Jim Doolittle

United States Department of Agriculture
Soil Conservation Service

Northeast NTC
Chester, PA 19013

Subject: Electromagnetic Induction (EM) survey of Animal Waste Storage Ponds, Michigan; 18 to 22 May 1992

Date: 29 May 1992

To: Homer R. Hilner
State Conservationist
USDA-Soil Conservation Service
1405 South Harrison Roam, Room 101
East Lansing, Michigan 48823

Purpose:
To provide electromagnetic induction (EM) training to SCS personnel and technical assistance in the use of this technique to survey animal waste holding ponds.

Participants:
Loren Brendt, Soil Correlator, SCS, East Lansing, MI
Jim Doolittle, Soil Specialist, SSQAS, SCS, Chester, PA
Frank Cousin, Assistant SCE, SCS, East Lansing, MI
Blake Covey, Geologist, SCS, MWNTC, Lincoln, NE
Sean Duffy, Geologist, SCS, East Lansing, MI
Fred Gasper, Assistant SCE, SCS, East Lansing, MI
Bill Frederick, Soil Specialist, SCS, East Lansing, MI
Jim Kearney, Engineering Geologist, MWNTC, SCS, Lincoln, NE
Ted Loudon, MECP, Michigan State University, East Lansing, MI
Gary Rinkenberger, Resource Conservationist, SCS, East Lansing, MI
Cindy Steele, Environmental Engineer, SCS, Huron, SD
Roger Windhorn, Geologist, SCS, Champaign, IL

Activities:
The equipment was calibrated and field tested on 18 May. A brief introduction to the various meters and the use of EM techniques was given on the morning of 19 May. Field training and surveys were conducted on 19 to 21 May. I returned to Chester, Pennsylvania, on 22 May.

Equipment:
The electromagnetic induction meters used were the EM31, EM38, and EM34-3 manufactured by GEONICS Limited. Measurements of conductivity are expressed as milliSiemens per meter (mS/m). Two-dimensional contour plots of the survey areas were prepared using SURFER software developed by Golden Software, Inc.

A right-angle prism was used to establish grid lines. A transit was used to determine surface elevations at each grid intersect. At each site, elevations were not tied to an elevation benchmark; the lowest recorded surface point was chosen as the 0.0 datum.

Discussion:
Studies (1, 2) have disclose unpredictable and localized seepage from swine and dairy lagoons. The use of EM techniques has been used to determine the presence and extent of these leachate plumes and to locate the placement of monitoring wells (3). While contaminants may be organic or inorganic, inorganics produce the most noticeable EM responses (4).

Washtenaw County Animal Waste Holding Facility - 19 May 1992
This waste holding facility, located near Manchester, Michigan, is about twelve years old. It supports a dairy operation. At this site, four observation wells have been installed and monitored since 1983. Observations made at one of four wells, Well E, have shown a dramatic and steady increase in ammonia.

Figure 1 is a two-dimensional contour plot of the ground surface. The contour interval is 2 feet. North is towards the upper margin of this figure. A strongly sloping area borders the south face of the animal waste facility. A wet area and drainageway are situated along the southeast corner (lower right) of the survey areas.

In Figure 1, the two wells located within the surveyed area are shown. Because of farm buildings and multiple fence lines, areas immediately adjacent to three sides of the animal waste facility were not surveyed. Farm implements interfered with survey operations along the northwest (left) side of this facility.

The grid covered a 450 by 300 foot area (approximately 3.1 acres). The grid interval was 50 feet. This provided 47 grid intersects or observation points. At each intersect, measurement were taken with the EM31 meter in both the horizontal and vertical modes (Figure 2) and the EM34-3 meter in the horizontal mode with 10 and 20 meter intercoil spacings (Figure 3). Table 1 (in the compendium to this report) lists the effective profiling depths of these meters with varied orientations and/or intercoil spacings.

---

1. Hegg, R.O., T. G. King, and T. V. Wilson. 1978. The effect on groundwater from seepage of livestock manure lagoons: Water Resources Research Institute Tech. Report No. 78. 47 p.

2. Ritter, W. F., E. W. Walpole, and R. P. Eastburn. 1984. Effect of an anaerobic swine lagoon on groundwater quality in Sussex County, Delaware. Agriculture Wastes. 10:267-284.

3. Brune, D. E. and J. Doolittle. 1990. Locating lagoon seepage with radar and electromagnetic survey. Environ. Geol. Water Sci. 16(3):195-207.

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

Interpretation of the EM data are based on the identification of spatial patterns in the data set (3). Several inferences can be made from Figures 2 and 3. Generally, apparent conductivity appears to increase with soil depth. Assuming that the clay content and mineralogy remains essentially constant, increases in apparent electrical conductivity with soil depth are most likely related to increases in volumetric water content or degree of saturation. The affects of spatial variations in soil wetness are most evident along the lower right margins (300 to 450 foot interval) of Figure 2 and 3. Water was observed to be standing on the soil surface in this portion of the study site.

