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 - Trip Report – Geophysical Assistance

May 2, 2013

TO: Christine Clarke
State Conservationist
NRCS, Amherst, Massachusetts

File Code: 330-20-7

Purpose:
To determine the thickness of organic deposits in cranberry beds located in Plymouth County with ground-penetrating radar (GPR). Radar data will be used in planning the restoration of these wetlands. Directions were also provided to Glenn Stanisewski on the operation of GPR and the processing procedures used to process radar data.

Principal Participants:
Jim Doolittle, Research Soil Scientist, NSSC, NRCS, Newtown Square, PA
Melissa Kenefick, Conservation Planner, MACD, West Wareham, MA
Nicole Kerstetter, Conservation Planner, MACD, West Wareham, MA
Glenn Stanisewski, Resource Soil Scientist, NRCS, West Wareham, MA

Activities:
All activities were completed on March 11-14, 2013.

Summary:

1. High-intensity GPR surveys were completed across the *Century Cranberry Beds* in Wareham, Massachusetts. The combined acreage of these two cranberry beds is about 15 acres. Ground-penetrating radar provided information on the depth and thickness of the organic deposits within these beds. This data will be used in planning a wetland restoration project that will recreate the natural stream channel across the wetland.

2. Heavy rains caused flooding and ponded conditions across the Cranebrook Bog complex (100 acres) in South Carver that was scheduled to be surveyed with GPR. As a consequence, the GPR survey of these beds could not be carried out during this visit.

3. Glenn Stanisewski has experienced difficulties establishing communications between his Trimble GeoXT GPS receiver and SIR-3000 radar unit. This problem was evaluated, and after field tests and phone conversations with a technical representative from Geophysical Survey Systems, Inc. (GSSI), it was learned that his Signal Data Recorder (SDR) is malfunctioning. The SDR needs to be returned to GSSI for repairs. Without a working SDR, Glenn cannot collect georeferenced radar data, which are vital to GPR surveys of cranberry beds and providing technical assistance to growers in southeastern Massachusetts.

4. Training on the calibration and operation of GPR and the use of several post-processing software functions that are best suited to radar data collected in soil investigations were provided to Glenn Stanisewski during this visit. Glenn has a very good understanding of the use and operation of GPR.

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 "Al" N. Averill, State Soil Scientist, NRCS, Amherst, MA
Luis Hernandez, Soil Survey Regional Director, NRCS, Amherst, MA
Glenn R. Stanisewski, Resource Soil Scientist, NRCS, West Wareham, MA
Melissa Kenefick, Conservation Planner, MACD, West Wareham, MA
Nicole Kerstetter, Conservation Planner, MACD, West Wareham, MA
James A. Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Newtown Square, PA
John W. Tuttle, Soil Scientist, Soil Survey Research & Laboratory, NSSC, NRCS, Wilkesboro, NC
Larry T. West, National Leader, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
Michael A. Wilson, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
Linda A. Kruger, Secretary, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE

GPR Investigation of *Century Cranberry Beds* in Plymouth County, Massachusetts.

Jim Doolittle
March 11-14, 2013

Background

A prerequisite for the effective use and management of "*natural*" (constructed in wetlands) cranberry beds is knowledge of the thickness, distribution, and volume of organic soil materials. The thickness of organic soil materials in *natural* cranberry beds is typically determined by probe-based methods. As probe-based methods are slow, tedious and expensive to conduct, observations are limited and provide only sparse coverage of *natural* cranberry beds. While relatively accurate, probe-based measurements contain a level of ambiguity that is caused by pushing the probe too far and into the mineral substrate, non-vertical soundings, topographic irregularities along the base of the organic soil materials, lateral variations in composition of the organic soil materials, and operator errors (rounding off measurements) (Parsekian et al., 2012; Rosa et al., 2009). Today, new and improved technologies are being used to inventory and map peatlands. In Plymouth County, ground-penetrating radar (GPR) is used to determine the thickness and volume of organic soil materials and characterize the internal structure of cranberry beds.

Ground-penetrating radar has been used for over thirty years to inventory and map peatlands. Ground-penetrating radar is a noninvasive geophysical tool designed to penetrate earthen materials and provided images of the shallow subsurface (0 to 30-m depths). Ground-penetrating radar can provide continuous streams of high-resolution subsurface information that can aid interpretations and supplement the sparse information obtained with traditional probe-based methods. Compared to traditional methods, GPR is faster and requires significantly less time and effort to obtain similar information on the thickness, volume, and geometry of peatlands (Jol and Smith, 1995).

