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

Subject: Soils – Geophysical Field Assistance **Date:** 13 November 2002

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Purpose:
The purpose of this investigation was to characterize the stratigraphy underlying three selected Carolina bays in Bladen County with ground-penetrating radar (GPR).

Participants:
Alex Adams, Technician, North Carolina State University, Raleigh, NC
Alex Baldwin, Student, North Carolina State University, Raleigh, NC
Tripp Cox, Technician, North Carolina State University, Raleigh, NC
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
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Wes Tuttle, Soil Scientist (Geophysical), USDA-NRCS, Wilkesboro, NC
Jeff White, Assistant Professor, Department of Soil Science, North Carolina State University, Raleigh, NC

Activities:
All activities were completed during the period of 4 to 6 November 2002.

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 dielectric permittivity, 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 the bays surveyed, soils are highly stratified, but do not appear to contain significant layers of finer textured materials that limit the GPR's penetration depth.

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 70 and 200 MHz antennas were used in this study. These antennas were selected because of their low frequency and portability. The narrow widths of these antennas eased their transport along constricted trails that had been cut through the dense vegetation of the selected bays. Hard copies of the radar data were printed in the field on a model T-104 printer.

The 100 and 120 MHz antennas were too large and cumbersome to be drag along the narrow, debris-laden trails that were blazed across each bay. On the condition that the antenna was in close contact and effectively coupled with the ground surface, the 200 MHz antenna provided tolerable subsurface imagery and observation depths within each bay. The lower frequency 70 MHz antenna is a specially designed, hand carried, air-launched transceiver. While providing excellent imagery in areas outside the Carolina bays, the 70 MHz antenna was ineffective within the bays. Image quality was diminished by multiples (ringing) that were produced by reverberated signals. The ringing is believed to be produced by strong reflections from the water table that was at or near the soil surface within the bays.

The RADAN NT (version 2.0) software program was used to process the radar profiles (Geophysical Survey Systems, Inc, 2001a). 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]

Study Sites:

Three bays selected for study were Tatum Millpond Bay, Causeway Bay, and Charlie Long Bay. These shallow, oval-shaped depressions are elongated in a northwest to southeast direction. Tatum Millpond Bay is located in Bladen Lakes State Park about 10miles northeast of Elizabethtown. This bay has a maximum northwest to southeast extent of about 4.2 miles and is about 2 miles wide. Causeway Bay is located about 5 miles east of White Lake. This bay has a maximum northwest to southeast extent of about 2.8 miles and is about 1 mile wide. Charlie Long Bay is located about 5 miles southeast of Ammon. This bay has a maximum northwest to southeast extent of about 2.2 miles and is about 1.2 miles wide.

Areas of Lynchburg, Torhunta, Croatan, and Pamilco soils have been mapped within the bays (Leab, 1990). The very deep, somewhat poorly drained Lynchburg soil formed in loamy marine sediments on the rims of bays. Lynchburg is a member of the fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults family. The very poorly drained Torhunta and Croatan soils were mapped within Tatum Millpond Bay. Torhunta is a member of the coarse-loamy, siliceous, active, acid, thermic Typic Humaquepts family. The very poorly drained Croatan soil formed in highly decomposed organic materials underlain by loamy textured marine and fluvial sediment in bays. Croatan is a member of the loamy, siliceous, dysic, thermic Terric Haplosaprists family. The very poorly drained Pamlico soil formed in decomposed organic materials underlain by dominantly sandy sediment in the interiors of bays. Pamlico is a member of the sandy or sandy-skeletal, siliceous, dysic, thermic Terric Haplosaprists family.

Survey Procedures:

At the time of this survey, the bays were covered by dense underbrush. In each bay, to facilitate survey work, trees and underbrush were hacked down and removed along a narrow trail that ran essentially from the rim into the interior of the bay. The lengths of these trails ranged from about 1260 to 2200 feet. Survey flags were inserted in the ground at intervals of 100 feet along each trail. These flags served as reference and potential observation points. Observation points were numbered sequential from 0 starting at the outermost (rim) position. Carrying the 70 MHz or pulling the 200 MHz antennas along a portion of each trail completed a radar survey. As the radar

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

antenna passed each flagged reference point, the operator impressed a vertical reference line on the radar profile to identify the reference point. The coordinates of these observation points will later be measured with a GPS receiver.

Multiple transects were conducted in each bay. Table 1 provides a summary of the radar traverses. “Lift” tests were periodically conducted to confirm the identity of the surface pulse. These test consisted of raising and lowering the antenna off of the ground surface to about head height. In the resulting imagery, the start of scan pulses remained at a constant interval while the reflections from the ground surface and subsurface interfaces dipped and climbed as the antenna was raised and lowered above the ground surface.

Table 1 - Summary of GPR transects.