A large, buried, gas pipeline crosses the study site in a general north-northwest/south-southeast direction. The presence of the pipeline produced a distinct pattern of anomalous EM measurements. The pipeline is best expressed in the simulation prepared from the 6 m profile prepared from the EM31(V) data. In Figure 2 (EM31(V) Measurements), the apparent conductivity is high (14 to 44 mS/m) in the vicinity of the pipeline, The response of the EM meters depends on the placement and orientation of the coils relative to the pipeline: maximum when directly over the pipeline and orientated parallel to its axis, minimum when directly over and orientated perpendicular to the axis.

In Figures 2 and 3, patterns suggesting possible seepage are restricted to the embankment and upper backslope areas along the southern face of the facility. In both plots, values of apparent conductivity are relatively high (12 to 22 mS/m) near the facility and decrease rapidly downslope from the structure (2 to 10 mS/m). This pattern suggests that seepage is limited and principally confined within the embankment area of the waste facility. The band of higher apparent conductivity values is not detectable beyond 50 feet from the edge of the facility. The well with high levels of ammonia, Well E, is located very close to the pit and within the embankment area. No inference of excessive or extensive seepage can be made from the EM data on the basis of this investigation. However, the response of the EM meter to elevated levels of various salts in different soils remains unclear.

Berrien Spring Waste Treatment Plant - 20 May 1992

The purpose of this survey was to use electromagnetic induction and ground-penetrating radar techniques to locate buried pipelines. The EM38 and EM31 meters were used to identify and locate three buried pipes. Theses pipes produced elevated EM responses when crossed with the meters parallel to their long axes. The GPR was used to confirm the location of two pipes. However, high rates of signal attenuation and background noise limited the effectiveness of the GPR at this site.

This site provided a useful exercise in the location of buried utilities in an area having high levels of cultural noise.

Michigan State University Animal Waste Holding Facility - 21 May 1992

This waste holding facility supports a swine operation. Several observation wells surround this facility but have not been monitored during the past several years

Figure 4 is a two-dimensional contour plot of the ground surface. The contour interval is 1 foot. North is towards the lower margin of this figure. Because of the presence of a roadway, farm buildings and multiple fence lines, the survey area was restricted north of the facility. A small drainageway entered the survey area near the northern end of column 200, meandered around the western edge of the facility, and exited the survey area near row 180 on column 400.

The grid covered a 400 by 300 foot area (approximately 2.75 acres). The grid interval was 50 feet. This provided 54 grid intersects or observation points. As a result of the complex pattern of apparent conductivity values between rows 350 and 400, an additional survey line (row 375), consisting of 6 observation points, was established. At each intersect, measurement were taken with the EM31 (Figure 5) and EM34-3 meters (Figure 6) in both the horizontal and vertical modes. A 10 meter intercoil spacings was used with the EM34-3 meter.

Several inferences can be made from Figures 5 and 6. Apparent conductivity values appear to increase with soil depth and is assumed to be related to increases in volumetric water content or degree of saturation.

In the right hand portion of each figure, the source of the noticeable linear anomaly (20 to 224 mS/m) is unclear. This anomalous zone appears to be centered on column 350. This anomalous zone may be artificial (related to buried cultural features or debris), represent sedimentation along the drainageway, or variations in soil conditions. As this linear anomaly is separated from the waste facility, contaminants from this source are not suspected based on these simulations.

In Figures 5 and 6, a restricted, wick-like pattern of higher apparent conductivities (24 to 36 mS/m) is evident along the eastern embankment area of the facility. However, this pattern is not evident on the shallow (2.75 m) profiles of the EM31 meter when orientated in the horizontal dipole mode. These patterns suggests and underlying area of potential seepage along the eastern edge of the waste facility. In these plots, values of apparent conductivity decrease rapidly away from the animal waste facility and do not appear to extend beyond 50 feet from the edge of the facility.

Results:
1. Participating geologists and environmental engineers received field training and operated the EM31 and EM34-3 meters. Each participant was provided with opportunities to evaluate these meters and to assess the applicability of EM techniques to their work assignments.

2. Each meter and coil orientation or spacing provided interpretative data concerning the surveyed sites. On the basis of the EM investigation, no inference of excessive or extensive seepage could be made at either of the two animal waste facilities. The ability of EM techniques to locate seepage and detect contaminant plumes requires a significant contrast in electrical conductivity between contaminated and uncontaminated areas. Detection of contaminants depends upon local ground conditions, presence of interfering cultural features, and the sensitivity and penetration depths of a particular meter.

3. Results from these field studies do not replace the need for direct sampling, but rather guide in the placement of monitoring wells and provide supplemental information.

I feel that this session was rewarding to all participants. It was my pleasure to work in your state and with members of your staff.

With kind regards.

