United States Department of Agriculture

NRCS

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SUBJECT: MGT – Geophysical Assistance

Date: June 6, 2012

TO: Denise C. Coleman
State Conservationist
NRCS, Harrisburg, Pennsylvania

File Code: 330-20-7

Purpose:
In March 2012, USDA-NRCS used electromagnetic induction (EMI) to map apparent conductivity across the Kravitz Tract. Areas of higher EC_a were associated with seep areas and wetter areas of bulrushes and sedges. The Kravitz Tract embraces a major portion of the area that is included in the *French Creek State Park Restoration Project*. A major goal of this restoration project is to restore 280 acres of wetlands and provide habitat for the federally endangered bog turtle. Based on soil observations made by John Chibirka, several probable sites for subsurface drainage pipes were identified. These areas were cleared of vegetation by PA DCNR, Bureau of State Parks, French Creek State Park, to facilitate detailed ground-penetrating radar (GPR) grid surveys. Detailed GPR surveys were conducted across six grids in an attempt to locate undocumented subsurface drainage pipes.

Participants:
John Chibirka, Resource Soil Scientist, USDA-NRCS, Leesport, PA
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Bradley Yothers, Soil Conservation Technician, USDA-NRCS, Leesport, PA

Activities:
Field activities were completed on April 16, 2012.

Summary:

1. Six sites were mowed and cleared of standing vegetation in preparation for detailed GPR grid surveys.

2. Within the Kravitz Tract, GPR provided satisfactory exploration depth and resolution of subsurface features. Major soil horizons (e.g., fragipan) and stratigraphic layers were evident on radar records.

3. Buried drainage pipes, if present, could not be positively identified on radar records. Ambiguities occur in the interpretation of buried drainage pipes as other features with the soil produced similar responses. If present, buried drainage lines provided no sustaining GPR response and, therefore, could not be traced laterally across the grid areas on three-dimensional (3D) pseudo-images using time-slicing techniques.

4. All two-dimensional (2D) radar records contained reflection hyperbolas that varied in depth and expression. However, no reflection hyperbola could be positively identified as a buried pipe. Soils contained a large number of features (e.g., tree roots, rock fragments, animal burrow and soil inhomogeneities) that produced reflection hyperbolas similar to buried drainage pipes.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to be of assistance in this study.

JONATHAN W. HEMPEL
Director
National Soil Survey Center

Attachment (Technical Report)

cc:
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The Use of Ground-Penetrating Radar (GPR) to Identify Undocumented Subsurface Drainage Pipes within the *Kravitz Tract* in Berks and Chester Counties, Pennsylvania, April 16, 2012

James A. Doolittle

Background:

The Kravitz Tract is a historically farmed and drained area that is part of the *French Creek State Park Restoration Project*. A major goal of this restoration project is to restore 280 acres of wetlands and provide habitat for the federally endangered bog turtle. Within the Kravitz Tract, water from surrounding slopes is presently being diverted by surface drains, but older, undocumented systems of buried drainage pipes are believed to be present within the site. The intent of the restoration project is to restore the original hydrology and a tussock-sedge habitat. Agencies involved in this project include the Natural Lands Trust, Pennsylvania Department of Conservation & Natural Resources, Bureau of State Parks, United States Fish and Wildlife Service, and the USDA Forest Service and Natural Resources Conservation Service. The focus of the geophysical surveys is to locate undocumented subsurface drainage systems, filled areas, former stream channels, and seep areas within the Kravitz Tract. This report documents the findings of detailed ground-penetrating radar (GPR) grid surveys that were conducted across six selected areas within the Kravitz Tract.

Kravitz Tract:

Kravitz Tract is a 135-acre subdivision of the French Creek State Park (Figure 1). It is located along the border of Berks and Chester Counties in southeastern Pennsylvania. The entrance to the Kravitz Tract is located along Harmonyville Road about 0.7 mile west of the community of Pine Swamp. The Kravitz Tract was operated as a private farm until it was purchased by the Pennsylvania Department of Conservation and Natural Resources in 2001. Presently, much of the former farm consists of abandoned fields that are naturally revegetating into very dense stands of trees, shrubs and underbrush.