Ground-penetrating radar can provide information on the depth and geometry of organic soil materials at a level of accuracy that is comparable to information obtained with probe-based methods (Parsekian et al., 2012, Rosa et al., 2009; Ulriksen, 1980). In a comparative study, Rosa et al. (2009) noted a high correlation between probe-based methods and GPR. The continuous profiling capability of GPR provides greater numbers of observations than the fewer, more widely spaced, probe-based observations. As a consequence, GPR often yields more accurate estimates of the thickness of organic soil materials and detailed information on the hydropedological framework of peatlands (Nolan et al., 2008; Rosa et al., 2009; Wastiaux et al., 2000).

Ground-penetrating radar has been used to estimate the thickness and volume of organic soil materials (Pelletier et al., 1991; Warner et al., 1990; Welsby, 1988; Collins et al., 1986; Worsfold et al., 1986; Shih and Doolittle, 1984; Tolonen et al., 1984; Ulriksen, 1982), distinguish layers having differences in degree of humification, bulk density and volumetric water content (Idi and Kamarudin, 2012; Nolan et al., 2008; Lapen et al., 1996; Warner et al., 1990; Chernetsov et al., 1988; Worsfold et al., 1986; Tolonen et al., 1984; Ulriksen, 1982), characterize the underlying mineral sediments, stratigraphy, hydrology and their relationships to present vegetation patterns (de Oliveira, 2012; Comas et al., 2004, Wastiaux et al., 2000; Warner et al., 1990) and to classify and map organic soils (Collins et al., 1986). Also, Lowe (1985) used GPR to assess the concentration of logs and stumps buried in organic soil materials. Holden (2004 and 2005) and Holden et al. (2002) used GPR to locate subsurface piping in organic soil materials and determine their hydrological conductivity. Comas et al. (2005 and 2011) used GPR to infer the underlying stratigraphic and hydrologic controls on pool formation in peatlands. Ground-penetrating radar has also been used to provide information on the properties of organic soil materials that effect geotechnical applications such as road, pipeline, and dike placement on peatlands (Jol and Smith, 1995; Saarenketo et al., 1992; Turenne, 1997; and Ulriksen, 1982).

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 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A 70 MHz antenna was used in this investigation. The 70 MHz antenna is the lowest frequency antenna that is available to NRCS.

The RADAN for Windows (version 6.6) software program (developed by GSSI) was used to process the radar records.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, horizontal high pass filtration, migration, and range gain adjustments (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). The *Interactive 3D Module* of RADAN was used to semi-automatically "*pick*" the depths to the organic/mineral soil interface on radar records. The picked data were exported to a worksheet (in an X, Y, and Z format; including longitude, latitude, and thickness of organic soil materials).

The SIR-3000 system contains a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan of the radar can be georeferenced (position/time matched). Following data collection, a subprogram within the RADAN for Windows is 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. 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 reading per second. The scanning rate of the GPR was 20 scans per second. The scanning time was set to either 350 or 400 ns (nanoseconds).

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., soil horizon, organic/mineral soil interface) 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):

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

In equation [2], C is the velocity of light in a vacuum (0.3 m/ns). In soils, the amount and physical state (temperature dependent) of water have the greatest affect on the E_r and v. Dielectric permittivity ranges from 1 for air, to 78 to 88 for water (Cassidy, 2009). Small increments in soil moisture can result in substantial increases in the relative permittivity of soils (Daniels, 2004). Using a 100 MHz antenna, Daniels (2004) observed that the relative dielectric permittivity of most dry mineral soil materials is between 2 and 10, while for most wet mineral soil materials, it is between 10 and 30. For organic soil materials, the E_r has been reported to range from 37 to 82 (Parsekian et al., 2012).

Based on the measured depth to the organic/mineral soil interface at three calibration points and using equations [1] and [2], the averaged v was estimated to be 0.0381 m/ns and the E_r was 62. However, both v

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

and E_r will vary spatially across cranberry beds and with depth. This variability affects the accuracy of soil depth measurements.

