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

Subject: Soils – Geophysical Field Assistance **Date:** 11 March 2003

To: Roy L. Vick, Jr.
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Purpose:
To evaluate the performance of GPR on Coastal Plain soils and, at the request of North Carolina State University, to conduct geophysical investigations of buried agricultural drain lines at the Tidewater Experiment Station in Plymouth, North Carolina.

Participants:
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Mohamed Youssef, Research Associate, Department of Biological and Agricultural Engineering, NCSU, Raleigh, NC

Activities:
All activities were completed during the period of 24 to 28 February 2003.

Results:

1. In an area of Dune land on the Outer Banks, the depth to a water table was mapped with a 200 MHz antenna to 35 m. Information was obtained on the performance of the 200 MHz antenna in areas of relatively dry sandy soils. A soil sample was taken from this area for analysis at the National Soil Survey Laboratory. This will help assess the mineralogical parameters that affect the performance of GPR in sandy soils.

2. GPR surveys were completed at two fields within the Tidewater Experiment Station in Plymouth, North Carolina. These fields have either experienced drainage problems or have ongoing drainage research projects. The GPR detected 4-inch diameter, plastic drain lines and provided interpretable images of the subsurface in areas of Portsmouth and Cape Fear soils. However, in an area of Cape Fear soil, GPR produced unambiguous images of buried plastic drain lines at a depth of 50 cm, but not at a depth of 100cm.

3. All radar records collected within the Tidewater Experiment Station have been made into bitmap files and mailed to Dr Skaggs under a separate cover letter.

4. An EMI survey was completed of one field at the Tidewater Experiment Station and provided additional information that complemented and helped to verify GPR interpretations.

It was our pleasure to work in North Carolina and members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist

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cc:
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Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) 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 powers the system. This unit is backpack portable and, with an antenna, requires two people to operate. The antennas used in this study have center frequencies of 200 and 400 MHz. Hard copies of the radar data were printed in the field on a model T-104 printer.

The RADAN NT (version 3.1) software program was used to process the radar records (Geophysical Survey Systems, Inc, 2001a).[1] Processing included color transformation, marker editing, distance normalization, and range gain adjustments. All radar records were converted into bitmap images using the RADAN to Bitmap Conversion Utility (version 1.4) developed by Geophysical Survey Systems, Inc.[1] Data were processed into a three-dimensional image using the 3D QuickDraw for RADAN Windows NT software developed by Geophysical Survey Systems, Inc.[1] This module permits the creation of 3D simulations and the simultaneous viewing of multiple radar records from the grid area. Once processed, arbitrary cross-sections, insets, and time slices can be viewed and selected images saved to files.

Geonics Limited manufactures the EM38 meter.[1] This meter is portable and requires only one person to operate. No ground contact is required with this meter. The EM38 meter 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, 1998). The Geonics DAS70 Data Acquisition System was used to record and store both EMI and GPS data. [1] The acquisition system consists of an EM38 meter, Allegro field computer, Trimble AG114 GPS

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

receiver, backpack and frame for GPS, and associated cables. With the logging system, the EM38 meter is keypad operated and measurements can either be automatically or manually triggered.

To help summarize the results of this study, the SURFER for Windows (version 8.0) developed by Golden Software, Inc., was used to construct two-dimensional simulations.[1] Grids were created using kriging methods with an octant search.

GPR:
Ground-penetrating radar is a time scaled system. The system measures the time it takes electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, stratigraphic layer) and back. To convert travel time into a depth scale requires knowledge of the velocity of pulse propagation. Several methods are available to 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 (Conyers and Goodman, 1997). The procedure involves measuring the two-way travel time to a known reflector that appears on a radar record and calculating the propagation velocity by using the following equation (after Morey, 1974):

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

Equation [1] describes the relationship between the propagation velocity (V), depth (D), and two-way pulse travel time (T) to a subsurface reflector. During this study, the two-way radar pulse travel time was compared with measured depths to known subsurface interfaces within each study site. Computed propagation velocities were used to scale the radar records.

Results:
<u>Jockey Ridge State Park:</u>
Radar surveys were conducted on a portion of a large sand dune on the Outer Banks. The site is located within Jockeys Ridge State Park, Nags Head, North Carolina. The traverse was conducted in an area that had been mapped as Dune land, 2 to 40 percent slopes (Tant, 1992). This miscellaneous area consists of sand dunes that are devoid of vegetative cover.

A 175 m traverse line was established across a north-facing slope of a large dune. Survey flags were inserted in the ground at intervals of 7.6 m and served as reference points. The elevation of each reference point was measured with a level and stadia rod. Relief was about 35 m. Elevations were not tied to a benchmark; the lowest recorded point was chosen as an arbitrary 0.0 m datum. Surveys were completed with the 200 MHz antenna at scanning times of 500 and 120 ns.

Based on measured depths (0.48 and 1.93 m) to the water table at two reference points, the velocity of propagation through relatively dry sands was estimated to be 0.14 m/ns. The dielectric permittivity was 4.5. Using a scanning time of 500 ns, a velocity of 0.14 m/ns, and equation [1], the maximum depth of penetration through dry sands is about 35 m (115 ft).

The radar records obtained with the 200 MHz antenna at Jockey Ridge were of exceptional quality. Not only was the water table clearly distinguishable beneath this portion of the dune, but also the geometry and structure of major stratigraphic layers were well expressed on radar records. Figure 1 is a representative radar record. The short, vertical lines at the top of the radar record represent the equally spaced (7.6-m) reference points along the radar traverse. The vertical scale along the left-hand margin of this figure is a time scale in nanoseconds. A time scale was required as the velocity of signal propagation varied with depth and ranged from 0.14 m/ns in relatively dry sands to 0.05 m/ns in the saturated sands below the water table.

In Figure 1, the surface has been terrain corrected to improve the visual presentation. Through a process known as "surface normalization" elevations are assigned to each reference point and the image is corrected for changes in elevation. Surface normalization adjusts the vertical scale to conform to changes in topography. After surface normalization, the water table appears as a horizontal or near horizontal reflector within the dune.

