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:** 30 April 2008

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

Purpose:
Ground-penetrating radar (GPR) was used to estimate the thickness of organic-rich materials that mantle the Cold Spring Dam in Bloomfield. These materials are subjected to slippage and pose a potential risk to the structure.

Participants:
Rudy Chlanda, Geologist, USDA-NRCS, Amherst, MA
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Joe Kavan, Civil Engineer, USDA-NRCS, Tolland, CT
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 field activities were completed on 21 April 2007.

Background:
The Cold Spring Dam in Bloomfield was completed in 1968. During construction, the dam was draped with organic materials, which had been previously removed and stacked at site during the construction of the dam. The as-built drawings of the structure indicate organic-rich material thickness as great as 15 ft. (4.6 m) on the face of the dam. Slippage of this material is evident along the dam. Recently, NRCS staff personnel have augured several holes midway up the face of the dam and found the thickness to range between 7 and 11 ft (2.1 to 3.3 m). The thickness of the organic-rich materials is greater near the base and thinner to virtually absent towards the top of the dam. Ground-penetrating radar was used to estimate the thickness of organic-rich materials along each face of the structure.

Summary:
The radar survey was completed in less than 1/2 day. The thickness of the organic-rich materials was estimated at 56263 points along the GPR traverse lines. Based on GPR interpretations, the average thickness of the organic-rich materials is about 1.8 m, with a range of about 0 to 3.2 m. One-half of the measurements had organic-rich materials between 1.5 and 2.3 m thick.

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

With kind regards,

Jim 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
R. Chlanda, Geologist, USDA-NRCS, 451 West Street, Amherst, MA 01002-2934
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 Suite A, Tolland, CT 06084-3917
S. McVey, Assistant State Soil Scientist, USDA-NRCS, 344 Merrow Road Suite A, Tolland, CT 06084-3917
W. Tuttle, Soil Scientist (Geophysical), National Soil Survey Center, USDA-NRCS, P.O. Box 974, Federal Building, Room G08, 207 West Main Street, Wilkesboro, NC 28697
L. West, National Leader, Soil Investigation 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. Antennas with center frequencies of 70 and 200 MHz were used in this study. The coordinates of each radar scan were recorded with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[1]

Radar records contained in this report were processed with the RADAN for Windows (version 6.6) software developed by GSSI. [1] Processing was used to improve interpretations. Processing included: GPS positioning, time zero adjustments, header editing, signal stacking, migration, and range gain adjustments.

Recent technological developments allow the automatic integration of GPR and GPS data. This integration effectively allows each scan of the radar to be geo-referenced resulting in very large data sets. With this setup, each scan on radar records is geo-referenced. Geo-referenced radar records can be imaged using the *3D QuickDraw Module* of RADAN for Windows. In addition, using the *Interactive 3D Module* of the RADAN processing software, depths to the base of the organic-rich materials were interpreted and depth estimates were automatically picked and outputted to worksheets (X, Y, Z format; containing latitude, longitude, and depth). Using this module, data can be easily exported into GIS for plotting and visualization.

Survey Procedures:
Back and forth traverses were conducted with the SIR-3000 and the 200 MHz antenna across the Cold Stream Dam (see traverse track on Figure 2). Radar record collected with the 70 MHz antenna were plagued by high levels of background noise and provided little meaningful subsurface information. A 200 MHz antenna, which provided good resolution of subsurface features and seemingly adequate penetration depths, was used. Though not available at the time of this investigation, a 120 MHz antenna would have provided greater penetration depths and slightly better imaging of subsurface features. Each radar traverse was stored as a separate file (in this report, the file number will be used to identify a GPR traverse). Radar record was reviewed in the field. During post-processing of radar data, it was noticed that position data were slightly offset from the Goggle Earth imagery used to display the data (See Figure 2).

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, bedrock, stratigraphic layer) and back. To convert the

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

travel time into a depth scale, 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 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):

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

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). Based on the depth to the organic-rich materials/mineral materials interface at two observation site along the dam, the estimated E_r is 12 and the v is 0.086 m/ns. The two observation points used for calibration of the GPR were located mid-way up the face of one slope. As the dielectric properties of embankment materials are variable, all measurements provided in this report should be considered as approximations only.

Interpretation of GPR Data:
Radar records were generally of good interpretative quality. Figure 1 is a portion of radar record from Cold Stream Dam. The depth scale is expressed in meters. The horizontal scale is expressed in decimal degrees of latitude and longitude. In Figure 1, a white line has been used to identify the interface that separates organic-rich from mineral materials. As both mediums are composed of stratified layers, a high-amplitude, planar reflection was commonly interpreted to represent the interface separating these contrasting materials. However, because of variations in the amount of organic materials in the overlying embankment materials, in some areas, the distinction between these layers was less clear and interpretations were consequentially more ambiguous. Areas of more ambiguous interpretations were often characterized by either multiple, low-amplitude, discontinuous reflectors; or multiple, high-amplitude, segmented reflections.