Study Sites:
Ground-penetrating radar surveys were completed across the *Century Cranberry Beds* (41.8000 ° N latitude, 70.6250 ° W longitude) in Plymouth County, Massachusetts. Figure 1 is a soil map of the *Century Cranberry Beds* from the Web Soil Survey.[2] These cranberry beds are mapped as Freetown coarse sand, 0 to 3 % slopes, sanded surface (map unit 55A) and Swansea coarse sand, 0 to 3 % slopes, sanded surface (map unit 60A). The very deep, very poorly drained Freetown soils formed in more than 130 centimeters of highly decomposed organic materials. The very poorly drained Swansea soils formed in 40 to 130 centimeters of highly decomposed organic material over sandy mineral sediments. These soils are in depressions or on flat, level areas on uplands and outwash plains. The Freetown soil series is a member of the dysic, mesic Typic Haplosaprists family. The Swansea soil series is a member of the sandy or sandy-skeletal, mixed, dysic, mesic Terric Haplosaprists family.

Figure 1. This soil map of the *Century Cranberry Beds* is from the Web Soil Survey.

Cranberry beds have surface layers of sandy fill-materials that are added to the original surface as a management practice. In beds that have been in production for longer than several decades, the surface layer consists of thick (40 to 130 cm), alternating layers of sand and organic materials (Jim Turenne, personal communication: http://nesoil.com/muds/cransoil.htm).

Survey Procedures:
Multiple GPR traverses were completed across each cranberry bed by carrying the 70 MHz antenna along the ground surface in a back and forth manner. Radar traverses were conducted parallel to ditches that

[2] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [3/21/2013].

drained these beds. Walking across each bed, a total of 66,880 georeferenced GPR measurements were collected. Each radar traverse was stored as a separate file.

Results:

Figure 2 is a representative three-dimensional (3D) rendition of a radar record from the *Century Cranberry Beds*. In this rendition, the depth scale is expressed in meters. The horizontal scale is expressed in the Universal Transverse Mercator (UTM) geographic coordinate system. A white-colored, segmented line has been used to highlight the interpreted organic/mineral soil interface. The relatively thick alternating layers of sandy fill materials and organic soil materials are evident in the upper part of this 3D rendition.

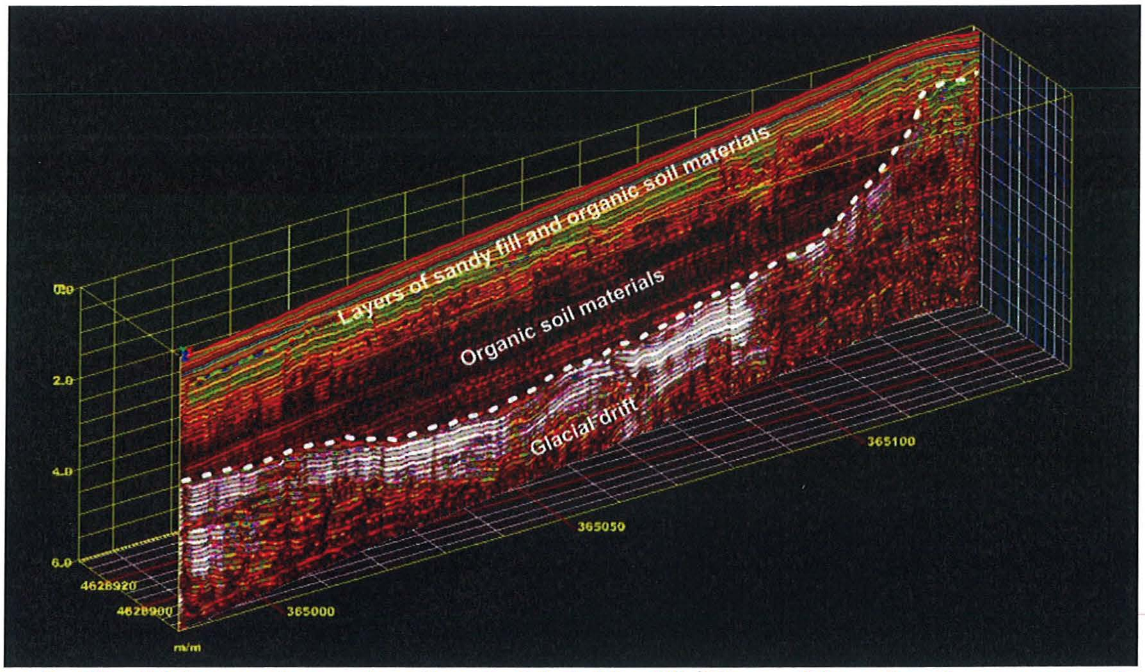

Figure 2. The thickness of organic soil materials is identified by a white-colored, segmented line in this 3D block diagram rendition of a radar record from the *Century Cranberry Beds*.

