United States Department of Agriculture

Natural Resources Conservation Service

c/o USDA Forest Service
11 Campus Boulevard
Suite 200
Newtown Square, PA 19073
(610) 557-4233; FAX: (610) 557-4200

Subject: Soils – Geophysical Field Assistance **Date:** 7 March 2005

To: Judith M. Doerner
State Conservationist
USDA-NRCS
60 Quaker Lane, Suite 46
Warwick, RI 02886-0111

Purpose:
Soil information was collected with ground-penetrating radar (GPR) on different soils and landscapes in southern Rhode Island. In addition, electromagnetic induction (EMI) was used to characterize a tidal marsh in southern Rhode Island. In conjunction with these studies, GPR training was provided to Rob Tunstead (soil, scientist, USDA-NRCS, W. Wareham, MA).

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Robert Tunstead, Resource Soil Scientist, USDA-NRCS, West Wareham, MA
Jim Turenne, Assistant State Soil Scientist, USDA-NRCS, Warwick, RI

Activities:
All activities were completed during the period of 14 to 17 February 2005.

Summary:
The soils of Rhode Island are very conducive to the effective use of GPR. During this investigation, GPR provided additional soil information on the depth and characteristics of organic soil layers within peatlands, the stratigraphy of barrier beach deposits, and the extent of ice-thrusted, finer-textured Cretaceous sediments. Electromagnetic induction was used to characterize the distribution and relative concentration of salts within a salt marsh.

It was my pleasure to work in Rhode Island and to be of assistance to your staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
D. Hammer, National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866

M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
K. Kolesinskas, State Soil Scientist USDA-NRCS, 16 Professional Park Road, Storrs, CT 06268-1299
B. Thompson, State Soil Scientist/MLRA Office Leader, USDA-NRCS, 451 West Street, Amherst, MA 01002-2995
R. Tunstead, Soil Scientist, USDA-NRCS, 15 Cranberry Highway, West Wareham, MA 02576
J. Turenne, Assistant State Soil Scientist, State, USDA-NRCS, 60 Quaker Lane, Suite 46, Warwick, RI 02886-0111
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697

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 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 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. Daniels (2004) discusses the use and operation of GPR. The 70, 120, and 200 MHz antennas were used in this investigation.

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

A GEM300 multifrequency sensor was used in the EMI salinity study at Charlestown Breachway State Park.[1] This sensor is manufactured by Geophysical Survey systems, Inc., The GEM300 sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation (1.3 m). Won and others (1996) have described the use and operation of this sensor.

A Garmin Global Positioning System Map 76 receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack) was used to record position data.[1]

To help summarize the results of the EMI study, SURFER for Windows, (version 8.0; developed by Golden Software, Inc.) and ArcView GIS were was used to construct simulations.[1]

Figure 1. Conducting a radar survey of a forested peatland with the 200 MHz antenna.

Field Methods:
GPR Surveys:
Areas of organic soils are considered most accessible for survey work during winter months when the upper part of the soil is frozen. Relatively warm weather patterns preceded the GPR investigations. Because of the warm weather, the ice that covered many of the peatlands had melted and ponded conditions limited and greatly impaired GPR operations. Many traverses were conducted across wooded peatlands similar to the one pictured in Figure 1. Within most swamps, trees and debris frequently snagged the antennas even along cleared pathways. The 70 MHz antenna

requires no ground contact and is easily carried through wet, wooded swamps. Unfortunately, this antenna was found to be defective and unusable at the time of this study.

Radar traverses were conducted across several sites. All traverses were completed with the GPR control unit carried in a backpack and the antenna carried or towed by hand. Along each traverse lines, reference points were spaced at equal intervals. These intervals varied from about 5 to 15 m. Along each traverse line, as the antenna passed each reference point; the operator impressed a mark on the radar record. Another person obtained the location of each reference point with a Garmin GPS receiver. All readings were obtained in the autonomous mode. The Latitude/Longitude coordinate systems were used. The horizontal datum is the North American 1983.

EMI Survey:

The GEM300 sensor was operated in the *station* mode. In the *station* mode, the sensor can be rotated at each reference point to record measurements in both the horizontal and vertical dipole orientations. A survey of a salt marsh was completed at operating frequencies of 9810 Hz and 14670 Hz. The GEM300 sensor held at hip height with its long axis parallel to the direction of traverse.

Results:

Ell Pond:

An 80-m radar traverse was conducted across a portion of Ell Pond. Ell Pond is a National Natural Landmark that is located near Hopkinsville, in Rockville Township, Rhode Islands. The traversed area is mapped as *Carlisle muck* (Rector, 1981). The very deep, very poorly drained Carlisle soil formed in woody and herbaceous organic materials. Carlisle is a member of the euic, mesic Typic Haplosaprists family. At Ell Pond, a thin layer of ablation till underlies the organic materials. The ablation till is underlain by parent rock. The vegetation within the site is principally Atlantic white cedar, high bush blueberry, and rhododendron. These species typify more acidic (dysic versus euic) organic soils.

