United States Department of Agriculture
Natural Resources Conservation Service

Chester, PA 19013
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Subject: SOI - Geophysical field assistance **Date:** 24 October 1995

To: Dean Fisher
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Purpose:
To provide technical assistance on the use of electromagnetic induction (EM) methods for soil and groundwater investigations. In addition, I gave a talk and a demonstration of the use of ground-penetrating radar (GPR) and electromagnetic induction techniques for archaeological investigations. The presentation and demonstration were given at the Annual Conference of South Dakota Parks and Recreation Association, Mitchell, South Dakota (28 September 1995).

Principal Participants:
Peter Anderson, Agricultural Engineer, NRCS, Brookings, SD
Roy Boschee, Agricultural Engineer, NRCS, Brookings, SD
Dan Brady, Soil Scientist, NRCS, Redfield, SD
Michelle Burke, Agricultural Engineer, NRCS, Pierre, SD
Jim Doolittle, Research Soil Scientist, NRCS, Chester, PA
Larry Edland, Assistant State Soil Scientist, NRCS, Bismarck, ND
David George, District Conservationist, NRCS, Salem, SD
Jay Gilbertson, East Dakota Water Development District
Sharon Huber, Agricultural Engineer, NRCS, Mitchell, SD
Gary Kirschman, Technician, NRCS, Madison, SD
Danny Merchen, Soil Conservation Technician, NRCS, Salem, SD
Jim Millar, Soil Survey Project Leader, NRCS, Redfield, SD
Carol Reed, Geologist, NRCS, Bismarck, ND
Loren Schultz, Resource Soil Scientist, NRCS, Aberdeen, SD
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Activities:
Two waste-holding facilities near Salem were surveyed with EM techniques on 26 September. Soil investigations were conducted using EM techniques in Spink County on 27 September. A presentation and a demonstration were given at the Annual Conference of South Dakota Parks and Recreation Association, in Mitchell, on 28 September 1995. On the morning of 29

September, a GPR survey was conducted near Lake Cochrane. I left for assignments in Colorado during the afternoon of 29 September.

Introduction:

Electromagnetic induction is a non-invasive geophysical technique which uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted average measurement for a column of earthen materials to a specified observational depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are produced by changes in the electrical conductivity of soils and other 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 clay 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).

Soil scientists have used EM techniques principally to identify, map, and monitor soil salinity (Cook and Walker, 1992; Corwin and Rhoades, 1982, 1984, and 1990; Rhoades and Corwin, 1981; Rhoades et al., 1989; Slavich and Petterson, 1990; Williams and Baker, 1982; and Wollenhaupt et al., 1986). Recently, the use of this technology has been expanded to included the assessment and mapping of sodium-affected soils (Ammons et al., 1989; Nettleton et al., 1994), depths to claypans (Doolittle et al., 1994; Stroh et al., 1993; and Sudduth and Kitchen, 1993), and edaphic properties important to forest site productivity (McBride et al., 1990).

Though seldom diagnostic in themselves, lateral and vertical variations in apparent conductivity have been used to infer changes in soils and soil properties. Electromagnetic induction techniques are not suitable for use in all soil investigations. Generally, the use of EM techniques has been most successful in areas where subsurface properties are reasonably homogeneous, the effects of one property (e.g. clay, water, or salt content) dominates over the other properties, and variations in EM response can be related to changes in the dominant property (Cook et al., 1989).

Equipment:

The electromagnetic induction meters were the EM38 and EM31, manufactured by Geonics Limited*. These meters are portable and requires only one person to operate. Principles of operation have been described by McNeill (1980, 1986). 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 about 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, 1980). For each meter, the lateral resolution is approximately equal to the intercoil spacing. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

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

Discussion:

McCook County - September 26 1995

Site 1

The waste-holding structure was located in an area of Crossplain-Clarno complex. The poorly drained Crossplain soil is a member of the fine, montmorillonitic, mesic Typic Argiaquolls family. The moderately-well drained Clarno soil is a member of the fine-loamy, mixed, mesic Typic Haplustolls family.

A 250 by 350 foot grid was established across the site (2.01 acres). Grid intervals were 25 and 50 feet. These intervals provided 55 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.

At each observation point, the relative elevation of the surface was determined using a level and stadia rod. Elevations were not tied to an elevation benchmark; the lowest recorded observation point was the 0.0 foot datum.

Figure 1 is a two-dimensional contour plot of the study site. The contour interval is 0.5 foot. Within the study site, relief was about 3 feet. In general, the surface slopes towards the waste-holding structure and an intermittent drainageway. The drainageway extents in a north-south direction from the southeast corner of the structure. Higher-lying areas are located in the eastern and southwestern portions of the study site.

Figures 2 and 3 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 10 mS/m.

Comparing the plots (figures 2 and 3), values of apparent conductivity, as a rule, decrease with increasing observation depth (responses in the horizontal dipole orientation were typically greater than those in vertical dipole orientation). The shallower, horizontal dipole measurements averaged 117.8 mS/m; the deeper, vertical dipole measurements averaged 112.3 mS/m. This relationship is believed to reflect the concentration of animal-waste and silage products in the surface layers of the soil. Sediment and animal wastes appear to have been carried by runoff from an adjoining field (located to the west of the site) and, more noticeably, where stock congregate (adjacent to the northwest corner of site). In addition, animal waste appear to have been carried by runoff from an animal holding area (located to the immediate north of the grid site). In figures 2 and 3, anomalously high EM responses in the eastern portion of the site are believed to have been caused by runoff and seepage from present and former silage piles.

In Figure 2, a zone of higher conductivity conform with the intermittent drainageway. As this pattern is not evident in Figure 3, the higher EM responses (in Figure 2) are believed to reflect concentrations of animal waste in the surface layers rather than increases in soil moisture with depth or landscape position.