James A. Doolittle
James A. Doolittle
Soil Specialist

cc:
J. Culver, National Leader, SSQA Staff, NSSC, SCS, Lincoln, NE
A. Dornbusch, Jr., Director, MWNTC, SCS, Lincoln, NE
S. Duffy, Geologist, SCS, 1405 Harrison Street Rm 101, East Lansing, MI 48823
C. Holzhey, Assistant Director, Soil Survey Division, NSSC, SCS, Lincoln, NE
J. Kearney, Engineering Geologist, MWNTC, SCS, Lincoln, NE
E. Knox, National Leader, SSIV, NSSC, SCS, Lincoln, NE
M. Schendel, Head, Engineering Staff, MWNTC, SCS, Lincoln, NE
C. Steele, Environmental Engineer, USDA-SCS, Federal Building 4th Street, Huron, SD
L. Tornes, State Soil Scientist, SCS, East Lansing, MI
R. Windhorn, Geologist, USDA-SCS, 1902 Fox Drive, Champaign, IL 61820

Review of Electromagnetic Induction Methods

Electromagnetic inductive (EM) is a surface-geophysical method in which electromagnetic energy is used to measure the terrain or apparent conductivity of earthen materials. This technique has been used extensively to monitor groundwater quality and potential seepage from waste sites (Brune and Doolittle, 1990; Byrnes and Stoner, 1988; De Rose, 1986; Greenhouse and Slaine, 1983; Greenhouse et al., 1987; and Siegrist and Hargett, 1989)

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. The 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).

Electromagnetic methods measure the apparent conductivity of earthen materials. Apparent conductivity is the weighted average conductivity measurement for a column of earthen materials to a specified penetration depth (Greenhouse and Slaine; 1983). The averages are weighted according to the depth response function of the meter (Slavich and Petterson, 1990). As EM measurements represent weighted averages, they do not reflect the conductivity of any single layer.

Variations in the meters response are produced by changes in the ionic concentration of earthen materials which reflects changes in sediment type, degree of saturation, nature of the ions in solution, and metallic objects. Factors influencing the conductivity of earthen materials include: (i) the volumetric water content, (ii) the amount and type of ions in soil water, (iii) the amount and type of clays in the soil matrix, and (iv) the soil temperature. Williams and Baker (1982), and Williams (1983) observed that, in areas of salt affected soils, 65 to 70 percent of the variation in measurements could be explained by the concentration of soluble salts. However, as water provides the electrolytic solution through which the current must pass, a threshold level of moisture is required in order to obtain meaningful results (Van der Lelij, 1983).

The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. Table 1 list the anticipated depths of measurements for the EM31, EM34-3, and EM38 meters. The actual depth of measurement will depend on the conductivity of the earthen material(s) scanned.

TABLE 1

Depth of Measurement
(all measurements are in meters)

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
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
EM38	1.0	0.75	1.5

The conductivity meters provide limited vertical resolution and depth information. However, as discussed by Benson and others (1984), the absolute EM values are not necessarily diagnostic in themselves, but lateral and vertical variations in these measurements are significant. The seasonal variation in soil conductivity (produced by variations in soil moisture and temperature) can be added to the statement by Benson. Interpretations of the EM data are based on the identification of spatial patterns in the data set appearing on two-dimensional contour plots.

References

Benson, R. C., R. A. Glaccum, and M. R. Noel. 1984. Geophysical techniques for sensing buried wastes and waste migration: an application review. IN: D. M. Nielsen and M. Curls (eds.) Surface and Borehole Geophysical Methods in Ground Water Investigations. NWWA/EPA Conference, San Antonio, Texas. p. 533-566.

Brune, D. E. and J. Doolittle. 1990. Locating lagoon seepage with radar and electromagnetic survey. Environ. Geol. Water Science 16(3):195-207.

Byrnes, T. R. and D. W. Stoner. 1988. Groundwater monitoring in karstic terrain; A case study of a landfill in northern New York. IN Proceeding of the FOCUS Conference on Eastern Regional Ground Water Issues. September 27-29 1988. Stamford, Connecticut. National Water Wells Assoc. Dublin, Ohio p. 53-76.

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

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. In Exploration "87 Proceedings. Application of Geophysics and Geochemistry. p. 666-677.

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

Slavich, P. G. and G. H. Petterson. 1990. Estimating average rootzone salinity from electromagnetic induction (EM-38) measurements. Aust. J. Soil Res. 28:453-463.

Van der Lelij. A. 1983. Use of electromagnetic induction instrument (Type EM-38) for mapping soil salinity. Water Resource Commission, Murrumbidgee Div., N.S.W. Australia. pp. 14.