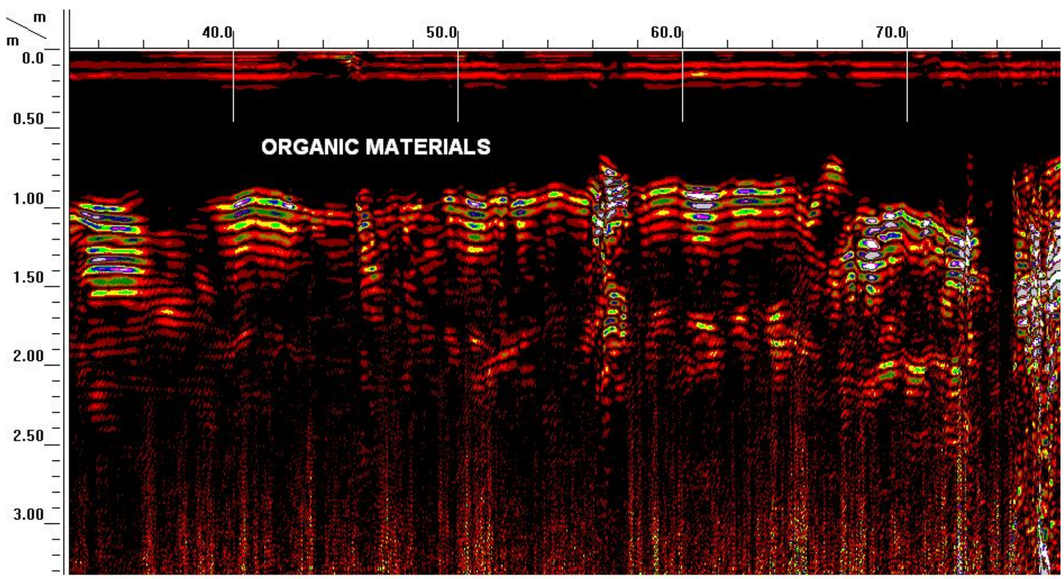

Figure 2. This radar record from Ell Pond shows the organic/rock interface and fracture patterns within the parent rock.

Figure 2 is a portion of a radar record that was collected with the 200 MHz antenna at Ell Pond. Abrupt and strongly contrasting changes in water content make the organic/mineral soil interface distinguishable on radar records. In this radar record, the overlying organic materials are free of subsurface reflectors. Based on previous work at this site, the underlying material is known to be ledge. The organic material/rock interface provided a conspicuous reflector that occurred at relatively shallow and uniform depths. In the radar record shown in Figure 2, this interface varies in depth from about 42 to 101 cm. Several narrow, vertically orientated patterns of segmented and reverberated reflections are evident on the radar record near the 46-, 57-, and 66-m marks. These reflectors are assumed to represent fractures. A conspicuous trough in the parent rock, which is border by a sharp vertical rock walls, is evident near the 74-m mark.

Very little information is available from the radar record concerning
the underlying parent rock. The absence of reflectors within the parent rock suggests fairly uniform materials (in terms of grain size, structure, and composition). On the radar record shown in Figure 2, the second set of radar reflections that appear at a depth of about 2-m represents *double return echoes*, a form of noise caused by the ricocheting of the reflected pulse between the soil surface and the organic/ rock interface. High frequency noise (appears as snow on the radar record) plagues the lower part of this radar record (below a depth of about 2.25 m).

The portion of Ell Pond that was surveyed is heavily wooded and contains substantial undergrowth. The vegetation and debris made it difficult to conduct the GPR survey (see Figure 1). The 200 MHz antennas was often wedged by the vegetation or lifted by surface debris. The GPR traverse line was relatively short and consisted of only 8 reference points. Along this traverse, a uniform and relatively shallow layers of organic materials covered the till and parent rock. These layers of organic soil materials averaged 89 cm thick with a range of 73 to 107 cm. The frequency distribution of soils by taxonomic classification along the traverse line is shown in Table 2. Measurements of organic soil layer thicknesses based on GPR interpretations are listed in the Appendix to this report.

Franks Big Pond:

Multiple traverses were conducted across the ice on Franks Big Pond to estimate the thickness of organic materials that covered the basin's bottom. Franks Big Pond is located in Richmond Township in southwestern Rhode Island. The traversed area is mapped as *Carlisle muck* (Rector, 1981).

