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

Subject: SOI -- Ground-Penetrating Radar (GPR) Assistance **Date:** August 13, 2002

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PURPOSE:
Ground-penetrating radar (GPR) was used to help characterize the depth and stratigraphy of organic and mineral deposits in selected wetlands of the Adirondacks. The US Environmental Protection Agency (EPA), Pennsylvania State University (PSU) and State University of New York at Cortland are participating in a cooperative study of wetlands. The study is being conducted in New York, Pennsylvania, and Virginia. This study is designed to test a modified hydrogeomorphic model (HGM) that has been developed by PSU. The present study uses noninvasive GPR methods to characterize subsurface deposits and look for communalities in substrate formations and sequences, which may be used for hydrologic classifications of wetlands.

PARTICIPANTS:
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ACTIVITIES:
All field activities were completed during the period of 16 to 18 July 2002.

STUDY SITES:
Ground-penetrating radar traverses were completed across six selected wetlands in the Huntington Wildlife Forest, Newcomb, New York. The wetlands are identified in Table 1.

Table 1. Study Sites Surveyed with GPR in Huntington Wildlife Forest

Site	Name	Type
Site 1	Fishing Brook Fringe	Riverine
Site 2	Boundary Pond Meadow	Riparian Depression
Site 3	Little Sucker Brook	Riverine
Site 4	First Meadow	Riverine
Site 5	Adjidaumo	Lake Fringe
Site 6	Deer Pond Bog	Riparian Depression

MATERIALS AND METHODS
Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974) and Doolittle (1987) 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 powered

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

the system. This unit is backpack portable and, with an antenna, requires two people to operate. The 120 MHz antenna was used in this study. Scanning time varied with penetration depths, which were influence by subsurface materials and stratigraphy. Scanning times ranged from 300 to 400 nanoseconds (ns).

Field Methods:
Traverse lines were established across wetlands. Along each survey line, flags were inserted in the ground at 5-m intervals and served as reference points. Pulling the 120 MHz antenna along each traverse line completed a radar survey file. As the radar antenna was pulled passed each flagged observation point, the operator impressed a vertical reference line on the radar profile to identify the observation point. The coordinates of these observation points will be measured with a GPS receiver.

CALIBRATION OF GPR

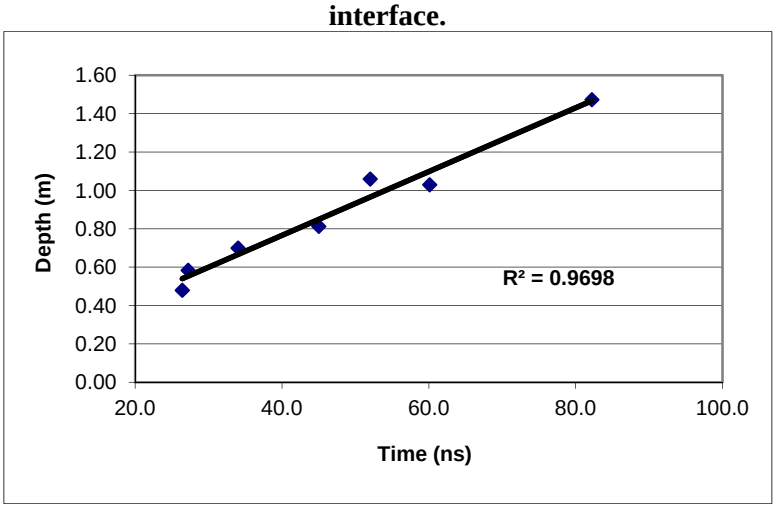
Ground-penetrating radar measures the time it takes electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, water table, stratigraphic layer) and back. To convert travel time to depth requires knowledge of the velocity of pulse propagation. Several methods are available 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 (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 the 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.

At seven sampling points, a strong (r = 0.97) and significant (.001 level of significance) relation was found between the two-way travel time and the measured depth to the organic/mineral interface (see Figure 1).

Figure 1. Relationship between the two-way travel time and the measured depth to the organic/mineral interface.



At the seven sampling points, the two-way radar pulse travel time was compared to the measured depth to a well-expressed organic/mineral interface and used with equation [1] to estimate the velocity of propagation (see Table 2). At the seven sampling points, the measured depth to the organic/mineral interface ranged from 0.48 to 1.47 meters.

At each sampling point, an estimated velocity of propagation was determined. These velocities are shown in Table 2. The velocity of propagation and the dielectric permittivity are affected by changes in soil moisture contents and are therefore spatiotemporally variable. In organic materials, water contents vary with degree of humification, which varies both vertically and laterally in these deposits. The calculated velocity averaged 0.038 m/ns and ranged from

0.034 m/ns to 0.043 m/ns at the seven points. The estimated dielectric permittivity averaged 62, but ranged from 48 to 76.

Table 2. Estimated Pulse Propagation Velocity and Dielectric Permittivity at Seven Observation Points

Location	Time (ns)	Depth(m)	Velocity	Er
Fishing Brook Fringe	34.0	0.70	0.041	52
Fishing Brook Fringe	60.1	1.03	0.034	76
Boundary Pond Meadow	82.2	1.47	0.036	69
First Meadow	27.2	0.58	0.043	48
Adjidamo	52.0	1.06	0.041	53
Deer Pond Bag	26.4	0.48	0.036	67
Deer Pond Bag	45.0	0.81	0.036	68

For all depth calculations used in this report a dielectric permittivity of 62 and a velocity of pulse propagation of 0.038 m/ns were used. Using this velocity of propagation and equation [1], the difference between the measured and predicted depth to the upper-most organic/mineral interface at the seven sampling points averaged 0.12 m with a range of 0.01 to 0.31 m. Depth to the organic/mineral interface were estimated, by measuring the 2-way travel time to the organic/mineral interface at each observation point on each radar profile, and using equation [1] and a velocity of pulse propagation of 0.038 m/ns.

Ground-Penetrating Radar:

In many areas, characterization of subsurface materials can be improved with GPR. Ground-penetrating radar is a noninvasive geophysical tool that is specifically designed to penetrate earthen materials and provided images of the subsurface to shallow (0 to 30 m) depths. GPR allows the collection of subsurface information in the absence of satisfactory number of cores or sufficient lateral or vertical perspective through excavations, cuts, or outcrops. However, GPR interpretations are verified with soil cores and exposures. Therefore, GPR does not eliminate the need for soil cores, but reduces the number required. GPR provides high-resolution information that can aid interpretations and the extrapolation of information obtained with traditional surveying techniques (Davis and Annan, 1989).

Ground-penetrating radar operates by transmitting pulses of electromagnetic energy into the subsurface. A receiving antenna records the energy that is reflected from subsurface boundaries or interfaces that separate layers of contrasting dielectric permittivity. The more abrupt and contrasting the difference in dielectric permittivity, the greater the amount energy that is reflected off an interface and the stronger the amplitude of the reflected signal. Subsurface layers with the same or similar dielectric properties reflect little electromagnetic energy and are indistinguishable with GPR. Dielectric permittivity is principally controlled by the water content of the material (Davis and Annan, 1989).

A majority of the sites investigated in the Huntington Wildlife Forest contained thick layers of peat. Ground-penetrating radar is a suitable geophysical tool for estimating peat thickness, stratigraphy, and subsurface topography of the organic/mineral soil interface (Ulriksen, 1982). Ulriksen (1980) and Remotec Applications Inc. (1982) reported that GPR provides information on the depth and volume of peat deposits that is comparable to information obtained with traditional, manual techniques. However, GPR requires less time and effort than conventional methods. GPR has been used to estimate the thickness and volume of peat deposits (Pelletier et al., 1991; Doolittle et al., 1990; Collins et al., 1986; Shih and Doolittle, 1984; Tolonen et al., 1984; Ulriksen, 1982; Welsby, 1988; and Worsfold et al., 1986), distinguish layers having differences in degree of humification and volumetric water content (Chernetsov et al., 1988; Lapen et al., 1996; Tolonen et al., 1984; Ulriksen, 1982; and Worsfold et al., 1986), and to classify organic soils (Collins et al., 1986). In addition, Lowe (1985) used GPR to assess the amount of logs and stumps buried in peat deposits. Welsby (1988) used GPR for post-production surveys of mined peat deposits.

While profiling depths as great as 8.1 to 10 m have been reported (Worsfold et al., 1986, and Ulriksen, 1980), GPR is not equally suitable for use on all organic soils. Soils having high electrical conductivity rapidly attenuate radar energy, restrict penetration depths, and severely limit the effectiveness of GPR. The electrical conductivity of peat is directly related to the concentration of total dissolved ions in the pore water (Theimer et al., 1994). For peat deposits,

the concentration of ions in the ground water is the principal factor influencing electrical. Theimer and others (1994) noted that the electrical conductivity is closely related to the chemistry of the underlying mineral sediments. Because of this relationship, electrical conductivity often increases towards organic/mineral soil interfaces (Theimer et al., 1994).

In general, GPR is more effective in acidic, low nutrient organic materials than in alkaline, high nutrient organic materials. The conductivity of organic soils is directly related to the concentration of ions in solution. Generally, profiling depths are greater in oligotrophic bogs than in minerotrophic fens (Malterer and Doolittle, 1984). Oligotrophic bogs are nutrient poor and have lower concentrations of the basic cations (calcium, magnesium, and potassium) than the more nutrient enriched minerotrophic fens. In some fens, such as coastal marshes, high concentrations of dissolved salts completely absorb and attenuate the radar's electromagnetic energy within shallow (0 to 50 cm) depths. In the nutrient poor minerotrophic peat deposits of the Adirondacks, and in the absence of more conductive inter-stratified layers of mineral materials containing silts and clays, profiling depths as great as 10 meters should be anticipated.

INTERPRETATIONS:

Peat deposits display considerable anisotropy in moisture content, bulk density, and often have uneven or sloping layer boundaries (Hanninen, 1992). These spatially variable properties affect the reliability of GPR interpretations (Hanninen, 1992). Differences in moisture contents allowed Chernetsov and others (1988) and Tolonen and others (1982) to distinguish layers with differences in degree of humification, bulk density, and dielectric permittivity. Hanninen (1992) identified layers of less humified Sphagnum peat from more highly decomposed Carex peat. However in surveys conducted by Remotec Applications Inc (1982) and Worsfold and others (1986), peat layers could not be clearly associated with radar reflections. These researchers concluded that GPR could not adequately characterize the physical and chemical properties of peat. GPR does not provide information on the type or quality of peat; ground truth samples are required.

Figure 2. Representative GPR profile from the Fishing Brook Fringe Site

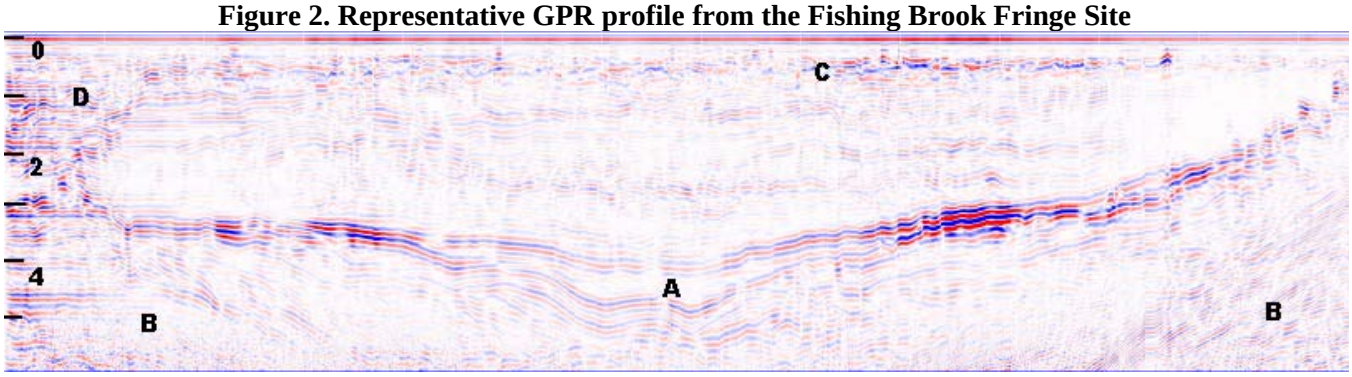


Figure 2 is a representative radar profile from the Fishing Brook Fringe Site. The radar profile has been processed. Processing included distance normalization, range gain adjustments, and high pass horizontal filtration to remove horizontal bands of noise (ringing). The horizontal scale has been compressed and the vertical scale is exaggerated. The white vertical marks at the top of the radar profile represent equally spaced (5-m) flagged observation points. The profile is 135 m long and contains 28 observation points. A depth scale (in meters) is provided along the left-hand margin of this figure. This scale is an approximation that is based on an average propagation velocity of 0.038 m/ns through peat. This scale is an approximation, as velocity will vary both horizontally and vertically. In this profile, the maximum penetration depth is estimated to be about 5.7 m through the peat.

This site represents a riverine wetland type. This peat deposit is located within a mainstream floodplain. The surface deposit is principally peat. The floodplain is underlain by glacial outwash over till. Streams continue to meander across the floodplain eroding the peat and depositing layers of alluvium. Based on radar interpretations made at 28 observation points along the radar traverse, the average depth to the organic/mineral soil contact is 3.13 m with a range of 0.77 to 4.58 m. One half of the observation points had peat thickness between 2.87 and 3.49 m.

In Figure 2, abrupt and strongly contrasting changes in water content makes the organic/mineral interface distinguishable on the radar profile. However, in the deepest part of this deposit, near "A," multiple layers are evident. Often transitional layers composed of both organic and mineral soil materials form at the lower boundary of peat deposits. As these transitional layers have moisture contents that are intermediary between the organic materials above and the mineral materials below, they produce weaker reflections that are more difficult to distinguish (Hanninen, 1992). The underlying mineral materials (see "B" in Figure 2) produce inclined planar reflectors suggesting outwash deposits rather than till. Radar imagery from till is more chaotic and generally lacks planar reflectors.

Planar reflectors are evident within the peat. These reflectors are presumed to represent layers having difference in degree of humification, water, and/or mineral contents. The strong near-surface reflector (see "c" in Figure 2) is believed to represent the water table. Stratifications were evident in all organic deposits. Based on limited soil borings, these layers are believed to represent deposits of mineral or organic/mineral materials. These layers are discontinuous and occur at variable depths. In some riverine settings, the deposits are close to the surface, near to channels, and believed to represent recent overwash deposits.
Observations revealed subsurface layers of organic/mineral soil materials throughout most of the wetlands. The radar traverse shown in Figure 2 extends from near the center of the deposit (left-hand border) to its boundary with upland soils (right-hand boundary). Streams have repeated flooded this wetland depositing alluvium that has admixed with organic materials near "D." These well expressed organic/mineral layers overly peat. At "D," the underlying organic/mineral soil interface is at a depth of about 2.8 m.

