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 2006

To: George W. Cleek
State Conservationist
USDA-NRCS
Federal Bldg.
2 Madbury Road
Durham, NH 03824-2043

Purpose:
The purpose of this visit was to work with Don Keirstead and provide advanced and progressive field training on the operation of the SIR-3000 ground-penetrating radar (GPR) unit. In addition, an electromagnetic induction (EMI) survey was completed of a tidal marsh with an EM38 meter, which has been loaned by the National Office to soil scientists working on subaqueous soils in New England. The EMI survey provided an opportunity to review the calibration of the EM38 meter, and the mechanics of data transfer and plotting.

Participants:
Scott Bailey, Geoecologist, USDA-FS, Campton, NH
Joel Detty, Graduate Student, Plymouth State University, Plymouth, NH
Dan Delea, Product Specialist, Geophysical Survey Systems, Inc., Salem, NH
Christian Doogan, Graduate Student, Plymouth State University, Plymouth, NH
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Donald Keirstead, Soil Conservationist, USDA-NRCS, Durham, NH
Kevin McGuire, Assistant Professor of Hydrology, Plymouth State University, Plymouth, NH
Michele Pruyn, Assistant Professor, Plant Biology Department, Plymouth State University, Plymouth, NH
Jim Turenne, Assistant State Soil Scientist, USDA-NRCS, Warwick, RI

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

Recommendations:

1. Don Keirstead is one of the best radar operators within NRCS. I am highly impressed by his skills with GPR.

2. GPR traverses were conducted in two remote areas within the USDA-Forest Service's Hubbard Brook Experiment Forest. While these sites proved hostile to GPR, lessons were learned on the use and operation of GPR in steeply sloping, rock-infested, forested watersheds.

3. An EM38 meter and data acquisition system has been purchased by the National Soil Survey Center and loaned to NRCS staffs in New England for use principally on subaqueous and salt-affected soils, and the assessment of contaminants emanating from agricultural waste sites. This technology is available to New Hampshire.

4. Geophysical Survey Systems, Inc. (Salem, NH) has developed a new EMI sensor, the *Profiler EMP-400*. GSSI learned of our scheduled field work in New Hampshire and took advantage of this occasion to conducted comparative field studies with our EM38 meter. This provided an opportunity for USDA-NRCS personnel to assess this newly developed sensor. A survey of a tidal marsh was conducted with the EM38 meter and Profiler EMP-400. While results of this survey are not completely available at this time,

participants were able to evaluate the operation of these two EMI sensors and assess their effectiveness and general suitability for the field work conducted by NRCS.

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

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, National Soil Survey Center, USDA-NRCS, 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
S. Hundley, State Soil Scientist, USDA-NRCS, Federal Bldg., 2 Madbury Road, Durham, NH 03824-2043
D. Keirstead, Soil Conservationist, USDA-NRCS, Federal Bldg., 2 Madbury Road, Durham, NH 03824-2043
B. Thompson, State Soil Scientist/MLRA Office Leader, USDA-NRCS, 451 West Street, Amherst, MA 01002-2995
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697

Equipment:
Radar data were collected with New Hampshire's TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[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. Both the 200 and 400 MHz antennas were used in the investigations that were conducted within the Hubbard Brook Experimental Forest.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program. Processing included: setting the initial pulse to time zero, header and marker editing, distance normalization, color transformation, range gain adjustments, migration, and terrain correction.

The EM38 meter is manufactured by Geonics limited (Mississauga, Ontario).[1] This meter weighs about 1.4 kg (3.1 lbs) and needs only one person to operate (see Figure 1). No ground contact is required with this instrument. 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 effective penetration depths of about 0.75 m and 1.5 m in the horizontal and vertical dipole orientation, respectively (Geonics Limited, 1998).

Figure 1. Jim Turenne completes an EMI survey with an EM38 meter and the DAS70 Acquisition System across an area of Tidal marsh along the Bellamy River near Dover.