In Figure 3, several small, plume-like areas appear to extend outwards from the waste-holding structure. These patterns are believed to reflect seepage of contaminants from the structure. However, as these patterns are not extensive and are restricted to within about 20 feet of the structure, they are considered unremarkable and the structure appears to be working satisfactorily.

In Figure 3, the affects of interference from a metal fence line can be seen along the northwest margin of the site. The vertical orientation is more susceptible to interference from the bordering fence line. Values of apparent conductivity become higher as the fence line is approached.

<u>Site 2</u>
The waste-holding structure was located within Camp America, a trailer park, south of Salem. The structure was in an area of the Crossplain-Clarno complex.

An irregularly shaped, 250 by 300 foot grid was established across the site (1.72 acres). The grid interval was 50 feet. This interval provided 29 grid intersections or observation points. At each observation point, survey flags were inserted in the ground, and measurements were taken with an EM31 meter, suspended at hip height, in both the horizontal and vertical dipole orientations.

Figures 4 and 5 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 5 mS/m.

Comparing the plots, values of apparent conductivity, as a rule, increases with increasing observation depth (responses in the horizontal dipole orientation were typically lower than those in vertical dipole orientation). The shallower, horizontal dipole measurements averaged 87.9 mS/m; the deeper, vertical dipole measurements averaged 132.7 mS/m. This relationship is believed to reflect increasing concentration of soluble salts (carbonates) and soil water with increasing soil depth.

In both figures (4 and 5), a broad pattern of higher EM responses occur in the southern and south-western portions of the site. This pattern is more pronounced in the measurements obtained in the vertical dipole orientation. This linear pattern intercepts the waste-holding structure. While the source of this higher conductivity is unknown, this pattern may reflect seepage of contaminants from the structure. The patterns appearing in these plots should help the assessment of this site, and, if necessary, guide the placement of monitoring wells.

Spink County - Estimating the depths to loamy till
The study site was located in an area of Forrestburg-Elsmere sandy loam, loamy substrata. The moderately-well drained Forrestburg is a member of the sandy over loamy, mixed, mesic Entic Haplustolls family. The

somewhat-poorly drained Elsmere soil is a member of the sandy mixed, mesic Aquic Haplustolls family. Forrestburg soils are moderately deep and Elsmere soils are deep to loamy till.

A 250 by 250 foot grid was established across the site (1.43 acres). The grid interval was 50 feet. This interval provide 36 grid intersections or observation points. At each observation point, survey flags were inserted in the ground, and measurements were taken with an EM38 meter placed on the ground surface and an EM31 meter held at hip height. With each meter, measurements were obtained in both the horizontal and vertical dipole orientations.

Basic statistics for the EM data collected at the Spink County site are displayed in Table 1. Variations in each meters response can be related to differences in soil type, landscape position, and depth to and thickness of contrasting materials.

Table 1
Spink County Site, South Dakota
(all values are in mS/m)

				Quartiles			
Meter	Orientation	Minimum	Maximum	1st	Median	3rd	Average
EM38	Horizontal	18.1	27.5	19.5	20.7	21.6	21.2
EM38	Vertical	10.9	16.9	12.0	12.9	13.8	13.2
EM31	Horizontal	20.0	28.1	21.4	22.3	23.1	22.6
EM31	Vertical	34.9	46.9	35.9	37.6	38.9	38.1

Figures 6 and 7 are two-dimensional plots of data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. Figures 8 and 9 are two-dimensional plots of data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each plot, the isoline interval is 2 mS/m.

The spatial patterns appearing in figures 6 to 9 are remarkably similar. Spatial patterns were similar and assumed to reflect the influence and the thickness of the more electrically resistive sands. However, pattern also reflected changes in soils, soil properties (depths to carbonates, rock fragments, texture) and/or depths to till.

The thickness of the sand mantle and the depth to loamy till varied across the site because of differences in erosion, deposition, and landscape position. Because of differences in clay, soluble salt, and water contents among the soil horizons and between the sands and the underlying till, vertical contrasts in electrical conductivity were assumed to exist. It was assumed that variations in the magnitude of the EM response could be used to provide estimates of the thickness of the sand mantle and/or the depth to till.

The depths to till were observed at seventeen observation points with a power probe. Observed depths to till averaged 71.3 inch and ranged from about 30 to 132 cm. A comparison of soil probe and EM data collected at the seventeen observation points (see Table 2) revealed a negative correlation between depth to till and EM response. These relationships conform with the basic conceptual model of the site. The medium-textured till was presumed to have higher clay, moisture, and soluble salt contents and to be more conductive than the overlying sand mantle. Areas having greater thicknesses of sands and depths to till generally had lower EM responses.

Table 2

Relationship Among EM Measurements and Depth to Till
(17 observations)

Meter and Orientation	r
EM38 Meter (Horizontal Dipole Orientation)	- 0.587
EM38 Meter (Vertical Dipole Orientation)	- 0.341
EM31 Meter (Horizontal Dipole Orientation)	- 0.647
EM31 Meter (Vertical Dipole Orientation)	- 0.552

The general increase in EM responses with depth conforms with the basic conceptual model of the site. For the purpose of this investigation, the site was assumed to consist of two principal layers: a sand mantle and an underlying loamy till. The medium-textured till has higher clay and water contents and was presumed to have higher apparent conductivity values than the overlying sands. However, variable soil properties (depth and concentration of water, clay, and calcium carbonates) weakened the relationships between EM responses and depths to till, and undermined the utility of using EM techniques at this site.

