United States Department of Agriculture	**Natural Resources Conservation Service**	**11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: Soils – Geophysical Field Assistance **Date:** 21 August 2008

To: Mike Watson
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Purpose:
The purpose of this visit was to work with Don Keirstead, deliver an EM31 meter with field computer for his use, and provide advanced and progressive field training on the operation of the SIR-3000 ground-penetrating radar (GPR) unit with the latest global positioning system (GPS) option and advanced programs available on RADAN processing software. In addition, a meeting was held with University of New Hampshire professors who are using electromagnetic induction (EMI) to monitor ecological sites on tidal marshes.

Participants:
Dave Burdick, Research Associate Professor of Marine Ecology and Restoration, University of New Hampshire, Durham, NH
Brian Jones, Application Specialist, Geophysical Survey Systems, Inc., Salem, NH
Matt Davis, Associate Professor of Hydrogeology, Department of Earth Sciences, University of New Hampshire, Durham, NH
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Karen Dudley, Resource Soil Scientist, USDA-NRCS, Concord, NH
Kimberly McCracken, State Soil Scientist, USDA-NRCS, Durham, NH
Greg Moore, Research Professor, Jackson Estuarine Laboratory, University of New Hampshire, Durham, NH

Activities:
All activities were completed during the period of 7 and 8 August 2007.

Summary:

1. This brief visit allowed Don Keirstead and me to conduct both electromagnetic and ground-penetrating radar field work together and discuss the operation of these tools and the interpretations of collected data. I provided Don with an update on new advances in GPR technology, especially the integration of GPR with global positioning systems (GPS) and the use of the interactive module of RADAN software.

2. Electromagnetic induction (EMI) surveys were completed of the area immediately downslope from an animal waste holding facility located on the University of New Hampshire's Organic Dairy Farm, in Lee, N.H. Results of these surveys indicate a potential plume of contaminates emanating from the waste-holding facility and trending in a southwestern direction towards a pond.

3. During field work at UNH Organic Dairy Farm, comparative EMI surveys were completed with the EM31and EM38 meters developed by Geonics Limited (Mississauga, Ontario) and the Profiler 400-EMP sensor developed by Geophysical Survey Systems, Inc. (Salem, NH). The Profiler 400-EMP is a competitively priced sensor with several incentives. It is lighter weight, more ergonomic, than the EM38 and the EM31 meters. In addition, it has a built in GPS system and effectively merges GPS and EMI data, without the need for additional software. This data can be quickly and easily downloaded as a comma delimited file into Excel for storage, manipulation, and importation into GIS. It is therefore considered a most attractive EMI sensor for use in NRCS. However, the collected EC_a values were anomalously high and atypical for uncontaminated areas of coarse textured Hinckley soils. Therefore, this sensor, with its present calibration, can not be recommended for use by NRCS in soil and agronomic applications at this time.

4. On Friday morning a meeting was held with faculty from the University of New Hampshire. Drs Dave Burdick and Greg Moore have been exploring the use of EMI to investigate potential ecological communities on tidal marshes

with Don Keirstead. This is a very promising and innovative research endeavor, for which Don Keirstead should be credited with initiating and organizing. During this meeting, discussions focused on general EMI theories, and the field techniques used and the interpretations made during the investigations of tidal marshes.

5. It was my intent to loan one of the National Soil Survey Center's EM31 meters with Allegro field computer to Don Keirstead for his work on agricultural waste systems in New Hampshire. Unfortunately the measurements displayed on the EM31 meter and Allegro field computer's screens were not the same as those recorded by the instrument. The meter needs to be returned to its manufacturer for recalibration and possible repairs.

It was my pleasure to work once again in New Hampshire and with Don Keirstead.

With kind regards,

James A. Doolittle
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cc:
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Background into Animal Waste Holding Structures:
Don Keirstead is interested in evaluating the effectiveness of EMI to detect contaminant plumes emanating from waste-holding facilities in New Hampshire. While NRCS provides technical assistance for their construction, the agency seldom monitors the effectiveness of installed animal-waste holding structures, which are designed to contain and limit seepage of contaminants. The relatively coarse-textured soils of New Hampshire pose a severe risk for potential seepage of contaminants from improperly installed or operated waste-holding facilities.

