UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

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Subject: Geophysical Assistance - Demonstration of Electromagnetic Induction Techniques; Yuma, Colorado; October 2 and 3, 1995

Date: 25 October 1995

To: Denise Hase
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Purpose:
To discuss and demonstrate the uses of electromagnetic induction (EM) techniques for assessing seepage from waste-holding facilities.

Participants:
Mahdi Al-Kaisi, Colorado State University, Ft. Collins, CO
Jim Doolittle, Research Soil Scientist, NRCS, Chester, PA
Dave Frank, Yuma City Commissioner, Yuma, CO
Jan Fritch, Resource Conservationist, Yuma, CO
Denise Hase, NCHD, Sterling, CO
Butch Horner, NCHD, Sterling, CO
Dawn Jackson, Range Conservationist, NRCS, Yuma, CO
William Kolling, NCHD, Sterling, CO
Derald Lang, CDPHE-WQCD, Ft. Collins, CO
Bruce Lindahl, Area Conservationist, NRCS, Greeley, CO
Lynn Lovell, Area Engineer, NRCS, Sterling, CO
Carmen McDaniel, NCHD, Sterling, CO
Ron Miller, Agronomist, NRCS, Greeley, CO
Jenny Montaque, Logan County, Sterling, CO
Mike Petersen, Area Soil Scientist, NRCS, Greeley, CO
Jay Rezek, Area Engineer, NRCS, North Platte, NE
Charles Schmidt, Area Engineer, Scotts Bluff, NE
Victor Sainz, CDPHE-WQCD, Ft. Collins, CO
Paul Vogelgesang, Farmer, Holyoke, CO
Roy Wheeler, Logan County, Sterling, CO
Robb Witt, NCHD, Sterling, CO

Activities:
A slide presentation on the uses of EM techniques for assessing groundwater contamination was shown at the Yuma City Community Center on the mornings of 2 and 3 October, 1995. Discussions were followed by

field demonstrations. During the field demonstrations, participants had the opportunity to use various EM meters.

Equipment:
The electromagnetic induction meters were the EM38, EM31, and EM34-3, manufactured by GEONICS Limited. The observation depth of an EM meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM38 meter has a fixed intercoil spacing of 1.0 m. It operates at a frequency of 13.2 kHz. The EM38 meter has effective observation depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). The EM31 meter has a fixed intercoil spacing of 3.66 m. It operates at a frequency of 9.8 kHz. The EM31 meter has effective observation depths of about 3.0 and 6.0 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1979). The EM34-3 meter has three reference cables which provide intercoil spacings of 10, 20, and 30 m. These intercoil spacings provide effective observation depths of from about 7.5 to 60.0 m (McNeill, 1980). Depending on the intercoil spacing, it operates at a frequencies of 0.4, 1.6, or 6.4 kHz.

To help summarize the results of this study, the SURFER for Windows program, developed by Golden Software, Inc., was used to develop two-dimensional plots of a demonstration site. The simulated grids were created using kriging methods with an octant search. The data was smoothed using cubic spline interpolation.

The EM data have been displayed in two-dimensional contour plots (figures 1 and 2). In these plots, to help emphasize the spatial distribution of apparent conductivity values, colors and filled contour lines have been used. Each plot represents the spatial distribution of apparent conductivity values over a specified observation depth. Other than showing trends in values of apparent conductivity (i.e. zones of higher or lower electrical conductivity), no significance should be attached to the colors themselves.

Discussion:
Studies have documented the advantages of using geophysical techniques for groundwater investigations (De Rosa, 1986; Goldman and Neubauer, 1994; and Greenhouse et al., 1987). One geophysical technique, electromagnetic induction or EM, has been used extensively in groundwater investigations (McNeill, J. D. 1991) and to detect and map the migration of contaminants from waste sites (Brune and Doolittle, 1990; Radcliffe et al., 1994; and Siegrist and Hargett, 1989). This technique provides non-invasive measurements of the subsurface and is applicable over diverse geographic areas and soil types. EM meters are highly portable and their use is considered one of the most rapid and cost-effective geophysical methods available (Palacky et al., 1981). Compared with other geophysical techniques, larger areas can be surveyed in greater detail at comparable cost with EM meters.