The Geonics DAS70 Data Acquisition System is used with the EM38 meter to record and store both apparent conductivity (EC_a) and position data.[1] The acquisition system consists of the EM38 meter, an Allegro CX field computer (Juniper Systems, North Logan, UT), and a Garmin Global Positioning System (GPS) Map 76 receiver (with CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack)(Olathe, KS).[1] When attached to the acquisition system, the EM38 meter is keypad operated and measurements can be automatically triggered. The NAV38 and Trackmaker38 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EC_a and GPS data.

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] The grid of EC_a data shown in this report (see Figure 4) was

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

created using kriging methods with an octant search. Using ArcView 3.3[1], Don Keirstead overlaid EC_a data collected with the EM38 meter on recent aerial photographs of the Tidal Marsh site. This provided an alternative and preferred method of displaying EC_a data (see Figure 6).

Figure 2. Dan Delea of Geophysical Survey Systems, Inc., conducts an EMI survey across the tidal marsh area with the newly-developed Profiler EMP-400.

Study Site:

Hubbard Brook, Grafton County:

The Hubbard Brook Experimental Forest is a 3,160 hectare reserve located in the White Mountain National Forest of New Hampshire. This experimental forest is managed by the USDA-Forest Service-Northern Research Station and is a component of the Long Term Ecological Research (LTER) Network. This site has produced extensive data on forest and aquatic ecosystems hydrology, biology, geology, and chemistry. Radar surveys were conducted in two remotely-located research sites (see Figure 3 for general locations of radar traverse sites). As these sites were not accessible by trails, GPR and survey equipment had to be carried relatively long distances over rugged and fatiguing terrains.

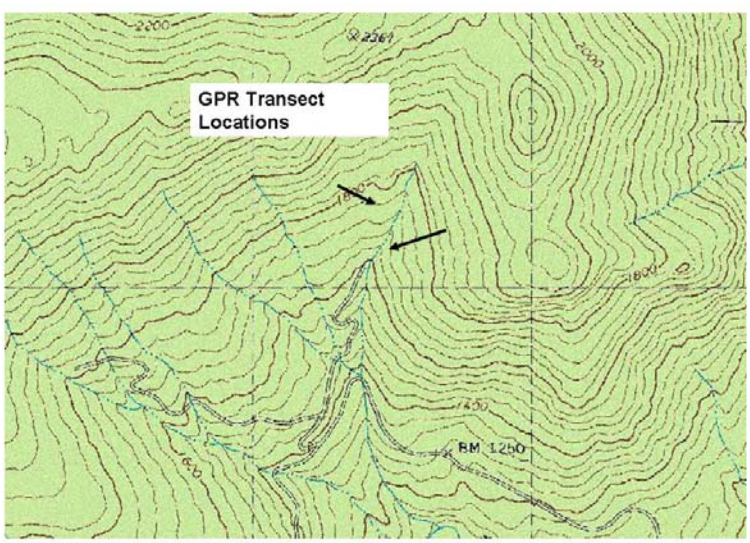

Figure 3. General locations of the two GPR traverse lines within Hubbard Brook.

Tidal Marsh Site, Strafford County:
The site (43.15408 N. Latitude, 70.857197 W. Longitude) is located in an area of Tidal marsh (Ta) near the Bellamy River in Dover, Strafford County, New Hampshire. A stream that meandered across the tidal marsh area was impassible and restricted the EMI surveys to one side of the tidal marsh.

Results:

Hubbard Brook:
The radar surveys at Hubbard Brook were conducted in steeply-sloping, rocky, forested terrains. This terrain is inhospitable to GPR field work. Steep and uneven slopes, large rock fragments, fallen debris, and tree limbs impeded GPR traverses even with the highly mobile, light-weight and compact SIR System-3000. The wider 200 MHz antenna frequently became lodged behind exposed larger rock fragments and between closely spaced tree limbs. It was exceedingly difficult to maintain ground contact with either the 400 or 200 MHz antenna. . Unwanted, spurious reflections were recorded as the antenna passed over fallen debris and rock fragments causing scattering losses and impairing the interpretation of radar records.

