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 October 2003

To: Joseph R. DelVecchio
State Conservationist
USDA-NRCS,
The Galleries of Syracuse
441 S. Salina St., Suite 354
Syracuse, NY 13202-2450

Purpose:
A sedimentation survey was completed using ground-penetrating radar (GPR) on the Park Station Reservoir, Chemung County, New York.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Christopher Henry, Civil Engineer, USDA-NRCS, Syracuse, NY
Dave Sullivan, Geologist, USDA-NRCS, Syracuse, NY
Wes Tuttle, Soil Scientist, USDA-NRCS-NSSC, Wilkesboro, NY
Mark Watts, District Manager, Chemung County SWCD, Horseheads, NY

Activities:
All field activities were completed on 22 September 2003.

Survey Area:
Park Station Reservoir is located in northern Chemung County, New York. It is north of the town of Erin. The reservoir has a surface area of over 40 hectares and a maximum depth of about 12.2 m (W. Grajko request letter of 5 June 2003). Park Station is one of three reservoirs that are being surveyed this year as part of the National Dam Rehabilitation Program.

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1.] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. A 12-volt battery powers the system. A 70 MHz antenna was used in this survey. The 70 MHz antenna is the lowest frequency antenna that is available to NRCS. This antenna provided adequate depth (greater than 12 m) and acceptable lateral resolution of subsurface features, even within the deeper portions of these reservoirs. Because of the anticipated maximum depth within this reservoir, the range was set at 720 nanoseconds (ns). In the shallower northern portion and arms of Park Station Reservoir a scanning time of 400 ns was used.

The position of each radar observation points was obtained with Trimble AG114 GPS Receivers.[1.] The receiver was operated in the manual mode. This receiver was operated using an external power source (portable 9-volt battery). All coordinates were expressed in terms of their latitude and longitude.

Background:

[1] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

Presently, more than fifty percent of the dams constructed by the USDA-Soil Conservation Service are older than 34 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 immediate rehabilitation. One of the primary issues of dam rehabilitation is reservoir sedimentation. Sedimentation is the major cause of the reduction in reservoir storage capacity. As part of a statewide assessment program, the USDA-NRCS is interested in determining the volume of sediments deposited within selected reservoirs. The primary objectives of lake sedimentation surveys are to determine current reservoir capacity, ascertain changes in storage volume, and determine the volume of accumulated sediments. Secondary objectives include estimation of lateral and longitudinal deposition of sediments and annual yield rates.

Conventional methods for conducting lake sedimentation surveys are slow and labor intensive. Acoustic equipment (fathometer) has been used to facilitate surveys of some reservoirs. However, this technology has difficulty resolving gradational contacts and penetrating aquatic vegetation and layers of organic materials. Recently, ground-penetrating radar (GPR) has been used to survey lakes (Haeni et al., 1987, Izbicki and Parker, 1991; Mellett, 1995; Moorman and Michel, 1997; Sellmann et al., 1992; Truman et al., 1991) and stream channels (Spicer et al., 1997). In these studies, bathymetric cross-sections or contour maps were prepared from radar traverses conducted along parallel traverse lines. Establishing traverse lines is a labor intensive and time consumptive task. The present study integrates GPS and GPR technologies for bathymetric surveys. The use of GPS is less labor intensive and time consuming than conventional positioning methods.

Survey Procedures:

The radar system was mounted in a boat and the 70 MHz antenna was towed alongside in an inflatable raft. The boat and raft made multiple traverses across each lake. Locations of traverse lines were arbitrary and were adjusted using identifiable features on the shore. Slight variations in speed of advance were experienced because of water currents, wind conditions, and bottom depths (in areas that were too shallow or obstructed with debris). As a consequence, horizontal scales or distances on the radar profile were variable. Observation points for both GPS and GPR were recorded simultaneously at intervals of either 10 or 15 seconds. Intervals varied with the length of traverse and speed of advance.

Calibration of GPR:

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the 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 (Morey, 1974):

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

The velocity of propagation is principally affected by the dielectric permittivity (E) of the profiled material(s) according to the equation:

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

Where C is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric permittivity of a material. The dielectric permittivity of air and water are 1 and 81 respectively.