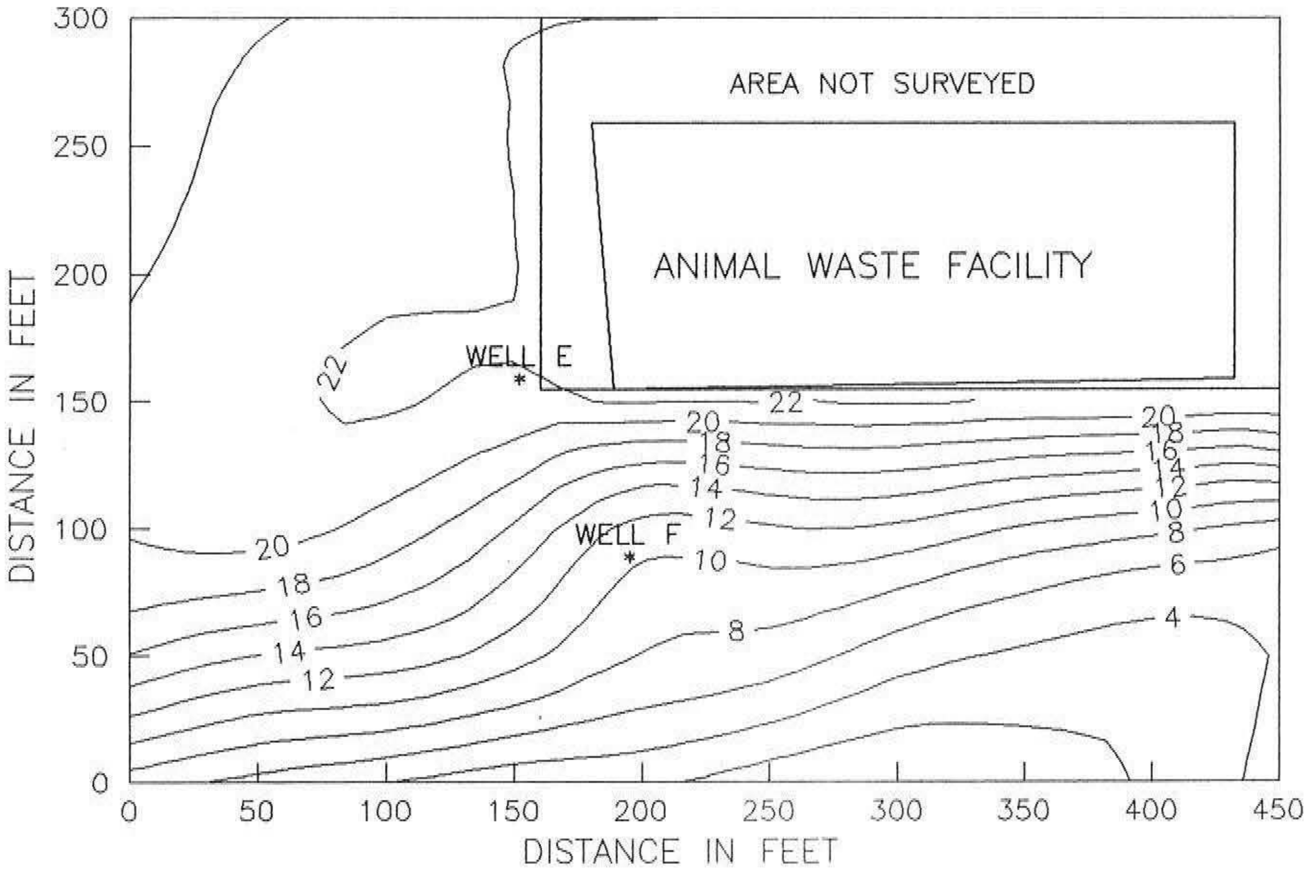
Williams, B. G. 1983. Electromagnetic induction as an aid to salinity investigations in northeast Thailand. CSIRO Inst. Biological Resources, Div. Water and Land Res. Canberra, Australia. Tech. Memo 83/27. pp. 7.

Williams, B. G. and G. C. Baker. 1982. An electromagnetic induction technique for reconnaissance surveys of soil salinity hazards. Australian J. Soil Res. 20(2):107-118.

