United States Department of Agriculture

Natural Resources Conservation Service

c/o USDA Forest Service
11 Campus Boulevard
Suite 200
Newtown Square, PA 19073
(610) 557-4233; FAX: (610) 557-4200

Subject: Soils-Geophysical Field Assistance **Date:** 22 May 2008

To: Margo L. Wallace
State Conservationist
USDA-NRCS,
344 Merrow Road, Suite A
Tolland, CT 06084-3917

Purpose:
Data on the depth to bedrock were collected with ground-penetrating radar (GPR) in areas of Nipmuck, Brimfield, and Brookfield soils. This data will be used to help confirm the percent composition (based on soil depth criterion) of the soils within the soil map unit surveyed.

Principal Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Shawn McVey, Assistant State Soil Scientist, USDA-NRCS, Tolland, CT
Donald Parizek, Soil Scientist, USDA-NRCS, Windsor, CT
Debbie Surabian, Soil Scientist, USDA-NRCS, Tolland, CT

Activities:
All activities were completed on 24 April 2008.

Summary:
Ground-penetrating radar (GPR) was used to estimate the depth to bedrock in areas of Nipmuck-Brimfield-Rock outcrop on 15 to 45 % slopes, and Nipmuck-Brookfield complex, 3 to 15 percent slopes, very bouldery. The synergy of GPR, global positioning systems (GPS), and geographical information systems (GIS) technologies were explored. This study represents the first merger of GPR, GPS, and GIS technologies within USDA.

It was my pleasure to work in Connecticut and to be of assistance to you and your staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
Soil Survey Research Staff
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

K. Kolesinskas, State Soil Scientist, USDA-NRCS, 344 Merrow Road, Suite A, Tolland, CT 06084-3917

M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250

S. McVey, Assistant State Soil Scientist, USDA-NRCS, 344 Merrow Road, Suite A, Tolland, CT 06084-3917

W. Taylor, Acting State Soil Scientist/MLRA Office Leader, USDA-NRCS, 451 West Street, Amherst, MA 01002-2995

W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room G08, 207 West Main Street, Wilkesboro, NC 28697

L. West, National Leader, Soil Survey Research and Laboratory Staff, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; 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. An antenna with a center frequency of 200 MHz was used in this study.

A Trimble AG114 GPS receiver was used to collect position data along each GPR traverse line. Using RADAN software (GSSI), these coordinates were attached to GPR profile data.

The SIR-3000 system provides a setup for the simultaneous use of a GPS receiver and serial data recorder (SDR). This setup is helpful for surveying soil delineations. With this setup, each scan on radar records can be georeferenced (position/time matched). Using the *Interactive Interpretation* module of the RADAN processing software, depths to the soil/bedrock interface were quickly, automatically, and reasonably accurately picked and outputted to a worksheet (X, Y, Z format; containing latitude, longitude, and depths to bedrock, and other useful data). An example of a portion of the data set that was recorded in this study is shown in Table 1. Using the *Interactive Interpretation* module, data can be easily exported into GIS for plotting and visualization. As evident from the positions (longitude and latitude) of the sequentially numbered radar scans (column 1) in Table 1, the system has hardly moved in the time required to collect the 17 radar scans shown in this example. In Table 1, "amplitude" (column 5) represents the strength of the GPR signal wave that was picked. Higher amplitude represents a stronger radar response to the interface, and typically greater and more abruptly contrasting dielectric properties between the materials.

Table 1
Shown is a portion of the data, which is picked from the radar record and exported using the Interactive Interpretation Module of the RADAN processing software.

