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:** July 18, 2006

To: Theresa M. Chadwick
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2 Madbury Road
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PURPOSE:
Training on the operation and interpretation of ground-penetrating radar (GPR) and electromagnetic induction (EMI) techniques was provided to Donald Keirstead and other soil scientists.

PARTICIPANTS:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Don Keirstead, Soil Scientist, USDA-NRCS, Durham, NH
Rob Tunstead, Soil Scientist, USDA-NRCS, West Wareham, MA
Olga Vargas, Soil Scientist, USDA-NRCS, Greenwich, NY

ACTIVITIES:
All field activities were completed during the period of 27 to 29 June 2006.

Summary:

1. This was the first time that the NRCS soil scientists assigned ground-penetrating radar responsibilities in New England and New York have assembled as a group. It is hoped that these soil scientists will maintain contact with one another, and share radar experiences and interpretations.

2. Ground-penetrating radar field exercises benefited all. System operations, settings, and radar interpretations were discussed.

3. In recent years, ground-penetrating radar systems and processing software have developed rapidly. Present systems rely heavily on the use of sophisticated software programs for maximum benefit. Systems operated in New York and Massachusetts, while functional, are outdated. System support by Geophysical Survey Systems, Inc. will continue for several more years, but eventually these systems will need to be replaced as components become no longer available from vendors.

4. Because of the increased emphasis on subaqueous soils, the availability to these soil scientists of a suitable electromagnetic induction platform with GPS capabilities is encouraged. Electromagnetic induction would render help to soil scientists tasked with mapping electrically conductive soils, and assessing saline soil conditions in areas of tidal marshes. While conducting EMI surveys in two areas of *Tidal marsh*, Don Keirstead observed relationships between apparent conductivity and the vegetation and micro-topography. He felt that the use of EMI provided not only an additional layer of soil information, but a greater understanding of the distribution of salts within areas mapped as *Tidal marsh*.

5. Procedures are available to plot geo-referenced EMI data onto aerial photographs using ArcView GIS. Jim Turenne (Assistant State Soil Scientist, Rhode Island) is very proficient in producing these plots (go to nesoil.com/gpr/contours.htm) (Turenne et al., 2006). These plots are very effective in linking patterns of apparent conductivity to surrounding topographic, vegetative, and cultural features.

It was my pleasure to work in New Hampshire and with members of the northeast ground-penetrating radar group.

With kind regards,

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MATERIALS AND METHODS

Equipment:

New Hampshire's TerraSIRch Subsurface Interface Radar (SIR) System-3000 was used in field exercises. This GPR unit is manufactured by Geophysical Survey Systems, Inc (GSSI).[1] The 200 and 400 MHz antennas were used during field exercises.

The radar records displayed 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.

Geonics Limited manufacturers the EM38DD meter used in reconnaissance surveys of tidal marshes.[1] This meter is cumbersome, but requires only one person to operate. No ground contact is required with this meter. Geonics Limited (2000) describes the use and operation of the EM38DD meter. The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One unit acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one unit acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on). Each meter has a 1 m intercoil spacing and operates at a frequency of 14,600 Hz. The EM38DD meter has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 2000).

The Geonics DAS70 Data Acquisition System (Geonics Limited, Mississauga, Ontario) was used with the EM38DD meter to record and store both apparent conductivity (EC_a) and GPS data.[1] The acquisition system consists of the EM38DD 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 EM38DD meter is keypad operated and measurements can either be automatically or manually triggered.

DISCUSSION:

Tour of Geophysical Survey Systems, Inc:

Figure 1. Northeast NRCS GPR operators tour the new headquarters for Geophysical Survey Systems, Inc., in Salem, New Hampshire. Pictured are Olga Vargas, Don Keirstead, Ken Corcoran (GSSI, Application Specialist), Jim Doolittle, Robert Tunstead, and Chris Hawkotte (GSSI, Vice-President of Sales).

