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: ENG -- Electromagnetic Induction (EMI) Assistance **Date:** 1 August 2006

To: Ronald R. Alvarado
State Conservationist
USDA-NRCS,
441 S Salina Street Room 520
Syracuse, NY 13202-2450

Purpose:

Electromagnetic induction (EMI) was used to assess the structural integrity and potential seepage from an animal waste lagoon in Otsego County, New York.

Participants:

Tony Capraro, District Conservationist, USDA-NRCS, Cooperstown, NY
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Dave Sullivan, State Geologist, USDA-NRCS, Syracuse, NY
Olga Vargas, Soil Scientist, USDA-NRCS, Greenwich, NY
William VanDeValk, Area Engineer, USDA-NRCS, Albany, NY

Activities:

This EMI survey was completed on 25 July 2006.

Observations:

1. Elevated values (15 to 40 mS/m) of soil EC_a are largely confined to the embankment of the manure storage lagoon and adjacent to farm structures. These areas are relatively extensive and believed to be caused by excess levels of animal wastes. An extensive pattern of moderate (15 to 20 mS/m) EC_a extends outwards from the northeastern side of the lagoon and the eastern side of farm structures.

2. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil sampling). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations.

3. All geo-referenced EMI data from this survey have been forwarded to Dave Sullivan and William VanDeValk by e-mail.

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

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:

R. Ahrens, Director, National Soil Survey Center, USDA-USDA, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866

T. Capraro, District Conservationist, USDA-NRCS, 967 County Highway 33, Cooperstown, NY 13326-4744

M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250

D. Hammer, National Leader for Soil Investigations, USDA-USDA, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866

D. Sullivan, State Geologist, USDA-NRCS, The Galleries of Syracuse, 441 South Salina Street, Suite 354,Syracuse, New York 13202-2450

W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 60, Federal Building, Room G-08, 207 West Main Street, Wilkesboro, NC 28697

P. Wright, Supervisory Civil Engineer, USDA-NRCS, The Galleries of Syracuse, 441 South Salina Street, Suite 354, Syracuse, New York 13202-2450

W. VanDeValk, Area Engineer, USDA-USDA, Leo O’Brien Federal Bldg., Room 333, Albany, NY

O. Vargas, Soil Scientist, USDA-NRCS, 2530 State Route 40, Greenwich, NY 12834-9627

Background:

Animal waste holding facilities provide economical means of handling large quantities of wastes from livestock operations. The perimeter areas of properly designed and constructed waste-holding facilities are assumed to self-seal within two to twelve months of operation (Swell et al., 1975; Miller et al., 1985). However, in some facilities, all areas do not effectively seal resulting in the discharge of contaminants. Brune and Doolittle (1990) describe these non-sealing events as being sporadic and unpredictable.

Electromagnetic induction (EMI) is a noninvasive geophysical tool that has been used to assess the structural integrity and detect contaminant plumes emanating from waste-storage facilities. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features.

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 produced by differences in the electrical conductivity of earthen materials. Electrical conductivity is influenced by 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 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. Computer simulated plots of EC_a data provide the basis for assessing site conditions and locating sampling or monitoring sites.

Electromagnetic induction has been used to investigate the migration of animal wastes (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 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 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 and EM38 meters were used in this study. These meters are manufactured by Geonics Limited (Mississauga, Ontario).[1] These meters need only one person to operate and require no ground contact. Lateral resolution is approximately equal to the intercoil spacing of the meter.

The EM31 meter weighs about 9 kg (19.9 lbs). McNeill (1980b) has described the principles of operation for the EM31 meter. The EM31meter has a 3.66 m (12 ft) 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 6 m (19 ft) in the vertical dipole orientation (McNeill, 1980b).

The EM38 meter weighs about 1.4 kg (3.1 lbs). 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 a theoretical penetration depth of about 1.5 m in the vertical dipole orientation (Geonics Limited, 1998).