Because of adverse terrain and soil conditions, radar records were generally of poor interpretable quality. Point reflectors (mostly buried rock fragments and tree roots) caused excessive signal scattering losses and numerous, unwanted point reflectors that masked the presence and continuity of soil and bedrock interfaces. Soil horizons are weakly developed in these soils and produce poorly expressed reflectors on radar records. The contact with the dense till and the underlying parent rock did provide more continuous and traceable interfaces on radar records. The higher-frequency 400 MHz antenna was more suitable for fieldwork and provided more interpretable radar imagery than the deeper-sensing 200 MHz antenna in this setting.

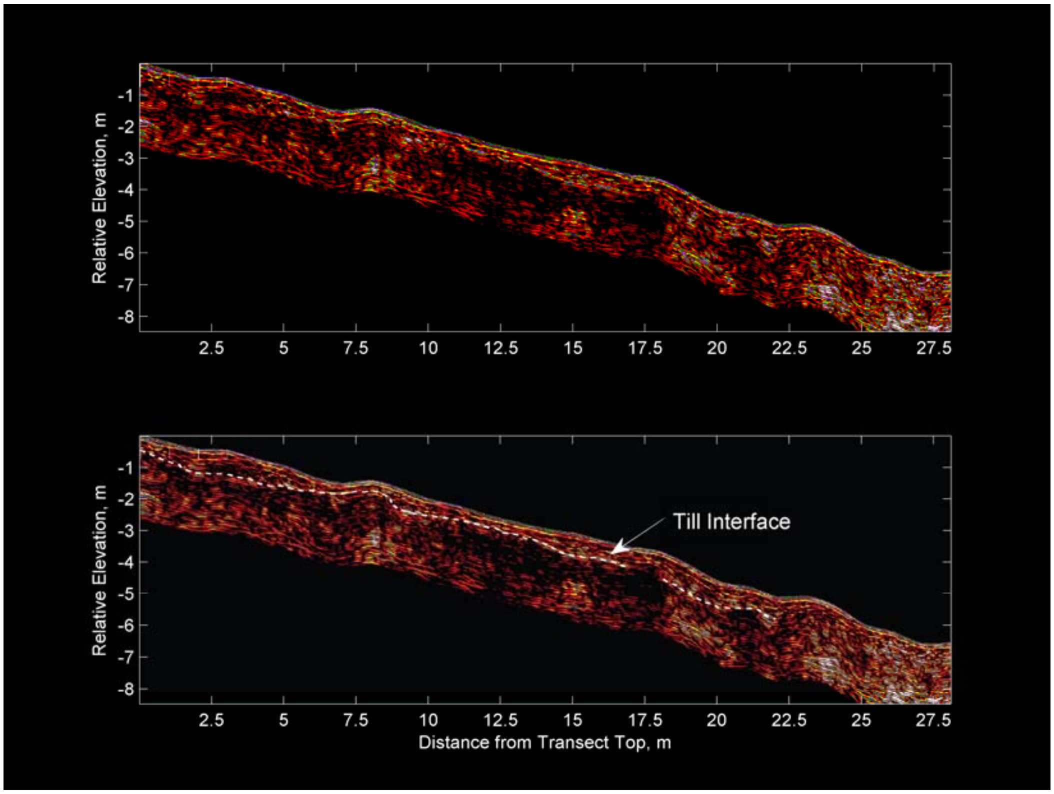

Figure 4. Radar record collected with the 400 MHz antenna at Hubbard Brook. Lower plot shows the interpretation of Dr Kevin McGuire of Plymouth State University.

Figure 4 contains two plots of the same radar traverse that was completed with the 400 MHz antenna. Both plots are identical; the bottom plot has been interpreted and annotated by Dr Kevin McGuire of Plymouth State

University. In these plots, the radar record has been *terrain corrected* to improve the visual presentation. Through a process known as *surface normalization*, measured elevations are assigned to each reference point (in the field, flagged position spaced at 1-m intervals) and the image is corrected according to these measured changes in relief. Surface normalization helps to improve the interpretative quality of radar records and the association of subsurface reflectors with landscape components. In Figure 4, the vertical scale has been compressed relative to the horizontal scale.

In the lower plot (see Figure 4), Dr McGuire has highlighted an interface that is believed to represent the contact of surficial soil materials with the underlying dense till. A deeper (1.5 to 2.7 m), more poorly expressed interface is believed to represent the bedrock interface. An area with excessive amounts of rock debris was traversed in the lower-lying, right-hand portion of the radar traverse (between the 2 and 28 m marks). This boulder-infested area adjoins an intermittent stream channel. On the radar record, this boulder-infested area is characterized by numerous, segmented, high amplitude (colored white in Figure 4) 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 National Office anticipates that soil scientists in New England will develop protocol for conducting EMI surveys on subaqueous soils.

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 were very high (averaged 448 mS/m) and variable (standard deviation of 200.9 mS/m) across the surveyed area of *Tidal marsh*. EC_a ranged from about 14 to 916 mS/m. One-half of the measurements had an EC_a that was between 278 and 594 mS/m. As EC_a is directly related to the concentration of soluble salts, spatial patterns evident in Figures 5 and 6 are assumed to reflect different degrees of soil salinity. Areas with higher EC_a are assumed to be more saline. Although sampling was relatively sparse (N=1612), and widely and unevenly spaced (see Figure 5 for locations of measurement points and EMI traverse lines), EC_a and associated salinity generally increase towards the source of the salinity (tidally influenced Bellamy River is located to the right or east), and away from the edges of the marsh. However, as evident in both figures, pockets of contrasting salinity exists throughout the survey area, signifying areas of contrasting hydropedologic properties.

Because of the increased emphasis on subaqueous soils, the availability electromagnetic induction sensors renders assistance to soil scientists tasked with mapping electrically conductive soils, and assessing saline soil conditions in areas of tidal marshes. While conducting this EMI survey of a *Tidal marsh*, relationships between apparent conductivity and the vegetation and micro-topography were observed. The use of EMI can provide an additional layer of soil information and greater understanding of the distribution of salts within areas mapped as *Tidal marsh*.

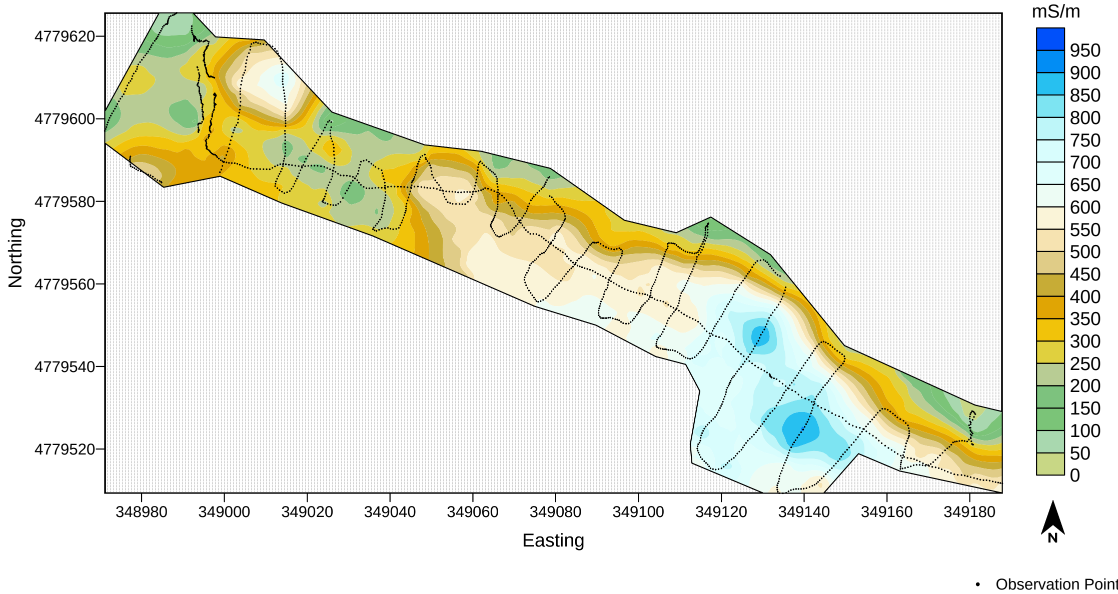

Figure 5. Plot of EC$_a$ *data collected in an area of Tidal marsh near Dover with the EM38 meter (Operated in the vertical dipole orientation).*

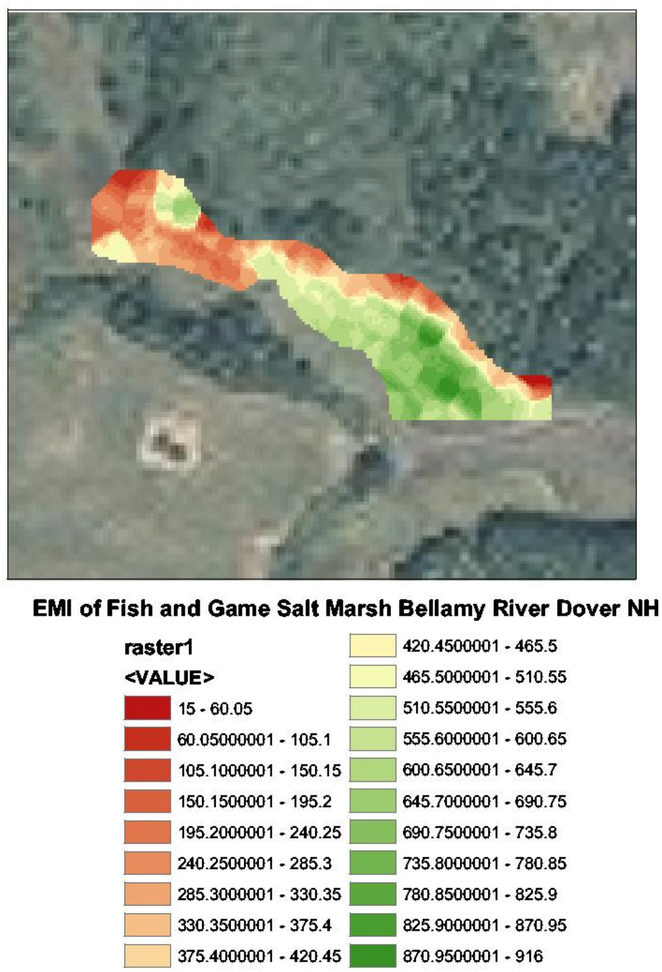

Figure 6. Alternative plot of the EC$_a$ *data collected with the EM38 meter at the Tidal Marsh Site. This image was prepared by Don Keirstead using ArcView GIS.*

References:

Geonics Limited, 1998. EM38 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario.

Greenhouse, J. P., and D. D. Slaine, 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2): 47-59.

Kachanoski, R. G., E. G. Gregorich, and I. J. Van Wesenbeeck, 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

Kruse, S. E., M. R. Brudzinski, and T. L. Geib, 1998. Use of electrical and electromagnetic techniques to map seawater intrusion near the Cross-Florida Barge Canal. Environmental & Engineering Geosciences 4(3): 331-340.

Lee, S-H., K-W. Kim, I. Ko, S-G Lee and H-S Hwang, 2002. Geochemical and geophysical monitoring of salinewater intrusion in Korea paddy fields. Environmental Geochemistry and Health 24: 277-291.

Meadows, D. G., J. P. Caballero, S. E. Kruse, and H. L. Vacher, 2004. Variation of salinity in brackish-water lenses of two Florida Keys. Journal of Coastal Research 20(2): 386-400.

Rhoades, J. D., P. A. Raats, and R. J. Prather, 1976. Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci. Soc. Am. J. 40:651-655.

Sam, R. and P. Ridd, 1998. Spatial variations of groundwater salinity in a mangrove-salt flat system, Cocoa Creek, Australia. Mangroves and Salt Marshes 2: 121-132.

Williams, B. G., and G. C. Baker, 1982. An electromagnetic induction technique for reconnaissance surveys of soil salinity hazards. Australian Journal of Soil Res. 20: 107-118.

Wollenhaupt, N. C., J. L. Richardson, J. E. Foss, and E. C. Doll, 1986. A rapid method for estimating weighted soil salinity from apparent soil electrical conductivity measured with an aboveground electromagnetic induction meter. Can J. Soil Sci. 66:315-321.