FIGURE 1

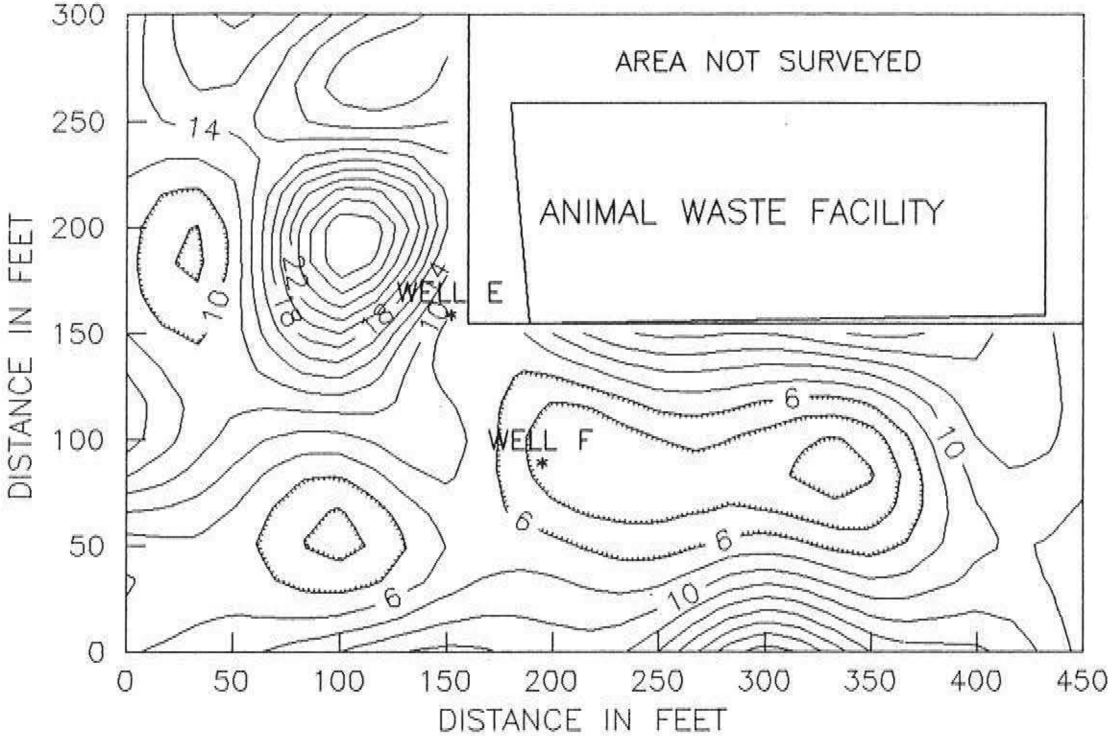
RELATIVE SURFACE ELEVATIONS

SITE 1 – WASHTENAW COUNTY, MICHIGAN

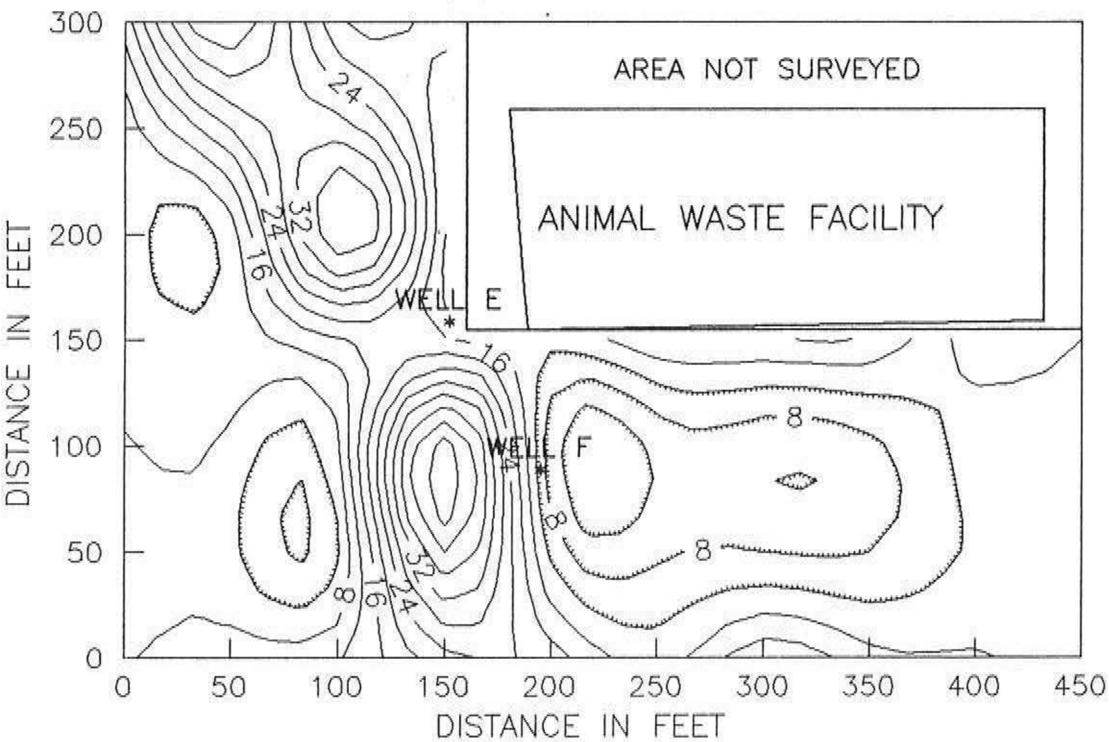


SITE 1 – WASHTENAW COUNTY, MICHIGAN

