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

Subject: ENG -- Ground-Penetrating Radar (GPR) Assistance **Date:** 18 October 2005

To: Paul Dorning
Coordinator
Upper Columbia RC&D
USDA Service Center
8825 E. Mission Avenue, Suite B
Spokane Valley, WA 99212

Purpose:
Ground-penetrating radar (GPR) was used to profile the thickness of organic soil materials beneath a wooden boardwalk that extends across a peatland at Camp Cowles on Diamond Lake in Pend Oreille County, Washington. The wooden boardwalk is in disrepair. The Boy Scouts of America wish to replace the boardwalk with a new walkway that will be handicap accessible. Estimates of the thickness and variations in depth of organic materials would greatly facilitate plans for this project

Participants:
Paul Dorning, Coordinator Upper Columbia RC&D, USDA-NRCS, Spokane Valley, WA
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Chandra Neils, Area Soil Scientist, USDA-NRCS, Spokane WA
Misty Seaboldt, Forester, USDA-NRCS, Spokane Valley, WA

Activities:
All field activities were completed on 8 October 2005.

Survey Area:
The survey line extended about 273 m in a southerly direction along a boardwalk that crosses an area of organic soils. This line extended from a point located near 48.12913 North Latitude and 117.22218 West Longitude to a point on the opposite side near 48.12665 North Latitude and 117.22240 West Longitude.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (North Salem, New Hampshire).[1] Daniels (2004) discusses the use and operation of GPR. The SIR System-3000 weighs about 9 lbs and is backpack portable. With an antenna, this system requires two people to operate. A 70 MHz antenna was used in this study. All radar records were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc).[1] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance normalization, range gain adjustments, migration, and signal stacking.

A Bitmap file of the radar record was prepared using the Radan to Bitmap software developed by Geophysical Survey Systems, Inc. [1] This utility allows the conversion of 8 or 16 bit radar records into 24 bit Windows bitmaps.

Survey Procedures:
The SIR System-3000 was carried in a backpack by the operator and the 70 MHz antenna was carried at a height of about 2 inches above the boardwalk by an assistant. Survey flags had been inserted in the soil at a distance of 7-m along the boardwalk. The survey flags served as referenced points. As the 70 MHz antenna passed each survey flag, the operated impressed a vertical mark on the radar record. Marks denote the locations of reference points on the radar record. At each reference point on the radar record the thickness of the organics and the depth to the organic/mineral soil interface was estimated.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time taken by electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer) and back. To convert the travel time into a depth scale, either the

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

velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (V) are described in the following equation (Daniels, 2004):

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

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to the equation (Daniels, 2004):

$$E_r = (C/V)^2 \qquad [2]$$

In equation [2], C is the velocity of propagation in a vacuum (0.299 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). The amount and physical state (temperature dependent) of water have the greatest effect on the E_r of earthen materials. Water has the highest possible E_r (80) and a velocity of propagation of 0.033 m/ns. Air has the lowest possible E_r (1) and a velocity of propagation of 0.30 m/ns.

A column of organics was probed with a soil core near the 50-m mark in Figure 1. At this coring point, the depth to the organic/mineral soil interface was a measured 275 cm. At this point, on the radar record, two high amplitude (colored white, blue, green, and yellow in Figure 1) reflectors are evident: a higher lying horizontal reflector and an underlying dipping reflector. High amplitude reflectors denote highly contrasting materials on the radar record. The dipping reflector was initially picked as the organic/mineral soil interface. A program on the SIR-3000 was used to automatically adjust the depth to this interface on the radar record to the measured depth of 275 cm. This procedure was assumed to have effectively scaled the radar record collected at this site. However, when the radar record was later processed and analyzed, this depth scale was found to be incorrect. The initial velocity of propagation was 0.0254 m/ns; an impossibility, as such a velocity would result in an unattainable E_r of 138.6. It was clear that either the wrong interface had been picked on the radar record or the depth to the organic/mineral soil interface was incorrectly measured or recorded. The shallower, horizontal subsurface interface shown in Figure 1 was reinterpreted as the organic/mineral soil interface that halted the soil coring. Using this reflector, the E_r was 51.2 and the velocity of propagation was 0.0418 m/ns. These values are acceptable and within the range of values given in tables for organic soil materials.

