United States Department of Agriculture

NRCS

Natural Resources Conservation Service
National Soil Survey Center
Federal Building, Room 152
100 Centennial Mall North
Lincoln, NE 68508-3866

Phone: (402) 437-5499
FAX: (402) 437-5336

SUBJECT: MGT – Geophysical Assistance

May 13, 2013

TO: Vicky Drew
State Conservationist, NRCS
Colchester, Vermont

File Code: 330-7

Purpose:
The purpose of this study is to use ground-penetrating radar (GPR) and terrain analysis methods to characterize and map the bathymetry and subaqueous soils with the inner basin of St. Albans Bay, Vermont.

Principal Participants:
Jim Doolittle, Research Soil Scientist, NSSC, NRCS, Newtown Square, PA
Steve Smith, Fish Biologist, U.S. Fish and Wildlife Service, Essex Junction, VT
Thomas Villars, Resource Soil Scientist, NRCS, White River Jctn., VT

Activities:
On February 26, 2013, personnel from the National Soil Survey Center (NSSC) and the Vermont NRCS Soil Resource Staff used a mobile GPR platform operated by U.S. Fish and Wildlife Service personnel to collect bathymetric measurements across ice-covered St. Albans Bay.

Summary:

1. In a one day period, more than 39 kilometers of geo-referenced GPR data were compiled across the inner basin of St. Albans Bay. The collected radar data will be used to document differences in substrates and subaqueous soil-landscape units based on bathymetry, slope, landscape shape, sediment type, and geographical location. Knowledge of the near-shore, submersed soil-landscapes of Lake Champlain and its bays is very important to address resource concerns that include water quality, sedimentation, eutrophication, and toxic algae blooms.

2. Using a velocity of propagation of 0.034 m/ns (dielectric permittivity of 78) and based on 124,438 radar picks, in the traversed areas of St. Albans Bay, the average water depth was 4.44 m with a range of 0.52 to 6.43 m.

3. We greatly appreciate the help of Reed Sims, GIS Specialist, Colchester, Vermont, in assisting with this project and digitizing the outlines of St. Albans Bay.

4. As part of this study, Dr. Zamir Libohova (Research Soil Scientist, Soil Survey Research & Laboratory, NSSC) will use GPR data and terrain analysis techniques to quantify terrain parameters (e.g., slope and landform units). This methodology will be used to identify subaqueous soil-landscape units, which can be used to partition submersed areas into more homogenous map units.

5. All interpreted radar data has been forwarded in Excel worksheet formats to Thom Villars and Dr. Zamir Libohova.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to be of assistance to you and your fine staff.

DAVID R. HOOVER
Acting Director
National Soil Survey Center

Attachment (Technical Report)

cc:
Albert Averill, State Soil Scientist, NRCS, Amherst, MA
James Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Newtown Square, PA
Luis Hernandez, Soil Survey Regional Director, NRCS, Amherst, MA
Zamir Libohova, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Lincoln, NE
John W. Tuttle, Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Wilkesboro, NC
Thomas Villars, Resource Soil Scientist, NRCS, White River Jctn., VT
Larry West, National Leader, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
Michael Wilson, Research Soil Scientist/Liaison Region 12, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
Gerald Smith, MLRA Soil Survey Office Leader, NRCS, Paul Smith MLRA Soil Survey Office, NRCS, Paul Smiths, NY

Technical Report on Subaqueous Soil Pilot Mapping Project: St. Albans Bay, Vermont, on February 26, 2013.

Jim Doolittle

Background:
Urban growth and changes in land management have resulted in the increased phosphorus enrichment, eutrophication, and sedimentation of Lake Champlain and its numerous bays (Poirier et al., 2012). Knowledge of the near-shore, submersed soil-landscapes of Lake Champlain and its bays is needed to deal with nutrient management, sedimentation, and water quality issues.

St. Albans Bay is a major, shallow embayment to Lake Champlain. The bay is composed of two sub-basins that are essentially divided by an island and submerged rise. St. Albans Bay receives inflow from Mills River and Jewett Brook. Since 1900, in response to urban development and increased waste effluent, storm water and sediment delivery, St. Albans Bay has experienced increased organic matter, phosphorus, nitrogen and sediment accumulations (Levine et al., 2012).

Distinct relationships exist among submersed soils, vegetation, habitats, sediments, and landscapes (Rabenhorst and Stolt, 2012; Demas and Rabenhorst, 1999; Bradley and Stolt, 2003; Osher and Flannagan, 2007). These relationships have fostered the recognition of subaqueous soil-landscape units. Subaqueous soil-landscape units are identified on the basis of bathymetry, slope, landscape shape, sediment type, and geographical location (Bradley and Stolt, 2003). Knowledge of the distribution of different subaqueous soil-landscape units and shallow water habitats have helped to partition diverse, shallow, submersed environments into more homogenous units, and improve the characterization and management of these ecosystems (Bradley and Stolt, 2003).