File #	Antenna	Time (ns)	Length	Bay
1	70 MHz	300	lift	Tatum Millpond
2	70 MHz	300	0 to 1700	Tatum Millpond
3	70 MHz	200	lift	Tatum Millpond
4	70 MHz	200	1700 to 0	Tatum Millpond
5	70 MHz	200	lift	Tatum Millpond
6	70 MHz	200	lift	Tatum Millpond
7	200 MHz	200	lift	Tatum Millpond
8	200 MHz	180	1700 to 700	Tatum Millpond
9	200 MHz	180	lift	Tatum Millpond
10	200 MHz	180	700 to 0	Tatum Millpond
11	200 MHz	180	lift	Causeway
12	200 MHz	200	0 to 700	Causeway
13	200 MHz	200	700 to 1260	Causeway
14	200 MHz	100	lift	Causeway
15	200 MHz	100	1260 to 0	Causeway
16	200 MHz	100	lift	Charlie Long
17	200 MHz	100	0 to 1000	Charlie Long
18	200 MHz	100	1000 to 2200	Charlie Long
19	200 MHz	300	lift	Charlie Long
20	200 MHz	300	2200 to 1000	Charlie Long
21	200 MHz	300	1000 to 0	Charlie Long
22	200 MHz	150	West side	Juniper
23	200 MHz	150	lift	Juniper
24	200 MHz	150	lift	Juniper
25	200 MHz	150	East side	Juniper

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 subsurface reflector. During this study, the two-way radar pulse travel time was compared with the depths to the organic/mineral soil interface at ten selected observation points within Tatum Millpond and Causeway bays, and used to estimate propagation velocities. The organic/mineral soil interface generally provided a high amplitude reflection that was identifiable on radar profiles. At the ten observation points, the measured depth to the organic/mineral soil interface ranged from 0.13 to 2.54 meters.

The velocity of propagation and the dielectric permittivity are spatiotemporally variable across these bays. The calculated velocity of propagation through the organic soil materials, which depends principally on changes in soil moisture, ranged from 0.034 m/ns to 0.058 m/ns at the ten observation sites. The estimated dielectric permittivity ranged from 26 to 75. Because of this variability it is difficult to reasonably predict depths to the organic/mineral soil interface across the expanded site using a single or mean velocity of propagation.

The measured depths and the two-way travel times to the organic/mineral soil interface at ten observation points were compared. Figure 1 shows the relationship between the two-way travel times and the depths to the organic/mineral soil interface at the ten observation points. A strong positive relationship exists between the depth to this interface and the two-way travel time ($r = 0.98$, significant at .001 level).

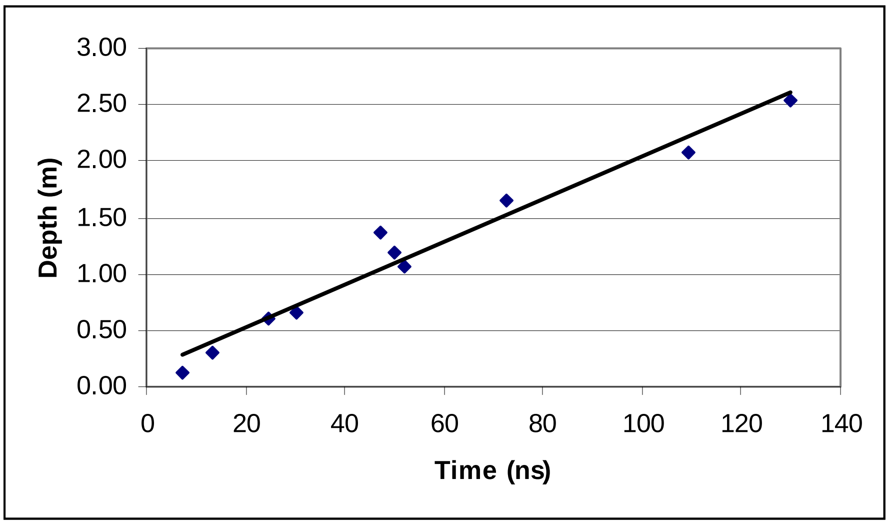

Figure 1. Relationship between two-way pulse travel time and the depth to the organic/mineral soil interface at ten observation points within the three bays.

Because of the variability in propagation velocities, a predictive equation based on the measured depths and the two-way radar pulse travel times to the organic/mineral soil interface was developed. The predictive relationship is:

$$D = 0.143 + (0.0189*T) \qquad [2]$$

Where D is the depth to the organic/mineral soil interface and T is the two-way travel time to this interface. Using predictive equation [2], the average difference between measured and predicted depth to the organic/mineral soil interface at the ten observation points was 0.11 m with a maximum difference of 0.33 m. Half of the predicted depths were within 0.06 to 0.13 m of the measured values.

The developed depth scale is based on the velocity of propagation through saturated organic materials. The laterally encompassing and underlying mineral soil materials have lower moisture contents and therefore lower dielectric permittivities and propagation velocities than the organics. The use of predictive equation [2] in mineral soil materials will provide erroneous and misleading depth scales. In Charlie Long Bay, two observations were made in predominantly coarse textured mineral soil materials. In each profile a finer textured (sandy loam) subsurface layer was identified. The measured depths to the coarse-loamy layers were 0.91 and 1.73 meters with dielectric permittivities of 14.2 and 18.7, and velocities of propagation of 0.079 and 0.069 m/ns, respectively.