The Geonics DAS70 Data Acquisition System was used with each EMI meter to record and store both EC_a and GPS data.[1] The acquisition system consists of either an EM31 or EM38 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, each EMI meter is keypad operated and measurements can either be automatically or manually triggered.

To help summarize the results of this survey, SURFER for Windows (version 8.0) software (Golden Software, Inc., Golden, Colorado) was used to construct two-dimensional simulations.[1] Grids of EC_a data were created using kriging methods with an octant search.

---

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

Survey Site:

The manure storage lagoon is located at the Kawapache Farm in Otsego County, New York. This farm is located about 5 km southwest of Richfield Springs, along County Highway 25. In 2001, the USDA-NRCS provided technical assistance for the construction of the waste storage lagoon. However, doubts exist as to whether the structure was constructed according to the design specifications. Prior to construction, a core sample was obtained and delivered to Atlantic Testing Laboratories, Inc., in Utica, New York. Results from a constant head permeability test were not conclusive due to the non-plastic consistency of the sample. As a consequence, it was recommended that the relatively coarse grained sediments at the site should be packed down with a sheep foot roller in order to meet design specifications for compaction. It is uncertain whether the site was adequately compacted with the sheep foot roller.

Figure 1. View from the west of the manure storage lagoon (higher ground enclosed by fence) and farm structures in the background (northeast).

Figure 2. View from the south of the manure storage lagoon (higher ground enclosed by fence) with farm structures in the background (north).

The manure storage lagoon is located in area of Lansing silt loam, 3 to 8 percent slopes. The very deep, well drained Lansing soils formed in glacial till derived from limestone and calcareous shale. Lansing is a member of the fine-loamy, mixed, active, mesic Glossic Hapludalfs family. Lansing soil is described as having moderate permeability within the solum and slow permeability within the substratum. Because of a somewhat limited risk of seepage, Lansing soil is rated as having moderate potential for lagoons (USDA-NRCS Soil Data Mart).

Field Procedures:

Separate surveys were conducted with each meter. Each meter was operated in vertical dipole orientation and 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. The EM38 meter was held about 5 cm (2 inches) above the ground surface and orientated with its long axis parallel to the direction of traverse. Each survey was completed by walking at a rather slow and uneven pace, in a random back and forth pattern across the more accessible portions of survey area. Cultural features, such as buildings, farm implements, and fence lines, were avoided where possible. Areas accessible to EMI were restricted at this site. The survey was hindered by multiple fence lines, dense undergrowth and uneven ground surfaces. Farm buildings, machinery and other artifacts were present within the survey area and produced unwanted background noise if approached too closely (see Figures 1 & 2).

A larger area was surveyed with the deeper-sensing (0 to 6 m) EM31 meter than with the shallower-sensing (0 to 1.5 m) EM38 meter. The EM31 meter was used to locate potential areas of seepage; the EM38 meter was used to assess overland flow from the manure storage lagoon. Recent catastrophic rains have caused the manure storage lagoon to overflow in some areas. Standing waters were observed adjacent to the structure and along drainage lines (see Figure 3).

Figure 3. View from the south of the manure storage lagoon (area on right that is enclosed by a fence) showing areas with standing water.

Results:

Both data sets (EM31 and EM38 data) were culled of anomalously high and low (negative) numbers that were clearly linked to inference from cultural features. Basic statistics for each meter are listed in Table 1.

Based on 3186 measurements obtained with the EM31 meter, EC_a averaged 13.3 mS/m with a range of -75.1 to 67.6 mS/m. At one-half of the observation points, the EC_a was between 9.7 and 15.4 mS/m. For areas of Lansing soil, EC_a of less than 15 mS/m are considered expected, and represent background levels. Areas of standing water did not seem to have an effect on EC_a measurements. Elevated EC_a was evident along the embankment of the manure storage lagoon. Some anomalously high EC_a readings were attributed to passing too close to the encompassing fence or crossing a concrete pad, which was located in the northwest corner of the lagoon (see Figure 5).

Table 1.

