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

Subject: Soils – Ground-Penetrating Radar (GPR) Field Assistance **Date:** 6 February 2008

To: Roylene Rides at the Door
State Conservationist
USDA-NRCS
60 Quaker Lane, Suite 46
Warwick, RI 02886-0111

Purpose:
To conduct ground-penetrating radar field investigations in Rhode Island.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Brian Oakley, PhD Research Assistant, Geosciences, University of Rhode Island, Kingston, RI
Maggie Payne, Soil Scientist, USDA-NRCS, Warwick, RI
Robert Tunstead, Resource Soil Scientist, USDA-NRCS, West Wareham, MA
Jim Turenne, Assistant State Soil Scientist, USDA-NRCS, Warwick, RI

Activities:
All activities were completed during the period of 22 to 24 January 2008.

Summary:
Ground-penetrating radar (GPR) traverses were completed over sites located in Kent, Washington, and Newport Counties, Rhode Island. Most soils in Rhode Island are well suited to GPR. Radar traverses provide high quality information on the depth to contrasting soil, stratigraphic, and lithologic materials. The data will be used to help determine the composition of soil map units. This information is desirable for the update of the Rhode Island soil survey and research needs of our cooperators. It was my pleasure to work in Rhode Island and to be of assistance to your staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
K. Kolesinskas, State Soil Scientist, USDA-NRCS, 344 Merrow Road, Tolland, CT 06084
J. E. Scherer, Soil Conservationist, USDA-NRCS, 60 Quaker Lane, Suite 46, Warwick, RI 02886-0111
R. Tunstead, Soil Scientist, USDA-NRCS, 15 Cranberry Highway, West Wareham, MA 02576
J. Turenne, Assistant State Soil Scientist, State, USDA-NRCS, 60 Quaker Lane, Suite 46, Warwick, RI 02886-0111
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (Salem, NH). [1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) discusses the use and operation of GPR. The 120, 200, and 400 MHz antennas were used in the reported studies.

Radar records contained in this report were processed with the RADAN for Windows (version 6.6) software developed by GSSI. [1] Processing included: header editing, setting the initial pulse to time zero, distance normalization, and range gain adjustments. Data collected for deeper stratigraphic investigations were migrated and stacked.

Field Methods:
Traverses were conducted with the SIR-3000 and a suitable antenna. A Garmin GPS76 or a Trimble R-8 RTK global positioning system (GPS) receiver was used to obtain the coordinates of each observation point along each GPR traverse line. Jim Turenne collected and filed all positioning data.

Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., bedrock, soil horizon, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to the 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:

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

where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v.

At the South Kingston Land Trust and the Watson Farm sites, based on the measured depth and the two-way pulse travel time to a known, subsurface reflector, and equation [1], the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profile were estimated. At the South Kingston Land Trust site, in an area of Bridgehampton soils, the estimated E_r was 16.2 (v = 0.0740 m/ns). At the Watson Farm site, in an area of Poquonock soils, the estimated E_r was 16.0 (v = 0.0745 m/ns). At the Warwick site, in an area of Windsor soils, the estimated E_r was 4.2 (v = 0.1454 m/ns). All soils were relatively moist at the time of this investigation.

Study Sites:
Sites were located in pastures, cultivated fields, or cleared areas in Kent, Newport, and Washington Counties. The South Kingston Land Trust site is located off of Matunuck Beach Road near Matunuck. This site consists of two fields (one in hay land, the other in cultivation) located on opposite sides of Matunuck Beach Road. The area is mapped as Bridgehampton silt loam, 0 to 3 percent slopes (BhA). The very deep, well drained and moderately well drained Bridgehampton soils formed in thick, silty deposits over glacial drift on outwash terraces and glaciated uplands. Solum thickness ranges from 100 to 142 cm and corresponds to the depth to contrasting glacial drift.

The Watson Farm site is located on northern Conanicut Island in Newport County. This site is in pasture and mapped as Poquonock loamy fine sand, 3 to 8 percent slopes (PsB). The very deep, well drained Poquonock soils formed in sand mantled, loamy till on uplands. Poquonock soils are moderately deep to a densic contact. Depth to bedrock is greater than 180 cm.

