United States Department of Agriculture

NRCS

Natural Resources Conservation Service
National Soil Survey Center
Federal Building, Room 152
100 Centennial Mall North
Lincoln, NE 68508-3866

Phone: (402) 437-5499
FAX: (402) 437-5336

Subject: Soils – Geophysical Investigations **Date:** 5 May 2014

To: Lawrence Tennity
State Engineer
USDA-Natural Resources Conservation Service
1221 College Park Drive, Suite 100
Dover, DE 19904-8724

Purpose:

Participants:
James Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Laurie Gandy, Soil Conservationist, USDA-NRCS, Newark, DE
Clarissa Havelow, Civil Engineering Technician, USDA-NRCS, Dover Delaware
Lawrence Tennity, State Engineer, USDA-NRCS, Dover Delaware

Activities:
All activities were completed on 23 April 2014.

Summary:

1. Neither GPR nor EMI provided clear evidence that supports the presence of a subterranean structure buried beneath the grid area next to the swimming pool at the Gandy's residence.

2. The EMI survey revealed two areas with anomalous apparent conductivity measurements. However, these responses were associated with two above ground features: the house and a metallic fence.

3. A weak similarity in spatial patterns was identified between a linear area with anomalously low EC_a and IP values (Figure 5) and an area on the time-sliced radar images (Figure 4). This may be coincidental, but the area may be worthy of ground-truth probings.

It was a delight and my pleasure to work with you, Laurie and Clarissa.

With kind regards,

James Doolittle
Research Soil Scientist
National Soil Survey Center

Background:
An old and unused swimming pool at the Gandy farm will be filled with dirt. Historic accounts mention the presence of three subterranean cellars adjacent to the farm house. One of these subterranean structures has been located between the farm house and the swimming pool. An inspection of this structure revealed deterioration and some siltation. As heavy trucks will be carrying fill materials across the nearby paved area, knowledge of the location of the other two structures is needed to prevent potential collapse. Ground-penetrating radar (GPR) and electromagnetic induction (EMI) surveys were carried out across the confined pavement area in an attempt to identify the locations of these two addition subterranean structures.

Study Site:
The study site is a paved area behind a house that is located at 987 Marl Pit Road in Middletown, Delaware. The soils at this site are mapped as Reybold silt loam, 2 to 5 percent slopes (ReB). The very deep, well drained Reybold formed in silty eolian deposits underlain by sandy and loamy fluvial-marine sediments. The depth to this stratigraphic discontinuity (eolian/fluvial-marine contact) ranges from 12 to 45 inches. The Reybold soil is a member of the fine-loamy, mixed, semiactive, mesic Typic Hapludults taxonomic family. Reybold soil is considered moderately suited to GPR.

Geophysical Equipment:
Ground-penetrating radar:
Ground-penetrating radar is a non-invasive, high-resolution geophysical method that transmits short pulses of high to ultra-high frequency (center frequencies from 12.5 MHz to 2.6 GHz) electromagnetic energy into the ground to detect subsurface interfaces. A time-scaled, reflective method, GPR measures the time that it takes pulses of electromagnetic energy to travel from an antenna to a subsurface interface and back. Interfaces often correspond to boundaries of major soil, stratigraphic, and lithologic layers or features. Whenever a pulse contacts an interface separating layers with different relative dielectric permittivity (E_r), a portion of the energy is reflected back to a receiving antenna. The more abrupt and contrasting the E_r on opposing sides of an interface, the greater the amount of energy that is reflected back to the antenna and the greater the amplitude of the recorded signal. To convert the travel time into a depth scale, the velocity of pulse propagation or the depth to a reflector must be known.

A TerraSIRch Subsurface Interface Radar (SIR) System-3000 (henceforth referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH), was used in this investigation.[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 4.1 kg (9 lbs.) and is backpack portable. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A relatively low frequency 270 MHz antenna was used in this study.