The velocity of propagation and the depth scale were determined by comparing the interpreted depth to known reflectors on the radar profile with the measured depths. Based on the measured depth and the two-way travel time to these interfaces, and equation [1], the velocity of propagation was estimated.

The measured depths to the lake bottom were compared with the radar imagery collected at three calibration points on the Park Station Reservoir. Depths to the lake bottom were measured with a stadia rod and ranged from 2.9 to 6.9 m. Based on the averaged round-trip travel time to the lake bottom, the velocity of propagation was estimated to be 0.033 m/ns and the dielectric permittivity was 80. The coefficient of correlation (r) between the measured depth and the

interpreted depth (using Equation [1]) to this interface was 0.997. However, at the three calibration points, differences between measured and interpreted depths to the lake bottom averaged 37 cm with a range of 20 to 48 cm.

On radar profiles, reflections from interfaces spaced closer than one half wavelength apart are indistinguishable due to constructive and destructive interference (Daniels, 1996). Daniels (1996) used the following equation to show the relationship between velocity of propagation (v), antenna center frequency (f), and wavelength (λ):

$$\lambda = v/f \qquad [3]$$

Equation [3] shows that the propagated wavelength will decrease with decreasing propagation velocity and increasing antenna frequency. Using equation [2] and an average velocity of 0.033 m/ns resulted in wavelengths of about 47 cm at a frequency of 70 MHz. Layers spaced closer than 47 cm would be difficult to distinguish separately on radar records.

Interpretations:

All radar records were of excellent interpretative quality. Figure 1 is a representative radar record from Park Station. The depth scale is meters and is plotted on the left-hand side of this figure. Although the radar provides a continuous profile of the lake, measurements of the water depth were restricted to observation points (vertical lines at the top of the radar profile). On this radar record, these lines were spaced at a time interval of 15 seconds. The strong horizontal reflector at the top of the radar record represents the reflection from the lake's surface. The first series of high amplitude parallel bands represents the lake bottom. In this radar record, this interface varies in depth from about 0.4 to 8 m. Within the first group of closely spaced multiple bands, the lowest continuous series of high amplitude bands represents the base of the post-impoundment sediments and the contact with the original bottom materials. This sequence of reflections appears twice at lower depths in this radar record. These multiples are double return echoes produced by energy wave reflecting back and forth between the lakes surface and bottom. They are a form of background noise.

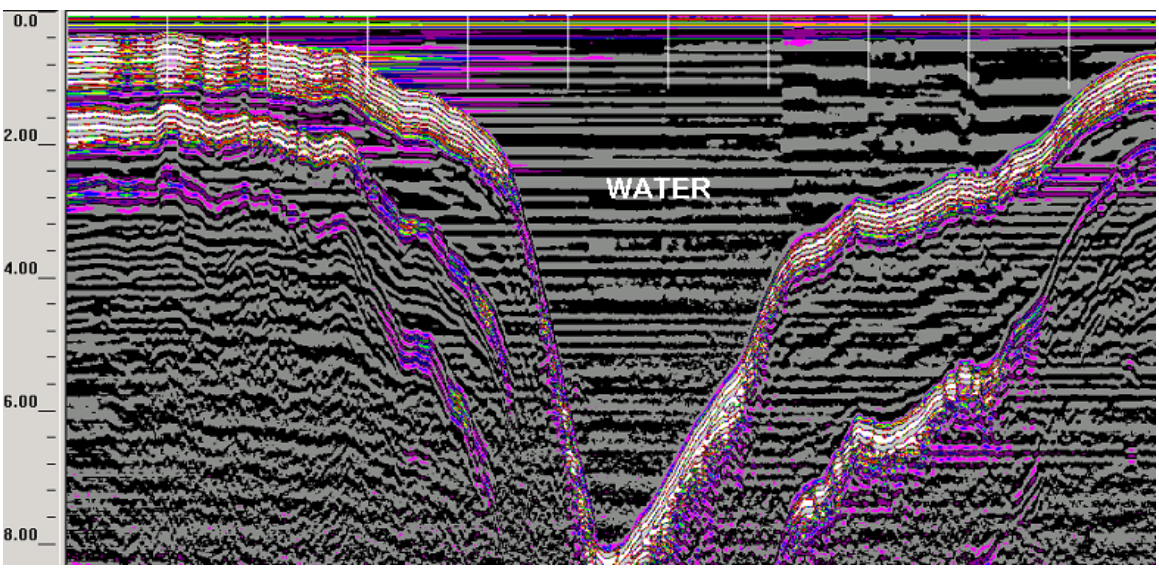

Figure 1. Representative radar record from Park Station Reservoir that was collected with a 70 MHz antenna.

