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

Subject: SOI -- Ground-Penetrating Radar Assistance **Date:** May 27, 2005

To: Theresa M. Chadwick
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PURPOSE:
Two geophysical tools, ground-penetrating radar (GPR) and electromagnetic induction (EMI), were used to support soil, archaeological, environmental and engineering site assessments in New Hampshire.

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ACTIVITIES:
All field activities were completed during the period of 16 to 18 May 2005.

Summary:

1. Ground-penetrating radar was used to map variations in the depth to densic materials in an area of Paxton soil. Depths to the densic material are relatively invariable and range from 51 to 72 cm. This contact appears to be laterally continuous and closely parallels the soil surface. On radar records, the contact varies spatially in amplitude suggesting differences in soil properties. Variations in soil moisture, grain size, or bulk density are the principal soil properties believed to be responsible for these amplitude differences.

2. The City of Portsmouth would like to restore a former inlet and wharfs as an attraction and marina in its historic downtown area. Thick deposits of fill blanket and hide these former features. In general, the effectiveness of GPR is seriously impaired by the conductive nature of the fill materials and the use of this tool offers, at best, ambiguous interpretations for this particular application at this site.

3. Electromagnetic induction was used to assess seepage and the structural integrity of two precast, animal-waste holding facilities. Results suggest that the two structures effectively contain animal

wastes. However, seepage or discharge from a former waste pit is believed to be responsible for an extensive pattern of anomalously high ground conductivity.

4. Both EMI and GPR were used to investigate an earthen dam located on Furnace Brook near the town of New Ipswich in Hillsborough County. Ground-penetrating radar was used along the base of the embankment to characterize not only the depth to parent rock, but the number and location of fractures within the underlying parent rock. Electromagnetic induction outlined the general location of a shallow ledge at the base of the dam's embankment. However, the embankment was too high for the EM31 meter to effectively profile the extent of the rock ledge beneath the structure. The embankment materials produced low (< 5 mS/m) and extremely invariable EC_a. As a consequence, EMI provided little information of the embankment.

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

With kind regards,

James A. Doolittle
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MATERIALS AND METHODS

Equipment:

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[1] . The use and operation of GPR are discussed by Daniels (2004). The SIR System-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 System-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, this system requires two people to operate. The 70, 200 and 400 MHz antennas were used during this visit.

The radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc, 2003).[1] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance normalization, signal stacking, filtration and range gain adjustments.

An EM31 meter was used in agricultural waste and dam site investigations. Geonics Limited (Mississauga, Ontario) manufactures this meter.[1] McNeill (1980b) has described the principles of operation of the EM31 meter. The EM31 meter has a 3.66-m intercoil spacing and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM31 meter provides theoretical penetration depths of about 3-m and 6-m in the horizontal and vertical dipole orientations, respectively (McNeill, 1980b). No ground contact is required with this meter. Lateral resolution is approximately equal to the intercoil spacing.

The Geonics DAS70 Data Acquisition System (Geonics Limited, Mississauga, Ontario) was used with the EM31 meter to record and store both apparent conductivity (EC_a) and GPS data.[1] The acquisition system consists of the EM31 meter, an Allegro field computer (Juniper Systems, Logan, Utah), and a Garmin Global Positioning System Map 76 receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack) (Garmin International, Inc., Olathe, Kansas).[1] With the acquisition system, the EM31 meter is keypad operated and measurements can either be automatically or manually triggered.

DENSIC MATERIAL STUDY:

Most soils in New Hampshire form in glacial till. Many of these soils are underlain by a layer of compacted, less permeable till of varying thicknesses. The occurrence of relatively permeable soil materials overlying less permeable layers promotes the development of perched water tables and influences the flow of water. Water moves laterally downslope above this confining layer (Hutchinson and Moore, 2000). The underlying compacted till is considered *densic materials* (Soil Survey Staff, 2003). Densic materials lack evidence of pedogenesis and have no thickness requirement (Gourley, 1998). Densic materials commonly are structureless (massive) or have platy or prismatic structure that result from vertical compression and lateral shear stress exerted by glacial ice (Gourley, 1998). Densic materials have a firm or very firm consistence and low to very low saturated hydraulic conductivity (Thompson, 1998). Provided that the interface restricts the penetration of roots, the contact is considered a *densic contact* (Soil Survey Staff, 2003).

Study Site:

The study site is located on the north flank of an oval shaped hill (drumlin) known as Hicks Hill. Hicks Hill is located to the immediate north of the intersection of Madbury and Knox Marsh Roads in the town of Madbury, Strafford County. Figure 1 is an aerial photograph of Hicks Hill showing the soil boundary

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

lines, the soil map unit symbols, and the locations of the GPR traverse lines. Soils are mapped as Paxton very stony fine sandy loam, 3 to 8 percent slopes (map unit (M.U.) PdB) and Paxton very stony fine sandy loam, 15 to 25 percent slopes (M.U. PdD). The very deep to bedrock, moderately deep to densic contact, well drained Paxton soil formed in lodgment till. Saturated hydraulic conductivity is moderately high to high in the solum and low to moderately high in the substratum. Paxton is a member of the coarse-loamy, mixed, active, mesic Oxyaquic Dystrudepts family.

