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

Subject: Soils – Geophysical Field Assistance

Date: 11 July 2007

To: Judith Doerner
State Conservationist
USDA-NRCS,
356 Mountain View Drive
Colchester, Vermont 05446-5824

Purpose:
The purpose of this visit was to deliver an EM31 meter with an Allegro field computer and related software to Kip Potter for use on agricultural-waste site investigations in Vermont. Field and classroom training exercises were provided on the use and operation of the EM31 meter, and the transfer and processing of data contained in the field computer.

Participants:
Susan Alexander, Agricultural Resource Specialist, Winooski Conservation District, Berlin, VT
Karen Deman, Geological Intern, Vermont Geologic Survey, Waterbury, VT
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Jeff Comstock, Soil Scientist, Vermont Dept. of Agriculture, Food & Markets, Agricultural Resource Management Section, Montpelier, VT
Chris Hakey, Engineering Technician, USDA-NRCS, Colchester, VT
Jon Kim, Geologist/Environmental Scientist, Vermont Geologic Survey, Waterbury, VT
Fletcher Potter, Soil Conservationists, USDA-NRCS, Colchester, VT
Bob Thompson, Civil Engineer, USDA-NRCS, Colchester, VT
David Weber, Soil Scientist, Vermont Dept. of Agriculture, Food & Markets, Agricultural Resource Management Section, Montpelier, VT
Stephanie Zeller, Civil Engineer, Vermont Dept. of Agriculture, Food & Markets, Agricultural Resource Management Section, Montpelier, VT

Activities:
All activities were completed during the period of 25 to 29 June 2007.

Summary:

1. An EM31 meter (S/N 9315002; AG0002518477) and an Allegro CE field computer (S/N 11492) were loaned to Kip Potter and the USDA-NRCS Vermont staff and the Vermont Geologic Survey from the National Soil Survey Center.

2. A general summary of the results and interpretations of the EMI surveys complete at agricultural waste facilities in Caledonia and Lamoille Counties are provided in this report.

3. All data collected during this field visit are in the hands of Kip Potter and Jon Kim.

4. I will furnish whatever assistance is needed by your staff to conduct EMI surveys with the loaned equipment.

It was my pleasure to work in Vermont 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, National Soil Survey Center, USDA-NRCS, 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
S. Gourley, State Soil Scientist, USDA-NRCS, 356 Mountain View Drive, Colchester, Vermont 05446-5824
F. Potter, Soil Conservationists, USDA-NRCS, 356 Mountain View Drive, Colchester, Vermont 05446-5824
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

Background:

Electromagnetic induction (EMI) is a noninvasive geophysical tool used to assess spatial and temporal variations in soils and soil properties at different depths and levels of resolution. Advantages of EMI are its portability, speed of operation, and flexible observation depths. 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 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). Apparent conductivity increases with increased soluble salt, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976). Apparent conductivity is related to the total ion concentration in soils.

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 are 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. Maps prepared from EMI data provide the basis for assessing site conditions and locating sampling or monitoring sites.

Electromagnetic induction has been used to map spatial and temporal variations in the concentration of soil nutrients (Cockx et al., 2005). Cockx et al. (2005) used EC_a to delineate zones with different risks of NO_3^- loss within a small pasture. However, in most soils, low nutrient concentrations are unlikely to be detected with EMI as differences in clay and moisture contents often mask subtle changes in nutrient levels (Heiniger et al., 2003). Eigenberg and Nienaber (1998) used EC_a to delineate soils with high nutrient buildup resulting from the application of animal wastes. They observed that differences in EC_a were primarily dependent on the ionic content of soils. Temporal variations in EC_a have been related to nutrient leaching, diffusion, and plant uptake within composting sites (Eigenberg and Nienaber, 2003).