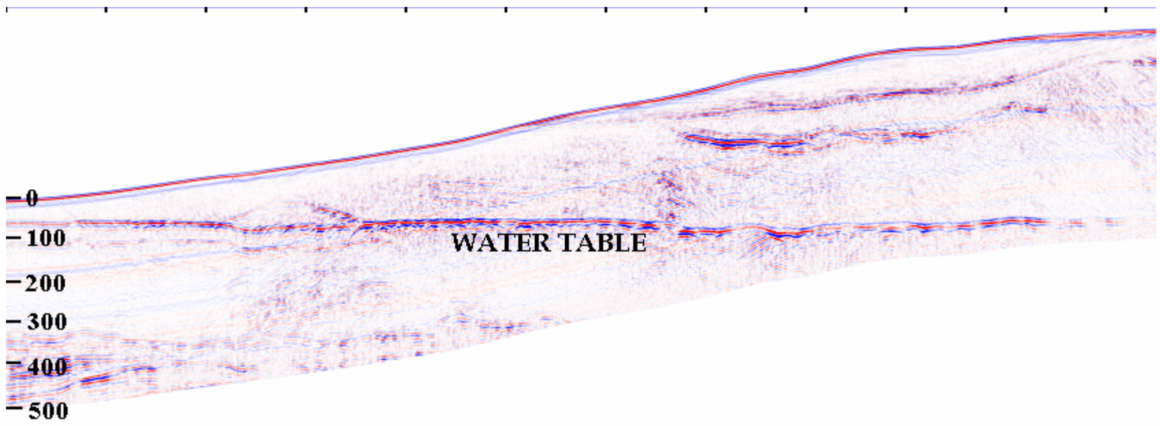

Figure 1. Representative radar record from an area of Dune land, 2 to 40 % slopes; Jockey Ridge, North Carolina.

The water table, major stratigraphic boundaries, and some internal features and bedding planes within stratigraphic units are evident in Figure 1. In the extreme right-hand portion of this figure, the water table is barely perceptible with the 200 MHz antenna at a depth of about 35 m. This appears to be the maximum depth of penetration for the 200 MHz in this area of dry sands. Thirty-five meters is the greatest penetration depth that USDA-NRCS has achieved with a 200 MHz antenna. (A maximum penetration depth of 38 m had been achieved on dunes along Cape Cod, Massachusetts, with a lower frequency, 120 MHz antenna.) This depth testifies to the transparent nature to GPR of unsaturated sands on the Outer Banks.

Fort Raleigh National Historic Park:

A GPR traverse was conducted along a 43 m line in an area that had been mapped as Baymeade fine sand, 1 to 10 percent slopes (Tant, 1992). The site is located within the Elizabethan Gardens at the Fort Raleigh National Historic Site, Roanoke Island, North Carolina. The deep, well drained Baymeade soil is a member of the loamy, siliceous, semiactive, thermic Arenic Hapludults family. Baymeade soil consists of 50 to 100 cm of sandy sediments (the A, E, E/Bh horizons) overlying an argillic horizon. This soil has an intermittent, often weakly expressed Bh or E/Bh horizon.

Traverses were conducted with the 400 MHz antenna. Survey flags were inserted in the ground at intervals of about 3 m and served as reference points. Based on measured depths (38 and 92 cm) to a weakly expressed spodic horizon at two reference points, the velocity of propagation through sands was estimated to be 0.09 m/ns. The dielectric permittivity was 10. Using a scanning time of 40 ns, a velocity of 0.09 m/ns through moist sands, and equation [1], the maximum depth of penetration is about 1.9 m.

The radar records obtained with the 400 MHz antenna in this area of Baymeade soil were of good interpretive quality. Figure 2 is a representative radar record. The short, vertical lines at the top of the radar record represent equally spaced (3 m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of 0.09 m/ns.

In Figure 2, a weakly expressed Bh horizon forms a continuous interface that slopes from a depth of about 40 to 88 cm in the extreme right- and left-hand portions of this radar record, respectively. The reflection from spodic horizon consists of three dark bands. Variations in the amplitude of these reflections are attributed to change in the organic matter content: portions with higher amplitude reflections are darker and are more organically enriched than portions with lower amplitude reflections. Several *point anomalies*, identified by their hyperbolic patterns, are evident in the upper part of the radar record. These features, though not confirmed, may represent buried artifacts (drainage or utility lines) or tree roots. With the 400 MHz antenna, the upper boundary of the argillic horizon, unlike the spodic horizon, is ambiguous and poorly defined. This rather broad and ill-defined interface consists of numerous, discontinuous reflectors that suggest a gradual increase in the concentration of lamella or clay content with depth. It may also be a consequence of the relatively high frequency and resolution of the antenna. An abrupt, contrasting, and continuous boundary should produce a distinct reflection such as evinced by the spodic horizon in Figure 2. It is reassuring to note that two soil horizons (spodic and argillic) needed to taxonomically classify soils have been identified with GPR and each displays a unique radar signature.

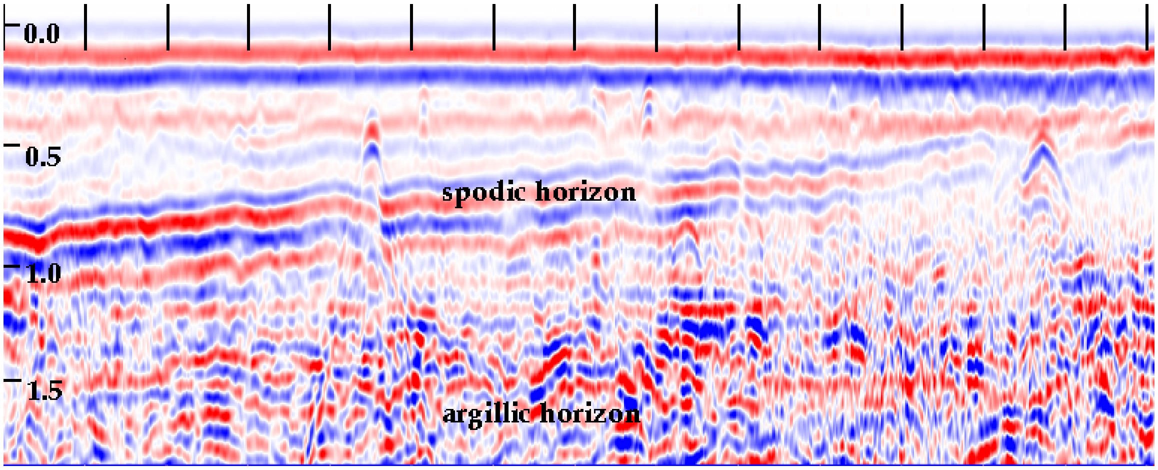

Figure 2. Representative radar record from an area of Baymeade fine sand, 1 to 10 % slopes; Roanoke Island, North Carolina.