Study Sites:

Six likely sites for buried drainage lines were selected based on observations made by John Chibirka. At each of these sites, grids were established along mowed corridors. The locations of these grids are shown in Figure 2. Grids 1, 2, 3, and 5 had dimensions of 2.5 by 20 m. Grid 4 had dimensions of 3.5 by 20 m. Grid 6 had dimensions of 2.5 by 10 m.

Grids 1, 2, and 3 were located on areas that had been mapped as Readington silt loam, 0 to 3 % slopes (ReA). Grids 4, 5, and 6 were located on areas that had been mapped as Croton silt loam, 0 to 3 % slopes (CwA). The deep and very deep, moderately well drained Readington (fine-loamy, mixed, active, mesic Oxyaquic Fragiudalfs) soils formed in medium-textured residuum weathered from noncalcareous shale, siltstone, and fine-grained sandstone. Readington soils have a fragipan that ranges in depth from about 50 to 90 cm. The deep, poorly drained Croton (fine-silty, mixed, active, mesic Typic Fragiaqualfs) soils formed in medium-textured materials over mainly sandstone, siltstone, or shale on uplands. Croton soils have a fragipan that ranges in depth from about 38 to 64 cm.

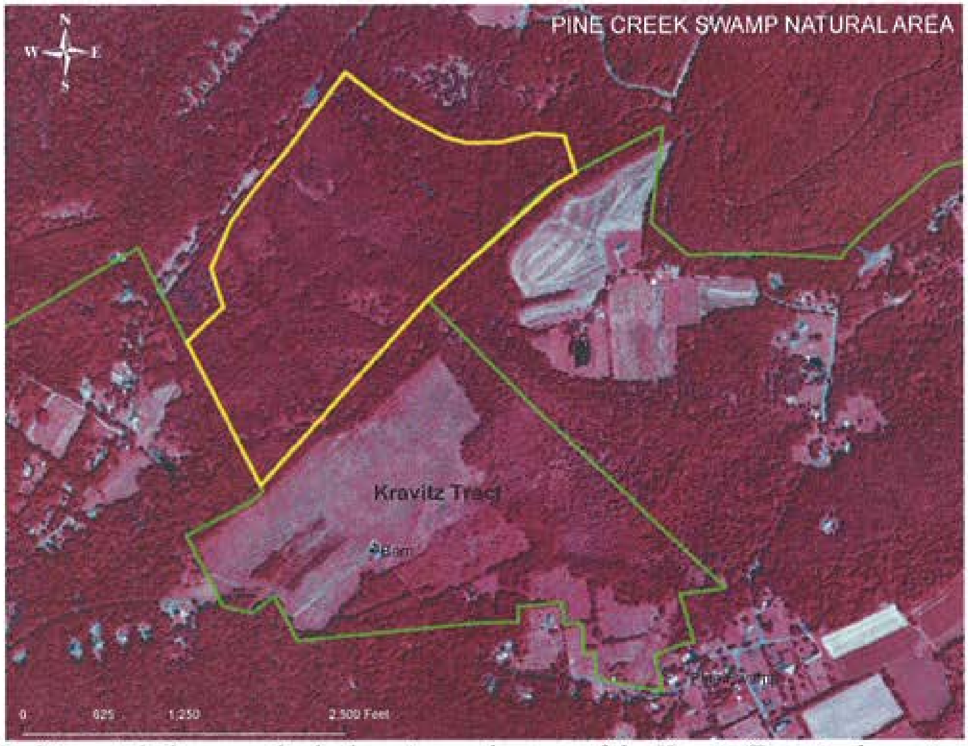

Figure 1. In this aerial photograph, the location and extent of the Kravitz Tract is shown in relationship to the Pine Creek Swamp Natural Area (outlined in yellow) and the community of Pine Swamp.

Figure 2. This Google Earth image shows the approximate locations of the six survey grids within the Kravitz Tract.

Locating subsurface drainage pipes with ground-penetrating radar (GPR):
Subsurface drainage pipes often exist in varying states of preservation. As pipes 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 pipes (Rogers et al., 2005). Maps or records showing the locations of drainage pipes are seldom kept and therefore, little is known about previously installed systems. The absence of surface expression makes finding buried drainage pipes a difficult task. Under suitable soil conditions, ground-penetrating radar can be used to determine the locations and map the geometry of subsurface drainage pipes. Ground-penetrating radar has been used to locate subsurface plastic and metal utility lines (Hayakawa and Kawanaka, 1998; La Flaleche et al., 1991; Wensink et al., 1991) and drainage pipes (Allred and Redman, 2010; Allred and Daniels, 2008; Allred et al., 2005, 2004a, 2004b; Boniak et al., 2002; Chow and Rees 1989).