With the 70 MHz antenna the lake-bottom sediments were penetrated. These layers consist of smooth, parallel lines. The sediments consist of recent lacustrine deposits. As no borings were made through these sediments at the time of this survey, the identity of these layers were not verified and the thickness of lake bottom sediments was not measured. Variations in sediments are distinguishable on radar profiles. However, the identity and composition of these layers are unknown. These layers can be grossly characterized as consisting principally of saturated silty sediments. This is of course an oversimplification, but is useful to approximate the relative thickness of these recent sediments.

A task of this investigation was to identify the water 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 depth to this interface was determined using a dielectric permittivity (E_r) of 80 and a velocity of propagation of 0.033 m/ns. The interpreted base of the post-impoundment sediments was identified as the deepest continuous high amplitude reflection. An Er of 25 and an average velocity of 0.060 m/ns were used to determine the thickness of the underlying saturated post-impoundment sediments (for saturated silts, E_r ranges from 10 to 40; Conyers and Goodman, 1997).

Results:

The radar survey of Park Station was completed in 1/2 day. Lake depths were recorded at 358 points using GPR and GPS. The coordinates of each of these points were recorded with GPS and are shown in Figure 2. An additional 178 measurements were obtained to define the shoreline (elevation 452.48 m) of Park Station Reservoir. It is apparent from Figure 2 that some areas of the reservoir were sparsely sampled. In future surveys, traverse lines should be more closely spaced and recording intervals of 10 sec should be used.