Scan #	Longitude	Latitude	Depth (m)	Amplitude	v (m/ns)	t (ns)
16	-72.282872	41.8900564	1.41	14	0.13	21.68
17	-72.2828719	41.8900564	1.41	15	0.13	21.68
18	-72.2828719	41.8900564	1.41	13	0.13	21.68
19	-72.2828718	41.8900564	1.41	18	0.13	21.68
20	-72.2828718	41.8900564	1.41	20	0.13	21.68
21	-72.2828718	41.8900564	1.41	19	0.13	21.68
22	-72.2828717	41.8900564	1.41	18	0.13	21.68
23	-72.2828717	41.8900564	1.41	22	0.13	21.68
24	-72.2828716	41.8900564	1.41	25	0.13	21.68
25	-72.2828716	41.8900564	1.40	22	0.13	21.53
26	-72.2828715	41.8900564	1.40	12	0.13	21.53
27	-72.2828715	41.8900564	1.40	14	0.13	21.53
28	-72.2828715	41.8900564	1.40	13	0.13	21.53
29	-72.2828714	41.8900564	1.40	15	0.13	21.53
30	-72.2828714	41.8900564	1.40	9	0.13	21.53
31	-72.2828713	41.8900564	1.40	10	0.13	21.53
32	-72.2828713	41.8900564	1.40	9	0.13	21.53

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

GPR readings (scans) are not continuous, but are taken at set intervals along traverse lines. In this study, the scanning rate was 60 scans/sec. Position data were recorded at a rate of one measurement/sec with the AG114 GPS receiver. In RADAN, the position of each radar scan is proportionally adjusted according to the time stamp of the two nearest positions recorded with the GPS receiver. As each scan of the radar is georeferenced, the integration of GPS with GPR results in an unimaginably large data set (91,981 data points were collected in this study). These techniques will have impact on how soil scientists will use GPR in the future to support soil survey operations.

Although GPS receivers might need only 3 satellites, the SIR-3000 requires a minimum of 4 satellites in order to somewhat accurately triangulate locations and provide a good solution. Any less and the GPS data will not be recorded. In addition, GPS signal reception is critical at the start and end of each radar traverse, as the first and last positions must be stored in the header of each radar file. This is often difficult in forested terrains with substantial relief. As traverse lines through forested areas are seldom straight and typically "snaking", there is a greater risk of spatial inaccuracies. When working in areas of low satellite visibility, some GPS data will be lost (bad signal). RADAN will interpolate (during post processing) data between the known GPS positions. The positioning of GPR scans will look somewhat jagged (GPS position error). Where the positioning becomes a straight line, interpolation has occurred as a result of bad or missing GPS data points.

Study Sites:
The two study sites are located in northeastern Tolland County. Site 1 is located off of Trask Road in the town of Willington. Here, the majority of the area traversed with GPR was mapped as Hollis-Chatfield-Rock outcrop complex, 15 to 45 % slopes (75E), but small areas of Hollis-Chatfield-Rock outcrop complex, 3 to 15 % slopes (73C), and Rippowam fine sandy loam (109) were included in the radar traverses. In this area, map unit 75E is being re-correlated as map unit 71E, Nipmuck-Brimfield-Rock outcrop, 15 to 45 % slopes; and map unit 73C is being re-correlated as map unit 72C, Nipmuck-Brookfield complex, 3 to 15 percent slopes, very bouldery.

Site 2 is located off of Webster Road in the town of Union. Here, the majority of the area traverses with GPR was mapped as Brookfield-Brimfield-Rock outcrop complex on 15 to 45 % slopes (71E), but areas of Sutton fine sandy loam, 2 to 5 % slopes, extremely stony (52C), and Charlton-Chatfield complex, 3 to 15 % slopes, very rocky (73C), were included in the radar traverse. Map unit 71E is also being re-correlated as Nipmuck-Brimfield-Rock outcrop, 15 to 45 % slopes; and map unit 73C is being re-correlated as map unit 72C, Nipmuck-Brookfield complex, 3 to 15 percent slopes, very bouldery.

