Route to Soil Scientists

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

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Subject: Geophysical investigations of Fragipans in Wayne County, Pennsylvania; August 10 and 11, 1995

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To: Janet L. Oertly
State Conservationist
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Purpose:
To assist graduate students from Pennsylvania State University assess the depth to fragipans in Wayne County, northeastern Pennsylvania.

Participants:
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Activities:
On 10 August, a grid was surveyed with both electromagnetic induction (EM) and ground-penetrating radar (GPR) techniques. On 11 August, multiple transects were completed with GPR in various areas of the watershed. The purpose of the multiple transects was to assess the appropriateness of GPR for other soil investigations within the watershed.

Equipment:
The electromagnetic induction meter was the EM38, manufactured by Geonics Limited*. The meter is portable and requires only one person to operate. Principles of operation have been described by McNeill (1986). The observation depth of an EM meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM38 meter has a fixed intercoil spacing of about 1.0 m. It operates at a frequency of 13.2 kHz. The EM38 meter has effective observation depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

The radar unit was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc. (GSSI).* The use and

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

operation of GPR have been discussed by Morey (1974), Doolittle (1987), and Daniels and others (1988). The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. Radar profiles were plotted on a model GS-608P thermal plotter/printer. The system was powered by a 12-VDC battery. The model 3110 (120 mHz), 3105 (300 mHz), and 3102 (500 mHz) antennas were used in this investigation.

The radar profiles included in this report were processed through RADAN software. Processing was limited to signal stacking, horizontal scaling, compression, customizing color transform and color tables, and annotations.

To help summarize the results of this study, the SURFER program was used. SURFER was developed by Golden Software, Inc. This software was used to develop two-dimensional plots of measurements within each grid sites. Simulated grids were created using kriging methods with an octant search. The data were smoothed using cubic spline interpolation.

Study Site:
The study site was located in an area of Mardin soils near Hamlin in southern Wayne County. Mardin soils are members of the coarse-loamy, mixed, mesic Typic Fragiochrept family. These moderately-well drained soils formed in till. Within the study site, map unit delineations included areas of Mardin channery loam, 3 to 5 percent slopes, Mardin channery loam, 5 to 15 percent slopes, and Mardin channery loam, 15 to 25 percent slopes.

Figure 1 is a two-dimensional contour plot of the study site. All measurements are in meters. The contour interval is 1 m. The shaded areas were not surveyed. Within the site, relief was about 31 m. The site consists of a convex shoulder, plane backslope and concave footslope. The lowest-lying and presumably wettest portion of the site was located in the southern portion of the site. This low-lying area extends beyond the study site into Ariel Creek.

Field Methods
A lazer level was used to establish grid lines and determine the surface elevation of each grid intersection.

An irregularly shaped, 36.6 by 65.8 m rectangular was established across the study site (about 0.24 ha). Survey flags were inserted in the ground at 3.66 m intervals. At each of the 140 grid intersections, measurements were obtained with an EM38 meter, placed on the ground surface, in both the horizontal and vertical dipole orientations. The radar survey was completed by pulling the 500 mHz antenna along eighteen parallel grid lines. Traverses were completed essentially parallel with the slope contours.

Discussion:

Electromagnetic induction

Electromagnetic induction techniques measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted average measurement for a column of earthen materials to a specified observation depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the (i) volumetric water content, (ii) type and concentration of ions in solution, (iii) temperature and phase of the soil water, and (iv) amount and type of clays in the soil matrix, (McNeill, 1980). The apparent conductivity of soils increases with increases in the exchange capacity, water content, and clay content (Kachanoski et al., 1988; Rhoades et al., 1976).

Figures 2 and 3 are two-dimensional plots of the EM data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. Though seldom diagnostic in themselves, lateral and vertical variations in apparent conductivity have been used to infer changes in soils and soil properties. Interpretations of the EM data are based on the identification of spatial patterns within data sets.

In each plot, the interval is only 0.5 mS/m. This narrow interval was necessary because of the relatively low range of apparent conductivities in both the horizontal (0.1 to 2.5 mS/m) and vertical (0.3 to 2.8 mS/m) dipole orientations. Generally, intervals of less than 2 mS/m are considered misleading as they often reflect observation errors.