Basic statistics for EMI surveys conducted with the EM31 and EM38 meters.
(With the exception of the number of observations, all values are expressed in mS/m.)

	EM31V	EM38V
Number	3186	1097
Minimum	-75.08	-7.88
Maximum	67.60	60.00
25 %-tile	9.70	6.88
75 %-tile	15.40	13.00
Mean	13.34	10.58
Standard Deviation	6.70	6.15

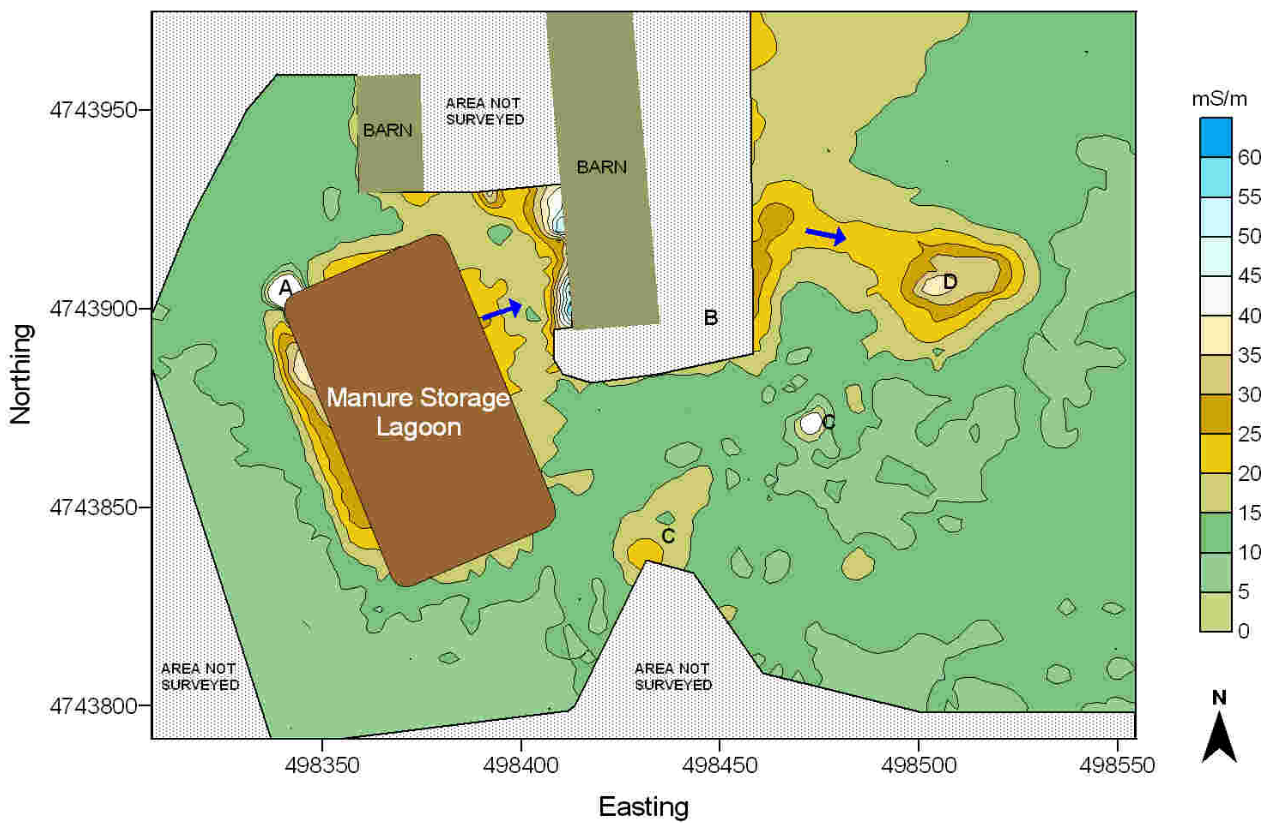

Figure 4. Plot of EC_a data collected with the EM31 meter in the vertical dipole orientation.