Electromagnetic induction is an imperfect tool and is not equally suitable for use in all soil investigations. Generally, the use of EM techniques has been most successful in areas where subsurface properties are reasonably homogeneous, the effects of one factor (clay, water, or salt content) dominates over the other factors, and variations in EM response can be related to changes in the dominant factor (Cook et al., 1989). In such areas, information is gathered on the dominant factor, and assumptions are made concerning the behavior of the other factors (Cook and Walker, 1992). Within the Spink County site, several factors (clay, water, and carbonate contents) varied across the site. Variations in these factors weakened the strengths of the desired relationships and made it difficult to attribute variation in the EM response to the depth to till alone.

Lake Cochrane-Lake Oliver Drainage Investigation - September 29, 1995
An unsuccessful attempt was made to use ground-penetrating radar and electromagnetic induction techniques to detect the remnants of a buried drain line between the two lakes.

The radar unit used in this study was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc. (GSSI). The SIR System-2 consists of a backpack portable, digital control unit (DC-2) with keypad, VGA video screen, and connector panel. Radar profiles were plotted on a model GS-608P thermal plotter/printer. The system was powered by a 12-VDC battery. The model 3110 (120 mHz) antenna was used in this investigation.

Three traverses were made across the area most likely to contain the buried drain line. The soils were highly conductive and rapidly attenuated the radar signals. Because of the highly attenuating nature of the soils, the maximum depth of observation was less than 20 inches.

Results:

1. This field investigation provided participants with additional training and exposure to the operation, interpretations, and applications of EM techniques.

2. Electromagnetic induction (EM) techniques have considerable potential for rapidly assessing suspected sources of surface or ground water contamination. Computer simulated plots, similar to those included in this report, can help engineers and conservationists assess site conditions, improve placement of monitoring wells or sample sites, and provide better confidence in land-management decisions. Deeper sensing meters (EM34-3, EM31) can be used by soil scientists and environmental specialists to help characterize aquifers and assess their vulnerability to contaminants.

3. The reliability of EM techniques must always be appraised based on the results of subsequent ground-truth observation and measurements.

4. The initial attempt to use of EM techniques to determine the depths to loamy till in an area of Forrestburg and Elsmere soils was unsuccessful. While the anticipated relationship was attained, the strengths of the derived correlations were too weak to construct predictive equations or models. The variability of several soil properties were sighted as reasons for the weak correlations. Additional studies are recommended to better understand the influence of these properties and to ascertain soils and soil conditions that are more suitable for EM investigations.

It was my pleasure to work with your staff.

