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:** 1 August 2006

To: Ronald R. Alvarado
State Conservationist
USDA-NRCS,
441 S Salina Street Room 520
Syracuse, NY 13202-2450

Purpose:
A lake sedimentation survey was completed on Batavia Kill Reservoir in Greene County, New York, using ground-penetrating radar (GPR).

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Dave Sullivan, Geologist, USDA-NRCS, Syracuse, NY
Linda S. Szeliga, District Conservationist, USDA-NRCS, Ghent, NY
Olga Vargas, Soil Scientist, USDA-NRCS, Greenwich, NY
Daniel j. Zielinski, Aquatic Biologist, New York State Department of Environmental Conservation, Stamford, NY

Activities:
The lake sedimentation survey was completed on July 26, 2006.

Survey Area:
A ground-penetrating radar lake sedimentation survey was completed on Batavia Kill Reservoir near the town of Hensonville, Greene County, New York. This survey was conducted in support of the National Dam Rehabilitation Program.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (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. A 70 MHz antenna was used in this survey. 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, stacking, and range gain adjustments.

An Allegro field computer (Juniper Systems, North Logan, Utah) and a Garmin Global Positioning System Map 76 receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack) (Garmin International, Inc., Olathe, Kansas) were used to collect the coordinates of each GPR observation point.[1] The Garmin GPS receiver was operated in the manual mode. Geodetic datum was WGS-84 (World Geodetic System of 1984). The UTM coordinate system was used with units expressed in meters.

To help summarize the results of the GPR survey, SURFER for Windows (version 8.0) software (Golden Software, Inc., Golden, Colorado), was used to construct the two-dimensional simulations shown in this report.[1] Grids of interpreted water depth and sediment thickness data were created using kriging methods with an octant search.

Background:

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

Presently, more than fifty percent of the dams constructed by the former USDA-Soil Conservation Service are older than 35 years and more than 1,800 will exceed their 50-year design life within the next 10 years (Caldwell, 2000). Many dams are in need of rehabilitation. One of the primary issues in dam rehabilitation is reservoir sedimentation. Sedimentation is the major cause of reduced reservoir storage capacity. As part of a statewide assessment program in New York, the USDA-NRCS is estimating the volume of sediments deposited within selected reservoirs. The primary objectives of lake sedimentation surveys are to determine current reservoir capacity, learn of changes in storage volume, and estimate the volume of accumulated sediments.

Traditional methods used to conduct lake sedimentation surveys are slow and labor intensive. Acoustic equipment (fathometer) has been used in the past to facilitate reservoir surveys in some states. However, this technology can not resolve gradational contacts nor penetrate layers of aquatic vegetation and organic materials. Recently, ground-penetrating radar (GPR) has been used to survey lakes (Haeni et al., 1987, Izbicki and Parker, 1991; Truman et al., 1991; Sellmann et al., 1992; Mellett, 1995; and Moorman and Michel, 1997) and stream channels (Spicer et al., 1997). The present survey integrates GPS and GPR technologies to improve the efficiency of bathymetric assessments. The synergistic use of these technologies affords a less labor intensive and time-consuming process than with conventional positioning methods.

Survey Procedures:
The SIR System-3000 was mounted in a boat and a 70 MHz antenna towed alongside in an inflatable raft (see Figure 1). The boat and raft made multiple traverses across the reservoir. Locations of traverse lines were arbitrary. These traverse lines were orientated according to changing lake conditions and shore geometries. Measurement points for both GPS and GPR were simultaneously recorded at 15 seconds intervals.

Figure 1. Conducting a lake sedimentation survey with GPR on Batavia Kill Reservoir.

Coordinates outlining the shoreline of the reservoir were obtained from digitized maps. Locations of GPR observation points were determined with GPS. For most points, GPS measurements were obtained in the differential mode. Differential correction requires data from four satellites. At times, fewer than four satellites were visible (do to restricted mast angle and the negative influence of nearby slopes and vegetation), and, as a consequence, some locations were recorded in the autonomous mode.

