United States Department of Agriculture

NRCS

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SUBJECT: MGT – Geophysical Assistance

March 25, 2015

TO: Christine S. Clarke
State Conservationist
NRCS, Amherst, Massachusetts

File Code: 330-20-7

Purpose:
To provide training on the use of the SIR-3000 ground-penetrating radar (GPR) and the RADAN 7.0 post-processing software. Ground-penetrating radar surveys were conducted across two cranberry beds located in Plymouth County, Massachusetts. Participants used three different radar control units and several low frequency radar antennas and evaluated their relative suitability for exploring peat deposits. Field investigations support a University of Massachusetts research project that is monitoring seasonal variations of nutrient exports from renovated cranberry beds.

Principal Participants:
Nick Alverson, Graduate Student, University of Massachusetts, Amherst, MA
Ken Corcoran, Application Specialist, Geophysical Survey System, Inc., Salem, NH
Jim Doolittle, Research Soil Scientist, USDA-NRCS, NSSC, Newtown Square, PA
Brian Jones, Application Specialist, Geophysical Survey System, Inc., Salem, NH
Maggie Payne, Resource Soil Scientist, USDA-NRCS, West Wareham, MA
Jim Turenne, Soil Scientist, USDA-NRCS, West Warwick, RI

Activities:
All activities were completed on March 17-18, 2015.

Summary:

1. Maggie Payne is the newest ground-penetrating radar operator in USDA-NRCS. The National Soil Survey Center is committed to ensuring that Maggie receives adequate training and continual guidance to successfully and confidently operate her SIR-3000 radar unit and use the RADAN signal processing software program and interactive analysis tools to interpret and display her radar data.

2. Application specialists from Geophysical Survey Systems, Inc., setup and reviewed communication procedures for Maggie's SIR-3000 control unit and her global positioning system (GPS) receivers (Trimble GeoXT and Garmin Global Positioning System Map 76 receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack)). Maggie can now georeferenced her radar data and import it into GIS.

3. High-intensity GPR surveys were completed across the *Edgewood Cranberry Beds* near Carver, Massachusetts. Ground-penetrating radar provided information on the depth and thickness of sand layers and organic soil materials within these beds. This data will be used in a research project that is monitoring seasonal variations of nutrient exports from renovated cranberry beds.

4. Training on the calibration and operation of GPR, and the use of several post-processing software functions that are best suit to radar data collected in soil investigations were provided to Maggie Payne during this visit. Maggie is an exceptional soil scientist and has a very good understanding of the use and operation of GPR. Her eagerness to learn and enthusiasm for GPR is greatly appreciated.

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

JONATHAN W. HEMPEL
Director
National Soil Survey Center

Attachment (Technical Report)

cc:
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GPR investigation of Edgewood Cranberry Beds in Plymouth County, Massachusetts.
March 17-18, 2015

Jim Doolittle

Background

The effective management of cranberry beds requires knowledge of the thickness, distribution, and volume of organic soil materials. Traditionally, this information has been determined using probe-based methods. However, probe-based methods are slow, tedious and expensive to use. As a consequence, observations are limited and provide only sparse, incomplete coverage of cranberry beds. While relatively accurate, probe-based measurements do contain a level of uncertainty or error that is caused by obstructions within the peat, pushing the probe too far into the mineral substrate, non-vertical measurements, and operator errors (rounding off measurements) (Parry *et al*., 2014; Parsekian *et al*., 2012; Rosa *et al*., 2009). Some of these limitations can be overcome by incorporating new and improved technologies into the inventory and mapping of peatlands. Since the late 1980s, USDA has used ground-penetrating radar (GPR) in Plymouth County to assist growers manage their cranberry beds. Ground-penetrating radar has provided detailed information on the thickness and volume of organic soil materials and has helped to characterize the structure and hydrology of cranberry beds.

Ground-penetrating radar is a noninvasive geophysical tool that is 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 using traditional probe-based methods. Compared to traditional methods, GPR is faster and requires significantly less time and effort to obtain greater volumes of information on the thickness, volume, and geometry of peatlands (Jol and Smith, 1995).

Ground-penetrating radar provides 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 more observations than probe-based observations. As a result, GPR often yields more accurate estimates of the thickness of organic soil materials and more 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 widely 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 (Proulx-McInnis *et al*., 2013; 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 hydrological 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. Operating procedures for the SIR-3000 are described by Geophysical Survey Systems, Inc. (2004). Antenna with center frequencies of 100, 120, and 200 MHz were used in this investigation (Figure 1). Different scanning time were used in different sections of the cranberry beds. Scanning times ranged from 200 to 400 ns (nanoseconds).

Figure 1. Maggie Payne adjust radar control unit for use on cranberry bed with GPS and a 120 MHz antenna (left). Maggie and Jim Doolittle discuss optimal settings, while others stand by with 120, 200, and 100 MHz antennas (right; antennas arranged from left to right).

The RADAN for Windows (version 7.0) software program (developed by GSSI) was recently purchased by the Massachusetts State NRCS Office for Maggie Payne. Different functions of this software program were reviewed and used to post-process the collected radar data.[1] Processing procedures used were: header editing, setting the initial pulse to time zero, color table and transformation selection, FIR filtration (signal stacking, horizontal high pass filtration), migration, and range gain adjustments. The *Interactive 3D Module* of RADAN was also reviewed and used to individually or semi-automatically "*pick*" the depths to the organic/mineral soil interface on radar records. The exportation of picked data as a csv file (in an X, Y, and Z format; including longitude, latitude, and thickness of organic soil materials) was demonstrated. The exportation of radar images as jpg files was also reviewed.

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 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. In this study, a Garmin Map 76 GPS receiver was used to collect position data (Garmin International, Inc., Olathe, KS).[1] Position data were recorded at a rate of one reading per second.

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

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 (0.2998 m/ns; 0.9836 ft/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 E_r of most dry mineral soil materials ranges from 2 to 10, while for most wet mineral soil materials, it ranges from 10 to 30. For organic soil materials, the E_r has been reported to range from 37 to 82 (Parsekian *et al*., 2012).

The velocity of propagation and the dielectric permittivity used in any investigation represent an averaged value for the entire depth of interest. These values are a composite of all layers profiled. Typically, each layer profiled will have a different *v* and E_r. At the time of this investigation, four major structural layers were observed in the cranberry beds: snow, sand, organic, and glacial drift. Each varied spatially in thicknesses and physico-chemical properties. This variability affects the accuracy of soil-depth measurements. Because of its highly variable thickness, conducting GPR surveys in the absence of a snow layer is recommended.

The most accurate method to convert the time-scale into a depth-scale, is to measure the depth to a known subsurface interface or feature that appears on a radar record. Based on a cored depth of 3.44 m and a two-way travel time of 133 ns to the organic/mineral soil interface, the estimated *v* and E_r were 0.0517 m/ns and 33.6 respectively. For saturated organic soil materials, this seemingly rapid *v* and low E_r were attributed to the relatively thick column of snow (52 cm) sand (62 cm), compared with the column of organic soil materials (182 cm) at the observation point.

Study Sites:
Ground-penetrating radar surveys were completed across the *Edgewood Cranberry Beds* (41.8774 ^{o} N latitude, 70.7274 ^{o} W Longitude) in Plymouth County, Massachusetts. Figure 2 is a soil map of this general area 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 soil materials. The Freetown soil series is a member of the dysic, mesic Typic Haplosaprists family. The very poorly drained Swansea soils formed in 40 to 130 centimeters of organic soil material over sandy mineral sediments. The Swansea soil series is a member of the sandy or

[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 [3/24/2015].

sandy-skeletal, mixed, dysic, mesic Terric Haplosaprists family. Both soils are considered to be highly suited to very deep penetration with GPR.

Cranberry beds have surface layers of sandy fill-materials that are added to the original surface as a management practice. Typically, in beds that have been in production for several decades, the surface layer consists of thick, alternating layers of sand and organic materials (Jim Turenne, personal communication: http://nesoil.com/muds/cransoil.htm). At the study site, the thickness of the sandy, human-transported materials was exceptionally thick (> 2 feet) and exceeded the phase qualifications for both soil series.

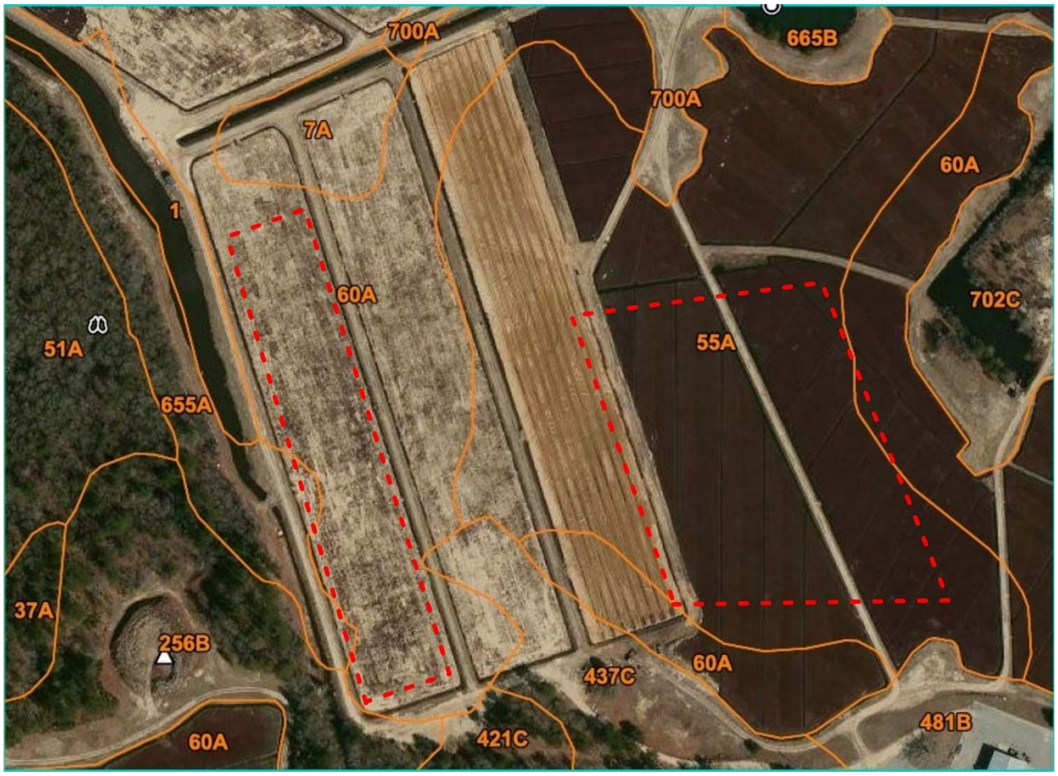

Figure 2. This soil map, which shows the cranberry beds that were surveyed with GPR (enclosed by red-colored, segmented lines), is from the Web Soil Survey.

Survey Procedures:
Multiple GPR traverses were completed across the cranberry beds by pulling the 120 MHz antenna along the ground surface. Each radar traverse was stored as a separate file. The GPS option was used with the SIR-3000 system.

Results:
Figure 3 is a representative two-dimensional (2D) radar record from the *Edgewood Cranberry Beds*. On this radar record, all scales are expressed in meters. Reflections from subsurface interfaces produce dark bands. Each interface is represented by a series of dark band that correspond to signal peaks (both positive and negative polarity peaks). These bands are separated by narrow white lines representing the zero-crossing between the polarity peaks. Typically, if two subsurface layers are not too closely spaced and their interface reflections are not superimposed, the interface will consist pf either two or three dark bands. For two closely-spaced interfaces to be resolved with a given antenna, they must be separated by a distance of at least ½ the propagated wavelength.

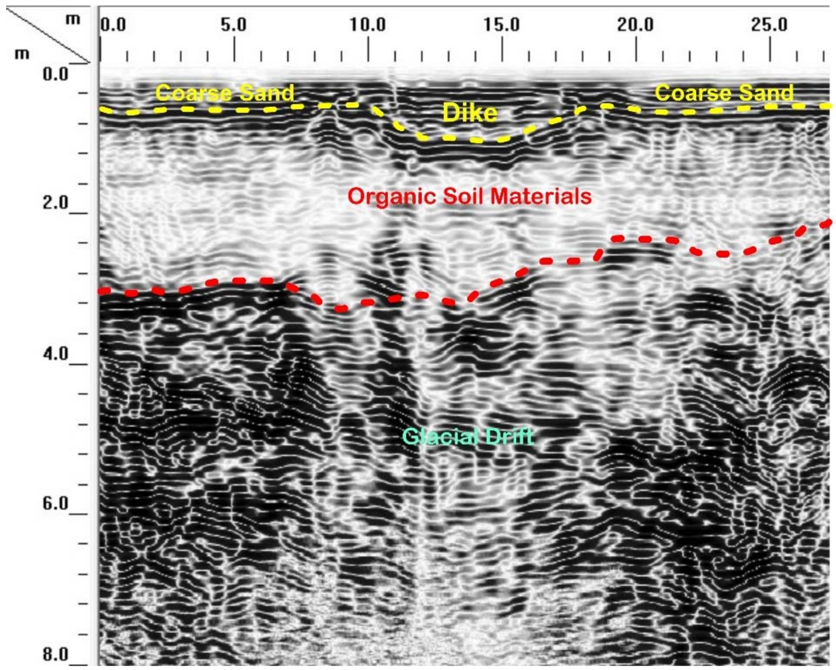

Figure 3. The inferred depth and thickness of sand layers and organic soil materials has been identified by a yellow- and red-colored, segmented lines on this 2D radar record from the Edgewood Cranberry Beds.

In Figure 3, a yellow-colored, segmented line has been used to emphasize the estimated interface separating the layers of coarse sand from the underlying organic soil materials. These materials have strongly contrasting dielectric properties and produce high amplitude reflections (black colored in Figure 3). On the beds that were surveyed with GPR, the sand layers are greater than 60 cm thick. On the radar record shown in Figure 3, the additional volume and weight of the sand from a constructed dike has depressed the sand into the underlying layers of organic soil materials. Because of the relative (relative to the organic material) higher velocity of signal propagation thru the over-thicken sands deposited in the dike, the depth to the underlying organic/mineral soil interface appears to bow downwards to greater depths beneath the dike.

Also shown on Figure 3, a red-colored, segmented line has been used to highlight the interpreted organic/mineral soil interface. This interface is segmented and not easily traced across the radar record. It is therefore more “interpretive”. Due to the non-uniqueness of reflections appearing on radar records, errors may occur in interpreting the source of buried layers and anomalies. Within the organic soil materials, weak, low-amplitude reflections suggest layering, which is probably the result of differences in the degree of decomposition and water content.

Figure 4 is a 3D image of a geo-referenced radar traverse line. In this image a different color table and color transform has been used. The depth scale is about 8 m. The sand /organic layer and the organic/mineral layer interfaces are evident and traceable across the entire length of the radar traverse. Variation in the expression of these interfaces is attributed to spatial and vertical variations in the contrast and abruptness of dielectric properties.

Figure 5 shows two Google Earth images of the reconstructed cranberry beds that were surveyed in this field investigation. The upper image is from 1995; the lower image is from 2014. Differences in the location and geometry of the cranberry beds, dikes, and drainage channels are evident.

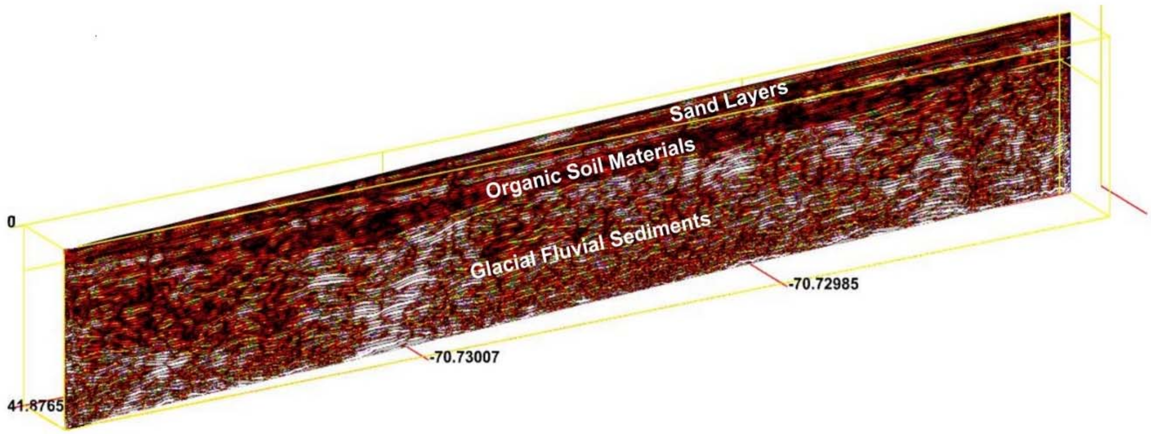

Figure 4. A 3D image of a georeferenced radar traverse conducted across a relatively shallow cranberry bed.

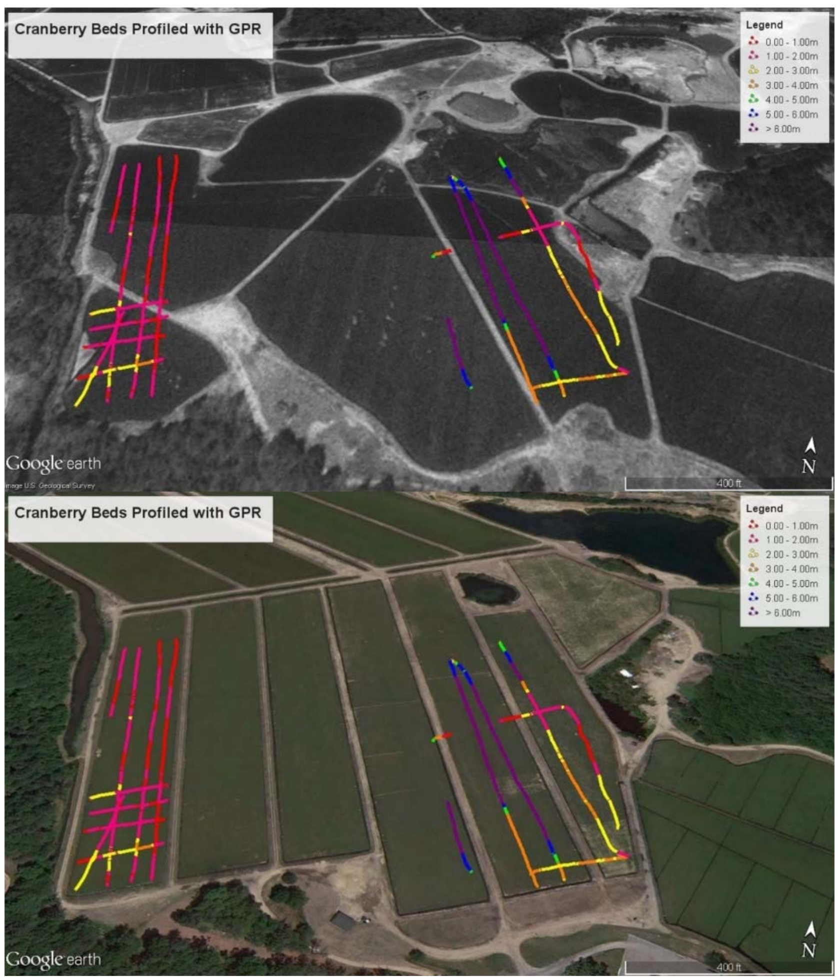

Figure 5. These Google Earth images show the interpreted depth to the organic/mineral soil interface across different reconstructed cranberry beds. The top image shows the layout of the cranberry beds in 1995, the lower image is from 2014.

Using the interactive module of RADAN 7.0, the depth to the organic/mineral soil interface was semi-automatically picked and mapped using the *EZ Tracker* option. The use of single point (simple point-and-click) methods for identifying subsurface layers is also available in RADAN 7.0 and was reviewed. The picked depths can be saved as a *csv* file and exported to an excel spreadsheet for statistical analysis. If GPS coordinate data are recorded, georeferenced data can be exported as a *KML* file. The *KML* files can be used to display data in Google Earth and Google Maps. Figure 5 shows the picked depth to organic/mineral soil layer displayed on historical Google Earth imagery. Seven, one-meter depth classes are shown in each image using the same color ramp.

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