In the interior portions of the *Century Cranberry Beds*, high rates of signal attenuation occurred, restricting the exploration depths of the 70 MHz antenna to about 4 m. As evident in Figure 3, the severe signal attenuation occurred over relatively narrow spatial and vertical distances. Typically in organic soil materials, a general and noticeable weakening of the reflected signal amplitudes occurs gradually with increasing soil depth. The abrupt and very severe attenuation of the organic/mineral soil materials interface evident on the radar records (see Figure 3) collected over portions of *Century Cranberry Beds*, suggests residual pools of more conductive pore waters in the deeper portions of the kettle holes that form these peatlands. The suggested increased conductivity of the pore water may be from nutrients applied to these cranberry beds. These interpretations require further investigations and sampling in order to be confirmed.

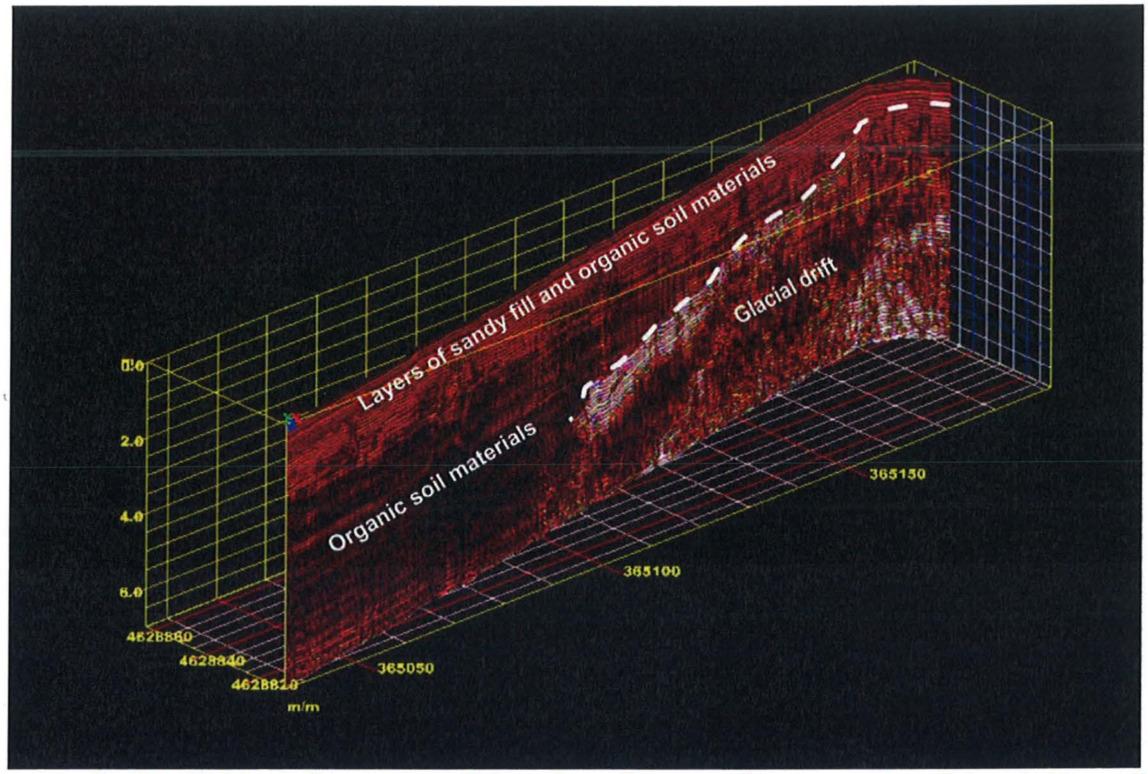

Figure 3. In this 3D block diagram rendition of a radar record, severe rates of signal attenuation restrict the effective exploration depth in deeper portions of the cranberry bed.

For the two *Century Cranberry Beds*, based on 64,602 radar interpretations, the average depth to the organic/ mineral soil materials interface was 2.7 m, with a range of 0.71 to 7.26 m. Within these two cranberry beds, one-half of the measurements were between 1.85 and 3.48 m.