<u>Tidewater Experiment Station:</u>
Field N:
Radar surveys were conducted in Field N at the Tidewater Experiment Station, Plymouth, North Carolina. Traverses were conducted in areas that had been mapped as Portsmouth fine sandy loam (Tant, 1981). More recently, a detailed (1:600) soil survey was completed of the Tidewater Experiment Station (Kleiss et al., 1993). The more recent and detailed soil survey shows the field mapped as Portsmouth fine sandy loam and Cape Fear loam (Kleiss et al., 1993). The very deep, very poorly drained Portsmouth soil formed in loamy marine sediments. Portsmouth is a member of the fine-loamy over sandy or sandy-skeletal, mixed, semiactive, thermic Typic Umbraquults family. The very deep, very poorly drained Cape Fear soil formed in clayey marine and fluvial sediments. Cape Fear is a member of the fine, mixed, semiactive, thermic Typic Umbraquults family. For both soils, a 2Cg horizon of stratified sandy materials underlies a finer-textured solum. Portsmouth soil has a fine-loamy solum with a CEC of 5 to 9 meq/100 g that ranges in thickness from 20 to 40 inches. Cape Fear has a fine textured solum with a CEC of 8 to 15-meq/100 g that ranges in thickness from 30 to 60 inches. The thicker, higher clay content of the Cape Fear soil makes it more attenuating and depth restricting to GPR than the Portsmouth soil.

Eight survey lines were established across Field N at the Tidewater Experiment Station. The lines were orientated in a north-south direction and parallel with the long axis of the field. Lines were about 524 m long and spaced 30.5 m apart. Along each line, survey flags were inserted in the ground roughly in front of the centers of eight small sheds that were located along the eastern boundary of the field (see Figure 3). The spacing between the sheds was variable, and ranged from 184 to 226 m. The centers of these buildings were located 41, 108, 177, 245, 314, 382, 438, and 495 m, from the origin (southeast corner) of the grid. The survey flags served as reference points. Traverses were conducted with the 200 MHz antenna with a scanning time of 110 ns. The antenna was towed behind an ATV.

Based on the measured depth to a buried drainage tile (about 1.0 m), the velocity of propagation through relatively moist to saturated, fine-loamy soil materials was estimated to be 0.06 m/ns. The dielectric permittivity was 23. Using a scanning time of 110 ns, a propagation velocity of about 0.06 m/ns, and equation [1], the maximum depth of penetration was about 3.4 m.

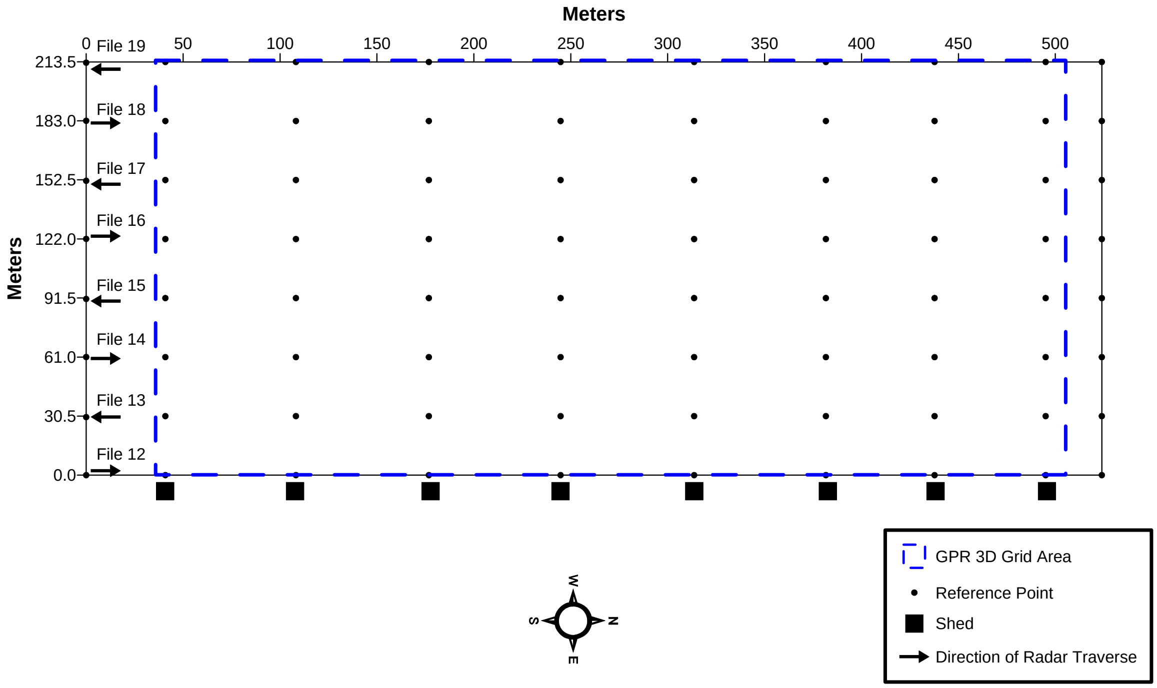

Figure 3. Grid setup for GPR survey of Field N, Tidewater Experiment Station Plymouth, North Carolina.

The radar records obtained with the 200 MHz antenna were of good interpretive quality. Figure 4 is a representative radar record from Field N. The short, vertical lines at the top of the radar record represent reference points that were spaced about 69 m apart along the radar traverse (a uniform spacing is required for processing). A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based an average velocity of propagation of 0.06 m/ns. Parallel, horizontal bands at depths of about 2.6 to 2.9 m represent low frequency system noise produce in these fairly attenuating soils. Observation depths are restricted to depths of less than 2.25 m.

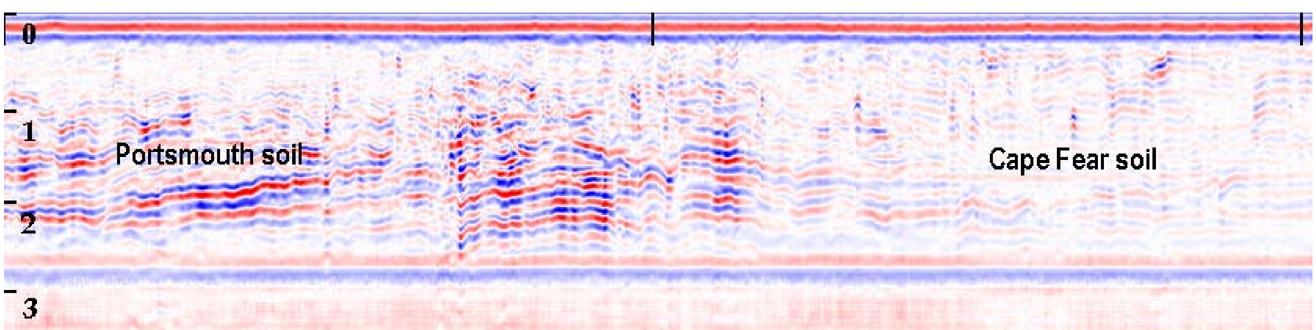

Figure 4. Representative GPR record from and area of Portsmouth and Cape Fear soils, Tidewater Experiment Station Plymouth, North Carolina.

Because of high clay contents within a thicker solum, rates of signal attenuation were noticeably higher in areas of Cape Fear than in areas of Portsmouth soil (right- and left-hand portions of Figure 4, respectively). Higher rates of signal attenuation in areas of Cape Fear soil weaken the amplitude and the interpretability of subsurface reflections.