Table 2. Soil Taxonomic Classification

Soil Series	Taxonomic Classification
Brimfield	Loamy, parasesquic, mesic Lithic Dystrudepts
Brookfield	Coarse-loamy, parasesquic, mesic Typic Dystrudepts
Chatfield	Coarse-loamy, mixed, superactive, mesic Typic Dystrudepts
Hollis	Loamy, mixed, active, mesic Lithic Dystrudepts
Nipmuck	Coarse-loamy, parasesquic, mesic Typic Dystrudepts
Rippowam	Coarse-loamy, mixed, superactive, nonacid, mesic Fluvaquentic Endoaquepts
Sutton	Coarse-loamy, mixed, active, mesic Aquic Dystrudepts

The very deep, well drained Brookfield, moderately deep, well drained Nipmuck, and the shallow, somewhat excessively drained Brimfield soils formed in till derived mainly from iron-sulfide bearing schist. Compared with Chatfield and Hollis soils, Brookfield, Brimfield, and Nipmuck soils have hues redder than 5YR in some part of the B horizon and profiles that are dominated by mica schist rock fragments. The Brookfield, Brimfield, and Nipmuck soils are thought to be post-active sulfate soils, which are in the final stage of the acid sulfate weathering process. This final weathering phase explains the high pedogenic iron content and low iron ratios. The very deep, poorly drained Rippowam soils formed in alluvial sediments. The very deep, moderately well drained Sutton soils formed in till. The taxonomic classifications of the aforementioned soil series are listed in Table 2.

Survey Procedures:
Two and one GPR traverses were completed at Sites 1 and 2, respectively. Traverses were conducted along trails that passed through forested terrains with moderate relief. Along these forested trails, the 200 MHz antenna provided a stable platform and remained closely coupled to the ground surface. This helped to reduce unwanted background noise caused by the jarring and uncoupling of the antenna with the soil surface. Each radar traverse was stored as a separate file. Radar records were reviewed in the field and the soil/bedrock interface identified.

Calibration of GPR:
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 a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (*v*) are described in equation [1] (after 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 equation [2] (after Daniels, 2004):

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

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*.

Based on the measured depth and the two-way pulse travel time to a known subsurface reflector (buried plate at 40 cm), the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profile were estimated using equations [1] and [2]. An estimated E_r of 5.19 resulted in a *v* of 0.1308 m/ns. Using a constant *v* of 0.1308 m/ns, a range of 75 ns and equation [1], the 200 MHz antenna was set to penetrate the subsurface to a depth of about 4.9 m

Results:
Figure 1 is a representative radar record from an area of Nipmuck-Brimfield-Rock outcrop, 15 to 45 % slopes, which was collected with the 200 MHz antenna at Site 2. In Figure 1, the contact of the soil materials with the underlying schist bedrock has been highlighted with a green-colored line. This contact forms a well expressed, high-amplitude, continuous reflector that is easily followed across this portion of the radar record. In other portions of the radar record, this interface is more irregular, segmented, variable in signal amplitude, and, as a consequence, not as easily identify. Rock fragments in the overlying soil; irregular bedrock surfaces, and fracturing made the identification of the soil/bedrock interface more ambiguous in portions of the radar records. Because of the lack of a single, well expressed, continuous, high-amplitude reflection, the picking of the soil/bedrock interface is more unclear in these portions of the radar records, and consequently, the accuracy of interpreted soil depth measurements is lessened. However, considering the limitations of traditional soil survey tools (spade and auger), and the interpretive nature and uncertainty associated with coring for bedrock in tills that

contain large amounts of rock fragments, radar interpretations, even in areas of ambiguity, are considered no less accurate, but infinitely faster and easier to collect.

Table 3 provides the basic statistics for the radar traverses completed at Sites 1 and 2. For both sites, the average depth to bedrock was moderately deep (50 to 100 cm). At Site 1, the averaged depth to bedrock was 60 cm, with a range of 0 to 176 cm. One half of the recorded depth measurements had depths to bedrock between 30 and 88 cm. At Site 2, the averaged depth to bedrock was 98 cm, with a range of 0 to 196 cm. One half of the recorded depth measurements had depths to bedrock between 70 and 127 cm.

Table 4 provides the frequency distribution of the radar measurements based on soil depth criterion for the two sites. At Site 1, soils are shallow (0 to 50 cm) at 45 % and moderately deep at 39 % of the measurement points (see Table 4). At Site 1, deep (100 to 150 cm) and very deep soils (>150 cm) soils represent minor inclusions and make up about 16% of the measurement points. At Site 2, based on soil depth classes, deep (40 %) and moderately deep (31 %) soils are co-dominant. At Site 2, soils are shallow at 17 % and very deep at 11 % of the measurement points.

