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

Subject: Soils – Geophysical Field Assistance **Date:** 9 September 2002

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Purpose:
The purpose of this investigation was to further characterize and document the presence, depth, and extent of finer-textured, more impermeable layers within selected portions of Juniper Bay with ground-penetrating radar (GPR).

Participants:
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Mike Vepraska, Professor, Department of Soil Science, North Carolina State University, Raleigh, NC
Jeff White, Assistant Professor, Department of Soil Science, North Carolina State University, Raleigh, NC

Activities:
All activities were completed during the period of 25 to 28 August 2002.

Background:
A Carolina Bay is being restored to its original wetland conditions by the North Carolina Department of Transportation. This action has been undertaken to receive wetland credits. Previous wetland restoration efforts have often failed to meet pursued goals. Several interrelated research projects are being carried out at Juniper Bay to ensure that the restoration projects meet desired objectives.

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2, 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-2 consists of a digital control unit (DC-2A) 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 antenna used in this study has a center frequency of 120 MHz. The scanning times were 190 (Grids 12 & 16) and 170 (Grids 1, 11, & 5) nanoseconds (ns). Hard copies of the radar data were printed in the field on a model T-104 printer.

The RADAN NT (version 2.0) software program was used to process the radar profiles (Geophysical Survey Systems, Inc, 2001a).[1] Processing included color transformation, marker editing, distance normalization, and range gain adjustments. All radar profiles were converted into bitmap images using the Radan to Bitmap Conversion Utility (version 1.4) developed by Geophysical Survey Systems, Inc.[2] Data were processed into a three-dimensional image using the 3D QuickDraw for RADAN

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

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

Windows NT software developed by Geophysical Survey Systems, Inc.[2] Once processed, arbitrary cross-sections, insets, and time slices were viewed and selected images saved to PowerPoint files.

Study Site:
Juniper Bay is a large Carolina Bay located near Lumberton, Robeson County, North Carolina. The bay is about 1.5 miles long and 1.0 mile wide. The bay was formerly cultivated and has an extensive system of open drainage ditches and covered drain lines. At the time of this survey, the bay was covered by dense underbrush. To facilitate survey work at selected grid and traverse sites, the underbrush was cut down with a "bush-hog."

Principal soils that have been mapped within Juniper Bay are Leon fine sand, Pantego fine sandy loam, Ponzer muck, and Rutlege loamy sand (McCachren, 1978). The very deep, poorly drained and very poorly drained Leon and the very poorly drained Rutlege soils formed in sandy Coastal Plain sediments. Leon soil is a member of the sandy, siliceous, thermic Aeric Alaquods family. Rutlege soil is a member of the sandy, siliceous, thermic Typic Humaquepts family. The very deep, very poorly drained Pantego soil formed in medium textured Coastal Plain sediments. Pantego soil is a member of the fine-loamy, siliceous, semiactive, thermic Umbric Paleaquults family. The very poorly drained Ponzer soil formed in highly decomposed organic materials that are underlain by medium textured marine and fluvial sediments. Ponzer soil is a member of the loamy, mixed, dysic, thermic Terric Haplosaprists family.

GPR:
Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. This system operates by transmitting short pulses of very high and ultra high frequency 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 a 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 video screen and can be stored on a hard disk for future playback, processing, and/or printing.

Ground-penetrating radar is not an appropriate tool for use in all soils (Doolittle, 1987). The performance of GPR is dependent upon the electrical conductivity of soils. Soils having high electrical conductivity rapidly attenuate radar energy, restrict penetration depths, and severely limit the effectiveness of GPR. The principal factors influencing the electrical conductivity of soils are: amount and type of salts in solution, amount and type of clay, porosity, and degree of water saturation. The penetration depth of GPR decreases as the clay content of soils increases. Within Juniper Bay, soils are highly stratified and contain layers of finer textured soil materials that limit the GPR's penetration depth. These layers vary in depth, thickness, and textural composition.

CALIBRATION OF GPR
Ground-penetrating radar is a time scaled system that 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 on the radar profile and calculating the propagation velocity by following equation (after Morey, 1974):

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

Equation [1] describes the relationship of the propagation velocity (V) to the depth (D) and two-way pulse travel time (T) to a reflector. During this study, the two-way radar pulse travel time was compared with the depth to finer textured soil materials at thirteen observation points, and used to estimate propagation velocities.