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

On Tuesday a tour had been arranged of GSSI's new facility located in Salem, New Hampshire. This provided NRCS GPR operators who are located in the northeast to become more familiar with one another and the staff at Geophysical Survey Systems, Inc. The GPR operators became acquainted with the people that they should contact for equipment repairs, training, and technical questions. Staff at GSSI discussed and exhibited the various radar systems and peripheral equipment that are available, and the frequency, suitability, and design of an array of antennas. In addition, new products, including the *Profiler* were discussed.

GPR field exercises and training:
On Wednesday, Olga Vargas and Don Keirstead participated in field exercises that covered antenna selection, survey designs, operating procedures, and radar interpretations.

The first exercise site was in an area mapped as *Gravel and borrow pits* in Lee, New Hampshire (-70.99833 East Longitude, 43.159167 North Latitude). The area surrounding this miscellaneous land area had been mapped as Hinkley loamy sands, 0 to 3 percent slopes, but is being updated as polygons of Windsor soil. The very deep excessively drained Windsor soil formed in sandy glacial outwash. Windsor is a member of the mixed, mesic Typic Udipsamments family.

Figures 2 and 3 contain representative radar records collected along a sidewall to the sand and gravel pit. These records were collected with a 200 MHz antenna. Based on the depth to a known reflector, the dielectric permittivity (E_r) was estimated to be 7.8 in the upper part (0 to 50 cm) of the soil profile. An E_r of 7.8 results in a propagation velocity of 0.107 m/ns. With a propagation velocity of 0.107 m /ns and a scanning time of 170 ns, the maximum penetration depth was (assuming a constant velocity) about 9.1 m, in Figures 2 and 3. On the radar records shown in Figures 2 and 3, the vertical or depth scale is expressed in meters. On the soil profile shown in Figure 2, the depth scale is in meters.

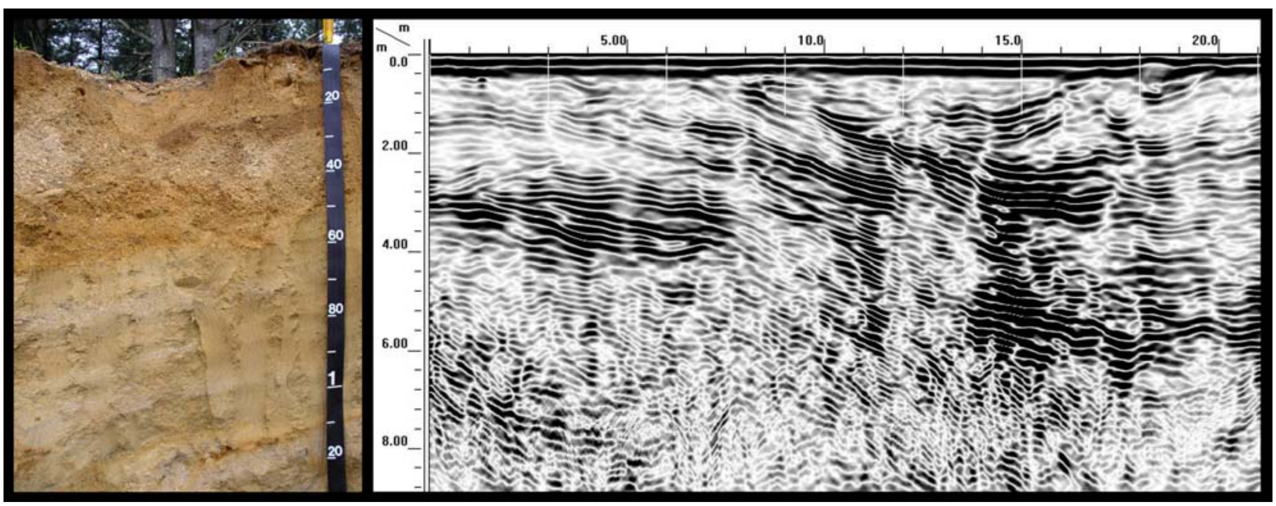

Figure 2. Soil profile (left) and a radar record (right) from an area of Windsor soils. The reflection patterns evident on this radar record suggest stratified layers of glacial outwash overlying till (courtesy of Tammy Umholtz, USDA-NRCS-NSSC).