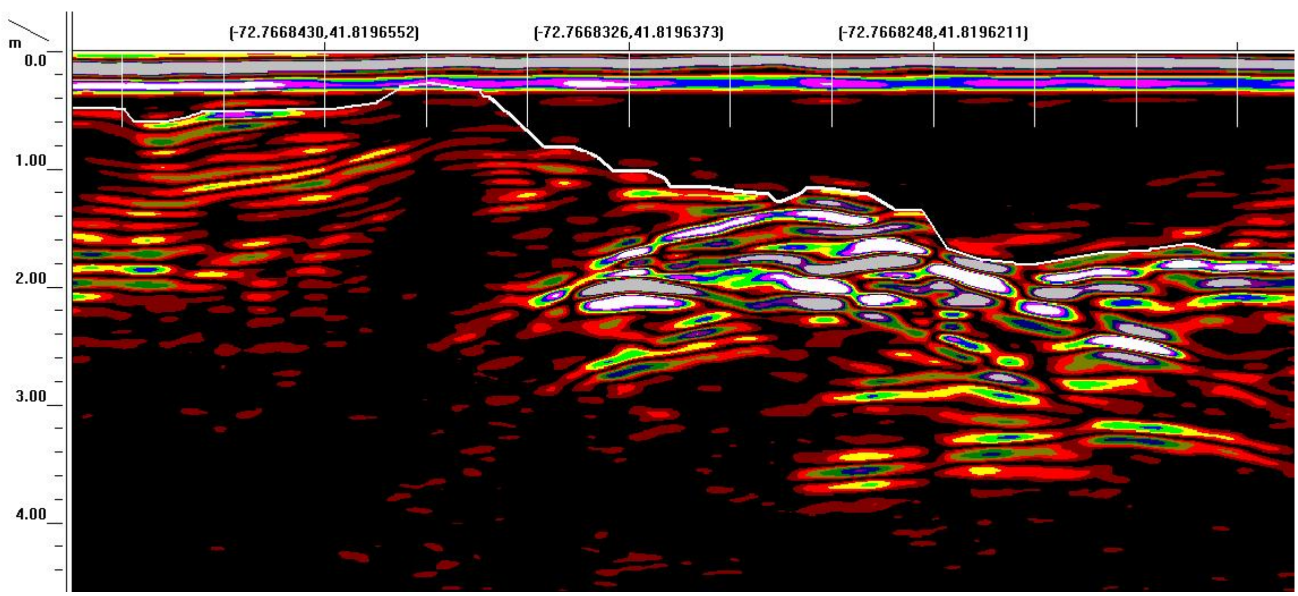

Figure 1. The contact between the organic-rich and mineral materials has been highlighted with a white-colored line on this radar record from the Cold Stream Dam.

Estimates of the thickness of the organic enriched materials:
The radar survey was completed in less than 1/2 day. The thickness of the organic-rich materials was estimated at 56263 points along the traverse lines (see locations in Figure 2). Based on GPR interpretations, the interpreted average thickness of the organic-rich materials is about 1.8 m, with a range of 0 to 3.2 m. One-half of the measurements had

organic-rich materials between about 1.5 and 2.3 m thick. The GPR-interpreted distribution of organic-rich materials, which have been grouped into 1 m depth classes, along the faces of Cold Stream Dam is shown in Table 1.

Table 1
Distribution of organic-rich materials covering the Cold Stream Dam according to 1 meter thickness classes.

Thickness (m)	Observations	Frequency (%)
<1	8534	0.15
1 to 2	22618	0.40
2 to 3	24812	0.44
3 to 4	299	001

Figure 2 is a Goggle Earth image of the Cold Stream Dam Site. In this image, the location of the GPR traverse line is shown. Colors have been used to identify the interpreted thickness of the organic-rich materials that cover the structure. The thinnest mantle of organic-rich materials is along the summit and centerline of the dam. It is evident from the image, that areas with the thinness mantle of organic-rich materials are displaced slightly to the north of the centerline of the dam. It is therefore concluded that the track of the radar shown in Figure 2 is not properly positioned in relationship to the imagery.

Figure 2. The thickness of organic-rich fill along the Cold Stream Dam as interpreted from radar records. All depths are expressed in meters.

References:

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