---
[1] Trade names are used for specific references and do not constitute endorsement.

The Warwick and East Greenwich sites are located in wooded park areas on opposite sides of Greenwich Bay. The Warwick site is in an area of Windsor loamy sand, 0 to 3 percent slopes (WgA). The very deep, excessively drained Windsor soils formed in sandy glacial outwash. The East Greenwich site is in an area of Hinckley gravelly sandy loam, rolling (HkC). The very deep, excessively drained Hinckley soils formed in water-sorted material on terraces and outwash plains.

Beaver Tail State Park is located near Beavertail Point on the southern tip of Conanicut Island. The area is mapped as Newport silt loam, 3 to 8 percent slopes (NeB). The very deep, well drained Newport soils formed in compact glacial till on uplands. Newport soils are moderately deep to dense basal till.

The taxonomic classifications of the soils identified in the study areas are listed in Table 1.

Table 1. Names and taxonomic classifications of major soils traversed with GPR

Soil Series	Taxonomic Classification
Bridgehampton	Coarse-silty, mixed, active, mesic Typic Dystrudepts
Hinckley	Sandy-skeletal, mixed, mesic Typic Udorthents
Newport	Coarse-loamy, mixed, active, mesic Typic Dystrudepts
Poquonock	Mixed, mesic Typic Udipsamments
Windsor	Mixed, mesic Typic Udipsamments

Results:

South Kingston Land Trust site:

Bridgehampton soils have a silty mantle that ranges in thickness from 100 to 142 cm. This coarse-silty mantle overlies contrasting layers of stratified sand and gravel or coarse-textured glacial till. Tables 2 and 3 show the thickness of the coarse-silty mantle as interpreted from the radar records collected along five traverse lines at this site. In these transects, a large proportion of the soils have a thinner silt mantles than are allowed by the official series description for Bridgehampton soils. Similar very deep, well drained soils with silt mantles less than 100 cm thick are recognized as Enfield (coarse-silty over sandy or sandy-skeletal, mixed, active, mesic Typic Dystrudepts). Enfield soil comprised about 54 percent of the observations made along these five traverse lines. In Figure 1, areas of Enfield and Bridgehampton soils are easily separated on the radar record.