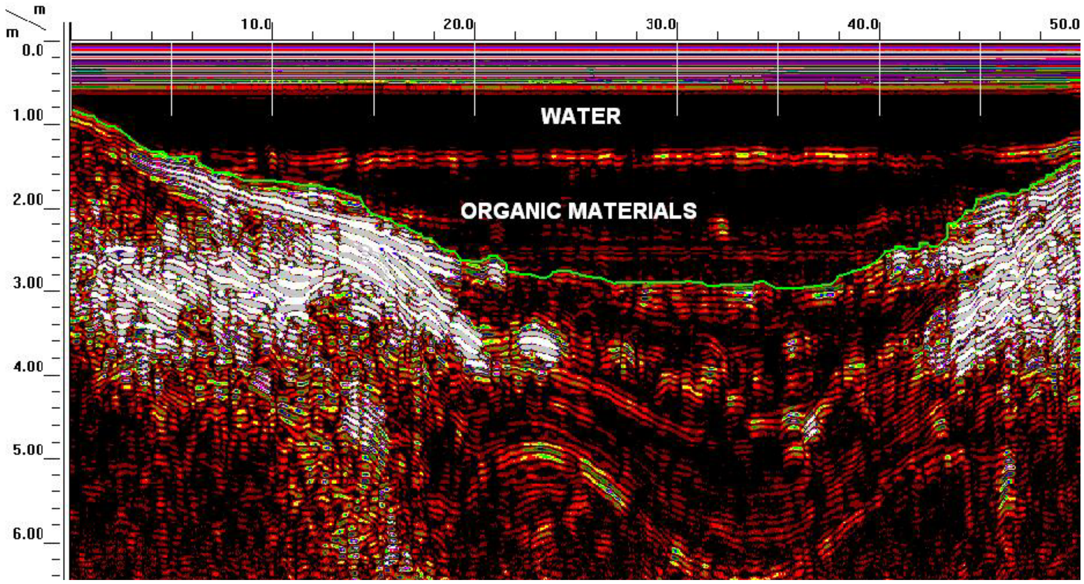

Figure 3. A radar record from Frank's Big Pond showing layers of water and organic materials overlying inclined layers of stratified drift and till.

Figure 3 is a representative radar record that was collected with a 200 MHz antenna on Franks Big Pond. The pond is relatively shallow and is underlain by organic soil materials. The water/organic soil material interface is evident as a moderate to low amplitude, planar reflector at a depth of about 130 cm on this radar record. The organic/mineral soil material contact varies in depth from about 80 to 290 cm and has been highlighted with a green-colored line on this radar record. In the lower part of the basin, overlying this interface are several low-amplitude, planar reflectors within the organic soil materials. Based on limited auger observations, these reflectors represent thin layers of mixed mineral and organic soil materials. These layers correspond to former overwash deposits.

Below the organic soil layers, the underlying mineral materials are characterized by inclined, low to high amplitude, planar reflectors, which suggest glacial outwash deposits. The form and depth of a kettle basin is evident between reference points 15- and 45-m. On this radar record, subsurface reflections in the stratified outwash deposits outline the form of a kettle basin to depths greater than 6 m. These deposits contain a large number of hyperbolic reflectors that are presumed to represent larger stones and boulders. Hyperbolic reflectors are most noticeable in the central core of the kettle at depths of about 3 to 4.5 m. The chaotic pattern of point reflectors in the lower (below 4 m) left-hand portion of this radar record suggest till.

Based on measurements made at 45 reference points, the average depth of the water within Franks Big Pond is 118 cm with a range of 0 to 137 cm. Below this layer of water, organic layers average 66 cm thick and range in thickness from 0 to 167 cm. The frequency distribution of soils by taxonomic classification along the traverse lines are shown in Table 2. Measurements of organic soil layer thicknesses based on GPR interpretations are listed in the Appendix to this report.

URI Peatland:
Multiple traverses were conducted across the ice on a peatland known as the URI Peatland in North Kingston. The traversed area is mapped as *Carlisle muck* (Rector, 1981).   Access to this peatland was limited because of thin ice and areas of open water. Figure 4 is a representative radar record from URI Peatland. The radar record was collected with a 200 MHz antenna.   This peatland contained comparatively thick layers of organic soil materials. In some areas of this peatland, the thickness of organic soil materials approached the maximum penetration depths of the 200 MHz antenna. As a consequence, the organic/mineral soil interface produces weak reflections and was difficult to clearly interpret in these deeper areas. A lower frequency antenna would provide greater penetration depths and more complete images of the organic/mineral soil materials contact.

In the 35-m radar traverse shown in Figure 4, the organic/mineral soil interface is undulating and varies in depth from about 3.4 to 6.0 m. Compared with the radar record shown in Figure 3, little information on the nature of the underlying glacial materials can be gleaned from the radar record shown in Figure 4.