Methods and Results

Three traverse line of varying lengths (12-, 27-, 30-m) were laid out across the north flank of Hicks Hill. Along each line, reference flags were inserted in the ground at intervals of 3-m. Radar surveys were completed by towing the 200 MHz antenna along these traverse lines. As the antenna was towed pass each reference point, a mark was impressed on the radar record.

On radar records, the depth to the Cd horizon (densic materials) was interpreted at each reference point. Depths to the densic material were comparatively invariable and the contact closely paralleled the soil surface. Based on 26 observations, the depth to Cd horizon averaged 62 cm with a range of 51 to 72 cm. These observations are consistent with the depths to the Cd horizon that was observed in four shallow excavations located near the traverse lines.

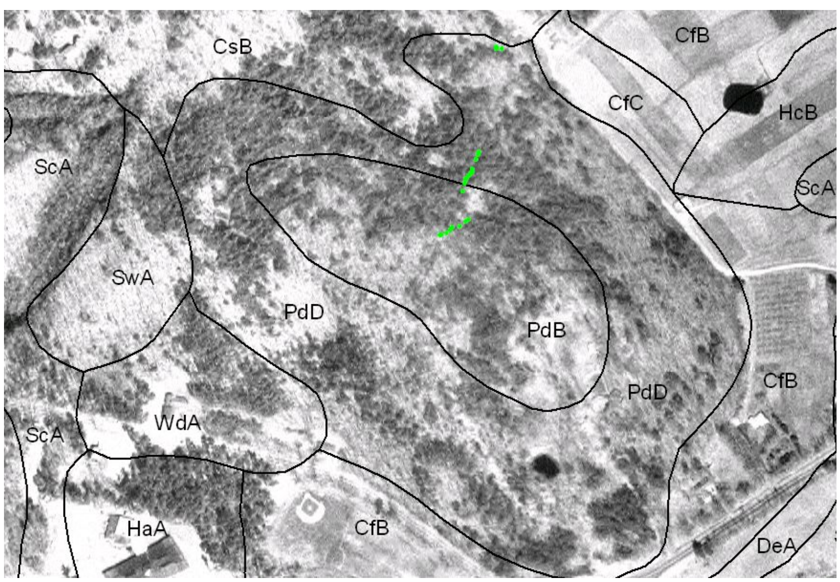

Figure 1. Aerial photograph of Hicks Hill showing the soil map unit boundary lines, soil map unit symbols, and locations of GPR traverse lines (green dots).

Figure 2 is a terrain corrected radar record from an area of Paxton very stony fine sandy loam, 15 to 25 percent slopes. This traverse line was located near a soil pit that was excavated along the base of the north flank of Hicks Hill. In this relatively low clay content soil, the depth of penetration is greater than 5 m. This record was collected with a 200 MHz antenna. At the time of this investigation, the densic contact was difficult to discern on radar records obtained with the 400 MHz antenna. The depth scale shown in Figure 2 is based on the two-way travel time to a known object buried at a depth of 64 cm.

In Figure 2, a white line has been used to highlight the interpreted depth to the Cd horizon. This interface is laterally continuous and closely parallels the soil surface. The interface varies in amplitude suggesting variations in soil properties. High amplitude reflections (white, blue, yellow, and green colored) suggest abrupt and contrasting soil properties. Low amplitude reflections (red and black colored) suggest similar properties or more gradational boundaries. Variations in soil moisture and/or bulk density are the principal soil properties responsible for these reflections. The clarity of this contact will vary with the contrast in soil moisture across the interface. The greater the contrast in soil moisture across this interface, the greater the amplitude of the reflected signal and the more distinguishable will be this contact.

In Figure 2, the material underlying the densic contact appears to consist of segmented planar reflectors. This internal geometry suggests water reworked till. In general, till lacks planar features and is characterized by a large number of chaotic point reflectors. Point reflectors evident on the radar record represent rock fragments. In places, these reflectors are superimposed upon and obscure the upper boundary of the densic material.