Electromagnetic induction has been used to investigate the migration of contaminants from animal waste-holding facilities (Eigenberg et al., 1998; Bowling et al., 1997; 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. Stevens et al. (1995) used EC_a as an indirect measure for NH_4 and K in animal waste slurries. 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 meter is manufactured by Geonics Limited (Mississauga, Ontario).[1] The EM31 meter weighs about 9 kg (19.9 lbs). 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. When placed on the soil surface, the EM31 meter provides theoretical penetration depths of about 6 m (19.7 ft) and 3 m (9.8 ft) in the vertical and horizontal dipole orientations, respectively (McNeill, 1980b).

The Geonics DAS70 Data Acquisition System is used with the EM31 meter to record and store both EC_a and position data.[1] The acquisition system consists of the EM31 meter, an Allegro CE 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 EM31 meter is keypad operated and measurements can be automatically triggered. The DAT31W software program (developed by Geonics Limited) is used to record, store, and process EC_a and GPS data.[1]

To help summarize the results of the EMI surveys, SURFER for Windows, version 8.0 (Golden Software, Inc., Golden, CO), was used to construct simulations of EC_a data.[1] Grids of EC_a data shown in this report were created using kriging methods with an octant search.

---

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

Field Methods:

EMI Surveys:

At each site, *random walk* or *wild-cat* EMI survey were conducted with the EM31 meter. The EM31 meter was operated in the deeper-sensing (0 to 6 m) vertical dipole orientation. Only quadrature phase data were collected and expressed as values of apparent conductivity (EC_a) in milliSiemens/meter (mS/m). The EM31 was operated in the continuous mode (measurements recorded at 1-sec intervals) with the DAS70 system. Using the DAT31W program, both GPS and EC_a data were simultaneously recorded on the field computer. The meter was held at hip height and orientated with its long axis parallel to the direction of traverse. Surveys were completed by walking at a uniform pace, in a random or back and forth pattern across each site.

Study Sites:

Sites discussed in this report are located in pastures and cultivated fields in Caledonia and Lamoille Counties. Data collected at the Catamount Site near Williston, in Chittenden County are not discussed in this report. The Caledonia County (Legis Farm) site is located off of Hardwick Farms Road near West Hardwick. This site consists of two survey areas (see 1 and 2 in Figure 1). Survey Area 1 extends southward from an animal waste holding facility (see "A" in Figure 1) along a grassed waterway. On either side (west or east) of this waterway, slopes rise across a bedrock controlled landscape. Survey Area 2 is situated in a cultivated field of corn and extends eastwards from stacking (see "B" in Figure 1) and animal loafing areas.

The soils in Survey Area 1 are mapped as Vershire-Lombard complex, 8 to 15 percent slopes (14C), and Dummerston very fine sandy loam, 3 to 8 percent slopes (16B). The soils in Survey Area 2 have been mapped principally as Dummerston very fine sandy loam, 3 to 8 percent slopes, but includes a small area of Cabot silt loam, 3 to 8 percent slopes (22B). These moderately deep to very deep, well drained to poorly drained soils form in loamy till on glaciated uplands. The poorly drained Cabot soils are shallow to dense basal till.

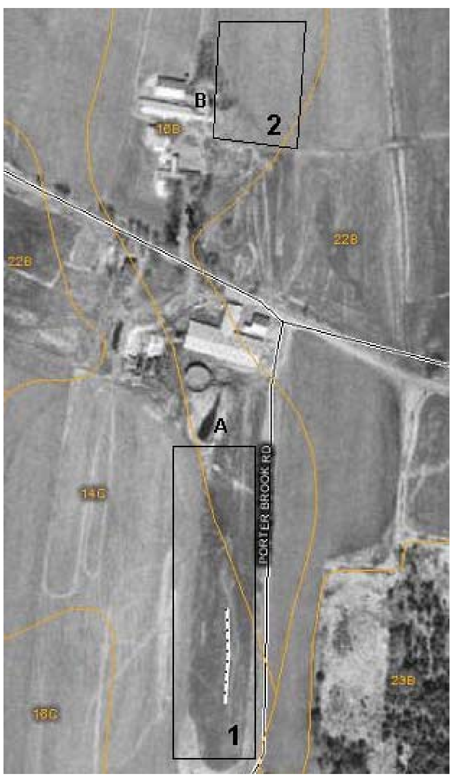

Figure 1. A soil map of the Caledonia County sites showing the locations of the two survey areas (enclosed with black lines).

