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

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PURPOSE:
A demonstration of ground-penetrating radar (GPR) and electromagnetic induction (EMI) equipment and methods was provided to the Mid-Atlantic Hydric Soil Committee Meeting in Hawley, PA. The Pennsylvania Soil Staff hosted this meeting. In addition, the subsurface stratigraphy of colluvial deposits surrounding vernal ponds along the north flank of South Mountain in south-central Pennsylvania was investigated with GPR. This project represents a cooperative study by the USDA-NRCS, Pennsylvania DNCR, and the Geology Department of Dickinson College.

PARTICIPANTS:
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Noel Potter, Professor of Geology, Dickinson College, Carlisle, PA
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ACTIVITIES:
All field activities were completed during the period of 17 to 20 June 2002.

RESULTS:
1. GPR and EMI field demonstrations were provided to a meeting of the Mid-Atlantic Hydric Soil Committee in Wayne and Pike counties, Pennsylvania. The use, operation, and interpretations of these geophysical methods were discussed and field demonstrated.

2. GPR was effectively used to characterize the subsurface stratigraphy in areas of Holly soil and to chart the depth and extent of a dense subsurface layer in an area of Gleneyre soil.

3. EMI methods were used to produce a high intensity soil map of field of Holly soils. Spatial patterns of apparent conductivity on a resulting computer simulation of the field were associated with variations in clay contents and depths to coarse-textured alluvial materials.

4. GPR was used to characterize the subsurface stratigraphy of areas surrounding vernal ponds along South Mountain in south central Pennsylvania. This project assisted the Pennsylvania Department of Conservation & Natural Resources, and the Geology Department of Dickinson College. Bitmap files of these radar profiles have been sent to Helen Delano of the Pennsylvania Department of Conservation & Natural Resources under a separate cover.

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

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
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STUDY SITES:

Compton and Decker Hollow sites:

These sites were used to demonstrate the use and operation of EMI and GPR to the Mid-Atlantic Hydric Soil Committee. The Compton Site was located in a drained, cultivated field near the town of Drinker. Soils mapped within the site include areas of Holly silt loam and Holly silt loam, ponded (Eckenrode, 1982). The very deep, very poorly and poorly drained Holly soil formed in loamy alluvium on flood plains. Holly is a member of the fine-loamy, mixed, active, nonacid, mesic Fluvaquentic Endoaquepts family.

The Decker Hollow Site is located in a wooded area that is dominated by hemlock vegetation near the town of Hawley. The site has been heavily bioturbated and consists of an undulating *cradle knoll* micro-topography. The dominant soil mapped within this site is Gleneyre (Tim Craul, personal communication). The very deep, very poorly drained Gleneyre soils formed in silty, lacustrine deposits. Gleneyre is a member of the coarse-silty over sandy or sandy-skeletal, mixed, mesic Typic Fluvaquents family.

Kings Gap Pond Site:

Vernal ponds are distinct features along the north flank of South Mountain in south central Pennsylvania. Typically, these ponds are dry during the summer months and are ponded during the other months. It is believed that these ponds develop as sinkholes in the colluvium that overlies the limestone (Southeast Friends of the Pleistocene, 2001). Sediment cores from the pond reveal layered silt and clay sediments (Southeast Friends of the Pleistocene, 2001).

MATERIALS AND METHODS

Equipment:

The radar 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. A 200 MHz and 400 MHz antennas were used in the demonstrations that were conducted in Lackawanna and Pike counties. A 70 and 200 MHz antennas were used in the study of vernal ponds along the flanks of South Mountain. A scanning time of 90 and 60 nanoseconds (ns) were used at the Compton and Decker Hollow sites, respectively. A scanning time of 200 and 150 ns was used in the study of vernal ponds.

Geonics Limited manufactures EM38DD meter.[1] Geonics Limited (2000) has described the principles of operation for 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 EM38Dpro Data Logging System was used to record and store both EMI and GPS data. [1] The logging system consists of an EM38DD meter, Allegro field computer, Trimble AG114 GPS receiver, and associated cables.

To help summarize the results of this study, the SURFER for Windows (version 7.0) program, developed by Golden Software, Inc.,[1] was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search.

GPR:

Calibration of GPR:

Ground-penetrating radar is a time scaled system. This tool measures the time it takes electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, water table, stratigraphic layer) and back. To convert travel time to depth requires knowledge of the velocity of pulse propagation. Several methods are available to

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

determine the velocity of propagation. These methods include use of table values, common midpoint calibration, and calibration over a target of known depth. The last method is considered the most direct and accurate method to estimate propagation velocity. The procedure involves measuring the two-way travel time to a reflector of known depth on a radar profile and calculating the propagation velocity by the following equation (after Morey, 1974):

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

Equation [1] describes the relationship of the average propagation velocity (V) to the depth (D) and the two-way pulse travel time (T) to a reflector.