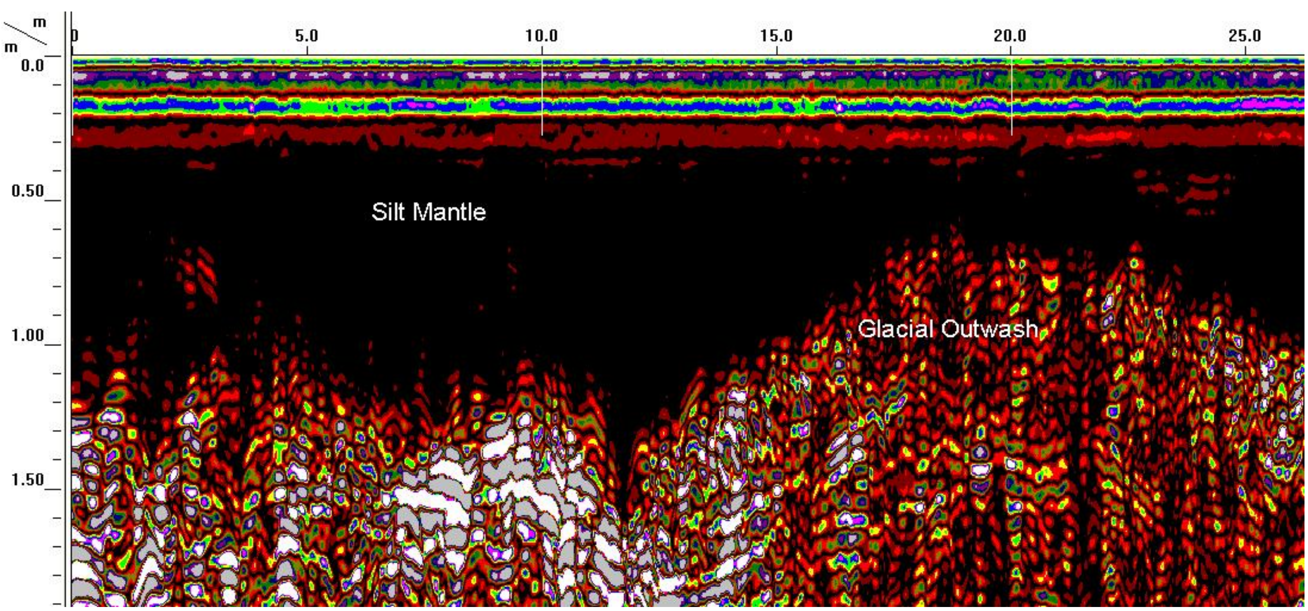

Figure 1. A representative portion of a radar record that was collected in an area of Bridgehampton silt loam, 0 to 3 % slopes.

Table 2. Thickest silty mantle for transects conducted in areas of Bridgehampton silt loam, 0 to 3 percent slopes.

Thickness of silt mantle (cm)	BhA-1	BhA-2	BhA-2	BhA-4	BhA-5
0-50	0	0	1	0	0
50-100	5	6	2	9	11
100-150	4	6	7	4	4
>150	1	0	0	0	1
Observations:	**10**	**12**	**10**	**13**	**16**

Table 3. Frequency distribution of data shown in Table 2.

Thickness of silt mantle (cm)	BhA-1	BhA-2	BhA-3	BhA-4	Bh-5A
0-50	0.00	0.00	0.10	0.00	0.00
50-100	0.50	0.50	0.20	0.69	0.69
100-150	0.40	0.50	0.70	0.31	0.25
>150	0.10	0.00	0.00	0.00	0.06

Watson Farm site:

Although this site is mapped as Poquonock soils, excavations made in this delineation revealed parent rock at depth of less than 152 cm. The radar record shown in Figure 2 is from a traverse conducted within this delineation of Poquonock loamy fine sand, 3 to 8 percent slopes. In this record, the contact of the overlying drift mantle with the underlying bedrock is fairly distinct despite a highly irregular and fractured bedrock surface, which provides scattered and relatively low amplitude reflections.

