states of preservation. As tiles become clogged with sediment or broken, a new system of pipes is often installed without removing the older system (Rogers et al., 2005). In agricultural fields, it is not uncommon to have multiple generations of drainage tiles (Rogers et al., 2005). Maps or records showing the locations of drainage tiles are seldom kept and therefore, little is known about previously installed systems. Ground-penetrating radar can be used to determine the locations and map the geometry of subsurface drainage tiles.

Drainage tiles are installed in more the poorly drained areas of fields, which often have soils with higher moisture and clay contents. With GPR, higher soil moisture and clay contents increase the rate of signal attenuation, limit the depth of penetration, and reduce the resolution of subsurface interfaces.

Chow and Rees (1989) were among the first to report the use of GPR to identify subsurface drainage tiles. They noted that buried drainage tiles often produce distinct hyperbolic patterns when a GPR antenna passes orthogonally across their long axes and planar reflectors when the GPR antenna passes parallel to their long axes. However, rock fragments, larger tree roots, and soil and moisture discontinuities can produce similar hyperbolic patterns, which confound interpretations (Chow and Rees, 1989).

In Ohio, Allred et al. (2004a and 2004b) reported that for grid surveys conducted over relatively small sites with a 250 MHz antenna, GPR detected 81 % of the known drainage tiles. These tiles were buried in soils with different textures (sandy loam to clay) at depths ranging from 0.5 to 1.0 m. In expanded studies, Allred et al. (2005, 2008) reported that the averaged effectiveness of GPR for detecting buried drainage tiles was about 74 %. The effectiveness of GPR for drainage tiles detection "requires careful consideration of computer processing procedures, equipment parameters, site conditions, and field operations" (Allred et al., 2005). Factors that need to be considered for the effective use of GPR include: variability in soil moisture and texture, drainage tile size, orientation, and depth, and survey procedures (Allred et al. 2005, 2008).

Table 1. Taxonomic classifications of the soils recognized at the Carter (KY) and Mason (WV) County Sites

Series	Taxonomic Classification
Allegheny	Fine-loamy, mixed, semiactive, mesic Typic Hapludults
Melvin	Fine-silty, mixed, active, nonacid, mesic Fluvaquentic Endoaquepts
Monongahela	Fine-loamy, mixed, semiactive, mesic Typic Fragiudults
Stendal	Fine-silty, mixed, active, acid, mesic Fluventic Endoaquepts
Stokly	Coarse-loamy, mixed, semiactive, acid, mesic Aeric Fluvaquents

At the request of district conservationists in Carter County, Kentucky, and Mason County, West Virginia, GPR was used to locate buried drainage tiles at two sites. The Carter County site (38.4556 N. latitude, 83.0647 W. longitude) is located in a meadow land along Buffalo Creek. This site is mapped as Allegheny loam on 0 to 2 % slopes (AIA). The area is however, more representative of the somewhat poorly drained Stendal silt loam (St) and Stokly fine sandy loam (Sv) than the well drained Allegheny soils, which are on higher-lying terraces. The Mason County site (38.7897 N. latitude, 82.0444 W. longitude) is located in a cultivated field about 6.2 miles southeast of Point Pleasant. The field extends northwards to the Kanawha River. This site is mapped as Melvin silt loam on 0 to 3 % slopes, occasionally flooded (MdA). The taxonomic classifications of the recognized soils at these two sites are listed in Table 1.