With kind regards

James A. Doolittle
Research Soil Scientist

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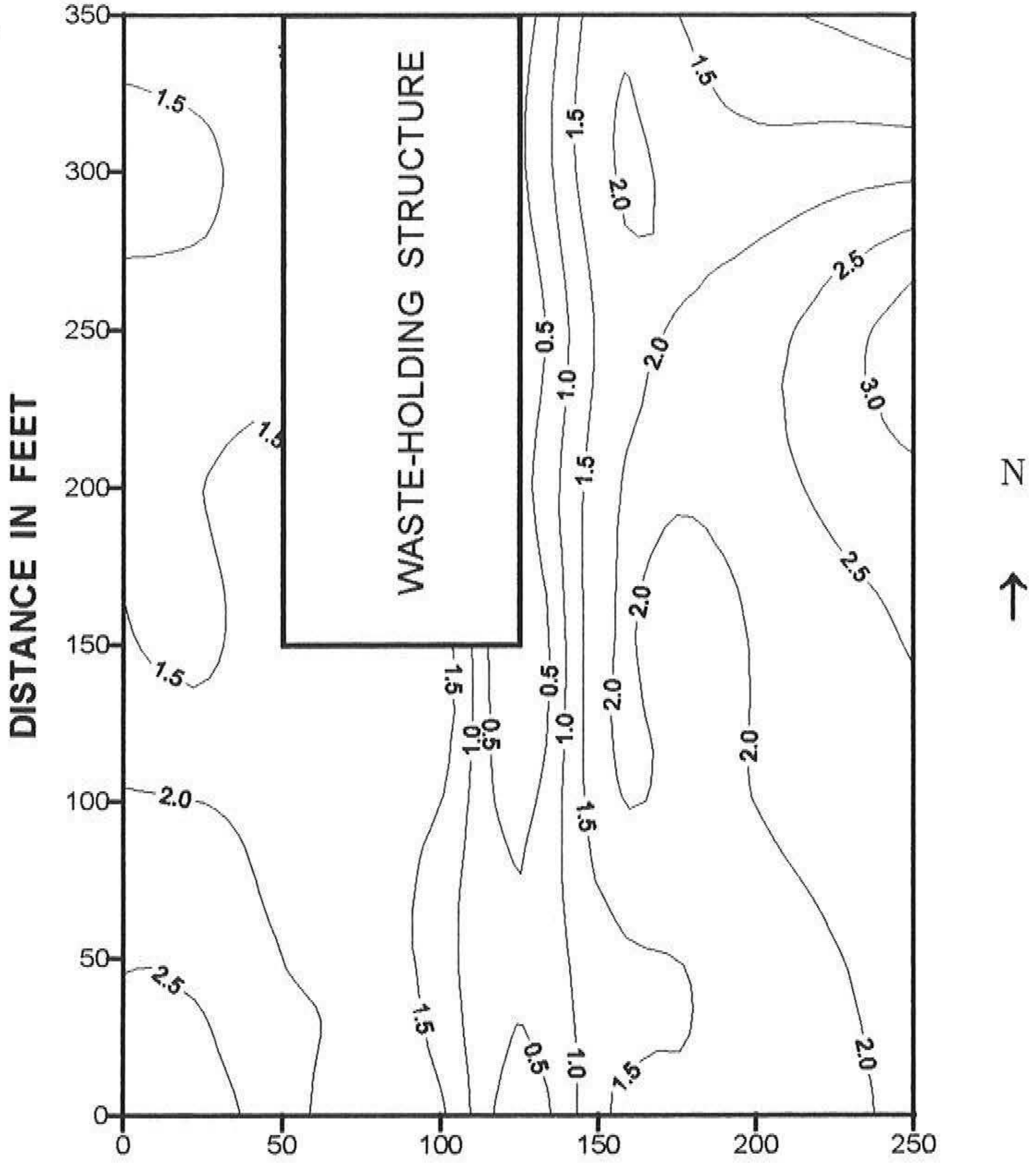
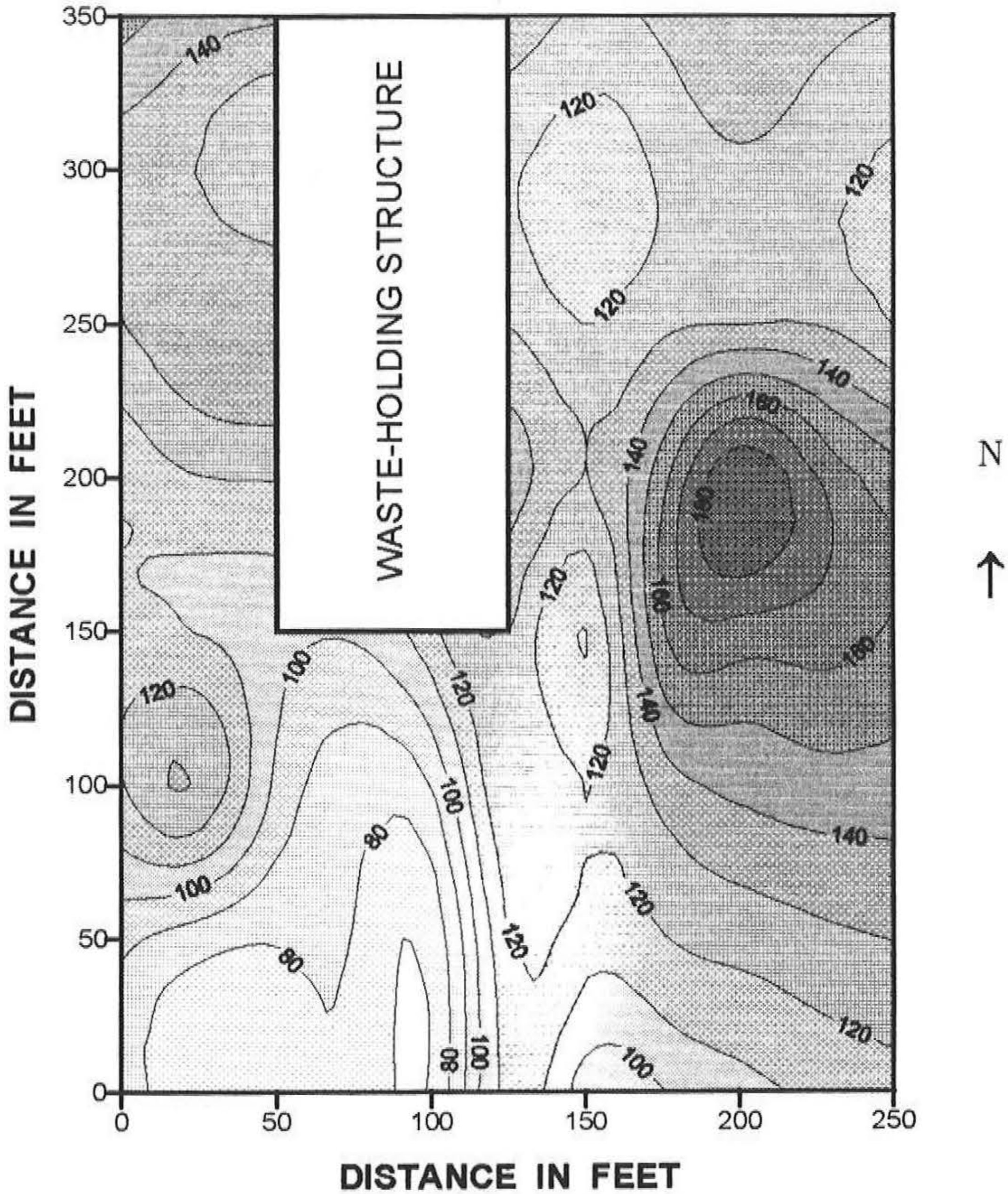
SITE 1
MCCOOK COUNTY, SOUTH DAKOTA
RELATIVE ELEVATION