The Lamoille County (McClure Farm) site is located in cultivated fields (corn) off of River Road near Johnson. The site is located on the floodplain of the Lamoille River, which is located to the north and east of the survey area. An elevated and abandoned railway crosses the study site from west-northwest to east-southeast. Farm buildings, an animal waste storage facility, and farm implements border the study area to the south. Soil delineations mapped within the survey area include: Adams loamy fine sand, 2 to 8 percent slopes (AdB), Ondawa fine sandy loam (On), and Podunk fine sandy loam (Po). The very deep, excessively and somewhat excessively drained Adams soils formed in glacial-fluvial or glacio-lacustrine sands. The very deep, well drained Ondawa and the moderately well drained Podunk soils formed in recent alluvium on floodplains.

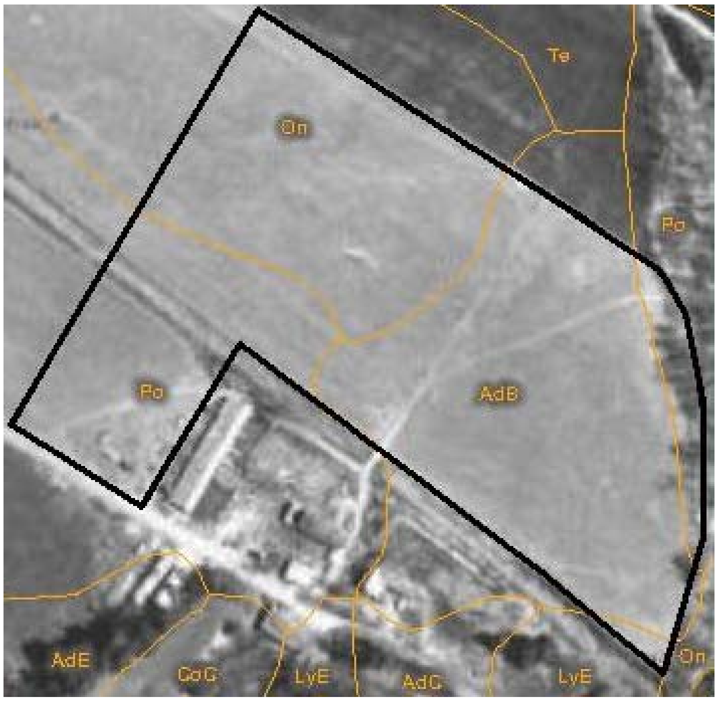

Figure 2. A soil map of the Lamoille County sites showing the locations of the survey area (enclosed with black lines).

The taxonomic classifications of the soils identified in the study areas are listed in Table 1.

Table 1. Taxonomic classifications of the soils identified in the study areas.

Soil Name	Taxonomic Classification
Adams	Sandy, isotic, frigid Typic Haplorthods
Cabot	Loamy, mixed, active, nonacid, frigid, shallow Typic Humaquepts
Dummerston	Coarse-loamy, mixed, active, frigid Typic Dystrudepts
Lombard	Coarse-loamy, mixed, active, frigid Typic Dystrudepts
Ondawa	Coarse-loamy, mixed, active, frigid Fluventic Dystrudepts
Podunk	Coarse-loamy, mixed, active, frigid Fluvaquentic Dystrudepts
Vershire	Coarse-loamy, mixed, active, frigid Humic Dystrudepts

Results:
Table 2 summarizes the basic statistics for the three EMI surveys. Within the three survey areas, EC_a ranged from about -47 to 205 mS/m. The large range and extreme values (both negative and positive) are attributed to the presences of contaminants, and scattered metallic artifact and cultural features. In general, soils at these sites can be characterized as being electrically resistive with very low EC_a (0 to 6 mS/m).

