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Natural Resources Conservation Service
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Subject: SOI -- Ground-Penetrating Radar Assistance **Date:** 8 July, 2002

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PURPOSE:
The purpose of this study was to use ground-penetrating radar (GPR) and electromagnetic induction (EMI) to help characterize soils and soil properties within the Mascoma Headwaters Wetland Project, Dorchester, New Hampshire.

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ACTIVITIES:
All field activities were completed during the period of 10 to 13 June 2002.

STUDY SITE:
An order-one soil survey has been completed of the Mascoma Headwaters Wetland Site. Soil mapped at this site include the Cohas, Lyman, Lyme, Madawaska, Metallak, Monadnock, Moosilauke, Peacham, Skerry, Sunapee, and Tunbridge series. Radar surveys were conducted in areas of Peacham and Sunapee soils. These soils formed in till on glaciated uplands. The very poorly drained Peacham soil is in depressions and drainageways. Peacham soil formed in organic materials less than 16 inches thick underlain by dense, loamy till. Peacham soil is shallow to dense basal till and very deep to bedrock. Peacham soil is a member of the coarse-loamy, mixed, active, nonacid, frigid, shallow Histic Humaquepts family. The very deep, moderately well drained Sunapee soil is a member of the coarse-loamy, isotic, frigid Aquic Haplorthods family. Though outside the range in characteristics and not taxonomically recognized, the areas of Sunapee soil traversed with GPR contained ortstein.

MATERIALS AND METHODS
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 powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. The 200, 400, and 900 MHz antennas were used in this study.

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

A GEM300 multifrequency sensor, manufactured by Geophysical Survey Systems, Inc.[1] was also used in this study. Won and others (1996) have described the use and operation of this EMI sensor. Measurements were obtained at a frequency of 9810 Hz in both the horizontal and vertical dipole orientations.

The coordinates of observation points were obtained with a Garmin GPS III receiver.[2] This receiver can continuously tracks up to twelve satellites to compute and update a position. It can store 500 waypoints and store a track log of 1900 points. It has a NMEA 0183 and RTCM 104 DGPS corrections interface.

Field Methods:

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 along the ground surface. Prior to conducting a radar traverse, the track was cleared of major debris and fallen tree limbs. As the antenna passed each observation point, the operator impressed a dashed vertical line on the radar record.

The location of observation points and the upland boundary of the wetland delineation of Peacham soil were obtained with Garmin GPS III receiver. The Latitude/Longitude coordinate systems were used. Horizontal datum is the North American 1983.

The Mascoma site contains 162 equally spaced control points (wooden stakes). These control points are spaced at 100-ft intervals. The coordinates of each observation point have been previously determined with GPS. At each control point, measurements were taken with the GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. The GEM300 sensor was operated at a frequency of 9810 Hz.

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, bedrock, 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 the two-way pulse travel time (T) to a reflector.

Within the Peacham site, at three sampling points, the two-way radar pulse travel time was compared to the measured depth to the organic/mineral interface and used with equation [1] to estimate the velocity of propagation. The measured depth to the organic/mineral interface ranged from 0.61 to 1.22 meters. At the three observation points, a strong relationship (r = 0.99) was found to exist between the two-way travel time of the radar pulse and the measured depth to this interface. The estimated velocity of propagation was 0.039 m/ns and the dielectric permittivity (E_r) was 56.

Within the Sunapee site, a metallic reflector was buried at a depth of about 50-cm (19.5 inches). The two-way radar pulse travel time was compared to the measured depth to this reflector and used with equation [1] to estimate the velocity of propagation. The estimated velocity of propagation was about 0.085 m/ns and the dielectric permittivity (E_r) was 12.

RESULTS

Wetland site:

A detailed GPR investigation was conducted within a delineation of Peacham soil. The purpose of this investigation was to prepare two- and three-dimensional plots and determine the thickness and volume of organic materials within this area of Peacham soil. Soil scientist had included deeper pockets of organic materials and Histisols in their mapping of Peacham soils.

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

The site was located in a drainageway that is enclosed by steep slopes. This reduced the Mast angle and increased the likelihood for multipath signals to be received by the GPS receiver. The very dense forest canopy further reduced the positional accuracy of GPS. As a consequence the resulting data were poor. Figure 1 shows the location of waypoints that defined the boundary of the wetland and the locations of GPR observation points. The boundary of the wetland is poorly defined with many GPR observation points occurring outside the perimeter of the wetland. The poor positional accuracy of these referenced locations made the construction of two- and three-dimensional diagrams and volumetric determinations of organic materials impractical. Better results may be obtained in months when foliage is off and the opacity of the overlying canopy reduced.