Figure 4 contains the plot of EC_a data collected with the EM31 meter. Areas with anomalously high (> 40 mS/m) EC_a are principally confined to the northwest portion of the lagoon and adjacent to farm structures. Interference from cultural features (fence, concrete pad, and barns) was observed in these areas during surveying. Elevated values (15 to 40 mS/m) of soil EC_a are largely confined to the embankment of the manure storage lagoon and adjacent to farm structures. These areas are relatively extensive and believed to be caused by excess levels of animal wastes. Rather extensive, patterns of moderate (15 to 20 mS/m) EC_a extend outwards from the northeastern side of the lagoon and moderately-high (20 to 30 mS/m) EC_a from the eastern side of the larger farm structure shown in Figure 4. The pattern adjoining the eastern side of the farm structure may be associated with an earlier "blow-out" from a below-ground waste-storage structure located near "B" in Figure 4. This pattern extends towards and area ("D" in Figure 4) where animal wastes were recently discarded or stacked on the surface. Arrows have been drawn on this plot to indicate direction of inferred flow. Insular livestock loafing areas adjacent to fences ("C" in Figure 4) were identified. These areas display high EC_a associated with higher levels of animal wastes.

Figure 5 shows the concrete pad that is located on the northwest corner of the manure storage lagoon. Here, EMI traverses approached the fence (with gate) too closely and crossed the concrete pad (with standing water and manure). These factors were responsible for the anomalous EC_a that was observed at "A" in Figure 4.

Figure 5. Anomalously high ECa were observed in this corner of the manure lagoon. The metal fence and concrete pad produced unwanted interference and caused the elevated EMI responses.

Based on 1097 measurements obtained with the EM38 meter, EC_a averaged 10.6 mS/m with a range of -7.9 to 60.0 mS/m (see Table 1). At one-half of the observation points, the EC_a was between 6.9 and 13.0 mS/m.

Figure 6 contains the plot of EC_a data collected with the EM38 meter. This survey was conducted principally to assess surface discharge from the manure storage lagoon. Once again, areas with anomalously high (> 40 mS/m) EC_a are confined to the northwest corner of the lagoon (see "A" Figure 6) and adjacent to farm structures (see "B" in Figure 6). As previously noted, interference from cultural features (fence, concrete pad, and barns) was observed in these areas during surveying. Arrows have been drawn on this plot to indicate direction of inferred flow through the upper 1.5 m of the reworked embankment materials. On the northeast side of the lagoon, areas of moderate (15 to 20 mS/m) EC_a are more restricted in the shallower-sensing EM38 data (Figure 6) than in the deeper-sensing EM31 data (Figure 4). This vertical trend suggests more conductive materials with depth.

Elevated EC_a was evident in the EM38 data along the higher-lying portions of the manure storage lagoon's embankment. Two areas on the down slope side of the lagoon (right-hand side in Figure 6) suggest possible routes of discharge from the lagoon. In Figure 2, these areas have been highlighted with directional arrows.