Values of apparent conductivity were exceedingly low and invariable across the site. The EM38 meter characterized the site as being composed of relatively resistive and homogeneous soil materials (see figures 2 and 3). Comparing figures 2 and 3, values of apparent conductivity, as a rule, increase with increasing observation depth (responses were less in the horizontal dipole orientation than in the vertical dipole orientation meter). In each plot, slightly lower responses were recorded on convex shoulder slopes. Slightly higher responses were recorded on the lower backslope and footslope positions. While generally assumed similar, these differences could reflect changes in soil moisture and clay contents, or depths to fragipan. Basic statistics for the collected EM data are displayed in Table 1.

Table 1

Fragipan Study Site in Wayne County, Pennsylvania

(all values are in mS/m)

Meter	Orientation	Minimum	Maximum	Quartiles 1st	Quartiles Median	Quartiles 3rd	Average
EM38	Horizontal	0.1	2.5	0.8	1.2	1.5	1.20
EM38	Vertical	0.3	2.8	1.2	1.6	2.0	1.58

Ground-penetrating radar

Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. This system operates by transmitting short pulses of electromagnetic energy into the ground from an antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the transmitting antenna. Whenever a pulse contacts an interface separating layers of differing electromagnetic properties, a portion of the energy is reflected back to the receiving antenna. The receiving unit amplifies and samples the reflected energy and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms are displayed on a VGA video screen, printed on a thermal recorder, or are stored on an internal disk drive for future playback and/or post-processing.

A. Interpretation of the radar profile -

Reflected radar waveforms were plotted on a raster-scan, thermal plotter/printer. Through a thermo-chemical reaction, radar images are developed as thermal sensitive paper is moved under a fixed thermal printhead. The intensity of these images are dependent upon the amplitude of the reflected signals.

Figure 4 is an example of a radar profile. The horizontal scale represents units of distance traveled along an antenna traverse. This scale is dependent upon the speed of antenna advance along a traverse line and the rate of paper advance through the thermal plotter. The vertical scale is a time or depth scale which is based on the velocity of signal propagation.

The four basic components of a radar profile have been identified in Figure 4. These components are the start of scan pulse (A), inherent antenna noise (B), surface image (C), and subsurface interface images (D). Each of these components, with the exception of the start of scan pulse, is generally displayed as a group of dark bands. The number of bands can be limited by high rates of signal attenuation or superimposed signals. These bands limit the ability of GPR to discriminate closely spaced interfaces. The dark bands occur at both positive and negative signal amplitudes. The narrow white band(s) separating the darker bands represent the neutral or zero crossing between positive and negative signal amplitudes.

The start of scan image (see A in Figure 4) results from direct feed-through of transmitted pulses into the receiver section of the antenna. Though a source of unwanted clutter, the start of scan pulse is often used as a time reference line.

Reflections unique to each of the system's antennas are the first series of multiple bands on radar profiles. Generally the width of these bands increases with decreasing antenna frequency or signal filtration. These reflection (see B in Figure 4) are a source of unwanted noise on radar profiles.

The surface image (see C in Figure 4) represents the ground surface. Below the image of the surface reflection are images from subsurface interfaces (see D in Figure 4). Interfaces can be categorized as being either plane or point reflectors. Most soil horizons and geologic strata appear as a series of continuous, parallel bands similar to those appearing in Figure 4. Features that produce these reflections are referred to as "plane reflectors." Small objects such as rocks, roots, or buried cultural features can produce a hyperbolic pattern similar to the feature appearing (weakly expressed) to the right of E in Figure 4. Features that produce these reflections are referred to as "point reflectors."

B. Calibration -

Generally, for most soil investigations, auger or coring data as well as exposures and observation pits are used to verify interpretations and confirm the depths to known reflectors. These data are used to determine the depth scale(s). However, in this study, few observations were made to confirm interpretations or observation depths.

The GPR is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g. soil horizon, stratigraphic layer, bedrock surface) and back. In order 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 relationship among depth (d), two-way, pulse travel time (t), and velocity of propagation (v) are described in the following equation (Morey, 1974):

$$v = 2d/t$$

The velocity of propagation is principally affected by the dielectric constant (e) of the profiled material(s) according to the equation:

$$e = (c/v)^2$$

where c is the velocity of propagation in a vacuum (0.3 m/s). The amount and physical state (temperature dependent) of water has the greatest effect on the dielectric constant of a material. Tabled values are available that approximate the dielectric constant of some materials (Morey, 1974). However, as discussed by Daniels and others (1988), these values are simply approximations.

Calibration trials were conducted near the grid site in an area of Mardin soils. In these trials, a variety of antennas and scanning times were used. The purposes of these trials were to determine the dielectric constant and velocity of propagation of electromagnetic energy through the surface soil layers, establish a crude depth scale, and optimize control and recording settings.