At the Compton site, the measured depth (D) and the two-way radar pulse travel time to a pipe buried at a depth of 50 cm were used to estimate the velocity of propagation. The estimated velocity of propagation was 0.054 m/ns. The dielectric permittivity was 30. At the Decker Hollow site, the measured depth (D) and the two-way radar pulse travel time to a dense, finer-textured strata at a depth of 86 cm were used to estimate the velocity of propagation. The estimated velocity of propagation in the upper part of the soil profile was 0.06 m/ns. The dielectric permittivity was 25. No ground-truth observations were obtained at the King Gap site. As a consequence, tabled values of 14 and 0.08 m/ns were used at the Kings Gap site to approximate the dielectric permittivity and velocity of propagation.

Interpretations:
The 200 MHz antenna provides satisfactory penetration depth (about 2.4 m) and definition of subsurface features in an area of Holly silt loam at the Compton site. Numerous planar reflectors were evident in the upper part of radar profiles. These slightly inclined and segmented reflectors are believed to represent truncated layers of alluvium. The reflectors were variable in amplitude, suggesting lateral changes in their textural composition. Knowledge of the highly variable and chaotic subsurface stratigraphy may be useful for characterizing soils and preferential or subsurface water flow.

Figure 1 is a representative radar profile from and area of Gleneyre soils at the Decker Hollow site. This profile was collected with a 400 MHz antenna. With a scanning time of 60 ns and a pulse velocity of 0.06 m/ns, the estimated profiling depth is about 1.78 m. A depth scale (in meters) has been drawn on the left side of the figure. The dark vertical lines at the top of the radar profile represent observation points. These observation points are spaced about 2 m apart. The well-expressed but poorly defined planar reflector in the upper part of this profile represents a dense layer of finer-textured (very fine sandy loam) material that grades into coarser textured materials with depth. The upper boundary of this dense layer is poorly defined and consists of short segments of varying signal amplitude. The discontinuous and variable characteristics of this interface are believed to reflect soil disturbances caused by tree falls, which is well documented in the cradle-knoll micro-topography of the site. Several point anomalies are evident in the upper part of the radar profile. These hyperbolic reflectors are produced by tree roots or coarse fragments in the soil. Faint, but recognizable reflectors are evident in the lower part of this profile and represent subsurface strata.

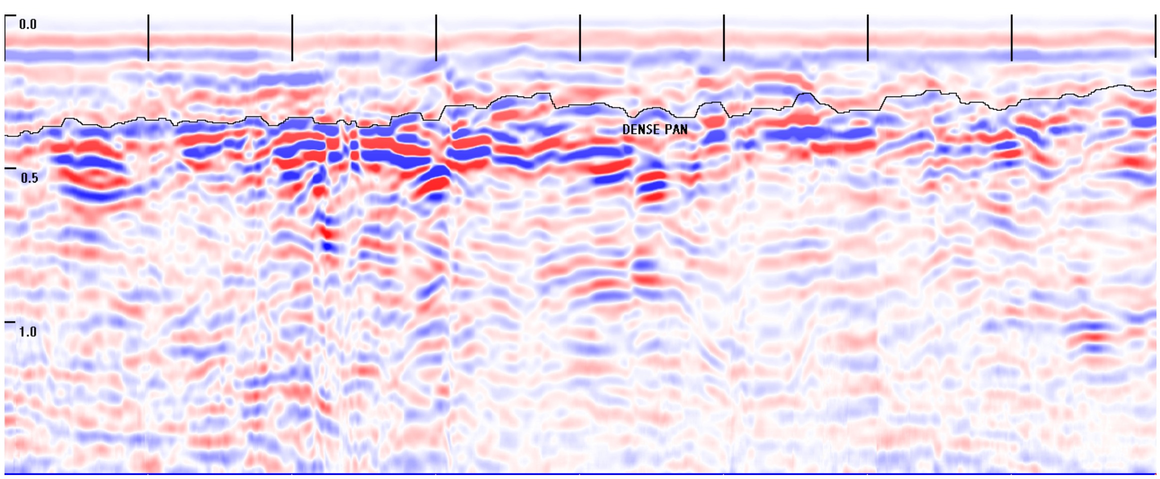

Figure 1. Representative radar profile obtained with a 400 MHz antenna in an area of Gleneyre soil.

Two orthogonal traverse lines were laid out at the King Gap Pond site. With a scanning time of 150 ns and an approximated propagation velocity of about 0.08 m/ns, the estimated profiling depth is about 6 m in well drained areas of colluvium. Because of shallow layers of fine-textured materials, penetration was severely restricted within the vernal pond. In adjoining, more sloping colluvial areas, this finer textured layer was absence and signal penetration was greater. The stratigraphic information contained in these radar profiles may be of use to geologists trying to unravel the origin and evolution of similar vernal ponds.