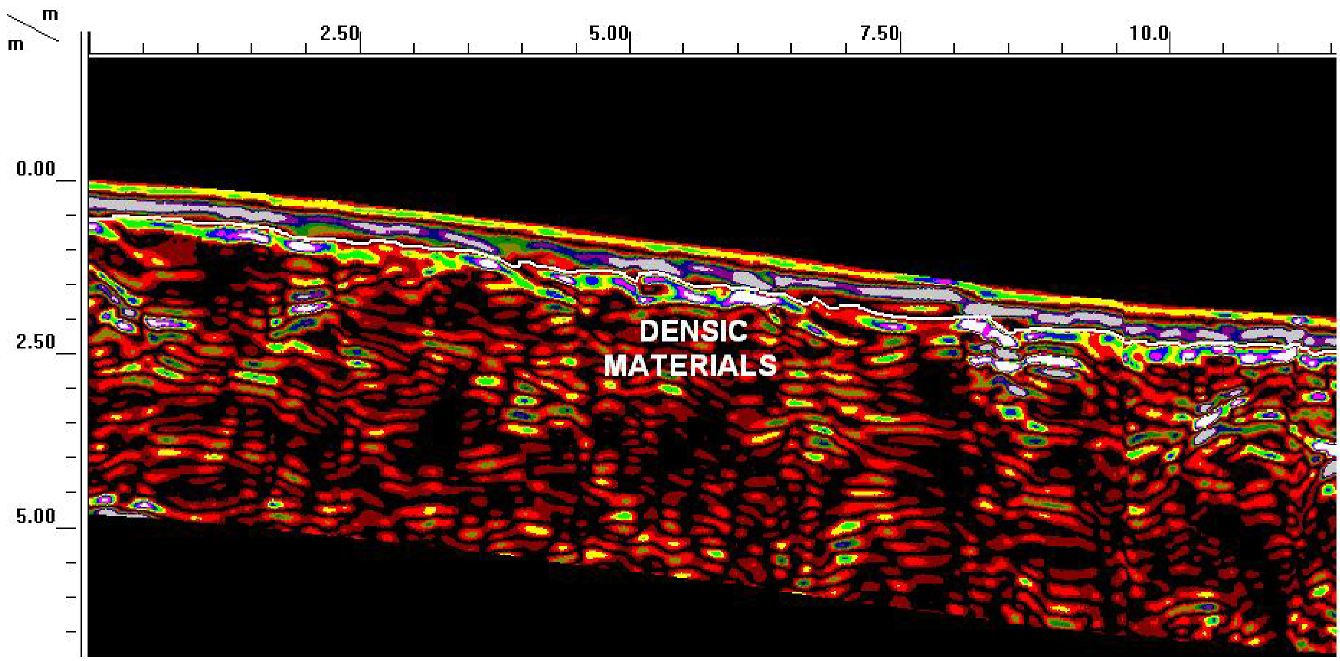

Figure 2. The upper boundary of the Cd horizon has been highlighted in this radar record from an area of Paxton soil.

GPR ARCHAEOLOGICAL SURVEY:

The City of Portsmouth would like to restore a former inlet and wharfs as an attraction and marina in its historic downtown area. The former inlet was located beneath the present-day Prescott Park. Prescott Park is located along the tidally influenced Piscataqua River, between Marcy and Mechanic Streets. The park is located directly across the Piscataqua River from the Portsmouth Naval Base. Thick deposits (>5 m) of fill and dredged materials blanket and hide the former inlet and it is not certain whether the pilings from the wharfs continue to exist. A reconnaissance survey was conducted with GPR in order to assess the feasibility of using this tool to identify these deeply buried features. The reconnaissance survey consisted of one traverse line that crossed a grassed portion of Prescott Park. The radar traverse line was parallel with Marcy Avenue and about 45 m into the park. The 70 MHz antenna was used in this study.

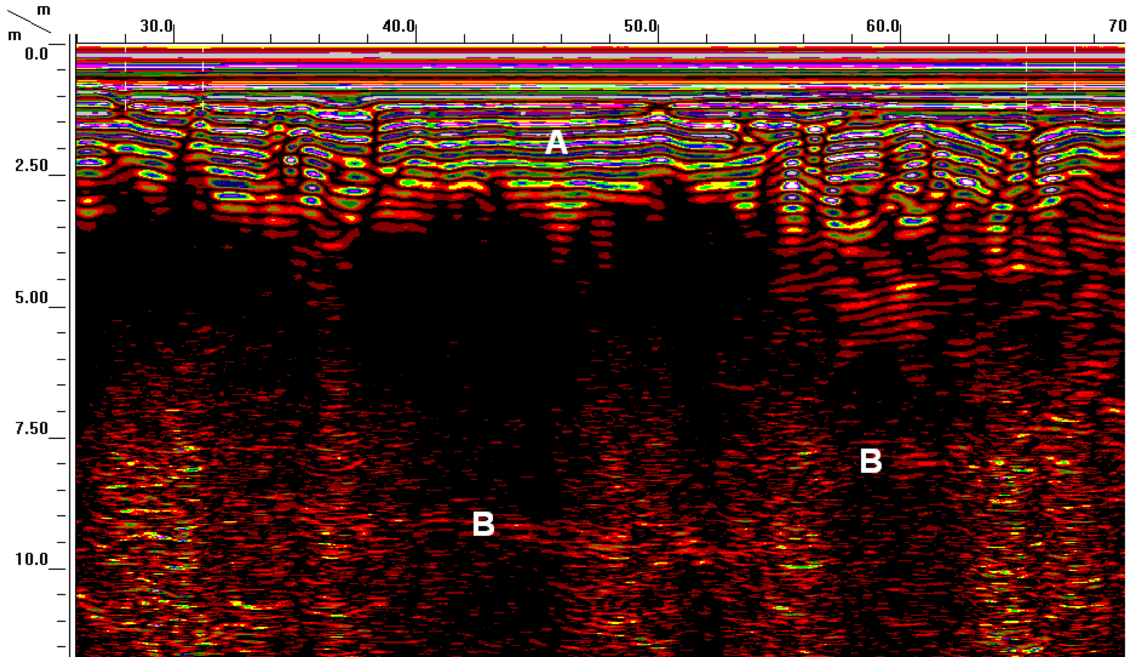

Figure 3. Radar record that was collected with the 70 MHz antenna in Prescott Park, Portsmouth, NH.