CONTOUR INTERVAL = 0.5 FOOT

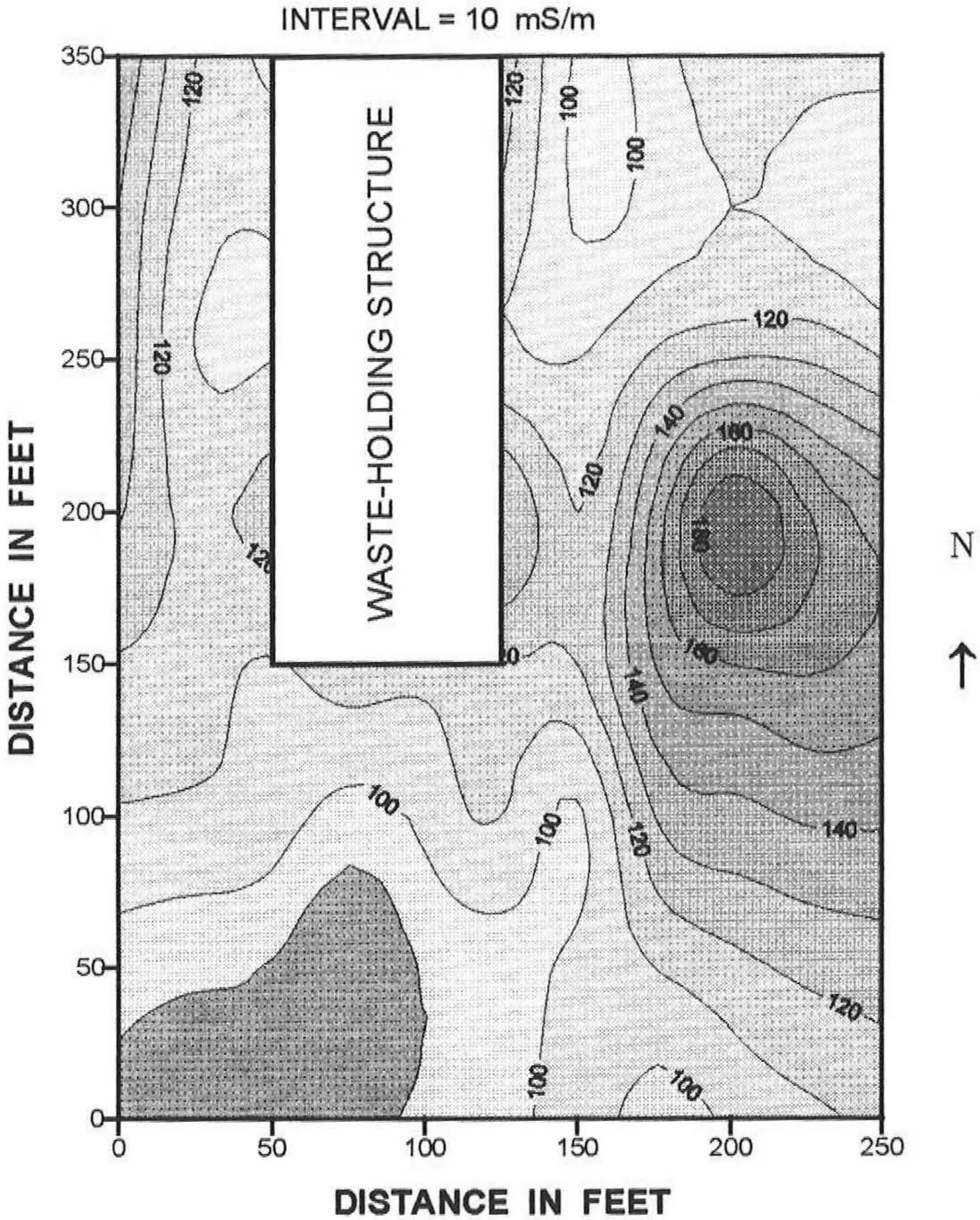


SITE 1
MCCOOK COUNTY, SOUTH DAKOTA
EM 31 SURVEY
HORIZONTAL DIPOLE ORIENTATION

INTERVAL = 10 mS/m

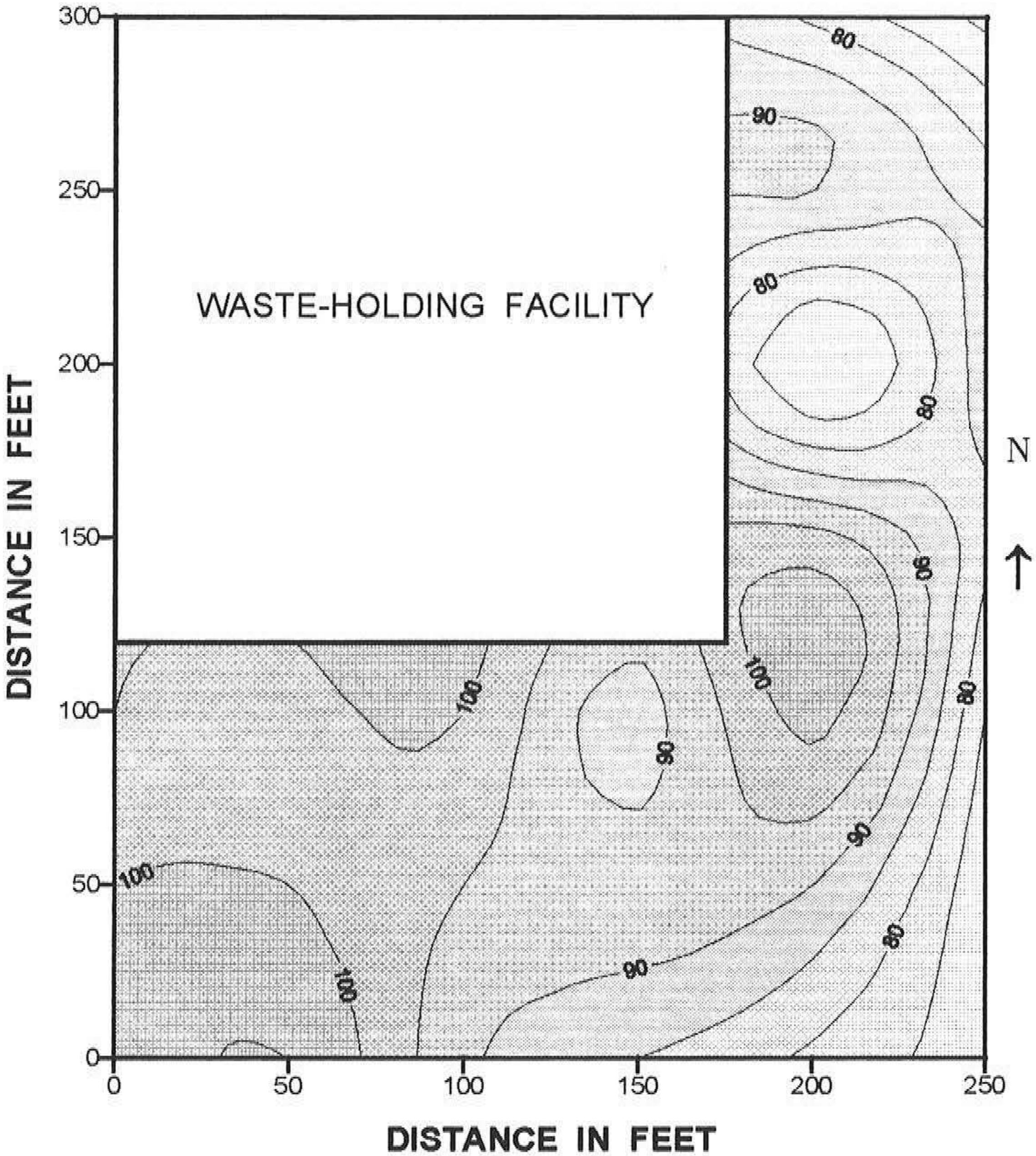


SITE 1
MCCOOK COUNTY, SOUTH DAKOTA