Animal waste-holding facilities are economical means of handling large quantities of wastes from confined livestock operations. Studies suggest that these structures self-seal within two to twelve months of operation (Swell et al., 1975; Miller et al., 1985). In general, the bulk perimeter area of most structures do self-seal to some extent. However, in some structures, a few areas do not seal resulting in the discharge of contaminants. Brune and Doolittle (1990) describe these non-sealing events as being sporadic and unpredictable.

Electromagnetic induction (EMI) is a noninvasive geophysical tool that has been used to assess seepage and the structural integrity of animal waste holding facilities. Electromagnetic induction has been used to investigate the migration of contaminants from animal wastes (Eigenberg et al., 1998; Drommerhausen, et al., 1995; Ranjan and Karthigesu, 1995; Radcliffe et al., 1994; and Brune and Doolittle, 1990). Typically soils affected by animal wastes have higher EC_a than soils that are unaffected by these contaminants. Electromagnetic induction has been used to infer the relative concentrations, extent, and movement of contaminants from waste-holding facilities. While EMI does not provide a direct measurement of specific ions or compounds, EC_a has been correlated with concentrations of chloride, ammonia, and nitrate nitrogen in soils (Eigenberg et al., 1998; Ranjan and Karthigesu, 1995; Brune and Doolittle, 1990).

Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. Electromagnetic induction can provide in a relatively short time, the large number of observations required to detect contaminant plumes emanating from waste-storage facilities. Maps prepared from properly interpreted EMI data provide the basis for assessing site conditions and locating sampling or monitoring sites.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity (EC_a) of earthen materials. Apparent conductivity is the weighted, average conductivity for a column of earthen materials (Greenhouse and Slaine, 1983). Variations in EC_a are produced by changes in the electrical conductivity of earthen materials. Electrical conductivity is influenced by the volumetric water content, type and concentration of ions in solution, temperature and phase of the soil water, and amount and type of clays in the soil matrix (McNeill, 1980a). In general, the EC_a of earthen materials will increase with increases in soluble salt, water, and/or clay contents (Kachanoski et al., 1988; Rhoades et al., 1976). In any soil-landscape, variations in one or more of these factors may dominate the EMI response.

Electromagnetic induction measures vertical and lateral variations in EC_a. Values of EC_a are seldom diagnostic in themselves. However, lateral and vertical variations in EC_a can be used to infer changes in soils and soil properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used.

Equipment:
The EM31 and EM38 meters were used in this study. Both meters are manufactured by Geonics Limited (Mississauga, Ontario).[1] Both meters require only one person to operate. No ground contact is required with either meter. Lateral resolution is approximately equal to the meter's intercoil spacing. McNeill (1980b) has described the principles of operation for the EM31 meter. The EM31meter has a 3.66-m (12-ft) intercoil spacing and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM 31 meter provides theoretical penetration depths of about 6-m (19-ft) in the vertical dipole orientation (McNeill, 1980b).

The EM38 meter weighs about 1.4 kg (3.1 lbs). The EM38 meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, it has an effective penetration depth of about 1.5 m in the vertical dipole orientation (Geonics Limited, 1998).

The Geonics DAS70 Data Acquisition System is used with the EMI meters to record and store both apparent conductivity (EC_a) and position data.[1] The acquisition system consists of an EMI meter, an Allegro CE field computer (Juniper Systems, North Logan, UT), and Trimble AG114 GPS receiver (with antenna, and accessories that are fitted into a backpack; see Figure 1) (Trimble Navigation limited, Sunnyvale, California).[1]

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

Brian Jones of Geophysical Survey Systems, Inc. (Salem, NH) demonstrated and operated a Profiler EMP-400 multifrequency conductivity meter (see Figure 2). The Profiler can be configured to simultaneously measure up to 3 frequencies between 1000 Hz and 16,000 Hz, in either the vertical or horizontal dipole mode. All survey acquisition parameters, GPS coordinates and EMI data are stored on internal memory. Files are structured in Excel spreadsheet format (ASCII text file) for simple downloading to a PC for presentation in GIS.

To help summarize the results of the EMI surveys, SURFER for Windows, version 8.0 (Golden Software, Inc., Golden, CO), was used to model the EC_a data.[1]

Figure 1. Don Keirstead operates and EM31 meter that is attached to an Allegro field computer and Trimble AG114 GPS receiver along the embankment to a waste-holding facility at the University of New Hampshire Organic Dairy Farm.