During calibration trials, multiple traverses were conducted with the 120, 300, and 500 mHz antennas. A scanning rate of 32 scans/sec was used in these trials and in all subsequent field work. Considerations of desired versus achievable depths of observation and the resolution of subsurface features influenced the selection of scanning times. Based on results of these trials, the 500 mHz antenna with a scanning time of 26 ns was found to provide the most satisfactory profiles of the fragipan.

Based on a known depth (55 cm) to a buried reflector, the velocity of propagation through the surface soil layers and a depth scale for radar profiles were estimated. Based on the round-trip travel time to this reflector, the velocity of propagation was estimated to be 0.1523 m/ns. The dielectric constant was estimated to be 3.88. A scanning time of 26 ns provided a maximum observation depth of about 198 cm. As the reflector was buried at a depth of less than 60 cm, the estimated velocity of propagation and dielectric constant were appropriate for only the surface layers in an area of moderately-well drained, medium-textured soil.

C. Performance -

Ground-penetrating radars do not perform equally well in all soils. The maximum observation depth of GPR is, to a large degree, determined by the conductivity of the soil and geologic materials. Materials having high electrical conductivities rapidly dissipate the radar's energy and restrict the depth of observation. The principal factors influencing the conductivity of soils and geologic materials to electromagnetic radiation are: (i) degree of water saturation, (ii) the amount and type of clay, and (iii) the amount and type of salts in solution.

Electromagnetic conductivity is essentially an electrolytic process that takes place through moisture filled pores. As water-filled porosity is increased, the velocity of signal propagation is reduced, the rate of signal attenuation is increased, and the observation depth of the radar is reduced. For the purpose of this investigation, it was assumed that soil water contents were relatively low, uniform in the surface layers, increased slightly with soil depth and clay content, and decreased with rock content.

Electrical conductivity is directly related to the concentration of dissolved salts in the soil solution. Ions absorbed to clay particles can undergo exchange reactions with ions in the solution and thereby contribute to the electrical conductivity of soils and geologic materials. The concentration of ions in solution is dependent upon the clay minerals present, the relative proportion of ions on exchange sites, the degree of water filled porosity, the pH of the solution, and the nature of the ions in solution. For the purpose of this investigation, it was assumed that the soils have formed from similar geologic materials (till) and have low and similar base saturations.

Soil texture (clay content) and mineralogy strongly influence the performance of GPR. The maximum observation depth of GPR increases as the clay content decreases. Generally, maximum observation depths are about 5 to 25 meters in coarse textured soils, 2 to 5 meters in moderately-coarse textured soils, 1 to 2 meters in moderately-fine textured soils, and less than 0.5 to 1.5 meters in fine textured soils. Observation depths increase as the proportion of low activity clays increases. For the purpose of this investigation, it was initially assumed that observation depths of 0.5 to 2 meters could be attained in areas of Mardin soils.

The amount of energy reflected back to an antenna from a subsurface interface is a function of the dielectric gradient existing between the adjoining materials. The greater or more abrupt the difference in dielectric properties, the greater the amount of energy reflected back to the antenna, and the more intense will be the amplitude of the image recorded on the radar profile. At the time of this study, the soils were exceptionally dry and the fragipan was difficult to detect with GPR. The upper boundary of the fragipan was not always abrupt or strongly contrasting with the overlying horizons. In many of the recorded observation pits, a Bw horizon or a weakly expressed fragipan overlay the layer of maximum fragipan expression. Because these features represent gradational or transitional material, the capacity of GPR to detect and define the fragipan was reduced.

Figure 5 is a representative radar profile from the calibration site. This figure consists of two traverses along the same line. The profile on the left contains a buried point reflector (A); the profile on the right has the buried point reflector removed. In the right-hand portion of Figure 5, the general location and trend of the fragipan has been approximated with a dark line.

Figure 6 is a representative radar profile from the study site. In Figure 6, the upper boundary of the fragipan has been highlighted and the depth scale has been approximated. Attempts to consistently identify the fragipan on radar profiles were problematic. At the time of this survey, this interface provided an extremely weak reflection. Interpretations were complicated by the presence of rock fragments and segmented soil layers. In some areas, the image of the fragipan was indistinct or masked by closely-spaced, overlying features (i.e. rock fragments, soil horizons). This interface was often difficult to perceive on radar profiles.

The radar survey, was completed in less than one 1.0 hr. Based on radar interpretations at 140 observation points, the depth to fragipan ranged from about 48 to 65 cm. Within the study site, the average depth to fragipan was about 63.78 cm. One-half of the observations had depths to fragipans between 55 and 59 cm. Figure 7 is a two-dimensional plot of the depths to the fragipan within the grid site.