A portion of the radar record from Prescott Park is shown in Figure 3. The depth scale used in this figure has been approximated using a dielectric constant of 14. High rates of signal attenuation severely restricted the penetration depth of the 70 MHz antenna. In Figure 3, more favorable penetration depths are achieved in the 55 to 70 m portion than in the 26 to 55 m portion of the radar record. In the former portion of the radar record, a thicker sequence of stratified layers is evident. The differences in penetration depths along this radar record are most likely the result of dissimilar materials and/or variations in salt water intrusion. Within the upper 2 to 3 m of the fill material, the soil appears well stratified. Below a depth of about 4 to 5 m, the radar record is plagued with background noise. The occurrence of clays (marine sediments) and/or intrusion of salts into the deeper fill materials are believed responsible for the low signal-to-noise level and the lack of well expressed interfaces below depths of 5 m. A weakly expressed interface (see B in Figure 3) is evident in the lower part of the radar record.

No unambiguous indication of the wharf or the inlet is evident on the radar record. In general, the effectiveness of GPR is seriously impaired by the conductive nature of the fill materials and the use of this tool offers, at best, ambiguous interpretations for this particular application at this site. Though highly interpretive, it is possible to imagine the shape of an inlet that has been filled with more conductive fill materials spanning the 26 to 54 m section of this radar record with a base identified by layer B.

EMI SURVEY OF AN ANIMAL WASTE-HOLDING FACILITY:

Animal waste-holding facilities are an economical means of handling large quantities of wastes from confined livestock operations. Electromagnetic induction (EMI) is a noninvasive geophysical tool that has been used by USDA-NRCS to assess seepage and the structural integrity of its designed animal waste-holding facilities. 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 have provided engineers with the basis for assessing site conditions, planning further investigations, 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 depth-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). The EC_a of earthen materials increases with increased soluble salt, water, and/or clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

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.

Electromagnetic induction has been used to investigate the migration of contaminants from animal-waste sites (Eigenberg et al., 1998; Drommerhausen, et al., 1995; Ranjan and Karthigesu, 1995; Radcliffe et al., 1994; Brune and Doolittle, 1990; Siegrist and Hargett, 1989; and Stierman and Ruedisili, 1988). 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 associated with concentrations of chloride, ammonia, and nitrate-nitrogen in soils (Eigenberg et al., 1998; Ranjan and Karthigesu, 1995; Brune and Doolittle, 1990).

Figure 4. Aerial photograph of the Farm complex showing the soil map unit boundary lines and symbols.

Study Site:
The study site is located about 0.5 miles southeast of Merrill Corner in Rochester County. Two precast concrete structures handle the wastes from 130 milking cows and 100 heifers. Figure 4 is an aerial photograph of the farm complex showing soil boundary lines and pertinent soil map unit symbols. The

first waste storage structure that was surveyed (Site 1) is located on the extreme right (east) of the farm complex (in Figure 4, the building located under the "u" in SuB). The second waste storage structure that was surveyed (Site 2) is located on the extreme bottom (south) of the farm complex (in Figure 4, the southern-most structure located in map unit RgA). Soil map units delineated in the survey area include Charlton fine sandy loam, 3 to 8 percent slopes (M.U. CfB), Gloucester fine sandy loam, 3 to 8 percent slopes (M.U. GlB), Ridgebury fine sandy loam, 0 to 3 percent slopes (M.U. RgA), and Sutton very stony fine sandy loam, 0 to 8 percent slopes (M.U. SuB). These soils formed in till. Ridgebury soil is shallow to densic materials. The taxonomic classifications of these soils are listed in Table 1.

Table 1. Taxonomic classification of soils mapped within the Farm Complex

Series	Taxonomic Classification
Charlton	Coarse-loamy, mixed, active, mesic Typic Dystrudepts
Gloucester	Sandy-skeletal, mixed, mesic Typic Dystrudepts
Ridgebury	Loamy, mixed, active, acid, mesic, shallow Aeric Endoaquepts
Sutton	Coarse-loamy, mixed, active, mesic Aquic Dystrudepts

Field Methods:
Figure 5 shows the operation of the EM31 meter with the DAS70 system. The EM31 meter was operated in the vertical dipole orientation with geo-referenced, EC_a measurements automatically recorded at 1-sec intervals. The EM31 meter was held at hip-height with its long axis parallel to the direction of traverse. Walking at a fairly brisk pace, in a random back and forth pattern across each survey area completed an EMI survey. Cultural features were avoided where possible. However, interference and anomalous EMI responses from these features are evident near farm structures in the datasets.