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., lake bottom, 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 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 (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). The amount and physical state of water (temperature dependent) have the greatest effect on the relative dielectric permittivity of a material. Water has an E_r of 80 and a velocity of propagation of 0.033 m/ns. The electrical properties of lake bottom sediments are variable. Base on a referenced value for saturated silts (Daniels, 2004), the bottom sediments were assumed to have an E_r of 25 and a velocity of propagation of about 0.06 m/ns

Interpretations:
Radar records were of good interpretative quality. Figure 2 is a representative radar record from the reservoir. The vertical scale is a time scale expressed in nanoseconds. The horizontal scale is a distance scale expressed in scans. Although the radar provides a continuous bathymetric profile of the reservoir, measurements of water depth and sediment thickness were restricted to geo-referenced observation points (white vertical lines at the top of the radar profile). On this radar record, these lines are spaced at an interval of 120 scans.

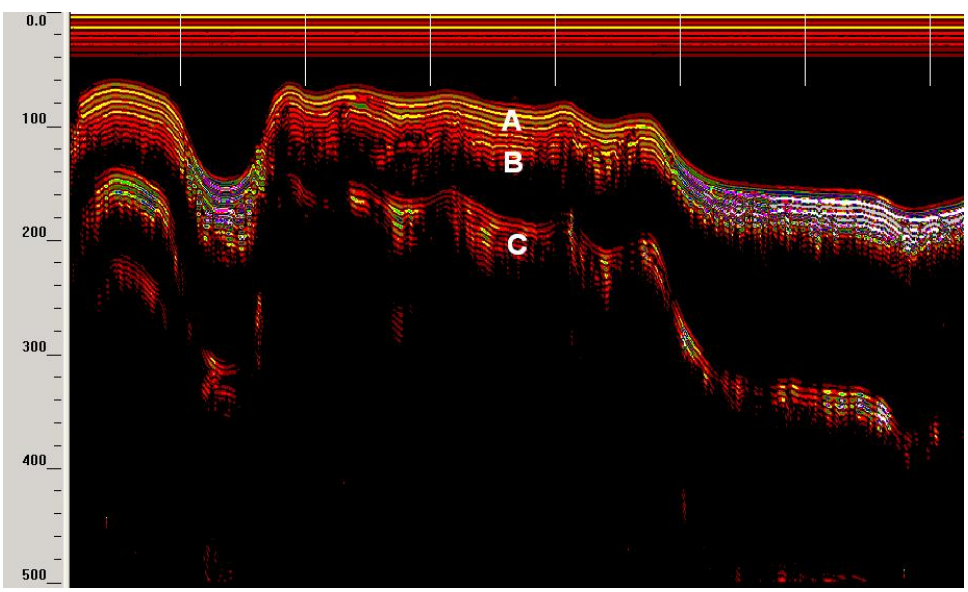

Figure 1. A representative radar record collected with 70 MHz antenna.

The horizontal reflector at the top of the radar record represents the reflection from the lake's surface and its multiples. The first series of continuous, moderate to high amplitude, subsurface bands (see "A") represents the lake bottom. On this radar record, this interface varies in depth from about 60 to 170 ns (about 96 to 288 cm, respectively). The lowest group (see above "B") of reflectors represents the base of the post-impoundment sediments and the contact with the original bottom materials. Reflectors from the original lake bottom appear more segmented, irregular, and inclined

than the overlying reflectors from the more recently deposited, lacustrine sediments. A “double-return echo” from the lake bottom is evident at “C.” This group of multiple reflectors is a form of noise and should be ignored.

With the 70 MHz antenna the lake-bottom sediments were penetrated. As no borings were made through these sediments at the time of the survey, the identity of these layers were not verified and the thickness of lake bottom sediments was estimated, but not measured. These recent deposits are assumed to consist principally of saturated silty sediments (Er of 25; propagation velocity of 0.06 m/ns). This is a simplification, but provides an approximation for estimates of the relative thickness of the post-impoundment sediments.