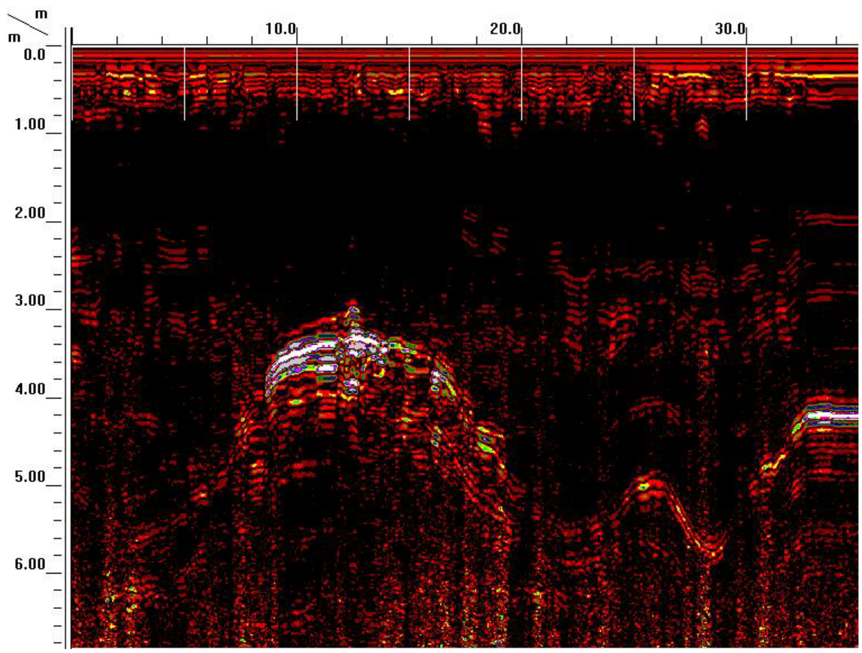

Figure 4. The undulating and weakly expressed nature of the organic/mineral soil material interface is evident in this radar record from the URI Peatland.

Based on measurements made at 22 reference points, the average thickness of organic materials is 2.89 m, with a range of 0 to 5.25 m. The frequency distribution of soils by taxonomic classification along the traverse lines are shown in Table 2. Measurements of organic soil layer thicknesses based on GPR interpretations are listed in the Appendix to this report.

Charlestown Beach:
A stratigraphic investigation of a barrier beach was conducted with GPR near the village of Quonochontaug, Rhode Island. The traversed area is mapped as Udipsamments (Rector, 1981). This area will be recorrelated as Brockatonorton and Hooksan soils. The very deep, excessively drained Hooksan and the moderately well drained Brockatonorton soils form in sandy marine sediments on dunes and backshore areas of barrier islands. Hooksan is nonsaline and lacks buried layers of organic soil materials. Hooksan is a member of the mesic, uncoated Typic

Quartzipsamments family. Brockatonorton is a member of the mixed,
mesic Aquic Udipsamments family. Brockatonorton soil ranges from nonsaline to moderately saline and contains buried layers of organic soil materials. The purpose of this investigation was to chart the internal dune structure, the water table, and the extent of buried organic materials beneath recent sand deposits on back dune areas.

Figures 5 and 6 are segments of the radar record that was collected across the foreshore and backshore of the low barrier beach that separates Block Island Sound from Ninigret Pond. The portions of the radar record shown in these figures have been *surface normalized*. This process adjusts the radar record for change in elevation. Elevation data were obtained at each reference point with a level and surveying rod.

In each radar record, the image of the water table has been highlighted with a green line and labeled. An area of high signal attenuation caused by saline ground water is evident in the extreme left-hand portion of Figure 5. This portion of the radar record is nearest to Block Island Sound. In Figure 6, contrasting layers of buried organic materials have also been identified within the sand deposits. These records are useful in depicting the geometry and structure of subsurface layers and documenting the evolution of barrier beaches and encroachment of saline waters.