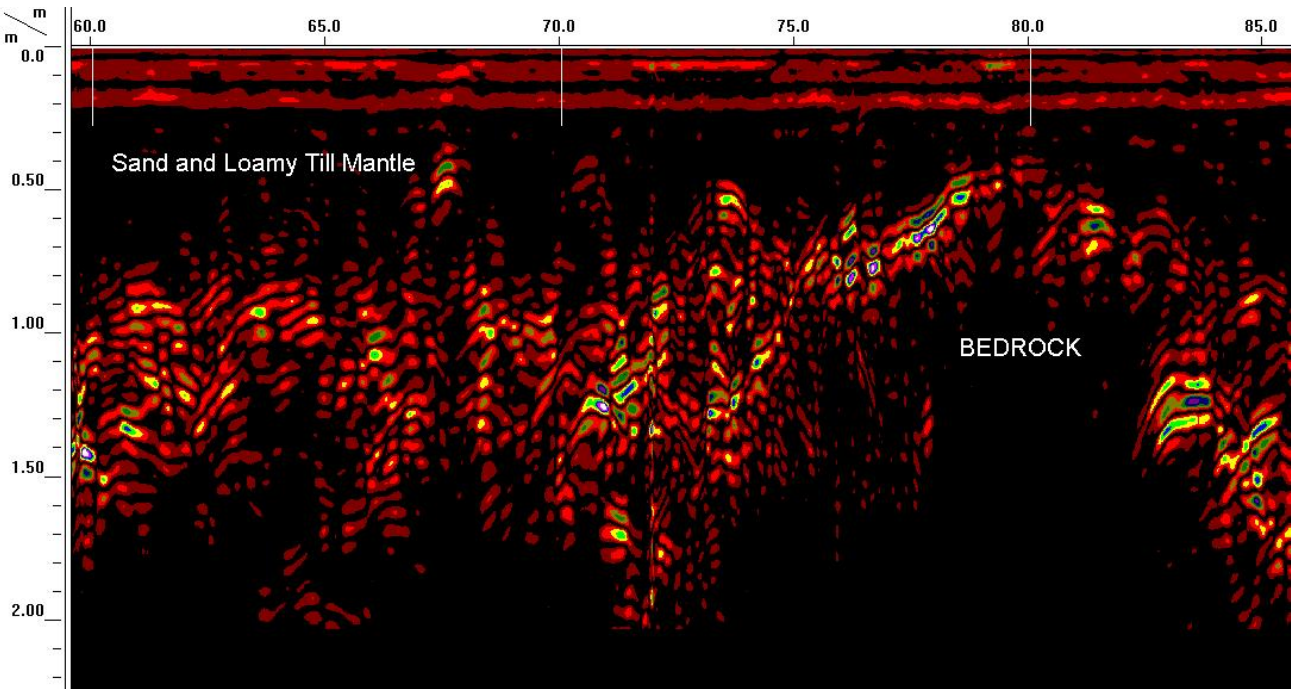

Figure 2. A portion of a radar record that was collected in an area of Poquonock loamy fine sand, 3 to 8 % slopes, that shows a weakly expressed, but relatively clear contact between the soil mantle and the underlying bedrock.

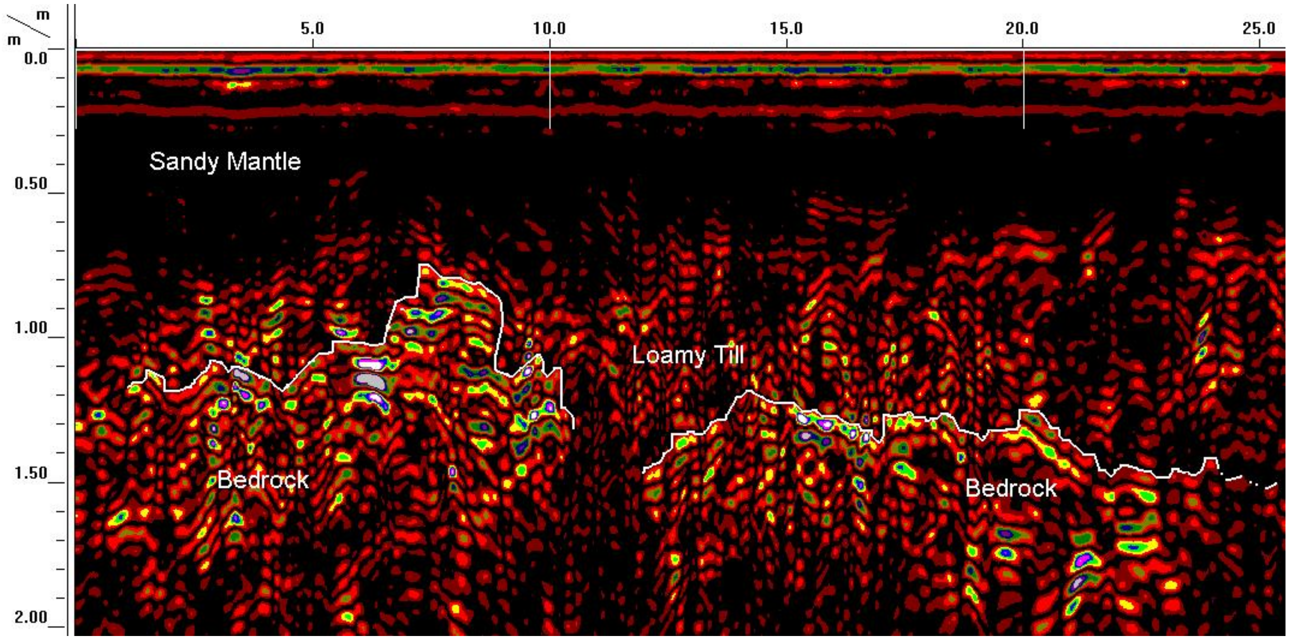

Figure 3. A portion of a radar record that was collected in an area of Poquonock loamy fine sand, 3 to 8 % slopes, that shows a highly complex and more difficult to interpret profile.