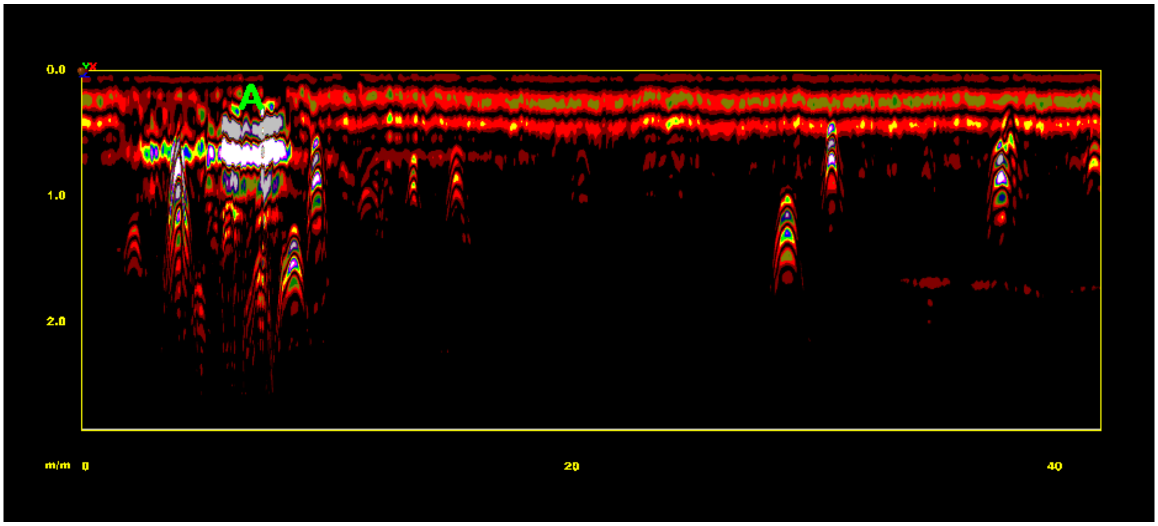

Figure 2. The hyperbolic patterns on this radar record from the Carter County site indicate several likely drainage tiles that were passed over orthogonally with a 200 MHz antenna in an area of Stendal and Stokly soils.

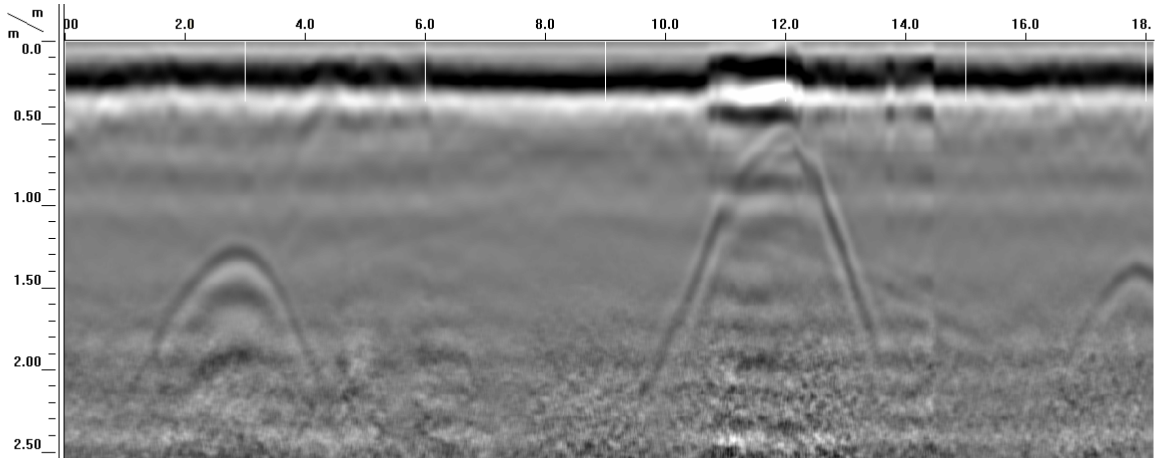

Figure 3. A buried (0.48 m) metal plate at distance mark 12-m results in a strongly expressed hyperbolic pattern on this radar record from an area of Melvin soils in Mason County, West Virginia. The two other hyperbolic patterns are believed to represent drainage tiles buried at depths between 1.2 and 1.3 m.

Figures 2 and 3 are representative radar records that were collected at the Carter and Mason County sites, respectively. In each radar record, the vertical and horizontal scales are in meters. Range gain adjustments and different color scales and transformations were used to increase the visibility of reflections from buried point reflectors. In Figures 2 and 3, each radar record contains several subsurface point reflectors, most of which are assumed to represent subsurface drainage tiles. The drainage tiles occur at different soil depths, reflecting multiple generations of drainage tile systems. The hyperbolic reflections indicate that the long axes of the drainage tiles were passed over orthogonally by an antenna (200 MHz). The letter "A" on the radar record in Figure 2 represents a wetter area with standing water that was traversed by the antenna. Heighten signal amplitudes and reverberations identify this area of ponded water.

From these studies, it is concluded that the GPR can be successfully employed on similar coarse- and medium-textured soils to locate buried drainage tiles. Global positioning systems (GPS) can be used with GPR to georeference the locations and map the geometry of tiles across fields.

Monongahela Soil

The presence, spatial continuity and expression of fragipans are difficult to describe with conventional soil survey tools. Fragipans form depth restrictive layers to water and tree roots and therefore play an important role in near-surface edaphic and hydrological processes.