Chow and Rees (1989) were among the first to report the use of GPR to identify subsurface agricultural drainage pipes. They noted that buried drainage pipes often will produce distinct *reflection hyperbolas* when a GPR antenna passes orthogonally across their long axes and planar reflection when the GPR antenna passes parallel to their long axes. Reflection hyperbolas appear on radar records as upside-down U-shaped features.

Grids are needed to identify and properly characterize the geometry of buried drainage lines with GPR. In Ohio, Allred et al. (2004a and 2004b) used a 250 MHz antenna to complete detailed GPR grid surveys over relatively small sites. They reported that GPR detected 81 % of the known drainage pipes. These pipes 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) and Allred and Redman (2010) reported that the averaged effectiveness of GPR for detecting buried drainage pipes was about 74 %. However, these researchers noted that the effectiveness of GPR for drainage pipe detection "requires careful consideration of computer processing procedures, equipment parameters, site conditions, and field operations" (Allred et al., 2005). Allred and Daniels (2008) noted that grid surveys and computer processing are essential for the detection of drainage pipes embedded in the GPR raw data. In addition, Allred et al. (2005, 2008) stressed several additional factors that need to be considered for the effective use of GPR in the detection of drainage pipes. These factors included: variability in soil moisture and texture, drainage pipe size, orientation, and depth, and survey procedures.

Equipment:
The radar unit used in this survey is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the 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. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A 200 MHz antenna was used in this study.

The RADAN for Windows (version 6.6) software program was used to process the radar records.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, and migration (refer to GSSI (2009), Jol (2009) and Daniels (2004) for discussions of these techniques).

The SIR-3000 system provides a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan on radar records can be georeferenced (position/time matched). Following data collection, a subprogram within the RADAN for Windows software program (GSSI) can be used to

[1] Trade names are used for specific references and do not constitute endorsement.

proportionally adjust the position of each radar scan according to the time stamp of the two nearest positions recorded with the GPS receiver. [2] A Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to collect position data.[2] Position data were recorded at a time interval of one reading per second. The scanning rate of the GPR was set at 64 scan/sec.

Ground-penetrating radar 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, buried feature) and back. To convert the travel time into a depth scale, 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 (Daniels, 2004):

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

Where C is the velocity of propagation in a vacuum (0.3 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.

Near the barn on the Kravitz Tract, a metallic reflector was buried in the ground at a depth of 50 cm. Based on the two-way travel time to this reflector and equations [1] and [2], the estimated v and E_r were 0.1167 m/ns and 6.62, respectively. These values were used to depth scale the radar imagery.

Survey Procedures:
Six small survey grids were established within the Kravitz Tract (Figure 2). At each grid site, two parallel survey lines were laid out and served as the grid limits and the two Y-axis lines. Along these two parallel axis lines, survey flags were inserted into the ground at 50 cm intervals. A distance-graduated rope was stretched between matching survey flags on these two opposing Y-axis lines. The 200 MHz antenna was towed along the graduated rope and as it passed each 100-cm graduation marked on the rope, a mark was impressed on the radar record. Following data collection along the line, the distance-graduated rope was sequentially displaced 50-cm to the next pair of survey flags to repeat the process across the grid site.

Results:
Ground-penetrating radar provided satisfactory exploration depth and resolution of subsurface features. Major soil horizons (e.g., fragipan) and stratigraphic layers were evident on radar records. However, ambiguities occur in the interpretation of buried drainage pipes as other features with the soil produced similar responses and unwanted background noise.

Buried drainage pipes, if present in the grid areas, could not be positively identify on radar records. If present, buried drainage lines provided no distinguishing characteristics and could not be traced laterally across the grid area on three-dimensional (3D) pseudo-images using time-slicing techniques. All two-dimensional (2D) radar records contained reflection hyperbolas that varied in depth and expression. However, no reflection hyperbola could not be positively identify as a buried pipe as other features within the soil, such as tree roots, rock fragments, animal burrow and soil inhomogeneities, produced responses that were similar to buried drainage pipes on radar records.