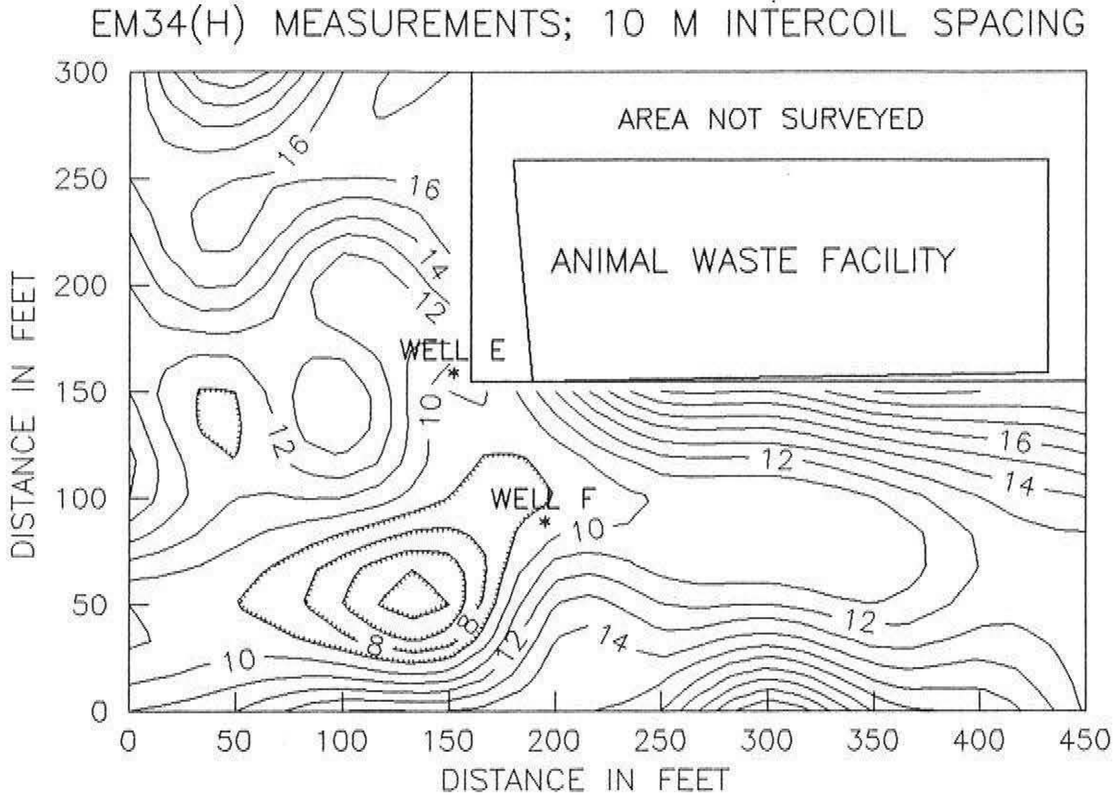
EM31(H) MEASUREMENTS

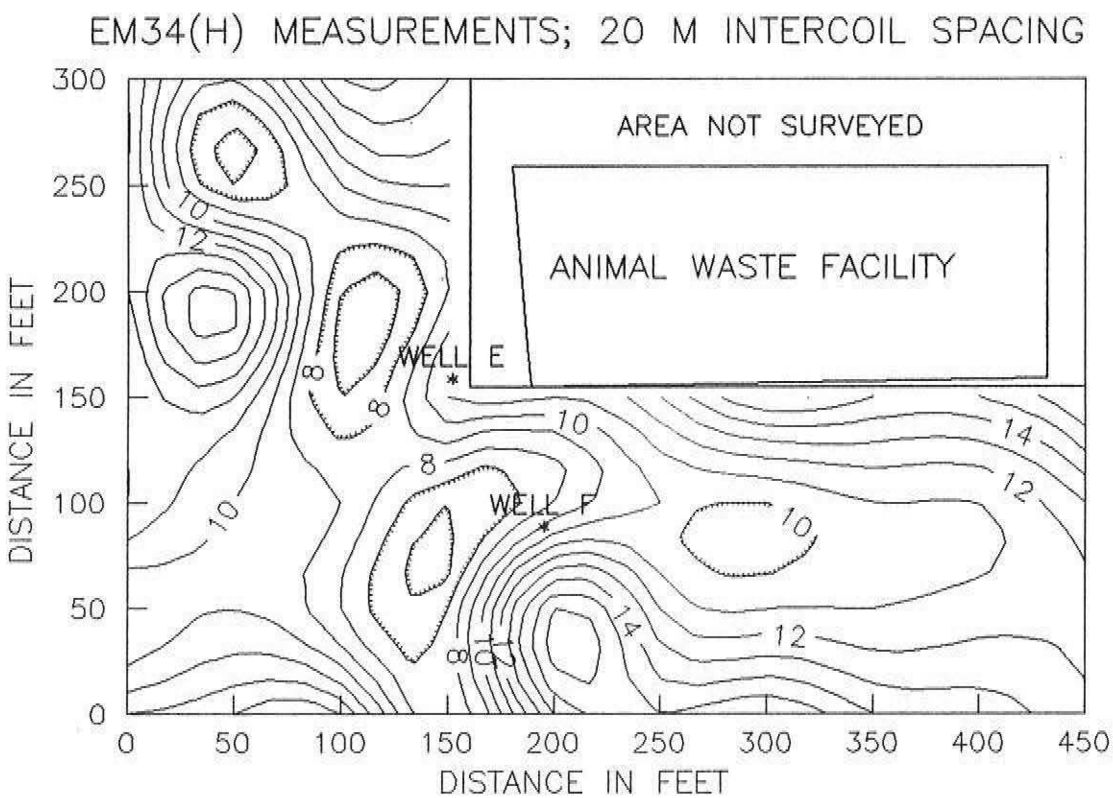


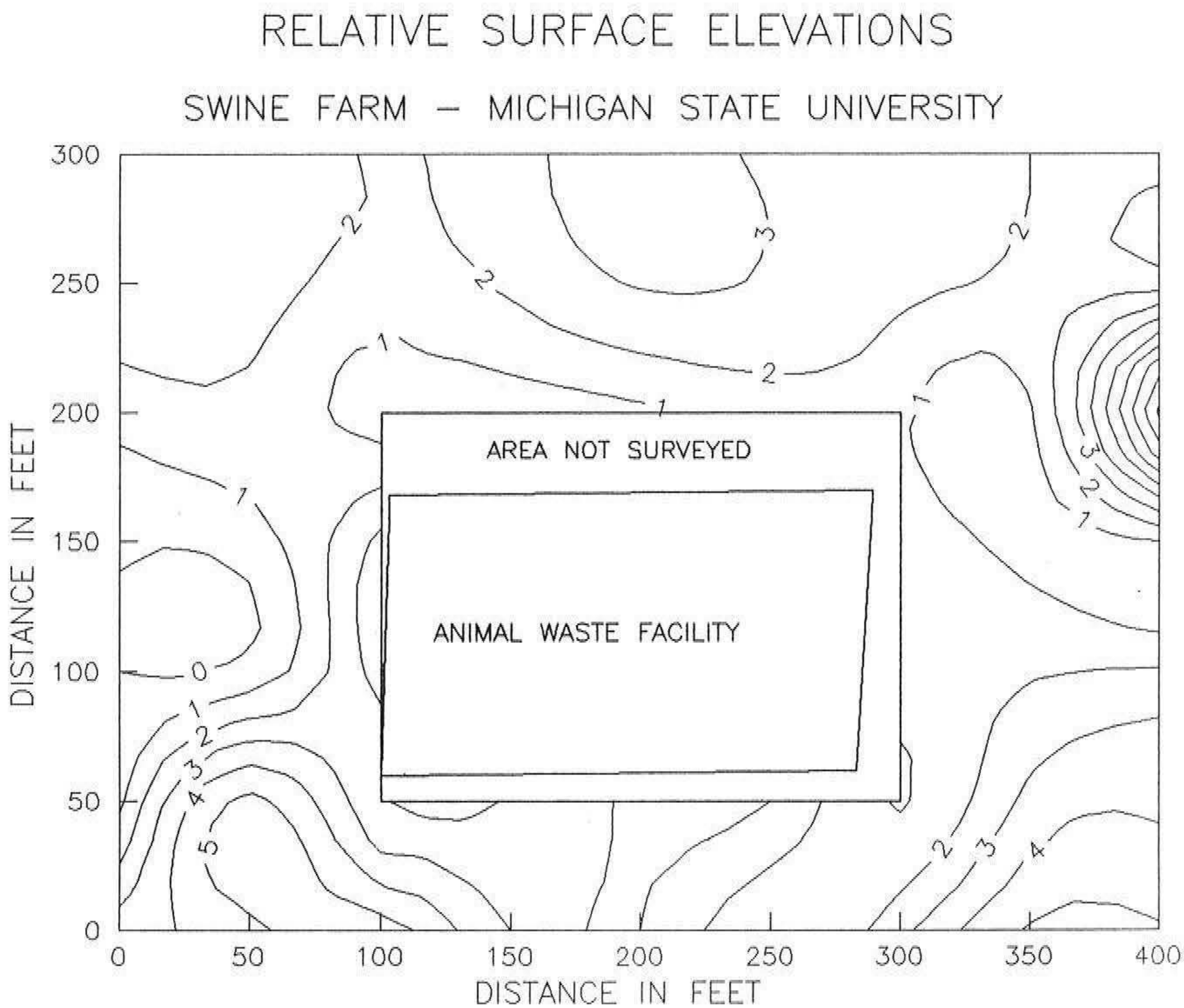
EM31(V) MEASUREMENTS



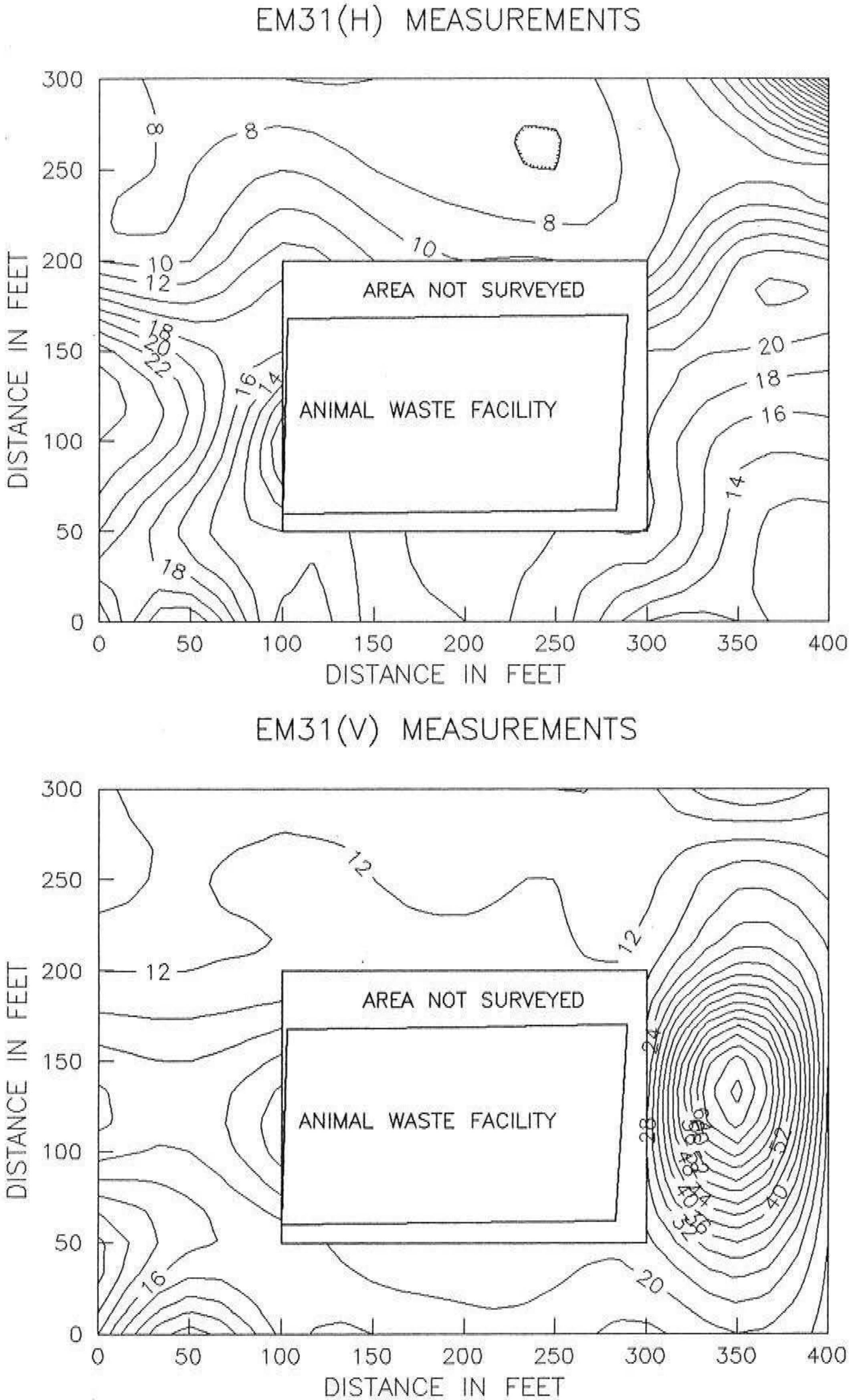