Radar profiles obtained within the 120 mHz antenna in other portions of the watershed contained reflections from numerous, often segmented soil horizons, and stratigraphic and lithologic layers. Typically, the layers varied laterally in expression. On some radar profiles, reflections from these layers were poorly expressed or partially masked by adjacent strata. The radar detects but does not identify subsurface interfaces. In areas where subsurface layers are numerous or segmented, a large number of auger or coring observations are required to satisfactorily interpret the radar profiles. During this brief investigation, it was not possible to obtain an adequate number of observations to verify interpretations.

Results:
Simulations of the grid site have been prepared and are included with this report. These simulations help to summarize subsurface conditions and may be useful for site assessments.

Electromagnetic induction is an imperfect tool and is not equally suitable for use in all soil investigations. Within the study site, EM responses indicate homogeneous soil conditions. However, because of exceeding low and invariable EM responses, the contribution of observation errors to these results were considered great. As a consequence, other than a general overview of the site, no further analysis was considered practical.

Ground-penetrating radar charted the depths to fragipans within the study site. In general, these profiles were of fair but interpretable quality. Based on ancillary studies in other portions of the watershed, GPR can be used to chart the depths to soil horizons, bedrock, and stratigraphic layers.

All data (disc) and radar profiles have been turned over to Miguel Calmon under a separate cover letter. I wish to thank you for this opportunity to work with Pennsylvania State University.

With kind regards.

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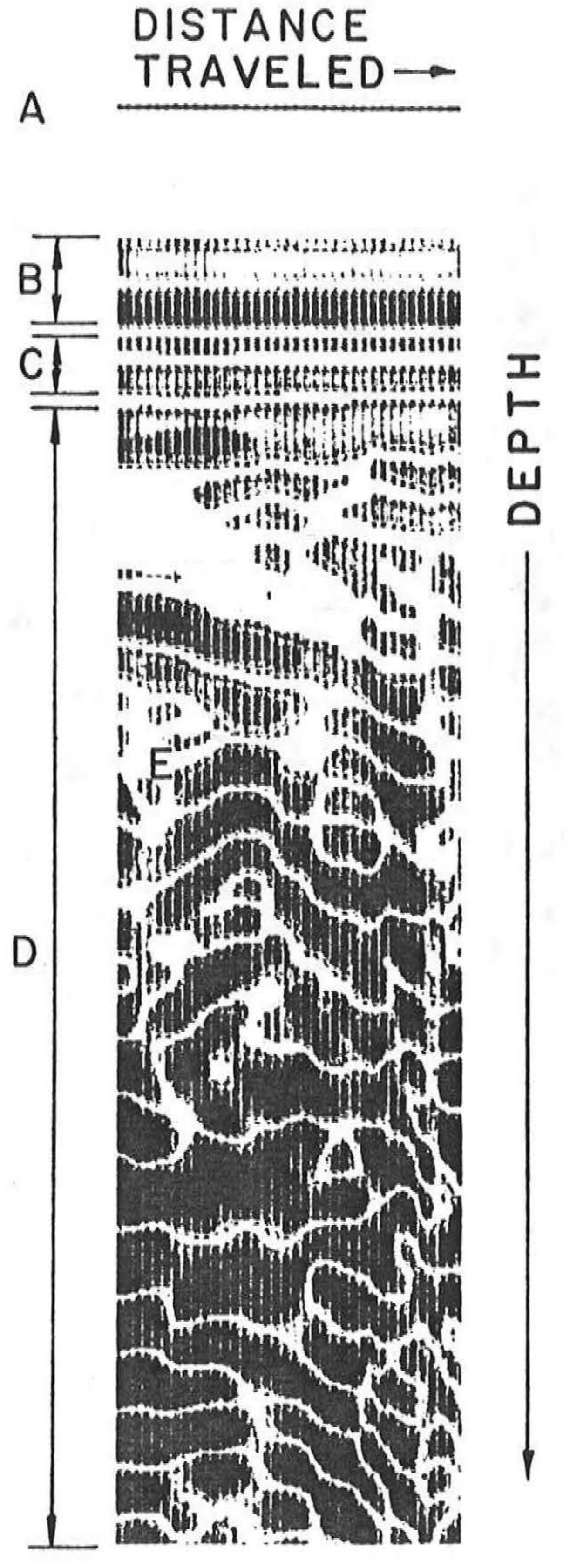

RADAR PROFILE