The RADAN for Windows (version 7.0) software program (developed by GSSI) was used to process the radar records.[1] The processing procedures used to improve target recognition included: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, horizontal high pass filtration, and migration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

EMI:
The Profiler EMP-400 sensor (here after referred to as the Profiler) is manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[1] The Profiler has a 1.22 m (4.0 ft) intercoil spacing and operates at frequencies ranging from 1 to 16 kHz. It weighs about 4.5 kg (9.9 lbs.). The Profiler is a multifrequency EMI meter that can simultaneously collect data in as many as three discrete frequencies. For each

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

frequency, in-phase and quadrature phase data are recorded. The calibration of the Profiler is optimized for 15 kHz and, as a consequence, apparent conductivity (EC_a) is most accurately measured at this frequency. Operating procedures for the Profiler are described by Geophysical Survey Systems, Inc. (2008).

An EMI survey was conducted along the same lines used by the GPR across the grid site. The sensor was held in the deeper sensing VDO orientation (Figure 1). The sensor's electronics are controlled via Bluetooth communications with a Trimble TDS RECON-400 Personal Data Assistant (PDA).[2] MagMap 2000 software (developed by Geometric, Inc., San Jose, CA) was used for post-acquisition processing of survey measurements [2]. To help summarize the results of the EMI survey, SURFER for Windows (version 10.0) software (Golden Software, Inc., Golden, CO) was used to construct the simulation shown in this report [2].

Figure 1. NRCS Engineering Technician Clarissa Havelow collects EMI data across the grid site with a Profiler EMP-400 sensor.

Survey procedures:

A survey grid was established across the paved area located immediately north of the house and west of a swimming pool. The dimensions of this grid were approximately 56 (X axis) by 20 (Y axis) feet. To facilitate the construction of the grid, two parallel, 20-ft survey lines were laid out (spaced 56-ft apart) and served as grid axis lines (Y axis). Along these two parallel axis lines, survey flags were inserted into the ground at a spacing of 2 ft. A reference line, with marks spaced at 4-ft intervals, was stretched between matching survey flags on the two opposing axis lines. The 270 MHz antenna was towed along this line. Following data collection, the line was sequentially displaced 2 ft to the next pair of survey flags to repeat the process.

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

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., soil horizon, stratigraphic layer, buried cultural feature) 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):

$$Er = (C/ v) 2 \qquad [2]$$

In equation [2], C is the velocity of light in a vacuum (0.3 m/ns). Typically, 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. Dielectric permittivity ranges from 1 for air, to 78 to 88 for water (Cassidy, 2009). Small increments in soil moisture can result in large increases in the E_r (Daniels, 2004).

Hyperbola velocity analysis was used to determine the E_r and v. Hyperbola velocity analysis involves matching an ideal form of a velocity-specified hyperbolic function to the form appearing on the radar record. Cassidy (2009) reported that hyperbolic matching methods produce estimated velocity values with error and variance of ±10% or worse. Based hyperbola matching, the average E_r was estimated to be 15.9, which corresponds to an average v of 0.0752 m/ns. This rather imprecise or "ballpark" measurement of E_r was used to depth scale the radar records.

Results:
Ground-penetrating radar:

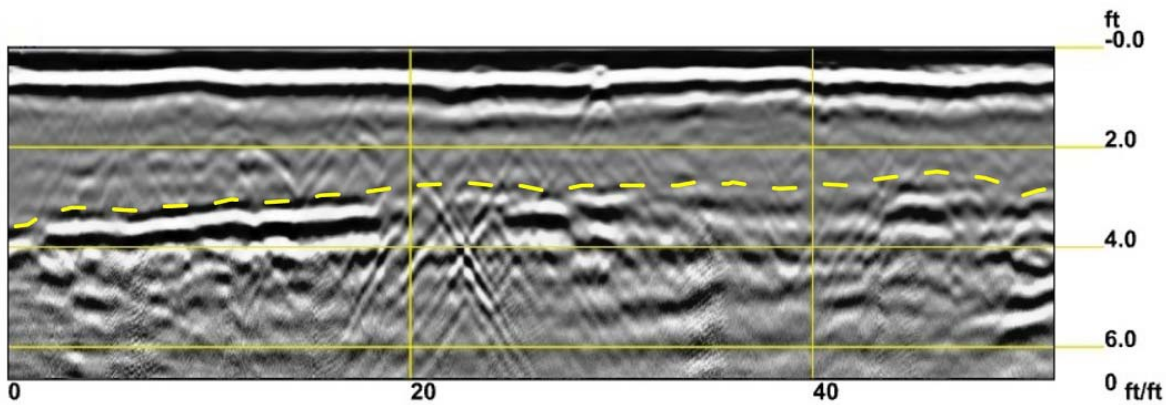

Figure 2. A representative 2D radar record from the grid site (Line Y = 8 ft). The segmented yellow-colored line represents the contact between silty eolian deposits and the underlying sandy and loamy fluvial-marine sediments of Reybold soils.