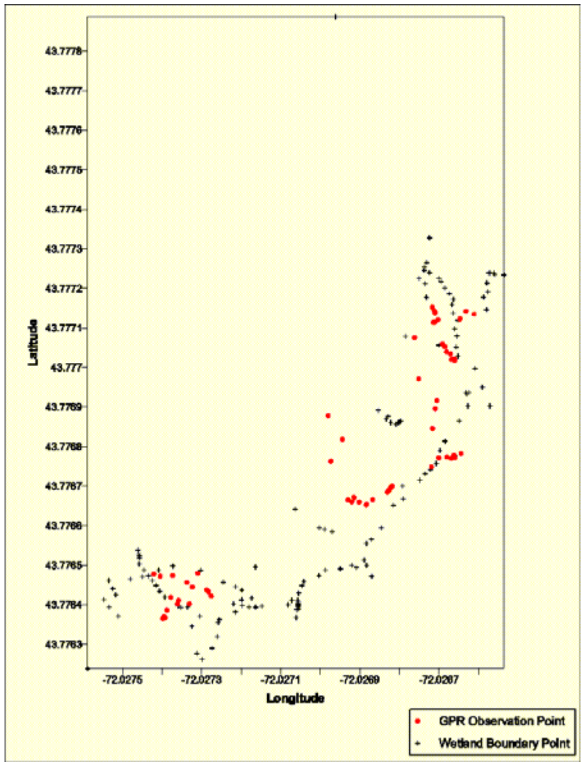

Figure 1. Delineation of an area of very poorly drained Peacham soil. The locations of all waypoints were collected with the GPS receiver.

Figure 2 is a representative radar profile obtained with a 200 MHz antenna from this area of Peacham soil. The short, black, vertical lines at the top of the radar profile represent equally spaced (2-m) observation points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the profile. The vertical scale is based on equation [1] and an average velocity of propagation of 0.039 m/ns. A dark line has been used to identify the organic/mineral soil interface. Along this traverse, soils at one-half of the observation points have organic layers greater than 40 cm thick. These soils are Histosols. A deep cavity of organic materials occurs in the central part of this traverse. Here, organic materials are more than 1 m thick and contain reflections from roots.

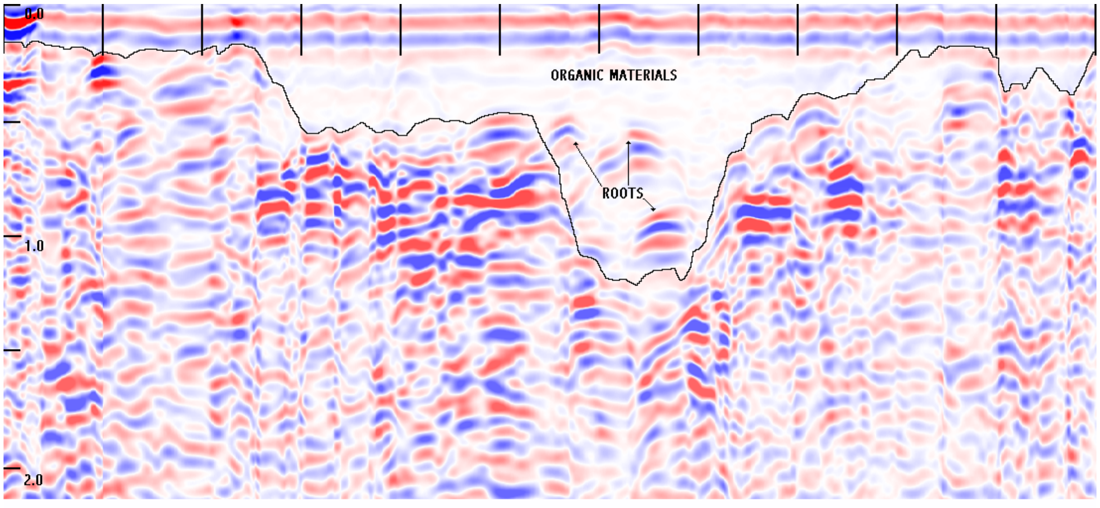

Figure 2. Representative radar profile from an area of Peacham soil.

Table 2 shows the frequency distribution of peat thickness along the radar traverses that were conducted in this area of Peacham soil. Areas of Peacham soil have layers of organic materials that are greater than 15 and less than 40 cm thick. Peacham soil represents 26 percent of the area traversed with GPR. About 48 percent of the area traversed with GPR has organic layers greater than 40 cm thick. Soils in these areas would be classified as Terric and Typic Haplosaprists. A critical depth of 1.3 m separates the Terric from the Typic taxonomic subgroups. Typic Haplosaprists represent about 7 percent of the transected areas.

Table 2. Area of Soil Map Unit 549 - Peacham soils
Frequency Distribution of Organic Soil Material
(All depths are in centimeters)

Depth Class	Number	Frequency
0 to 15	16	0.26
15 to 40	16	0.26
40 to 130	25	0.41
>130	4	0.07

Ortstein site:

Ortstein is defined as a spodic horizon that is at least weakly cemented (Soil Survey Staff, 1999). To be taxonomically recognized, ortstein must form a continuous, shallow cemented horizon in more than half of each pedon (Soil Survey Staff, 1999). Mokma and others (1990 and 1994) used GPR to determine the depth and continuity of ortstein in Michigan. There, most areas with ortstein were mapped as Saugatuck soil. Saugatuck is a member of the sandy, ortstein, mixed, mesic Typic Endoaquod family. In these studies, increased reflected signal amplitudes from the spodic horizon were associated with the presence of ortstein. Areas of lower reflected signal amplitudes were associated with less strongly cemented ortstein or tongues of E horizon materials. Areas within Mascoma that contain ortstein have been mapped as somewhat poorly drained Sunapee soil with ortstein. The Sunapee soil formed in till that is highly transparent to GPR.

In areas where soil morphological features are relatively simple, continuous, and strongly contrasting, GPR interpretations are relatively straightforward and unambiguous. However, in soils that contain extraneous reflections, reverberations, diffractions, and noise from undesired subsurface features, interpretations are more difficult. In such cases, the extraction of desired information is more complicated. Within many areas of Macoma, tree fall activity has resulted in pronounced *cradle knoll* micro-topography and the severe disturbance of soil horizons. Soil disturbances have made subsurface reflectors more difficult to identify and trace laterally on radar profiles. Gravel, cobbles, and tree roots produce undesired reflections that further complicate radar interpretations.

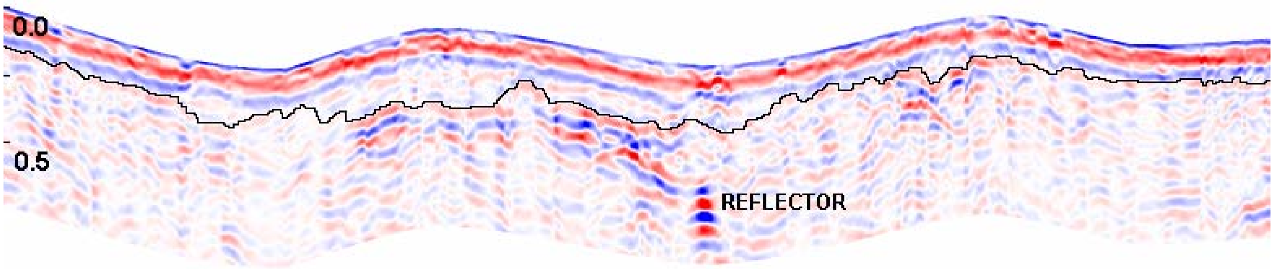

Figure 3. Representative radar profile of an area of Sunapee soil with ortstein. Radar profile obtained with a 400 MHz antenna.

Figure 3 is a representative radar profile obtained with a 400 MHz antenna from the area of Sunapee soil. Layers of ortstein were observed in this soil. This profile has been *terrain corrected* to show the apparent topography along the radar traverse line. A vertical scale (in meters) appears along the left-hand margin of the profile. The vertical scale is based on equation [1] and an average velocity of propagation of 0.085 m/ns. The reflector is a metallic plate that was buried at a depth of about 50-cm.

In Figure 3, a dark line has been used to identify the top of the spodic horizon. In this area of Sunapee soil with ortstein, an E horizon overlies a Bh horizon that overlies a Bsm horizon. However, in some pedons, because of disturbance, the E horizon was absent. Generally, in a majority of the observed soil profiles, the Bsm horizon was well expressed. However, this horizon could not be identified by changes in signal amplitudes alone and was not distinguishable from the overlying Bh horizon with either the 900 or 400 MHz antennas. Changes in signal amplitude were more strongly associated with the abruptness and contrast of the albic/spodic interface than with the Bh/Bsm interface. Because of the disturbance and lateral variability in the expression of the albic and spodic horizons, this interface was most challenging to identify and trace laterally on radar profiles.

<u>EMI Survey:</u>
Electromagnetic induction (EMI) is a noninvasive geophysical tool that can be used for detailed site assessments. Advantages of EMI are its portability, speed of operation, flexible observation depths and moderate resolution of subsurface features. This geophysical tool can provide in a relatively short time the large number of observations that are needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for delineating and assessing site conditions, planning further investigations, and locating sampling or monitoring sites.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are caused by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the type and concentration of ions in solution, the amount and type of clays in the soil matrix, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980). The apparent conductivity of soils increases with increased soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

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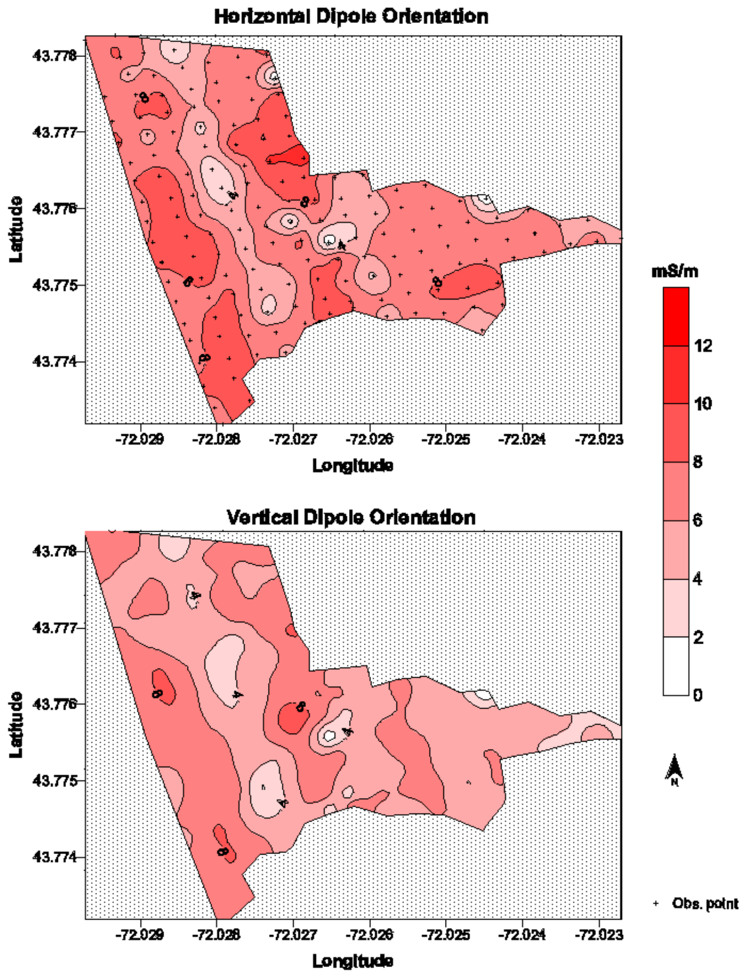

Figure 4. EMI survey of the Mascoma site. Survey was conducted with the GEM300 sensor at an operating frequency of 9810 Hz. All values are expressed in mS/m.

Electromagnetic induction is not suitable for use in all investigations. Generally, the use of EMI has been most successful in soils and earthen materials where subsurface properties are reasonably homogeneous and one property (e.g. salt, clay, or water content) exerts an overriding influence over soil electrical conductivity. In these areas, variations in apparent conductivity can be directly related to changes in the dominant property (Cook et al., 1989).

Figure 4 shows the spatial distribution of apparent conductivity as measured with the GEM300 sensor (9810 Hz) in the shallower-sensing horizontal (upper plot) and the deeper-sensing vertical (lower plot) dipole orientations. In each plot, the isoline interval is 2 mS/m. The locations of the 162 control or observation points are shown in the upper plot. At all observation points, apparent conductivity decreased with increasing depth of observation (measurements obtained in the shallow-sensing, horizontal dipole orientation were higher than those obtained in the deeper-sensing, vertical dipole orientation). This relationship is associated with the higher water and clay contents of the overlying soil and the resistive nature of the underlying bedrock. In the shallower-sensing, horizontal dipole orientation, apparent conductivity averaged 6.8 mS/m with a range of 0 to 11.1 mS/m. Half of these observations had values of apparent conductivity between 6.0 and 8.1 mS/m. In the deeper-sensing, vertical dipole orientation (lower plot, Figure 5), apparent conductivity averaged 5.8 mS/m with a range of 0 to 9.9 mS/m. Half of these observations had values of apparent conductivity between 4.8 and 6.9 mS/m.

In Figure 4, distinct linear bands of contrasting apparent conductivity are evident in each plot. These bands trend in a NNW to SSE orientation across the Mascoma Site. The linear bands cut across surface drainage lines and did not appear to be influenced by changes in surface moisture or soil drainage classes. These patterns are believed to reflect differences in the depth to bedrock, lithology, or fracture patterns. Areas with lower values of apparent conductivity are believed to have shallower depths to bedrock, or resistive lithology, and/or less fracturing and weathering (differences in the intensity weathering or the degree of fracturing will affect moisture and clay contents).

FINDINGS:

1. Folistic and histic epipedons are differentiated based on the number of days in which they are saturated. GPR was unable to distinguish thin surface layers of organic materials and differentiate folistic from histic epipedons. However, GPR is an efficient tool for the assessments of the thickness and volume of organic materials greater than 40 cm thick. Unfortunately, because the opacity of the overlying canopy to GPS signals, two- and three dimensional plots showing the subsurface topography and peat thickness within a representative area of Peacham soil could not be produced. Returning to the site when foliage is off should improve results.

2. GPR can be used to characterize the depth and continuity of spodic horizons. However, because of variations in soil properties and disrupted soil horizons attributed to tree falls, characterization was less straightforward than desired. Ortstein could not be distinguished based on changes in signal amplitude.

3. An EMI survey revealed distinct linear patterns that trend in NNW to SSE orientation across the site. These patterns are believed to reflect differences in the depth to bedrock, lithology, or fracture patterns.

It was my pleasure to work in New Hampshire and with members of your fine staff.

With kind regards,

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References

Conyers, L. B., and D. Goodman. 1997. Ground-penetrating Radar; An introduction for archaeologists. AltaMira Press, Walnut Creek, CA.

Cook, P. G., M. W. Hughes, G. R. Walker, and G. B. Allison. 1989. The calibration of frequency-domain electromagnetic induction meters and their possible use in recharge studies. Journal of Hydrology 107:251-265.

Daniels, D. J. 1996. Surface-Penetrating Radar. The Institute of Electrical Engineers, London, United Kingdom.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. pp. 11-32. In: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20.

Greenhouse, J. P., and D. D. Slaine. 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2): 47-59.

Kachanoski, R. G., E. G. Gregorich, and I. J. Van Wesenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

McNeill, J. D. 1980. Electrical Conductivity of soils and rocks. Technical Note TN-5. Geonics Ltd., Mississauga, Ontario.

Mokma, D. L., J. A. Doolittle, and L. A. Tornes. 1994. Continuity of ortstein in sandy spodosols of Michigan. Soil Survey Horizons 35: 6-10.

Mokma, D. L., R. J. Schaetzl, J. A. Doolittle, and E. P. Johnson. 1990. Ground-penetrating radar study of ortstein continuity in some Michigan Haplaquods. Soil Sci. Soc. Am. J. 54:936-938.

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. pp. 212-232. IN: Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction, held at Henniker, New Hampshire. Aug. 11-16, 1974.

Rhoades, J. D., P. A. Raats, and R. J. Prather. 1976. Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci. Soc. Am. J. 40:651-655.

Soil Survey Staff. 1999. Soil Taxonomy, A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Agriculture Handbook No. 436. 2nd edition. USDA-Natural Resources Conservation Service. U.S. Government Printing Office, Washington, DC.

Won, I. J., Dean A. Keiswetter, George R. A. Fields, and Lynn C. Sutton. 1996. GEM-2: A new multifrequency electromagnetic sensor. Journal of Environmental & Engineering Geophysics 1:129-137.