Figure 5. Conducting an EMI agricultural waste survey with an EM31 meter, an Allegro field computer, and a Garmin Global Positioning System Map 76 receiver.

Results:
Table 2 summarizes the basic statistics for the EMI surveys that were conducted at the study sites. Basic statistics were similar at both sites. At Site #1, EC_a averaged 22.8 mS/m with a range of 5.5 to 61.8 mS/m. One half the observations had values of EC_a between 16.8 and 26.9 mS/m. At Site #2, EC_a averaged 21.6 mS/m with a range of 6.4 to 82.3 mS/m. One half the observations had values of EC_a between 13.9 and 25.7 mS/m. Higher values of EC_a are attributed to high concentrations of animal wastes and interference from metallic cultural features.

Table 2
Basic statistics for the EMI surveys conducted within the Farm Complex.
(All values are in mS/m)

	Site #1	Site#2
Number Observations	240	848
Average	22.8	21.6
Standard deviation	9.1	12
Minimum	5.5	6.4
Maximum	61.8	82.3
1st Quartile	16.8	13.9
3rd Quartile	26.9	25.7

Figure 6 is the plot of EC_a data collected with the EM31 meter at Site #1. Access to this site was extremely limited. A steep slope borders the east and northeast sides of the precast concrete structure. A very restricted zone (< 4 m) of relatively high EC_a (20 to 34 mS/m) borders the eastern and northern sides of the precast concrete structure. On each surveyed side of the structure, a noticeable plume-like pattern of higher EC_a (>30 mS/m) appears. These anomalous patterns are spatially constrained, but do represent potential areas of seepage. These patterns appear to extend outward from the structure in a zone that is less than 4 m wide. However, signal interference from the adjoining structure, resulting in some higher EMI responses, cannot be ruled out as well.

At Site #1, milk wastes are contained in a filtering system that bends around the northern and eastern perimeter of the survey area shown in Figure 6. This system consists of several filtering ponds (located in lower-lying areas at the base of the slopes). In the northern part of the survey area, the anomalous zone of very high (> 50/mS/m) EC_a is attributed to wastes within this system. Values of EC_a are lowest (less than 18 mS/m) along the slopes between the storage structure and the lower-lying filtering system. It was along these sloping areas beneath the precast concrete structure that seepage, if present, was anticipated to be most likely manifested.

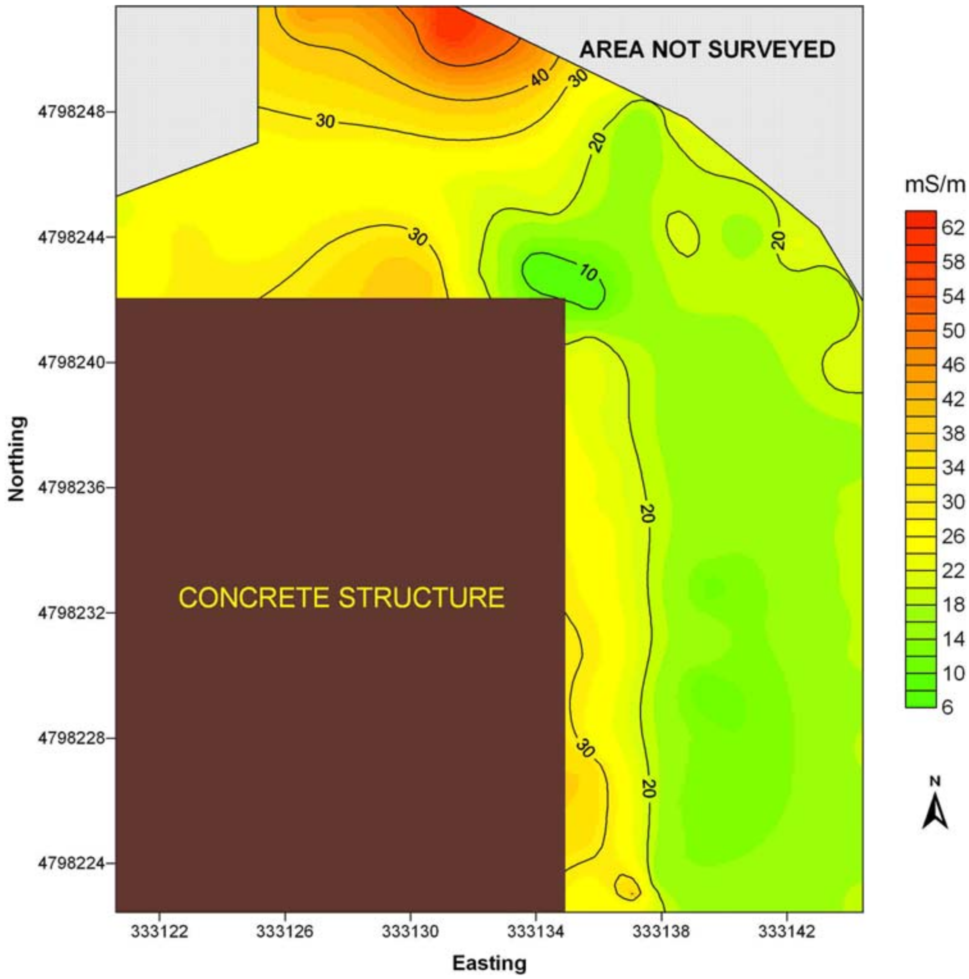

Figure 6. Plots of EC_a collected at Study Site #1 with the EM31 meter.