Electromagnetic induction techniques measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted average measurement for a column of earthen materials to a specified observation depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the (i) volumetric water content, (ii) type and concentration of ions in solution, (iii) temperature and phase of the soil water, and (iv) amount and type of clays in the soil matrix, (McNeill, 1980). The apparent conductivity of soils increases with increases in the exchange capacity, water content, and clay content (Kachanoski et al., 1988; Rhoades et al., 1976).

For surveying, the meter is placed on the ground surface or held above the surface at a specified distance. A power source within the meter generates an alternating current in the transmitter coil. The current flow produces a primary magnetic field and induces electrical currents in the soil. The induced current flow is proportional to the electrical conductivity of the intervening medium. These electrical currents create a secondary magnetic field in the soil. The secondary magnetic field is of the same frequency as the primary field but of different phase and direction. The primary and secondary fields are measured as a change in the potential induced in the receiver coil. At low transmission frequency, the ratio of the secondary to the primary magnetic field is directly proportional to the ground conductivity. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. Table 1 lists the anticipated observation depths for various meters with different intercoil spacings and coil orientations. Information on variations in conductivity with depth can be achieved by varying coil orientation, intercoil spacing, and frequency.

TABLE 1

Depth of Measurement
(all measurements are in meters)

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
EM38	1.0	0.75	1.5
EM31	3.7	2.75	6.0
EM34-3	10.0	7.5	15.0
	20.0	15.0	30.0
	40.0	30.0	60.0

Demonstration:
Interpretations of the EM data are based on the identification of spatial patterns within data sets. Figures 1 and 2 show the simulated results of a demonstration survey conducted in an area adjoining a portion of the southern embankment to the Yuma City municipal ponds.

A 350 by 75 foot grid was established across the demonstration site (0.6 acre). The grid interval was 50 feet. This interval provided 32 grid intersections or observation points. At each observation point, survey flags were inserted in the ground and measurements were taken with an EM31 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

Figures 1 and 2 are two-dimensional plots of apparent conductivity measurements simulated from data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each plot, the isoline interval is 2 mS/m.

Comparing the plots, values of apparent conductivity, as a rule, increase slightly increasing observation depth (responses in the horizontal dipole orientation were typically less than those in vertical dipole orientation). The shallower, horizontal dipole measurements average 44.6 mS/m; the deeper, vertical dipole measurements average 44.4 mS/m. This relationship is believed to reflect increases in clay, soluble salt, and moisture contents with increasing depth. In figures 1 and 2, anomalously high EM responses in the eastern portion of the site were believed to have been caused by seepage from the municipal ponds.

In both plots, a meaningful anomaly having a "plume-like" appearance or pattern occurs in the eastern portion of the survey area. Plume-like anomalies should emanate from and have progressively decreasing conductivity values with increasing distances away from a contaminant source. These patterns are evident in both plots and are believed to reflect seepage of contaminants from the structures. The plume-like pattern emanates from a point near the boundary of two municipal ponds.

Summary:

1. Geophysical techniques have considerable potential for rapidly examining sites for groundwater contamination. Electromagnetic induction surveys can not determine the chemical composition of contaminant plumes. However, this technique can be used to delineate the location(s) and extent of plumes and facilitate remedial investigations and monitoring well placement.

2. Electromagnetic induction can be used to detect and map seepage from waste-holding facilities. This technique can aid investigators determine where seepage is occurring prior to the initiation of a sampling program. As a consequence, this technique can be an integral component of remedial investigations.

3. EM investigations can increase the level of confidence in monitoring well placement and reduce the number of wells needed to characterize a site.

4. The results of EM investigations are qualitative and often inconclusive unless supported by ground truth observations (such as well logs and water quality data). The reliability of EM techniques must be appraised based on the results of subsequent ground-truth observations and measurements.

5. If accepted as an integral component of remedial investigations, standardization of survey procedures and data presentation will be necessary.

6. EM techniques are susceptible to cultural interference (from surface or near surface metal objects, transmitters, and power lines).

It was my pleasure to work with you and your staff. If I can be of further assistance please do not hesitate to ask.

With kind regards.

James A. Doolittle
Research Soil Scientist

cc:
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C. Holzhey, Assistant Director, NSSC, NRCS, Lincoln, NE
D. Johnson, State Conservationist, NRCS, Lakewood, CO

References:

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

De Rosa, N. 1986. Applications of surface geophysical methods to ground water pollution investigations. p. 118-140. IN: Evaluation of Pesticides in Ground Water. American Chemical Society. Washington, D. C.