In order to assess and characterize subaqueous soil-landscape units, greater knowledge of water depth, bottom topography, sediment type and thickness, and subaqueous processes is needed (Demas and Rabenhorst, 1999, 2001). As noted by Rabenhorst and Stolt (2012), the inability to visually observe the subaqueous land surface and the general lack of high-quality topographic (bathymetric) imagery are daunting problems facing soil scientist tasked with mapping subaqueous soils. Traditional tools and methods used to sample and map subaqueous soil-landscapes have proven to be slow, labor-intensive, and costly to operate. As a consequence, these tools do not provide adequate site coverage (Erich et al., 2010; Demas and Rabenhorst, 2001). Alternative tools are needed to complement existing survey techniques and reduce field costs. To be effective, these tools must be relatively fast, accurate, inexpensive to use, and capable of characterizing the spatial variability of soil properties at scales commensurate with the intended use or interests (Jaynes et al., 1995). One such tool is ground-penetrating radar (GPR). Ground-penetrating radar provided continuous, highly detailed information on water depth, bottom sediment type, thickness, and topography in many freshwater systems. Ground-penetrating radar has been used extensively for bathymetric surveys of freshwater lakes (Sambuelli and Bava, 2012; Doolittle et al., 2010; Fischer et al., 2007; Arcone et al., 2006; O'Driscoll et al., 2006; Buynevich and Fitzgerald, 2003; Hunter et al., 2003; Moorman, 2001; Moorman and Michel, 1997; Mellett, 1995; Sellmann et al., 1992; Izbicki and Parker, 1991; Truman et al., 1991; Haeni et al., 1987) and rivers (Sambuelli et al., 2009; Feurer et al., 2008; Spicer et al., 1997; Kovacs, 1991; Annan and Davis, 1977). In these studies, GPR provided continuous, detailed information on bottom-sediment type, thickness, and bathymetry. These studies illustrate how GPR can provide more comprehensive coverage of submersed sediments than possible from core data alone.

The purpose of this investigation is to obtain data on water depths, bottom topographies, and sediment types within the inner basin (1,761 acres) of St. Albans Bay, Vermont. This information will be used to develop field methods and data processing techniques for the rapid assessment and mapping of subaqueous soils in bodies of fresh water.

Study Sites:
Figure 1 is an aerial photograph of the inner basin of St. Albans Bay in Franklin County, Vermont. The outer reach of the survey area and also the inner basin extends from near Hathaway Point (left) to Lime Rock Point (right). The survey area includes Lazy Lady Island. Jewett Brook (see "A" in Figure 1) flows into St. Albans Bay in the extreme northeastern corner of the inner basin. The delta of Mill River (see "B" in Figure 1) can be seen extending into the inner basin from the eastern shore. These streams carry sediments and nutrients into the Bay.