Figure 2 is a two-dimensional (2D) radar record from line Y = 8 ft. This radar record is representative of the GPR data collected within the grid. Other than the GPR trace being adjusted to zero time (i.e., to correctly assign a position for the surface, which is dependent on the characteristics of the soil material in

contact with the antenna), this radar record has not been processed. In Figure 2, the distance and depth scales are expressed in feet. Reflections from the soil surface produce the high amplitude (intense white and black colors) bands in the upper part (0 to 1.5 ft) of this radar record. Several reflection hyperbolas are evident on this radar record, especially between the 10 and 30 ft distance marks. As these reflectors occur in the upper part of the soil profile, many may represent tree roots, soil inhomogeneities, rock fragments, burrows, or artifacts related to former structures.

A yellow-colored, segmented line has been used to highlight a major subsurface interface on the radar record shown in Figure 2. This interface, though varying in amplitude and expression, is continuous across the survey line. This interface is presumed to represent the contact between the silty eolian mantle and the underlying sandy and loamy fluvial-marine sediments of Reybold soil. The polarity of this reflector appears to change near the 20-ft distance mark. In addition, the clarity of this reflector decreases to the right of the 20-m distance mark in Figure 2. When the dielectric permittivity of the upper layer is higher than that of the lower layer, the reflection coefficient will be positive and the polarity of the reflected wave will be the same as the incident wave (true for first 20 ft). When the dielectric permittivity of the upper layer is lower than that of the lower layer, the reflection coefficient will be negative and the reflected wave will have its polarity reversed or out-of-phase with the incident wave (between the 20 and 56 ft distance mark). The change in polarity is believed to represent an increase in soil moisture and E_r within the underlying marine sediments.

3D Pseudo-Images and Amplitude Slice Analysis:
The effective visualization of radar data is the key to GPR interpretations. The analysis of subsurface structures, distributions, and geometries are often improved using three-dimensional (3D) pseudo-images of gridded sites. Three-dimensional GPR allows visualization of data volumes from different perspectives and cross-sections (Beres et al., 1999). This can assist identification, outline the structure and geometry, and improve the interpretation of subsurface features. In areas of electrically resistive materials, Grasmueck and Green (1996) noted that, compared with 2D GPR, 3D GPR can provide superior resolution and detail of subsurface features. Beres et al. (1999) observed that 3D GPR improves the definition of subsurface structural trends and results in more complete and less ambiguous interpretations than traditional 2D GPR records.

Figure 3 is a 3D pseudo-image of the grid site. This pseudo-image has a 20 by 15 by 4 ft inset cube graphically removed. In order to construct this 3D pseudo-image, GPR data were collected along a series of 11, closely spaced (2-ft interval) traverse lines that were aligned parallel with the x-axis (right-foreground). Each traverse line was approximately 56 ft long. These procedures produced a 56 by 20 ft (1120 ft^2) grid area. In the pseudo-image shown in Figure 3, all measurements are expressed in feet. Because data were continuously recorded along the x-axis (right-foreground), greater detail is evident along this axis than along the y-axis (left-foreground), where data were collected at 2-ft intervals (traverse line spacing). As a consequence, data shown along the y-axis are spatially aliased, “smeared”, and more poorly represented.

In Figure 3, the base of the inset cube is at a depth of approximately 4 ft. The contact of the silty eolian mantle with the loamy and sandy fluvial-marine sediments is clearly expressed as a series of white-black-white bands along the sidewalls of the cube. This interface varies in amplitude and in some area is faint and difficult to trace laterally. Here, the weakness of the reflections from this interface is attributed to a less abrupt and more gradational boundary, and/or partial masking by reflections from overlying features or the presence of excess soil moisture. Along the lower right-front wall of this 3D pseudo-image, near the 20 to 48 ft distance marks, noise attributed to cell phones causes signal interference and produces some incoherent reflection patterns.