Figure 4 is a two-dimensional (2D) simulation of the *Century Cranberry Beds* showing the interpreted thickness of the sandy-fill and organic soil materials over the glacial drift. This simulation is based on the 64,602 radar depth measurements. This simulation was prepared using kriging gridding methods to construct a 69 row by 100 column grid consisting of 6900 grid nodes. In Figure 4, the approximate locations of two constructed dikes are also shown.

In the simulation shown in Figure 4, noticeable shelves that are shallower to mineral soil materials are evident in both the western and eastern portions of the cranberry beds as well as in the peripheral areas to these wetlands. The imagery of the deeper portions of the cranberry beds suggests a preexisting channel that passed diagonally through these wetlands in a north-northeast to south-southwest direction.

A significant, interior portion of the *Century Cranberry Beds* lacked deeper radar imagery showing the organic/mineral soil materials interface because of excessive rates of signal attenuation. In Figure 4, the depths to the organic/mineral soil materials interface were interpreted by the modeling program across these deeper areas that lack signal returns. In Figure 5, the areas that lacked radar imagery of the organic /mineral soil materials interface are shown. This information may be useful in the reconstruction planning and, if caused by high soil pore water conductivity, to understand the hydrology of these wetlands.

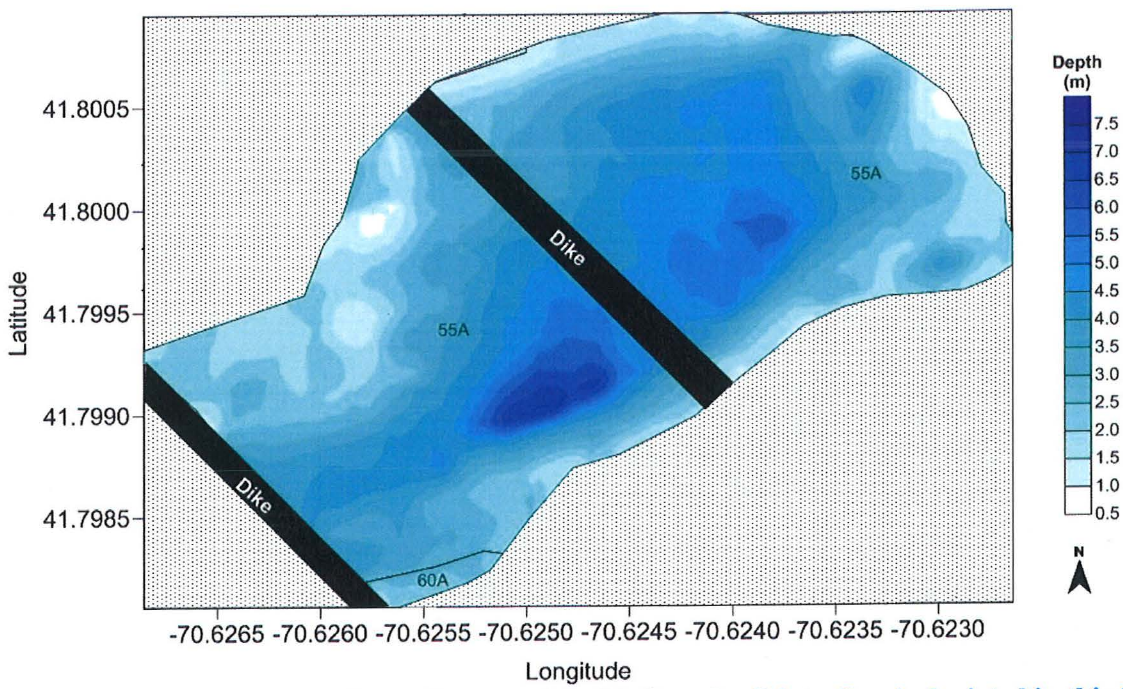

Figure 4. The interpreted depths to the organic soil/mineral soil interface is depicted in this 2D simulation of the *Century Cranberry Beds*.