Figure 2 is a representative radar profile from the King Gap Pond site. The vertical scale is a time scale and is expressed in nanoseconds. The dark segmented lines at the top of the radar profile represent flagged observation points that are space about 3 m apart. An edge of the vernal pond was traversed in the extreme left-hand portion of the radar profile. Depth of penetration was severely restricted in this portion of the radar profile due to the high clay content of the soil. In the left-hand and central portions of this profile, the continuous, parallel horizontal bands at a depth of about 90 ns represent low amplitude background noise. In conductive soils, unwanted multiples of low frequency noise commonly occurs on radar profiles. This form of background noise results from signal dispersion and the high gain setting used to amplify weaker subsurface reflections. Dispersion of electromagnetic energy in soils causes pulse broadening.

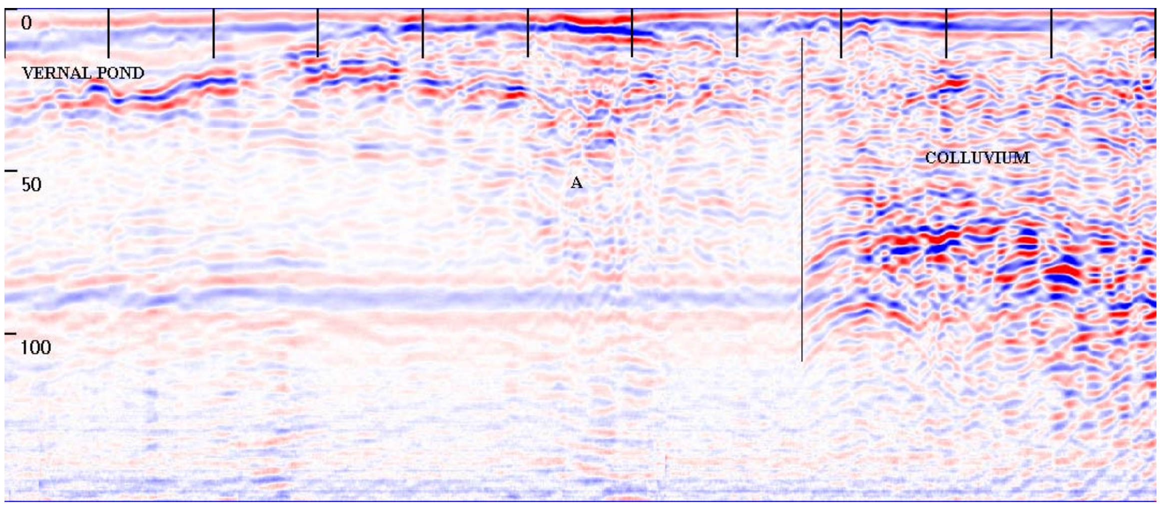

Figure 2. Representative radar profile obtained with a 200 MHz antenna at King Gap Pond site.

In Figure 2, two anomalous features are apparent. An area of deeper penetration is evident near “A.” The deeper penetration is attributed to lower clay contents. The shape of this feature suggests a filled solution feature. Signal amplitude and the depth of penetration noticeably increase to the right of the vertical line drawn in Figure 2. The abrupt change in signal amplitude and penetration depth suggests a sudden and critical shift in the clay and/or moisture contents. Geologists should investigate these features more thoroughly.

Two additional traverses were conducted across Kimble Pond site. This pond was located along the eastern face of South Mountain. Kimble Pond lacks layers of fine-textured material that are associated with the King Gap Pond site. As a consequence, depths of penetration were greater in Kimble Pond. Kimble Pond was enclosed by a low wall that was designed (for research purposes) to restrict the movement of salamanders. In addition, a portion of this pond had been used as a refuge dump. These features restricted the radar survey and introduced unwanted background noise into the radar records. These sources of noise impaired interpretations.

EMI:

A high intensity EMI survey was conducted at the Compton site in Wayne County as part of the demonstration for the Mid-Atlantic Hydric Soil Committee. The site was located in an area that had been mapped as Holly silt loam and Holly silt loam, ponded (Eckenrode, 1982).

Electromagnetic induction is a noninvasive geophysical tool that is used for high intensity surveys and detailed site assessments. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. Results of EMI surveys are interpretable in the field. This geophysical method can provide in a relatively short time the large number of observations that are needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for characterizing site conditions, planning further investigations, and locating sampling or monitoring sites.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific observation depth (Greenhouse and Slaine, 1983). Electromagnetic induction measures vertical and lateral variations in apparent conductivity. Values of apparent conductivity are seldom diagnostic in themselves, but lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, the spatial distributions of apparent conductivity are often shown in two- and three-dimensional plots.