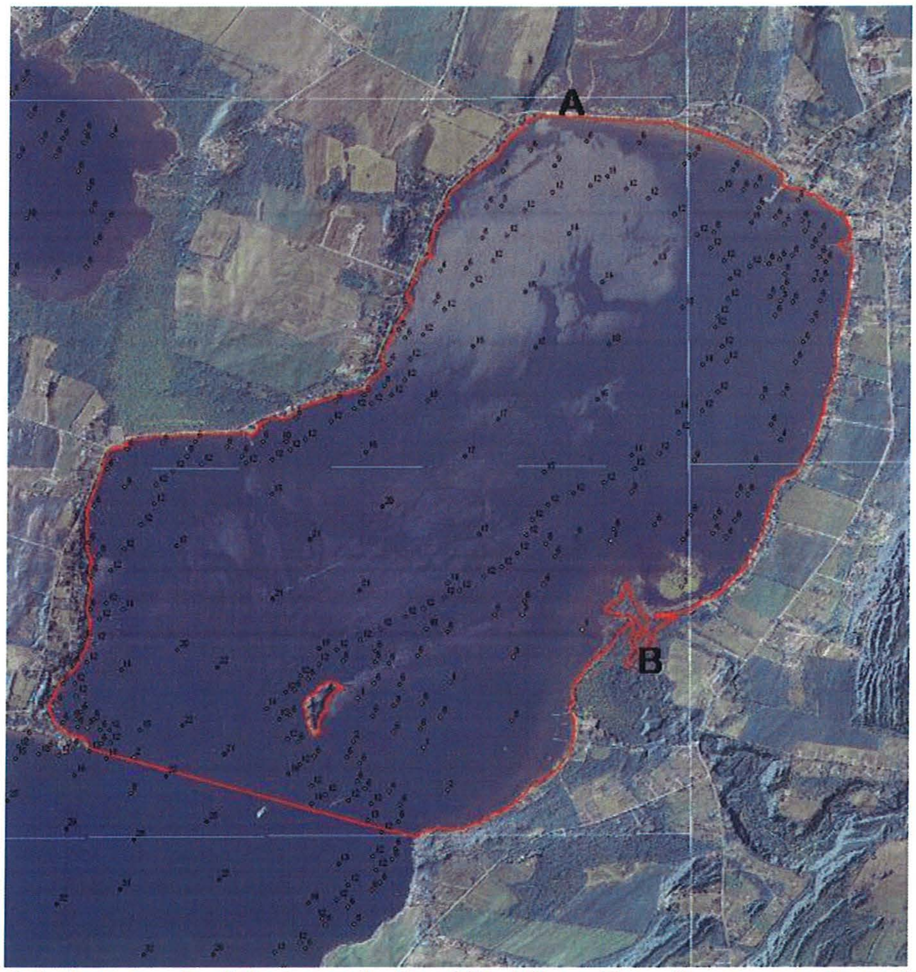

Figure 1. Aerial photograph of the inner basin of St. Albans Bay. Survey area is enclosed by red-colored line. Recorded depths are expressed in feet (from other sources).

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. (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)

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

and is backpack portable. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A 120 MHz antenna was used in this study. Because of equipment problems, in order to complete this assignment, a SIR-3000 was borrowed from the New Jersey NRCS State Office.

Recent technical developments allow the integration of GPR and GPS data. The SIR-3000 system has a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan on radar records can be georeferenced (position/time matched). Following data collection, a subprogram within the RADAN for Windows (version 6.6) software program (GSSI) can be used to proportionally adjust the position of each radar scan according to the time stamp of the two nearest positions recorded with the GPS receiver.[1] A Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to collect position data.[1] Position data were recorded at a rate of one per second along GPR traverse lines. The scanning rate of the GPR was set at 24 scan/sec.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records. Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, and migration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). Using the *Interactive 3D Module* of the RADAN, depths to the water/bottom-sediment interface were semi-automatically and reasonably accurately picked, and outputted to a worksheet (X, Y, Z format; including latitude, longitude, depths to interface or layer, and other useful data).

To help summarize the results of this survey, SURFER for Windows (version 10.0), developed by Golden Software, Inc. (Golden, CO), was used to construct simulations of the interpreted depth data.[1]

Figure 2. ***This mobile GPR platform was used to facilitate the GPR survey of St. Albans Bay.***

Methods:
Mobile GPR surveys were conducted across the ice-covered portions of St. Albans Bay. A four-wheel drive ATV (Figure 2) was used as a mobile platform to rapidly complete the GPR surveys. A 120 MHz antenna was towed behind the ATV. Over a one-day period, more than 31.6 km (19.6 miles) of

continuous, geo-referenced GPR data were recorded over the inner basin of St. Albans Bay. During this survey, several ground-truth core observations were taken to confirm interpretations and scale the radar imagery. Average ice thickness was estimated to be about 36 cm (14 inches) at the time of this survey.

Calibration:
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., soil horizon, stratigraphic layer, lake bottom) 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] (Daniels, 2004):

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

The velocity of propagation is dependent upon the relative dielectric permittivity (E_r) of the profiled material(s). The relative dielectric permittivity is a dimensionless, complex number. The relationship between E_r and v is embedded in the large dielectric contrast that exists between water (~80) and air (~1) and is expressed in Equation [2] (Daniels, 2004):

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

Where C is the velocity of propagation in a vacuum (0.3 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In earthen materials, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v.

Based on five probings conducted across St. Albans Bay, the average v though a column of snow, ice, and shallow water was 0.034 m/ns. The average E_r though this column was 77.8.

Results:
Figures 3 is a *Goggle Earth* image of the surveyed portion of St. Albans Bay showing the locations of the GPR traverse lines. Each traverse line is colored-coded based on the interpreted depth to the water/bottom sediment interface. In Figure 3, the color-coded estimated depths are expressed in meters. Using Equation [3], these estimates are based on the measured scanning time to the water/bottom sediment interface and an average radar pulse propagation velocity of 0.034 m/ns.

Figure 4 is a two-dimensional contour plot of the bathymetry of St. Albans Bay's inner basin. This simulation was prepared from 124,438 radar measurements. Compared with the GPR bathymetric data that was collected over Missisquoi and Maquam Bays, St. Albans Bay is deeper. A relatively deep trough extends in a north-northeast to south-southwest direction across the inner basin and towards St. Albans Bay's outlet to Lake Champlain. Based on the interpreted radar data, the average water depth within the inner basin of St. Albans Bay is 3.5 m with a range of 0.0 to 7.7 m. One-half of the bathymetric measurements were between depths of 2.0 and 4.8 m. As evident in Figure 4, sediments from Mill River form a noticeable delta and shelf that extends into the inner basin from the eastern shore.