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[2] Trade names are used for specific references and do not constitute endorsement.

Because of the large number of reflection hyperbolas occurring on the radar records, the *Auto-Target module* (ATM) of RADAN 6.6 was used to search the raw data for reflection hyperbolas. This module is useful for large 3D data sets where finding a pipe can be very labor-intensive (GSSI, 2009). Once the *ATM* process was completed, the picked reflection hyperbolas were reviewed in the *Interactive 3D module* where they could be edited, if needed. The picked data were outputted into a spreadsheet file. While the ATM is considered good for finding reflection hyperbolas within data sets, detection of reflection hyperbolas is impaired when 1) hyperbolas are closely-spaced or overlapping, 2) hyperbolas are irregularly shaped and do not appear "hyperbolic enough", and 3) hyperbolas occur just under the reflection from a strong soil layer and are partially masked.

Figures 3 through 7 provide 2D radar records and 3D pseudo-images from the six grid sites. In each figure, the 2D radar record is for the first traverse that was completed in each grid (X = 0 m). In addition, each figure contains the ATM *picks* of reflection hyperbolas within both the 50 to 100 cm and the 100 to 150 cm depth intervals (as viewed from directly overhead the grid site). On the radar images, all measurements are in meters.

In the 2D radar record shown in Figure 3, six arrows have been used to identify the *picks* shown for the X = 0 m line in the 50 to 100 cm depth interval plot. In the plot for the 100 to 150 cm depth interval, several lineations of pick can be envisaged; all having a similar inclination (lower right to upper left). A drainageway parallels the upper boundary of the *pick plots* and the observed pick lineations may represent buried drainage pipes.

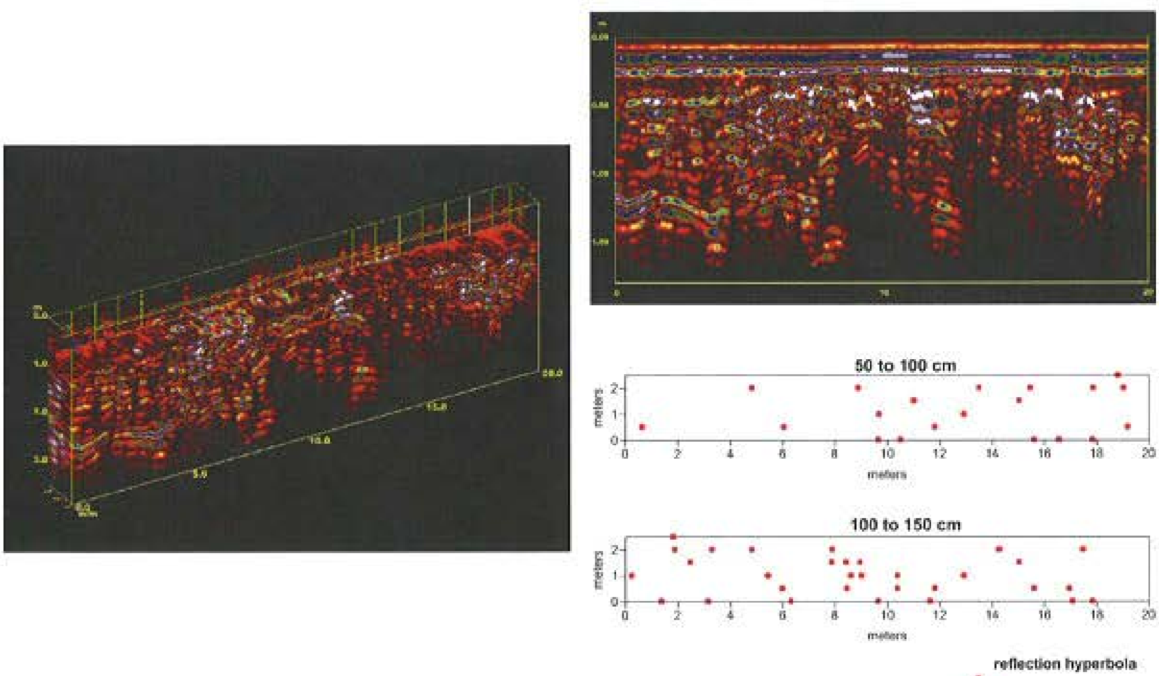

Figure 3. A three-dimensional (3D) pseudo-image of Grid Site 1 with an inset cube removed to a depth of 80 cm across the grid area (left-image). Radar record (upper-right) from line X = 0 m with five arrows indicating the locations of the picks that were automatically selected by the RADAN software program for the 50 to 100 cm depth interval (lower-right)((viewed from directly overhead).