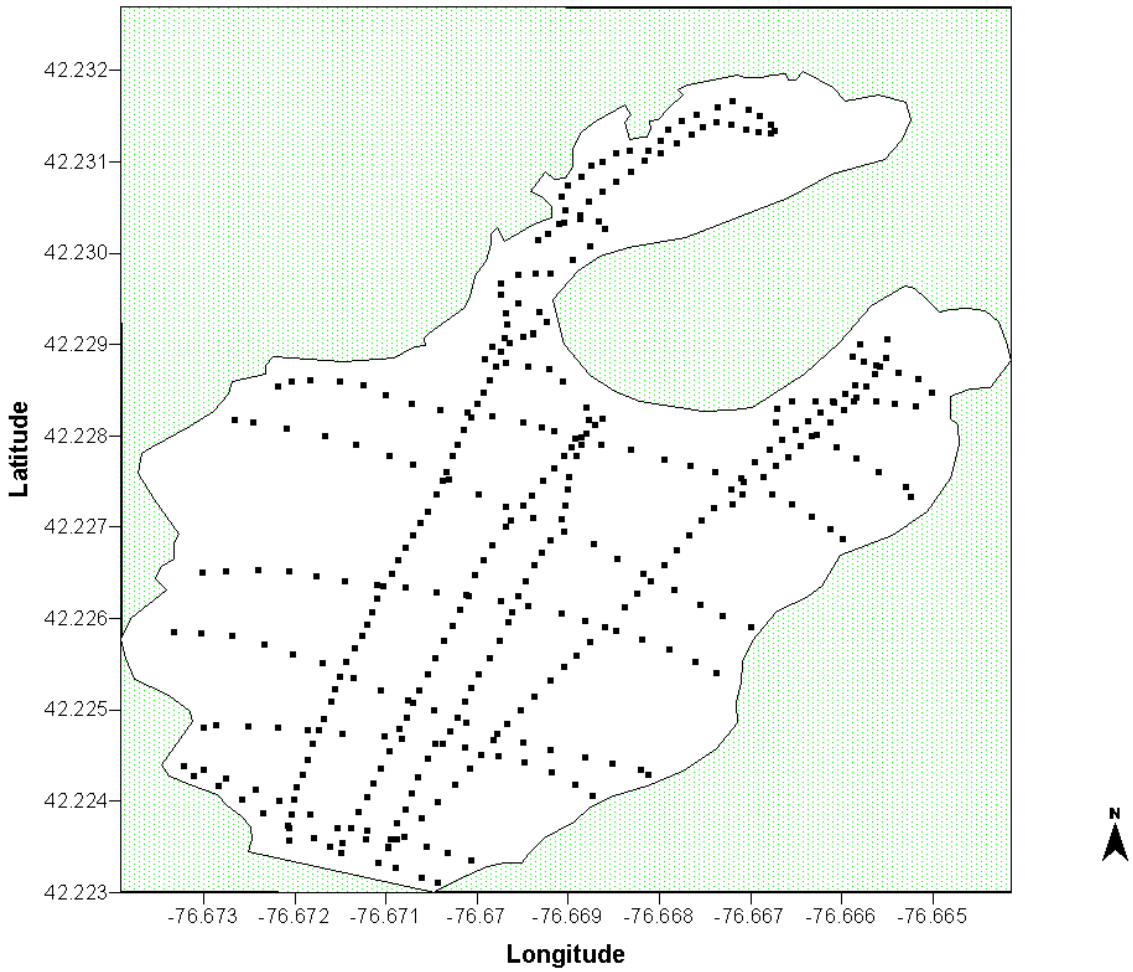

Figure 2. Location of GPR reference points on Park Station Reservoir.

At the time of the survey the lake level was at 452.48 m. Based on radar (358 points) and *shore line* (178 points) data, the average depth of Park Reservoir is 3.54 m. Measured depths ranged from 0 to 11.68 m. Figure 3 shows the distribution of water depths measured by this survey. Because of sedimentation and very shallow water depths, a portion of the northern arm was not surveyed (see hatched area in Figure 3). Water deepens rapidly away from most shorelines and two distinct deep channels are evident within the reservoir. At the present lake level, the reservoir has a total water capacity of about 2,173,277.5 m^3.