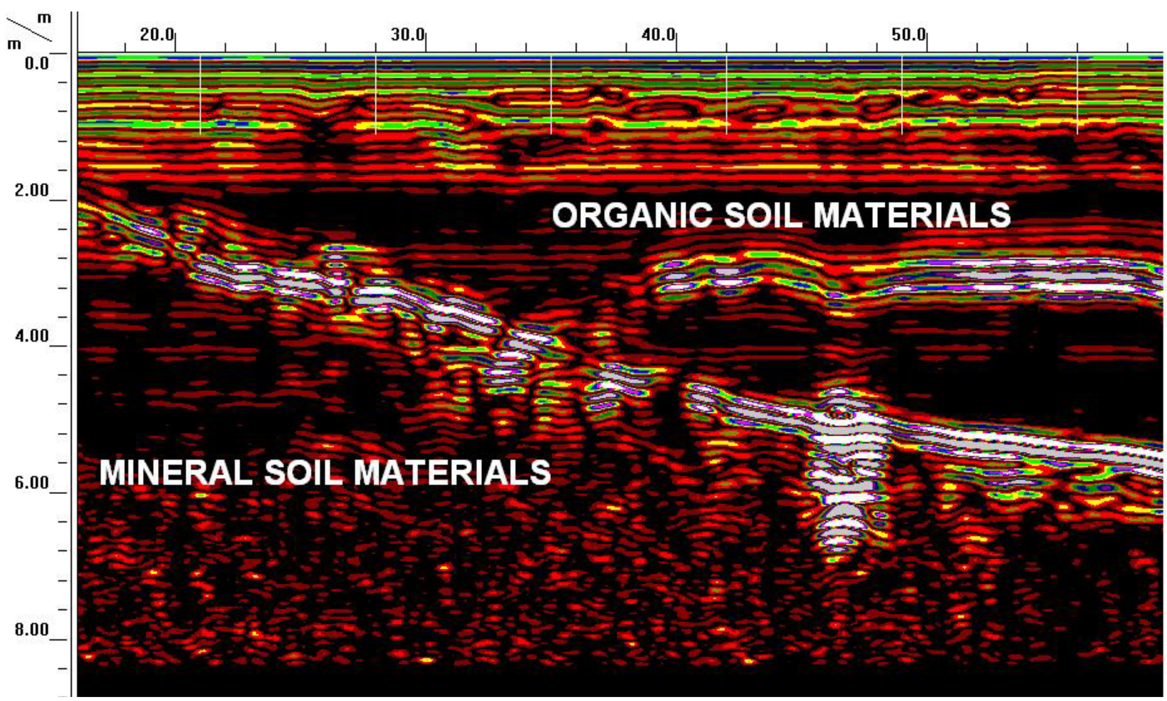

Figure 1. A representative radar record collected with 70 MHz antenna.

<u>Interpretations:</u>
Radar records were of good interpretative quality. Figure 1 is a representative portion of the radar record from the boardwalk. On this radar record, all scales are in meters. The depth scale is based on a propagation velocity of 0.0418 m/ns through the organics. Please note the vertical exaggeration of this record. Although the radar provides a continuous profile of the organic soil materials within the peatland, measurements of peat thicknesses were restricted to the reference points (white vertical lines at the top of the radar record). These reference points were spaced in the field at an interval of approximately 7-m.

On the radar record shown in Figure 1 the surface of the boardwalk is represented by the two uppermost horizontal lines. Below these reflections are reflections from the soil surface, near surface soil layers and multiples (ringing of reflected signals (a form of unwanted noise)). A high amplitude reflector is seen dipping from about 2 m (along left-hand margin of Figure 1) to a depth of about 5.4 m (along right-hand margin of Figure 1). This interface is assumed to represent the bottom of a former lake basin. This interface was continuous across the radar record, though signal attenuation resulted in its poorer definition in deeper portions of the former lake basin. In Figure 1, near the 35-m reference mark, a less inclined, more horizontal interface extends away from the more inclined basin's interface. This reflector is believed to represent the organic/mineral soil interface that halted coring. In Figure 1, based on an assumed averaged velocity of propagation (0.0418 m/ns), the depth to this organic/mineral soil interface ranges from 2.78 to 3.54 m. While the thickness of the mineral layer cannot be accurately measured on this radar record, it appears to separate two separate layers of organic materials.