Both Portsmouth and Cape Fear soils contain multiple, very gently inclined, seemingly continuous, subsurface reflections. These reflections are believed to represent strata compose of contrasting grain and particle sizes. These reflections are more pronounced in the less attenuating Portsmouth soil. Several high amplitude *point anomalies* are evident in the upper part of radar records. These features, though not confirmed, probably represent buried agricultural drains or tree stumps.

A three-dimensional file was created from the GPR data collected in Field N. To create this file only the area immediately in front of the eight buildings was used (see 3D grid area in Figure 3). For purposes of modeling it was assumed that the distance between the centerline of each shed was a uniform 69 m. The grid consisted of eight, 483 m lines that were spaced 30.5 m apart. This created a 483 by 213 m grid. A file was created from the eight radar records collected within the grid area. This file consists of the orderly succession of parallel radar lines that are processed together. To create a three-dimensional display, radar records were appended to one another in order of increasing Y-coordinates. Simulations can be created from this file having the X-axis parallel, and the Y-axis orthogonal to the radar traverse lines. A macro was created to further process (migration and gain functions) this radar record.

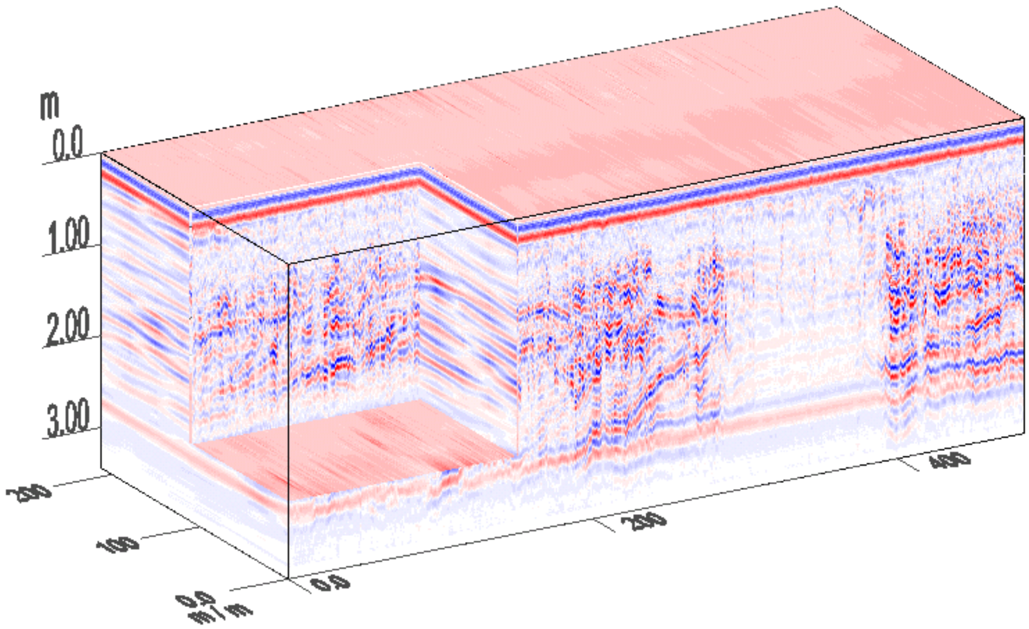

Figure 5. 3D Cutout Cube Diagram of Field N, Tidewater Experiment Station Plymouth, North Carolina.

Figure 5 is a “chair” diagram that has been generated from the radar data. A sub-block has been removed from the cube along different X and Y axes coordinates. The 3D software allows the viewing of data from any angle and the analysis of reflector continuity through cutouts of the cube. In Figure 5, all measurements are in meters. Because of the coarse spacing (30.5 m) between the eight traverse lines and the considerably greater density of data collected along each traverse line, spatial aliasing did occur. Spatial aliasing is the effect of missing a subsurface feature or generalizing the data because they "falls between" two traverse lines. With a more intensive sampling of the field, spatial aliasing can be reduced. However, prudent and efficient expenditures of resources will establish a practical limit on the intensity of sampling.

Figure 6 is a fence diagram showing four lines that are parallel with the x-axis and extending across the grid in a south to north direction. All units are in meters. Fence diagrams provide a mechanism for viewing successive radar traverses and analyzing subsurface information. In Figure 6, a conspicuous zone of lower-amplitude signal reflections extends east to west across the northern part of Field N (roughly between distant measures 300 and 483 m). This zone of attenuated radar reflections represents an area of Cape Fear soil with its thicker, finer-textured and more attenuating solum. While the boundary to this soil delineation is fairly distinct, a modest zone of intermediary signal amplitudes is apparent. No abrupt interface is evident that would imply an abrupt textural change from the fine-loamy Portsmouth to the fine textured Cape Fear soil. The radar record suggests a gradual fining of materials into this channel-like feature.

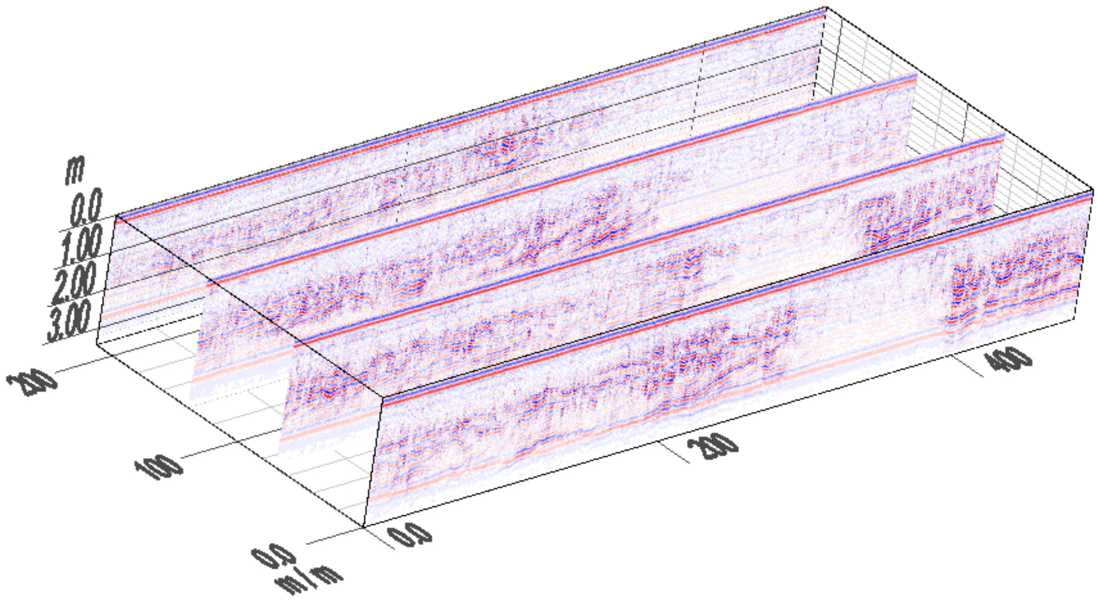

Figure 6. An X fence diagram showing the depth and geometry of subsurface strata within Field N, Tidewater Experiment Station.