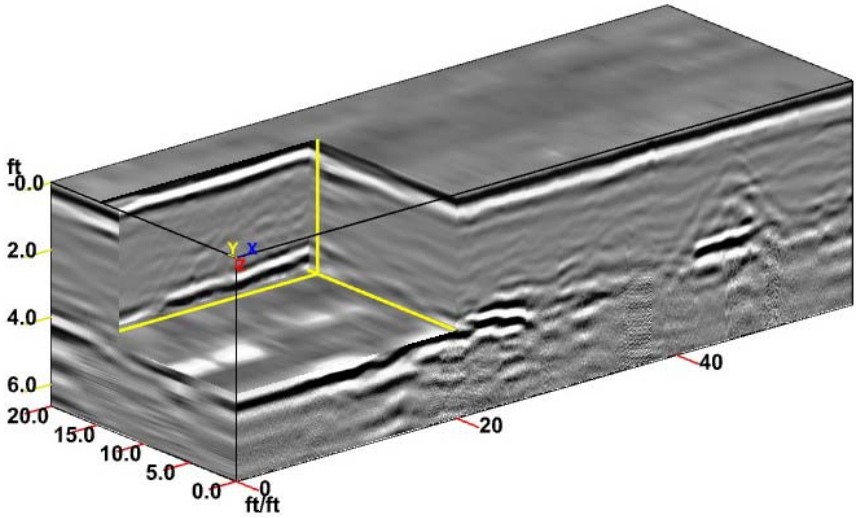

Figure 3. A 3D pseudo-image of the grid site with a 20 by 15 by 4 ft inset cube removed.

One advanced signal processing method that is commonly used in GPR investigations is *amplitude slice analysis* (Conyers, 2004). This analysis method explores differences in signal amplitudes within the 3D pseudo-image in "time-slices" (or depth-slices). In each time-sliced image, the reflected radar energy is averaged horizontally between adjacent, parallel radar traverses and in specified time (or depth) windows (Conyers, 2004). Each amplitude time-slice image shows the distribution of reflected signal amplitudes, which can indicate changes in soil properties or the presence of buried artifacts. In many instances, amplitude time-slice images have been used to distinguish and identify artifacts and to reduce interpretation uncertainties.

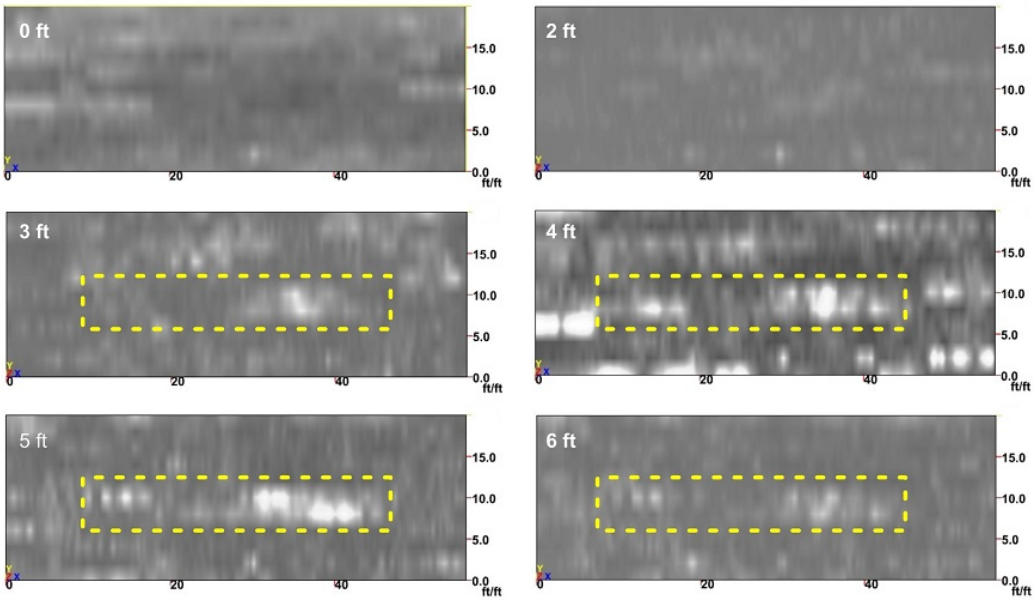

Figure 4. These six time-sliced images show reflected signal amplitudes at different soil depths.

