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

Subject: Soils – Geophysical Field Assistance **Date:** 18 August 2009

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 conduct electromagnetic induction (EMI) surveys of two agricultural waste sites in Grafton County. During this visit setup, calibration, and survey procedures for the newly acquired EM38MK2-1 meter were reviewed with Don Keirstead.

Participants:
Dean Bascom, District Conservationist, USDA-NRCS, Woodsville, NH
Dan Delea, Application Specialist, Geophysical Survey Systems, Inc., Salem, NH
Donna Doel, Soil Conservationist, USDA-NRCS, Woodsville, NH
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Brian Jones, Application Specialist, Geophysical Survey Systems, Inc., Salem, NH
Don Keirstead, Resource Conservationist (Ecology), USDA-NRCS, Durham, NH

Activities:
All activities were completed during the period of 12 and 13 August 2009.

Summary:

1. This brief visit allowed Don Keirstead and me to conduct electromagnetic field work together and discuss the operation of different EMI tools and the interpretations of collected field data. Based on observations and concerns made during the conduct of the EMI surveys in Grafton County, the second day of this visit was spent reviewing and discussing EMI calibration (both manual and automatic), software menus and settings, and field procedures.

2. Electromagnetic induction (EMI) surveys were completed at two sites in Grafton County, New Hampshire. These surveys revealed higher apparent conductivity (EC_a) levels in areas suspected to have larger concentrations of animal wastes. These surveys revealed the extent of suspected ground contamination detectable with EMI meters. Maps of EC_a may be used to improve existing and/or install additional manure storage facilities and other barnyard improvements.

3. Comparative EMI surveys were completed with the EM31and EM38MK2-1 meters developed by Geonics Limited (Mississauga, Ontario) and the Profiler 400-EMP sensor developed by Geophysical Survey Systems, Inc. (Salem, NH). Results from these surveys were closely similar.

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:
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
J. Hempel, Director, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
D. Hvizdak, State Soil Scientist/MLRA Office Leader, USDA-NRCS, 451 West Street, Amherst, MA 01002-2995
D. Keirstead, Soil Conservationist, USDA-NRCS, Federal Bldg., 2 Madbury Road, Durham, NH 03824-2043
K. McCracken, Assistant State Conservationist, USDA-NRCS, Federal Bldg., 2 Madbury Road, Durham, NH 03824-2043
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697
L. West, National Leader, Soil Survey Research and Laboratory Staff, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866

Background into Animal Waste Holding Structures:
The effectiveness of electromagnetic induction (EMI) to detect contaminant plumes emanating from waste-holding facilities were evaluated at two farms in New Hampshire. While NRCS provides technical assistance for their construction, the agency seldom monitors the effectiveness of installed animal-waste holding structures, which are designed to contain and limit overland flow and seepage of contaminants. The relatively coarse-textured soils of New Hampshire pose a severe risk for potential seepage of contaminants from improperly installed or operated waste-holding facilities.

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

Electromagnetic induction measures vertical and lateral variations in EC_a. Values of EC_a are seldom diagnostic in themselves. However, lateral and vertical variations in EC_a can be used to infer changes in soils and soil properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used. 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 contaminants emanating from waste-storage facilities and barnyards. Maps prepared from properly interpreted EMI data provide the basis for assessing site conditions and locating sampling or monitoring sites.

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

Equipment:
The EM31, EM38MK2-1, and Profiler EMP-400 meters were used in this study. The EM31 and EM38MK2-1 meters (see Figure 1) are manufactured by Geonics Limited (Mississauga, Ontario).[1] Both meters require only one person to operate. No ground contact is required with either meter. Lateral resolution is approximately equal to the meter's intercoil spacing. Apparent conductivity is typically expressed in milliSiemens/meter (mS/m).

McNeill (1980b) has described the principles of operation for the EM31 meter. The EM31 meter has a 3.66-m (12-ft) intercoil spacing and operates at a frequency of 9,810 Hz. The meter weighs 12.4 kg (27 lbs). When placed on the soil surface, the EM31 meter provides theoretical penetration depths of about 6-m (19-ft) in the vertical dipole orientation (McNeill, 1980b).

The EM38-MK2-1 meter operates at a frequency of 14,500 Hz and weighs about 5.4 kg (11.9 lbs). The meter has one transmitter and receiver coil that are separated at a distance of 1.0 m. This configuration provides nominal penetration depths of about 1.5 and 0.75 m in the vertical and horizontal dipole orientations, respectively. The EM38-MK2-1 meter, in either dipole orientation, provides measurements of both the quadrature-phase (EC_a) and the in-phase (susceptibility) components. Operating procedures for the EM38-MK2-1 meter are described by Geonics Limited (2007).

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

The Geonics DAS70 Data Acquisition System is used with the Geonics Limited's EMI meters to record and store both EC_a and position data.[1] The acquisition system consists of an EMI meter, an Allegro CX field computer (Juniper Systems, North Logan, UT), and either a Garmin Map76 or Trimble AG114 GPS receiver (with antenna, and accessories that are fitted into a backpack; see Figure 1) (Garmin International, Inc. Olathe, Kansas; Trimble Navigation limited, Sunnyvale, California).[1]

The Profiler EMP-400 multi-frequency conductivity meter is manufactured by Geophysical Survey Systems Inc (Salem, NH). This system is comprised of a transmitter, receiver, electronics enclosure, and PDA. The meter weighs 5.5 kg (9.9 lbs), has a 1.21 m (4 ft) intercoil spacing. It is charged by a re-chargeable Lithium Ion battery or 8 (eight) AA batteries. The Profiler EMP-400 multi-frequency conductivity meter (see Figure 2) can be configured to simultaneously measure up to 3 frequencies between 1000 Hz and 16,000 Hz, in either the vertical or horizontal dipole mode. All survey acquisition parameters, GPS coordinates and EMI data are stored in an internal memory. Files are structured in Excel spreadsheet format (ASCII text file) for simple downloading to a PC for presentation in GIS.

To help summarize the results of the EMI surveys, SURFER for Windows, version 8.0 (Golden Software, Inc., Golden, CO), was used to model the EC_a data.[2]

Figure 1. Jim Doolittle operates EM31 meter as Don Keirstead pauses momentarily in his survey with an EM38MK2-1 meter.

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

Figure 2. Brian Jones of GSSI operates a Profiler EMP-400 multi-frequency sensor.

Results of the surveys conducted with the EM31, EM38MK2-1, and Profiler EMP-400 meters were similar. Because of the similarity of results, only the results of the EMI survey conducted with the EM31 meter will be discussed in this report.

Sites:
Two sites in Grafton County were surveyed with EMI. The first site is located on the farm of Gary Peters that is off of Goose Lane Road in Woodsville, New Hampshire. This dairy farm has approximately 45 heads of Holsteins. Manure is stored on a concrete stacking pad. Runoff from the barnyard and stacking pad, however, often flows into a roadside ditch. The runoff is then directed and flows through a culvert pipe into a corn field on the other side of Goose Lane Road. The survey area is located in a field of corn (see Figure 5) and in a delineation of Groveton fine sandy loam, 0 to 3 % slopes (27A). The very deep, well drained Groveton soils formed in loamy deposits overlying sandy sediments on stream terraces.

Table 1. Taxonomic classifications of the soils mapped within the EMI survey areas.

Soil Series	Taxonomic Classification
Groveton	Coarse-loamy, isotic, frigid Typic Haplorthods
Lyman	Loamy, isotic, frigid Lithic Haplorthods
Marlow	Coarse-loamy, isotic, frigid Oxyaquic Haplorthods
Pillsbury	Coarse-loamy, mixed, active, acid, frigid Aeric Epiaquepts
Tunbridge	Coarse-loamy, isotic, frigid Typic Haplorthods

The second site is at the farm of Mark Morrison, which is located on Littleton Road in Monroe, New Hampshire (see Figure 3). Mark Morrison operates a certified organic dairy with approximately 50 heads of mixed breed Jersey-Holstein. The present manure storage is inadequate and long-term barnyard issues of traffic and roof-runoff have contributed to nutrient runoff into an adjacent wetland/ wet meadow. In addition, milk-house waste-water discharges into this wetland/ wet meadow. Mark will be applying for assistance to install a manure storage facility and other barnyard improvements.

Figure 3. This soil map from the Web Soil Survey shows the area that was surveyed at the Morrison Farm.

The area surveyed at the Mark Morrison farm is in pasture. The survey area was principally located in a delineation of Tunbridge-Lyman complex, 8-15 % slopes (90C), but included areas of Marlow fine sandy loam, 15-25% slopes (76D), and Tunbridge-Lyman complex, 3-8 % slopes (90B). A large wetland area of Pillsbury fine sandy loam, 0-3 % slopes, very stony (647A), is located to the east and south of the survey area. The shallow, somewhat excessively drained Lyman and the moderately deep, well drained Tunbridge soils formed in a thin mantle of till overlying frost fractured schist, phyllite, granite or gneiss bedrock on glaciated uplands. The well drained Marlow soils formed in loamy till on glaciated uplands. Marlow soils are moderately deep to a densic contact and very deep to bedrock. The very deep, poorly and somewhat poorly drained Pillsbury soils formed in compact, loamy till on glaciated uplands. Pillsbury soils are shallow or moderately deep to a densic contact and very deep to bedrock. Because of low clay and soluble salt contents, and the relatively shallow depths to electrically resistive bedrock, these soils have low apparent conductivity. Because of wetness caused by a perched, fluctuating water table that is at or near the soil surface, Pillsbury soils should have a slightly higher conductivity. The taxonomic classifications of the soils named at each site are listed in Table 1.

Results:

Table 2 lists the basic statistics for the EMI surveys that were completed at both sites with the EM31 meter. In general, values of EC_a were relatively low at each site. These values are representative of soils that have formed in electrically resistive materials with low clay contents. At the Peter's Farm, in an area of Groveton soils, EC_a averaged about 4.4 mS/m with a range of -1.4 to 15.2 mS/m. One-half of the EC_a measurements were between 1.9 and 6.7 mS/m. Negative EC_a values reflect the presence of small metallic artifacts that are either on the surface or buried within the site. Evidently, the EM31 meter passed close enough to these artifacts to elicit these negative EMI responses. At the Morrison's Farm, soil, terrain, and site conditions were more variable. This variability is manifested in a higher averaged (about 11.0 mS/m) and more variable (range of -13.0 to 95.4 mS/m) EC_a. At the Morrison's Farm, one-half of the EC_a measurements were between 5.8 and 13.2 mS/m.

Table 2. Basic statistics for the EMI surveys that were conducted at the Gary Peters' and Mark Morrison's Farms in Grafton County, New Hampshire with the EM31 meter operated in the vertical dipole orientation.

	Peters Farm	***Morrison Farm***
Number	925	1399
Minimum	-1.40	-13.03
25%-tile	1.90	5.80
75%-tile	6.70	13.20
Maximum	15.20	95.40
Mean	4.44	10.99
Standard Deviation	3.22	8.55

Figures 4 show two plots of EC_a data collected with the EM31 meter in the deeper-sensing (0 to 5 m), vertical dipole orientation at the two sites. The same color ramp, but different scales have been used in these plots. In each plot, the black-colored and possibly the dark blue-colored polygons are assumed to represent natural background levels of EC_a.

At the Peters' Farm site (upper plot in Figure 4), the EMI survey was restricted on the south by Goose Lane Road. In Figure 4 (upper plot), the white-colored line extending into the field from Goose Lane Road represents the location of the offending culvert. This culvert is indicated by a black arrow in Figure 5. Also evident in Figure 5 is the portion of the corn field that is most noticeably affected by the animal wastes.

In Figure 4 (upper plot), a white arrow indicates the direction (northwest) of observed surface runoff across the field. Spatial patterns in this plot do confirm that a zone of higher EC_a (> 10 mS/m) does extend outwards in a west north-westerly direction from the culvert. A larger zone of moderate EC_a (6 to 10 mS/m) appears to extend outwards from the culvert, but more noticeably along the road in an east south-easterly direction. While the reasons for this zone are unclear, the pattern may be attributed to deeper seepage, the affects of road salts, or variations in soil properties. While the area most affected by animal wastes is evident in this plot, the concentrations of wastes mapped by EMI must be determined by ground-truth measurements.

At the Morrison's Farm site (lower plot in Figure 4), the EMI survey revealed comparatively high (>25 mS/m) values of EC_a adjacent to the loafing area for the herd and the manure piles. In addition two areas of livestock gathering are evident: 1) along the crest of the ridge near the loafing area (see "A" in Figure 4), and 2) at a feeder located midway down a side slope (see "Feeder" in Figure 4). These areas have conspicuous accumulations of animal-wastes on the soil surface, which contribute to these higher EC_a. A noticeable plume-like pattern extends in a south south-westerly, down slope direction from the area of the manure piles, past the feeders, and into the adjoining wetland area (see arrow in lower plot of Figure 4). Values of apparent conductivity within this plume-like strip are only between 10 and 15 mS/m, but are higher than the more unaffected (by waste products) background areas in this plot, which are less than 10 mS/m. As this strip of higher EC_a contains several wetter, seepage areas, the cause of the increased conductivity can be attributed to greater moisture and/or nutrient contents. Once again, EMI has provided evidence of the spatial distribution of contaminants, but conclusions as to the significance of these patterns must await ground-truth sampling and verification.