Table 2
Basic Statistics for the EC_a data that was collected with the EM31 meter at the three Survey Areas.
(EC_a measurements are expressed in mS/m)

Site	Observations	Minimum	25%-tile	75%-tile	Maximum	Mean	Std. Deviation
Lagis Site 1	1888	-3.1	-0.4	4.4	34.9	2.88	5.21
Lagis Site 2	1505	-47.4	1.8	8.4	204.8	7.59	14.78
McLure Site	4084	-1.6	1.3	8.6	40.7	5.59	5.43

Lagis Survey Area 1:

Figure 3 shows the spatial distribution of EC_a within Survey Area 1 (Lagis Site 1), Caledonia County. Apparent conductivity was generally very low and invariable across the survey area. Within the survey area, EC_a averaged only 2.88 mS/m with a standard deviation of 5.21 mS/m. One-half of the EC_a measurements were between -0.4 and 4.4 mS/m. Higher-lying, more sloping areas are presumed to be shallower to parent rock and have EC_a values less than 4 mS/m. Negative values (0 to -3.1 mS/m) were recorded over areas that are presumably very shallow to parent rock. These rather broad areas of negative values reflect very electrically resistive materials and the calibration of the EM31 meter. A noticeable plume of higher EC_a emanates from the base of the animal waste storage facility and extends outwards and down slope along the grassed waterway. However, what are considered anomalously high EC_a values extend outwards from the waste-holding facility and down slope along the waterway for only 80 m.

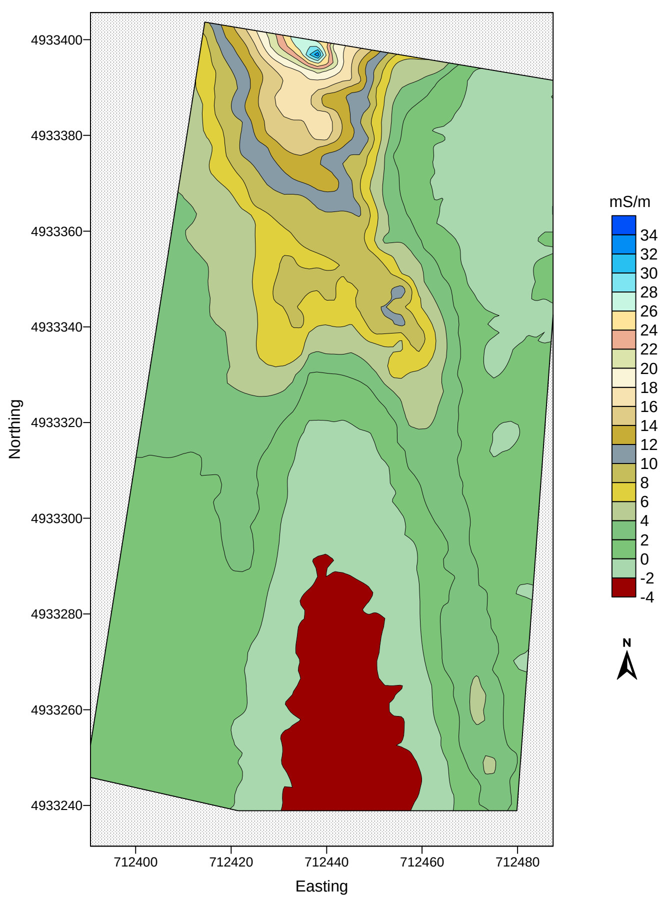

Figure 3. Spatial EC_a patterns within Survey Area 1 of the Caledonia County Site reveals an inferred contaminant plume emanating from the base of a waste storage facility and areas of very resistive soils that are shallow or moderately deep to parent rock.