Goldman, M. and F. Neubauer. 1994. Groundwater exploration using integrated geophysical techniques. Surveys in Geophysics. 15: 331-361.

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.

Greenhouse, J. P. M. E. Monier-Williams, N. Ellert, and D. D. Slaine. 1987. Geophysical methods in groundwater contamination studies. Exploration '87 Proceedings. Application of Geophysics and Geochemistry. p. 666-677.

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. 1979. EM31 operating manual for EM31 noncontacting Terrain conductivity meter. Geonics Ltd., Mississauga, Ontario. p. 35.

McNeill, J. D. 1980. Electrical Conductivity of soils and rocks. Technical Note TN-5. Geonics Ltd., Mississauga, Ontario. p. 22.

McNeill, J. D. 1986. Geonics EM38 ground conductivity meter operating instructions and survey interpretation techniques. Technical Note TN-21. Geonics Ltd., Mississauga, Ontario. p. 16.

McNeill, J. D. 1991. Advances in electromagnetic methods for groundwater studies. Geoexploration 27:65-80.

Palacky, G. L., I. L. Ritsema, and S. J. De Jong. 1981. Electromagnetic prospecting for groundwater in Precambrian terrains in the Republic of Upper Volta. Geophysical Prospecting. 29:932-955.

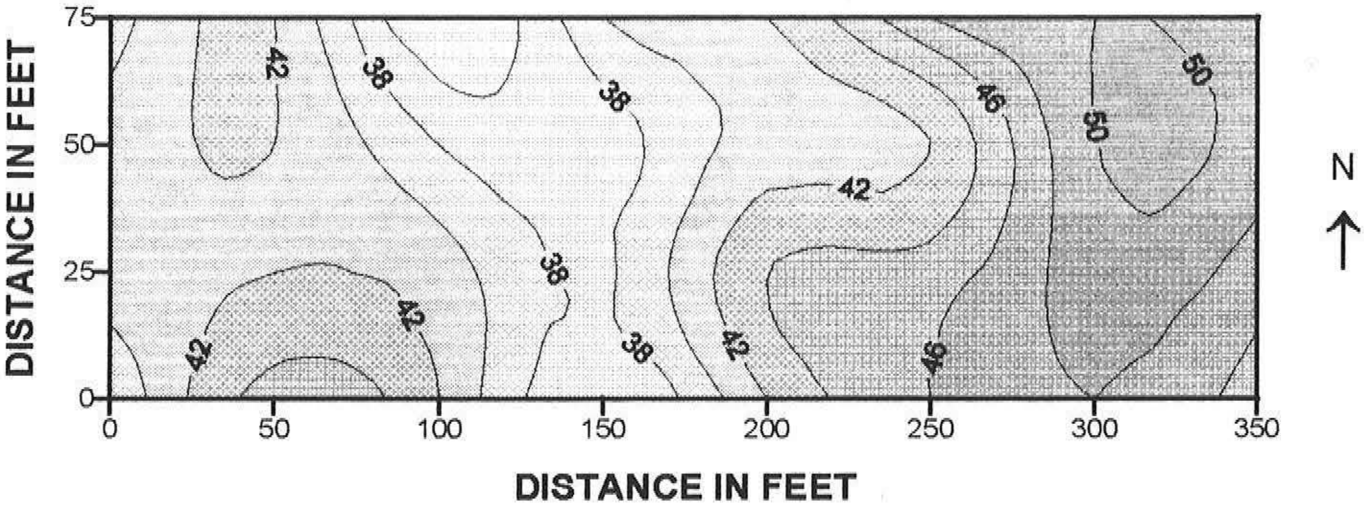
Radcliffe, D. E., D. E. Brune., D. J. Drohmerhausen, and H. D. Gunther. 1994. Dairy loafing areas as sources of nitrate in wells. p. 307-313. IN: Environmentally Sound Agriculture; Proceedings of the second conference. 20-24 July 1994. American Society of Agricultural Engineers. St. Joseph, MI.,

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.

Siegrist, R. L. and D. L. Hargett. 1989. Application of surface geophysics for location of buried hazardous waste. Water Management and Research 7:325-335.

DEMONSTRATION PLOT
YUMA CITY MUNICIPAL PONDS

EM31 METER
HORIZONTAL DIPOLE ORIENTATION



DEMONSTRATION PLOT
YUMA CITY MUNICIPAL PONDS

EM31 METER
VERTICAL DIPOLE ORIENTATION