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

Subject: SOI -- Ground-Penetrating Radar Assistance **Date:** 27 October 2000

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PURPOSE:
This study supports NRI Grant 9901125. The purpose of this study was to use ground-penetrating radar (GPR) techniques to help characterize wetland/hydrological interactions at two sites located near Lake Arbutus in the Huntington Wildlife Forest.

PARTICIPANTS:
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ACTIVITIES:
All field activities were completed during the period of 3 to 5 October 2000 at the Huntington Research Center in the central Adirondacks.

STUDY SITE:
The site is located within the Huntington Research Forest in southwestern Essex County, New York. Two wetlands were selected for GPR surveys: one a hillslope wetland, the other a beaver meadow. The wetlands were located near the northeast corner of Arbutus Pond. Elevations range from about 490 to 500 meters. These closely adjoining wetlands were located within the same catchment area. Both wetland has been intensively characterized and monitored with stream gages, piezometers, and water table wells.

The wetlands were located in areas of the Greenwood mucky peat. The Greenwood series is a member of the dysic Typic Borohemists family. The Greenwood series consists of very deep, very poorly drained soils formed in organic deposits more than 51 inches thick.

MATERIALS AND METHODS
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-2) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. The 120 MHz and 200 MHz antennas were used in this study. Scanning times of 150, 200, and 300 nanoseconds (ns) were used with the 200 MHz antenna. Scanning times of 200 and 300 ns were used with the 120 MHz antenna. The scanning rate was 32 scan/second. Hard copies of the radar data were printed in the field on a model T-104 printer.

Field Methods:
Three traverse lines were established across each study site. Traverse lines were arranged to pass by each set of piezometers and wells. Survey flags were inserted in the ground at intervals of about 4 m and served as observation points (see Table 1 for the number of observation points along each traverse line). Prior to the GPR survey, many fallen tree limbs, smaller trees, and bushes

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

were cleared along these lines. Even so, the lines contained many fallen logs, trees, irregular ground surfaces, and areas of open water that would hinder and trouble the radar survey. Pulling the 200 and 120 MHz antenna along each line completed a radar traverse. As the study was conducted through wooded areas, all traverses were completed with the GPR control unit carried in a backpack and the antenna pulled by hand. As the antenna passed each observation point, the operator impressed a dashed vertical line on the radar record. Double dashed lines identified wells on the radar profiles. Some wells also served as observation points. Double dashed lines and all wells that did not serve as observation points were removed in the accompanying Bitmap files.

Traverse Line	# Observations	Antenna	Scanning Time	File Number
1	9	200 MHz	150 ns	Cort01
2	13	200 MHz	150 ns	Cort02
3	8	200 MHz	150 ns	Cort03
1	9	200 MHz	200 ns	Cort04
2	13	200 MHz	200 ns	Cort05
3	8	200 MHz	200 ns	Cort06
4	20	200 MHz	200 ns	Cort07
5	31	200 MHz	200 ns	Cort08
6	19	200 MHz	200 ns	Cort09 &10
6	19	120 MHz	200 ns	Cort11
4	20	120 MHz	200 ns	Cort12
5	31	120 MHz	200 ns	Cort13
5	31	120 MHz	300 ns	Cort14
1	9	120 MHz	300 ns	Cort15
2	13	120 MHz	300 ns	Cort16
3	8	120 MHz	300 ns	Cort17

Table 1 – Summary of Traverses. Traverse lines 1 to 3 were located in the hillslope wetland; traverse lines 4 to 6 were located in the beaver meadow. Sequential file numbers refer to the recorded data files and should be used to identify radar traverses.

CALIBRATION OF GPR

Ground-penetrating radar is a time scaled system. This system measures the time it takes electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, water table, stratigraphic layer) and back. To convert travel time to depth 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. 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 average propagation velocity (V) to the depth (D) and two-way pulse travel time (T) to a reflector. Observations were made at five holes excavated with a Dutch auger within the hillslope wetland. The uppermost organic/mineral interface was clearly expressed and identifiable on all radar profiles. At each observation point, the measured depth (D) and the two-way radar pulse travel time to the organic/mineral interface were used to estimate the velocity of propagation. The measured depths to the five organic/mineral interfaces ranged from 0.0.36 to 3.04 meters. The estimated velocity of propagations to these interface are shown in Table 2.

The velocity of propagation is both temporally and spatially variable. Temporal variations are attributed to snowmelt, rainfall, and throughflow 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, sand, silt, clay, and moisture contents). Within the study sites, the velocity of propagation increases with soil depth. Changes in the velocity of propagation principally reflect differences in soil water contents. The estimated velocity of propagation ranged from 0.072 m/ns to 0.039 m/ns. The estimated dielectric permittivity ranged from 17 for surface layers to 59 for very deep (3 m) organic deposits. Because of this variability it would be difficult to accurately predict depths to subsurface interfaces across these sites using a single or mean velocity of propagation.

Mineral Soil Interface	Depth	Time	Velocity	Permittivity
Sandy loam	0.36	9.90	0.072	17
Mucky ls	0.61	22.20	0.055	30
Silt loam	1.85	86.40	0.043	49
Silt loam	2.64	130.80	0.040	55
Silt loam	3.04	155.55	0.039	59

Table 2 – Estimated Velocities of Propagation. Estimates were determined using the two-way travel time to subsurface reflections that appeared on radar profiles, the measured depths to the soil interface, and equation [1]. Depths are expressed in meters. Time is expressed in ns. Velocity is expressed in m/ns.

Because of the variability in propagation velocities with soil depth, a predictive equation, based on measured depths to subsurface interfaces and two-way travel times, was used. The measured depth and the two-way travel time to five subsurface interfaces were compared. A strong ($r = 0.9989$) and significant (0.001 level) relationship was found to exist between the two-way travel time of the radar pulse and the measured depth to these interfaces.

A least square line was fitted to the data and used to predict the depth to water table at all observation points. The relationship is expressed as:

$$D = 0.20 + (0.019*T) \qquad [2]$$

Where D is depth in meters and T is the two-way travel time in nanoseconds to the interface.

For the five observed depths to organic/mineral soil interfaces, using predictive equation [2], the average difference between the measured and the predicted depth was 0.04 m with a range of -0.12 to 0.01 m.

		Depths		
Interface	Time	Measured	Interpreted	Difference
Sandy loam	9.9	0.36	0.39	-0.03
Mucky ls	22.2	0.61	0.62	-0.01
Silt loam	86.4	1.85	1.84	0.01
Silt loam	130.8	2.64	2.69	-0.05
Silt loam	155.6	3.04	3.16	-0.12

Table 3 - Comparison of Measured and Interpreted Depths to Soil Interfaces. Interpreted depths were determined using the two-way travel times to the identified subsurface interface reflection that appeared on radar profiles and predictive equation [2]. Depths are expressed in meters. Time is expressed in nanoseconds.

RESULTS

The 200 and 120 MHz antennas provided improved penetration depths and comparable resolution to the data collected with the 300 MHz antenna in 1996 at these sites (see my trip report to Dr. Jeff McDonnell dated 17 October 1996). The radar records provide a wealth of subsurface information for each site. Most noteworthy, the radar profiles show a large number of planar reflectors within the organic materials. In organic soil surveys conducted in the states of Massachusetts, Florida, Minnesota and Wisconsin, I have seldom seen so many conspicuous planar reflectors buried within the organic deposits. The survey sites within these states were generally on more level outwash or till plains, and were not bounded by steep slopes.

Based on auger observations conducted within the hillslope wetland, many of these planar reflectors are believed to represent thin strata of mucky sands and/or mucky loamy sand materials. Some planar reflectors identified on radar profiles were indistinguishable in the auger holes. Some of these reflectors represent a slight increase in sand fraction that was heard, but not recorded, as the Dutch auger passed through the layer. Others may represent differences in degree of humification. An immediate use of the radar record is to confirm the presence and extent of multiple dissimilar strata within the profiled organic materials. These strata undoubtedly influence the hydrology of these deposits.

Figure 1 is an example of a radar profile collected in the hillslope wetland with the 200 MHz antenna. This radar profile has been processed through the WINRAD software package. Processing was limited to signal stacking, distance normalization, color transforms and table customizing. Signal stacking, color transformation and table customization were used to reduce background noise and signal amplitudes.