The results from Grid 2 are shown in Figure 4. This grid was located near a wet area, which was suspected to be the result of a ruptured subsurface drainage pipe. The 2D radar record and the 3D pseudo image provide evidence of inclined stratification in the subsurface. Where reflections from these inclined stratifications breach the base of the inset cube of the 3D pseudo-image (Figure 4, left), they produce linear reflections that are similar to ones that would be produced by the long axis of a subsurface drainage pipe. Hence, these stratifications introduce additional uncertainty in interpretations. Several weakly expressed, reflection hyperbolas are evident in the 2D radar record and can be associated with picks seen in the pick plots (lower-left plots in Figure 4).

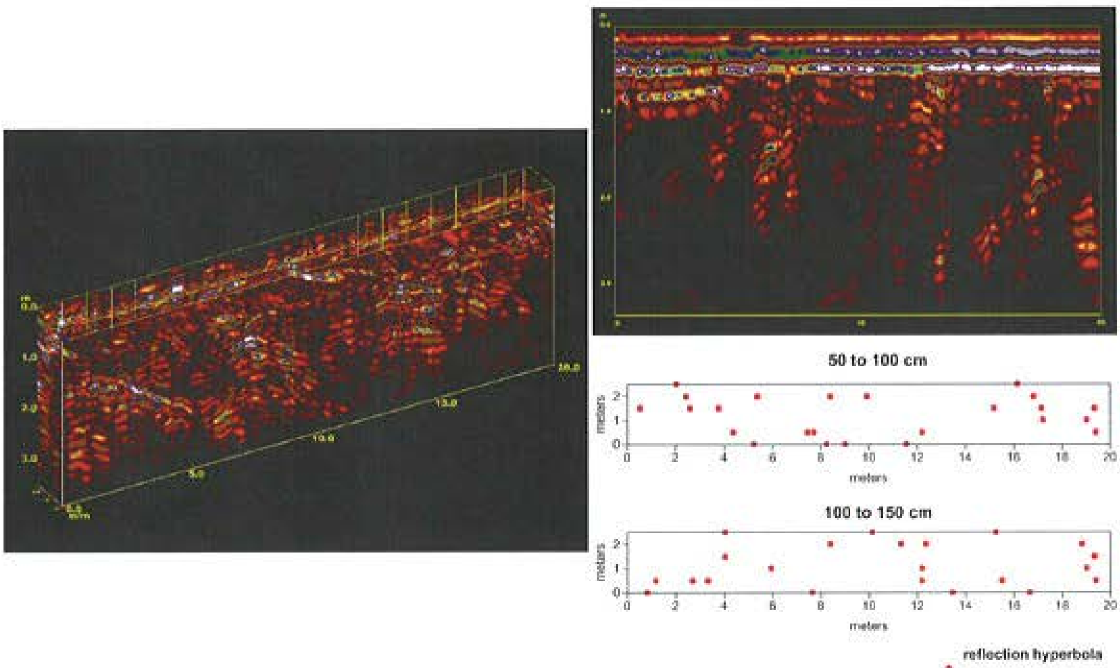

Figure 4. A 3D pseudo-image of Grid Site 2 with an inset cube removed to a depth of 80 cm across the grid area (left-image). Radar record (upper-right) from line X = 0 m (reversed direction from that shown in 3D pseudo image). The locations (viewed from directly overhead) of the ATM selected reflection hyperbolas within the grid area for the 50 to 100 cm and the 100 to 150 cm depth intervals (lower- right).

The results from Grid 3 are shown in Figure 5. Multiple, weakly-expressed reflection hyperbolas are evident in both the 2D radar record and the 3D pseudo-image. The *ATM* identified more reflection hyperbolas than I would have selected. In Figure 5, two, prominent reflection hyperbolas have been indicated with arrows in the 2D radar record and the 3D pseudo-image. These hyperbolas would be my best guess as drainage pipes. However, neither one appears to have been selected by the *ATM*. Reflection hyperbolas that were picked by the *ATM* appear less well-expressed and dispersed randomly across the grid area. Only in the 100 to 150 meter plot of the selected picks are linear trends, which are suggestive of buried drainage pipes, evident.