Figure 3. Representative GPR profile from the Adjidaumo Site

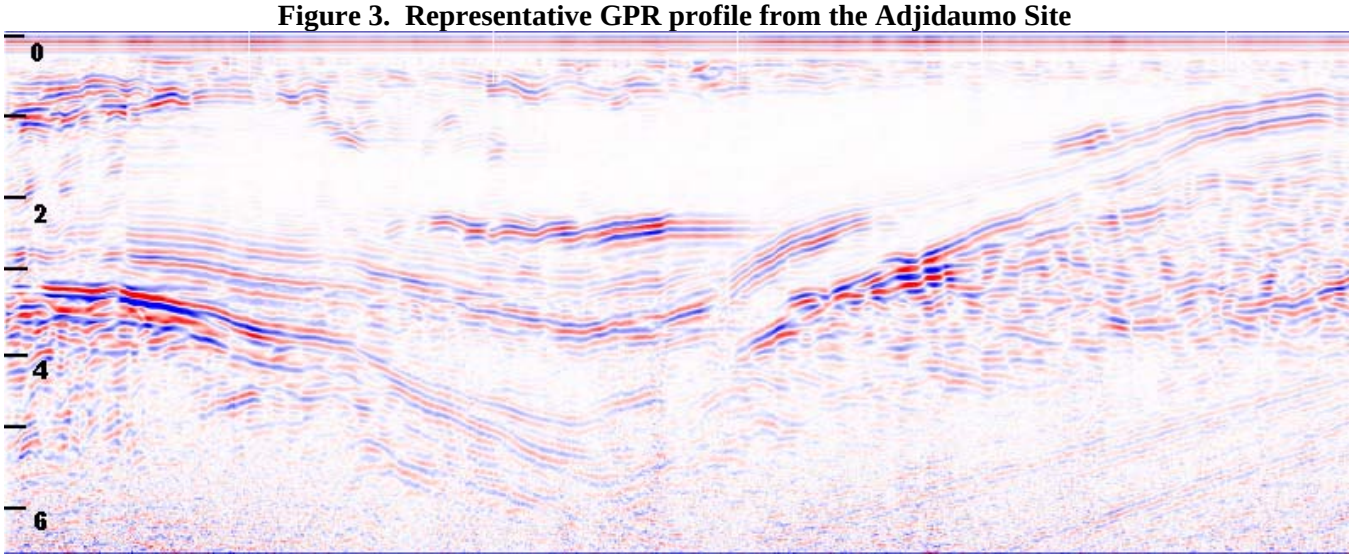


Figure 3 is a representative radar profile from the Adjidaumo Site. The radar profile has been processed. Processing included distance normalization, range gain adjustments, and high pass horizontal filtration to remove horizontal bands of noise (ringing). The horizontal scale has been compressed and the vertical scale is exaggerated. The white vertical marks at the top of the radar profile are equally spaced at intervals of 10 m. The radar profile in Figure 3 is 55 m long and contains 6 marked observation points (each spaced 10 m apart). A depth scale (in meters) is provided along the left-hand margin of this figure. This scale is an approximation that is based on an average propagation velocity of 0.038 m/ns through peat. In this profile, the maximum penetration depth is about 6.7 m through peat.

This site represents a lake fringe wetland type. There is no perceived channel in this wetland. The peat contains layers of mineral and organic/mineral soil materials. High amplitude reflections represent strongly contrasting layers. Low amplitude reflections suggest gradational or transitional layers of less contrasting organic-mineral compositions. The intensity of the imagery in Figure 3 suggests that these layers vary lateral in composition. Some are discontinuous. Without ground-truth observations, the identity of these reflectors is uncertain, as is the thickness of the peat deposit. These layers affect the hydrology of the wetland. The underlying outwash has a unique and identifiable graphic signature multiple inclined and overlapping planar reflectors.

RESULTS:
Eight transects were completed with GPR at the six sites listed in Table 1. These transect were variable in length and ranged from 40 to 140 m. Seven of the eight transects had measurable layers of peat. Only at Little Sucker Brook were the organic deposits too thin to be measured with GPR. Based on 130 observations made at seven sites, the thickness of surface organic deposits averaged about 2.4 m, with a range of about 0.4 to 6.3 m. One half of the observations had organic materials between 0.9 to 3.4 m thick.

A majority of the wetlands had measurable peat thickness. A majority of the investigated peat deposits contains multiple layers of mineral soil materials that influence the hydrology of these wetlands. Scientists working in these wetlands should be made aware of these features. Ground-penetrating radar is an effective tool for characterizing the internal stratigraphy of these wetlands.

Bitmap files of all the radar profiles and an excel spreadsheet of all the interpreted depth data have been forwarded to Dr. Chris Cirmo. It was my pleasure to have this opportunity to work in New York.

With kind regards,

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