Lagis Survey Area 2:

Figure 4 shows the spatial distribution of EC_a within Survey Area 2 (Lagis Site 2), Caledonia County. As with Survey Area 1, EC_a was generally very low and invariable across Survey Area 2. Compare with Survey Area 1, EC_a was slightly higher and more variable within Survey Area 2. Within the survey area, EC_a averaged only 7.59 mS/m with a standard deviation of 14.78 mS/m. One-half of the EC_a measurements were between 1.8 and 8.4 mS/m. A noticeable plume of higher EC_a emanates from the base of a concrete-floored, waste-stacking area and extends outwards and down slope in a southeasterly direction across a cultivated field of corn. Waste products are suspected to pool in a lower-lying area (see A in Figure 4) that adjoins a field boundary. Here anomalously high EC_a values were recorded.

Two comparatively narrow lineaments that are orientated in a north-northeast to south-southwest direction are evident in the plot shown in Figure 4. Each lineament displays higher EC_a than adjoining areas. Each lineament also displays a *pater noster* pattern with zones of higher EC_a alternating and connected with zones of lower EC_a. These lineaments conform to fracture traces observed in the underlying schist. The higher EC_a within these fractures is attributed to contaminants flowing into and following broken and more permeable materials.

Figure 4. Spatial EC_a patterns within Survey Area 2 of the Caledonia County Site reveals inferred overland flow of contaminant emanating from a waste stacking area and subsurface flow along fracture traces in the underlying parent rock.

If the hypothesis of contaminants following fracture traces is correct, it is possible that wastes from the stacking area may follow the western most trace (see Figure 2) southwestward and contaminate the well of a house that is located in this general area. Follow up EMI surveys have been considered to confirm this hypothesis.

McClure Site:

Figure 5 shows the spatial distribution of EC_a within the McClure Site in Lamoille County. Apparent conductivity was generally higher in areas that border the farm structures. Across most of the cultivated field that adjoins these structures to the north and northeast, EC_a was very low and invariable. Within the study area, EC_a averaged 5.59 mS/m with a standard deviation of 5.43 mS/m. One-half of the EC_a measurements were between 1.3 and 8.6 mS/m. Areas of Adams, Ondawa, and Podunk that were distant from the farm structures displayed EC_a values less than 6 mS/m. Negative values (0 to -1.6 mS/m) were recorded over areas of Podunk soil. These rather narrow areas of negative values reflect very electrically resistive materials and the calibration of the EM31 meter.

A noticeable plume of higher EC_a emanates appears to emanate from the barn and waste-pit facility and trend in a northwesterly direction, which parallels the flow of the nearby Lamoille River. Two areas (see A and B in Figure 5) where winter wastes were stacked have anomalously high EC_a values (> 20 mS/m). It is inferred from the spatial EC_a patterns that contaminants are moving northwestward from these stacking areas across the cultivated field.