SITE 1 — WASHTENAW COUNTY, MICHIGAN





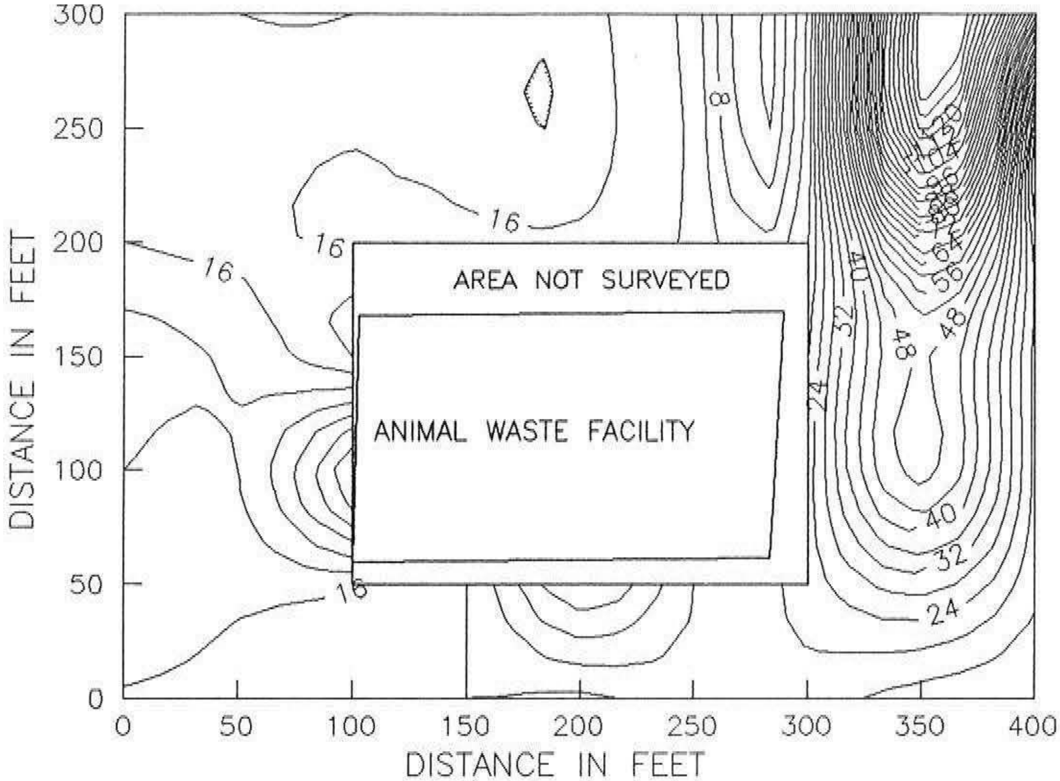

RELATIVE SURFACE ELEVATIONS
SWINE FARM – MICHIGAN STATE UNIVERSITY
AREA NOT SURVEYED
ANIMAL WASTE FACILITY
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
150
200
250
300
350
400

SWINE FARM – MICHIGAN STATE UNIVERSITY



SWINE FARM – MICHIGAN STATE UNIVERSITY

EM34(H) MEASUREMENTS; 10 M INTERCOIL SPACING



EM34(V) MEASUREMENTS; 10 M INTERCOIL SPACING