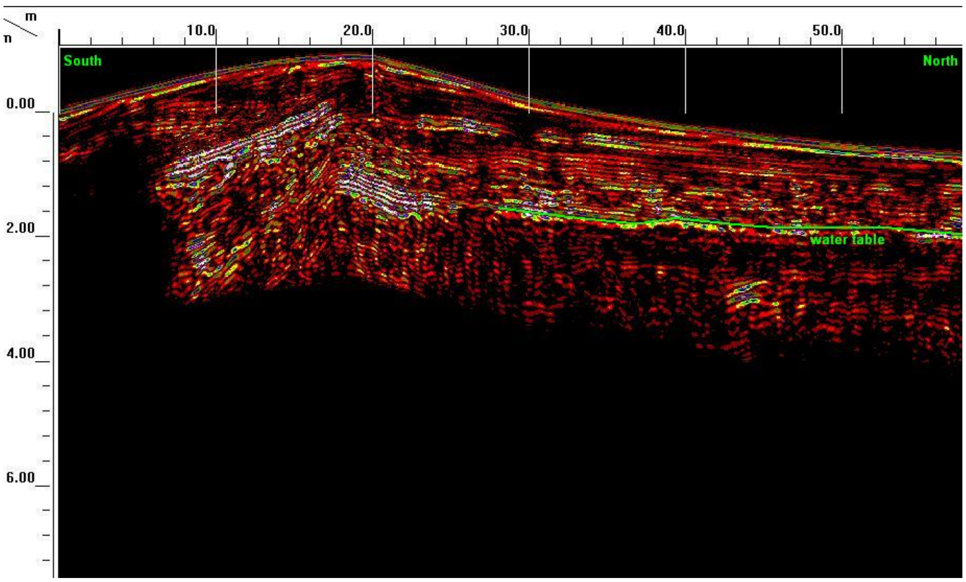

Figure 5. A terrain corrected radar record of a dune and an area of Hooksan soil at Charlestown Beach.

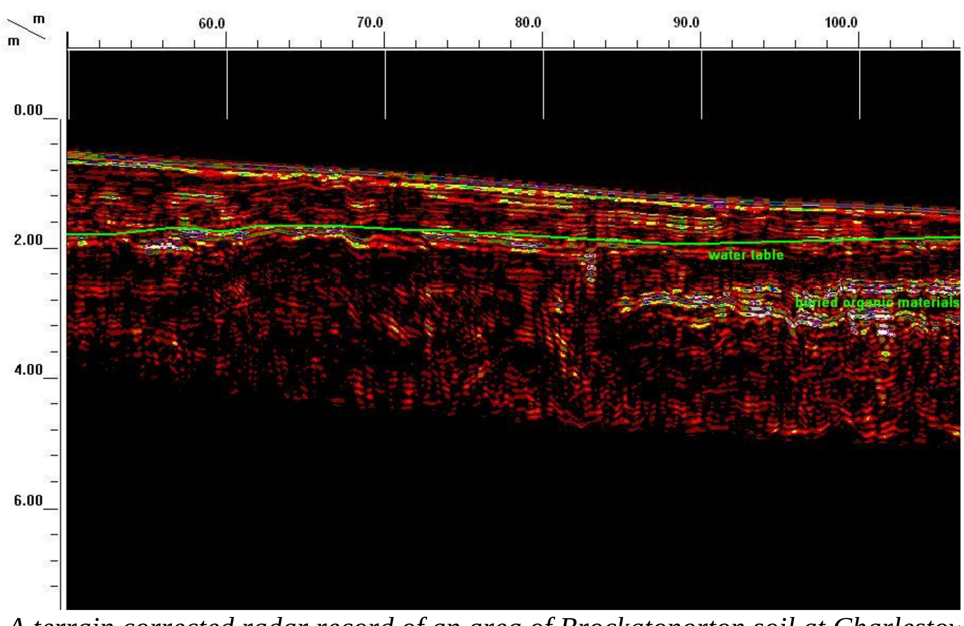

Figure 6. A terrain corrected radar record of an area of Brockatonorton soil at Charlestown Beach.

Block Island:
On Block Island, finer-textured Cretaceous sediments have been thrusted upwards by glaciers. These masses of clays are not widespread, but form prominent cliffs. These Cretaceous sediments consist of unconsolidated and semi-consolidated gravels, sands, silts, and clays (Tuttle and others, 1961; Sirkin, 1976). The Cretaceous sediments are unconformably overlain by glacial drift. Block Island is capped by two glacial drift sheets representing two ice advances, one of late Wisconsinan age and one that predates the late Wisconsinan (Sirkin, 1976). The purpose of this investigation was to use GPR to identify subsurface erosional remnant and map the extent of the Cretaceous coastal-plain strata on Block Island.

Multiple radar traverses were conducted near Black Rock and the Clay Head Conservancy in an attempt to chart the extent of the thrusted Cretaceous sediments. For this study, the maximum profiling depth of the 200 MHz antenna was set to about 6 meters. Based on nine traverse at Black Rock and four at Clay Head, these sediments appear limited in extent and confined principally to locations near the southern shore of Block Island.

Figure 7 shows an area underlain by these ice-thrusted Cretaceous sediments near Black Rock. Cretaceous sediments underlie a 32 m section of this traverse line. These finer-textured sediments are more attenuating to the radar signal than the surrounding coarser-textured glacial drift. In Figure 7, a green line highlights the interpreted upper surface and the lateral extent of the Cretaceous sediments. The virtual absence of subsurface reflectors attests to the presence of these finer-textured sediments. On either side of these sediments, chaotic reflectors suggest glacial till.