A task of this investigation was to identify the lake bottom and the base of the post-impoundment sediments on each radar record. The interface separating water from saturated sediments was easily identified and trace laterally on all radar records. The interpreted base of the post-impoundment sediments was identified as the deepest continuous, moderate to high amplitude, planar reflector. Although an E_r of 25 and an average velocity of 0.060 m/ns were used to determine the general thickness of the underlying saturated post-impoundment silty sediments, saturated silts are known to have an E_r that can range from 10 to 40 (Conyers and Goodman, 1997).

Results:

At the time of this survey, based on radar interpretations made at 223 observation points, the averaged depth of water within this reservoir is 3.31 m with an observed range of about 0.40 to 7.28 m. At one-half of the GPR observations points, the depth of water was between 1.76 and 4.60 m. Also based on radar interpretations at the 223 observation points, recent sediments averaged 80 cm thick with a range of about 40 (minimum interface spacing detectable with a 70 MHz antenna) to 139 cm. At one-half of the observations points, the thickness of recent sediments was between about 66 and 94 cm.

Two-Dimensional Plots:

Plots of the interpreted radar data are shown in Figure 3. In each plot, a different gradational color spectrum has been assigned to individual water depth or sediment thickness intervals. In the plot of water depths (left-hand plot), the color bar interval is 0.50 m. In the plot of sediment thicknesses (right-hand plot), the color bar interval is 0.25 m. The approximate outline of the reservoir is shown. This outline was achieved by digitizing data points off of base maps.