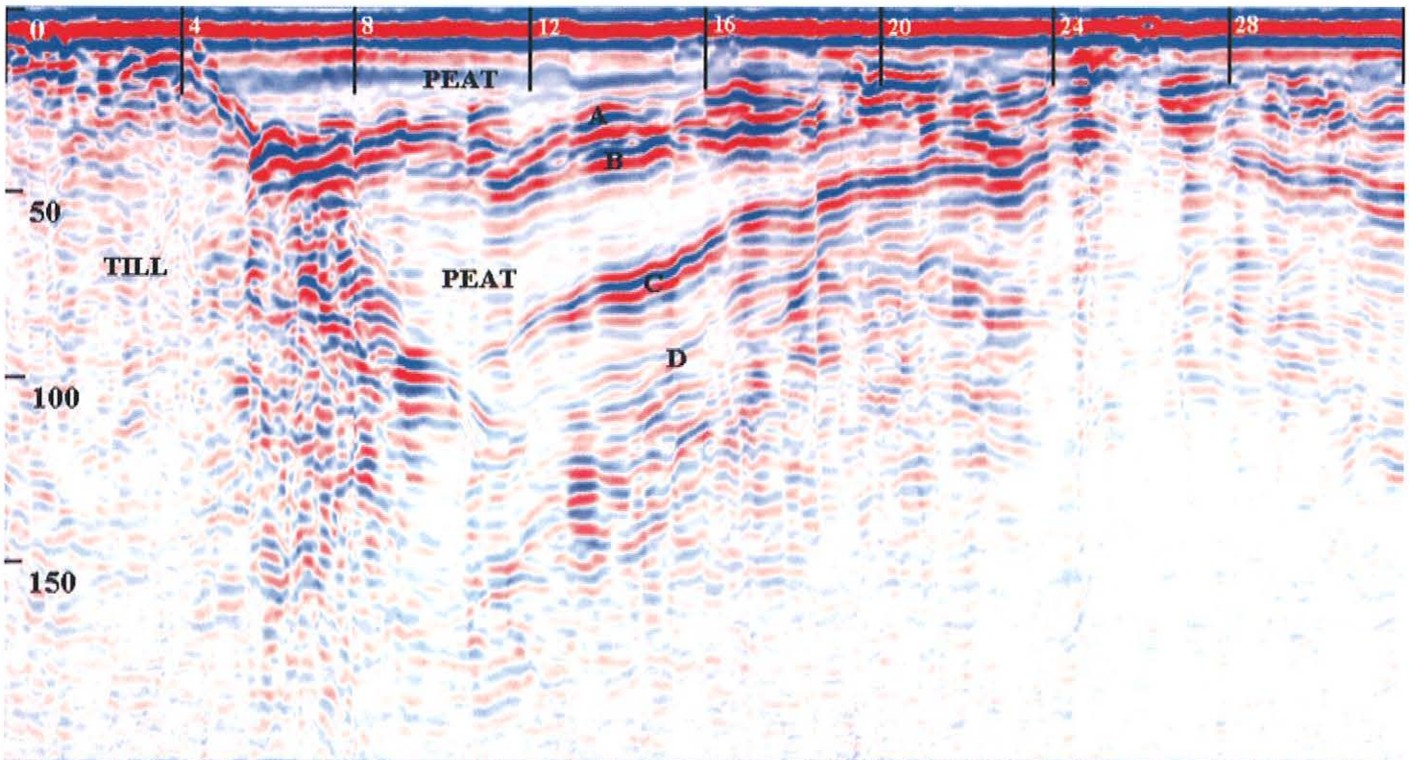

Figure 1 – Representative Radar Profile from the Hillslope Wetland. Vertical scale is a time scale and is expressed in ns. The horizontal scale is in m.

The horizontal scale represents units of distance traveled along the traverse line. The nine dark vertical lines at the top of the radar profile represent equally spaced observation points. These points are numbered and are spaced at an interval of 4 m. The vertical scale along the left-hand border of Figure 1 is a time scale. The scanning time used in this traverse was 200 ns. In Figure 1, using equation [2] and a scanning time of 200 ns, the maximum depth of observation is about 4 m. In Figure 1, the vertical scale is exaggerated (about 4.4 times). Depths to any subsurface interface can be estimated determining the two-way travel time to the interface and using equation [2].

In Figure 1, the parallel, multiple reflections at the top of the radar profile represent the soil surface. Several high amplitude planar reflectors have been identified (see A, B, C, and D). These reflectors are believed to represent either strata of mineral, or organic and mineral materials that are sandwiched between or underlie layers of organic materials. Along this traverse line, the deepest part of the hillslope wetland basin is near observation point 12 m. The bottom of the wetland appears to be layered with multiple strata of dissimilar, but unknown compositions (grain size).

Hard copies of all radar profiles have been provided to the principal investigator. In addition, all radar profiles have been processed and copies of bitmap files forwarded with this report to the principal investigator. To obtain the depth to any interface that appears on these files, please follow the following steps:

1. Refer to Table 1 and obtain the two-way travel time.
2. Determine the two way travel time to the interface (scaled fraction of the two way travel time).
3. Use equation [2] to determine the depth.

It was my pleasure to work with you and Steven at the Huntington Wildlife Forest.

With kind regards,

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