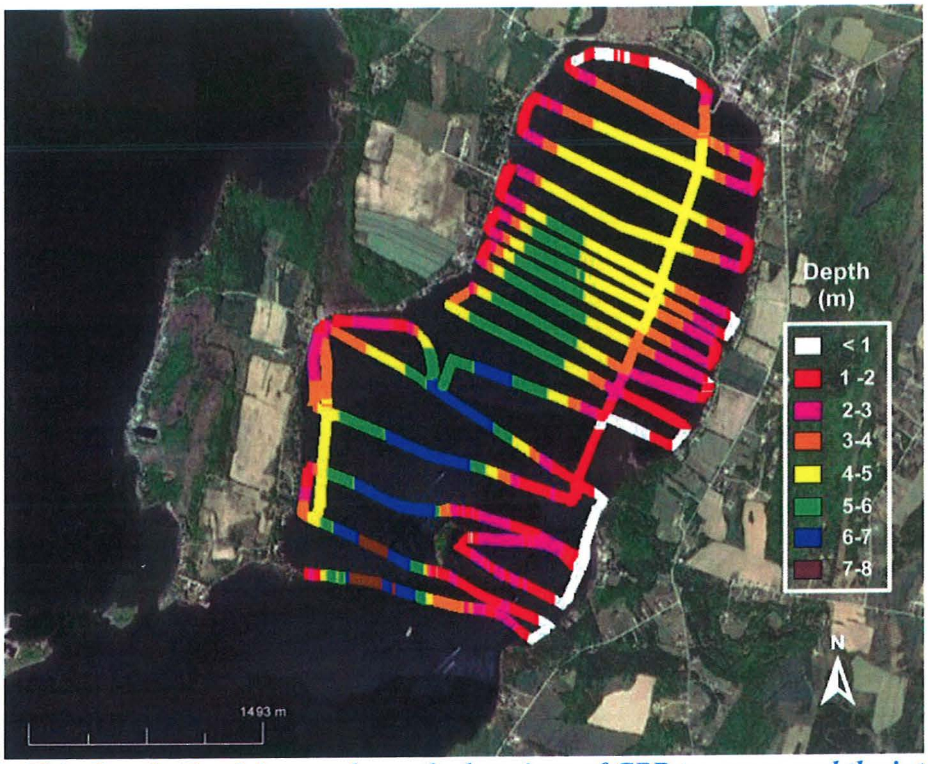

Figure 3. ***This Google Earth image shows the locations of GPR traverses and the interpreted water depths (in meters) across the portion of St. Albans Bay that was surveyed with GPR (courtesy of Brian Jones, GSSI).***

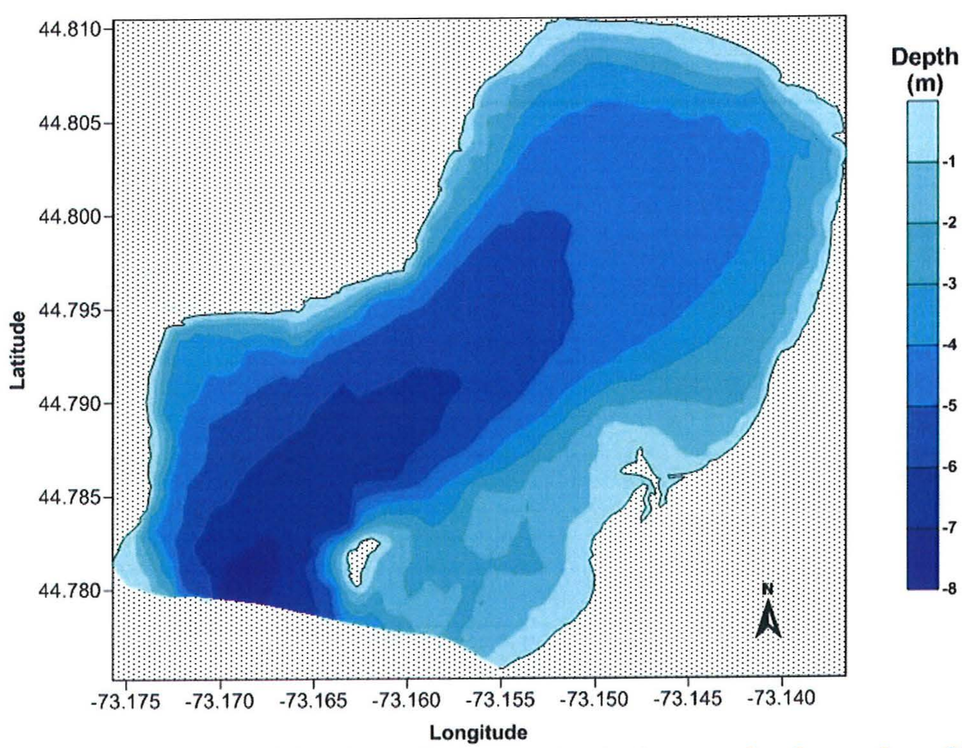

Figure 4. ***This two-dimensional plot shows the interpreted bathymetry for the portion of St. Albans Bay was surveyed with GPR.***