EM 31 SURVEY
VERTICAL DIPOLE ORIENTATION



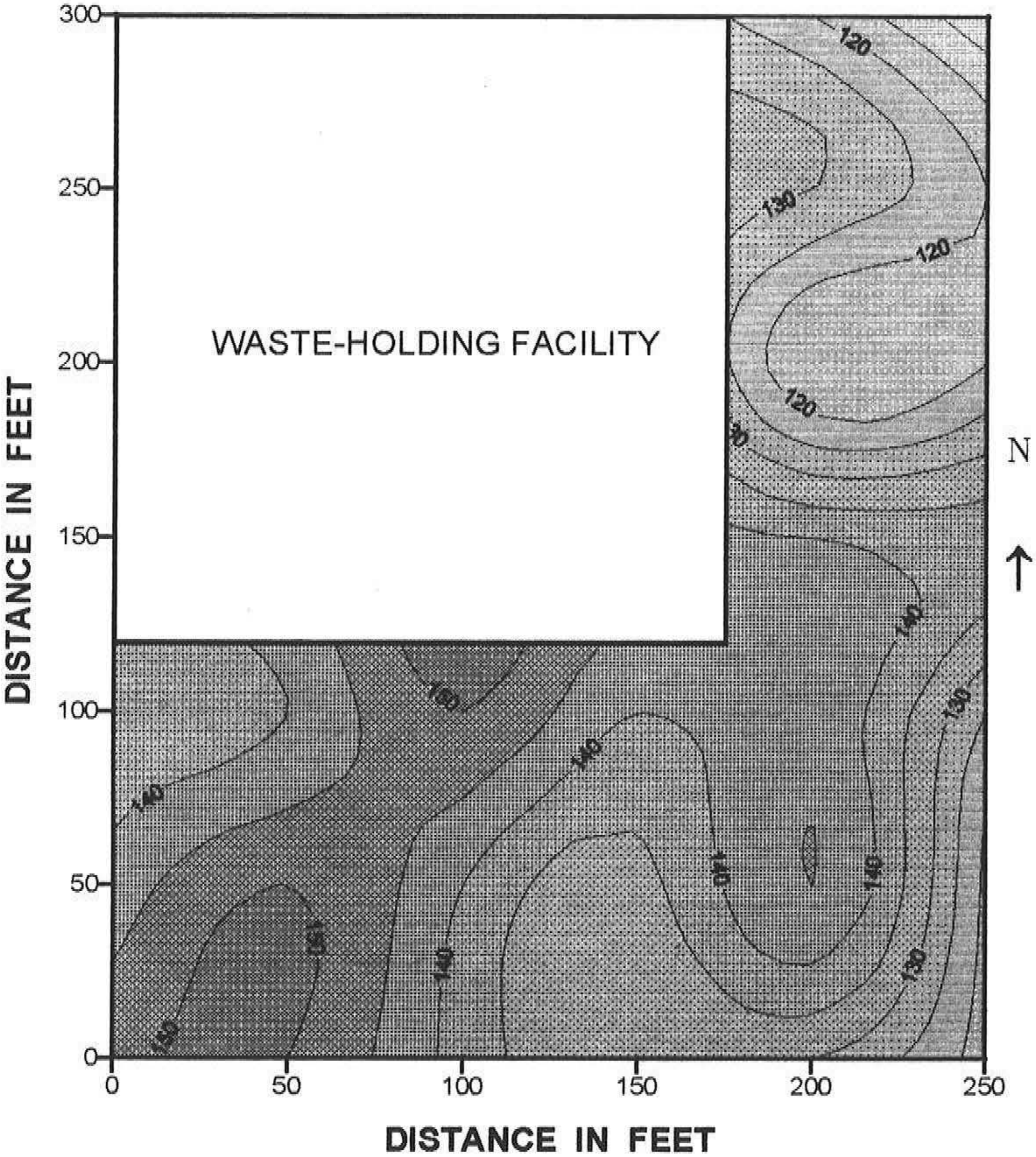
SITE 2
MCCOOK COUNTY, SOUTH DAKOTA
EM 31 SURVEY
HORIZONTAL DIPOLE ORIENTATION

INTERVAL = 5 mS/m



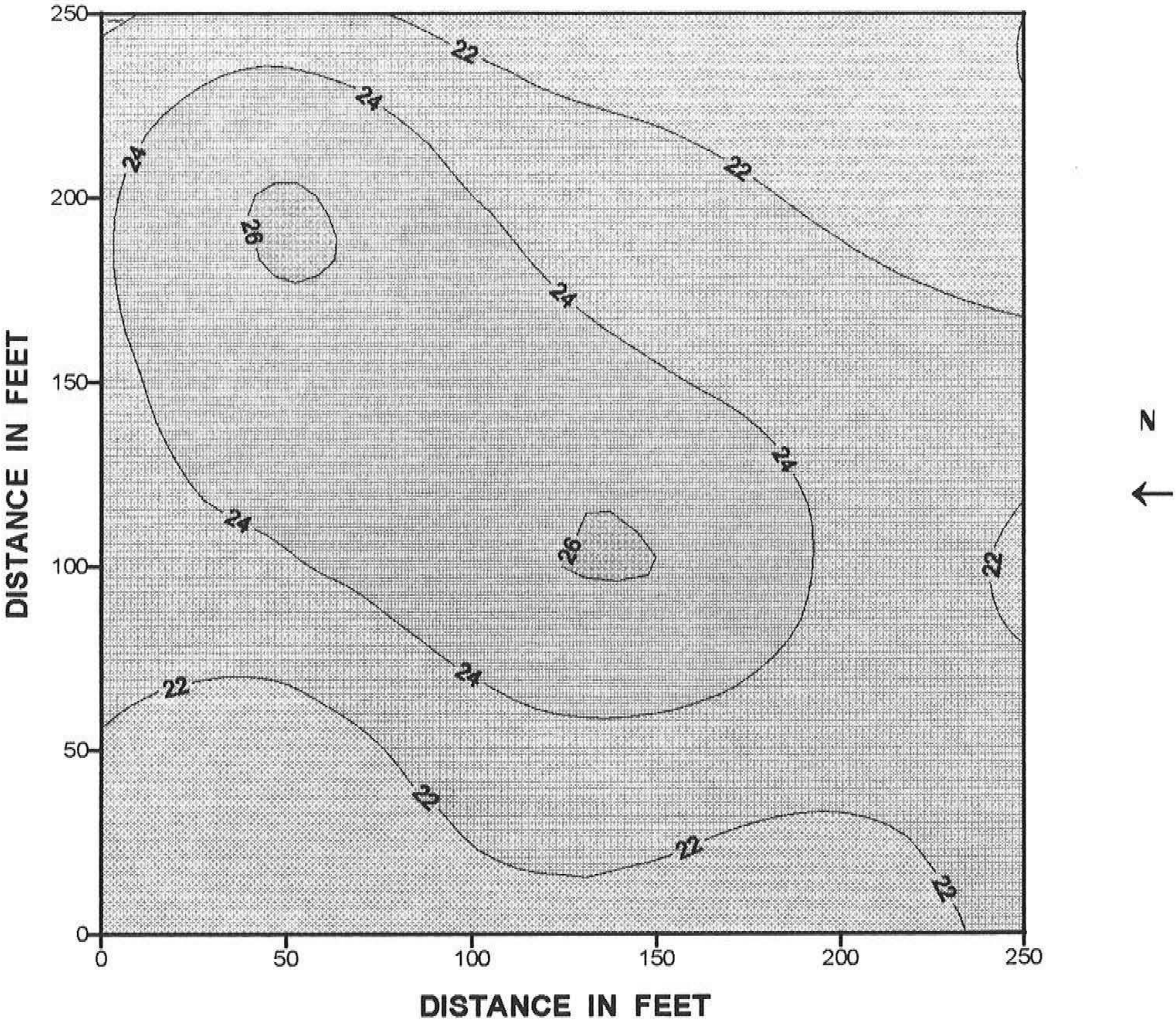
SITE 2