The results from Grid 4 are shown in Figure 6. The soil contains a very large number of randomly dispersed reflection hyperbolas. These hyperbolas vary in depth and expression, with few standing out as being characteristic of buried pipes. No spatial patterns, which suggest the linear pattern of a subsurface drainage pipe, are evident in either the 50 to 100 cm or the 100 to 150 cm depth interval plots. The large number of picks could have masked the presence of a buried drainage pipe.

The results from Grid 5 are shown in Figure 7. A major subsurface interface extends across the grid area at depth ranging from 1.5 to 2.1 m. This interface presumably separates layers with different textures and moisture contents. The presence of this layer will undoubtedly influence the preferential flow of moisture thru the soil profile. The *ATM* identified more reflection hyperbolas than I would have in this grid area. However, no linear patterns suggestive of buried drainage pipes are manifested in the data set.

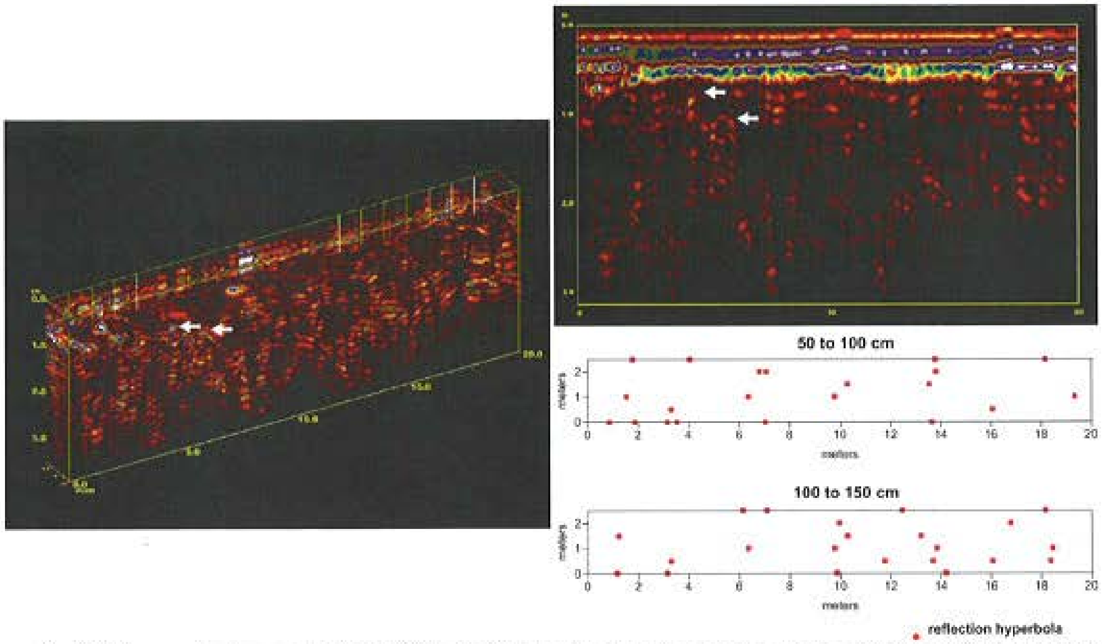

Figure 5. A 3D pseudo-image of Grid Site 3 with an inset cube removed to a depth of 80 cm across the grid area (left-image). Radar record (upper-right) from line X = 0 m. The locations (viewed from directly overhead) of the ATM selected reflection hyperbolas within the grid area for the 50 to 100 cm and the 100 to 150 cm depth intervals (lower- right).