Figure 7 contains plots of EC_a collected with the EM31 meter at Site #2. At this site, background levels of EC_a are generally less than 12 mS/m and occur in lower-lying more imperfectly drained areas that distantly border the precast concrete structure and farm complex to the southeast and southwest. A broad zone of comparatively high (20 to 80 mS/m) EC_a surrounds the eastern and southern sides of the precast concrete structure. The high EC_a within this zone is believed to reflect measurable and worrisome levels of contaminants from animal wastes. Apparent conductivity within this zone decreases away from the precast concrete structure suggesting possible seepage and /or overland flow. A former waste pit was located in the area to the immediate east of the precast concrete structure. The wide and broadly sweeping pattern of higher (>20 mS/m) EC_a may reflect former seepage from the older and now removed animal waste-holding facility, and not seepage from the present precast concrete structure. In the immediate vicinity of the precast concrete structure, signs of potential seepage are generally restricted to the embankment materials where some signal interference from the structure can not be ruled out. A detached zone of higher (>20 mS/m) EC_a is apparent in the northwestern portion of the study area. This area of higher EC_a is believed to represent waste products that were deposited by overland flow from the adjoining farm complex (located to the north and east).

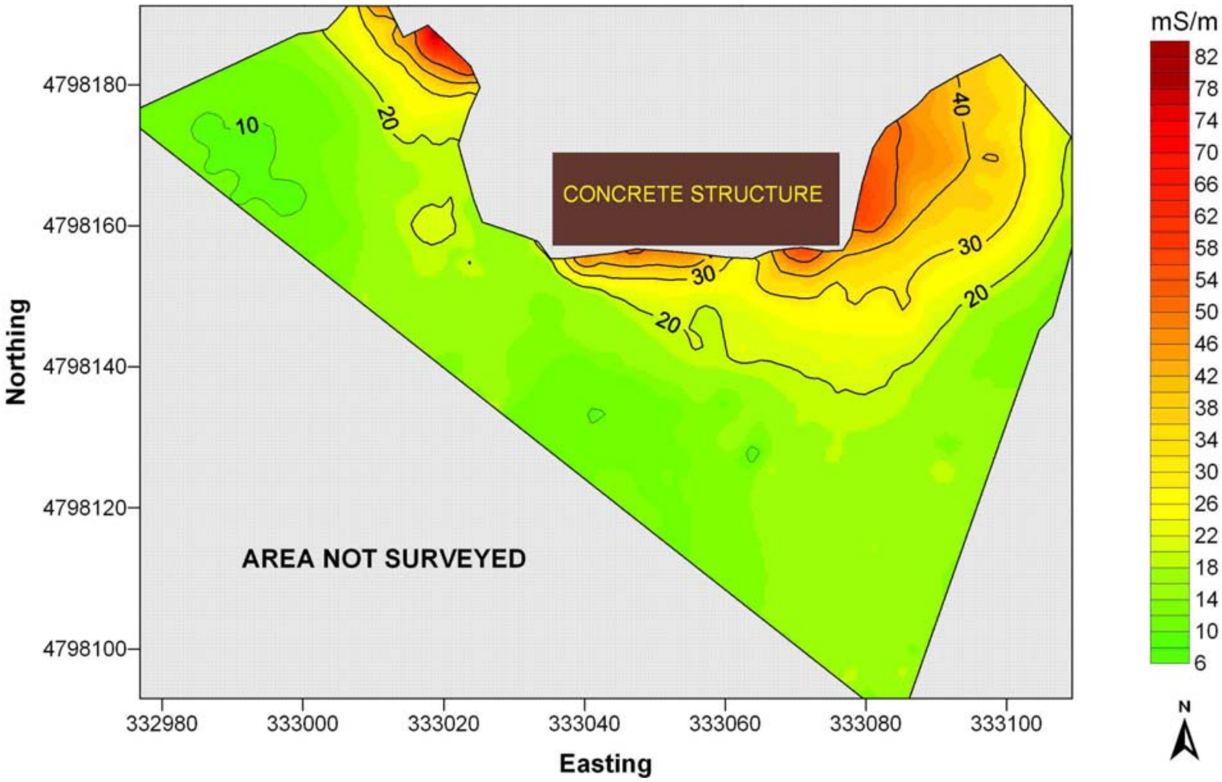

Figure 7. Plots of EC_a collected at Site #2 with the EM31 meter.