The velocity of propagation is both temporally and spatially variable. Temporal variations are attributed to rainfall and through flow events that influence soil moisture contents. Lateral and vertical variations in propagation velocity occur as a result of changes in soil properties (i.e., amount of organic matter, clay, and moisture contents). Figure 1 shows the relationship between the averaged propagation velocity and the depth to finer textured soil materials at the thirteen observation points. At the thirteen observation points, the measured depth to finer textured soil materials ranged from 0.61 to 2.21 meters. Because of the presence of a water table and increased saturation with increased soil depth, the velocity of propagation slows with increasing soil depth. A negative relationship exists between the depth to finer textured soil materials and the velocity of propagation (r = -0.712, significant at .01 level).

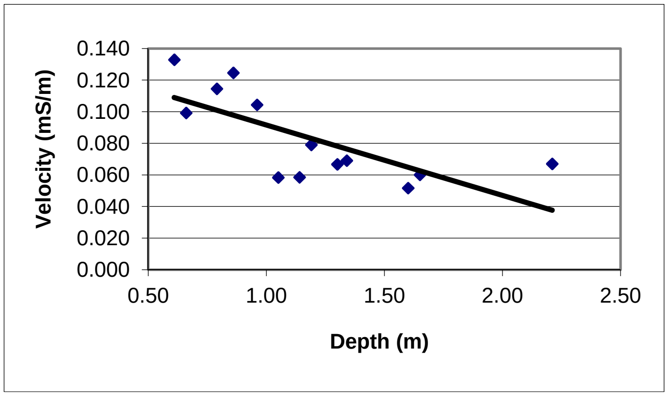

Figure 1. Relationship between propagation velocity and depth at thirteen observation points within Juniper Bay.

The velocity of propagation and the dielectric permittivity are spatiotemporally variable across Juniper Bay. The calculated velocity of propagation, which depends principally on changes in soil moisture with depth, ranged from 0.052 m/ns to 0.133 m/ns at the thirteen observation sites. The estimated dielectric permittivity ranged from 5 to 33. Because of this variability it is difficult to reasonably predict depths to finer textured soil materials across the expanded site using a single or mean velocity of propagation.

The measured depth and the two-way travel time to finer textured soil materials at the thirteen observation points were compared. A strong (r = 0.9478) and significant (.001 level) relationship was found to exist between the two-way travel time of the radar pulse and the measured depth to finer textured soil materials (see Figure 2).

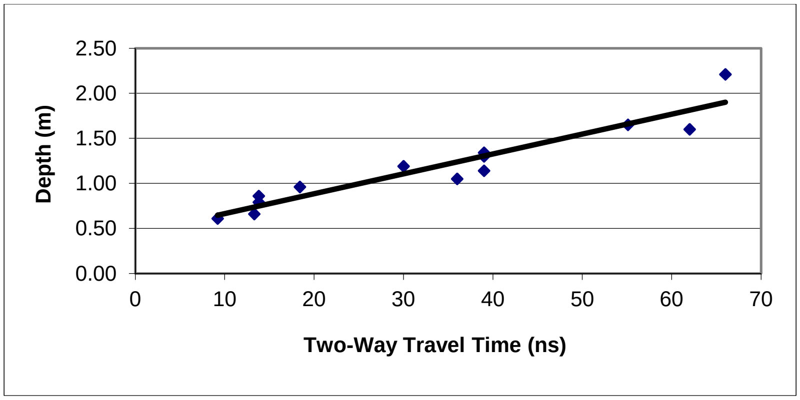

Figure 2. Relationship between depth and pulse travel time at thirteen observation points within Juniper Bay.

Because of the variability in propagation velocities and the known complexity of soil patterns, a predictive equation based on the measured depths and the two-way radar pulse travel times to finer textured soil materials was developed. The predictive relationship is:

$$D = 0.443 + (0.0221*T) \qquad [2]$$

Where D is the depth to finer textured soil materials and T is the two-way travel time to finer textured soil materials. Using predictive equation [2], the average difference between measured and predicted depth to finer textured soil materials at the thirteen observation points was 0.11 m with a maximum difference of 0.31 m. Half of the predicted depths to finer textured soil materials were within 0.04 to 0.16 m of the measured values.

All figures shown in this report have a variable depth scale that is based on equation [2]. This is a novel rather than conventional approach. Hopefully it will improve the correlation between depths inferred from radar profiles and measured on soil cores. However, three-dimensional radar images contained in the PowerPoint files that have been mailed to Dr White at NCSU have a uniform depth scale. The processing program assumes a constant velocity throughout the entire depth range.

This scale is based on an average estimated velocity of propagation of 0.06 m/ns (dielectric permittivity of 24). In addition, all bitmap files forwarded to NCSU lack a depth scale.

Field Procedures:
Survey procedures were modified to facilitate the construction of 3-D images and the interpretation of subsurface features. To construct three-dimensional displays, the imagery between adjoining radar profiles is interpolated. As a consequence, the quality and detail of a three-dimensional display will increase as the spacing between survey lines is decreased (Geophysical Survey Systems, Inc., 2001b). As a general rule, lines should be spaced so that the radar beams from adjacent lines overlap at the depth of interest (Geophysical Survey Systems, Inc., 2001b). Generally these lines should be closely spaced (0.5 to 1 m apart). However, because of the size of the areas selected for survey, economy dictated a wider spacing.

Table 1. Dimensions and Sizes of Grids used for 3D Modeling.

Grid	X Axis (m)	Y Axis (m)	Area (ha)
1	105	32	0.34
5	105	32	0.34
11	100	32	0.32
12	90	30	0.27
16	90	28	0.25

The dimensions and size of each grid used in 3D modeling is shown in Table 1. GPR Surveys were conducted along equally spaced (1, 2, or 4 m), essentially east-west trending grid lines. Surveys were conducted by towing the 120 MHz antenna in a back and forth manner along grid lines that were parallel to the x-axis. Along each line, as the antenna was towed passed an observation point, a vertical mark was impressed on the radar profile. Observation points were spaced at 5 m intervals along the x-axis. The origin of each grid varied. For grids 12 and 16, the origin was located in the southeast grid corner. For grids 1, 5, and 11, the origin was located in the northeast grid corner. Line numbers reflect the y coordinates and the line spacing. The compendium on the last page of this report contains the file numbers (corresponds with line number) for each grid. For each file the direction of travel is also specified.

For all 3D images, the origin (X = 0, Y = 0) is the northeast corner of the grid. Relocation of the origin was done for the 3D images prepared for grids 12 and 16 only. [This does not affect the line numbering shown in the compendium.] Because of poor and erratic signal positioning, the first file (Line Y = 0) was omitted from the construction of the 3D images for Grid 12. Following the omission of this line from [only] the 3D data set, grid lines were renumbered accordingly.

Interpretations:
Participants expressed concern as to the location of the soil surface on radar profiles. To facilitate the identification of the soil surface on radar profiles, a separate radar file was collected at each grid site. For this file the antenna was raise and lowered while transmitting energy. Figure 3 shows the results of this procedure at Grid 12. In Figure 3, the vertical scale is in nanoseconds (ns). The surface pulse has been highlighted with a dark line in Figure 3. As the antenna is raise to shoulder height, the surface pulse separates from the start of scan pulse at the top of the radar profiles and becomes recognizable. The start of scan pulses at the top of the radar profile does represent time 0 ns and serves as reference lines.

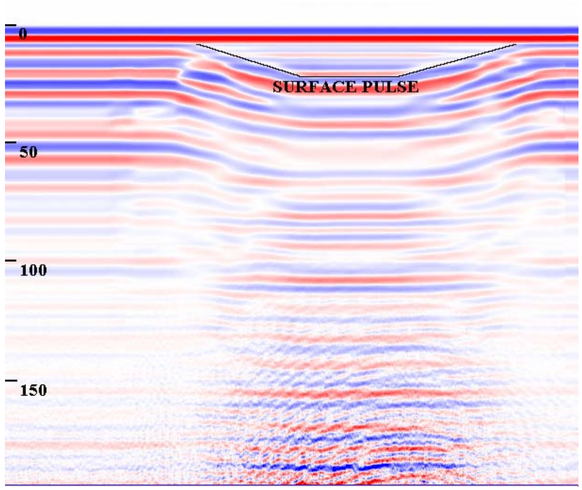

Figure 3. The surface pulse as illustrated by the rising and lowering of a 120 MHz antenna.

Grid 12

This was the first grid completed. It is located in the east-central portion of Juniper Bay. The dimensions of the grid were 30 by 90 m. One-meter spacing between radar traverse lines made this the most intense survey design used in this investigation. This resulted in 30, east-west trending radar profiles. Each profile was 90 m long. Figure 1 is the profile of the first radar traverse completed within this grid.

In Figure 4, the equally spaced, black, vertical marks at the top of the radar profile represent flagged observation points spaced at 5 m intervals. The radar profile is 90 m long and contains 19 observation points. A variable depth scale (in meters) is provided along the left-hand margin of this figure. This scale is based on equation [2]. The soil is drier in the upper part and the velocity of propagation is relatively fast resulting in a narrow interval between indicated depths. In the lower part of the profile, the soil is saturated and the velocity of propagation is slower resulting in a wider interval between indicated depths. With a time window of 190 ns, the maximum depth of penetration is about 4.6 m.

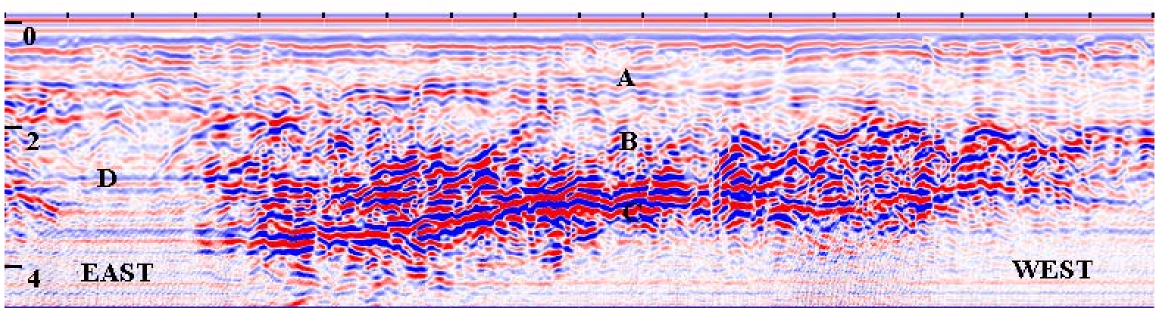

Figure 4. A representative radar profile from Grid 12.

In Figure 4 and all remaining enclosed radar profiles, the location of the soil surface has been placed below the start of scan pulse. While correct, this is visually objectionable and non-conventional. In addition, the use of a variable depth scale is also a departure from standard practices.

Figure 4 can be interpreted using radar facies. A radar facies is defined as a “mappable three-dimensional sedimentary unit composed of reflections whose parameters differ from adjacent units” (Jol and Smith, 1991). Parameters used in interpretations include the amplitude, continuity, and configuration of radar reflections. In radar facies analysis a portion of a radar profile that has a unique and identifiable graphic signature (a distinct, aggregate configuration, appearance, or pattern) is used to identify a stratigraphic units composed of like materials and distinguishable sedimentary structure or geometry.

Three distinct radar facies are evident in Figure 4. The upper-most facies (A) consists of horizontally discontinuous, parallel reflectors. These reflectors have low signal amplitudes suggesting weak dielectric gradients across interfaces. Because of low signal amplitudes, these layers are believed to be similar in terms of clay and/or moisture contents. The middle facies (see "B") appears as complex oblique reflectors having slightly inclined to sigmoid forms. These layers appear to be more inclined towards the east than towards the west and their geometry suggest the migration of accreting deposits. High amplitudes suggest layers of contrasting materials. The lower-most interface (see "C") is a wavy continuous high amplitude reflector that appears to cut across the complex oblique reflectors. As this interface limits radar penetration it is believed to represent layers of medium or finer textured soil materials. As signal penetration is greater than 3 m, the aggregate clay content of these soils is considered lower than in other portions of the bay.

In Figure 4, radar energy is severely weakened and depths of penetration limited around "D." Lateral change in the clay content of the overlying layers may have caused this higher rate of signal attenuation.

Grid 16
The dimensions of this grid were 30 by 90 m. It is located in the southeast portion of Juniper Bay. For economy of time, the interval between adjoining radar traverse lines was opened up to two-meters. This resulted in 16, east-west trending radar profiles. However, the first line surveyed was omitted from 3D processing because of erratic synchronization of the surface pulse. Each profile was 90 m long. Figure 5 is the profile of the last radar traverse completed within this grid.

In Figure 5, the equally spaced, black, vertical marks at the top of the radar profile represent flagged observation points spaced at 5 m intervals. The radar profile is 90 m long and contains 19 observation points. A variable depth scale (in meters) is provided along the left-hand margin of this figure. With a time window of 190 ns, the maximum depth of penetration is about 4.6 m.

In Figure 5, the depth of observation is generally less than 2 m. Soils within Grid 16 were observed to have a histic epipedon. In general, clay contents were generally greater in the upper part of the mineral soil profile than observed within Grid 12. This would account for the more limited observation depths (< 2m) achieved in Grid 16. Only one facies has been identified in this profile: horizontally discontinuous, parallel reflectors. The interface labeled "A," though segmented, appears to continue across the profile. This interface is well expressed in the extreme left-hand portion of this profile. However, at "A," the interface loses amplitude suggesting a more gradual or less contrasting boundary with overlying materials. While the layers in this profile appear nearly horizontal, slight and occasional dips or hyperbolic patterns are evident. The origin of these features was not adequately verified, but their appearance suggests depositional processes and/or the presences of buried tree roots. The parallel, continuous, horizontal bands in the lower part of the profile represent background noise.

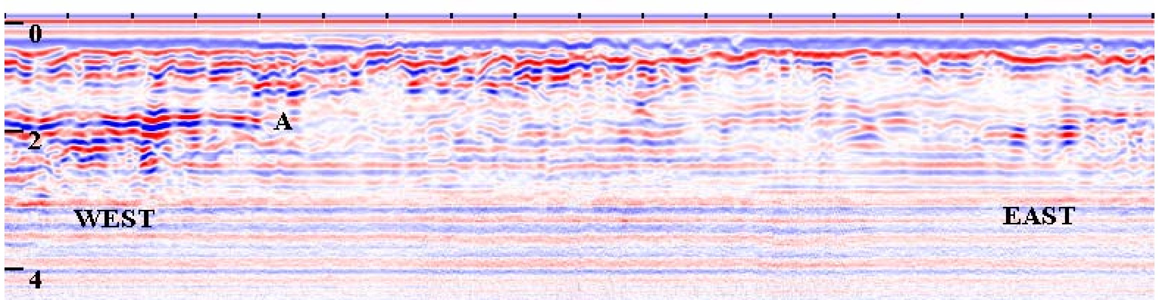

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Figure 5. A representative radar profile from Grid 16.

Grid 1
The dimensions of the grid were 32 by 105 m. It is located in the northwest portion of Juniper Bay. Four-meter spacing was used between radar traverse lines. This resulted in 9, east-west trending radar profiles. Each profile was 105 m long. Figure 6 is the profile of the first radar traverse completed within this grid. In Figure 6, the equally spaced, black, vertical marks at the top of the radar profile represent flagged observation points spaced at 5 m intervals. The radar profile is 105 m long and contains 22 observation points. A variable depth scale (in meters) is provided along the left-hand margin of this figure. With a time window of 170 ns, the maximum depth of penetration is about 4.2 m.

The grid was located near the northwest corner of the bay. Soils were generally slightly drier than in other, more interior portions of the bay. Observation depths exceeded 2 m in a conspicuous shallow trough that extended across the grid area in a general north to south direction. Two facies are observable in this profile. The upper facies consists of horizontal discontinuous parallel reflectors. Internal features within this facies have convex and concave forms that create a more uneven appearance. The lower facies consist of a discontinuous wavy high amplitude reflector. This interface has a high clay content that limits the observation depth.

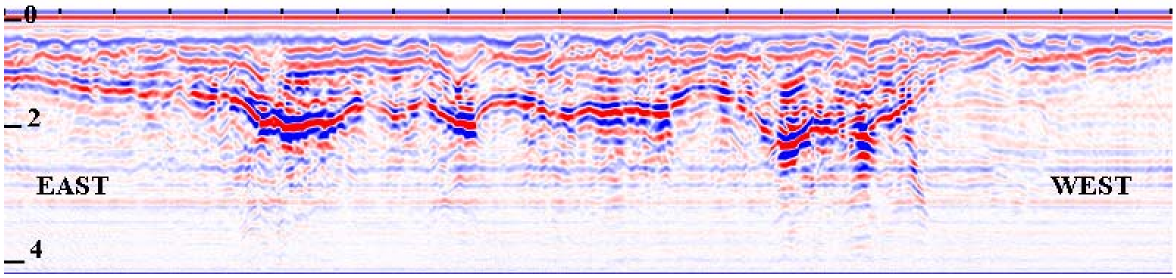

Figure 6. A representative radar profile from Grid 1

Grid 5

The dimensions of the grid were 32 by 105 m. It is located in the southwest portion of Juniper Bay. Four-meter spacing was used between radar traverse lines. This resulted in 9, east-west trending radar profiles. Each profile was 105 m long. Figure 7 is the profile of the first radar traverse completed within this grid.

In Figure 7, the equally spaced, black, vertical marks at the top of the radar profile represent flagged observation points spaced at 5 m intervals. The radar profile is 105 m long and contains 22 observation points. A variable depth scale (in meters) is provided along the left-hand margin of this figure. With a time window of 170 ns, the maximum depth of penetration is about 4.6 m.

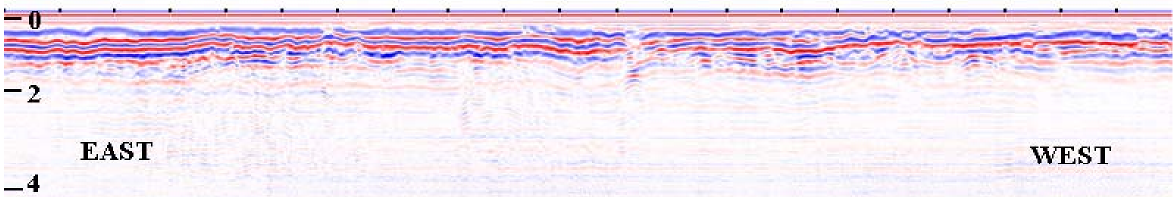

Figure 7. A representative radar profile from Grid 5.

Soils had from 60 to 90 cm of organic materials in the upper part of their profiles. Overwash deposits overlay the organic layers. The depth of signal penetration was mostly limited to less than 1.5 m by the underlying medium to fine textured mineral soil materials. These layers varied not only in clay content but also in thickness. Profiles generally "sanded-out" with increasing soil depth. The organic/mineral soil interface forms a horizontally continuous, high amplitude reflector in the upper part of this profile. Breaks in the continuity of this interface are attributed to superimposed reflection from buried roots.

Grid 11

The dimensions of the grid were 32 by 100 m. It is located near the center of Juniper Bay. Four-meter spacing was used between radar traverse lines. This resulted in 9, east-west trending radar profiles. Each profile was 100 m long. Figure 8 is the profile of the first radar traverse completed within this grid.

In Figure 8, the equally spaced, black, vertical marks at the top of the radar profile represent flagged observation points spaced at 5 m intervals. The radar profile is 100 m long and contains 21 observation points. A variable depth scale (in meters) is provided along the left-hand margin of this figure. With a time window of 170 ns, the maximum depth of penetration is about 4.6 m.

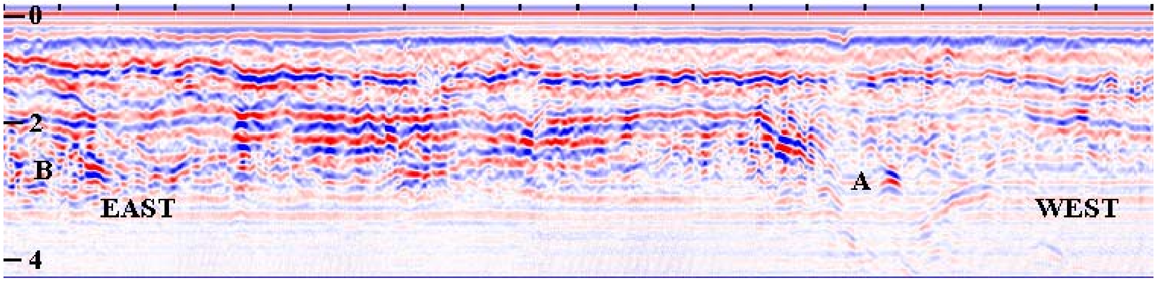

Figure 8. A representative radar profile from Grid 11.

Soils had from 35 to 70 cm of organic materials in the upper part of their profiles. The depth of signal penetration was generally limited to less than 3.0 m by thin layers of medium to fine textured mineral soil materials. These layers varied not only in clay content but also in thickness. Profiles generally "sanded-out" with increasing soil depth. Two facies are identified in this profile: horizontally discontinuous, high amplitude reflectors, and a discontinuous wavy low amplitude reflector. The latter limits observation depth. A noticeable depression is evident near "A." However, this feature is of limit extent and does not continue across the grid area.

Results:

1. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil core data and logs). The use of geophysical methods can reduce the number of core observations, direct their placement, and supplement their interpretations.

2. The velocity of propagation is spatiotemporally variable. Because of the presence of the water table and more saturated conditions with increased soil depths, the velocity of propagation decreased with increased soil depth. Based on thirteen observations, a strong ($r = 0.95$) and significant (.001 level) relationship was found to exist between the two-way pulse travel time and the measured depth to finer-textured soil materials. A predictive equation was developed to improve the correlation between depths to finer textured soil materials inferred from radar profiles and measured in soil cores.

3. Ground-penetrating radar has provided improved understandings of the subsurface geometry and stratigraphy of Juniper Bay. Radar facies, groupings of subsurface reflections with similar characteristics and geometries, as well as reflection terminations were used to characterize and delineate subsurface deposits.

4. All radar files have been stored on disks. All radar profiles have been processed through WINRAD NT software and converted into bitmaps. Three-dimensional diagrams of each grid site have been prepared and stored in PowerPoint. A CD containing the bitmap and PowerPoint files has been forwarded with a copy of this trip report to Dr Jeff White at North Carolina State University. Geomorphologists developing hypotheses regarding the evolution of the Carolina Bays may find these diagrams helpful.

5. Dr White will present a poster presentation entitled "Stratigraphy of a NC Carolina Bay Using Ground-penetrating Radar" at the Annual Meeting of Soil Science Society of America in Indianapolis this fall. The poster will discuss results from this investigation.

It was my pleasure to work in North Carolina and assist North Carolina State University.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:

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Compendium – Transect Data

Grid 1

File	Direction	Y Line (m)
2	E-W	0
3	W-E	4
4	E-W	8
5	W-E	12
6	E-W	16
7	W-E	20
8	E-W	24
9	W-E	28
10	E-W	30

Grid 5

File	Direction	Y Line (m)
13	E-W	0
14	W-E	4
15	E-W	8
16	W-E	12
17	E-W	16
18	W-E	20
19	E-W	24
20	W-E	28
21	E-W	30

Grid 11

File	Direction	Y Line (m)
24	E-W	0
25	W-E	4
26	E-W	8
27	W-E	12
28	E-W	16
29	W-E	20
30	E-W	24
31	W-E	28
32	E-W	30

Grid 12

File	Direction	Y Line (m)
3	E-W	0
4	W-E	1
5	E-W	2
6	W-E	3
7	E-W	4
8	W-E	5
9	E-W	6
10	W-E	7

Grid 12 (continued)

File	Direction	Y Line (m)
11	E-W	8
12	W-E	9
13	E-W	10
14	W-E	11
15	E-W	12
16	W-E	13
17	E-W	14
18	W-E	15
19	E-W	16
20	W-E	17
21	E-W	18
22	W-E	19
23	E-W	20
24	W-E	21
25	E-W	22
26	W-E	23
27	E-W	24
28	W-E	25
29	E-W	26
30	W-E	27
31	E-W	28
32	W-E	29
33	E-W	30

Grid 16

File	Direction	Y Line (m)
36	E-W	0
37	W-E	2
38	E-W	4
39	W-E	6
40	E-W	8
41	W-E	10
42	E-W	12
43	W-E	14
44	E-W	16
45	W-E	18
46	E-W	20
47	W-E	22
48	E-W	24
49	W-E	26
50	E-W	28
51	W-E	30