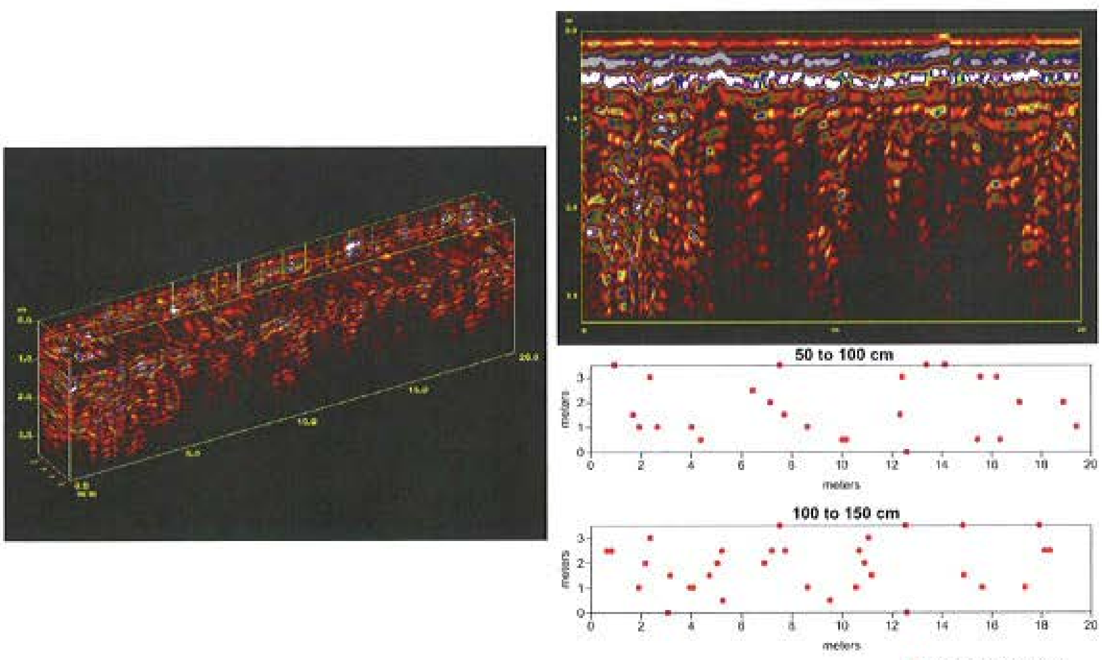

Figure 6. A 3D pseudo-image of Grid Site 4 with an inset cube removed to a depth of 80 cm across the grid area (left-image). Radar record (upper-right) from line X = 0 m. The locations (viewed from directly overhead) of the ATM selected reflection hyperbolas within the grid area for the 50 to 100 cm and the 100 to 150 cm depth intervals (lower- right).