GEOPHYSICAL SURVEYS AT FURNANCE BROOK DAM #14

Furnace Brook Dan # 14 is located on Furnace Brook near the town of New Ipswich in Hillsborough County. The earthen dam was completed in 1964, and is a floodwater retarding structure within the Souhegan River Watershed. The dam is a Class C (high hazard) structure with a drainage area of about 6.0 square kilometers. The dam is about 8.5 m high, 457 m long, and has a top width of about 4.3 m. The designed sediment pool contains 2.9 hectare meter of storage with a depth of about 3 m at the dam.

In April of 1987, following severe storms and snowmelt, floodwaters rose too slightly above the emergency spillway and flowed downslope. A boil occurred about 35 m from the base of the bend in the dam. The boil is believed to have resulted from the flow of water under pressure through cracks or fractures in the underlying bedrock during the high reservoir. This study was conducted at the request of the State Engineer to evaluate the potentials of using EMI and GPR to investigate floodwater retarding structures in New Hampshire.

EMI Survey

The bend portion of the dam was surveyed with an EM31 meter. The purpose of this survey was to evaluate whether EMI could provide information concerning the structural integrity of the earthen dam. The dam is composed of electrically resistive SM (silty sand) materials. These materials display very low and invariable EC_a. Because of the very low EC_a, the groundwater is assumed to have a very low ionic concentration

Field Methods:

The EM31 meter was operated in the continuous mode with measurements recorded at 1-sec intervals. The EM31 meter was held at hip-height with its long axis parallel to the direction of traverse. Walking at a fairly brisk pace, in a random back and forth pattern across each survey area completed an EMI survey.

Results:

Apparent conductivity was extremely low and invariable across the portion of the dam that was surveyed. Based on 1563 observations, EC_a averaged 4.65 mS/m with a range of 0.2 to 29.9 mS/m. One half the observations had values of EC_a between 3.40 and 4.97 mS/m. As system and calibration errors are generally about 2 mS/m, EMI is more suited to areas with higher and more contrasting EC_a.

Figure 8 contains the plot of EC_a collected with the EM31 meter in the vertical dipole orientation. In this plot, the isoline interval is 1 mS/m. The base and top of the earthen embankment are shown in this plot. A black line running through the dam represents the approximate location of a 75 cm diameter pre-cast concrete conduit. In Figure 8, the approximate locations of two boils have been identified with red dots. The high conductivity near the riser is probably caused by the presence of corrugated steel conduits.

Low (< 5 mS/m) and extremely invariable EC_a characterize the embankment materials. Within the embankment, areas with EC_a between 5 and 7 mS/m may identify the locations of drains or wetter areas within the structure. Higher values (> 10 mS/m) of EC_a were observed over a rock outcrop near the base of the embankment. The general outline of a shallow ledge is indicated in this plot. This ledge influences the flow of water and may be responsible for the seepage from the structure. However, the embankment is too high (8.5 m) to be effectively profiled with the EM31 meter (about 5 m profiling depth at hip height). As a consequence the extent of the rock ledge was not distinguishable beneath the structure with this meter.

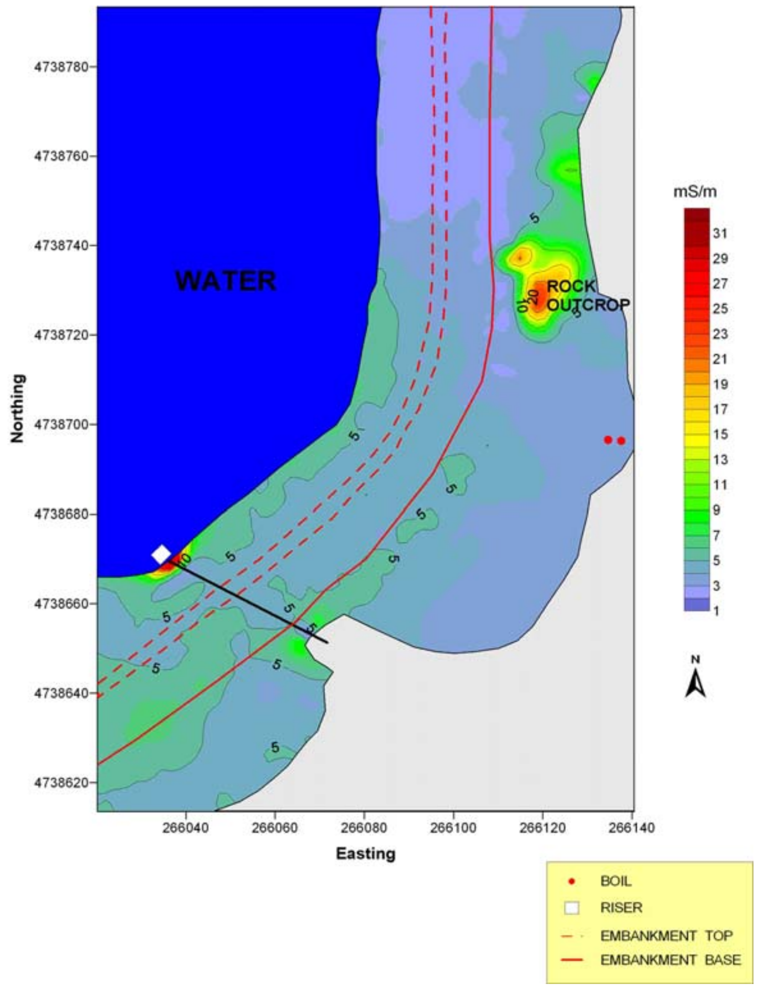

Figure 8. Plot of EC_a collected with the EM31 meter in the vertical dipole orientation along a portion of Furnace Brook Dan # 14.