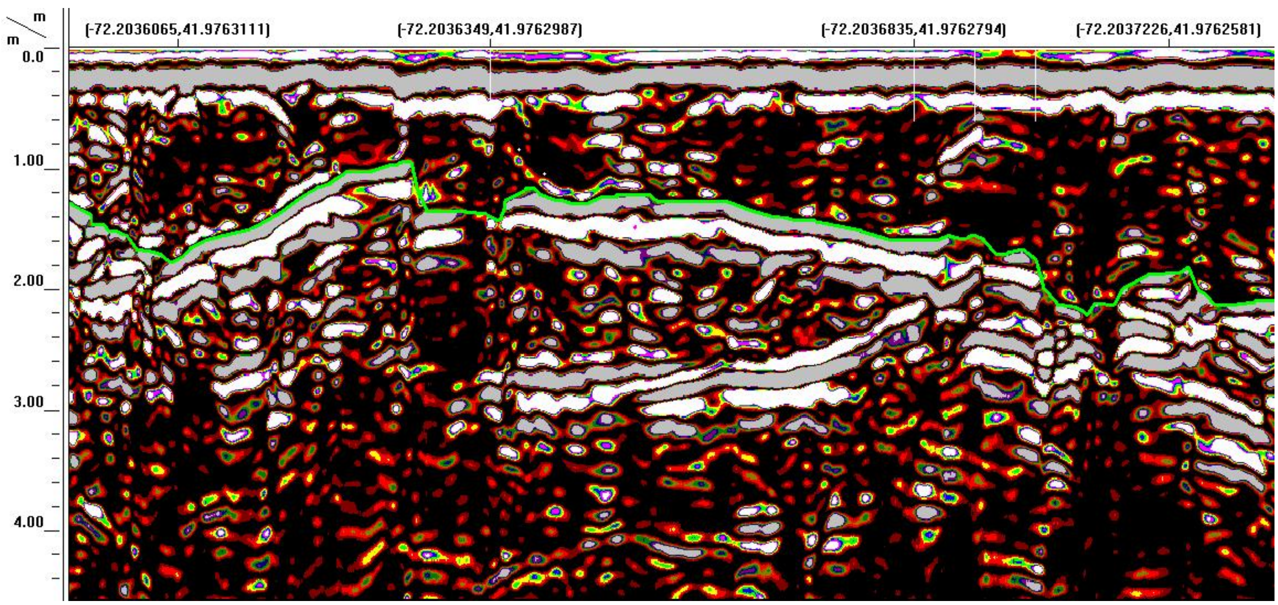

Figure 1. In this radar record from an area of Nipmuck-Brimfield-Rock outcrop, 15 to 45 % slopes, the bedrock surface has been highlighted with a green-colored line.

Table 3. Depth to bedrock statistics for the GPR traverses that were completed at Sites 1 and 2.

	Site 1	**Site 2**
Number	65526	26455
Average	0.60	0.98
Standard Deviation	0.37	0.42
Minimum	0.00	0.00
25%-tile	0.30	0.70
75%-tile	0.88	1.27
Maximum	1.76	1.96

Table 4. Frequency distribution of observations

	Site 1	Site 2
Shallow	45%	17%
Moderately Deep	39%	31%
Deep	15%	40%
Very Deep	1%	11%

The images shown in Figure 2 were prepared by Debbie Surabian by importing the radar data into ArcGIS 9.2. This represents the first merger of GPR, GPS, and GIS technologies within USDA. Large, tabular, georeferenced GPR data sets and meaningful display formats should greatly improve the utility of GPR within the Soil Survey Program. Many MLRA offices should find the integrated use of these evolving technologies a great leap forward in addressing depth to bedrock issues, map unit composition, and other quality control concerns.