Drainage Study Field

Ground-penetrating radar has been shown to be an effective tool for imaging near-surface features in some soils. This technique has been used to locate buried drains, irrigation pipes, agricultural tile lines, and utility cables (Allred et al., 2000; Annan et al., 1984; Asmussen et al., 1986; Chow and Rees, 1989; Kier, 1989). Successful detection of these linear features is dependent principally on soil properties and to a lesser degree by the depth, type and dimensions of the buried cultural features. At the Tidewater Experiment Station, a GPR survey was conducted in a field in which 4-inch diameter, plastic drainage lines were installed at depths of either 50 or 100 cm. The field had been mapped as Cape Fear loam (Kleiss et al., 1993).

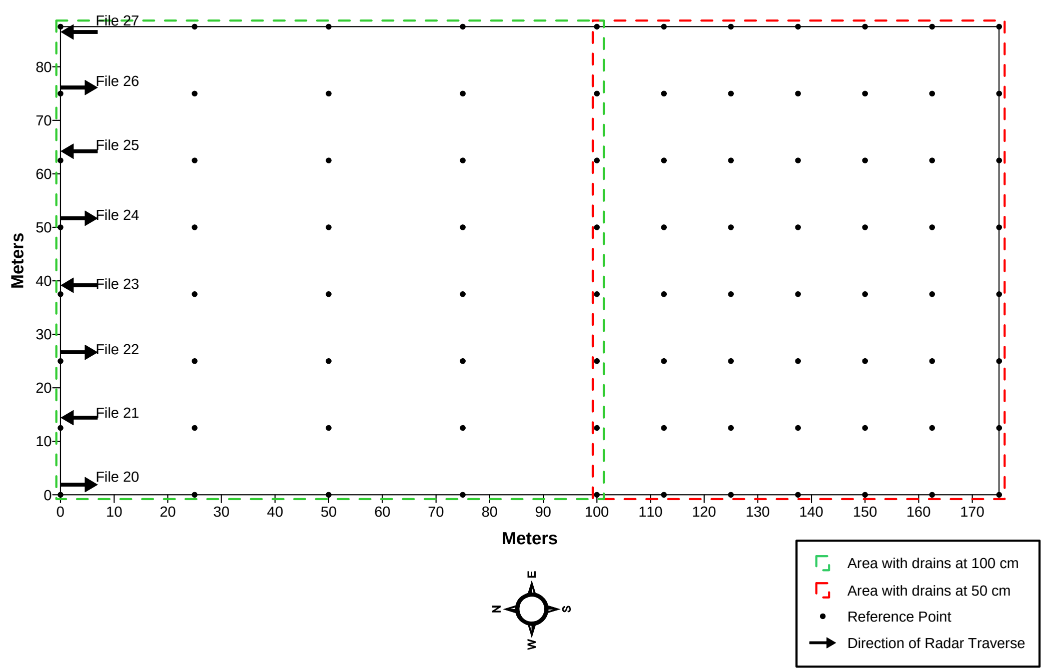

Figure 7. Grid setup for GPR survey of Drainage Study Field, Tidewater Experiment Station.

Eight survey lines were established across the field. These lines were orientated in a north-south direction and parallel with the long axis of the field. Lines were about 175 m long and spaced about 12.5 m apart. Along each line, survey flags were inserted in the ground over known drain lines (see Figure 7). The spacing between the drains was 12.5 m in the southern portion and 25 m in the northern portion of the field. The survey flags served as reference points. Traverses were conducted with the 200 MHz antenna with a scanning time of 70 ns. The antenna was towed behind an ATV.

Based on the measured depth to the plastic drain lines (0.5 m) and a hyperbola-matching velocity-analysis program, the velocity of propagation through saturated fine-loamy and fine-textured soil materials was estimated to be 0.054 m/ns. The dielectric permittivity was 30. Using a scanning time of 70 ns, a velocity of 0.054 m/ns, and equation [1], the maximum depth of penetration is about 1.9 m.

The radar records obtained with the 200 MHz antenna were of good interpretive quality. However the field was highly disturbed with instrumentation, several low ridges, furrows, and swales. It was difficult to maintain a constant speed with the ATV and the rough terrain often jarred the antenna producing unwanted noise on the radar record. Small, shallow pools of surface water produced high amplitude reverberated signals, which masked underlying subsurface features.

Figure 8 is a representative radar record from the southern portion of this field, which contained drains buried at depths of 50 cm (see area enclosed by red dashed line in Figure 7). The short, vertical lines at the top of the radar record represent reference points that were spaced about 12.5 m apart and over known drain lines. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of 0.054 m/ns. The horizontal band at a depth of about 1.8 m represents low frequency system noise produce in this attenuating medium. Observation depths are generally restricted to depths of less than 1.5 m.

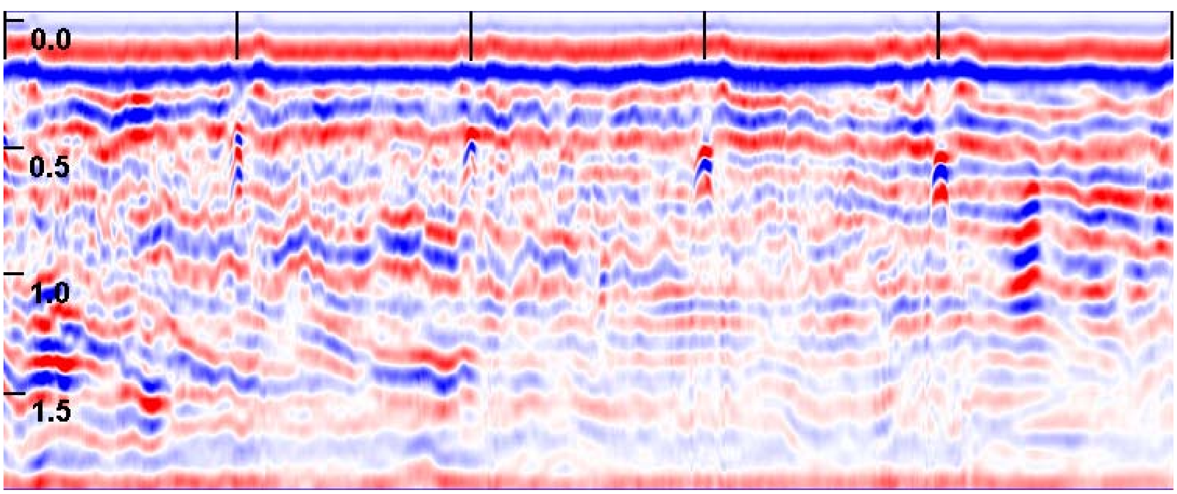

Figure 8. GPR record showing drainage tiles buried at depths of 50 cm.