Results:

Table 1 lists data interpreted from the radar record. Columns represent the reference point number (in terms of distance along the traverse line), and the interpreted depths to the first and second interfaces that were identified on the radar record collected along the boardwalk. These depths are based on a constant velocity of 0.0418 m/ns through the underlying materials. The use of this velocity provides a close approximation of the actual depths. However, velocity of signal propagation does not remain constant with depth, but varies with the porosity and water content of each layer. The images seen on the radar record suggest that two layers of organic soil materials are separated by a buried mineral layer. Additional ground-truth coring is needed to confirm this interpretation, verify the velocity of signal propagation through the three layers (inferred to be an organic/mineral/organic layer sequence), and to derive more accurate depth assessments. If interpretations made in this report are correct, it is likely that the boardwalk designs may need to be modified to account for the relatively thin layer of mineral soil materials and the deeper, second layer of organic materials.

Table 1.

Interpreted data from the radar record from the GPR traverse conducted along the boardwalk. Projected depths to the 1st and 2nd organic/mineral soil interfaces are based on an assumed constant velocity of 0.0418 m/ns.

Meters	Depth (1st)	Depth (2nd)	Meters	Depth (1st)	Depth (2nd)
0	-0.75	---	140	-3.35	-5.98
7	-1.08	---	147	-3.42	-6.62
14	-1.47	---	154	-3.79	-7.35
21	-2.13	---	161	-3.79	-7.96
28	-2.98	-2.98	168	-3.71	-8.03
35	-3.31	-3.89	175	-3.52	-7.94
42	-2.71	-4.82	182	-4.10	-8.29
49	-2.79	-5.21	189	-3.93	-7.83
56	-2.73	-5.50	196	-3.60	-7.94
63	-2.96	-5.74	203	-3.52	-7.83
70	-3.15	-5.98	210	-3.54	-7.66
77	-3.29	-6.34	217	-3.68	-7.61
84	-3.42	-6.62	224	-3.46	-7.39
91	-3.52	-6.89	231	-3.89	-7.61
98	-3.66	-6.84	238	-4.12	-7.74
105	-3.46	-6.47	245	-4.02	-6.97
112	-3.17	-5.96	252	-3.06	-6.47
119	-3.13	-5.74	259	-2.46	-5.81
126	-3.23	-5.59	266	-2.05	-4.16
133	-3.17	-5.74	273	0.00	0.00

Assuming a constant velocity of 0.0418 m/ns through the underlying layered organic and mineral soil materials, a bitmap presentation of the radar record is shown in Figure 2. This record contains no horizontal or vertical scales. However, on this radar record, the vertical scale has been highly exaggerated. Processing used to produce the radar record shown in Figure 1, cannot be used with the Radan to Bitmap utility software. As a consequence, the imagery shown in Figure 3 represents the raw, unprocessed radar data. On this radar record, several vertical patterns are evident. These patterns represent unwanted background noise, which are attributed to cultural noise (cell phones) or atmospherics.

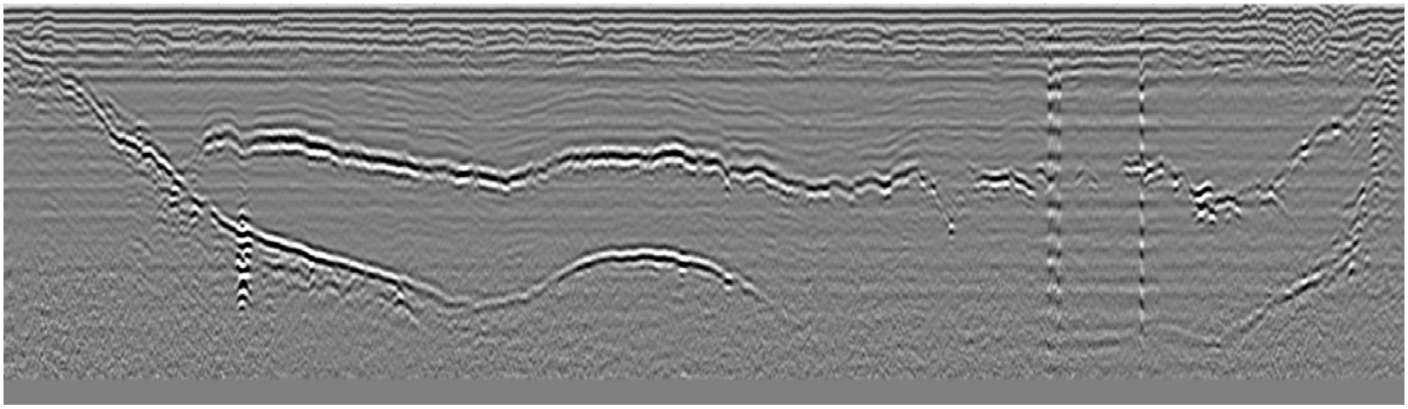

Figure 2 The bitmap file of the radar record showing two high amplitude subsurface reflectors. .