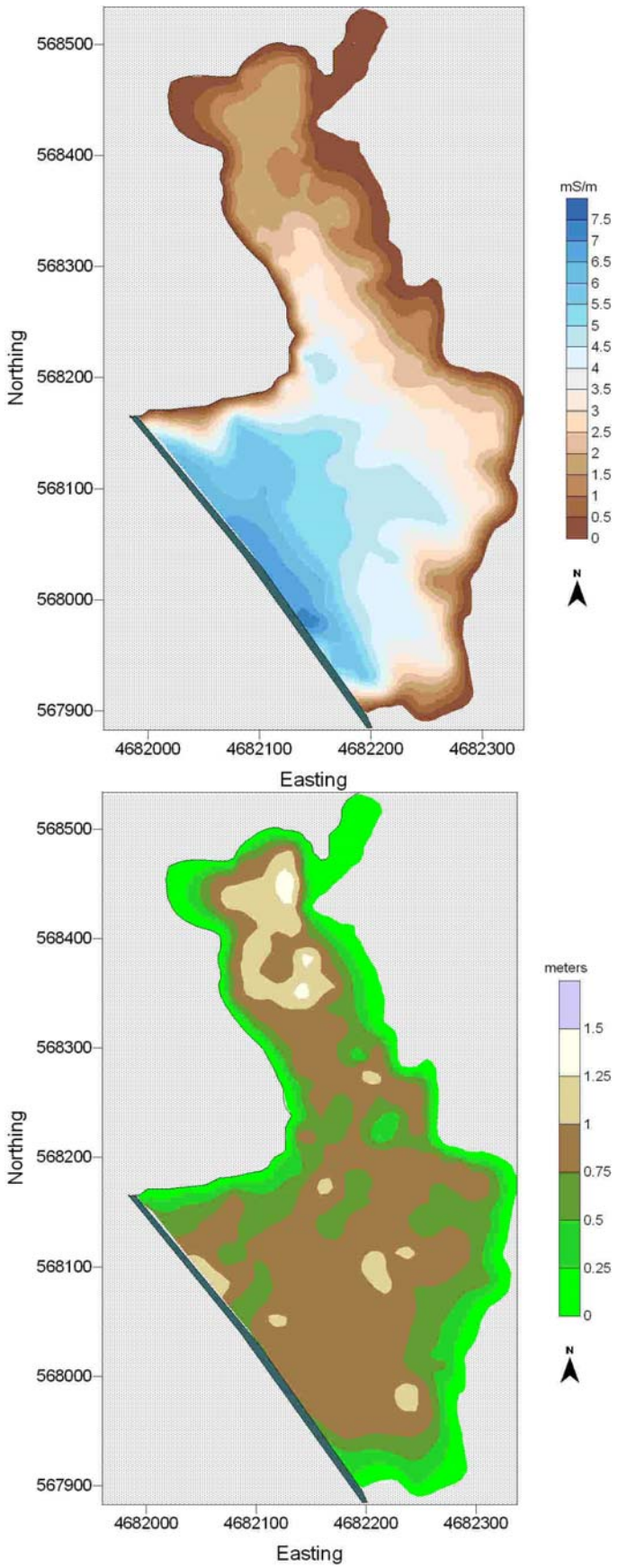

Figure 3. Two dimensional contour plots showing the interpreted water depth (left-hand plot) and sediment thickness (right-hand plot) within Batavia Kill Reservoir.

Discussion:
Sources of measurement error are variations in the velocity of propagation through the post-impoundment sediments. As the textural composition and moisture content of the post-impoundment sediments is unknown, the sediments were presumed to be saturated silts with an estimated dielectric permittivity of 25. Ancillary coring data would have greatly increased our knowledge of the composition, dielectric properties, and thickness of the post-impoundment sediments. In the absence of this data, estimations of the sediment thickness are constrained and subject to slight errors.

In addition, errors in identifying the base of the post-impoundment sediments may have occurred in areas with alluvial sediments that predated the impoundment of water. The dielectric contrast between water and the post-impoundment sediments is abrupt and contrasting. This characteristic provided a clear and easily identifiable interface on radar records. Though less contrasting, the contrast between the saturated lower-density, post-impoundment sediments and the higher-density pre-impoundment materials appears substantial. As a consequence, this interface was easily identified at most observation points. However, misidentification of the base of the post-impoundment sediments will result in slight estimation errors.

It was my pleasure to work in New York and with members of your fine 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
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
S. Indrick, State Soil Scientist, USDA-NRCS, 441 South Salina Street, Room 520, Suite 354, Syracuse, NY 13202-2450
S. Lorance, Supervising Aquatic Biologist, NYS DEC, 65561 State Highway 10, Stamford, NY 14467
D. Sullivan, Geologist, USDA-NRCS, 441 S Salina ST RM 520, Syracuse, NY 13202-2450
L. Szeliga, District Conservationist, USDA-NRCS, 1024 State Route 66, Ghent, NY 12075
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697
O. Vargas, Soil Scientist, USDA-NRCS, 2530 State Route 40, Greenwich, NY 12834-9627
P. Wright, Supervisory Civil Engineer, USDA-NRCS, 441 S Salina ST RM 520, Syracuse, NY 13202-2450

References:
Caldwell, L. W. 2000. Good for another 100 years: The Rehabilitation of Sergeant Major Creek Watershed. Presented at the *Association of State Dam Safety Officials*, September 28-30, 2000, Providence, RI.

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

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

Haeni, F. P., McKeegan, D. K., and D. R. Capron. 1987. Ground-penetrating radar study of the thickness and extent of sediments beneath Silver Lake, Berlin and Meriden, Connecticut. US Geological Survey Water-Resources Investigation Report 85-4108.

Izbicki, J. A. and G. W. Parker. 1991. Water depth and thickness of sediment in Reservoirs 1 and 2, Framingham and Ashland, Massachusetts. US Geological Survey Open-File Report 91-508.

Mellett, J. S. 1995. Profiling of ponds and bogs using ground-penetrating radar. Journal of Palelimnology. 14:233-240.

Moorman, B. J. and F. A. Michel. 1997. Bathymetric mapping and sub-bottom profiling through lake ice with ground-penetrating radar. Journal of Palelimnology 18:61-73.

Sellmann, P. V., A. J. Delaney, and S. A. Arcone. 1992. Sub-bottom surveying in lakes with ground-penetrating radar. USA CRREL Report 92-8.

Spicer, K. R., J. E. Costa, and G. Placzek. 1997. Measuring flood discharge in unstable stream channels using ground-penetrating radar. Geology. 25(5): 423-426.

Truman, C. C., L. E. Asmussen, and H. D. Allison. 1991. Ground-penetrating radar: A tool for mapping reservoirs and lakes. Journal of Soil and Water Conservation. 46(5): 370-373.