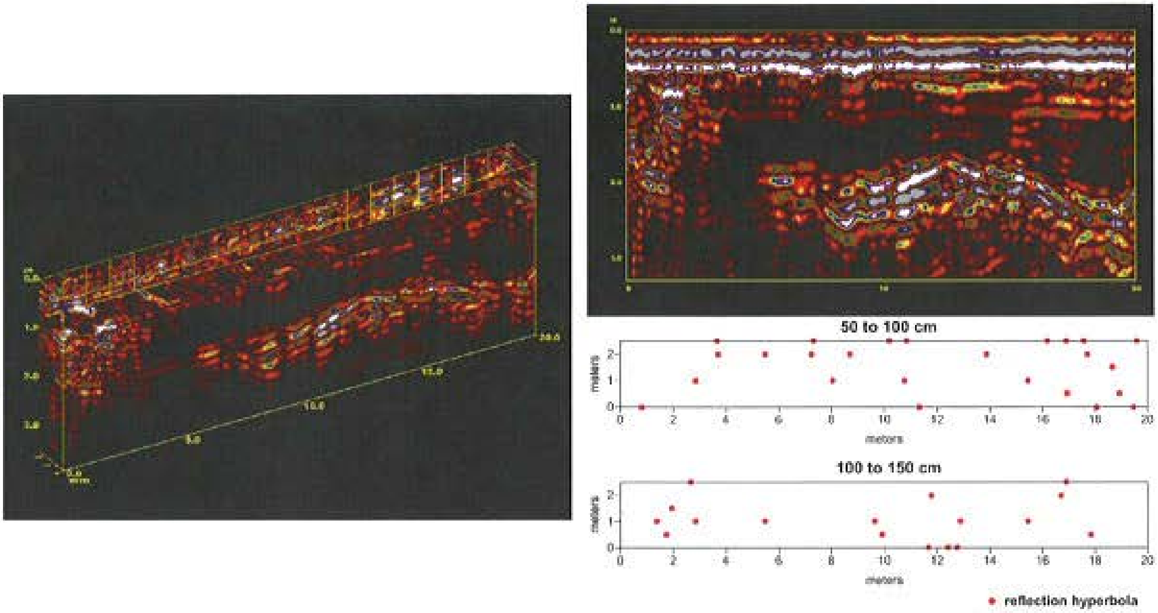

Figure 7. A 3D pseudo-image of Grid Site 5 with an inset cube removed to a depth of 80 cm across the grid area (left-image). Radar record (upper-right) from line X = 0 m. The locations (viewed from directly overhead) of the ATM selected reflection hyperbolas within the grid area for the 50 to 100 cm and the 100 to 150 cm depth intervals (lower- right).

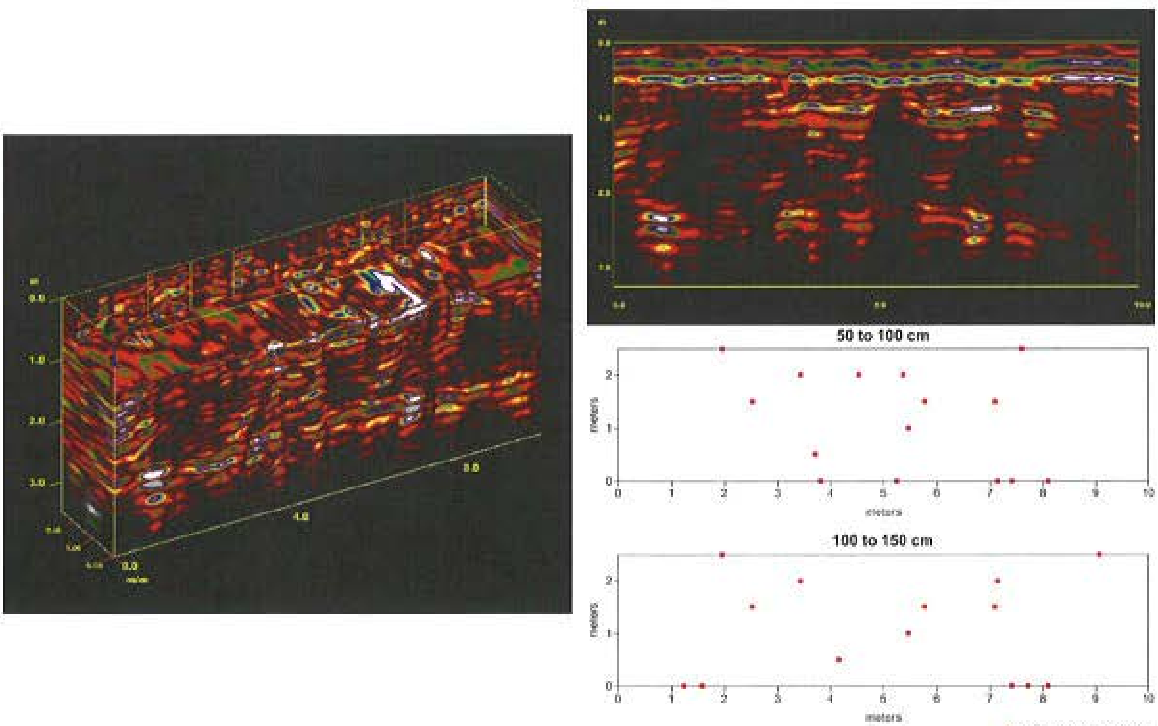

Figure 8. A 3D pseudo-image of Grid Site 6 with an inset cube removed to a depth of 80 cm across the grid area (left-image). Radar record (upper-right) from line X = 0 m. The locations (viewed from directly overhead) of the ATM selected reflection hyperbolas within the grid area for the 50 to 100 cm and the 100 to 150 cm depth intervals (lower- right).

The results from Grid 6 are shown in Figure 8. Two major subsurface interfaces extend across the grid area at depths of about 1.0 and 2.0 to 2.5 m. The upper interface may represent the upper boundary of the fragipan, which separate horizons of different density and moisture contents. The lower interface is believed to separate layers having different textures and moisture contents. The *ATM* identified a scant amount of reflection hyperbolas. No linear pattern suggestive of a buried drainage pipe is evident in these plots.

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