Radar Facies:
The bottom sediments of St. Albans Bay can be differentiated on the basis of radar facies analysis. A *radar facies* is a mappable 3D unit composed of GPR reflections whose parameters (internal reflection patterns and characteristics) differ from adjoining units. Compared with Missisquoi and Maquam Bay, the radar facies of St. Albans Bay were less distinct and more difficult to interpret. Without additional core observations, only three major facies have been identified across the surveyed portions of St. Albans Bay: *Stratified Sandy and Coarse-Loamy Deposits*, *Duplex Deposits*, and *Rock Outcrop*.

Stratified Sandy and Coarse-Loamy Deposits:
These relatively coarse and medium textured deposits have noticeable inclined, segmented planar reflectors, which represent contrasting strata. Because of the low clay and silt contents, attenuation is relatively low and deep subbottom penetration depths can be obtained in these deposits. Figure 5 is a representative radar record of the *Stratified Sandy and Coarse-Loamy Deposits* facies. Double return echoes or multiples are evident at depths greater than 4.0 m. Multiples represent unwanted noise and mimic the reflections evident at shallower depths. Multiples occur when radar pulses encounter highly-reflective materials causing multiple reflections to occur between the highly-reflective subsurface layer and the surface.

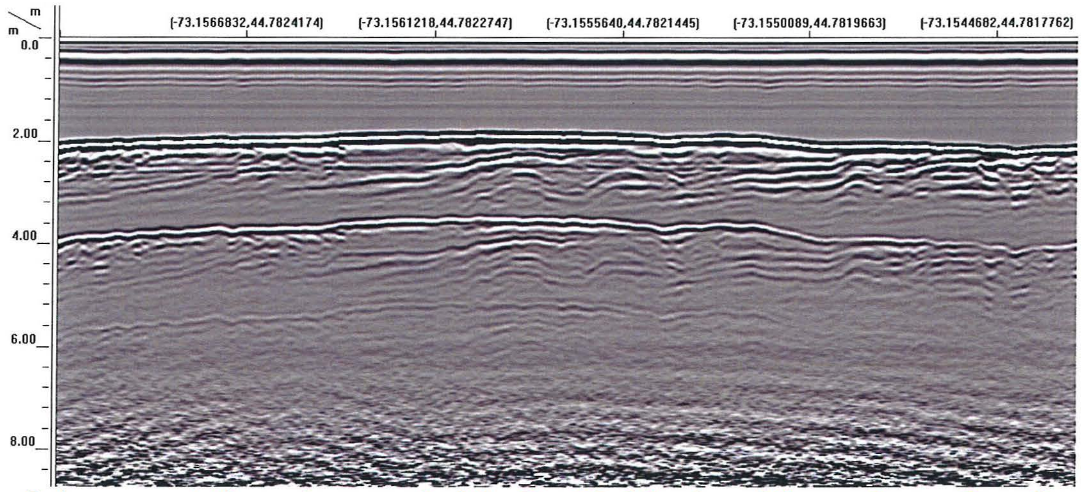

Figure 5. A representative radar record of the *Stratified Sandy and Coarse-Loamy Deposits* radar facies.

The radar record shown in Figure 6 is another example of the *Stratified Sandy and Coarse-Loamy Deposits* facies. In this example the surface is more sloping and forms a prominent submerged scarp or ridge. Note the multiples in the lower part of this radar record.