<u>GPR Survey</u>

Field Methods:

Six parallel traverse line of varying lengths (30, 60, 66, 54, 63,and 39 m) were laid out on the level area along the eastern base of the embankment and near the boils. A GPR survey was completed by towing the 200 MHz antenna along each of these traverse lines. Using the GPS receiver, reference points were marked on the radar record at intervals of about 3-m. This procedure resulted in the radar covering a linear distance of 312 m and recording 110 reference points.

Results:

Figure 9 is a portion of a radar record from the survey area. All scales are in meters. The depth scale was approximated by using an estimated dielectric constant of 8 and velocity of propagation of 0.105 ns/m. The white vertical lines at the top of the radar record represent the reference points that were logged with the GPS receiver.

In general, penetration depths and resolution of subsurface features with the 200 MHz antenna were quite satisfactory at this site. Though not confirmed, the radar imagery suggests the occurrence of parent rock at relatively shallow (> 3 m) depths. In Figure 9, a white line has been used to identify the interpreted depth to bedrock. Inhomogeneities and fractures within the parent rock produce reflections. Because of the size of the propagating wavelengths (about 52 cm with the 200 MHz antenna), and the small contrast in electrical properties and the geometry (size, shape, orientation) of the parent rock, there is little scattering (reflected, refracted or diffracted) of the propagating electromagnetic wave. As a consequence, the bedrock appears reflection-less except along fractures. A large number of reflections that are presumed to be fractures are evident in the parent rock. In figure 9, an especially noticeable zone of highly fractured parent rock is evident between the 9 and 12 m marks. The high amplitude reflections at the base of the radar record (> 4 m) suggest contrasting parent rock. Because of the complexity of subsurface reflectors, the interpretation of the soil/bedrock interface was challenging and ambiguous in some areas.

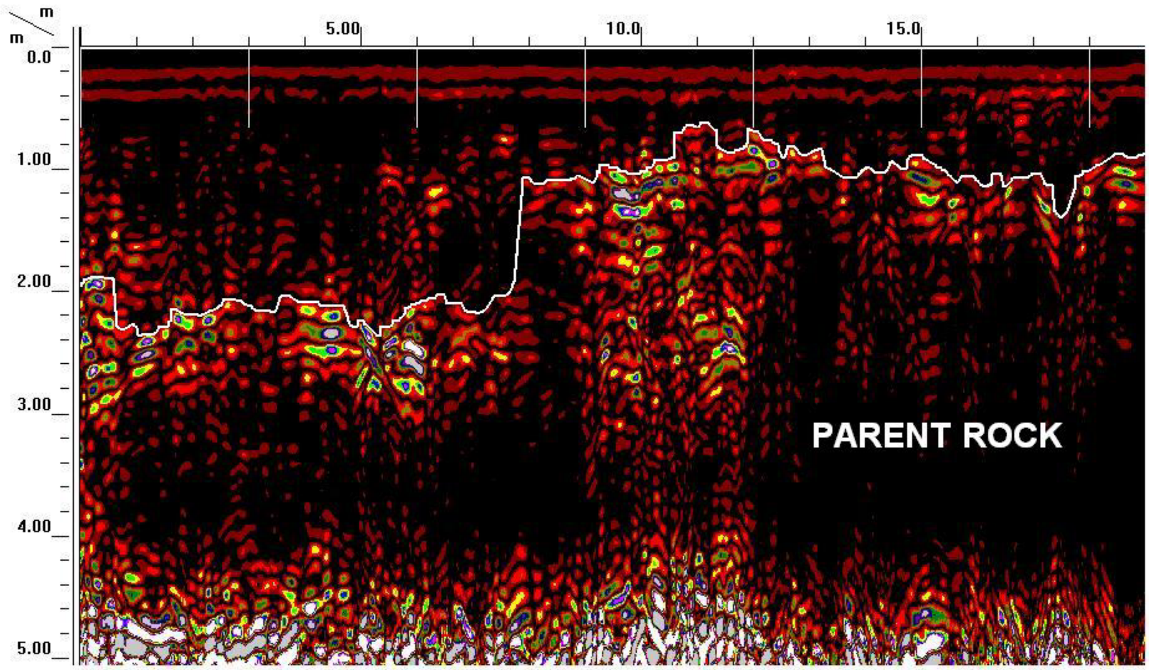

Figure 9. Portion of a radar record from the area immediately downstream from Furnace Brook Dan # 14.

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