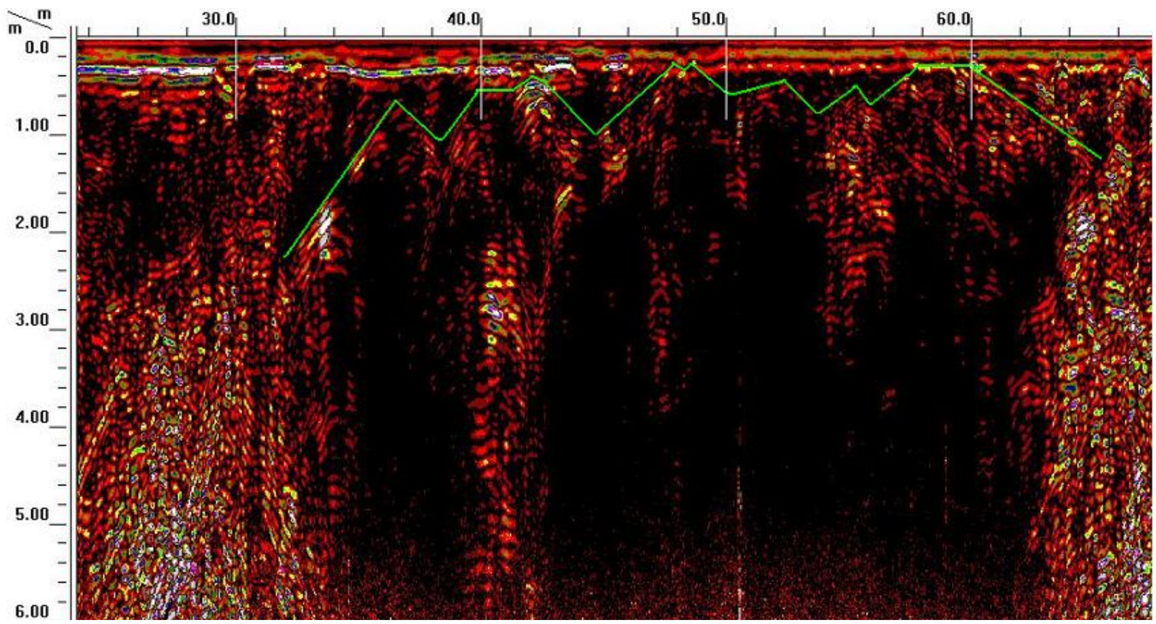

Figure 7. A radar record from Block Island showing an ice thrusted.

EMI Survey of Charlestown Breachway State Park:
While EMI has been used extensive to assess salinity in irrigated croplands, reports of its use in coastal areas that are influenced by salt water intrusion is limited (Meadows et al., 2004; Lee et al., 2002; Kruse et al., 1998; Sam and Ridd, 1998). The purpose of this survey was to assess the practically of using EMI to assess salinity within salt marshes along the coast of Rhode Island.

The study site is located in a salt marsh southwest of the village of Charlestown. Soils mapped within the study site included Brockatonorton, Jamaica, Matunuck, and Pawcatuck. The very deep, poorly drained Jamaica soil formed in a 40 to 80 inches mantle of *anthro-transported* sandy soil materials. Jamaica soil is on modified landscapes in and near urbanized areas. Jamaica is a member of the mixed, mesic Typic Psammaquents family. The very deep, very poorly drained Matunuck and Pawcatuck soils are in tidal marshes. Matunuck soil formed in thick sand deposits. Matunuck is a member of the sandy, mixed, mesic Typic Sulfaquents family. Pawcatuck soil formed in organic deposits over sandy mineral materials. Pawcatuck is a member of the sandy or sandy-skeletal, mixed, euic, mesic Terric Sulfihemists family. Unique plant communities grow on each soil. Spartina is generally restricted to areas of Matunuck and Pawcatuck soils. Bayberry and phragmities typify areas of Jamaica soil.

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). The EC_a of soils 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 general, EC_a values above 60 mS/m indicate excess amounts of soluble salts.

Figure 8 contains plots of the data collected with the GEM300 sensor, operated at a frequency of 9810 Hz, in the shallower-sensing horizontal (left-hand) and deeper-sensing vertical (right-hand) dipole orientations. The locations of observation points are shown in the left-hand plot. These observation points are based on a random walk through the most accessible areas of the salt marsh. A large pond occurs within the survey area but is not shown in either plot. The UTM scale is in meters. In ach plot the isoline interval is 20 mS/m. Areas with EC_a less than 60 mS/m are shown in white; areas having EC_a greater than 60 mS/m are shown in shades of red.