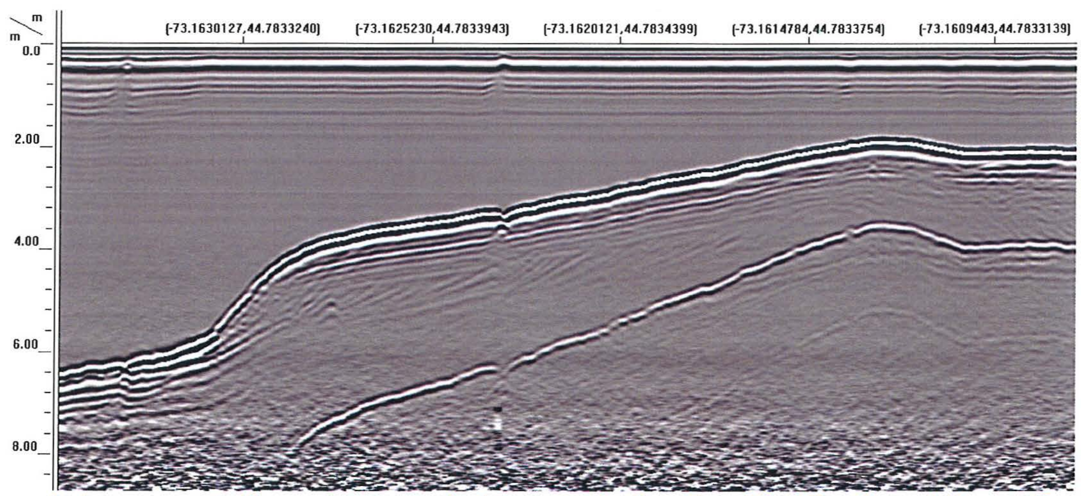

Figure 6. A representative radar record of a more sloping *Stratified Sandy and Coarse-Loamy Deposits* radar facies.

<u>*Duplex Deposits* Facies:</u>
Borrowed from an Australian term, the *Duplex Deposits* is a radar facies that appears to have two, closely spaced, contrasting soil textural layers. This narrow radar facies occurs in the deeper, often less sloping portions of the inner basin. It is characterized by two subsurface linear reflectors: a smooth, shallower reflector of lower signal amplitude and a more irregular, deeper reflector of higher signal amplitude (Figure 7). It is inferred by the lower amplitude of the upper reflector that this interface (water/first bottom sediment) is less contrasting suggesting a gradual transition from water to rather fluid soil materials (organic and/or mineral) with high n-values. The fluid soil materials represent more recent deposits. Typically the deeper subset of this radar facies displays higher signal amplitude and has a slightly more crenulated topography. The cause(s) of this crenulated appearance is unknown, but suggests a more turbulent submersed environment. As the *Duplex Deposits* radar facies occurs in the deeper parts of the bay, the lower contrasting textural layer may represent silty lacustrine deposits. Ground-truth core observations are needed to confirm these interpretations.

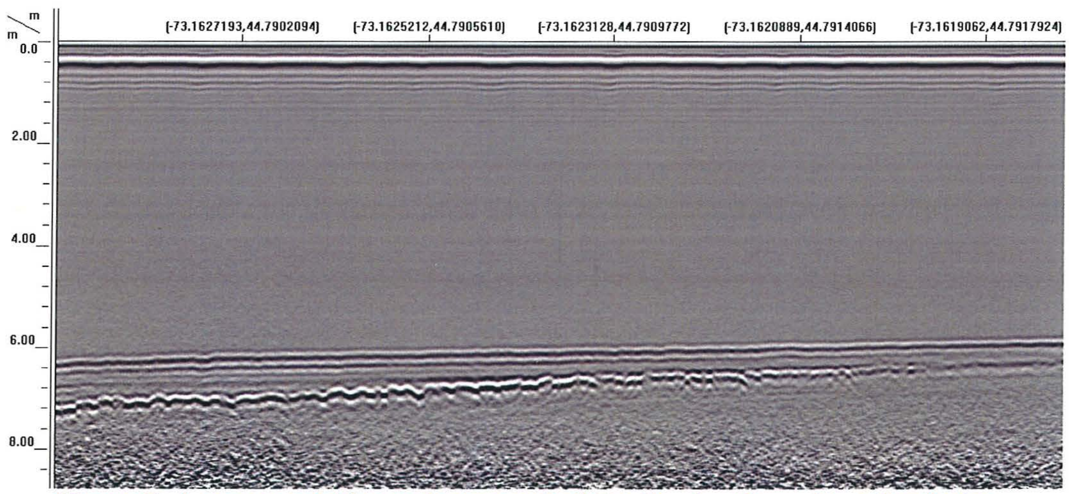

Figure 7. A representative radar record of the *Duplex Deposits* radar facies.

<u>Rock Outcrop Facies:</u>
Though rather limited in extent areas of the *Rock Outcrop* facies were noticed across the bottom of St. Albans Bay. This radar facies is characterized by a highly irregular to broken interface with the overlying

water column and steep side slopes. An image of *Rock Outcrop* facies appears in the middle of the radar record shown in Figure 8. On either side of the *Rock Outcrop* radar facies, areas of the *Stratified Sandy and Loamy Deposits* radar facies appear. Note the multiples in the left-hand portion of this radar record.