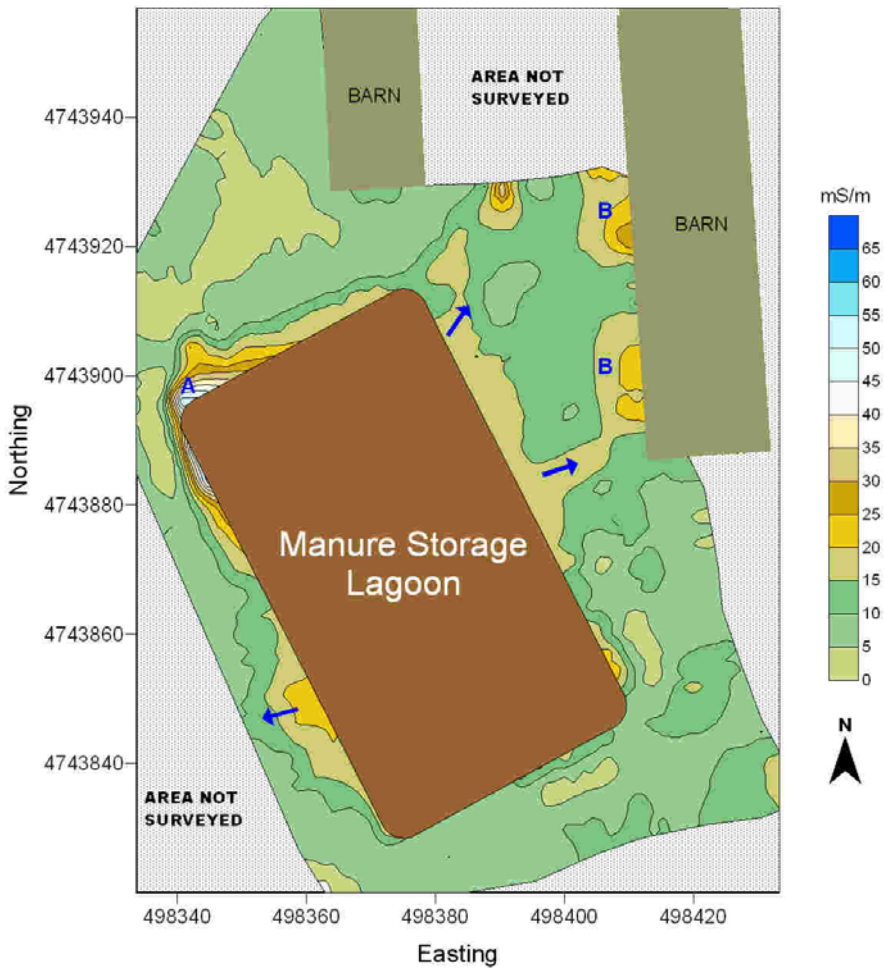

Figure 6. Plot of EC_a data collected with the EM38 meter in the vertical dipole orientation.

References:

Brune, D. E. and J. A. Doolittle. 1990. Locating lagoon seepage with radar and electromagnetic survey. Environ. Geol. Water Sci. 16:195-207.

Case, R. J. 1989. Soil survey of Columbia County, New York. USDA-Soil Conservation Service and Cornell University Agricultural Experiment. Government Printing Office, Washington DC.

Drommerhausen, D. J., D. E. Radcliffe, D. E. Brune, and H. D. Gunter. 1995. Electromagnetic conductivity survey of dairies for groundwater nitrate. J. Environmental Quality, 24: 1083-1091.

Eigenberg, R. A., R. L. Korthals, and J. A. Nienaber. 1998. Geophysical electromagnetic survey methods applied to agricultural waste sites. J. Environmental Quality, 27:215-219.

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.

McNeill, J. D. 1980a. Electrical Conductivity of soils and rocks. Technical Note TN-5. Geonics Ltd., Mississauga, Ontario.

McNeill, J. D. 1980b. Electromagnetic terrain conductivity measurement at low induction numbers. Technical Note TN-6. Geonics Limited, Mississauga, Ontario.

Miller, M.H., J.B. Robinson, and R.W. Gillham. 1985. Self-sealing of earthen liquid manure storage ponds: I. A case study. Journal of Environmental Quality 14:553-538.

Radcliffe, D. E., D. E. Brune, D. J. Drohmerhausen, and H. D. Gunther. 1994. Dairy loafing areas as sources of nitrate in wells. 307-313 pp. IN: Environmentally Sound Agriculture, Proceedings of the Second Conference. 20-24 July 1994. American Society of Agricultural Engineers. St. Joseph, MI.

Ranjan, R. S., and T. Karthigesu. 1995. Evaluation of an electromagnetic method for detecting lateral seepage around manure storage lagoons. ASAE Paper 952440. ASAE, St. Joseph, MI.

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.

Swell, J. I., J. A. Mulling and H. O. Vaigneur. 1975. Dairy lagoon systems and groundwater quality. 286-288 pp. IN: Proceeding of the Third International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan.