United States Department of Agriculture | Natural Resources Conservation Service | 5 Radnor Corporate Center, Suite 200 Radnor, PA 19087-4585

Subject: Geophysical Assistance -- Electromagnetic induction

Date: 2 November 1998

To: Margo L. Wallace
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USDA-NRCS,
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Purpose:

To provide electromagnetic induction (EMI) field assistance and training. Surveys were conducted in support of on-going animal-waste management investigations.

Participants:

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Activities:

All field activities were completed on 27 October 1998.

Equipment:

The electromagnetic induction meter used in this study is the EM31 manufactured by Geonics Limited.[1] This meter is portable and requires only one person to operate. McNeill (1980a) has described principles of operation. No ground contact is required with this meter. This meter provides limited vertical resolution and depth information. Lateral resolution is approximately equal to the intercoil spacing. The EM31 meter operates at a frequency of 9,800 Hz and has theoretical observation depths of about 3 and 6 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1980a). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

To help summarize the results of this study, the SURFER for Windows software program developed by Golden Software Inc. was used to construct two-dimensional simulations.[1] Grids were created using kriging methods. In each of the enclosed plots, shading and filled contour lines have been used. These options were selected to help emphasize spatial patterns. Other than showing trends and patterns in values of apparent conductivity (i.e., zones of higher or lower electrical conductivity), no significance should be attached to the shades themselves.

Background:

Potential threats to human health and the environment associated with animal-waste management systems have prompted increased attention on the methods used to assess their effectiveness. The Agricultural Waste Management Field Handbook specifies that once an animal-waste management system has been constructed; it should be monitored continuously to

[1] Trade names have been used to provide specific information. Their use does not constitute endorsement.

determine its effectiveness (Conservation Engineering Division, 1997). Monitoring provides a method to assess efficacy and to estimate solute loss and contamination risks from animal-waste management systems.

Monitoring wells, soil coring and chemical analysis protocols provide direct measurements of contaminant levels at specific sites. Monitoring wells placed near animal-waste management systems are used to help assess the distribution of contaminant plumes caused by seepage (Collins et al., 1975). However, the direction of ground-water flow can not be determined from surface observations alone. As a consequence, multiple wells are needed to adequately assess the integrity of a waste-holding facility. Monitoring wells and sampling conventions are expensive and time consuming. As a consequence, the number of monitoring wells is limited. A limited number of monitoring wells can not provide comprehensive coverage of a site (can miss contaminant plumes). The frequency of collecting samples varies with the age of the system and presumed, associated risks. By the time traces of contamination are detected in samples, the surrounding aquifer may already be adversely affected by the contaminants. Seepage does not occur uniformly around the perimeter of animal-waste management systems, but often occurs at specific, unpredictable locations (Ritter et al., 1984). Because of the nonuniform and unpredictable nature of seepage from animal-waste management systems, it is difficult to assess groundwater and surface water contamination from localized monitoring and sampling techniques. In studies conducted by Ritter and others (1984), samples from only some distant monitoring wells were contaminated. In this study (Ritter et al., 1984), contamination of the wells could not be directly linked to the waste management systems. Because of the unpredictable and site specific nature of contaminant plumes, results based on a limited number of observations can be conflicting or inconclusive. Alternative, more comprehensive sampling techniques are needed.

Electromagnetic induction (EMI) is a noninvasive geophysical tool that can be used for detailed site investigations. Advantages of EMI are its portability, speed of operation, flexible observation depths (with commercially available systems from about 0.75 to 60 m), moderate resolution of subsurface features, and comprehensive coverage. Results of EMI surveys are interpretable in the field. This geophysical method can provide in a relatively short time the large number of observations needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions, planning further investigations, and siting monitoring wells.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity 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). Variations in apparent conductivity are produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils 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, 1980b). The apparent conductivity of soils increases with increases in soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Electromagnetic induction measures vertical and lateral variations in apparent electrical conductivity. Values of apparent conductivity are seldom diagnostic in themselves, but lateral and vertical variations in these measurements 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.

Electromagnetic induction has been successfully used to investigate the migration of contaminants from waste sites (Brune and Doolittle, 1990; Drommerhausen, 1995; Eigenberg et al., 1998; Radcliffe et al., 1994; Ranjan and Karthigesu, 1995; Siegrist and Hargett, 1989; and Stierman and Ruedisili, 1988). Electromagnetic induction has been used to infer the relative concentration, extent, and movement of contaminants from animal-waste management systems. Electromagnetic induction does not provide a direct measurement of specific ions or compounds. However, measurements of apparent conductivity have been correlated with specific ions that are mobile in the soil and associated with animal wastes. Apparent conductivity has been correlated with concentrations of chloride, ammonia, and nitrate nitrogen in the soil (Brune and Doolittle, 1990; Ranjan and Karthigesu, 1995; Eigenberg et al., 1998).

Results:

Study Site #1:

The site is located near the town of Coventry. The waste-holding facility is unlined and was constructed in 1988. An irregularly shaped 300 by 350-foot grid was established on the western and southern sides of the facility. The grid interval was 50 feet. Survey flags were inserted in the ground at each grid intersection and served as observation point. This procedure provided 47 observation points. Measurements were taken at each observation point with an EM31 meter placed on the ground surface in both the horizontal and vertical dipole orientations. The survey was completed in about 2 hours.

Table 1 summarizes the apparent conductivity measurements. Values of apparent conductivity were low and essentially invariable across most of the surveyed area. The apparent conductivity of the upper 3 meters (measured with the EM31 meter in the horizontal dipole orientation) averaged 11.7 mS/m with a standard deviation of 7.19. One-half of the observations had values of apparent conductivity between 8.8 and 11.0 mS/m. The apparent conductivity of the upper 6 meters (measured with the EM31 meter in the vertical dipole orientation) averaged 12.2 mS/m with a standard deviation of 6.94. One-half of the observations had values of apparent conductivity between 10.0 and 11.5 mS/m.

Table 1
Basic Statistics
EMI Survey
Unlined Agricultural-Waste Holding Facility
Coventry, Connecticut
(All values are in mS/m)

				Quartiles			
Meter	Orientation	Minimum	Maximum	1st	Median	3rd	Average
EM31	Horizontal	7.5	46.0	8.8	9.5	11.0	11.7
EM31	Vertical	9.0	55.0	10.0	10.5	11.5	12.2

Figure 1 contains two-dimensional plots of apparent conductivity. The left-hand plot represents data collected with the EM31 meter in the horizontal dipole orientation. The right-hand plot represents data collected with the EM31 meter in the vertical dipole orientation. The location of the waste-holding facility has been shown in each plot. In each of these plots, the isoline interval is 3 mS/m.

In both plots, spatial patterns indicate that the facility is operating well with minimal seepage. However, two conspicuous areas (labeled "A" and "B") of high apparent conductivity are evident in these plots. A manure stacking area is located near "A." Wastes in the stacking area are responsible for the elevated apparent conductivity measurements near "A." In the shallower sensing (0 to 3 m) horizontal dipole orientation, comparatively high measurements were recorded in the extreme southeastern corner of the survey area. Here, the outlet of a subsurface drain flushes wastes into an emphermal channel. Apparent conductivity was high (>40 mS/m) near the outlet. Although apparent conductivity decreased with increasing distance from the outlet, values remained relatively high along the drainageway. High values were observed along the coarse of the drainageway and into an adjoining field located about 300 from the outlet. This pattern suggests a potential problem that should be studied more fully and addressed.

Another stacking area is located to the immediate north of the survey area and to the northwest of the waste-holding facility. Runoff from this stacking area is believed to contribute to the high apparent conductivity near "B."

The results of the EMI survey at Study Site #1 provided little evidence supporting seepage from the unlined animal waste-holding facility. No extensive plume-like pattern emanating from the facility was distinguishable. Electromagnetic induction did detect two conspicuous plumes of high apparent conductivity emanating from waste stacking areas. Both plumes were extensive and related to surface runoff.

Study Site #2:
The site is located near the town of Coventry. The waste-holding facility is lined and was constructed in 1996. A 350 by 200-foot grid was established on the southern side of the facility. The grid interval was 50 feet. Survey flags were inserted in the ground at each grid intersection and served as observation point. This procedure resulted in 40 observation points. This procedure provided 40 observation points. Measurements were taken at each observation point with an EM31 meter placed on the ground surface in both the horizontal and vertical dipole orientations. The survey was completed in about 1.5 hours.

Table 2 summarizes the apparent conductivity measurements. Values of apparent conductivity were exceedingly low and invariable across most of the surveyed area. The apparent conductivity of the upper 3 meters (measured with the EM31 meter in the horizontal dipole orientation) averaged 8.34 mS/m with a standard deviation of 1.75. One-half of the observations had values of apparent conductivity between 6.5 and 9.0 mS/m. The apparent conductivity of the upper 6 meters (measured with the EM31 meter in the vertical dipole orientation) averaged 8.21 mS/m with a standard deviation of 1.89. One-half of the observations had values of apparent conductivity between 6.5 and 9.5 mS/m.

Table 2
Basic Statistics
EMI Survey
Lined Agricultural-Waste Holding Facility
Coventry, Connecticut
(All values are in mS/m)

Meter	Orientation	Minimum	Maximum	Quartiles 1st	Quartiles Median	Quartiles 3rd	Average
EM31	Horizontal	6.0	13.0	6.5	8.0	9.0	8.34
EM31	Vertical	5.5	12.5	6.5	7.5	9.5	8.21

Figure 2 contains two-dimensional plots of apparent conductivity. The upper plot represents data collected with the EM31 meter in the horizontal dipole orientation. The lower plot represents data collected with the EM31 meter in the vertical dipole orientation. The bar at the top of each plot represents the approximate location of the waste-holding facility. A road is located to the immediate east of the study area. In each of these plots, the isoline interval is 2 mS/m.

In both plots, a conspicuous area (labeled "A) of relatively higher (10 – 13 mS/m) apparent conductivity is evident in the eastern half of the study site. A portion of this area is located immediately downslope of a former manure stacking area described by the landowner. Waste residue from the former stacking area may be responsible for the slightly higher apparent conductivity measurements near "A." Changes in soil type may be another causal factor for the higher apparent conductivity. In addition, road salts may also contribute to the slightly higher values along the eastern border of the study site.

The results of the EMI survey at Study Site #2 provided little evidence supporting seepage from the animal waste-holding facility. If seepage or surface runoff of contaminants exist from the facility, concentrations are too low to afford detection by EMI methods.

CONCLUSIONS:

1. Interpretations contained in this report are considered preliminary estimates of site conditions. These interpretations do not substitute for direct observations, but rather reduce their number, direct their placement, and supplement their interpretations. Interpretations should be verified by ground-truth observations.

2. The results of the EMI survey at Study Site #1 provided little evidence supporting seepage from the unlined animal waste-holding facility. No extensive plume-like pattern emanating from the facility was distinguishable. Electromagnetic induction did detect two conspicuous plumes of high apparent conductivity emanating from waste stacking areas. Both plumes were extensive and related to surface runoff.

3. The results of the EMI survey at Study Site #2 provided little evidence supporting seepage from the animal waste-holding facility. If seepage or surface runoff of contaminants exist from the facility, concentrations are too low to afford detection by EMI methods.

It was my pleasure to work again in Connecticut and with members of your fine staff.

With kind regards,

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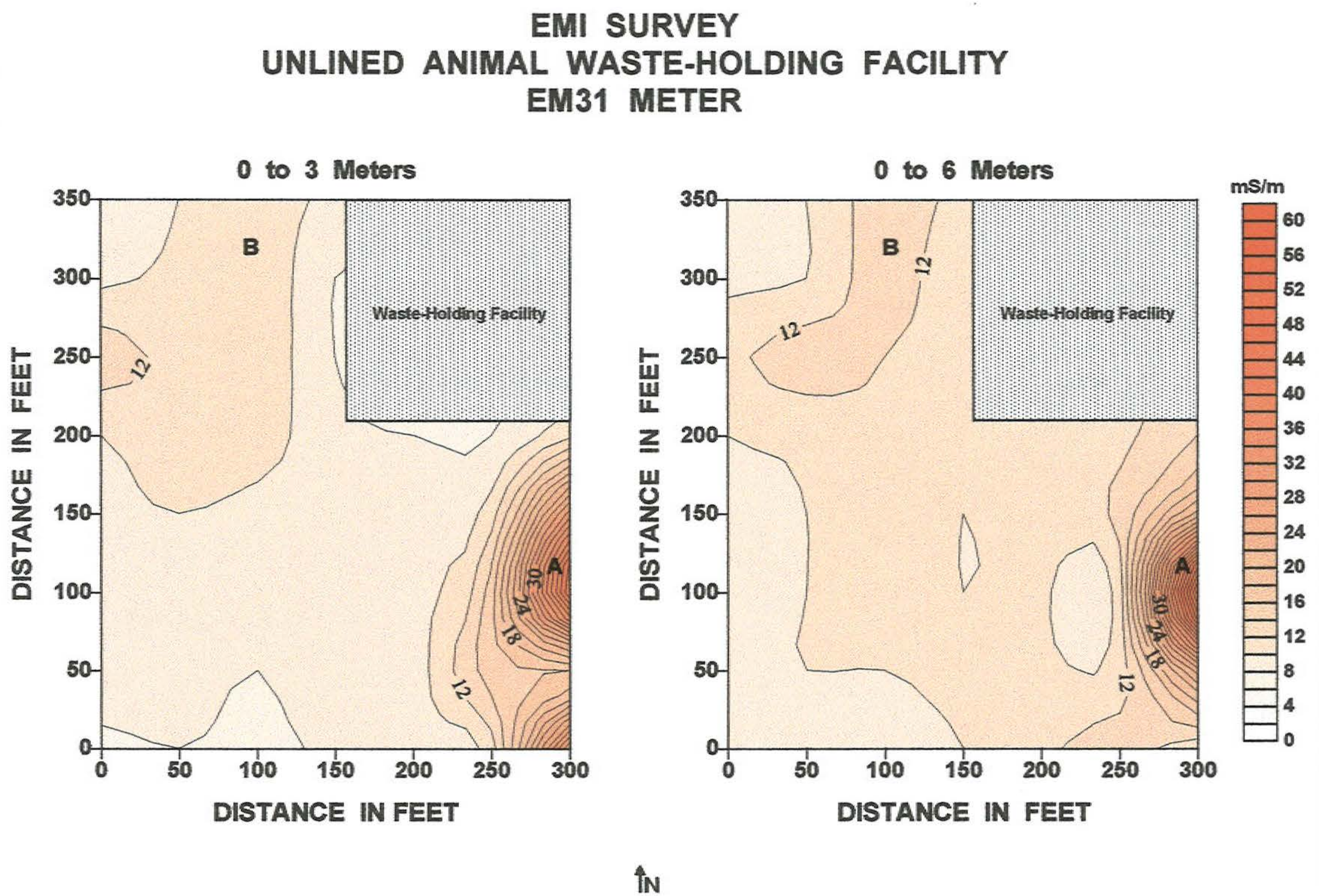
EMI SURVEY
UNLINED ANIMAL WASTE-HOLDING FACILITY
EM31 METER
0 to 3 Meters
0 to 6 Meters
Waste-Holding Facility
Waste-Holding Facility
A
B
A
B
12
18
24
30
12
12
18
24
30
12
12
12
DISTANCE IN FEET
DISTANCE IN FEET
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
150
200
250
300
350
0
50
100
150
200
250
300
mS/m
60
56
52
48
44
40
36
32
28
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N

Figure 1

EMI SURVEY
LINED ANIMAL WASTE-HOLDING FACILITY
EM31 METER

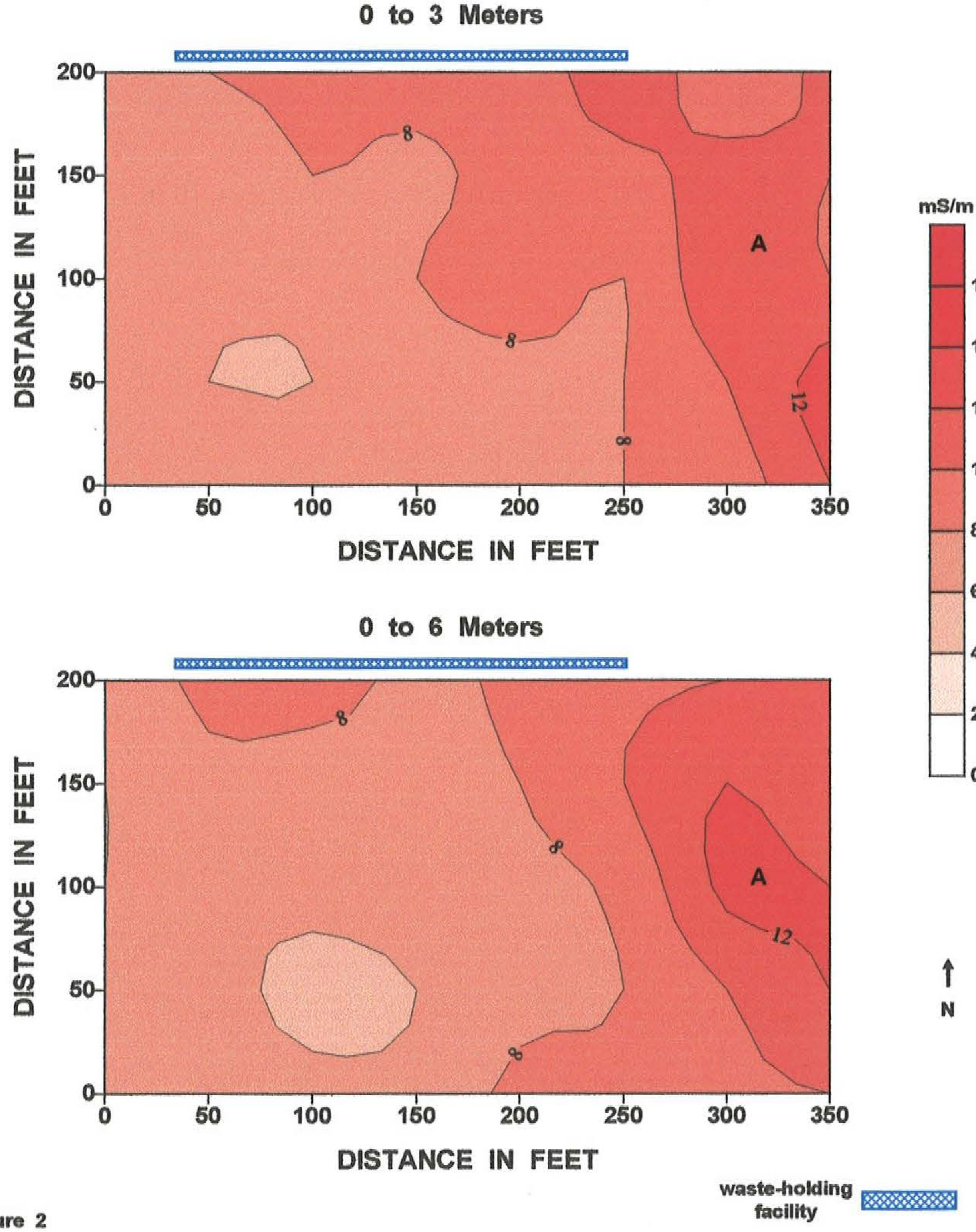

Figure 2