While the contact of the glacial drift with the underlying bedrock is identifiable on the radar record shown in Figure 2, in significant portions of the radar records, the soil/bedrock contact was difficult to unambiguously identity. The analysis provided in Figure 3 is considered highly interpretive and ambiguous in some portions of the radar record. The sand mantle is identifiable because it generally lacks reflectors. The contact of the sand mantle with the underlying loamy till can be approximated on this record, but some areas seem to indicate include bodies in the sand mantle and suggest mixing or slight stratifications. Because of the large number of rock fragments in the till and the irregular topography and highly fractured character of the underlying bedrock, the contact between these two bodies is more ambiguous and interpretative. In Figure 3, a white line has been used to highlight the interpreted depth to bedrock. Based on radar interpretations soils are shallower than allowed for in the official description of the Poquonock series. The radar interpretations do confirm the landowner's suspicions and the need to revise or rename this soil delineation.

Tables 4 and 5 show the depth to bedrock as interpreted from the radar records collected along two traverse lines in this area of Poquonock loamy fine sand, 3 to 8 percent slopes. In these transects, all observations have shallower depths to bedrock that are allowed by the official series description for Poquonock soils

Table 4. Depth to bedrock at GPR observation points for transects conducted in areas of Poquonock silt loam, 3 to 8 percent slopes.

Soil Depth (cm)	PsA-1	PsA-2
0-50	1	0
50-100	5	8
100-150	4	7
>15	0	0
Observations:	**10**	**15**

Table 5. Frequency distribution of data shown in Table 4.

Soil Depth (cm)	PsA-1	PsA-2
0-50	0.10	0.00
50-100	0.50	0.53
100-150	0.40	0.47
>150	0.00	0.00

Warwick and East Greenwich sites:

Brian Oakley is completing his thesis work on the Quaternary geology of Glacial Lake Narragansett. He has collected sub-bottom cores in Greenwich Bay to reconstruct the history and sequence of deposition into this glacial lake. Ground-penetrating radar is being used to link this sub-bottom information with the terrestrial deltas that fed into the lake (topset/foreset contact).

Figure 4 contains a representative portion of a radar record that was collected with the 200 MHz antenna at the Warwick site. The depth scale used on this radar record is an approximation that is based on an E_r for relatively dry sand (4.8) and a constant v of 0.1360 m/ns. The velocity of propagation is strong influenced by variations in soil moisture, which increases. Therefore, v does not remains constant with soil depth (a source of errors as only one depth scale can be shown on radar records). In the upper part of this radar record, foreset beds can be observed dipping towards the left and into former Glacial Lake Narragansett. A faint planar discontinuity can be traced horizontally across this radar record at a depth of about 50 to 100 cm. The strongly-expressed, dipping beds are cut by a high-amplitude, horizontal reflector at an estimated depth of about 350 to 400 cm (based on the estimated E_r). This interface is believed to represent the water table. Below the water table, the sands are saturated, the dielectric permittivity increases (range from 20 to 30), the propagation velocity slows, and the projected depths are exaggerated.

Figure 5 is a radar record that was collected with the 120 MHz antenna along the same portion of the traverse line shown in Figure 4. While greater depths of penetration are achieved with the lower frequency 120 MHz antenna, resolution of subsurface features is less. However, the water table and the general stratigraphic sequence are adequately captured with the 120 MHz antenna. Radar records collected with the two antennas give slightly different views of the subsurface. As with the record collected with the 200 MHz antenna (Figure 4), the depth scale used in the record obtained with the 120 MHz antenna is based on an E_r of 4.8, which graphically must be falsely assumed to remains constant with depth. Immediately below the reverberations of the strong surface pulse, a partially masked, planar discontinuity can be traced horizontally across this radar record between depths of 50 to 100 cm. In the upper part of the radar record shown in Figure 5, foreset beds can be observed dipping towards the left and into former Glacial Lake Narragansett. The dipping foreset beds are intersected by a high-amplitude, horizontal reflector at an estimated depth of about 350 to 400 cm. This interface is believed to represent the water table. Below the water table, the sands are saturated, the E_r increases (range from 20 to 30), and the v slows. Changes in these parameters are not modeled in Figure 5 and as a consequence, the projected depth of 20 m is an exaggeration.