Ground-penetrating radar has been used to chart the depth, lateral extent, and expression of fragipans (Doolittle et al., 2000; Lyons et al., 1988; Olson and Doolittle, 1985). However, results have varied in terms of degrees of success, with the effectiveness of GPR being highly site and parent material specific. The purpose of this survey was to obtain radar records of the Monongahela soil near its type location in Cabell County, West Virginia. The very deep, moderately well drained Monongahela soils formed in old alluvium derived largely from acid sandstone and shale on terraces. Depth to the fragipan (Btx horizon) ranges from 22 to 52 inches. Monongahela is a member of the fine-loamy, mixed, semiactive, mesic Typic Fragiudults taxonomic family.

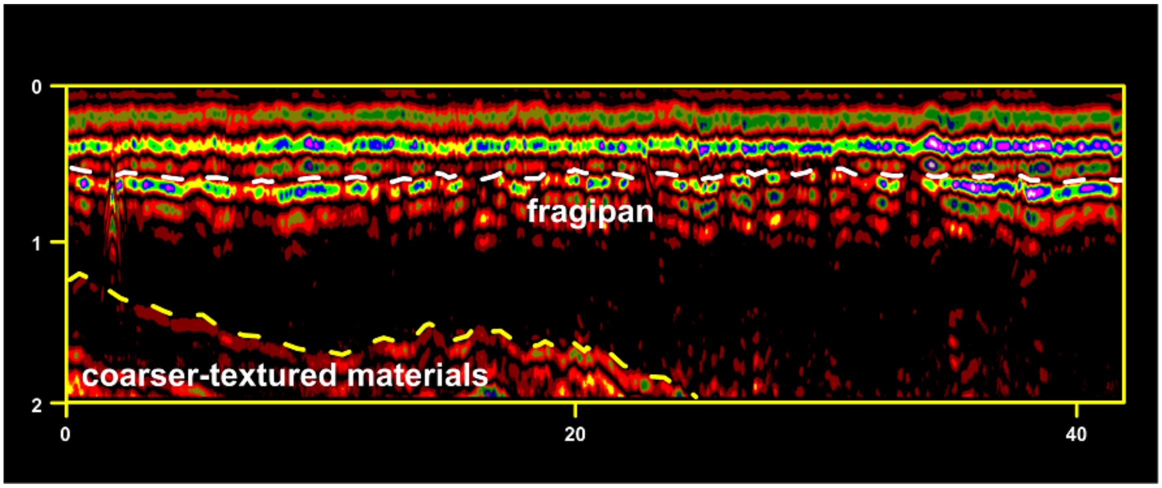

Figure 4. This radar record was collected with a 200 MHz antenna in an area of Monongahela soils. The interface separating the Bt and Btx horizon is identified with a white-colored, segmented line.

Monongahela soils have relatively thin surface layers and the depth to the argillic horizon ranges from only 7 to 17 inches. Because of its shallow depth, the argillic horizon is difficult to identify on radar records collected with the 200 MHz antenna. In Figure 4, the argillic horizon is not identifiable because its reflection is buried within the strong surface pulse reflections (consisting of multiple, parallel, planar reflections). On the radar record shown in Figure 4, immediately below the reflections from the surface pulse is a subsurface interface that can be traced across the entire radar record. This interface, which is highlighted by a white-colored segmented line, represents the upper boundary of the fragipan. Reflections from this interface vary in amplitude suggesting variability in properties of the Btx horizon and contrast with the overlying Bt horizons. Reflections vary from very weak (red) to very strong (white). In places, the interface cannot be seen (colored-black) and identified on the radar record. Here, the Bt and Btx lack sufficient contrast in dielectric properties or the boundary is too gradual to be detected with GPR.

A landowner stated that based on excavations made near this study site, the soils are underlain by relatively coarse-textured alluvial deposits (deposited by the pre-glacial Teays River). In Figure 4, though not confirmed by ground-truth observations, a subsurface interface has been identified as the contact separating assumed medium- and coarse-textured alluvial deposits.

<u>GPS Option:</u>

Recent technological developments have allowed the integration of GPR with global positioning systems (GPS). This integration effectively geo-references each scan appearing on radar records. This option is presently available on the SIR-3000 and requires connection to the Signal Data Recorder (SDR). This setup was tested at the Monongahela site with a Garmin76 GPS receiver. Proper communication requires the Garmin76 to be programmed to *NEMA out* with a baud setting of *4800*. The synergism of GPR and GPS technologies permits the collection of large, georeferenced GPR data sets, which can be stored, manipulated, analyzed, and displayed in GIS. These collection, analysis, and display formats should greatly improve the utility of GPR in soil investigations.

The GPS option was used to trace the depths to the coarser-textured sediments identified in Figure 4. Based on 6134 radar measurements, the estimated average depth of coarser-textured sediments is 1.81 m, with a range of about 1.2 to 2.7 m. Along the radar traverse, one half of the measurements were between about 1.6 and 2.0 m.

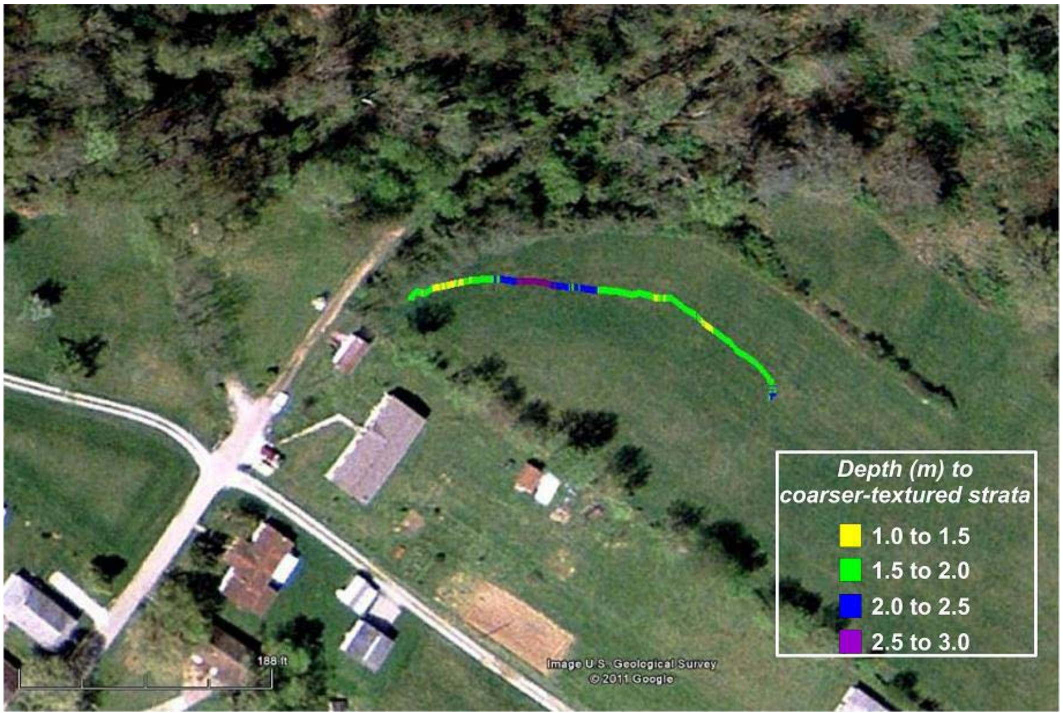

Figure 5. This Google Earth image shows the locations of GPR traverses and the interpreted depth to coarser textured sediments.

Figure 5 contains a *Goggle Earth* image of the Monongahela site. In this image, the location of the GPR traverse line is shown. The traverse line is colored-coded based on the interpreted depth (in meters) to the coarser textured sediments indentified in Figure 4.

Electromagnetic Induction (EMI):
Two electromagnetic induction (EMI) meters, and EM31 and EM38, have been transferred to Richard Jones for use in MO 13 and 18. During this visit, a PowerPoint presentation on the use of EMI in soil and resource assessments was provided to participants. While conducting GPR surveys in Carter County, Kentucky, opportunities arouse to use the EM38 meter. The district conservationist requested geophysical assistance to locate potential seepage areas emanating from two stock watering ponds located in Greenup County. It was decided that electromagnetic induction (EMI) would be the preferred tools as it would probably provide more useful information on the spatial distribution of soil moisture than GPR. However, it was stressed that unless the water contains high amounts of ions, the presence and areal extent of seepage from these earthen structures would be difficult to detect with EMI.

Equipment:
An EM38 meter (Geonics Limited; Mississauga, Ontario) was used to survey the areas surrounding two livestock watering-ponds.[2] The EM38 meter operates at a frequency of 14,600 Hz and weighs about 1.4 kg (3.1 lbs). This meter has one transmitter and one receiver coil that are spaced 1-m apart. When placed on the soil surface, the EM38 meter has effective penetration depths of about 0.75 m and 1.5 m in the horizontal (HDO) and vertical (VDO) dipole orientations, respectively (Geonics Limited, 1998).

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

A Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to georeferenced data collected with the EM38 meter.[2] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both GPS and EMI data.[2] The RTmap38 program (Geomar Software, Inc., Mississauga, Ontario) was used with the EM38 meter to display and record both GPS and EC_a on the Allegro CX field computer.[2]

To help summarize the results of the EMI surveys, the SURFER for Windows (version 9.0) software (Golden Software, Inc., Golden, CO) was used to construct the three-dimensional simulations shown in this report.[2] Grids were created using kriging methods with an octant search.

Survey procedures:
Pedestrian surveys were completed at both sites with an EM38 meter. The meter was operated in the vertical dipole orientation with its long axes orientated parallel to the direction of traverse, and held, about 5 cm (about 2 inch) above the ground surface. At each site, EMI surveys were restricted and confined by fence lines. Measurements of apparent conductivity (EC_a) were recorded at a rate of two measurements per second. The apparent conductivity data discussed in this report are not temperature corrected.

Results:
Across both sites apparent conductivity was generally low and invariable. At the first structure (38.4517 N. latitude, 83.0352 W. longitude), based on 2060 observations, EC_a averaged only 5.26 mS/m and ranged from about 0.0 to 14.5 mS/m. One half of the observations were between about 4.1 and 6.4 mS/m. At the second structure (38.4477 N. latitude, 83.0345 W. longitude), based on 875 observations, EC_a averaged only 6.04 mS/m, but had a range of about 0.0 to 153.2 mS/m. The higher EC_a at this site was attributed to the meter passing over buried metallic artifacts in the extreme western portion of the survey area. However, even at this site, the majority of the EC_a measurements were between about 2.2 and 6.7 mS/m.

Figure 6 and 7 are three-dimensional simulations of structures 1 and 2, respectfully. Elevation data used to construct these simulations were derived from GPS measurements. Different color scales have been used in each plot.

In each plot (see Figures 6 and 7), a line of slightly greater apparent conductivity is evident midway down the structure’s slope. This line of slightly higher EC_a appears to parallel the slope contours. Though the reason for the higher conductivity is not confirmed at this time, spatial patterns of slightly higher EC_a do suggest potential seepage areas for water from the ponds.

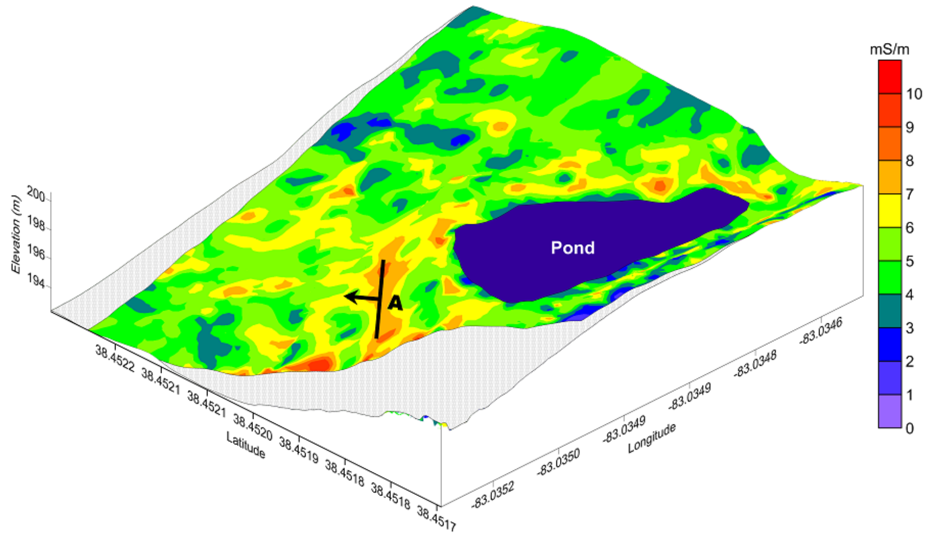

Figure 6. This three-dimensional representation of structure 1 in Greenup County, Kentucky, shows the spatial distribution of apparent conductivity across the surveyed area. "A" denotes an area of slightly higher EC_a that is down slope from the pond and associated with seepage.