MCCOOK COUNTY, SOUTH DAKOTA
EM 31 SURVEY
VERTICAL DIPOLE ORIENTATION

INTERVAL = 5 mS/m



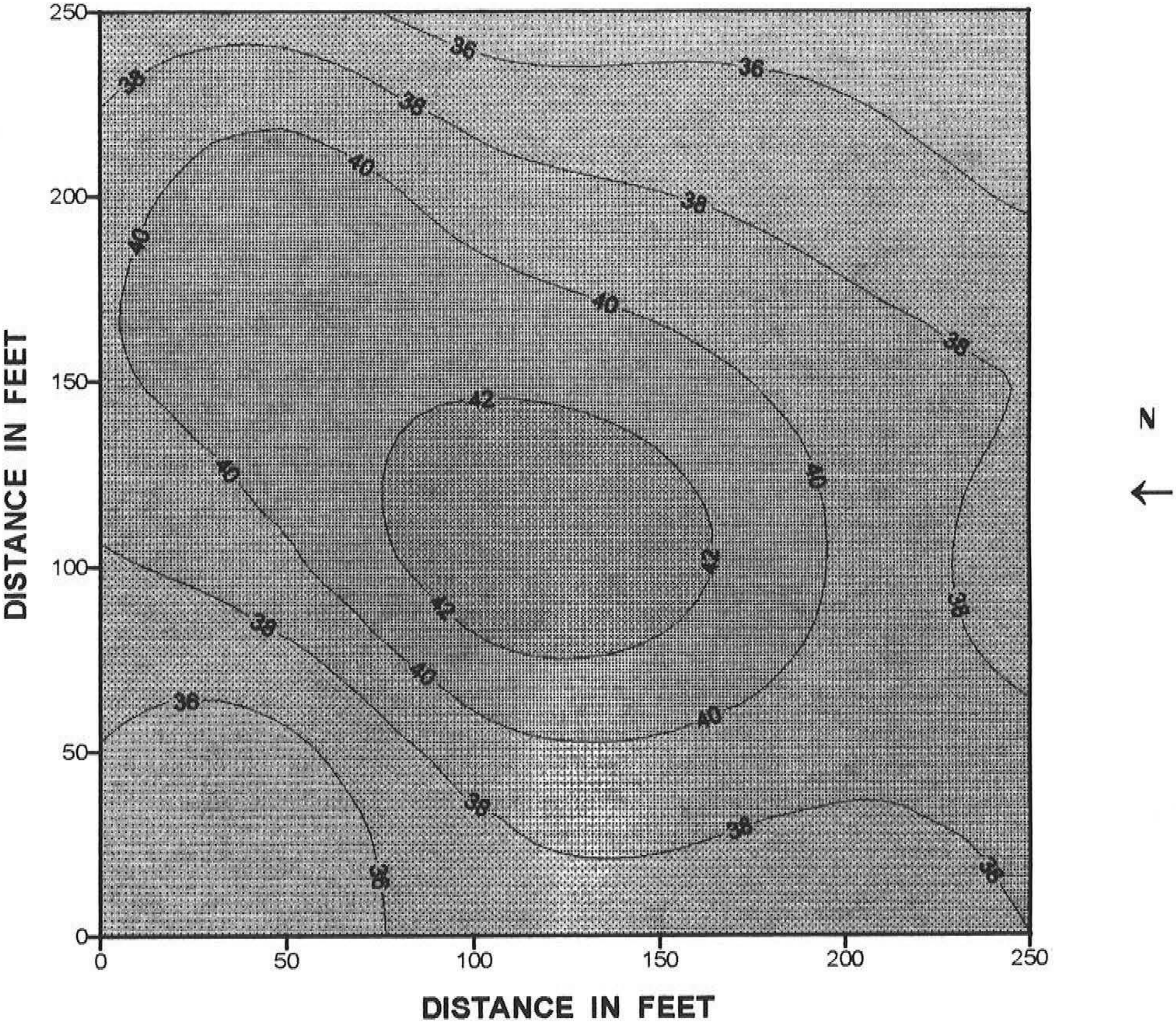
AREA OF FORRESTBURG-ELSMERE COMPLEX

EM 31 METER
HORIZONTAL DIPOLE ORIENTATION



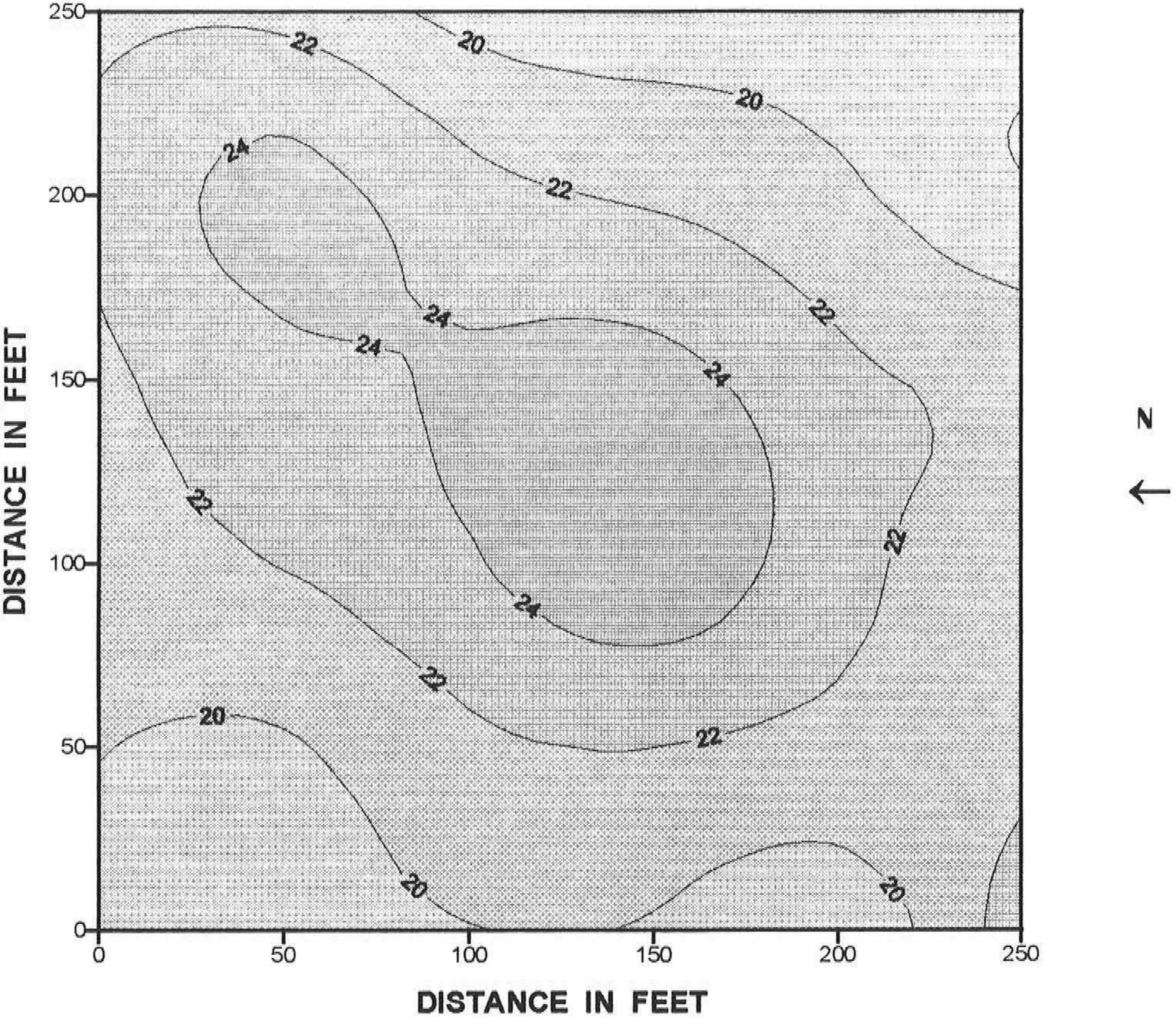
AREA OF FORRESTBURG-ELSMERE COMPLEX

EM 31 METER
VERTICAL DIPOLE ORIENTATION



AREA OF FORRESTBURG-ELSMERE COMPLEX

EM 38 METER
HORIZONTAL DIPOLE ORIENTATION



AREA OF FORRESTBURG-ELSMERE COMPLEX

EM 38 METER
VERTICAL DIPOLE ORIENTATION