The dark vertical lines at the top of Figure 8 overly buried drain lines. These 4-inch diameter plastic drains were crossed at right angles with the 200 MHz antenna producing conspicuous, high amplitude, hyperbolic reflections at a depth of about 50 cm. The actual shape of these reflectors varies with the speed and angle at which these features were crossed. In Figure 8, the reflections from the soil surface appear to rise over the drains. The apparent rise in the soil surface at these locations is attributed to a localized acceleration in the velocity of propagation caused by increased soil compaction. Differences in soil compaction affect not only the soil's bulk density and moisture content, but also the propagation velocity of the radar signals. A continuous reflector can be traced across the upper part of the radar record at a depth of about 20 to 30 cm. This interface represents the upper boundary of the argillic horizon.

Small objects such as rocks, roots, and some buried cultural features can produce hyperbolic reflections. Features that produce these reflections are *point anomalies.* In Figure 8, the four prominent point anomalies represent the buried, plastic drain lines. These lines are embedded in the clayey subsoil. In areas of Cape Fear soil, GPR can be used to quickly and nondestructively to locate and map shallow (0 to 50 cm) drainage and irrigation systems.

Figure 9 is a fence diagram showing three lines that are parallel with the x-axis and extending across the southern portion of the grid area in a north to south direction. The origin of this diagram is located in the northwest corner of this portion of the grid area. Each line is 62 m long. In each of the radar records shown in Figure 9, reflections from four buried drain lines can be identified. However, in places, these reflections are obscured by signal attenuation or the reflections from other subsurface interfaces and features. In the radar record for line 87.5 m, a small trench was crossed, jarring the antenna, and producing the noise and disrupted features near position 40 m.

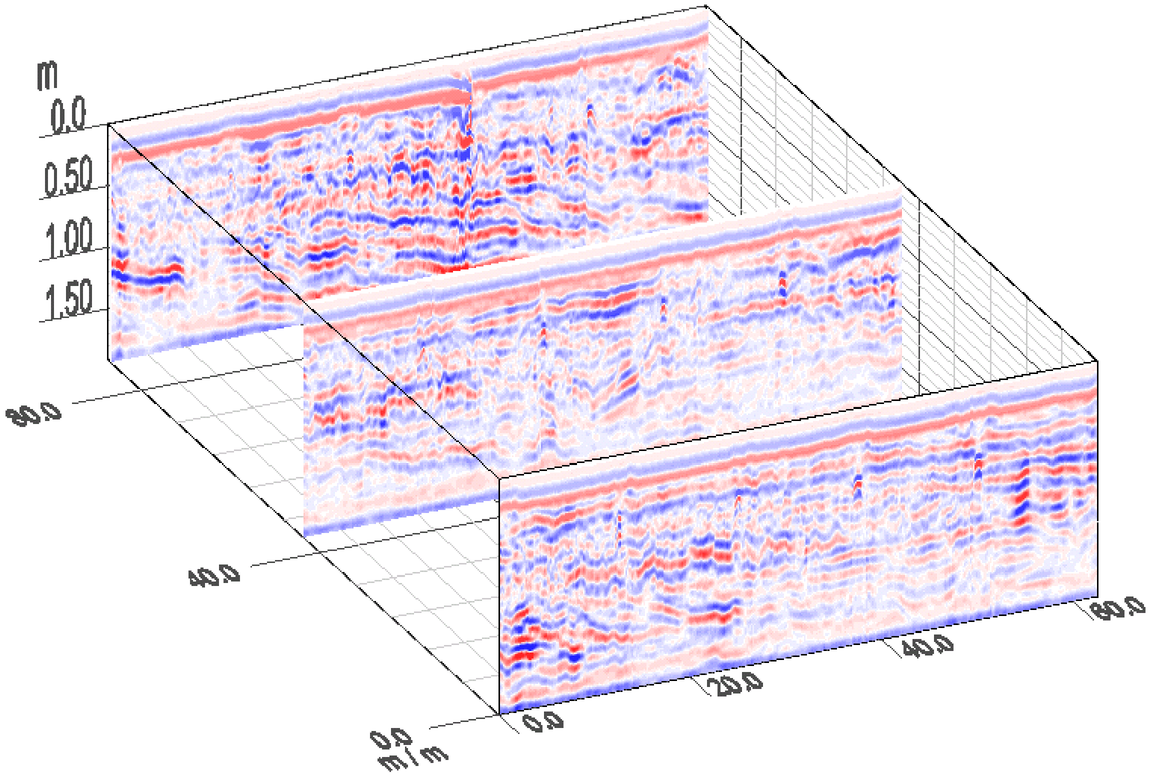

Figure 9. 3D Fence Diagram showing buried drains at 50 cm.

Figure 10 contains a horizontally- or time-sliced image of the southern portion of the field that contains drain lines buried at 50 cm. For added reference, the radar record from line 12.5 meters is also shown. The three-dimensional image has been sliced at a depth of 60 cm. This is equivalent to removing the upper 60 cm of soil across the entire grid area. In this format and at this depth, reflections from the drain lines appear as four continuous, high amplitude, linear reflections that stretch across this time-sliced image. An additional drain line is located at positions X = 0 m. This reflection was truncated during the construction of this diagram and is not clearly expressed in this diagram.