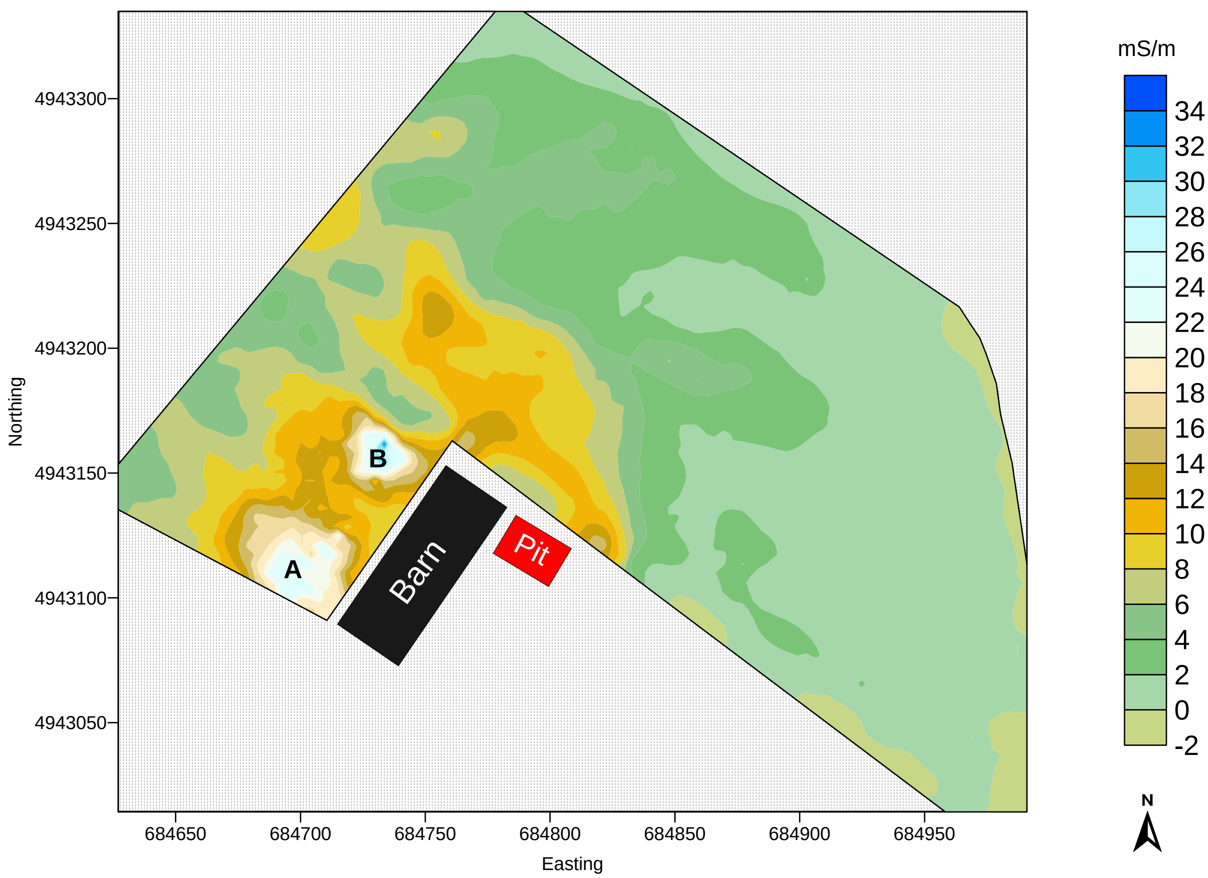

Figure 5. Spatial EC_a patterns within the McClure Site reveals inferred overland flow of contaminant emanating from winter waste stacking area (see A and B) and the subsurface flow from a waste-holding facility (see Pit).

References:

Bowling, S. D., D. D. Schultz, W. E. Wolt, 1997. A geophysical and geostatistical method for evaluating potential surface contamination from feedlot retention ponds. ASAE Paper 972087. ASAE, St. Joseph, MI.

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

Cockx, L., M. Van Meirvenne, and G. Hofman, 2005. Characterization of nitrogen dynamics in a pasture soil by electromagnetic induction. Biol. Fertil Soils 42: 24-30.

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.

Eigenberg, R. A., and J. A. Nienaber, 1998. Electromagnetic survey of cornfield with repeated manure applications. J. Environmental Quality 27: 1511-1515.

Eigenberg, R. A., and J. A. Nienaber, 2003. Electromagnetic induction methods applied to an abandoned manure handling site to determine nutrient buildup. J. Environmental Quality 32: 1837-1843.

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.

Heiniger, R. W., R. G. McBride, and D. E. Clay, 2003. Using soil electrical conductivity to improve nutrient management. Agronomy J. 95: 508-519.

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.

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.

Stevens, R. J., C. J. O'Bric, and O. T. Carton, 1995. Estimating nutrient content of animal slurries using electrical conductivity. J. Agric. Sci. (Cambridge) 125: 233-238.