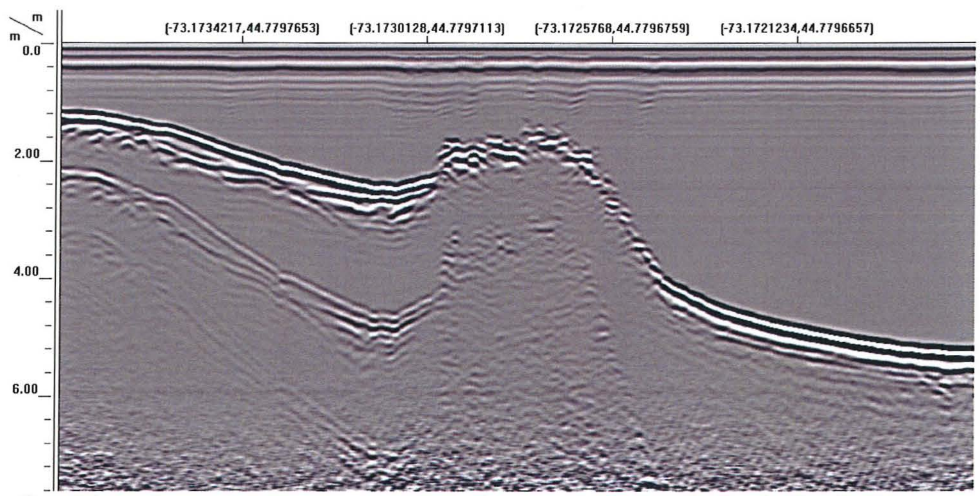

Figure 8. On this radar record, an area of *Rock Outcrop* radar facies is flanked by areas of the *Stratified Sandy and Loamy Deposits* radar facies. Note the multiples in the left hand portion of the radar record.

Distribution of Major Facies in St. Albans Bay:

Figure 9 is a 2D simulation of St. Albans Bay's inner basin showing the distribution of the major facies identified in this study. Areas colored red represent the *Rock Outcrop* radar facies. The shallower, peripheral areas of the bay are dominated by the *Stratified Sandy and Coarse-Loamy Deposits* radar facies. The deeper, less sloping interior section of the bay is dominated by the *Duplex Deposits* radar facies.

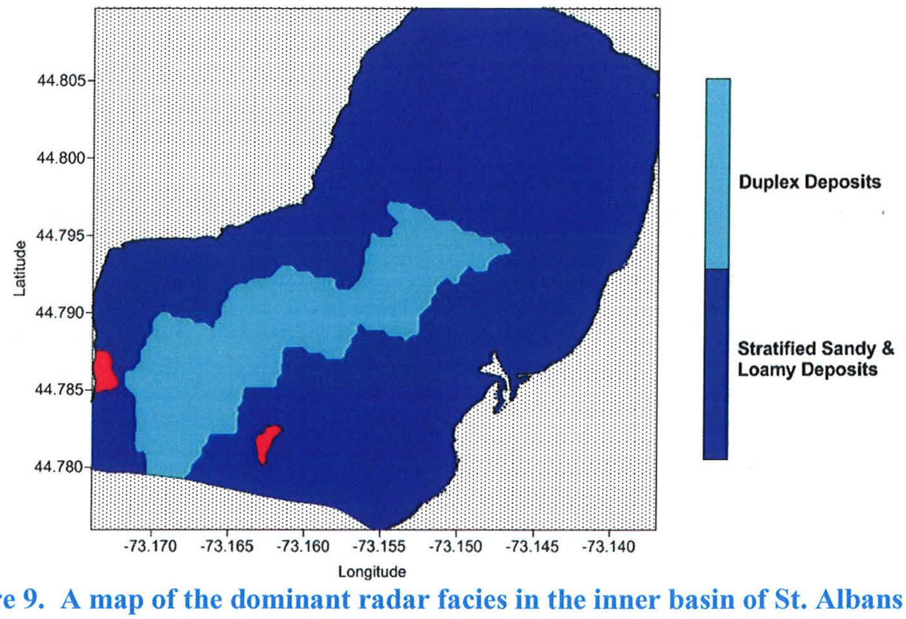

Figure 9. A map of the dominant radar facies in the inner basin of St. Albans Bay.

Reference:

Annan, A.P., and J.L. Davis, 1977. Impulse radar applied to ice thickness measurements and freshwater bathymetry. 63-65 pp. *In*: Report of Activities, Part B, Paper 77-1B. Geological Survey of Canada, Ottawa, Canada.

Bradley, M.P., and M.H. Stolt, 2003. Subaqueous soil-landscape relationships in Rhode Island estuary. *Soil Science Society of America Journal* 67: 1487-1495.

Buynevich, I.V., and D.M. Fitzgerald, 2003. High-resolution subsurface (GPR) imaging and sedimentology of coastal ponds, Maine, U.S.A.: Implications for Holocene back-barrier evolution. *Journal of Sedimentary Research* 73 (4) 559-571.