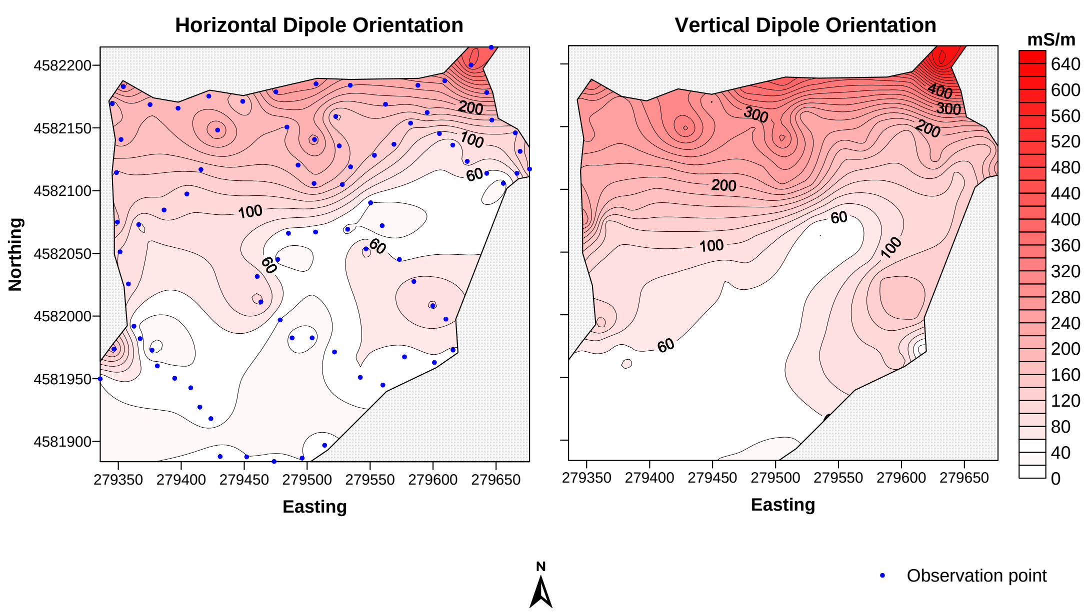

Figure 8. Plots of data collected at the Charlestown Breachway State Park with the GEM300 Sensor. The frequency is 9810 Hz.

Values of EC_a were highly variable across the investigated area. Because sampling was sparse (N=85) and widely spaced, computer interpolated plots are highly generalized. However, spatial patterns of EC_a are evident. Apparent conductivity increased toward tidal areas and away from higher-lying dunes (see figures 8 and 9). In general, EC_a increased and became more variable with increasing observation depth (lower frequency or vertical dipole orientation) (see Table 1). This trend indicates the presences of 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. The area having EC_a less than 60 mS/m is more restricted at lower soil depths (left-hand plot). This suggest a greater influence of salt water at lower soil depths.

Apparent conductivity averaged about 101 mS/m and ranged from about -7 to 394 mS/m at a frequency of 14670 Hz, in the horizontal dipole orientation (shallowest observation depth). One half the observations had values of EC_a between about 37 and 147 mS/m. At a frequency of 9810 Hz, in the vertical dipole orientation (deepest observation depth), EC_a averaged 174 mS/m and ranged from about 24 to 628 mS/m. One half the observations had values of EC_a between about 63 and 247 mS/m.

Table 1. Basic Statistics for EMI Survey

	9810V	9810H	14670V	14670H
Average	173.5	116.8	149.4	101.2
Standard Deviation	125.8	86.7	119.9	83.9
Minimum	24.00	6.50	15.	-7.1
Maximum	627.8	7.097	563.8	393.7
25% Quartile	63.0	49.4	50.3	37.0
75% Quartile	247.3	171.3	222.1	146.6

Procedures are available to plot geo-referenced EMI data onto aerial photographs using ArcView GIS. Figure 9 provides integrated examples from the survey area. In these plots, patterns of EC_a are easily identified and related to surrounding topographic, vegetative, and cultural features. Compared with the plots shown in Figure 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. The location of a small pond that is located in the survey area has been shown in the lower plot in Figure 9.