References:

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

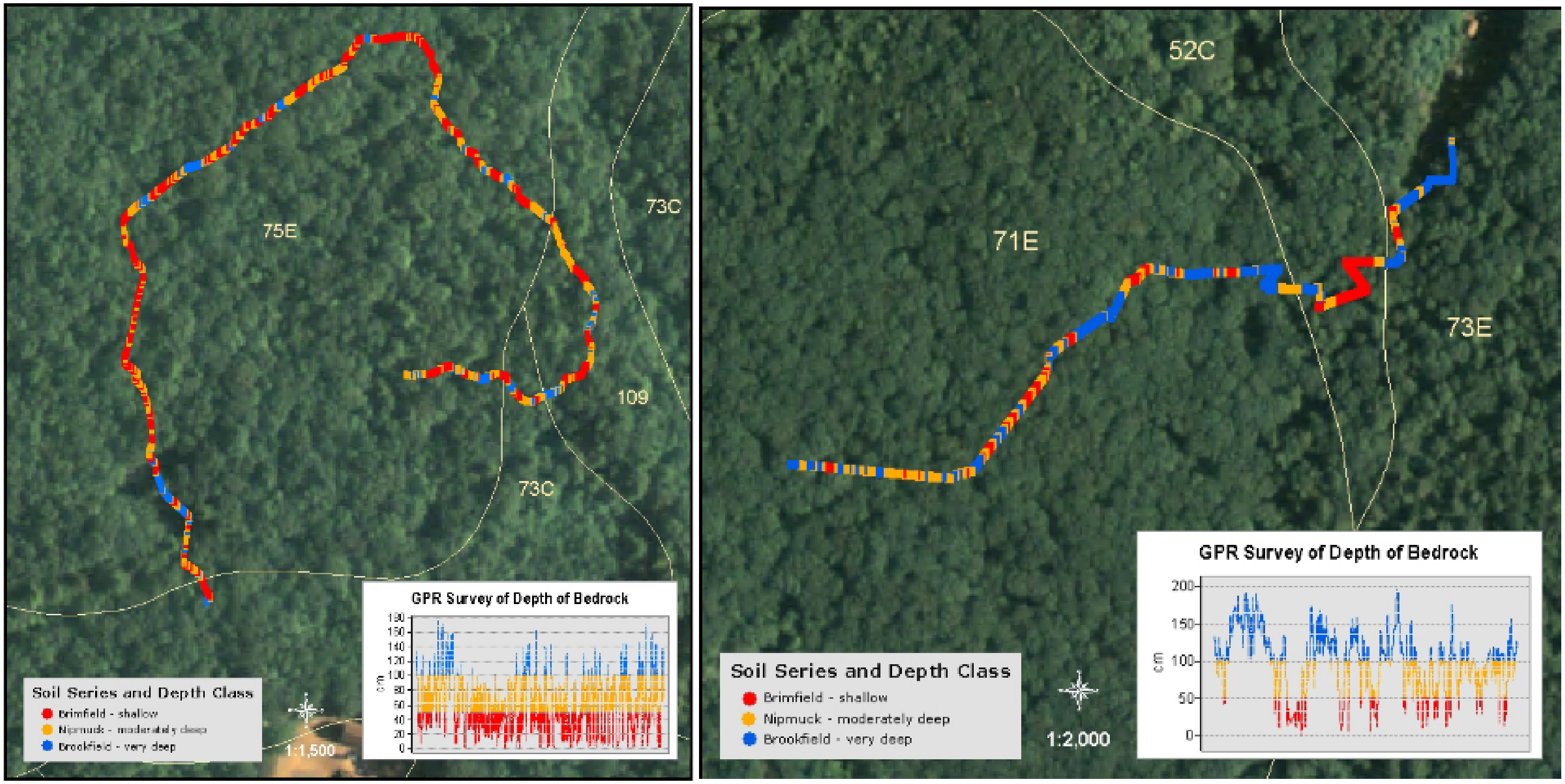

Figure 2. These images were prepared by importing radar data into ArcGIS 9.2 (courtesy of Debbie Surabian). Each image shows the location of the GPR traverse lines. Different colors are used to show the different depths (by soil depth classes) to bedrock along the traverse lines.