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

Delaney, A.J., P.V. Sellmann, and S.A. Arcone, 1992. Sub-bottom profiling: a comparison of short-pulse radar and acoustic data. 149-157 pp. *In*: Hanninen, P., and S. Autio (ed.) Fourth International Conference on Ground-Penetrating Radar. 7 to 12 June 1992. Rovaniemi, Finland. Geological Survey of Finland, Special Paper 16.

Demas, G.P., and M.C. Rabenhorst, 1999. Subaqueous soils: pedogenesis in a submersed environment. *Soil Science Society of America Journal* 63: 1250-1257.

Doolittle, J., J. Turenne, T. Villars, 2010. Characterizing subaqueous landscape units with ground-penetrating radar. *FastTimes* 15(4): 34-39.

Fischer, T.G., W.L. Loope, W. Pierce, and H.M. Jol, 2007. Big lake records preserved in a little lake's sediment: an example from Silver Lake, Michigan, USA. *Journal of Paleolimnology* 37: 365-382.

Feurer D., J.-S. Bailly, C. Puech, Y.L. Coarer, and A.A. Viau, 2008. Very-high-resolution mapping of river-immersed topography by remote sensing. *Progress in Physical Geography* 32(4): 403-419.

Haeni, F.P., D.K. McKeegan, 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. Hartford, Connecticut.

Hunter, L.E., M.G. Ferrick, and C.M. Collins, 2003. Monitoring sediment infilling at the Ship Creek Reservoir, Fort Richardson, Alaska, using GPR. 199-206 pp. *In*: Bristow, C.S., and H.M. Jol (eds.) *Ground Penetrating Radar in Sediments*. Special Publication 211, Geological Society of London, London, United Kingdom.

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. 18 p.

Jol, H., 2009. Ground Penetrating Radar: Theory and Applications. Elsevier Science, Amsterdam, The Netherlands.

Kovacs, A., 1991. Impulse radar bathymetric profiling in weed-infested fresh water. CRREL Report 91-10. U. S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover New Hampshire.

Kovacs, A., and R.M. Morey, 1990. Sea ice thickness versus impulse radar time-of-flight data. *Cold Regions Science and Technology* 18: 91-98

Levine, S.N., A. Lini, M.L. Ostrofsky, L. Bunting, H. Burgess, P.R. Leavitt, D. Reuter, A. Lami, P. Guilizzoni, and E. Giles, 2012. The eutrophication of Lake Champlain's northeastern arm from paleolimnological analyses. Journal of Great Lakes Research 38: 35-48.

Lundberg, A., H. Thunehed, and J. Bergström, 2000. Impulse radar snow surveys – Influence of snow density. *Nordic Hydrology* 31(1): 1-14.

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

Moorman, B.J. 2001. Ground-penetrating radar applications in paleolimnology. 1-25 pp. *In*: Last, W.M. and J.P. Smol (eds.). Tracking Environmental Change using Lake Sediments: Physical and Chemical Techniques. Kluwer Academic Publishers, Dordrecht, The Netherlands.

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

O'Driscoll, M.A., S.R. Riggs, D.V. Ames, M.M Brinson, D.R. Corbett, and D.J. Mallinson, 2006. Geomorphic, ecologic, and hydrologic dynamics of Merchant Millpond, North Carolina. Hydrology and Management of Forested Wetlands, Proceeding of International Conference, 8-12 April 2006, New Bern, North Carolina.

Osher, L.J., and C.T. Flannagan, 2007. Soil/landscape relationships in mesotidal Maine estuary. *Soil Science Society of America Journal* 71: 1323-1334.

Poirier, S.C., J.K. Whalen, and A.R. Michaud, 2012. Bioavailable phosphorous in fine-sized sediments transported from agricultural fields. *Soil Science Society of America Journal* 76(1): 258-267.

Rabenhorst, M.C., and M.H. Stolt, 2012. Subaqueous soils: pedogenesis, mapping, and applications. pp. 173–204. *In*: Lin, H. (Ed.), Hydropedology: Synergistic Integration of Soil Science and Hydrology. Academic Press, Elsevier.

Sambuelli, L., C. Calzoni, and M. Pesenti, 2009. Waterborne GPR survey for estimating bottom-sediment variability: A survey of the Po River, Turin, Italy. Geophysics 74(4): B95-B101.

Sellmann, P.V., A.J. Delaney, and S.A. Arcone. 1992. Sub-bottom surveying in lakes with ground-penetrating radar. CRREL Report 92-8. U. S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

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.

Stevens, C.W., B.J. Moorman, S.M. Solomon, and C.H. Hugenholtz, 2009. Mapping subsurface conditions within near-shore zones of an Arctic delta using ground penetrating radar. *Cold Regions Science and Technology* 56: 30-38.

Sand, K., and O. Bruland, 1998. Application of georadar for snow cover surveying. *Nordic Hydrology* 29(4/5): 361-370.

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.