Figure 2. Brian Jones of GSSI operates a Profiler EMP-400 sensor with a Trimble AG332 GPS receiver at the University of New Hampshire Organic Dairy Farm.

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[2] 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) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) discusses the use and operation of GPR. Antennas with a center frequency of 200 and 400 MHz were used in this study.

Radar records contained in this report were processed with the RADAN for Windows (version 6.5) software program (GSSI, Salem, NH). Minimal processing was required, which included: setting the initial pulse to time zero, header editing, color transformation and range gain adjustments. In this study, the scanning rate was set to 32 scans/sec on the GPR control unit. As each scan of the radar can now be georeferenced, the integration of GPS with GPR results in incredibly large data sets. The SIR-3000 system and the RADAN (version 6.5) software provide a setup for the simultaneous use of a GPS receiver and serial data recorder (SDR). With this setup, each scan on radar records can be georeferenced (position/time matched). Using the *Interactive Interpretation Module* of the RADAN processing software, depths to the contrasting layers can be quickly, automatically, and reasonably accurately picked and outputted to a worksheet (X, Y, Z format; containing latitude, longitude, depths to subsurface layer or feature, and other useful data).

Study Site:
The University of New Hampshire Organic Dairy Farm is located on Lee Hook Road in Lee, NH. This farm serves as a research center and emphasizes methods that encourage natural biological cycles and controls. The animal-waste holding facility and study site are located in an area of Hinckley loamy sand on 8 to 15 % slopes (HaC) (see Figure 3).

The very deep, excessively drained Hinckley (sandy-skeletal, mixed, mesic Typic Udorthents) soils formed in water-sorted sands and gravels. The low clay, soluble salt and moisture contents of Hinckley soil results in characteristically very low EC_a.

Figure 3. Location of animal waste-holding facility within the University of New Hampshire's Organic Dairy Farm.

Results:
<u>EMI Survey of *Animal Waste Holding Structure*:</u>
Table 1 shows the basic statistics for the EMI surveys that were completed with three different EMI sensors at the study site. While values of EC_a are seldom diagnostic in themselves, in any given soil, a distinct range of conductivity should be measured. This range will vary with spatial and temporal differences in soil properties (e.g., clay and moisture contents), but is

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restricted by observed soil series criteria. Hinckley soil is coarse textured and very electrically resistive. The high values of EC_a measured in higher-lying and presumably unaffected areas of this soil with the Profiler 400-EMP were considered anomalously high and uncharacteristic for areas of Hinckley soils (see Table 1).

Table 1.
Basic statistics for the EMI surveys conducted at the UNH Organic Dairy Farm with three different EMI sensors.

	Profiler 400-EMP	Profiler 400-EMP	EM31 meter	EM38 meter
	HDO	VDO	VDO	VDO
Number	659	1581	807	827
Minimum	-31.40	-37.64	-2.70	-68.50
25%-tile	-3.58	35.33	-0.70	2.00
75%-tile	15.03	111.651	5.40	6.13
Maximum	71.37	330.68	20.50	34.13
Mean	19.99	76.05	2.62	3.87
Standard Deviation	15.75	47.51	3.66	5.28

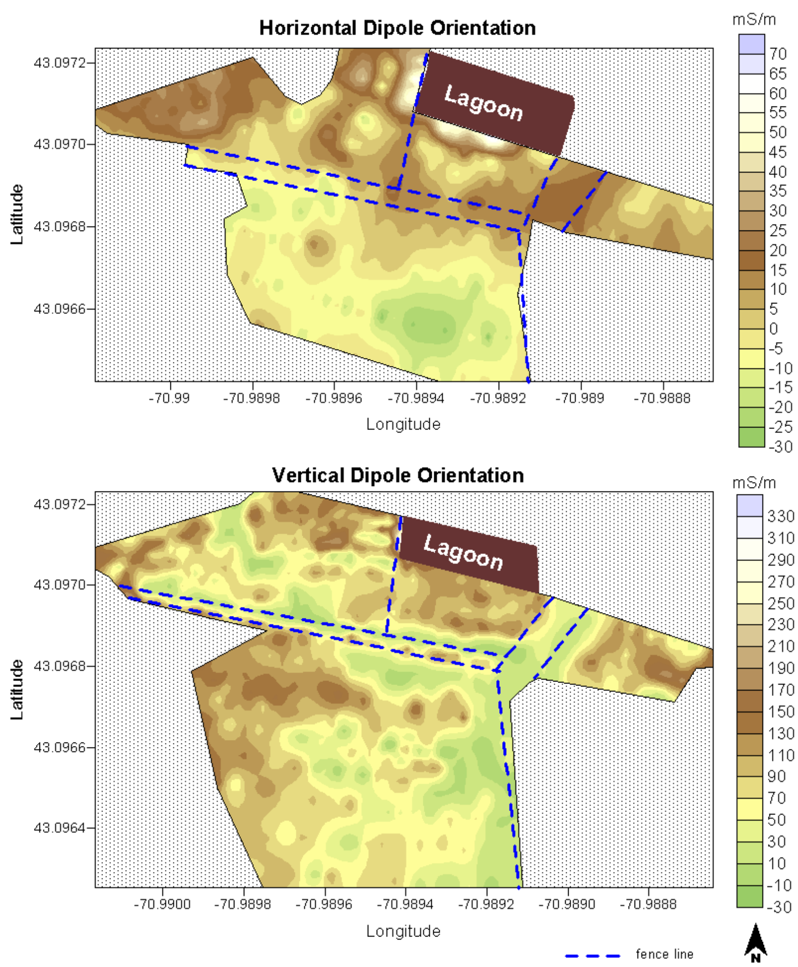

Figure 4. Plot of EC_a *data collected with the Profiler 400 at the UNH Organic Dairy Farm site.*

The Profiler 400-EMP is a competitively priced EMI sensor. It is lighter weight, more ergonomic, than the EM38 and the EM31 meters. It has a built in GPS system and effectively merges GPS and EMI data, without the need for additional software. This data can be quickly and easily downloaded as a comma delimited file into Excel for storage, manipulation, and importation into GIS. It is therefore considered a most attractive EMI sensor for use in

NRCS. However, some recorded values are considered anomalously high and atypical for uncontaminated areas of coarse textured soils (as Profiler 400-EMP has been developed for use in the Geotechnical arena where clear detection of subsurface artifacts is needed, a higher setting may be intentional). As the EC_a measured in uncontaminated areas of Hinckley soils is considered uncharacteristically high, this sensor can not be recommended for use by NRCS in soil and agronomic applications at this time.

Figures 4 and 5 show plots of EC_a data collected with the Profiler 400-ESP and EM31 meter respectively. Areas in the far western and eastern portions of the study area represent presumably uncontaminated areas of Hinckley soils. An included depression with wetter (higher conductivity) soils is located in the west central portion of each plot. Contaminants from the waste-holding facility are presumed to flow into this lower-lying depression, which adjoins a small pond (see Figure 3). The Profiler 400-ESP (vertical dipole orientation) and the EM31 meter both captured the higher conductivity of this lower lying area and a contaminant plume that emanates from the waste-holding facility and flows towards this feature. However, the general pattern and continuity of the supposed contaminate plume is better captured in the data collected with the EM31 meter.

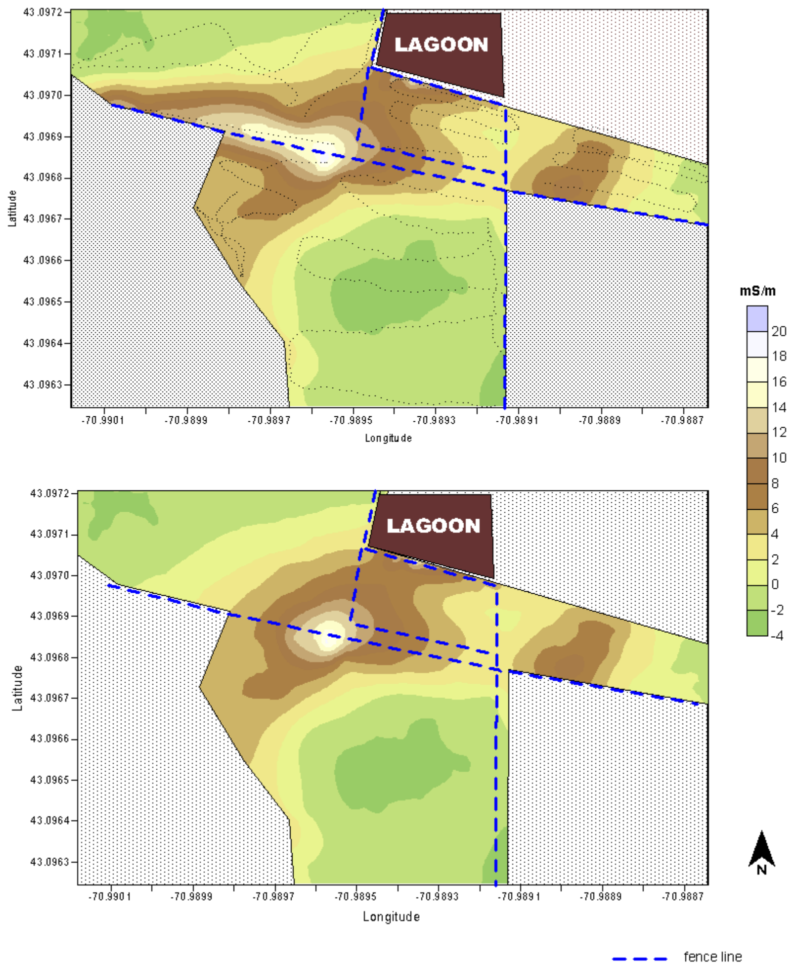

Figure 5. Plot of EC_a *data collected with the EM31 meter operated in the vertical dipole orientation at the UNH Organic Dairy Farm site.*

Like many waste-holding facilities, the one that was surveyed was adjacent to farm structures, and the site was littered by metallic fence lines and farm equipment, which produced anomalous EMI responses when approached to near with the EMI sensors. In the lower plot in Figure 5, those measurement points collected with the EM31 meter, which were too near a metallic fence line, have been removed. The resulting plot of data is considered to be a reasonably accurate portrayal of a contaminant seepage pattern emanating from the waste-holding facility.

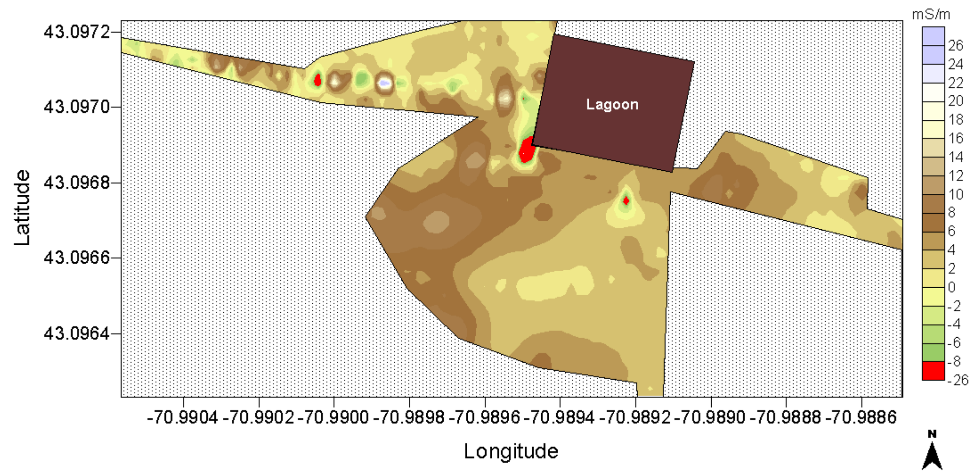

Figure 6. Plot of EC_a *data collected with the EM38 meter operated in the vertical dipole orientation at the UNH Organic Dairy Farm site.*

Figure 6 shows spatial EC_a patterns across the survey site as collected with the EM38 meter in the vertical dipole orientation. These spatial patterns are similar to the ones from the data collected with the EM31 meter. Compared with data collected with the EM31 meter, EC_a values are higher in the EM38 meter's data set. This reflects the shallower observation depth of the EM38 meter and is believed to reflect the presence of organic materials and slightly higher clay and moisture contents in surface layers

<u>GPR Survey:</u>

A relatively new development in ground-penetrating radar (GPR) technology could significantly change the way soil scientists collect, interpret, and store some soil data. A new mapping module included in GPR processing software allows the georeferencing of GPR data collected with a suitable global positioning system (GPS) receiver.

During the 1990s, it was realized that GPR data needed to be more fully integrated with available soil data and maps. A logical trend was to integrate GPR with GPS. As noted by Rial et al. (2005), under favorable conditions GPR/GPS integration allows for the accurate positioning of radar data and its importation into geographical information systems (GIS). However, this integration would await developments in both technologies. These developments have now occurred. New mapping module included in GPR processing software provides the capability of not only "visually georeferencing GPR data" (GSSI, 2008), but "widening the scope of GPR surveys" (Gustafsson, 2007).

Figure 7 provides an example of a radar record, which has been georeferenced and displayed as a three-dimensional (3D) pseudo-image. With the new options available in RADAN and entire radar records can be shown in 3D images. In the pass, because of the size of radar data files, the radar operator could only show portions of longer radar records. The radar record shown in Figure 6 was obtained in an area of Hinckley soils at the University of New Hampshire's Organic Dairy Farm. The location of this traverse line appears on a Goggle Earth image that is shown in Figure 8. In Figure 7, a major subsurface channel or depression, which is filled with stratified layers of sand and gravel, is evident at "A". Weaken reflective signals at "B" suggest an area of greater rates of signal attenuation, which, at this site, is attributed to potential contamination from animal wastes.

Also shown in Figure 8, is a color-coded radar traverse line located near the base of the embankment to the animal waste-holding facility. Three monitoring wells have been installed along this line. Based on information on the thickness of sands and gravel and the depth to a finer-textured layer, the radar record was depth scaled. Along this line, the thickness of sands and gravel deposits are mostly (84%) greater than 2 m and the soils are properly classified as Hinckley. However, the depth to a finer-textured subsurface layer is within a depth of 2 m (in Figure 8, the sections that are colored white) along 16 % of this traverse line. Here the soils are not Hinckley, as they have marine clays within depths of 2 m.

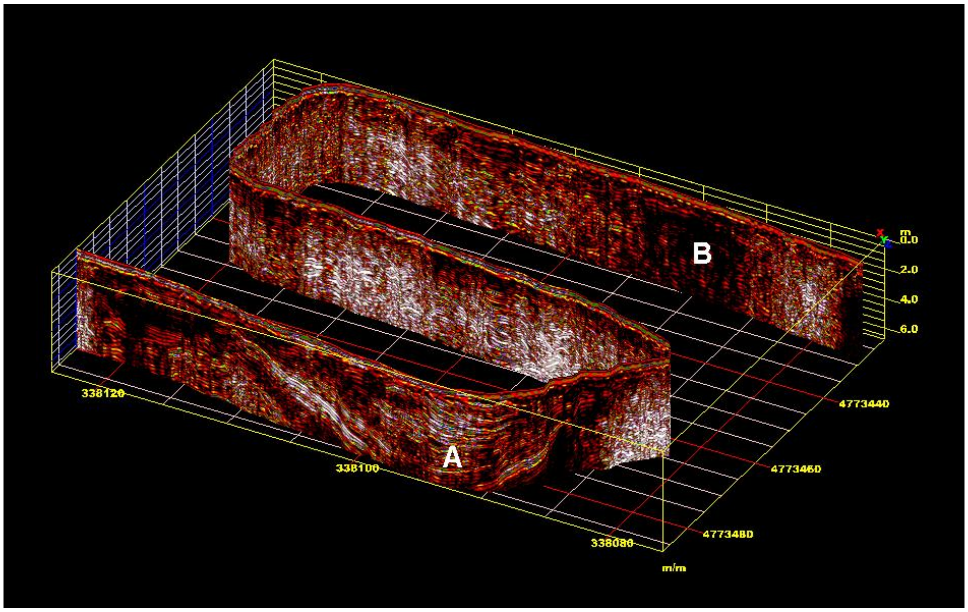

Figure 7. With the new GPS option, the entire length of a radar traverse can be graphically displayed in a georeferenced three-dimensional pseudo-image.

Figure 8. This Goggle Map image of the UNH Organic Dairy Farm complex shows the locations of two GPR traverse lines.

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