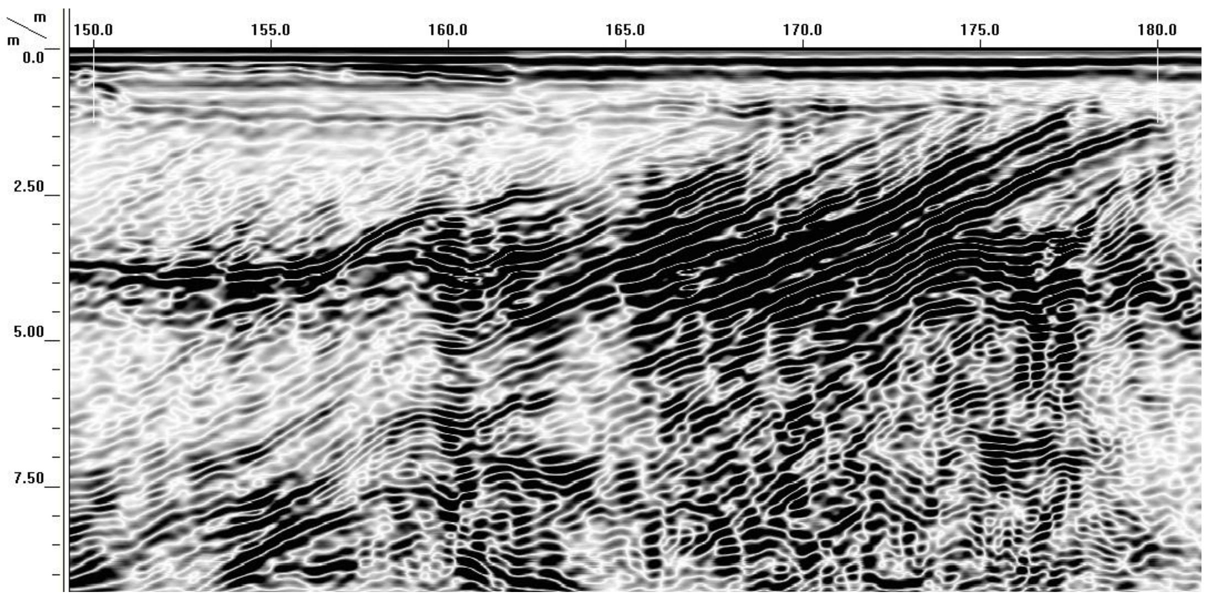

Figure 4. This portion of a radar record was collected with a 200 MHz antenna in an area of Windsor loamy sand, 0 to 3 percent slopes. Fore-set beds dip towards the left into the basin of Glacial Lake Narragansett.