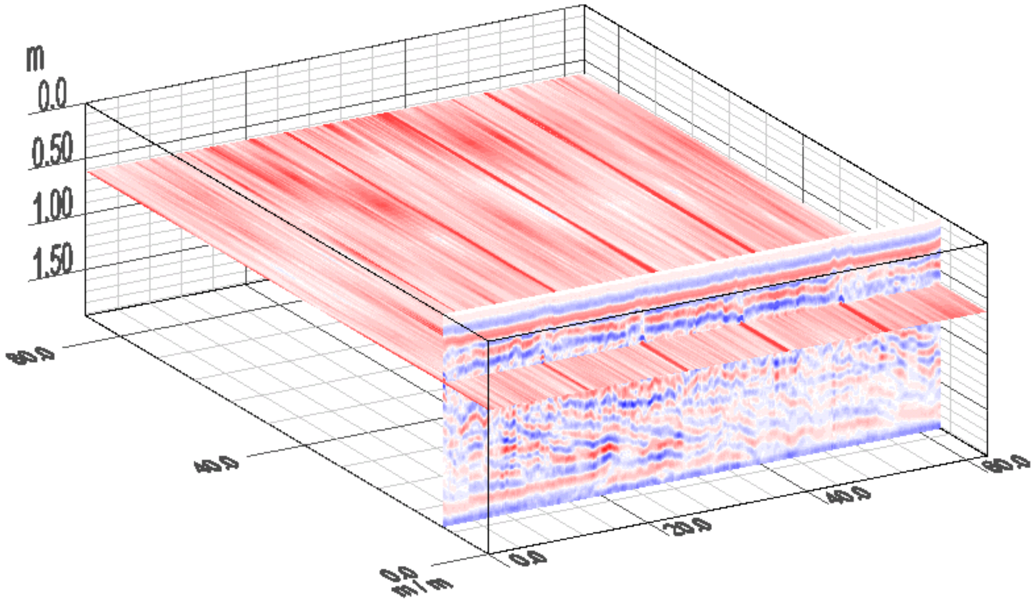

Figure 10. Horizontally-sliced 3D image showing the continuity of high amplitude reflections from four buried drain lines.

Figure 11 is a radar record from the northern portion of this field. Here the 4-inch diameter, plastic drain lines were buried at depths of 100 cm (see area enclosed by red dashed line in Figure 7). The traverse line is 100 m long. The short, vertical lines at the top of the radar record represent reference points that were spaced about 25 m apart along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of 0.054 m/ns.

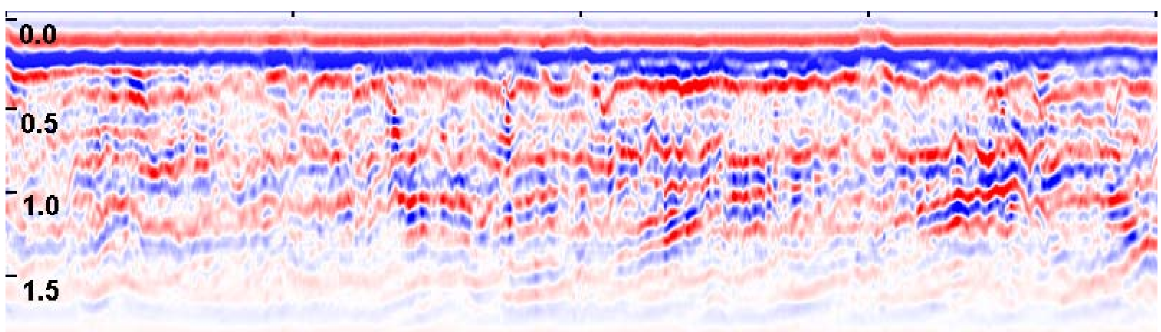

Figure 11. GPR record having drainage tiles buried at depths of 100 cm.

The dark vertical lines at the top of Figure 11 overly buried drain lines. At a depth of 100 cm, substantial attenuation has weakened the radar signal and the size of the drains (4 inch diameter) may be too small relative to its depth to be detected with GPR. In addition, undesired reflections from soil horizons, stratigraphic layers within the 2Cg horizon, and other more conspicuous point anomalies in the soil obscure reflections from the drain lines. As in Figure 8, because of increased soil compaction that results in increased propagation velocity, the soil surface appears to rise over each drainage line. Also evident in Figure 11 is the reflection from the argillic horizon and the disruption in soil patterns caused by the excavation of the trench for the drain lines. In general, at a depth of 1 m, reflections from the 4-inch diameter plastic drain lines are low amplitude and difficult to detect on the radar record.

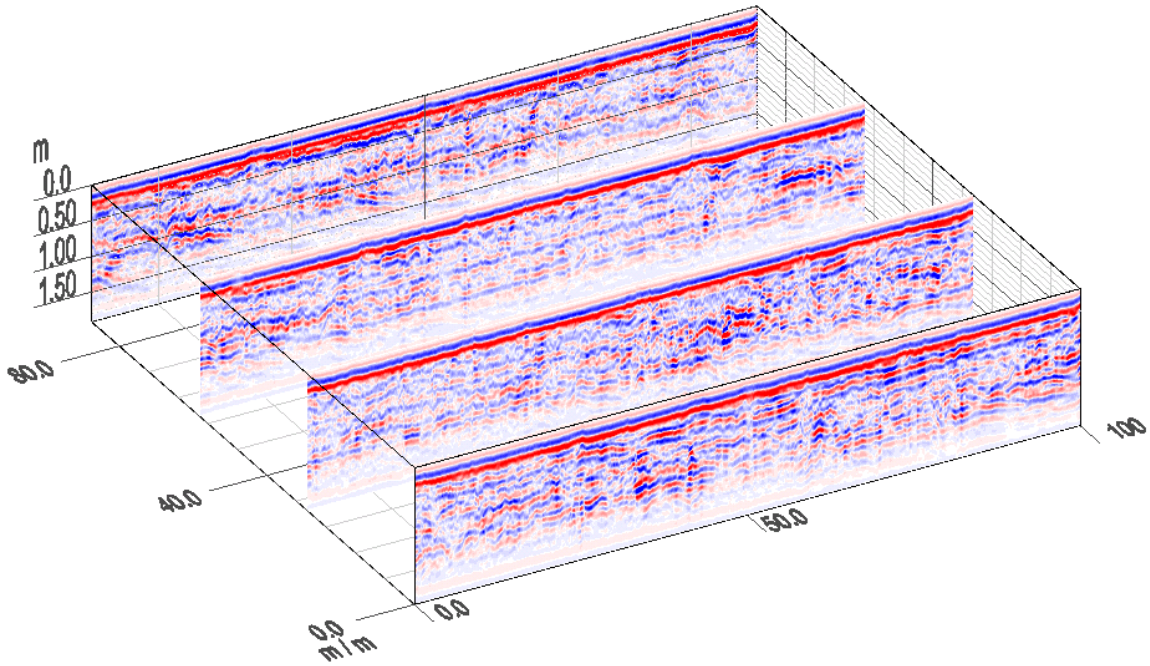

Figure 12. 3D Fence Diagram of portion of field with drains buried at 100 cm.

Figure 12 is a fence diagram showing four radar records that are parallel with the x-axis and extending across the portion of this field with drains buried at a depth of 100 cm. The origin of the grid is located in the northwest corner of this portion of the field. While this diagram provides information on subsurface horizons and features, the drain lines are obscured.

Figure 13 contains a horizontally- or time-sliced image of the northern portion of the field, which contains drain lines buried at 100 cm. For added reference, the radar record from line 50 meters is also shown. All units are in meters. The three-dimensional image has been sliced at a depth of 106 cm. Subsurface reflections have masked the drains that are known to be located at X = 0, 25, 50, 75, and 100 m. In striking contrast to Figure 10, the drain lines do not provide identifiable, high amplitude reflections that can be distinguished from the background noise of the soil. In this area of Cape Fear soil, GPR is inappropriate for locating drain lines at depths of 1 or more meters.