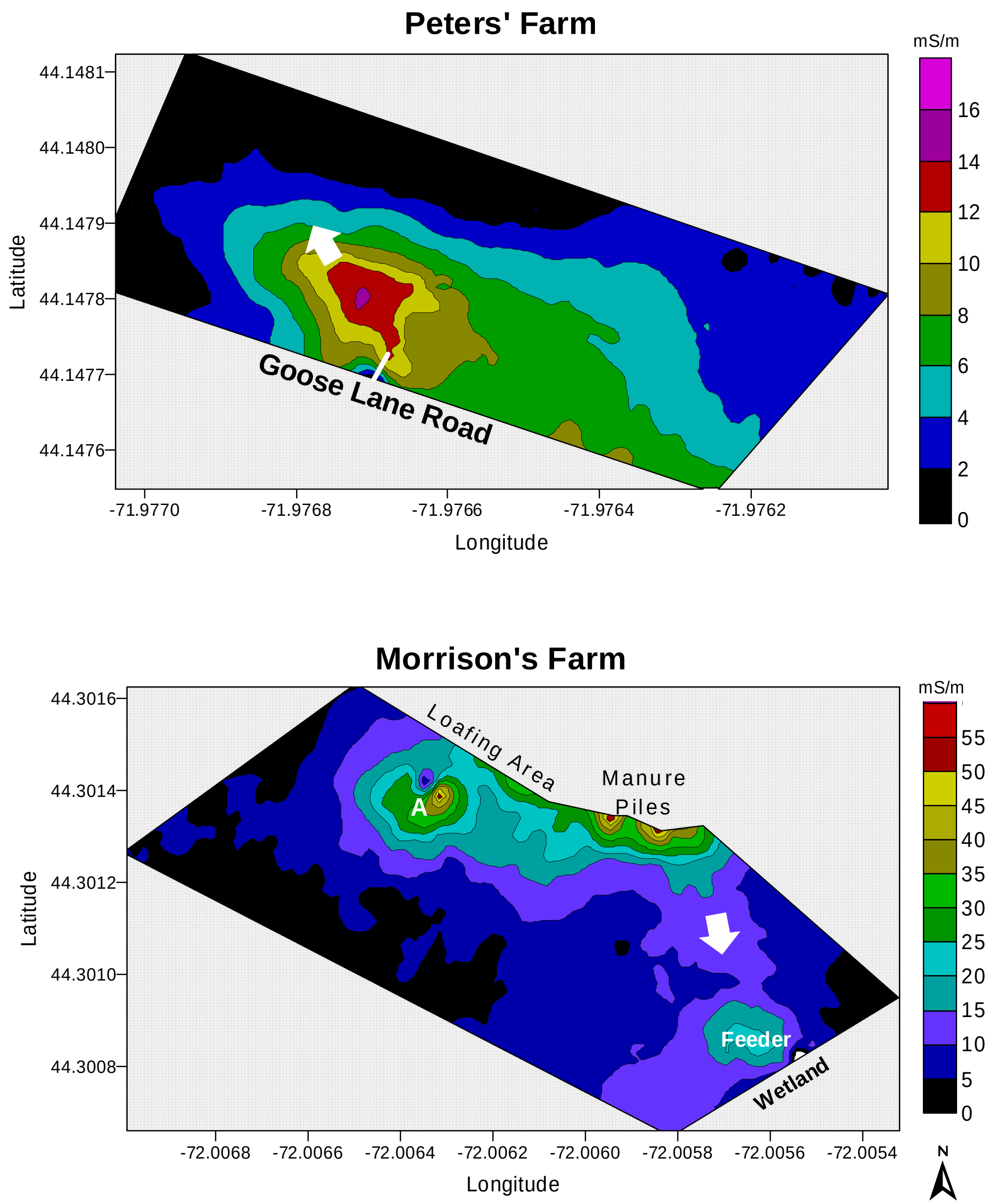

Figure 4. Plot of EC$_a$ *data collected with the EM31 meter operated in the vertical dipole orientation ay the Peters'(upper plot) and Morrison's (lower plot) Farms.*

Figure 5. This image shows the portion of the Peters' corn field that is most affected from discharge of animal wastes from a culvert (see arrow).

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