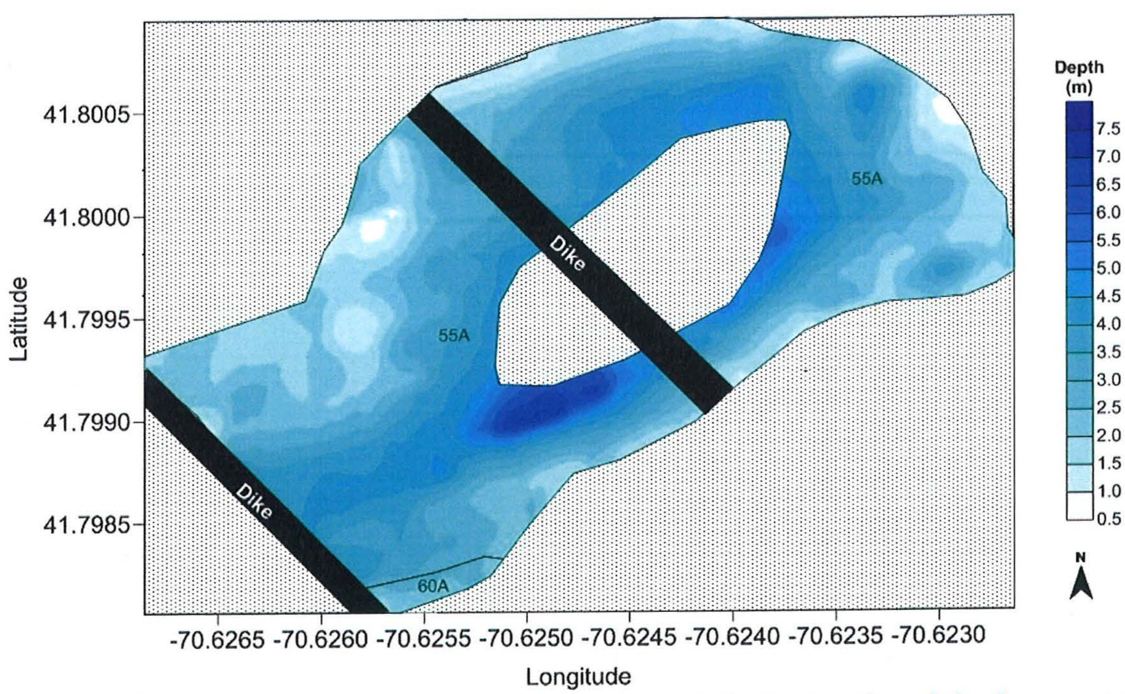

Figure 5. In this 2D simulation of the *Century Cranberry Beds*, the location of the deeper, more attenuating zone where the organic soil/mineral soil interface was lost is shown.

References:

Cassidy, N.J. 2009. Electrical and magnetic properties of rocks, soils, and fluids. In *Ground Penetrating Radar: Theory and Applications*, ed. H. M. Jol, 41-72 pp. Elsevier Science, Amsterdam, The Netherlands.

Chernetsov, E.A., N.A. Beletsky, and M.Y. Bae, 1988. Radar profiling of peat and gyttja deposits. 15-21 pp. In: Proceedings 8th International Peat Congress, Leningrad, USSR. International Peat Society, Jyska, Finland.

Collins, M.E., G.W. Schellentrager, J.A. Doolittle, and S.F. Shih, 1986. Using ground-penetrating radar to study changes in soil map unit composition in selected Histosols. *Soil Science Society of America Journal* 50: 408-412.

Comas, X., L. Slater, and A. Reeve, 2004. Geophysical evidence for peat basin morphology and stratigraphic controls on vegetation observed in a northern peatland. *Journal of Hydrology* 295: 173-184.

Comas, X., L. Slater, and A. Reeve, 2005. Stratigraphic controls on pool formation in a domed bog inferred from ground penetrating radar (GPR). *Journal of Hydrology* 315: 40-51.

Comas, X., L. Slater, and A. Reeve, 2011. Pool patterning in a northern peatland: geophysical evidence for the role of postglacial landforms. *Journal of Hydrology* 399: 173-184.

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

de Oliveira, M.A.T., J.L. Porsani, G.L. de Lima, V. Jeske-Pieruschka, and H. Behling, 2012. Upper Pleistocene to Holocene peatland evolution in Southern Brazilian highlands as depicted by radar stratigraphy, sedimentology and palynology. *Quaternary Research* 77 (3): 397-407.

Holden, J., 2004. Hydrological connectivity of soil pipes determined by ground-penetrating radar tracer detection. *Earth Surface Processes and Landforms* 29: 437-442.

Holden, J., 2005. Controls of soil pipe density in blanket peat uplands. *Journal of Geophysical Research* 110.