Interpretations:
In general, the quality of the radar profiles was considered fair. All profiles were marred by discontinuous images. Lifting, tilting, and jarring the antenna over roots and debris produced choppy, discontinuous patterns on radar profiles. In each bay, greater penetration depths were achieved in the drier rim margins. Segments of the radar profiles from bay interiors generally were more depth restricted with higher levels of background noise in the lower parts. However, with the 200 MHz antenna, penetration depths did exceed expectations. None of the bays appear to be underlain within depths of 2 m by significant layers of finer textured mineral soil materials that would act as aquitards.

All bays contained soils with organic surface layers. However, Tatum Millpond and Causeway bays contained significant deposits of organic materials. It is contemplated that organic deposits of variable thickness formerly covered Carolina bays. As Juniper Bay did not contain organic soils, it was speculated that past management practices and fires had removed these organic layers. The organic deposits within the three bays contained thin strata of mixed sand and organic soil materials suggesting periodic flooding and deposition of mineral soil materials. In general these layers appeared as segmented, parallel reflectors on radar profiles. These layers appear to be more numerous and shallower near the rims of the bays.

In Tatum Millpond Bay, based on 18 observations along one transect, organic soil materials averaged 1.21 m thick with a range of 0.18 to 2.57 m. Twenty-two percent of the observed soils had surface layers less than 40 cm and composed of organic materials. Thirty-nine percent of the soils had organic layers between 0.4 and 1.52 m thick. As stratified sandy deposits underlay these soils, these soils are Pamlico and members of the sandy or sandy-skeletal, siliceous, dysic, thermic Terric Haplosaprists family. Thirty-nine percent of the soils had organic layers greater than 1.52 m thick. These soils are members of the Dysic, thermic Typic Haplosaprists family.

In Causeway Bay, based on 14 observations along one transect, organic soil materials averaged 0.93 m thick with a range of 0.14 to 1.76 m. Twenty-one percent of the observed soils had surface layers less than 40 cm and composed of organic materials. Fifty-eight percent of the soils had organic layers between 0.4 and 1.52 m thick. As stratified sandy deposits underlay these soils, these soils are Pamlico and members of the sandy or sandy-skeletal, siliceous, dysic, thermic Terric Haplosaprists family. Twenty-one percent of the soils had organic layers greater than 1.52 m thick. These soils are members of the Dysic, thermic Typic Haplosaprists family.

Soils observed within Charlie Long Bay were mineral. It was not possible to distinguish layers of organic materials within this bay with GPR. They were either to shallow or lack sufficient contrast with the underlying mineral soil materials to be detected with the 200 MHz antenna. Charlie Long Bay contained several essential planar, subsurface reflectors. One reflector was identified as a spodic horizon; another reflector was identified as a finer textured (sandy loam) layer. The lowest continuous reflector (though it varied from a strong to faint reflection across the radar profile) detected with the 200 MHz antenna occurred between scanning times of 150 and 250 nanoseconds. No other interfaces were distinguishable below this interface. Using our estimated velocity of propagation of 0.069 m/ns and equation [1] would place this layer at depths of about 5.2 to 8.6 meters. Using a more conservative "tabled value" for saturated sand (velocity of 0.05 m/ns; dielectric permittivity of 35), these scanning times would provide observation depths of about 3.8 to 6.3 m. If this layer represents an aquitard, it occurs at significantly deeper depths than the aquitard observed in many areas of Juniper Bay.

Results:

1. Radar surveys were completed in three Carolina bays under some of the most adverse terrain conditions that I have ever experienced in my twenty-two years of operating GPR. As a consequence, the quality of the radar profiles is below satisfaction and of only limited interpretive value.

2. 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.

3. All bays contained soils with organic surface layers. Significant areas of organic soils were distinguished with GPR in Tatum Millpond and Causeway bays. Areas of organic soils were indistinguishable with GPR in Charlie Long Bay. It is believed that organic deposits of variable thickness formerly covered many Carolina bays.

4. The organic deposits within the three bays contained thin strata of mixed sand and organic soil materials suggesting periodic flooding and deposition of mineral soil materials. These layers appear to be more numerous and shallower near the rims of the bays.

5. 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 ten observations, a strong ($r = 0.98$) and significant (.001 level) relationship was found to exist between the two-way pulse travel time and the measured depth to organic/mineral soil interface. A predictive equation was developed to improve the correlation between depths to this interface inferred from radar profiles and measured in soil cores.

6. All radar files have been stored on disks. All radar profiles have been processed through WINRAD NT software and converted into bitmaps. A CD containing the bitmap files has been forwarded with a copy of this trip report to Dr Jeff White at North Carolina State University.

7. Two additional surveys were completed along the east and west sides of Juniper Bay. These profiles will be used to characterize the hydrogeology of these areas.

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

With kind regards,

James A. Doolittle
Research Soil Scientist

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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