Variations in apparent conductivity are caused by changes in the electrical conductivity of earthen materials. Electrical conductivity is influenced by the volumetric water content, phase of the soil water, temperature, type and concentration of ions in solution, and amount and type of clays in the soil matrix (McNeill, 1980). Apparent conductivity is principally a measure of the combined interaction of the soil's soluble salt content, clay content and mineralogy, and water content. The apparent conductivity of soils increases with increased soluble salts, clay, and water contents (Kachanoski et al., 1988; Rhoades et al., 1976). In any soil-landscape, variations in one or more of these factors may dominate the EMI response.

Field Procedures:
Data were collected in the continuous mode with the Geonics EM38Dpro Data Logging System. The EM38DD meter was carried at a height of about 6 cm above the ground surface. Walking at a fairly uniform pace along parallel rows, in a back and forth pattern across the field completed the EMI survey. Both EMI and GPS data were recorded at a rate of one observation per second. Four traverses were conducted across the field (see Figure 3). This resulted in 866 observations.

Interpretations:
Figure 3 shows the spatial distribution of apparent conductivity collected with the EM38DD meter in the deeper sensing (0 to 1.5 m) vertical dipole orientation. In Figure 3, the isoline interval is 3 mS/m. The location of each observation point and traverse is shown in Figure 3.

Apparent conductivity averaged 5.53 mS/m with a range of 0.1 to 17.1 mS/m. Half of these observations had values of apparent conductivity between 3.8 and 7.0 mS/m. Differences in apparent conductivity were slight and believed to principally reflect differences in clay content.

In Figure 3, areas of low apparent conductivity are better drained and have lower clay contents and/or shallower depths to coarse-textured alluvial materials. In the southeast corner of the field, an area of slightly finer-textured materials is manifested by higher (>7 mS/m) apparent conductivity values. In the northern part of the field, two comparatively large, isolated areas of higher apparent conductivity are associated with areas of ponded water and/or slightly higher clay contents. The bands of lower (<4 mS/m) apparent conductivity along the western portion of the field are associated with more sloping and better-drained soils that are shallower to sands and gravels.

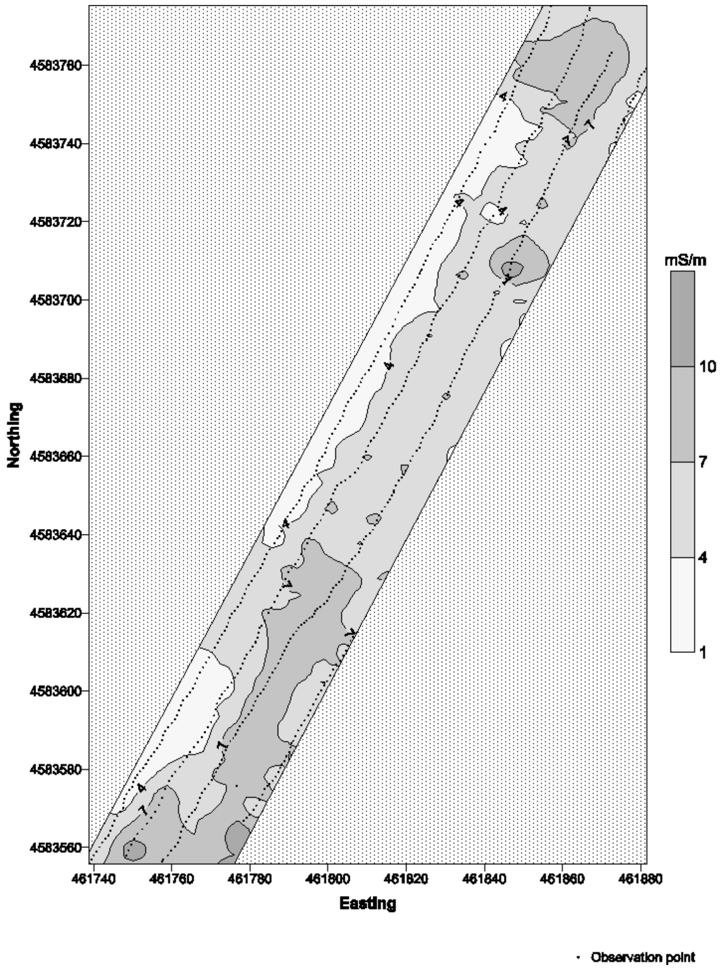

Figure 3. Spatial patterns of apparent conductivity in an area of Holly soils measured with an EM38DD meter in the vertical dipole orientation.

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