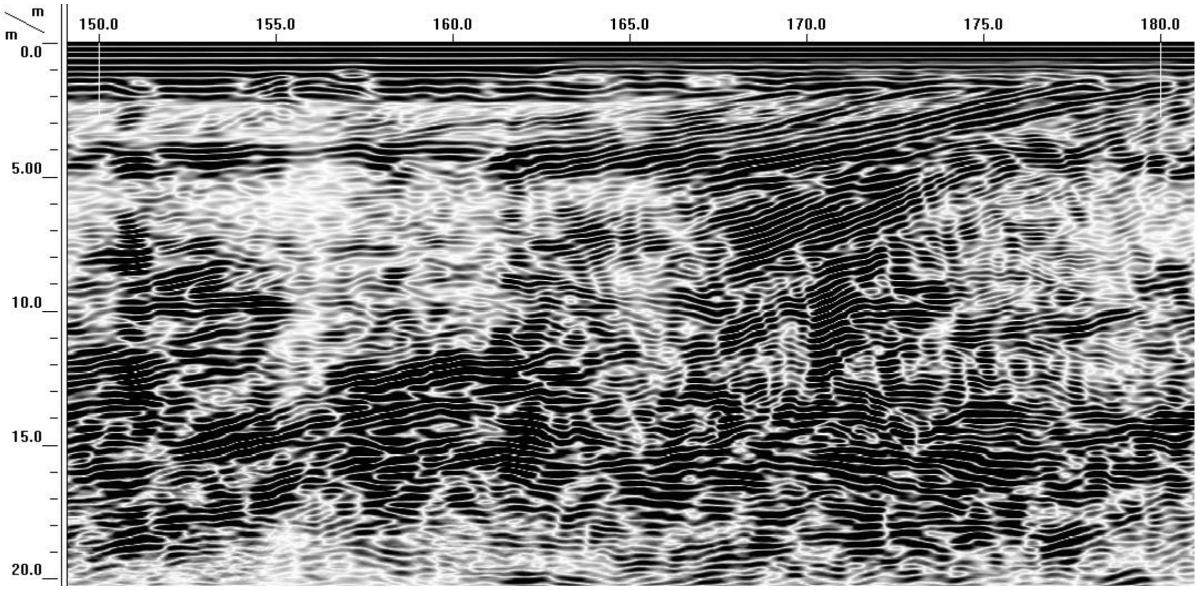

Figure 5. This portion of a radar record was collected with a 120 MHz antenna in an area of Windsor loamy sand, 0 to 3 percent slopes. Compare with the data collected with the 200 MHz, fore-set beds are less clear, but the water table (@ 3 to 4 m) is more clearly expressed.

The same radar record that is shown in Figure 5 is shown in Figure 6. In Figure 6, the depth scale reflects saturated sands with an E_r of 20 and a *v* of 0.067 m/ns. This depth scale is considered flawed but more accurate than the one shown in Figure 5. Ground truth observations of the depth to the water table and the composition of the soils and stratigraphic materials are needed to provide a more accurate depth assessment.

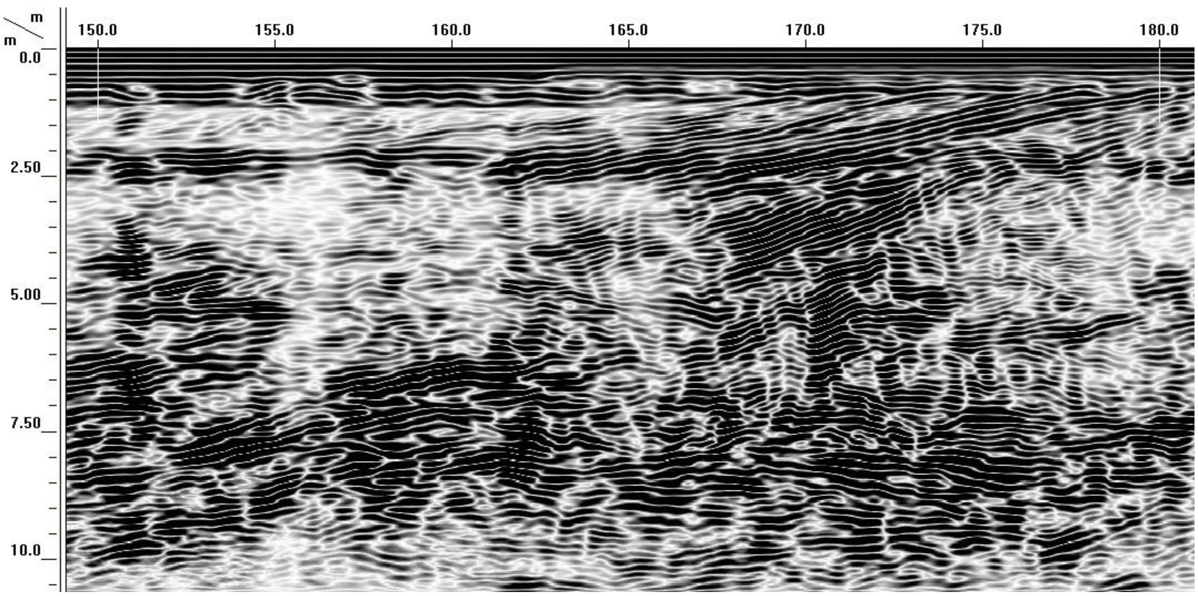

Figure 6 Same portion of a radar record shown in Figure 5, but with the dielectric constant set to 20.

<u>Beaver Tail State Park:</u>
At the time of this survey, the weather had turned cold and adverse with snow squalls. The radar records were of poor quality and lack sufficient ground-truth observations to make any meaningful interpretations.

Reference:

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