Holden, J., T.P. Burt, and M. Vilas, 2002. Application of ground-penetrating radar to the identification of subsurface piping in blanket peat. *Earth Surface Processes and Landforms* 27: 235-249

Idi, B.Y., and M.N. Kamarudin, 2012. Imaging stratigraphy of Pontian Peatland, Johor, Malaysia with ground penetrating radar. *Asian Journal of Earth Sciences* 5(2): 36-49.

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

Jol, H.M., and D.G. Smith, 1995. Ground penetrating radar surveys of peatlands for oilfield pipelines in Canada. *Journal of Applied Geophysics* 34: 109-123.

Lapen, D.R., B.J. Moorman and J.S. Price, 1996. Using ground-penetrating radar to delineate subsurface features along a wetland catena. *Soil Science Society of America Journal* 60: 923-931.

Lowe, D.J., 1985. Application of impulse radar to continuous profiling of tephra-bearing lake sediments and peats: an initial evaluation. *New Zealand Journal of Geology and Geophysics* 28: 667-674.

Nolan, J.T., A.D. Parsekian, L.D. Slater, and P.H. Glasner, 2008. Geophysical characterization of the Red Lake Peatland Complex, northern Minnesota. In: *Proceeding of the Symposium on the Application of Geophysics to Engineering and Environmental Problems* 21(2): 1044-1047.

Parsekian, A.D., L. Slater, D. Ntarlagiannis, J. Nolan, S.S. Sebesteyen, R.K. Kolka, and P.J. Hanson, 2012. Uncertainty in peat volume and soil carbon estimated using ground-penetrating radar. *Soil Science Society of America Journal* 76: 1911-1918.

Pelletier, R.E., J.L. Davis, J.R. Rossiter, 1991. Peat analysis in the Hudson Bay Lowlands using ground-penetrating radar. 2141-2144 pp. In: Proceedings of the International Geoscience and Remote Sensing Symposium. Helsinki, Finland. June 1991.

Rosa, E., M. Larocque, S. Pellerin, S. Gagné, and B. Fournier, 2009. Determining the number of manual measurements required to improve peat thickness estimations by ground penetrating radar. *Earth Surface Processes and Landforms* 34: 377-383.

Saarenketo, T., K. Hietala, and T. Salmi, 1992. GPR applications in geotechnical investigations of peat for road survey purposes. 293-305 pp. In: P. Hanninen and S. Autio (eds.) Fourth International Conference on Ground-Penetrating Radar, 7 to 12 June 1992. Rovaniemi, Finland. Geological Survey of Finland, Special Paper 16.

Shih, S.F., and J.A. Doolittle, 1984. Using radar to investigate organic soil thickness in the Florida Everglades. *Soil Science Society of America Journal* 48:651-656.

Tolonen, K., A. Rummukainen, M. Toikka, and I. Marttila, 1984. Comparison between conventional and peat geological and improved electronic methods in examining economically important peatland properties. 1-10 pp. In: Proceedings 7th International Peat Congress, Dublin, Ireland, June 18-23, 1984. The Irish National Peat Committee, 76 Lower Baggot St., Dublin, Ireland.

Turenne, J., 1997. Understanding cranberry soil maps. *Cranberries* (April 1997): 15-18.

Ulriksen, P., 1980. Investigation of peat thickness with radar. 126-129 pp. In: Proceeding of 6th International Peat Congress. Duluth, Minnesota. August 1980.

Ulriksen, C.P.F., 1982. Application of impulse radar to civil engineering. Doctoral Thesis. Department of Engineering Geology, Lund University of Technology. Lund, Sweden.

Warner, B.G., D. Nobes, and B.D. Theimer, 1990. An application of ground penetrating radar to peat stratigraphy of Ellice Swamp, southwestern Ontario. *Canadian Journal of Earth Science* 27: 932-938.

Wastiaux, C., L. Halleux, R. Schumacker, M. Streel, and J.M. Jacqmotte, 2000. Development of the Hautes-Fagnes peat bogs (Belgium): new perspectives using ground-penetrating radar. *SUO* 51(3): 115-120.

Welsby, J. 1988. The utilization of geo-radar in monitoring cutover peatlands. 99-107 pp. In: Proceedings 8th International Peat Congress, Leningrad, USSR. International Peat Society, Jyska, Finland.

Worsfold, R.D., S.K. Parashar, and T. Perrott. 1986. Depth profiling of peat deposits with impulse radar. *Canadian Geotechnical Journal* 23(2): 142-145.