A pseudo-cross sectional profile of the two organic layers is shown in Figure 3. This presentation provides a picture of the subsurface as presently interpreted from the radar record. However, additional ground-truth corings are needed to verify interpretations.

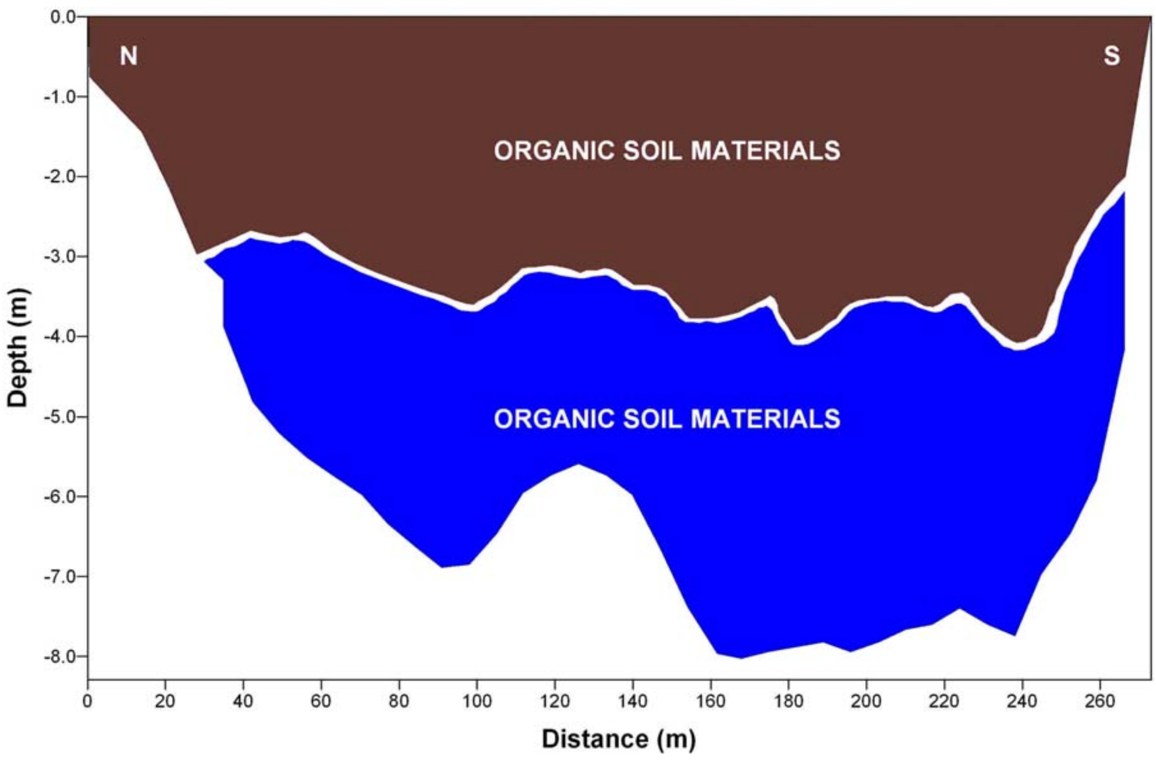

Figure 3. A cross sectional profile showing the interpreted thickness and depths of two inferred layers of organic soil materials that are assumed to be separated by a comparatively thin layer of mineral soil materials beneath the existing boardwalk. Depth scale assumes a constant velocity of 0.0418 m/ns.

It is unfortunate that multiple corings were not completed at the time of the GPR survey. However, at the time of the radar survey, depth scales and interpretations seemed clear. Additional corings would have improved interpretations and helped to confirm the identity of the interfaces captured on the complete radar record. With additional soil corings, the data in Table 1 may be corrected and used to improve interpretations. The bitmap file of the radar record (Figure 2) has been forwarded to you by e-mail.

It was my pleasure to work on this project. I deeply appreciated the assistance of Chandra Neils.

With kind regards,

Jim Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Director, Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
D. Hammer, National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
C. McGrath, MLRA Office Leader, USDA-NRCS, 1201 NE Lloyd Blvd., Suite 900, Portland, OR 97232
R. Myhrum, Acting State Soil Scientist, USDA-NRCS, Suite 450, West 316 Boone Avenue, Spokane, WA 99201-2348
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697

References

Daniels, D. J. 2004. Ground Penetrating Radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.