In Figure 2, the upper part of the radar record consists of inclined planar reflectors indicative of sandy glacial outwash. In the lower part of the radar record, at depth ranging from about 4 to 6 m, reflectors appear more chaotic and less aligned. These patterns suggest dissimilar materials and possibly a deposit of glacial till.

The radar record displayed in Figure 3 was collected on a side slope into the sand and gravel pit. The radar record has been *surface normalization*. In this post-processing procedure, elevations are assigned to each reference point so that the radar records can be corrected for changes in surface topography. Surface normalized presentations aid soil/landscape correlations and improves interpretations. In addition, surface normalization provides a more accurate geometric reconstruction of subsurface interfaces.

On the radar record shown in Figure 3, the water table has been identified with a green colored line. The water table occurs close to the surface in the center (left-hand portion of record) and deepens in depth beneath the sides (right-hand portion of record) of the excavated pit. In areas of coarse-textured soils, the capillary fringe is abrupt and offers a strongly contrasting reflector that separates the unsaturated vadose from the phreatic zones. Generally, water tables are only evident on radar records in sandy soils. As the clay content of soils increases, the capillary fringe becomes more diffuse and the boundary between the two zones is too gradual to be detected with GPR. Lower frequency antennas (< 300 MHz) have bandwidths that are most suited to the detection of water tables in coarse textured soils.

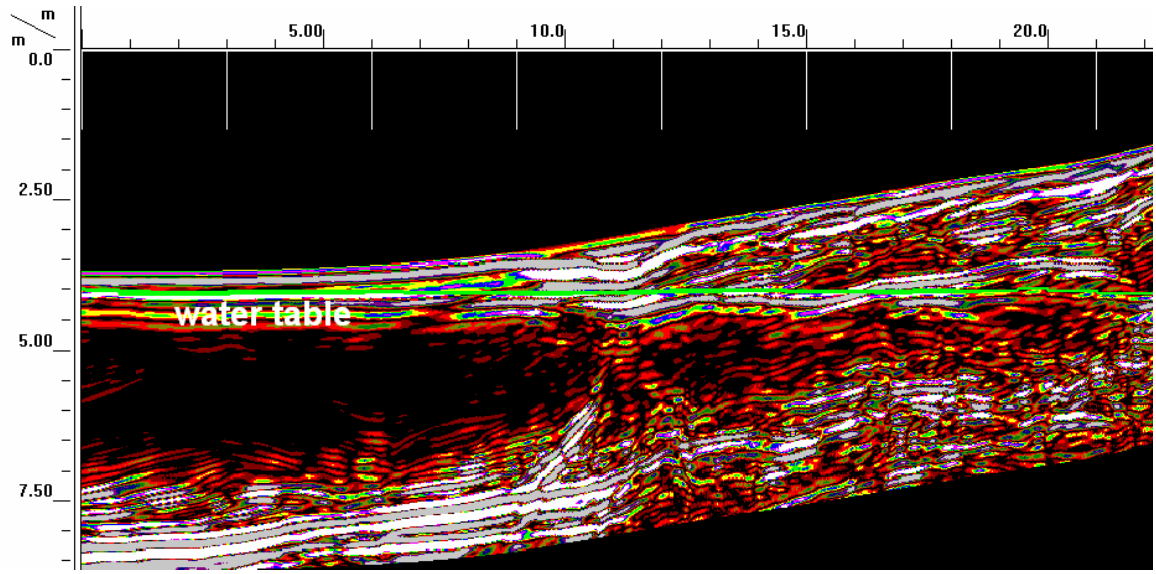

Figure 3. A processing step known as surface normalization helps to identify the water table (green-colored line) on this radar record.

The second exercise site was located in a wooded area near the intersection of Mast Road and Main Street on the outskirts of Durham (-70.94769 East Longitude, 43.13950 North Latitude). Soils were mapped as Hollis-Charlton very rocky fine sandy loams, 3 to 8 percent slopes. The dominant soil within the traversed areas is Chatfield. The moderately deep, well drained and somewhat excessively drained Chatfield soil formed in till overlying crystalline bedrock (gabbro basalt). Chatfield is a member of the coarse-loamy, superactive, mesic Typic Dystrudepts family.

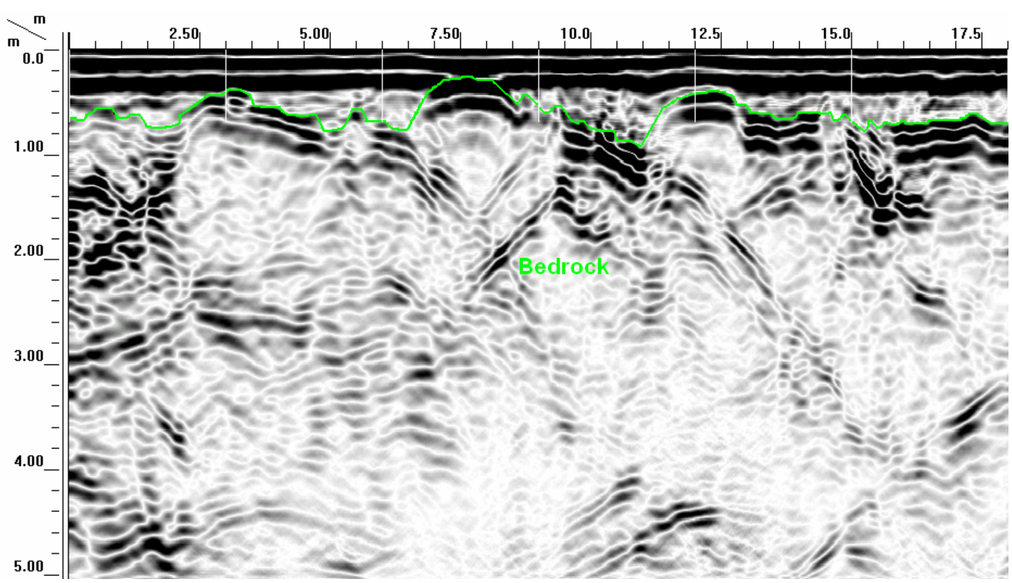

Figure 4. A representative radar record collected with a 200 MHz antenna in an area of Chatfield soil.

Figure 4 is a representative radar record collected in this area of Chatfield soil. The record was collected with a 200 MHz antenna. Based on the depth to a known reflector, the dielectric permittivity (E_r) was estimated to be 10.1 in the upper part of the soil profile. This E_r results in a propagation velocity of 0.094 m/ns. With a propagation velocity of 0.094 m /ns and a scanning time of 110 ns, the maximum penetration depth was (assuming a constant velocity) about 5.1 m. On the radar records shown in Figure 4, the vertical or depth scale is expressed in meters.

A green-colored line has been drawn on the radar record shown in Figure 4 to highlight the interpreted bedrock surface. Along this portion of the traverse line, depths to parent rock are moderately deep and shallow. Compared with the overlying glacial till, the parent rock is relatively homogenous and lacks subsurface reflectors. This aids identification of the soil/bedrock interface. Reflections within the parent rock principally represent fracture or exfoliation planes, and veins of dissimilar materials. Although the radar record was migrated, diffraction tails are evident from some of the subsurface reflectors.

EMI Survey of *Tidal marsh* map units in Strafford County:

While electromagnetic induction (EMI) has been used extensively to assess soil salinity in croplands, published reports on its use in coastal areas influenced by salt water intrusion are limited (Meadows et al., 2004; Lee et al., 2002; Kruse et al., 1998; Sam and Ridd, 1998). The purpose of this survey was to acquaint Don Keirstead with the effectiveness of using EMI to assess salinity within tidal marshes in New Hampshire.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity (EC_a) of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific observation depth (Greenhouse and Slaine, 1983). Soil EC_a increases with increases in soluble salts, clay, and water 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. However, in areas of saline soils, 65 to 70 percent of the variance in EC_a can be explained by changes in the concentration of soluble salts alone (Williams and Baker, 1982). Moderate to high correlations have been found between EC_a and soil salinity (Williams and Baker, 1982; and Wollenhaupt et al., 1986).

Values of EC_a are seldom diagnostic in themselves, but lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Several models have been developed that relate EC_a to the conductivity of the saturated extract (EC_e). In most areas, an EC_a above 60 mS/m suggest excess amounts of soluble salts.

Two areas of map unit Ta, *Tidal marsh*, were selected along Piscataquoa Road, east of Durham, in Strafford County. Tidal Marsh Site #1 is located near a bridge than spans the Oyster River near the outskirts of Durham (see Figure 5).

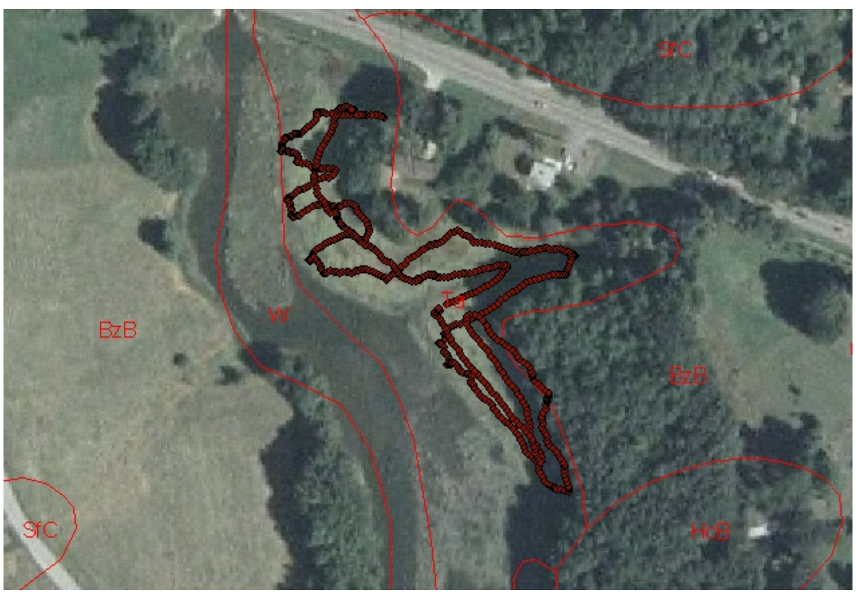

Figure 5. An orthophotogrphic image with soil symbols and polygon lines of Tidal Marsh Site #1 was prepared using ArcView GIS. The locations of EMI observation points have been identified.

Tidal Marsh Site #2 is located further east, near the confluence of the Bellamy and Oyster Rivers in Strafford County. The western boundary of this survey area was located just east of Black River Road (see Figure 5). In Figures 5 and 6, the locations of observation points and traverse lines are based on a random walk through accessible areas of the tidal marshes.

Figure 6. An orthophotogrphic image with soil symbols and polygon lines of Tidal Marsh Site #2 was prepared using ArcView GIS. The locations of EMI observation points have been identified.

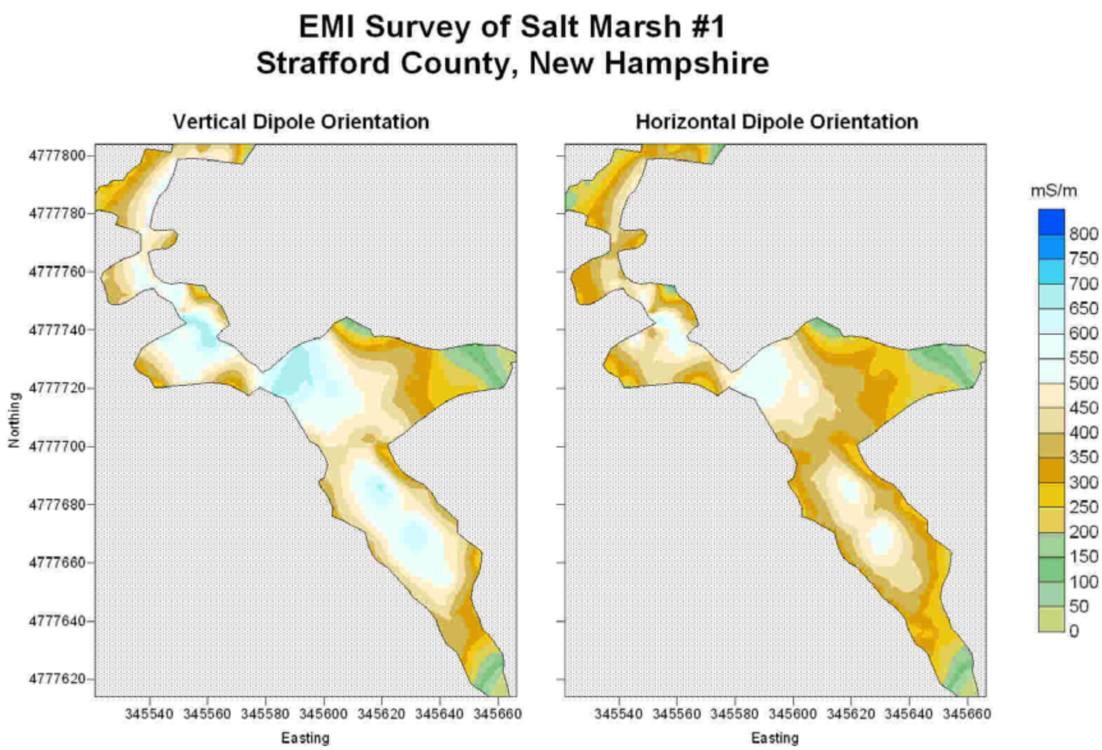

Figure 7. Plots of EC_a *data collected at Salt Marsh #1 Site with the EM38DD meter.*

Figure 7 contains plots of the EC_a data collected with the EM38DD meter at Salt Marsh #1 site. Oyster River and upland (non-tidally influenced) areas form the western and eastern boundaries of the survey area, respectively. The two spatial EC_a plots represent data collected in the shallower-sensing (0 to 75 cm) horizontal (HDP; right-hand plot) and deeper-sensing (0 to 150 cm) vertical (VDP; left-hand plot) dipole orientations. The UTM scale is in meters. In each plot, the isoline interval is 50 mS/m.

Values of EC_a were highly variable across the surveyed area mapped as *Tidal marsh*. Because sampling was sparse (N=728) and widely spaced, the computer interpolated plots shown in Figure 7 are highly generalized. However, spatial patterns of

EC_a are evident. Apparent conductivity increased toward the centers of polygons mapped as Tidal *marsh*. Lower EC_a values are apparent nearest the stream banks of the Oyster River and the bordering upland areas to the *Tidal marsh* polygons. In general, EC_a increased and became more variable with increasing observation depth (vertical dipole orientation) (see Table 1). This trend suggests the presence of slightly more conductive (saline) materials with increasing soil depth. This vertical trend in EC_a is attributed principally to increased salinity of the soil water at lower depths.

Table 1

Basic EMI Statistics for EMI surveys.
(Other than the number of observations, all values are in mS/m)

	Tidal Marsh Site #1		Tidal Marsh Site #2	
	HDP	**VDP**	**HDP**	**VDP**
Number	728	728	1377	1377
Mean	333.29	402.95	367.26	404.55
Standard Deviation	128.50	151.06	105.87	120.71
Minimum	-1.88	6.88	0.00	35.00
Maximum	663.25	738.13	760.00	799.00
25%-tile	259.00	318.38	297.50	321.00
75%-tile	410.63	499.00	434.38	475.00

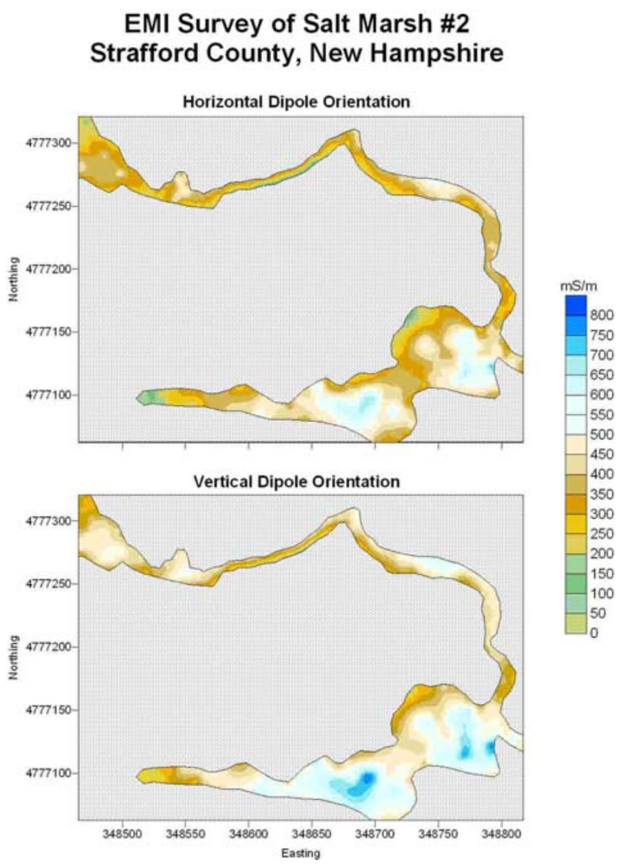

Figure 7. Plots of EC_a *data collected at Salt Marsh #21 Site with the EM38DD meter.*

Figure 8 contains plots of the EC_a data collected with the EM38DD meter at Salt Marsh #2 site. This area is near the confluence of the Oyster and Bellamy Rivers and the coast. The two spatial EC_a plots represent data collected in the shallower-sensing horizontal (HDP; upper plot) and deeper-sensing vertical (lower plot) dipole orientations. The UTM scale is in meters. In order to aid comparison, the same color ramp and isoline interval (50 mS/m) were used in both Figures 7 and 8.

Values of EC_a were highly variable across the investigated area. Because sampling was relatively sparse (N=1377) for the comparatively large area that was surveyed, the computer interpolated plots shown in Figure 8 are considered generalized. However, similar spatial patterns of EC_a are evident at this site as were apparent at Salt Marsh #1 Site. Apparent conductivity increased away from the upland areas that border the *Tidal marsh* polygons. Although this site is located closer to the coast and is susceptible to more prolonged periods of tidal flooding and greater concentrations of salts in solution, basic EC_a statistic were surprisingly similar between the two sites (see Table 1). As at the previous site, EC_a increased and became more variable with increasing observation depth (vertical dipole orientation) (see Table 1). This vertical trend in EC_a is attributed principally to increased salinity of the soil water at lower depths.

While conducting the EMI surveys at each site, Don Keirstead notes relationships among EC_a, vegetation patterns, and micro-topography. He felt that the use of EMI provided not only an additional layer of soil information, but insight into the distribution of salts within Tidal marshes.

Procedures are available to plot geo-referenced EMI data onto ortho-photographs using ArcView GIS. Jim Turenne (Assistant State Soil Scientist, Rhode Island) is very proficient in developing these plots. These plots are very effective in showing and relating patterns of EC_a to surrounding topographic, vegetative, and cultural features. Compared with the plots shown in Figures 7 and 8, which were prepared with the Surfer software program, the visual imagery in the ArcView GIS presentation makes spatial patterns of EC_a easier to understand, orientate, and relate to cultural, vegetative, and topographic features.

Reference:

Geonics Limited. 2000. EM38DD ground conductivity meter: Dual dipole version operating manual. Geonics Ltd., Mississauga, Ontario.

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