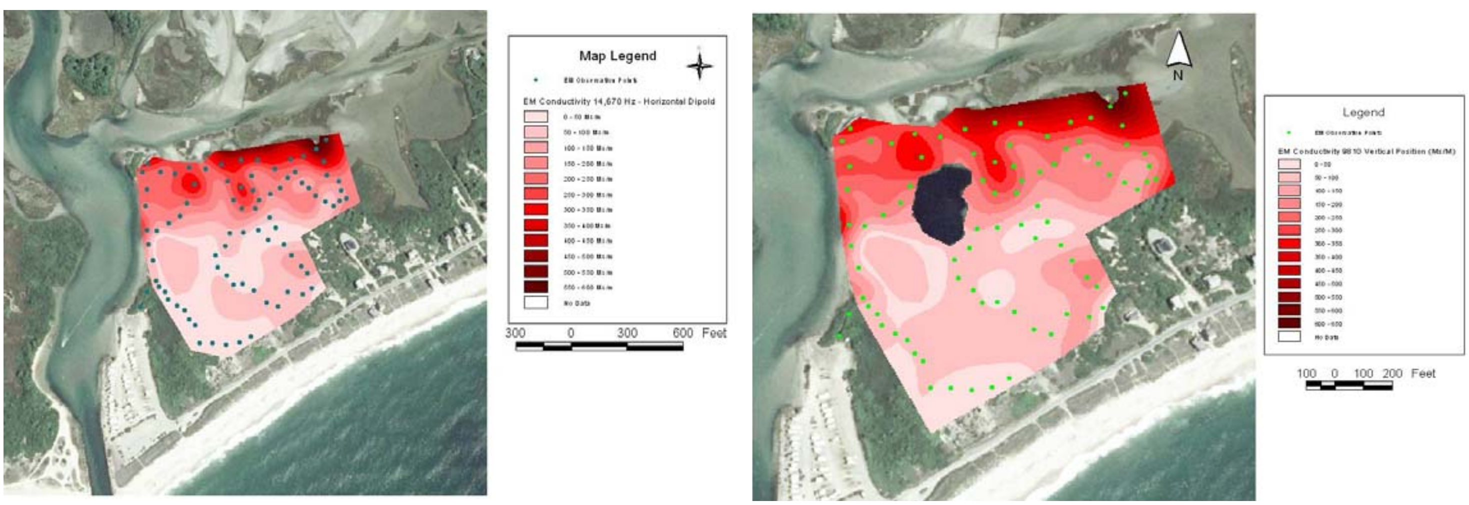

Figure 9. ArcView GIS images *of data collected at the Charlestown Breachway State Park with the GEM300 Sensor at a frequency of 14670 Hz (left-hand plot) and 9810 Hz (right-hand plot).*

While measured values of EC_a did vary slightly with different frequencies and dipole orientations, spatial patterns evident in the plots shown in figures 8, 9, and 10 are remarkable similar. As spatial patterns are similar, survey results can be presented using only one frequency to reduce processing and display preparation time. This similarity cast doubts on the value of multifrequency soundings. The use of one frequency with measurements taken in both the horizontal and vertical dipole orientation provides as much useful information as multi-frequency measurements taken in both dipole orientations.

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Table 1

Frequency Distribution of Organic Soil Material Thickness by Study Area

(All depths are in centimeters; "#" signifies number of observations)

Nell Pond

Depth	#	Freq.	Great Group
0 to 40	0	0.00	
40 to 130	8	1.00	Terric
>130	0	0.00	Typic
SUM	22		

Franks Big Pond

Depth	#	Freq.	Great Group
0 to 40	21	0.47	Histic epipedon
40 to 130	18	0.40	Terric
>130	6	0.13	Typic
SUM	45		

URI Peatland

Depth	#	Freq.	Great Group
0 to 40	3	0.14	Histic epipedon
40 to 130	3	0.14	Terric
>130	16	0.72	Typic
SUM	22		

Appendix
Summary of GPR Transect Data on Thickness of Organics

ELL POND

Obs.	Organics (m)
1	1.02
2	0.82
3	0.90
4	0.92
5	1.07
6	0.76
7	0.73
8	0.90

Franks Pond

Obs.	Organics (m)
1	0.20
2	0.35
3	0.92
4	1.14
5	0.57
6	0.15
7	0.12
8	0.55
9	1.18
10	1.50
11	1.17
12	0.20
13	0.20
14	0.20
15	0.34

Franks Pond

Obs.	Organics (m)
16	1.05
17	1.66
18	1.47
19	0.66
20	0.38
21	0.20
22	0.20
23	0.29
24	0.86
25	1.16
26	0.54
27	0.20
28	0.20
29	0.20
30	0.20
31	0.49
32	0.50
33	0.22
34	0.20
35	0.20
36	0.20
37	0.43
38	0.81
39	1.31
40	1.55
41	1.61
42	1.67
43	1.28
44	0.68
45	0.33

URI PEATLAND

Obs.	Organics (m)
1	0.80
2	1.17
3	1.38
4	1.44
5	0.88
6	0.24
7	0.36
8	0.35
9	2.17
10	3.45
11	3.93
12	3.47
13	3.66
14	4.40
15	4.96
16	5.25
17	3.33
18	3.37
19	4.96
20	4.96
21	5.05
22	4.00