Figure 4 contains six, time-sliced images from the 3D pseudo-image shown in Figure 3. In each of these images, the grid area is viewed from directly overhead. These time-sliced images represent six different

depths (0, 2, 3, 4, 5, and 6 ft). Each time-slice averages the reflections amplitudes spatially and over a depth interval of about 9 inches. No coherent spatial pattern suggesting the walls of a buried structure is manifested on these images. However, below a depth of 3 ft, persistent clusters of high-amplitude (colored white) reflectors have been enclosed by yellow-colored, segment lines. This area of the grid may be worthy of core investigations.

Electromagnetic induction:

Based on 556 measurements, the apparent conductivity (EC_a) averaged 78.6 mS/m with a range of -84.0 to 499.0 mS/m. This wide range in EC_a is anomalous for Reybold soil and reflects the presence of metallic artifacts within and surrounding the grid area.

Figure 5 shows the spatial patterns of apparent conductivity (EC_a; expressed in mS/m) and inphase response (IP; expressed in ppt) measured with the Profiler. Anomalous EC_a measurements were recorded at both ends of the grid. The grid area is border on the south and north by the farm house and a metallic fence. These structures produced the anomalous EC_a measurements along the left and right edges of the grid site shown in Figure 5. Neither the EC_a nor inphase measurements and spatial patterns provide evidence supporting the presence of a subterranean cellar or structure beneath the grid site. However, there is a linear pattern of anomalously low ECa and IP values in the same general area that was enclosed by yellow-colored, segment lines on the time-sliced radar images shown in Figure 4.

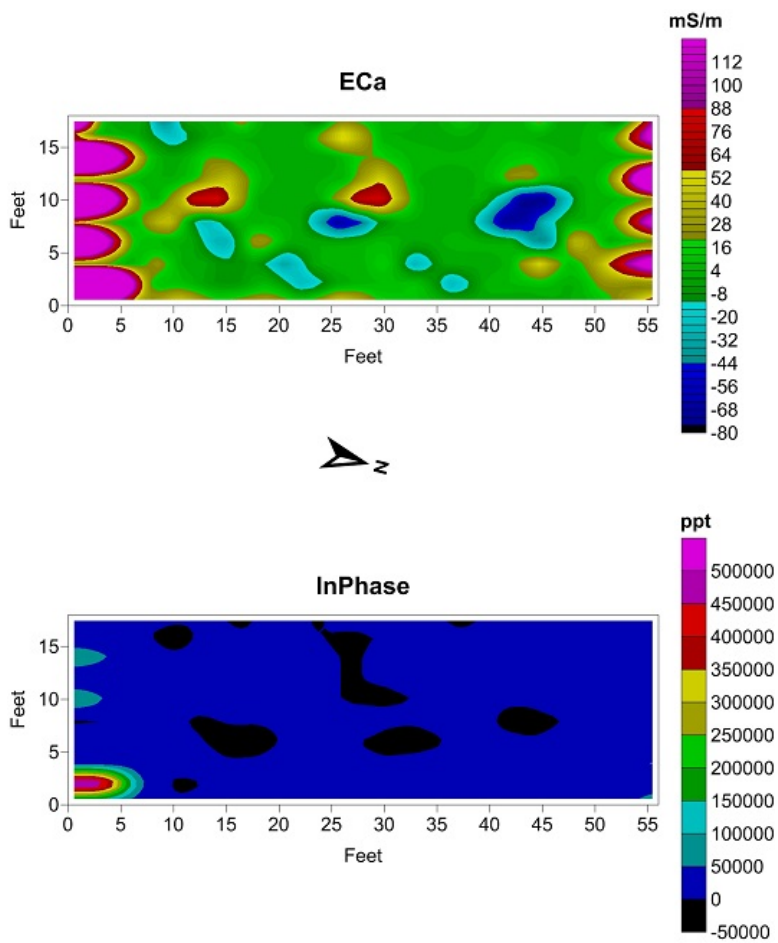

Figure 5. Plots of apparent conductivity (upper) and apparent magnetic susceptibility (lower) measured with the Profiler across the grid area.

References:

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