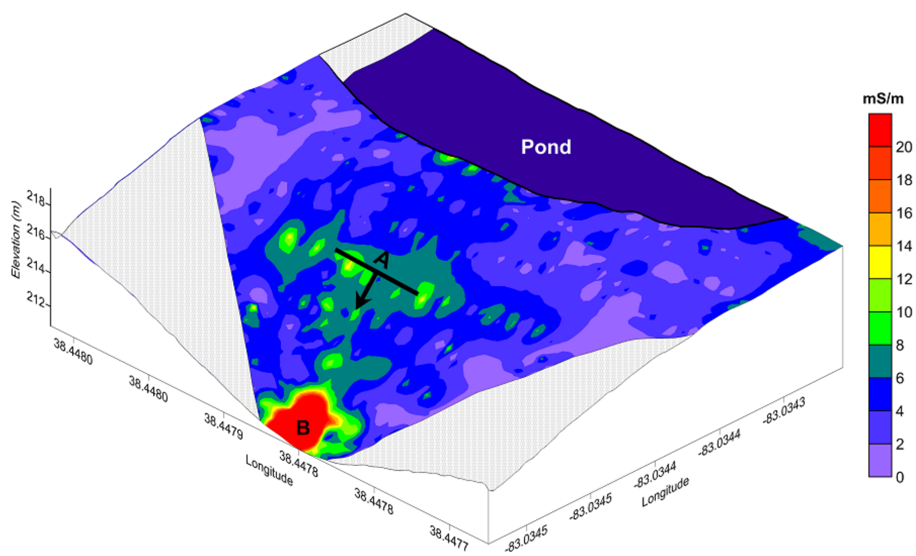

Figure 7. This three-dimensional representation of structure 2 in Greenup County, Kentucky, shows the spatial distribution of apparent conductivity across the surveyed area. "A" denotes an area of slightly higher EC_a that is down slope from the pond and associated with seepage.

References:

Allred, B., and J.J. Daniels, 2008. Agricultural drainage pipe detection using ground-penetrating radar. In Handbook of Agricultural Geophysics. Allred, B. J., J. J. Daniels, and M. Reza Ehsani (eds.). CRC Press; Boca Raton, Florida. Pp 363-374.

Allred, B.J., J.J. Daniels, N.R. Fausey, C. Chen, L. Peters, and H. Youn, 2005. Important considerations for locating buried agricultural drainage pipe using ground penetrating radar. *Applied Engineering in Agriculture* 21(1): 71-87.

Allred, B.J., N. Fausey, J. Daniels, C-C. Chen, L. Peters., and H.S. Youn, 2004b. GPR detection of drainage pipes in farmlands**.** Proceedings of the Tenth International Conference Ground Penetrating Radar, GPR 2004, Delft, The Netherlands. Volume 1, Pp. 307-310.

Allred, B. J., N. Fausey, Jr., L. Peters, C. Chen, J. Daniels, and H. Youn, 2004. Detection of buried agricultural drainage pipes with geophysical methods. *Applied Engineering in Agriculture* 20(3): 307-318.

Chow, T.L., and H.W. Rees, 1989. Identification of subsurface drain locations with ground-penetrating radar. *Canadian Journal of Soil Science* 69: 223-234.

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

Doolittle, J., G. Hoffmann, P. McDaniel, N. Peterson, B. Gardner and E. Rowan. 2000. Ground-penetrating radar interpretations of a fragipan in Northern Idaho: *Soil Survey Horizons* 41(3): 73-82.

Doolittle, J., D. Surabian, S. McVey, and D. Parizek, 2009. Three “G’s” for Soil-Bedrock Depth Interpretations. *Soil Survey Horizons* 50(1): 25-29.

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

Jol, H., 2008. Ground Penetrating Radar: Theory and Applications. Elsevier Science, Amsterdam, The Netherlands.

Lyons, J.C., C.A. Mitchell and T.M. Zobeck. 1988. Impulse radar for identification of features in soils: *Journal of Aerospace Engineering* 1:18-27.

Olson, C.G. and J.A. Doolittle. 1985. Geophysical techniques for reconnaissance investigations of soils and surficial deposits in mountainous terrain: *Soil Science Society of America Journal* 49: 1490-1498.

Rogers, M.B., J.R. Cassidy, and M.I. Dragila, 2005. Ground-based magnetic surveys as a new technique to locate subsurface drainage pipes: A case study. *Applied Engineering in Agriculture* 21(3): 421-426.