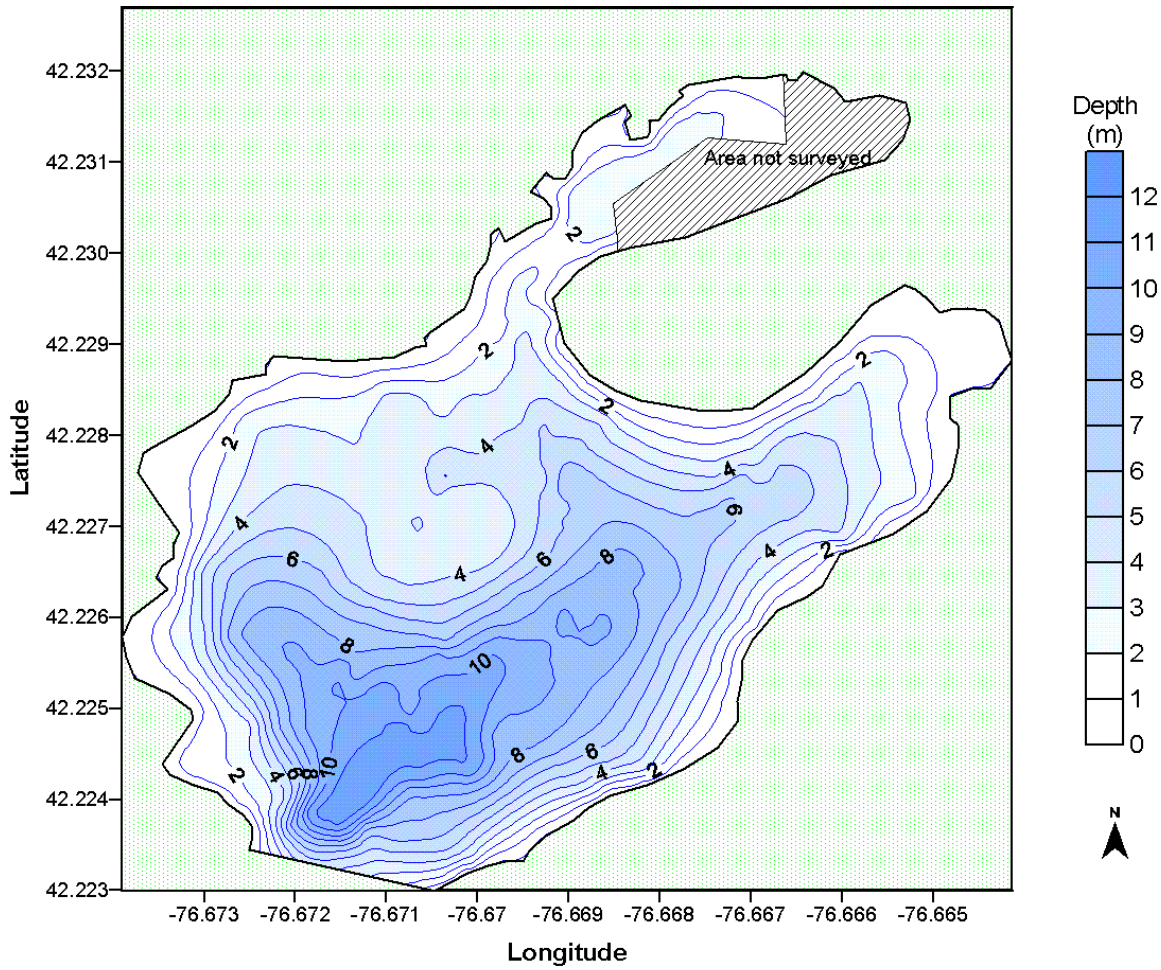

Figure 4. Results of GPR Bathymetric Survey of Park Station Reservoir.

Discussion:

Major sources of error are variations in the velocity of propagation through water and the post-impoundment sediments, and errors in identifying the base of the post-impoundment sediments. The dielectric contrast between water and the post-impoundment sediments was abrupt and contrasting. This characteristic provided an easily identifiable interface on radar records. Though less contrasting the contrast between the saturated low-density post-impoundment sediments and the higher-density pre-impoundment materials is substantial and this interface was identifiable on most radar records. However, misidentification in the base of the post-impoundment sediments could result in significant error in the estimation of sedimentation. 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 error.

Conclusions:

1. The survey crew made a fine team and completed the radar surveys on Park Station Reservoir in about two hours. The survey was comprehensive and efficiently conducted. This report documents the integrated use of innovated technologies to complete lake sedimentation surveys.

2. The accuracy of contour maps depends on the distance between observation points and traverse lines. In future surveys, traverse lines should be more closely spaced and recording intervals of 10 sec should be used. Ancillary coring data is needed to improve our understanding of the composition, dielectric properties, and thickness of the post-impoundment sediments.

3. All radar profiles and a disc containing spreadsheets of the GPS and GPR data have been forwarded to Dave Sullivan. Dave and Chris Henry may use computer aided drafting (CAD) software to manage and manipulate the data. The initial topographic survey of the lake should be digitized. If digitized, the earlier survey can be compared with the present survey. Dave will prepare the final products of this survey.

It was my pleasure to work in New York and with members of your fine staff.

With kind regards,

Jim Doolittle
Research Soil Scientist

cc:
B. Ahrens, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Acting Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
W. Grajko, State Conservation Engineer, USDA-NRCS, 441 South Salina Street, Room 520, Suite 354, Syracuse, NY 13202-2450
S. Indrick, State Soil Scientist, USDA-NRCS, 441 South Salina Street, Room 520, Suite 354, Syracuse, NY 13202-2450
C. Olson, National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
D. Sullivan, Geologist, USDA-NRCS, 441 South Salina Street, Room 520, Suite 354, Syracuse, NY 13202-2450
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697

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. 1996. Surface-Penetrating Radar. The Institute of Electrical Engineers, London, United Kingdom.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. 11-32 pp. In: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20.

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.

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. 212-232 pp. In: Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction, held at Henniker, New Hampshire. Aug. 11-16, 1974.

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.