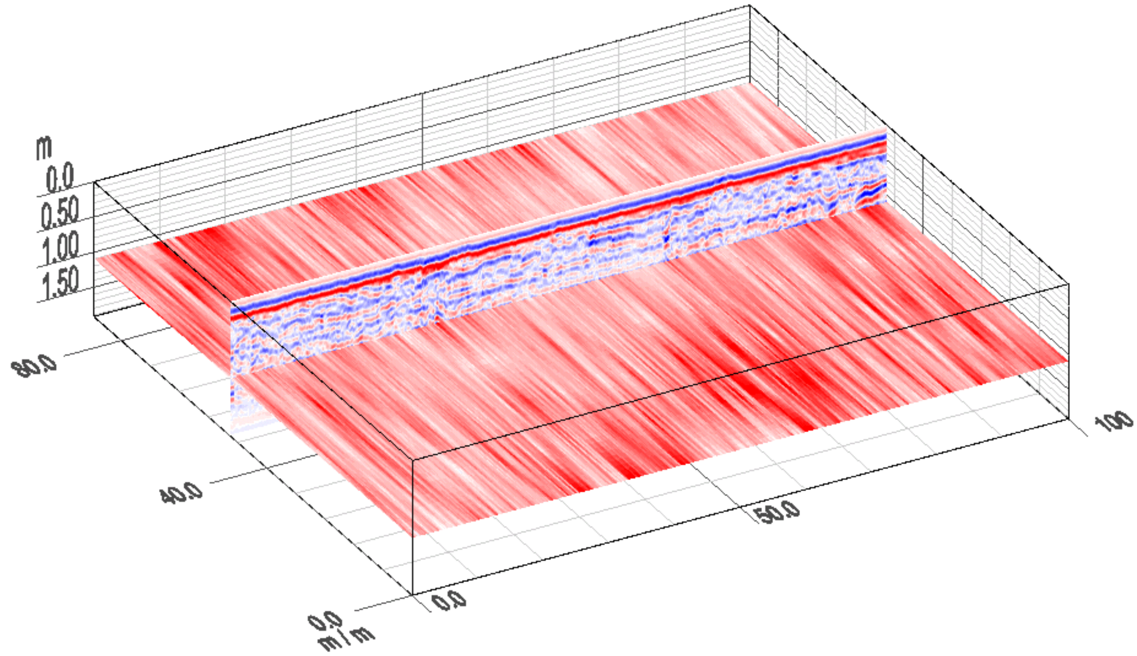

Figure 13. Horizontally-sliced 3D image of area having drain lines buried at a depth of 100 cm.

EMI:

Field N, Tidewater Experiment Station

An EMI survey of Field N was completed by walking at a fairly uniform pace along the parallel grid lines (shown in Figure 3) in a back and forth pattern across the entire grid area. Surveys were completed with the EM38 meter carried about 8 cm above the ground surface in vertical dipole orientation. The meter was operated in the continuous mode with measurements recorded at a 1-sec interval.

A total of 2704 measurements were recorded with the EM38 meter. Apparent conductivity averaged 12.8 mS/m with a range of 9.2 to 21.8 mS/m. Half of these observations had values of apparent conductivity between 11.6 and 13.2 mS/m.

Figure 14 is a plot showing the distribution of apparent conductivity measured with the EM38 meter in the vertical dipole orientation. In Figure 14, a conspicuous band of higher conductivity crosses the northern portion of the survey area in an east to west trending linear pattern. This band of higher apparent conductivity conforms to the area of Cape Fear soil identified with GPR (see Figure 6) and mapped by Kleiss and others (1993). Other portions of the field having lower apparent conductivity conform to the areas that had been mapped as Portsmouth soil. The higher conductivity of Cape Fear soil is attributed to its higher clay content. The linear pattern of this unit suggests an ancient riverbed or streambed.

Soil auger observations were made to confirm interpretations at points *A* and *B* in Figure 14. Point *A* had a clayey subsoil (silty clay) that extended from 14 inches to over 54 inches in depth. At this observation point the recorded conductivity was 17 mS/m. In contrast, point B had an apparent conductivity of 10 mS/m. Here the subsoil was also fine textured (clay/sandy clay), but was thinner (18 to 36 inches). Below the subsoil, stratified sandy clay loam and sandy loam sediments occurred. The soil at B had a thinner subsoil with less clay and contained more sand throughout the subsoil and underlying strata. John Gagnon added that the lower sand contents at point "A" were a result of slower moving waters refilling an ancient streambed with finer-textured materials.

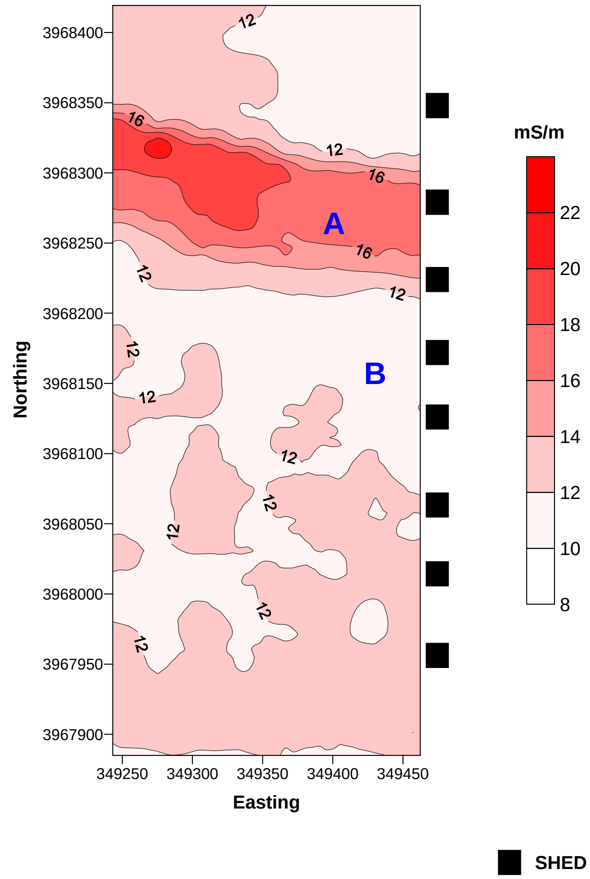

Figure 14. Spatial pattern of apparent conductivity within Field N as measured with the EM38 meter. All distances are measured in meters.

A good association was made between the EMI survey and the detailed soil survey (Kleiss, 1993). The ancient streambed channel was delineated out separately from the other areas in the detailed soil survey of this field. The EMI survey proved to be a good tool for supporting the separation of the soil mapping units.

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